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INSULAtE-project results

Improving energy efficiency of multifamily buildings, indoor environmental quality and occupant health

REPORT

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Foreword

This work was carried out as a a part of project "Improving Energy Efficiency of Housing Stock: Impacts on Indoor Environmental Quality and Public Health in Europe" (INSULAtE).

Thank you for Anne Hyvärinen, Head of Unit of Living Environment and Health (THL), Matti Pentti, Head of Department of Civil Engineering (TUT), and Eugenijus Valatka, Head of Faculty of Chemical Technology (KTU), for providing facilities and oversight for the project.

Project partners included the National Institute for Health and Welfare (THL), coordinating the project and being responsible for occupant surveys, and Tampere University of Technology (TUT) responsible for building related studies. From Lithuania, Kaunas University of Technology (KTU) was responsible for exposure assessment. Project group members included Ulla Haverinen-Shaughnessy (project coordinator), Mari Turunen (project manager), Tiina Räisänen (financial manager), Maria Pekkonen (researcher), Liuliu Du (visiting researcher) from THL; Virpi Leivo (researcher), Anu Aaltonen (researcher), and Mihkel Kiviste (senior researcher) from TUT; and Tadas Prasauskas (researcher) and Dainius Martuzevicius (professor) from KTU. A comprehensive list of the project group members and more information about the project can be found from www.insulateproject.eu. Thank you for the project group members for good collaboration. We also wish to thank the building owners and occupants for participating in the field studies.

Steering board members included Aino Nevalainen (chairman), Ralf Lindberg (TUT, 2010–2013), Kati Takala (Finnish Energy Industries), Derrick Crump (Cranfield University, UK), and Matthias Braubach (WHO European Centre for Environment and Health, Germany). We thank the steering board members for constructive comments and recommendations.

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March 10th, 2016
The authors

Abstract

Liuliu Du, Virpi Leivo, Dainius Martuzevicius, Tadas Prasauskas, Mari Turunen, and Ulla Haverinen-Shaughnessy; Improving energy efficiency of multifamily buildings, indoor environmental quality and occupant health - INSULAtE-project results. National Institute for Health and Welfare. Report 17/2016. 228 pages. Helsinki, Finland 2016. ISBN 978-952-302-772-5 (pdf)

Within the EU, the Energy Performance of Buildings Directive (EPBD) and the Energy Efficiency Directive are the main legislative tools aimed at reducing energy consumption in both new and existing buildings. National policies and programs exist in almost all European countries and are aimed at improving the energy efficiency of the building stock. Improved energy efficiency can also impact indoor environmental quality (IEQ) and occupants' health and wellbeing. The INSULAtE-project (2010-2015) was focused on an assessment of improved energy efficiency of multifamily buildings, with the aim of demonstrating the effects of energy retrofits on IEQ and occupant health.

This report presents the main results from the Finnish and Lithuanian case studies. Data from existing multi-family buildings (46 from Finland and 20 from Lithuania) were collected both before and (usually about one year) after energy retrofits, with temperature; ventilation and air tightness measurements; measurements of particle matter, chemical pollutants and radon; and analyses of mineral fibers and microbes from settled dust, i.e. objective and quantitative measures, combined with occupant surveys.

Baseline results before the retrofits from the two countries demonstrated differences in IEQ and occupants' satisfaction with it; for example, the relatively high indoor temperatures observed in Finnish apartments could indicate over heating, whereas elevated carbon dioxide concentrations found in some Lithuanian apartments indicated inadequate ventilation. After the retrofits, the average temperatures remained unchanged in Finland, while thermal conditions were significantly improved in Lithuania. Ventilation rates were slightly improved in Finnish case buildings, but remained similar or decreased in Lithuanian cases. Differences related to indoor air pollutant levels were found to be mainly due to temporal variations; however, in some cases the effects of indoor sources may have been increased after the retrofits. Occupants reported higher satisfaction with indoor air quality as well as less daily noise disturbance related to traffic or industry after the retrofits in both countries. In addition, occupants from Lithuania significantly more frequently reported a suitable winter temperature. However, it should be noted that long term effects has not been assessed.

Along with demonstrating the effects of improving energy efficiency on IEQ, the project has developed an assessment protocol that can be used to complement building investigations and energy audits. IEQ assessment could provide more comprehensive information about the condition and performance of the building as compared to the traditionally used building investigation and energy auditing protocols. The results of the project can be used to support the implementation of policies and programmes related to energy performance of buildings in Europe.

Keywords: Energy efficiency, health, indoor environmental quality, multi-family buildings, retrofit

Tiivistelmä (Abstract in Finnish)

Liuliu Du, Virpi Leivo, Dainius Martuzevicius, Tadas Prasauskas, Mari Turunen ja Ulla Haverinen-Shaughnessy; Improving energy efficiency of multifamily buildings, indoor environmental quality and occupant health - INSULAtE-project results [Rakennusten energiatehokkuuden parantaminen, sisäympäristön laatu ja asumisterveys - INSULAtE projektin tuloksia]. Terveyden ja hyvinvoinnin laitos. Raportti 17/2016. 228 sivua. Helsinki, Finland 2016. ISBN 978-952-302-772-5 (verkkojulkaisu)

Energiatehokkuusdirektiivi ja rakennusten energiatehokkuusdirektiivi (EPBD) ovat merkittävimmät lainsäädännölliset keinot, joilla pyritään parantamaan uusien ja olemassa olevien rakennusten energiatehokkuutta Euroopan unionissa. Lähes kaikissa EU-maissa pyritään rakennusten energiatehokkuutta parantamaan kansallisin säädöksin ja ohjelmin. Energiatehokkuuden parantamiseen tähtäävät toimet voivat vaikuttaa myös sisäympäristön laatuun sekä asukkaiden terveyteen ja hyvinvointiin. INSULAtE-hankkeen (2010–2015) tavoitteena oli selvittää asuinrakennusten energiatehokkuutta parantavien korjausten vaikutuksia sisäympäristön laatuun ja asukkaiden terveyteen.

Hankkeessa kerättiin tietoja yhteensä 46 asuinkerrostalokohteesta Suomessa ja 20 kohteesta Liettuassa. Tietoja kerättiin sekä ennen energiakorjauksia että (yleensä noin vuosi) korjausten jälkeen suorittamalla lämpötila, ilmanvaihto- ja ilmanpitävyysmittauksia, mittamaalla hiukkas-, epäpuhtaus- ja radonpitoisuuksia sekä analysoimalla pinnoille laskeutuneen pölyn mikrobi- ja kuitupitoisuuksia. Mittausten lisäksi asumisterveyttä ja –tyytyväisyyttä kartoitettiin kyselylomakkeilla.

Ensimmäisissä mittauksissa ennen korjauksia maiden välillä paljastui eroja sekä sisäympäristön laadussa ja asukkaiden tyytyväisyydessä. Suomalaisissa asunnoissa esiintyi suhteellisen korkeita sisälämpötiloja. Osassa liettualaisissa asunnoista mitattiin kohonneita hiilidioksidipitoisuuksia, mikä voi viitata riittämättömään ilmanvaihtoon.

Keskilämpötilat eivät Suomessa muuttuneet korjausten jälkeenkään, mutta Liettuassa sisälämpötila parani huomattavasti. Suomessa ilmanvaihto oli hieman parantunut tutkimuksessa mukana olleissa taloissa, mutta Liettuassa ilmanvaihto heikkeni tai pysyi ennallaan. Sisätilojen epäpuhtauspitoisuuksien muutokset liittyivät pääasiassa mittausajankohdasta johtuviin eroihin, joskin joissakin tapauksissa sisätiloissa olevien hiukkaslähteiden vaikutus saattoi olla korjausten jälkeen suurempi. Asukkaat olivat tyytyväisempiä sisäilman laatuun ja raportoivat vähemmän päivittäistä tieliikenteeseen ja teollisuuteen liittyvää melua korjausten jälkeen molemmissa maissa. Lisäksi Liettuassa sisälämpötilaa talvella sopivana pitävien osuus kasvoi merkittävästi. On huomattava, että pitkän aikavälin vaikutuksia ei ole arvioitu.

Hankkeen puitteissa kehitettiin kattava arviointimalli, jota voidaan soveltaa rakennuksen kunnon arvioinnissa ja energiaselvitysten tekemisessä. Perinteisten kuntotarkastusten ja energiaselvitysten rinnalla sisäympäristön laadun arviointi voi tarjota lisätietoa rakennuksen kunnosta ja energiatehokkuudesta. Hankkeen tuloksia voidaan hyödyntää rakennusten energiatehokkuutta tukevien säädösten ja ohjelmien toimeenpanemisessa Euroopassa.

Avainsanat: Energiatehokkuus, terveellisyys, sisäympäristön laatu, asuinkerrostalot, korjaus

Sammandrag (Abstract in Swedish)

Liuliu Du, Virpi Leivo, Dainius Martuzevicius, Tadas Prasauskas, Mari Turunen och Ulla Haverinen-Shaughnessy; Improving energy efficiency of multifamily buildings, indoor environmental quality and occupant health - INSULAtE project results [Förbättrad energieffektivitet i byggnader, inomhusmiljöns kvalitet och boendehälsa – resultat från projektet INSULAtE]. Institutet för hälsa och välfärd. Rapport 17/2016. 228 sidor. Helsingfors, Finland 2016. ISBN 978-952-302-772-5 (nätpublikation)

Direktivet om energieffektivitet och direktivet om byggnaders energiprestanda (EPBD) är de mest betydande lagstiftningsåtgärderna i syfte att förbättra energieffektiviteten i nya och befintliga byggnader i Europeiska unionen. I så gott som alla EU-länder strävar man efter att förbättra byggnaders energieffektivitet genom nationella bestämmelser och program. Åtgärder som siktar på att främja energiprestandan kan också påverka inomhusmiljöns kvalitet och invånarnas hälsa och välbefinnande. Målet med projektet INSULAtE (2010–2015) var att klarlägga vilken effekt renoveringar som förbättrar energieffektiviteten i bostadshus har på inomhusmiljöns kvalitet och på invånarnas hälsa.

I projektet samlades uppgifter om totalt 46 flervåningsbostadshus i Finland och 20 i Litauen. Uppgifter samlades både före energirenoveringarna och (vanligen cirka ett år) efter renoveringarna med hjälp av mätning av temperatur, ventilation och lufttäthet, genom att mäta partikel-, förorenings- och radonhalter och genom att analysera mikrob- och fiberhalterna i damm på ytor. Förutom genom mätningar kartlades boendehälsan och -tillfredsställelsen med hjälp av frågeformulär.

Vid de första mätningarna före renoveringarna framgick skillnader mellan länderna både när det gäller inomhusmiljöns kvalitet och hur nöjda invånarna är med boendet. I de finländska bostäderna var inomhustemperaturerna relativt höga. I en del av de litauiska bostäderna mättes höga koldioxidhalter, vilket kan vara ett tecken på otillräcklig ventilation.

Efter renoveringarna förekom inga förändringar i medeltemperaturerna i Finland, men i Litauen förbättrades inomhustemperaturerna avsevärt. I Finland hade ventilationen blivit lite bättre i de hus som ingick i undersökningen, men i Litauen blev ventilationen sämre eller förblev oförändrad. Förändringarna i föroreningshalterna inomhus berodde huvudsakligen på skillnader mellan olika mätningstillfällen, även om inverkan av källorna till partiklar inomhus i vissa fall kunde vara större efter renoveringarna. I bägge länderna var invånarna nöjdare med kvaliteten på inomhusluften och rapporterade mindre dagligt buller på grund av vägtrafik och industri efter renoveringarna. Därtill ökade andelen invånare som ansåg att inomhustemperaturen är lämplig på vintern kraftigt i Litauen. Det är viktigt att beakta att effekterna på lång sikt inte har bedömts.

Inom ramen för projektet utvecklades en heltäckande bedömningsmodell som kan tillämpas vid bedömningen av byggnadens skick och vid energiutredningar. Vid sidan av traditionella besiktningar och energiutredningar kan bedömningen av inomhusmiljöns kvalitet komma med tilläggsinformation om byggnadens skick och

energiprestanda. Projektets resultat kan utnyttjas vid verkställande av bestämmelser och program som stödjer byggnaders energieffektivitet i Europa.

Energieffektivitet, sundhet, inomhusmiljöns kvalitet, flervåningsbostadshus, renovering

Contents

1 Introduction

1.1 Background

Domestic and international efforts are needed in order to mitigate climate change. It has been estimated that the largest potential for energy saving and decreasing greenhouse gas emissions is in the building sector, where some 27% of energy is used in residential buildings [1]. European Commission has adopted the recast 2010 Energy Performance of Buildings Directive (EPBD) to reduce the building energy consumption and strengthen the energy performance requirements, requiring that by the end of 2020 all new buildings are so-called nearly zero-energy buildings (nZEBs), and also existing buildings subjected to major retrofits meet minimum energy performance requirements adapted to the local climate [2].

The importance of buildings in health policies is also evident. The Fourth Ministerial Conference on Environment and Health observed the need for environment and health to be at the core of policies on housing and energy use. The World Health Organization (WHO) resolution on environment and health has called for policies that will protect public health from the impacts of major environment-related hazards such as those arising from climate change and housing [3]. WHO has also considered the scientific evidence regarding possible health gains, and where relevant, health risks of climate change mitigation measures in the residential housing sector [4].Overall, it is important to look for opportunities where health gains and sustainability objectives can be mutually reinforcing.

National policies and programmes of interest are those, which are developed in order to fulfill the EPBD, aiming to minimum energy performance for new and renovated buildings. Two countries, Finland and Lithuania, who participated in INSULAtE-project, have very distinct premises and characteristics with respect to energy use, building stock, and ways in implementing national policies within EU.

As a response to the climate, Finnish standards for energy efficiency of buildings have already been relatively high, limiting the potential for reducing energy loss throughout the building envelope and related environmental and health burdens. For example, according to a recent survey, over 90% of the Finns are satisfied with indoor temperatures during winter, and there is no difference between Northern and Southern Finland in this respect [5]. Nevertheless, the EPBD is being implemented in Finland, resulting in more precise national building regulations. For example, old regulations on thermal insulation (the National Building Code of Finland, Code C3, “Thermal insulation in buildings”) were updated and implemented 2012 into energy efficiency regulations [6].

With respect to the Finnish housing stock, most of the existing apartment buildings have been constructed in 1960-1980 (Figure 1): part of them has already been renovated and a large quantity will be renovated in the next decades, providing an opportunity to improve energy efficiency. To support energy improvements, Housing Finance and Development Centre of Finland permit funds for approximately 3000 buildings annually. The annual budget of the energy improvements for the year 2014 was about € 16.5 million and estimated amount of energy saved is as much as 1.5 TWh per year [7].

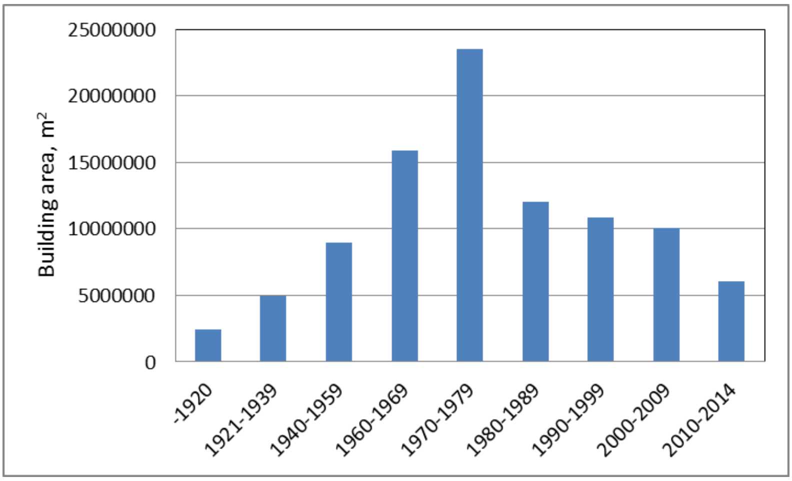

Figure 1. Building area (m^2) of Finnish apartment buildings by year of construction[8]

In Lithuania, thermal quality of the building stock has changed significantly after the collapse of the former Soviet Union. Since 1992, when the National Building Code was introduced, the required U-values of the building elements are approaching the ones applied in Finland and other Scandinavian countries. However, the buildings constructed earlier represent the old style of construction, requiring high energy consumption for heating [9]. About 66% of the population lives in multifamily houses built before 1993. A national program for retrofit of multifamily buildings was started in 2005 with expected energy savings of 1.7 TWh per year [10]. The retrofits most commonly involve adding thermal insulation, changing windows, and glazing of balconies, but do not typically include changes in the ventilation systems.

Whereas the national programmes presented above – and similar ones found in almost all EU member states - are intended to reduce the economical and environmental burdens related to the energy consumption, the programs are also assumed to have various effects on indoor environmental quality (IEQ) and occupant health and wellbeing. However, evaluating these effects is not typically included in the assessment of these policies. There are almost none large-scale assessments on this topic, and those that exist are on a local or national scale only.

Policies aimed to improve energy efficiency of buildings are likely impact on certain environmental exposures, resulting in a ‘non-additive’ effect. The most important pathways related to environmental exposures and health are considered to relate to indoor temperature and ventilation characteristics– which in turn affect thermal comfort and indoor air quality (sources and concentrations of various pollutants), as well as emissions to the outdoor environment and cost to the household. For example, a policy to improve energy efficiency by adding insulation is likely to reduce exposure to excess cold, but may unintentionally lead to a reduction of indoor air quality. Or a number of policies may have synergistic effects, in which case, a combination of policies may reach optimal results.

A limited number of studies worldwide have assessed the potential effects of improved energy efficiency on health. Follow-up studies include a health-monitoring project in Frankfurt, Germany, implemented by the WHO Housing and Health Program. The project assessed 131 insulated and 104 non-insulated dwellings, the results suggesting 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 [11]. In the UK, government supported energy efficiency improvements under the Warm Front scheme. 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 [12]. 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 [13]. In New Zealand, improving insulation of dwellings in low income communities (1350 households) showed increased bed temperature with improved health [14]. A recent study from US assessed the effects of green healthy housing improvements in a low-income housing development (44 units at the baseline), and reported energy and water costs savings along with positive changes in self-reported health among adults [15].

In lieu of population based studies, additional information can be drawn from case studies. For example, Kazimieras-Zavadskas et al. [16] assessed five dwellings, based on which they proposed an approach to multi-attribute assessment of dwellings before and after refurbishment and/or renovation and evaluation of its efficiency. Noris et al. [17] presented a protocol for maximising energy savings and indoor environmental quality improvements, and tested the protocol in 17 apartments of three buildings in California.

There exist also some modelling studies utilizing existing data sources. Modelling studies may be useful especially with respect to subtle outcomes (such as health effects), which would require large sample sizes to detect in field settings. Mavrogianni et al. [18] presented a modelling approach to estimate a risk of overheating due to climate change and the urban heat island phenomenon. One of their suggestions was that information of insulation characteristics after retrofitting is crucial for accurate identification of dwellings with the greatest overheating potential. However, currently such information may not be available from the registries. Milner et al. [19] modelled current and future distributions of indoor radon levels in UK based on estimated reduced home ventilation rates as a part of energy efficiency measures and associated changes in life-years due to lung cancer mortality. They concluded that unless specific remediation is used, reducing ventilation in dwellings will improve energy efficiency only at the expense of population wide adverse impact on indoor exposure to radon and risk of lung cancer. Fabian et al. [20] evaluated the impact of building interventions on IEQ and pediatric asthma health care use, and related cost comparison utilizing a discrete event simulation model. The results indicated benefits of bundlet building interventions based on their effects on health and costs, and highlighting the tradeoffs between weatherization (tightening the building envelope), indoor air quality, and health.

Fisk et al.[21] reviewed effects of climate change on IEQ and health, and associated no-regret mitigation measures. Changes to buildings or their operation were identified that could reduce the projected adverse health effects of climate change. Examples included improved roof insulation, roof coatings that reflect more solar energy, more air conditioning to reduce indoor overheating, and improved particle filtration systems; consideration should be given to selecting climate neutral solutions so that the improvements will not lead to worsening situation in the long run. Whereas these studies provide useful information on potential effects of different retrofit solutions and ways to assess them, it appears that a reliable assessment of effects of improving energy efficiency of buildings requires more long-term population based studies using validated protocols.

1.2 Guidelines and regulations

1.2.1 Buildings and energy efficiency

Assessment of energy efficiency follows nationally agreed methods of estimating energy consumption [22], following a comparative methodology framework EU has established for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements. The methods in use have evolved in the past decades and they vary across European countries.

For example, Finland has had regulations on the energy efficiency of buildings in the National Building Code since 1976, including minimum requirements for the thermal insulation and ventilation of new buildings. (The earliest guidance values for thermal insulation have been published by Finnish Association of Civil Engineers in 1969.) Before 2012, the main focus was on thermal properties of building structures, aiming to decrease the space heating demand. Regulations have been revised several times recently due to the implementation of the EPBD. Table 1 shows how requirement for minimum thermal resistance (U-values) of building envelope structures have changed across time.

Table 1. Minimum thermal resistance (U-values) of building envelope structures.

Envelope structures	Year of construction W/m^2 K								
	-1969	1969-	1976-	1978-	1985-	10/2003-	2008-	2010-	2012-
Outer wall	0.81	0.81	0.40	0.35	0.28	0.25	0.24	0.17	0.17
Slab on ground	0.47	0.47	0.40	0.40	0.36	0.25	0.24	0.16	0.16
Slab in crawl space	0.47	0.47	0.40	0.40	0.40	0.20	0.20	0.17	0.17
Floor facing outdoor	0.35	0.35	0.35	0.29	0.22	0.16	0.16	0.09	0.09
Roof	0.47	0.47	0.35	0.29	0.22	0.16	0.16	0.09	0.09
Door	2.2	2.2	1.4	1.4	1.4	1.4	1.4	1.0	1.0
Window	2.8	2.8	2.1	2.1	2.1	1.4	1.4	1.0	1.0

In addition to Energy Efficiency Directive of new buildings (recast Directive on the energy performance of buildings, 6/2013), minimum energy requirements were developed and extended for existing buildings undergoing retrofits (Government Decree on the improving of energy efficiency of existing buildings, 4/2013). According to statistics, the actual U-values of outer wall and roof structures in apartment buildings have followed the development of regulatory values based on year of construction (Figure 2)[23].

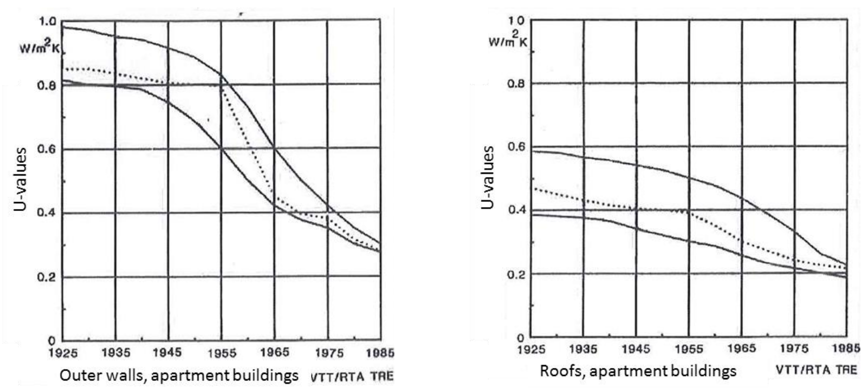

Figure 2. U-values of outer walls and roofs in apartment buildings based on year of construction. Average values, minimum and maximum values.

Energy certificates were taken into use in the beginning of 2008. In the newest building code, the energy efficiency value (E-value) is calculated based on the total energy consumption multiplied with energy source coefficient. It is based on the so-called standard use of the building as well as on certain components, such as ventilation, warm water, lighting, and indoor temperature. Commonly agreed outdoor climate values are used, for instance Helsinki-Vantaa corresponds to climate zone 1. Following energy label classifies buildings on a scale ranging from A (high) to G (poor). The limits for energy consumption values for each EE class are depending on the building type. For apartment buildings, the EE classes are presented on Table 2. New building must be in class “C” or higher.

Table 2. Energy efficiency scale for apartment buildings in Finland.

Energy efficiency class	Total energy consumption (include energy source weighting factor, E-value (kWh/m^2, year)
A	E-value ≤ 75
B	76 ≤ E-value ≤ 100
C	101 ≤ E-value ≤ 130
D	131 ≤ E-value ≤ 160
E	161 ≤ E-value ≤ 190
F	191 ≤ E-value ≤ 240
G	241 ≤ E-value

Preceeding the E-valuewas so-called ET-value. There were also seven EE classes (A to G) in ET-value classification. However, the calculation rules are different and ET-values are not comparable with E-values. Major difference is that E-values are calculated with weighing factors of energy sources. Energy certification is valid for ten years. Hence, some buildings still only have an ET-value.

Measured energy consumption is another way of assessing energy efficiency of a building. Table 3 presents energy consumption in Finnish apartment buildings in 2014. Mostly used energy source for heating is district heating. The energy used in apartment buildings has remained between 60 to 70 GWh for the past six years [24].

In Lithuania, implementation of the EPBD started when certification requirements for new buildings came into force on January 1, 2007. Newest requirements for new buildings in relation to EPBD recast became effective on January 9, 2013. Energy performance requirements are not obligatory for existing buildings which are for sale or rented, but the evaluation procedure and certification requirements for existing buildings after major retrofits have been required since January 1, 2009.

Buildings are classified into nine energy performance (EP) classes, ranging from A++ (NZEB) to G (energy-inefficient). The evaluation of buildings does not refer to their purpose of use, but to their technical specifications. There are normative requirements for thermal resistances of residential building envelope (Table 4). The normative U-values are depended on a corrective factor K, which takes into account outdoor temperature of the building site.

Table 3. Energy used in apartment buildings in Finland 2014.

	Wood	Peat	Coal	Heavy fuel oil	Light fuel oil	Natural gas 1)	Heat pump energy 2)	District heating	Electricity 3)	Total
Living, total, GWh	14 723	46	3	85	4 130	435	4 652	18 190	21 356	63 619
Heating of apartment buildings	**14 723**	**46**	**3**	**85**	**4 130**	**323**	**4 652**	**18 190**	**13 424**	**55 576**
Permanent apartment buildings, total	13 022	45	3	85	4 078	322	4 510	18 188	12 656	52 909
- Detached houses	12 785	40	3	-	3 271	95	4 051	2 102	9 736	32 083
- Row houses	148	1	-	-	221	75	415	2 874	1 774	5 508
- Apartment buildings	89	4	-	85	586	152	44	13 212	1 146	15 318
Recreational dwellings	1 701	1	0	-	52	1	142	2	768	2 667
Home appliance	**-**	**-**	**-**	**-**	**-**	**112**	**-**	**-**	**7 932**	**8 043**
- Lighting	-	-	-	-	-	-	-	-	1 919	1 919
- Cooking	-	-	-	-	-	112	-	-	578	689
- Other electric devices	-	-	-	-	-	-	-	-	5 435	5 435
From heating of apartment buildings										
- Heating of saunas	1 800	-	-	-	-	-	-	-	1 119	2 919
- Heating of service water	469	15	1	24	801	68	681	5 161	2 565	9 784

1) Including liquid gas.
2) Energy taking by heat pumps from soil, air or water for heating buildings. Electricity needed in heat pumps is included into electricity used in heating.
3) Electricity used in heating includes direct electric heating or electric storage heating, electric extra heaters, electric floor heating, electricity used in heat pumps, electricity used in heating service water, electric sauna stoves and electricity used in heating and heat distribution systems.

Table 4. Normative requirements for thermal resistances of residential building envelope in Lithuania.

Envelope structures	Normative U-values, W/m2 K			
	Class B	Class A	Class A+	Class A++
Roofs Ceiling in contact outdoor	0.16·K*	0.10·K	0.09·K	0.08·K
Floors contact with ground Floors over unheated basement and crawl spaces	0.25·K	0.14·K	0.12·K	0.10·K
External walls	0.20·*K*	0.12·*K*	0.11·*K*	0.10·*K*
Windows	1.6·*K*	1.0·*K*	0.85·*K*	0.70·*K*
Door and gates	1.6·*K*	1.0·*K*	0.85·*K*	0.70·*K*

*K=20/(Ti-Te), Ti indoor temperature, Te outdoor temperature.

The energy mix of Lithuania differs from the one of the EU-28: the most notable difference is a much higher share of gases and much lower share of solid fuels. Compared to 1995, the share of nuclear has decreased from 36% to 0%, due to the closure of the Ignalina nuclear power plant. Consequently, all other energy sources increased their share of gross inland energy consumption. The share of solid fuels and petroleum and products increased from 2% to 5% and from 35% to 40%, respectively. However, the share of renewable energy is experiencing the most striking change, with a sharp increase by 18 %. The share of gases increased from 23% to 35%.

The housing sector has estimated to have the largest energy saving potential. Lithuanian multi-family buildings consume about 9.5 TWh of energy per year, and refurbished buildings can save about 4.75 TWh per year. Multi-family buildings can be divided into four categories according to their level of heat consumption:

1. Buildings using a low amount of energy (10 kWh/m^2 per month); these are newly constructed or high-quality buildings (4.6%).
2. Buildings using an average amount of energy (15 kWh/m^2 per month); these are newly constructed or other insulated houses (17.3%).
3. Buildings using a high amount of energy (25 kWh/m^2 per month); these are old houses targeted for renovation (55.7%).
4. Buildings using a very high amount of energy (35 kWh/m^2 per month); these are old, very poorly insulated buildings (22.4%).

The average annual heat consumption in Lithuanian buildings is significantly higher (about 209 kWh/m^2) as compared to Scandinavian countries (about 128 kWh/m^2) [25]. The reason is closely related to energy performance of the Lithuania's building stock.

More than 37,267 multi-family buildings in Lithuania contain three or more apartments. Since the majority of multi-family buildings (about 35,000 buildings) in Lithuania were built before 1993 according to already outdated building codes, most of the buildings are uneconomical and consume a significant amount of energy[26].

Some 66 % of the population lives in multi-family buildings built before 1993, out of which 26 % were built before 1960, 65 % were built in 1960–1990, and 9 % were built after 1990. As a result, household expenses for space heating in Lithuania are significantly higher than in many other EU countries: for 50 m^2 dwelling, it accounts for 13.3% of total household expenses in Lithuania, while it reaches 8.0% in Estonia and only 1.5% in Scandinavian countries[27]. Most (97%) of the apartments are private, and only 3 % belong to the municipal rental stock.

Specific energy consumption by households is above EU average and decreased at a slightly slower pace than the EU average. This could mean that there remains untapped potential to improve energy efficiency in the residential sector. In 2014, Lithuania reinvested all the revenues from the auctioning of ETS allowances (EUR 17.3 million) to improve energy efficiency of buildings and for installation of renewable energy resources in public and private buildings. Between 2014 and 2020, EU Cohesion Policy will invest some EUR 540 million in energy efficiency improvements in residential and public buildings and in enterprises, as well as in high efficiency cogeneration and district heating in Lithuania. These investments are expected to contribute to around 30 000 households with improved energy consumption classification, and decreased primary energy consumption of public buildings of around 60 000 000 kWh per year.

1.2.2 Indoor environmental quality

Table 5 shows guideline values related to indoor environmental quality from WHO [28] and EU [20], as well as national values: Finland [29] and Lithuania [30, 31]. In Finland, a government decree for housing and health was issued in 2015 [32]. The decree has specified new action limits, while the guideline values are still the same. For example, the action limit for indoor carbon dioxide (CO_2) concentration is given relative to outdoor condition (1150 ppm above outdoor level). Total volatile organic compounds (TVOCs) are included, as well as single organic compound with the limit of 50 µg m^{-3}.

Table 5. Guidelines from WHO, EU or national levels.

Parameter	Unit	WHO	EU	National guideline	
				Finland	Lithuania
Tc	°C	-	-	16-18 [1]	-
Tw	°C	-	-	18-26 [2]	18-22
RHc	%	-	-	-	-
RHw	%	-	-	20-60	35-60 [3]
CO_2	ppm	-	-	1150 > outdoor	1200
CO [4]	ppm	8.6 (8h); 25 (1h)	10 (8h)	7	2.43 (24 hr)
$PM_{2.5}$	µg/m^3	25 (24 hr)	25 (yr)	-	40 (24hr)
PM_{10}	µg/m^3	50 (24 hr)	50 (24 hr); 40 (yr)	-	50 (24hr)
NO_2	µg/m^3	40 (yr); 200 (hr)	200 (hr); 40 (yr)	-	40 (24 hr)
Formaldehyde	µg/m^3	100 (30 min)	-	50 (yr)	100 (30 min) 10 (24 hr)
Radon	Bq/m^3	100 (yr)	-	100/200/400 [5]	400
TVOCs	µg/m^3	-	-	400	100 [6]

[1]Floor temperature is 18 °C from guideline in 2003.
[2]Recommended "good level" of room temperature is 21 °C ("adequate level" is 18 °C), and should not be above 26 °C, unless high temperatures is due to outdoor temperature. During the heating season, indoor temperature should not exceed 23..24 °C;
[3]In Lithuania, the values for RHw only refers to heating season
[4]Values refer to maximum daily 8 hour mean.
[5]Guideline values in Finland: 100 Bq m^{-3} (new buildings); 200 Bq m^{-3} (built after 1992).
[6]Lithuanian guidline is for aliphatic hydrocarbons of C1-C10 structure (100 mg/m^3).

1.3 Objectives

Aims of the INSULAtE project were to comprehensively demonstrate the impacts of improving energy efficiency (EE) of buildings on indoor environmental quality (IEQ) and occupant health utilizing objective and quantitative measures, combined with validated survey tools for health impact assessment. Also testing of new technologies for monitoring changes in indoor environmental conditions and occupant health were included as a part of the project activities. Along with demonstrating the effects of improving EE on IEQ and health, the project aimed to improve the knowledgebase in order to support the implementation of the policies related to energy performance in Europe.

Specific objectives of the project include the following:

1) To develop a common protocol for assessment of the impacts of building energy efficiency (EE) on indoor environmental quality (IEQ) and health

2) To demonstrate the effects (both positive and negative) of EE on IEQ and health in 2-3 European countries

3) To develop guidance and support the implementation of the related policies; transnational networking and dissemination of information.

2 Material and methods

2.1 Recruitment and schedule

Multi-family buildings that were planned to be retrofitted 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 3). The buildings were chosen from among volunteers: primary criteria were planned retrofits, which had to be related to energy efficiency and finished before the fall of 2015. Also some control buildings, which were not retrofitted during the project, were included.

Recruited apartments were selected from volunteering occupants, who did not receive any monetary compensation for participating in the study. Buildings were added to the study on a continuous basis starting from December 2011. The retrofit usually took place in the following year after the baseline measurements.

In the first phase, case studies were performed in 16 multi-family buildings (94 apartments) from Finland and 20 buildings (96 apartments) from Lithuania. In the second phase, 31 multifamily buildings were included so that the total number of multifamily buildings studied in Finland was 47. Additional case studies were performed in a set of single-family and multi-family houses and school buildings from inland, Lithuania, Latvia, Estonia, and UK. These additional case studies were conducted for feasibility assessment, as well as in connection with testing of new methods (data not shown).

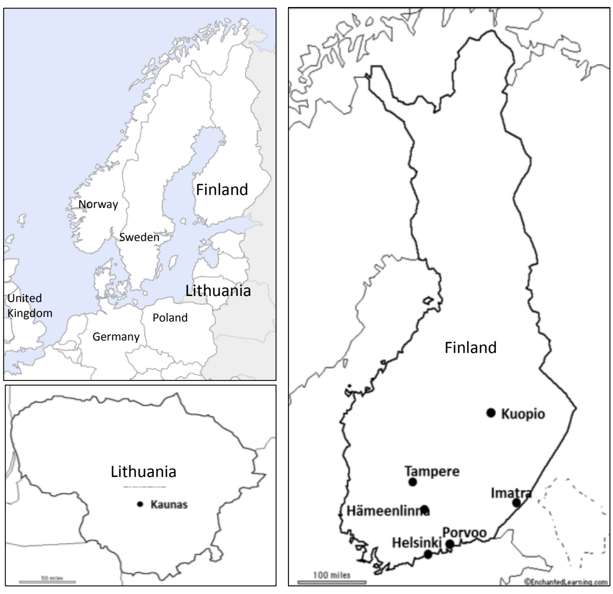

Figure 3. Maps showing the study locations, and regions of recruited buildings.

2.2 Methodologies

2.2.1 Building investigations

Building investigations are an essential part of planning of retrofit process, as they provide information about the condition of buildings. They commonly start from collecting existing information from available documents and interviewing building owners and occupants, followed by building walkthroughs utilizing checklists and other non-destructive assessment methods, and are complemented by measurements as necessary.

In INSULAtE project, necessary background information about building characteristics and condition was collected from the building owners by a questionnaire, including building dimensions and volume, thermal resistances of building envelope, types of heating and ventilation systems, retrofit history, and energy consumption (see Appendix A). In addition, field technicians collected information utilizing checklists and basic measurements (see Appendix B), including external shadowing and solar facing, air tightness, indoor-outdoor pressure difference, and air flows through vents in bathroom, kitchen, or closetz (if applicable). Table 6 summarizes building investigations conducted.

Table 6. Building investigations conducted in INSULAtE project.

Parameter [unit]	Method
Thermal resistances of building envelope	Questionnaires to building owners/house managers
Air tightness of building envelope	Questionnaires to building owners, blower door testing in some cases[1]
Air pressure differences [Pa]	Measured (usually) against outdoor and staircase[2]
Air exchange rate [ACH, 1/h]	Calculated based on measured air flows from ventilation outlets and information on the apartment volumes[3]
Thermal index	Calculated based on measured envelope surface temperatures[4,5] and indoor and outdoor temperatures
Continuous indoor temperature [T, °C] and relative humidity [RH, %]	Data loggers[6] with one hour resolution. Average T and RH in occupied zone, T and RH at the coldest spot.
Indoor absolute humidity [g/m^3] and moisture gain [g/m^3]	Calculated based on measured indoor T and RH and meteorological data of outdoor T and RH.
External shadowing and solar facing	Visual inspection
Condition and operation of heating and ventilation systems	Questionnaires to building owners
Energy sources and distribution	Questionnaires to building owner

[1]Minneapolis blower door model 4, according to standard EN13829 method B (under pressurized).
[2]Testo 512 differential pressure meter with pressure range of 0 to 2 hPa, resolution 0.001 hPa, overload 10 hPa and accuracy ±0.5% of fsv. The temperature range is 0 to 60°C and resolution 0.1°C.
[3]Testo 417 rotating vane anemometer with built-in 100mm vane and temperature probe. The vane has a +0.3 to +20 m/s measurement range, ±(0.1 m/s +1.5% of mv) accuracy and 0.01 m/s resolution. The temperature probe has 0 to +50 °C measurement range, ±0.5 °C accuracy, and 0.1 °C resolution. Each ventilation outlet was measured; measured values were not reliable if the outlet was irregular or the air flow was too small.
[4]Testo 830 T1 infrared temperature meter with 1-point lazer. Range -30...+400 °C, accuracy 0.5 °C.
[5]Thermal camera,ThermaCAM B2, FLIR Systems AB, Ruotsi. Range -20…55 °C, 160x200 pixels. Measurement range -15…+45 C, accuracy +-2°C or 2%.
[6]DT-172 logger, Shenzhen Everbest Machinery Industry Co., Ltd, China. T range -40 -+ 70 °C, accuracy ± 1 °C; RH range 3 - 100%, accuracy ± 3%

2.2.2 Environmental monitoring

A comprehensive IEQ assessment covers four environmental aspects including thermal conditions, indoor air quality (IAQ), and visual and aural comfort. Previous studies had indicated that the main effects related to improved energy efficiency surround thermal conditions and the potential for poor IAQ if ventilation is insufficient [33]. Therefore, measurements of IEQ parameters focused on thermal conditions and IAQ, while aspects related to visual (lighting) and aural (noise) comfort were evaluated by occupant surveys.

Data loggers and passive samplers were set up during the first visit in each apartment (Table 7). Following visits were scheduled 24 hours, one week, and two months later for picking up loggers and samplers. The visits were primarily conducted during heating seasons in order to minimize outdoor impacting the results. In some cases, the monitoring was extended over summer. Follow-up visits (after retrofits) were done during corresponding season as the first visits.

Two months continuous monitoring of temperature (T) and relative humidity (RH) was initially planned, which in some cases was extended for over one year in order to study seasonal variations. Two loggers per apartment were placed, one 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), presented as Tc and RHc. The other logger was placed to on average occupied zone, e.g., middle of the living room (1.2-1.5 m above ground, i.e. human breathing zone as seated), presented as Tw and RHw. All units used in the study were new and recently manufacturer calibrated.

Outdoor data during the measurement 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).

For carbon dioxide (CO_2) and carbon monoxide (CO) measurements, new, factory calibrated sensors for were utilized. Side-by-side simultaneous tests before and after the baseline measurements were conducted, based on which replicate precision ranged from 5% to 11%, and sensors were sent to manufacturer’s calibration as needed.

Table 7. Indoor environmental monitoring and sampling.

Parameter [unit]	Method
Carbon dioxide (CO_2) and carbon monoxide (CO) concentrations [ppm]	Every minute during a 24-hour period[1]
Indoor and outdoor 24-hour particulate matter (PM) concentrations and size distributions [µg/m^3]	Every minute during a 24-hour period using optical particle counters[2] Especially PM10.0 and PM2.5 concentration. Utilized in calculation of I/O-ratio
Nitrogen dioxide (NO_2) concentrations [µg/m^3]	Passive sampler exposed for 7 days[3]
Formaldehyde (CH_2O) [µg/m3]	Passive sampler exposed for 7 days[4]
Volatile organic compounds (VOCs, represented by benzene, toluene, ethylbenzene and xylenes (BTEX)) [µg/m^3]	Passive sampler exposed for 7 days[5]
Radon concentrations [Bq/m^3]	Passive sampler exposed for one[6] or two[7] months
Concentrations of bacteria and fungi in settled dust samples [Cell/(m^2*day)][8]	Samples collected on SDBs[9] for two months, vacuumed onto filter casettes[10] and analyzed using qPCR technique[11]
Concentrations of mineral fibers in settled dust [fiber/cm^2]	Samples collected on Petri dishes for one week, replaced on dustlifters[12] and analyzed using Optical microscope[13]

[1]HD21AB/HD21AB17, Delta OHM, Italy. Range 0 - 5000 ppm, accuracy ±50 ppm or ± 3%
[2]OPCs, Handheld 3016 IAQ, Lighthouse Inc, USA
[3]Difram100 Rapid air monitor containing trietanolamine (TEA) absorbent (Gradko, Ltd., England)
[4]Radiello™ Cartridge containing 2,4-dinitrophenylhydrazine coated Florisil adsorbent (Sigma-Aldrich)
[5]Radiello sorbent tubes preloaded with an active charcoal adsorbent
[6]Gamma dose rate measurements with standard electrets E-PERM™, Rad Elec Inc.
[7]Alpha track method
[8]Unit refers to cell equivalents per square meter
[9]20 × 45 cm standardized-placed acquisition-surfaces
[10]0.45µm MCE filter membranes, Zefon International, US
[11]quantitative polymerase chain reaction (qPCR)
[12]BM-Dustlifters (BVDA International, the Netherlands)
[13]Microscope Optika B–500 TiPh, Italy

With respect to particulate matter (PM), indoor vs. outdoor concentration ratios (I/O ratio), concentration decay rates ($PM_{2.5}$), background (night time) concentrations ($PM_{2.5}$), and $PM_{2.5}/PM_{10}$ concentration ratios were calculated based on the original data. These are additional indicators used to assess the behaviour of indoor and outdoor pollution sources and their impact to IAQ.

I/O ratio shows the magnitude of the indoor pollutant concentration against outdoor concentration. If I/O<<1, there are no indoor pollution sources and IAQ primarily is affected by outdoor air. In case of 0.5<I/O<1, presence of indoor sources is recognized, but they are not prevailing. In case of I/O>1, there are strong pollution sources indoors, affecting IAQ. In case of strong indoor pollution events, I/O ratios up to 10 has been observed. PM concentration decay rates indicate the percentage of the pollutants removed in 1-hour period when there are no activities affecting indoor concentrations. The particles are removed from air mainly due to ventilation and deposition on surfaces, while they may come to indoor environment with supply air. Night time concentrations of pollutants indicates the pollution levels originating primarily from outdoor air, but also from continuous indoor activities (such as humidifiers). $PM_{2.5}/PM_{10}$ ratio indicates particle size distribution. Larger particles as reflected by PM_{10} are occurring due to mechanical generation (such as resuspension due to walking and vacuuming), while smaller particles ($PM_{2.5}$) are either emitted from thermal sources or formed from gaseous pollutants by chemical reactions.

Nitrogen dioxide (NO_2) samples were analysed by Gradko, which laboratory was accredited by United Kingdom Accreditation Service. Formaldehyde (CH_2O) samplers were analysed with ultra-fast liquid chromatography coupled with UV/VIS and diode matrix detectors system (Prominence UFLC, Shimadzu, Japan). The analysis of VOCs samples was performed by gas chromatography (GC MS-QP2010 Ultra, Japan) coupled to mass spectrometer (GC/MS) using helium (He) as a carrier gas. The equipment was calibrated before the analyses by injecting standard solutions of compounds: BTEX (benzene, toluene, ethylbenzene, xylenes).

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 [34]. Lithuania used samplers suggested by the Lithuanian Radiation Protection Centre, with one month measurement period [35-37].

Settled dust was collected on settled dust boxes (SDBs). 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 centres to be analysed for selected fungal and bacterial groups using previously published qPCR assays and approaches [38-41].

Settled dust was also collected on petri-dishes, which were then prepared for fibre analysis by using adhesive gel tapes to transfer fibres on a microscope slide. Analysis and counting was performed by the PCOM method, with an integrated camera and software for fibre dimension analysis. This method allows determining not only the surface density of fibres, but also their structure properties, and visually distinguishes mineral fibres from the non–mineral.

2.2.3 Occupant surveys

Occupant surveys were used to collect information concerning occupant perceived housing satisfaction, including thermal comfort, satisfaction with IAQ, lighting, and noise disturbance (see Appendix C). One adult per apartment was asked to fill in a questionnaire, which have been developed, tested, and used in previous housing and health studies [5]. 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 behaviour, health and well-being; and background information (e.g. respondent's age and gender). In addition to the questionnaire, 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.

A total of 234 and 187 occupants (response rate 94% and 75%) responded to the questionnaire in Finland, whereas 57 and 27 occupants (response rate 59% and 28%) responded in Lithuania before and after retrofit, respectively.

2.3 Data analysis

A macro-embedded 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.

Concentrations for continuous measurements, e.g., CO_2, CO, and PM were calculated only for samples that reached 75% or more of the intended 24 h period ($\geqslant$ 18 h). Table S1 summarizes these data during the study period.

For continuous variables, correlation coefficients were calculated. Descriptive statistics such as frequencies, means (medians), 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 or Mann Whitney U (nonparametric) tests were used for test the differences in medians, and F and Tukey's tests for means.

The maximum moisture content of air (without condensation) or saturated vapor density is depended on temperature according to empirical formula [42]:

$$V_{sat} = \left[4.85 + 3.47 \times \frac{T}{10} + 0.945 \times (\frac{T}{10})^2 + 0.158 \times (\frac{T}{10})^3 + 0.0281 \times (\frac{T}{10})^4 \right] \times 10^{-3} \tag{1}$$

where V_{sat} = saturated vapor density, g m^{-3}, and T=temperature, ºC. The relative humidity (RH, %) express relation between moisture content in air (V_{air}) and saturated vapor density (V_{sat}).

$$RH = \frac{V_{air}}{V_{sat}} \times 100\% \tag{2}$$

where V_{sat} (g m^{-3}) is calculated using formula (1);.

According to the Finnish Housing Health Guide, thermal index (TI) values were calculated based on following formula (1):

$$TI = \frac{(T_S - T_O)}{(T_i - T_O)} \times 100\% \qquad (3)$$

where T_s = surface temperature, ºC; T_o = outdoor temperature, ºC; and T_i = indoor temperature, ºC.

Air change rate (ACR) during the night time was calculated from the time profiles of CO_2 concentrations. Night-time ACRs were estimated based on the average number of occupants in the considered volume and average CO_2 level [43]:

$$ACR_{night} = \frac{Q_{night}}{V_{night}} \times t_{night} \qquad (4)$$

where ACR_{night} = air change rate during the night time, h^{-1}; Q_{night} = air flow rate during the night time, m^3 h^{-1}; V = volume of bedroom or dwelling according to the opening state of the door at night; t_{night} = the duration of night (1 to 5:00 am, where the occupants were supposed to be sleeping).

With

$$Q_{night} = \frac{Metabolic\_rate(night)}{\left(C_{night} - C_{out}\right) \times 10^{-6}} \qquad (5)$$

Where

$$\begin{aligned} Metabolic\_rate(night) &= \sum_{occupants} individual\ Metabolic\_rate(night) \\ &= \sum_{occupants} CO_2 metabolic\ rate(age, sex) \times OR \end{aligned} \qquad (6)$$

Where

$$OR = \frac{Number\ of\ timesteps\ with\ the\ individual\ present\ in\ the\ volume}{Total\ number\ of\ timesteps\ in\ the\ period} \qquad (7)$$

where OR represents occupancy ratio. Metabolic-related CO_2 levels were given by the reference[43]. The outdoor CO_2 level was assumed to be constant.

Questionnaire data were analyzed using SPSS Statistics version 22 for descriptive statistics and compared to corresponding reference data available from Finland [44]. General estimation equations (GEEs) were used for multivariate analyses. The models were fitted with unstructured covariance structure and binominal link-function. In these models, individual responders and buildings, as well as time of questionnaire were identified by the ID-, building-, and time (1st/2nd) - variables, and the results were adjusted for respondents' gender and age.

In the following chapters, buildings that were retrofitted are referred to as "cases" and buildings that were not retrofitted as "controls". Similarly, occupants from retrofitted buildings are referred to as "case" group and occupants from control buildings as "control" group. First (1st) measurement refers to the baseline situation (before retrofits in case buildings) and second (2nd) measurement to the situation at the follow-up (after retrofits in case buildings).

3 Results from Finland

3.1 Buildings and energy

3.1.1 Building characteristics

Characteristics of the recruited buildings were collected from the building owners or house managers (Table 8). The final sample included 46 buildings (241 apartments) from Finland. Out of these buildings 38 buildings were retrofitted (referred to as “cases”), while rest of them were “controls”. The average age of the recruited buildings was 43 years and their average floor area is 3,430 m^2. Most of the buildings (90%) have district heating, while some of them have water circulated radiators or local central heating/fireplace. The majority of the buildings have mechanical ventilation system (85%). (Note: some buildings had limited or missing information.)

Table 8. Characteristics of the recruited buildings in Finland.

Parameters	N	Percent, %	Average	SD
No. of buildings	45	98	-	-
No. of apartments	36	78	43	27
No. of floors	32	70	5	3
Building age, year	42	91	43	13
Building area, m^2	22	48	3430	2494
District heating	31	90	-	-
Ventilation system				
Mechanical	34	85	-	-
Natural	34	15	-	-

3.1.2 Retrofit activities

Figure 4 shows the percentages of case buildings with different types of retrofits, categorized into buildings that were undergoing "focused" (N=28) and "deep" (N=9) energy retrofits. Focused energy retrofits (FER) included system upgrades, e.g. lighting and HVAC equipment, or replacing windows (only); while deep energy retrofits (DER) represented more comprehensive energy efficiency measures, addressing multiple systems at once.

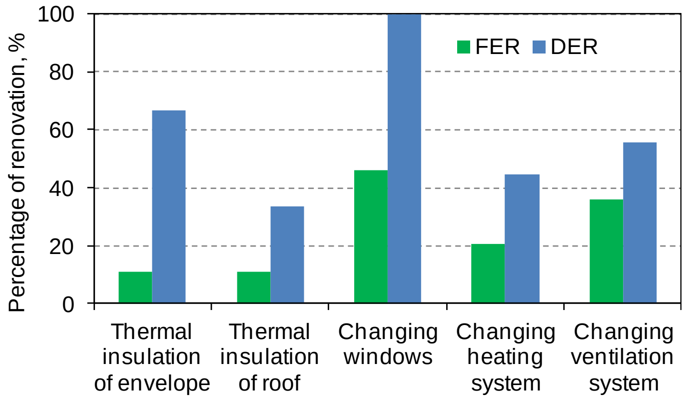

Figure 4. Percentage of buildings with different types of retrofits in Finland (FER: focused energy retrofits; DER: deep energy retrofits).

3.1.3 Energy efficiency and sources

Figure 5 presents ET-values of the case buildings before retrofits. Energy certificates are valid for ten years and therefore only one building had energy certificate with E-value. Also after the retrofits, none of the buildings had obtained new energy certificates with E-value.

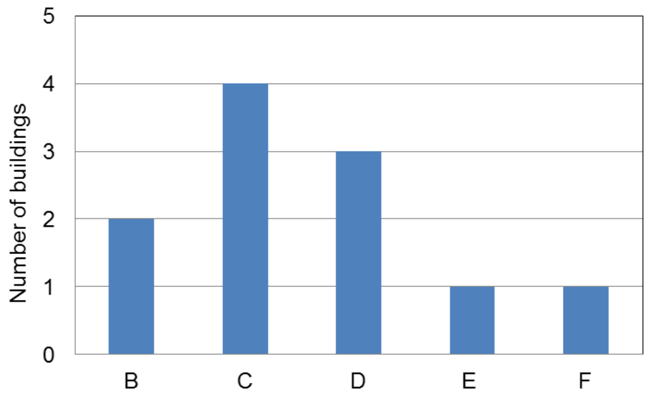

Figure 5. ET-values before retrofits in Finland.

Figure 6 presents normalized space heating energy consumption before and after retrofits. All buildings had district heating. An average of 21 % reduction in the heating energy consumption was observed after retrofits as compared to the situation before retrofits.

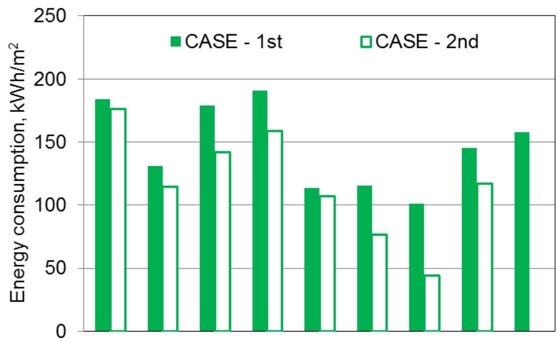

Figure 6. Heating energy consumption in Finland.

3.2 Building investigations

3.2.1 Thermal resistances and airtightness

Theoretical thermal resistance values (or U-values, W/m^2 K) of the case buildings fulfilled the regulations existing at the time of construction. Since most of the case buildings were constructed between 1960 and 1980, Table 9 presents the most typical U-values of the envelope structures. Figure 7 shows U-values of three case buildings before and after retrofits in Finland. Most typically old windows (U-value 2.1 W/m^2 K) were replaced with new windows (U-value 1.0 W/m^2).

Table 9. Most typical U-values of the structures of case buildings in Finland.

Structure	U-value, W/m^2 K
Outer walls	0.40 … 0.28
Roof	0.40 … 0.36
Floors	0.40 … 0.29
Windows	2.1
Doors	1.4

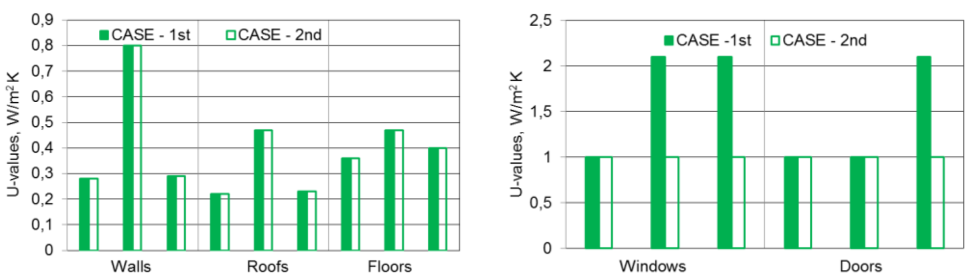

Figure 7. U-values of three case buildings in Finland.

Balconies in the case buildings were usually glazed. Balcony glazing improves thermal conditions of the balcony and reduces energy losses of the building envelope. Based on the field measurements [45] the average temperature of an open balcony was about 0.8 °C higher and in glazed balcony about 3.7 °C higher than outdoor temperature during heating season. Heat losses through balcony are expected to be lower, respectively.

In previous studies average airtightness of 56 apartments in multifamily buildings has been measured [46]. The average n_{50}-value was 1.6 h^{-1} ranging from 0.3 to 5.3 h^{-1}, and it was below 1 h^{-1} in 49% of these apartments. From our case buildings, air tightness was measured from three buildings (16 apartments before retrofits and 12 apartments after retrofits). The results of these measurements are shown in Table 10.

One apartment in building 1 had extremely high air leakage (10.8 h^{-1} before retrofit and 5.9 h^{-1} after retrofit), which was related to a potential air leakage within suspended ceiling to neighbour apartments or air ducts. Excluding the extreme values, air leakages before retrofits varied from 1.2 to 2.5 h^{-1} and after retrofits from 0.6 to 2.3 h^{-1}. In case building 1 and 2, air leakage values generally decreased, whereas in case building 3 the values slightly increased in the two apartments measured after retrofits. The reason for the increased values were found to be unsealed installations related to renewed ventilation systems and were later on corrected by the contractor.

Table 10. Results from air tighetness measurements in three Finnish case buildings.

Building	Case 1, n_{50} [h^{-1}]		Case 2, n_{50} [h^{-1}]		Case 3, n_{50} [h^{-1}]	
Apartment	1st	2nd	1st	2nd	1st	2nd
1	10.8[1)]	5.9	1.7	0.6	2.1	2.3
2	2.5	1.6	1.9	0.8	1.3	1.6
3	2.1	0.9	1.8	1.3	2.4	-
4	1.8	1.5	1.7	0.8	1.2	-
5	2.0	1.1	2.4	1.3	1.4	-
6	-	-	-	-	1.5	-
Average	3.9	2.2	1.7	2.0	1.9	1.0
SD	3.9	2.1	0.5	0.5	0.3	0.3
Median	2.1	1.5	1.5	2.0	1.8	0.8

3.2.2 Air pressure differences and air change rates

Table 11 presents pressure differences between indoors and both staircase and outdoors. As expected, the pressure differences are usually lower in buildings equipped with natural ventilation. The pressure differences are slightly higher after retrofits in the case buildings with mechanical ventilation. The pressure differences in the control buildings are about the same in both measurements.

Pressure differences against staircase are a bit lower and against outdoor a bit higher after retrofits in buildings equipped with natural ventilation. Since one-time pressure difference measurement is strongly depended on weather conditions (such as wind and temperature) during the time of the measurements, and the number of measurements conducted is relatively low (15 before and 10 after retrofits), it is not possible to draw definite conclusions based on these results.

Table 11. Pressure difference (∆P) against staircase and outdoors in Finland.

∆P, Pa	CASE_Mechanical				CASE_Natural			
	Staircase		Outdoors		Staircase		Outdoor	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
N	134	89	128	89	15	10	15	10
Ave	-4.2	-4.9	-13.8	-14	-4.5	-3.8	-7.0	-7.9
SD	2.7	5.0	5.5	9	3.9	1.6	4.2	2.7
Med	-4.1	-5.2	-13	-11.6	-3.1	-4.0	-5.7	-8.0
5th	0.1	0.1	0.1	0.2	0.1	0	0.1	0.1
95th	1.6	3.1	3.2	5.6	2.0	1.0	2.1	1.7

	CONTROL_Mechanical			
N	11	10	11	10
Ave	-4.2	-4.9	-13.8	-14
SD	2.7	5.0	5.5	9
Med	-4.1	-5.2	-13.0	-11.6
5th	0.1	0.1	0.1	0.2
95th	1.6	3.1	3.2	5.6

Table 12 presents results from ACR measurements.

Table 12. Air change rate (ACR) in Finland.

ACR, 1/h	CASE_Mechanical		CASE_Natural		CONTROL_Mechanical	
	1st	2nd	1st	2nd	1st	2nd
N	119	70	11	8	10	8
Average	0.43	0.48	0.25	0.25	0.59	0.45
SD	0.23	0.24	0.12	0.09	0.26	0.15
Median	0.42	0.43	0.24	0.21	0.60	0.40
5th	0.09	0.18	0.08	0.15	0.25	0.26
95th	0.87	0.85	0.45	0.39	0.97	0.63

ACR is slightly higher after retrofits in the case buildings with mechanical ventilation, while it is same before and after retrofits in the case buildings with natural ventilation. ACR is lower based on the second measurement in the control buildings. It should be taken into account that the number of measurements in the control buildings is low.

3.2.3 Thermal index

Table 13 presents thermal indexes based one-time surface temperature, indoor and outdoor temperature measurement data. The thermal index was higher after retrofits in the case buildings, while in the control buildings the trend is opposite. There are some uncertainties related to the measurement. Most typically the coldest spot of envelope or surface temperature was measured near by balcony door. The field inspectors had to open the balcony door for installing outdoor T / RH meter and PM counter on the balcony prior to measuring surface temperatures. Opening the door could have lowered the surface temperatures resulting in lower thermal index values.

Table 13. Thermal index (TI) in Finland.

TI	CASE		CONTROL	
	1st	2nd	1st	2nd
N	134	101	8	7
Average	49.2	59.4	54.2	49.8
SD	19.5	16.3	10.3	10.8
Median	49.6	59.9	56.5	51.1
5th	19.0	32.5	37.6	36.9
95th	84.7	84,8	63.7	66.2

3.3 Environmental measurements and sampling

3.3.1 Thermal conditions

Table 14 presents result from T and RH monitoring. In the case study buildings, no differences were found for Tc/Tw after retrofits, but the percentage for apartments above “good level” of room temperature (21 ºC) increased by 4 % of the time, whereas frequency (5%) of high Tw (>23 °C) and low RHw (<20%) dropped by 8%. In the control buildings, indoor T in occupied zone (Tw) and cold spot (Tc) remained similar during 1st and 2nd measurements, but percentage of apartments with RHw values below recommended level (<20%) in the occupied zone decreased by 26% during the sampling period, which could be related to outdoor contitions (Figure 8).

Table 14. Indoor and outdoor temperature and relative humidity in Finland.

Statistics	Tw, °C CASE 1st	Tw, °C CASE 2nd	Tw, °C CONTROL 1st	Tw, °C CONTROL 2nd	Tc, °C CASE 1st	Tc, °C CASE 2nd	Tc, °C CONTROL 1st	Tc, °C CONTROL 2nd	Outdoor T, °C CASE 1st	Outdoor T, °C CASE 2nd	Outdoor T, °C CONTROL 1st	Outdoor T, °C CONTROL 2nd
N	156	118	30	21	145	103	16	13	164	120	30	21
Ave	22.9	22.7	23.0	22.4	20.5	20.5	20.0	20.5	2.4	3.4	-6.3	-0.8
SD	1.2	1.2	0.9	1.0	1.6	1.8	1.3	1.2	5.3	5.0	4.3	4.2
Med	22.9	22.8	23.0	22.4	20.7	20.8	20.0	20.5	2.2	2.1*	-4.9	-0.6*
5th	21.0	20.9	21.0	21.4	17.7	17.6	18.0	18.9	-5.8	-1.3	-12.0	-5.6
95th	24.7	24.6	24.0	23.7	22.8	23.5	22.0	22.1	10.6	11.4	-0.1	4.0
	RHw, %				**RHc, %**				**RHo, %**			
N	162	119	30	21	145	103	16	13	164	120	30	21
Ave	28.4	29.6	20	23.9	31.1	33.4	25	29.7	75.7	79.3	80	81.6
SD	6.8	6.5	5.4	5.5	7.3	6.7	6.1	3.9	8.3	7.4	9.8	9.2
Med	28.1	30.1*	18.0	24.0*	31.2	33.1*	22.0	27.7*	73.5	79.2*	87.2	89.1
5th	17.8	18.8	14.0	15.8	20.4	23.2	18.0	24.8	66.2	67.1	67.3	71.4
95th	38.6	38.3	30.0	31.9	42.2	43.7	35.0	35.1	90.8	91.4	90.6	92.3

*$p<0.05$ based on Mann-Whitney U Test (paired samples)

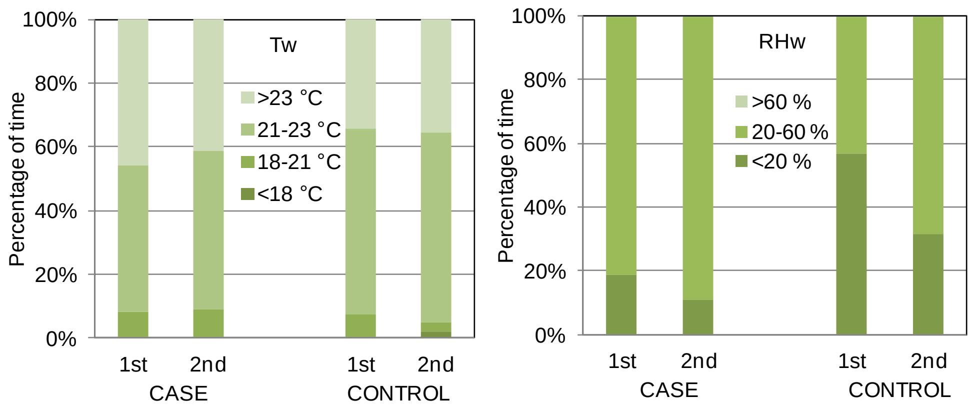

Figure 8. Percentages of time for different indoor temperature and relative humidity categories in Finland.

Table 15 presents indoor moisture content (MC) or absolute humidity calculated from Tw and RHw data as well as indoor moisture gain (MG), i.e., difference between indoor and outdoor moisture content, calculated based on indoor and outdoor T and RH data (see Equation 1).

Table 15. Indoor moisture content (MC) and moisture gain (MG) in Finland.

Statistics	MC, g/m³				MG, g/m³			
	CASE		CONTROL		CASE		CONTROL	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
N	135	101	8	7	135	101	8	7
Average	5.8	6.0	4.8	5.7	1.1	1.0	1.6	1.3
SD	1.5	1.2	1.1	0.7	0.9	0.8	0.9	0.8
Median	5.6	5.9	5.1	5.6	1.0	1.0	1.5	1.2
5th	3.5	4.4	3.5	4.8	0.0	-0.1	0.4	0.3
95th	8.3	8.0	6.3	6.8	3.0	2.6	2.6	2.4

The average indoor moisture content is higher based on the second measurements in all buildings (both cases and controls), which is related to higher average outdoor T and RH. However, the average indoor moisture gain is slightly lower based on the second measurements, indicating more effective ventilation and/or lower moisture load from indoor activities.

As shown in Table 16, we also calculated continuous “thermal indexes” (TIc) using measured data from cold spot and outdoor temperature data (see Equation 3). These values are generally higher than thermal index values calculated using coldest surface temperature (see Table 13). Temporal variation was assessed by calculating daily, weekly and monthly ranges, and no significant differences were found.

Table 16. Continuous “thermal index” (TI_C) in Finland.

TIc	CASE		CONTROL	
	1st	2nd	1st	2nd
N	143	102	16	13
Average	87.9	88.1	89.6	89.6
SD	6.7	8.3	5.2	5.9
Median	89.4	88.5	89.8	90.4
5th	75.6	73.3	80.8	80.8
95th	97.1	100.4	96.7	96.8

Estimated TIc by calendar week is presented in Figure 9. In the case buildings, median levels at the follow-up (2nd measurement) are slightly higher and the results appear to indicate a decreasing trend with higher outdoor temperatures. In the control buildings, the median levels showed similar pattern during both measurements; variations could be related to limited sample size (N=5 to 10 per week).

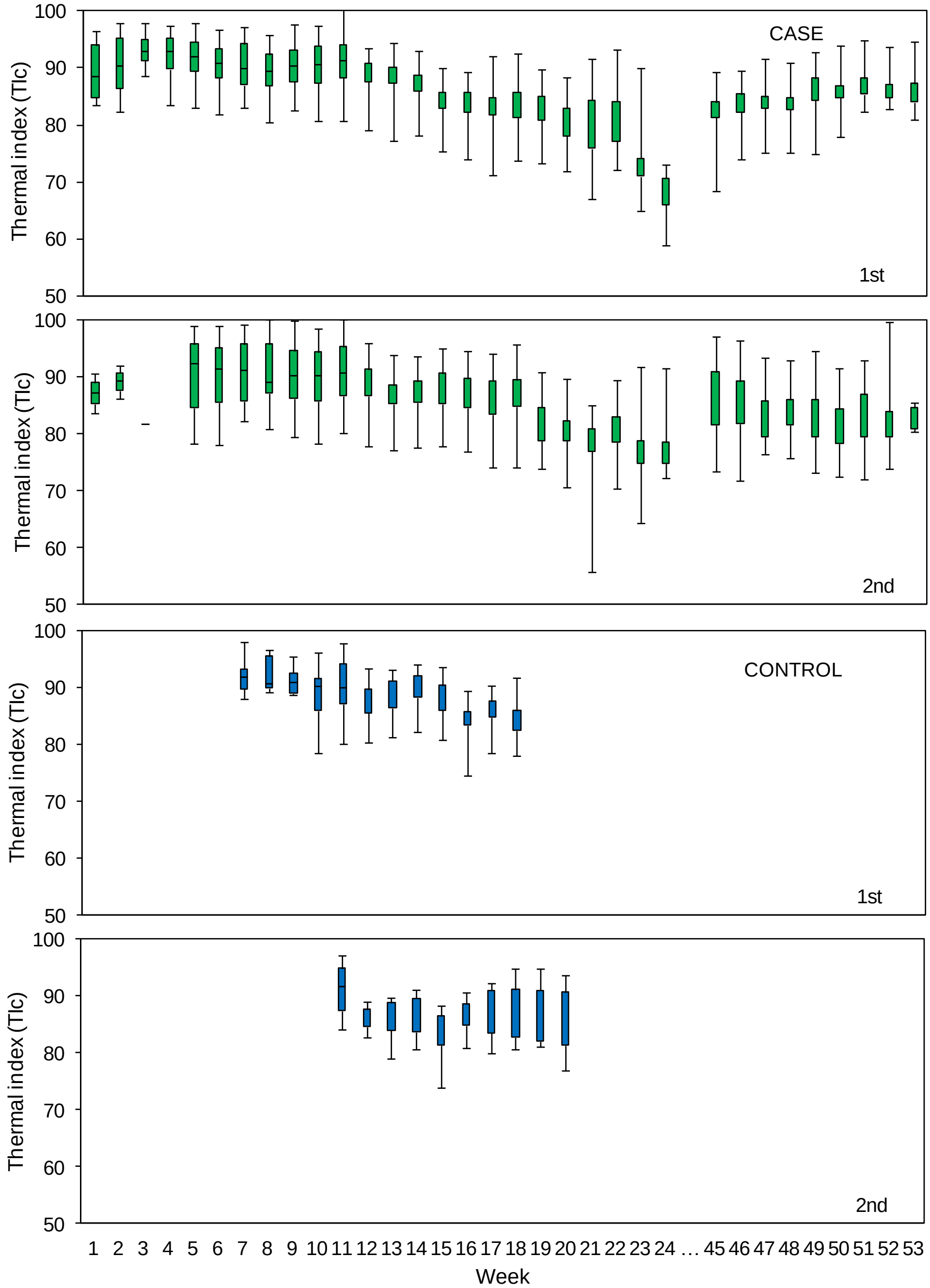

Figure 9. Continuous "thermal index" (TIc) by calendar week in Finland (N≥ 5 included).

3.3.2 Carbon dioxide

As presented in Table 17, CO_2 levels are slightly lower in the case buildings after retrofits (p=0.06 using Mann-Whitney U Test for paired observations). Similar trend is seen for night time concentrations (Table 18). Reduced percentages of time when average CO_2 concentrations are exceeding the guideline value (1000 ppm) and action limit (1500 ppm assuming outdoor concentration 350 ppm) are shown in Figure 10.

ACRs during the night time were calculated based on CO2 concentrations and no significant differences were found between 1st and 2nd measurements (Table 19). However, it seems that ACR based on CO2 concentrations are slightly lower after retrofits, while an opposite trend was seen with ACR based on airflow measurements. It could be useful to check the ventilation adequacy using CO2 measurements, since air flow measurements do not necessarily account for the effects of air leaks or air tightness of the building envelope and occupants or their behaviour (e.g. ventilation by opening windows and doors).

Table 17. CO_2 concentrations (ppm) in Finland.

CO_2, ppm	CASE		CONTROL	
	1st	2nd	1st	2nd
N	179	127	32	30
Average	738	697	628	625
SD	241	231	107	121
Median	683	635	629	609
5th	493	460	481	467
95th	1196	1103	819	838

Table 18. Average CO_2 concentrations (ppm) during night time (from 5 pm to 8 am in Finland.

CO_2,ppm	CASE_Mechanical		CASE_Natural		CONTROL_Mechanical	
	1st	2nd	1st	2nd	1st	2nd
N	119	70	15	10	11	9
Average	674	660	712	610	657	590
SD	166	185	158	147	129	105
Median	649	617	666	616	633	546
5th	460	461	582	484	508	482
95th	979	1034	1003	908	864	762

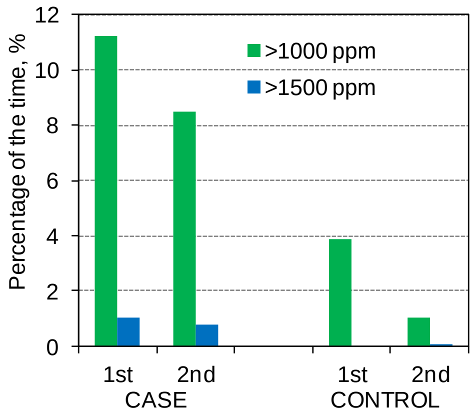

Figure 10. The percentage of time when CO_2 concentrations are exceeding 1000 ppm and 1500 ppm in Finland.

Table 19. Air change rate (ACR) based on CO_2 measurements during the night time in Finland.

ACR,	CASE		CONTROL	
1/h	1st	2nd	1st	2nd
N	101	74	14	7
Average	0.58	0.53	0.53	0.51
SD	0.99	0.37	0.3	0.3
Median	0.4	0.45	0.43	0.52
5th	0.16	0.14	0.25	0.23
95th	1.22	1.17	1.04	0.94

3.3.3 Particulate matter

Both $PM_{2.5}$ and PM_{10} levels measured in all apartments in Finland were within recommended limits (Table 20). Although Finland does not have specific guideline values for indoor PM, average values are below limits set by WHO. Moreover, even 95th percentile for indoor PM concentrations were below the limits. Outdor PM values were substantially higher, which indicates good filtration of outdoor pollutants. At the same time, indoor pollution sources or activity emitting particles was also low. Based on average values, no statistically significant differences were seen between the case and control buildings.

Table 20. Indoor and outdoor PM levels in Finland.

PM, µg/m^3	INDOOR				OUTDOOR			
	CASE		CONTROL		CASE		CONTROL	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
				PM2.5				
N	157	107	18	13	138	99	16	11
Ave	8.34	8.46	5.97	5.15	8.26	6.92	7.28	5.38
SD	14.65	17.71	5.88	5.78	7.55	6.10	4.77	5.04
Med	5.25	4.29	4.36	2.34	6.02*	5.47*	8.09	4.40
5th	1.89	1.40	2.11	1.18	1.85	1.12	1.10	1.01
95th	22.44	18.39	14.41	14.46	21.00	18.05	12.70	14.94
				PM10				
N	157	107	18	13	138	99	16	11
Ave	21.95	17.81	17.02	16.91	22.96	19.33	15.59	13.91
SD	27.25	21.12	14.88	23.20	21.96	21.52	15.92	8.96
Med	14.56	12.37	11.85	9.59	16.68	13.23	11.69	9.20
5th	5.62	4.64	5.61	4.14	4.22	2.52	2.87	4.12
95th	53.60	45.80	46.85	48.75	70.91	46.23	49.83	25.54

*$p<0.05$ based on Mann Whitney's test (paired samples)

The distribution of I/O ratios in Finish appartments is log-normal, with the median of 0.85 ($PM_{2.5}$) and 1.0 (PM_{10}), which indicates that the activities of inhabitants are most likely contributing to the IAQ in at least 50% of apartments (Table 21). The mean is affected by large values of I/O which reach 8.0 for PM_{10}, showing significant contribution of indoor activities to IAQ. This may be caused due to a variety of activities, including cooking, dusting, vacuuming, intensive walking, etc. Median I/A ratios for $PM_{2.5}$ are slightly higher at the follow-up (2nd measurements) in both case and control buildings. However, with respect to PM_{10}, median I/O ratio increases in the case buildings, whereas the trend is opposite in the control buildings. Although the change is not statistically significant, this could indicate that indoor sources of coarse particles may have more influence after retrofits in some cases. Median value for PM concentration decay rate is 0.47 h^{-1}, which means that the $PM_{2.5}$ concentration is reduced to almost half of its initial value during one hour period (Table 22).

Table 21. Indoor to outdoor PM ratios (I/O) in Finland.

I/O	$PM_{2.5}$				PM_{10}			
	CASE		CONTROL		CASE		CONTROL	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
N	136	96	16	11	136	96	16	11
Ave	1.74	2.73	1.46	1.99	2.14	2.52	1.99	1.58
SD	3.37	6.04	1.33	2.01	3.80	3.46	2.03	1.43
Med	0.85	0.91	0.78	1.14	1.00	1.27	1.27	0.79
5th	0.35	0.31	0.37	0.35	0.32	0.32	0.47	0.28
95th	4.76	10.38	3.64	5.67	8.01	10.44	5.28	4.12

Table 22. $PM_{2.5}$ indicators in Finland.

Statistics	Decay rate, 1/h				$PM_{2.5}$ background concentrations, µg/m³			
	CASE		CONTROL		CASE		CONTROL	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
N	148	105	17	14	156	105	18	13
Ave	0.49	0.52	0.64	0.53	3.63	3.27	2.14	2.11
SD	0.22	0.25	0.26	0.30	8.75	5.93	1.33	2.57
Med	0.47	0.47	0.60	0.51	2.40	1.99	2.30	1.19
5th	0.21	0.20	0.29	0.18	0.53	0.55	0.38	0.33
95th	0.83	1.03	1.01	0.96	7.41	6.67	3.88	6.26
	PM2.5/PM10 ratio							
N	155	106	18	13				
Ave	0.46	0.45	0.49	0.36				
SD	0.17	0.15	0.14	0.08				
Med	0.44	0.44	0.47	0.37				
5th	0.24	0.28	0.31	0.25				
95th	0.75	0.71	0.72	0.47				

The retrofit process did not affect the concentration decay rate. This observation is consistent with air change rate estimates. Overall, PM2.5 background concentrations were very low. The medians were slightly smaller at the follow-up (2nd measurements) in both case and control buildings, which could be related to similar trend seen in the outdoor concentrations. Finally, based on the PM2.5/PM10 ratio, almost half of particles were fine particles, which is typical for urban environments. The retrofits did not seem to have an effect on this particular indicator.

3.3.4 Carbon monoxide

Thirty to fifteen apartments had CO concentrations detected in the measurements, and the average levels were negligible (maximum concentrations were 1.38 and 0.65 ppm based on 1st and 2nd measurements, respectively). This shows that there were no major CO sources in the measured apartments, either originating from local combustion (such as cooking or fireplaces) or supplied from outdoor air (e.g. due to local traffic).

3.3.5 Gaseous pollutants

Results from analyses of CH_2O, NO_2, and selected VOCs (BTEX) are presented in Table 23. The levels were below recommended values, indicating good air quality in the apartments. There were some statistically significant differences spotted before and after retrofit in case of CH2O and BTEX's, namely, the medians decreasing from 18.2 to 16.4 for CH2O and increasing from 6.5 to 9.1 for BTEX after retrofits. However, differences of similar magnitude were observed in control buildings as well, thus we do not attribute these changes to retrofit process per se. While the concentrations of these pollutants could increase if the retrofit activities included indoor installations, such as new flooring or furniture, the effects of new materials could be diminished by use of low emitting materials or improved ventilation.

Table 23. Concentrations of gaseous pollutants in Finland.

Gaseous pollutants, µg/m^3	CH_2O				BTEX			
	CASE		CONTROL		CASE		COTROL	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
N	140	103	16	13	134	102	16	13
Ave	19.5	18.6	16.4	13.2	9.3	10.7	7.7	8.9
SD	7.7	8.0	5.1	3.4	12.0	6.7	6.3	4.5
Med	18.2	16.4*	15.9	13.5	6.5	9.1*	5.4	7.0
5th	9.1	10.1	8.5	7.8	1.6	5.2	2.8	4.4
95th	34.5	32.0	24.2	18.6	26.6	20.8	22.0	16.5

		NO_2		
N	145	104	16	13
Ave	7.2	7.0	3.9	5.7
SD	3.8	4.7	1.6	2.9
Med	6.2	6.0	3.9	4.9
5th	3.6	3.1	1.9	3.3
95th	13.5	12.5	6.4	10.4

*p<0.05 based on Mann Whitney's test (paired samples)

3.3.6 Radon

The highest levels of radon at the baseline (1st measurement) reached 350 Bq/m^3, with 12 apartments in six buildings exceeding 200 Bq/m^3. After retrofits three apartments in one building exceeded 200 Bq/m^3. These buildings were built before 1992, so the national guideline levels were not exceeded. However, it is recommended to consider renovation if 200 Bq/m^3 is exceeded. No significant differences were found after retrofits (Table 24).

Table 24. Radon concentrations in Finland.

Radon,	CASE		CONTROL	
Bq/m^3	1st	2nd	1st	2nd
N	132	88	13	12
Average	81	68	48	51
SD	71	57	23	30
Median	60	50	40	40
5th	20	20	26	26
95th	270	187	88	103

3.3.7 Fungi and bacteria in settled dust

Results from microbial analyses of settled dust are shown in Table 25. Data with sampling period > 40 days were included. The samples were analysed for selected groups of fungi and bacteria, i.e., *Cladosporium herbarum* (Cherb), *Penicillium spp./Aspergillus spp./Paecilomyces variotii* (PenAsp), Gram-positive and Gram-negative bacteria, and total fungi. Significant differences were found in both case and control groups, indicating temporal variation. However, Cherb, PenAsp, and total fungi showed higher reductions after retrofits in the case buildings. Perhaps removal of old building materials, cleaning activities, or improved ventilation or filtration after retrofits could explain some of the differences. The practical implications of decreased microbial content of settled dust is not readily know, as the methods are still under development.

Table 25. Content of selected fungi and bacteria in settled dust in Finland.

Microbial content Cell/(m²*day)	Cherb				PenAsp			
	Case		Control		Case		Control	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
N	81	56	11	10	81	56	11	10
Average	104	24	8	17	3124	604	1308	940
SD	249	69	7	32	9031	1179	2072	1199
Median	23	7*	7	5*	493	158*	236	609*
5th	0	0	1	0	39	0	78	52
95th	329	70	20	71	11382	2844	4809	2888
	Grampos				Gramneg			
N	81	56	11	10	81	56	11	10
Average	20585	29564	19190	25294	27995	5667	7430	8680
SD	35502	166490	26844	48698	70421	12341	8971	17437
Median	6498	1363*	6727	1569*	7944	1386*	5602	1816*
5th	661	5	2192	690	1254	3	557	210
95th	84411	32936	65560	117834	108162	23364	24318	38577
	Total fungi							
N	81	56	11	10				
Average	1579	321	404	431				
SD	3463	585	434	667				
Median	477	97*	148	138*				
5th	56	25	37	43				
95th	8381	1308	1076	1650				

*p<0.05 based on Mann Whitney's test (paired samples)

3.3.8 Mineral fiber

Surface concentration/density of mineral fibres (fiber/cm^2) was calculated from samples collected from 21 multifamily buildings (137 apartments) during the 1st measurements and in 16 buildings (73 apartments) during the 2nd measurement (Table 26). No statistically significant differences were found.

With respect to the case buildings, no minerals fibers were seen in 73% (88 of 121 apartments) before retrofits and the percentage remained same (45 of 62 apartments) after retrofits. From the control buildings, no mineral fibers were seen in 88% (14 from 16) of the apartments at the baseline (1st measurement) and 73% (8 from 11) apartments at the follow-up (2nd measuremement).

Table 26. Surface concentrations of mineral fibres in Finland.

Fiber/cm^2	Case		Control	
	1st	2nd	1st	2nd
N	121	62	16	11
Average	1.38	0.42	0.14	0.31
SD	7.83	0.77	0.38	0.52
Median	0.00	0.00	0.00	0.00
5th	0.00	0.00	0.00	0.00
95th	2.25	2.25	1.12	1.12

3.4 Occupant surveys

Information on occupants' background and housing characteristics, thermal conditions and perceived health and wellbeing was collected directly from the occupants. A total of 234 occupants (response rate 94%) answered to the questionnaire at the baseline (1st measurement), and 187 (75%) answered at the follow-up (2nd measurement).

3.4.1 Background characteristics

Table 27 shows some background characteristics of the respondents and their apartments. P-values shown in the tables are referring to the statistical testing of group level differences between 1st and 2nd measurements using chi-square test. The test does not take into account the dependency between the samples. Therefore, the test results are only used for screening purposes. Where significant differences were found on the group level, the results were further analysed using General Estimating Equations (GEEs).

We also tested the differences between the case and control buildings using chi-square test, but these results should be treated with caution due to small number of respondents from control buildings. A larger proportion of the respondents in the case buildings were females, and kept furry pets indoor less frequently than the respondents in the control buildings. On the other hand, the respondents in the control buildings were significantly more often tenants, they were younger, and had lived in their current apartment a shorter period of time, and had less children living in their apartments. Mechanical air supply and wood burning fireplace were more common in the control buildings at the baseline. At the follow-up the differences remained significant for tenure status and number of children living in their apartment. In addition, the respondents from the case buildings reported exercising more frequently.

Based on the preliminary screening, the respondents from the case buildings reported higher proportion of apartments having glazed balcony, trickle vents, and mechanical supply air after retrofits, corresponding with the targeted retrofit actions. Also saunas became significantly more common in the case group after retrofits.

Table 27. Questionnaire respondents' background characteristics in Finland.

Background characteristics	CASE					CONTROL				
	1st		2nd		p	1st		2nd		p
	N	%	N	%		N	%	N	%	
Gender, female	127	63	101	63	0.98	16	52	6	55	0.87
Smoking in the dwelling, never	187	94	142	90	0.15	27	90	10	91	0.93
Furry pets	27	14	22	14	0.90	6	20	3	27	0.62
Exercising several days per week										
Near dwelling	125	65	98	67	0.90	23	79	6	55	0.22
On the way to work	43	39	25	34	0.34	12	57	6	76	0.89
Elsewhere	52	43	50	53	0.40					
Percent of income spent for housing					0.42					0.12
< 15 %	42	22	26	17		8	26	1	10	
16–25%	62	33	39	26		10	32	4	40	
26-35%	37	19	40	27		1	3	2	20	
36–50%	33	17	30	20		7	23	1	10	
51–65%	10	5	10	7		4	13	0	0	
> 65 %	7	4	4	3		1	2	2	20	
Tenure status					0.28					0.69
Own	138	68	111	70		13	42	4	36	
Rent	65	32	46	29		17	55	7	64	
Other*	0	0	1	1		1	3	0	0	
Balcony	110	54	86	53	0.88	21	68	7	64	0.80
Covered balcony	**96**	**47**	**99**	**62**	**0.01**	12	39	4	36	0.89
Mechanical exhaust	62	31	49	30	0.98	9	29	6	55	0.13
Mechanical supply	**16**	**8**	**34**	**21**	**0.00**	10	32	3	27	0.76
Trickle vents	**31**	**15**	**66**	**41**	**0.00**	8	26	2	18	0.61
Wood burning fire place / oven	1	1	1	1	0.87	3	10	2	18	0.45
Sauna	**86**	**42**	**85**	**53**	**0.05**	17	55	4	46	0.59
	Mean	SD	Mean	SD	p	Mean	SD	Mean	SD	p
Age mean	57.9	19	58.2	17.4	0.88	47.5	18.6	49.6	16.1	0.75
Years lived in the current dwelling	13	13	13.2	12.5	0.87	7.8	10.1	11.3	11.2	0.37
Number of persons in the dwelling										
Adults (18-65 yrs)	1.4	0.6	1.4	0.7	0.91	1.1	0.6	1.1	0.6	0.79
Children (7-17 yrs)	0.8	0.9	0.8	0.8	0.87	0.4	0.7	0.8	1	0.39
Children (<7 yrs)	0.5	0.7	0.5	0.7	0.99	0.1	0.3	0	0	0.66

*includes: employers' housing, right of residence apartment, and others

3.4.2 Thermal conditions

Results related to occupant self-reported thermal conditions are shown in Table 28.

Table 28. Thermal conditions in Finland.

Thermal conditions	CASE					CONTROL				
	1st		2nd		p	1st		2nd		p
	N	%	N	%		N	%	N	%	
Typical temperature during heating season					0.33					0.35
<18°C	3	2	0	0		0	0	1	9	
18-20°C	33	17	19	12		9	30	4	36	
20-22°C	108	55	96	61		16	53	4	36	
22-24°C	46	23	39	25		5	17	2	17	
>24°C	7	4	4	3		0	0	0	0	
Thermal conditions in summer										
Suitable warm	111	58	92	57	0.93	15	48	8	73	0.16
Too cold	2	1	3	2	0.48	0	0	0	0	-
Too hot	103	51	68	42	0.11	14	45	6	55	0.59
Draughty	5	3	6	4	0.48	0	0	0	0	-
Cold floor surfaces etc.	5	3	2	1	0.40	0	0	1	9	0.09
Thermal conditions in winter										
Suitable warm	130	64	105	65	0.82	17	55	6	55	0.99
Too cold	45	22	36	22	0.97	15	48	3	27	0.22
Too hot	17	8	13	8	0.92	1	3	0	0	0.55
Draughty	58	29	34	21	0.10	5	16	3	27	0.42
Cold floor surfaces etc.	53	26	39	24	0.68	8	26	8	36	0.50
Open windows daily in kitchen for temperature control										
Summer	102	50	65	40	0.06	10	32	7	64	0.07
Winter	29	14	18	11	0.38	1	3	2	18	0.10
Open windows daily in bedroom for temperature control										
Summer	141	70	99	62	0.11	17	55	8	73	0.30
Winter	79	39	59	37	0.66	7	23	4	36	0.37
Open windows daily in living room for temperature control										
Summer*	**110**	**54**	**66**	**41**	**0.01**	9	29	5	46	0.32
Winter	37	18	22	14	0.24	2	8	2	17	0.26
Did not attempt to adjust thermostats in the past 12 mo.	85	43	70	44	0.86	18	58	4	40	0.32

* Further analysed with GEEs

Occupants from the control buildings reported significantly less opening windows daily in the living room as compared to the occupants from the case buildings at the baseline, and a similar (non-significant) trend was seen in the winter. After retrofits, occupants from the case buildings reported significantly higher temperatures during heating season as compared to the occupants from the control buildings.

In the case buildings, the respondents reported slightly higher indoor temperatures after retrofits as compared to the situation before retrofits, but the group level differences were not statistically significant. Similarly, reporting of too hot summer temperatures was less frequent among respondents from the case buildings after retrofits, as well as reporting of draught during winter.

There was a significant difference between 1st and 2nd measurements among the respondents in the case buildings in reporting less frequent daily opening of windows in their living room for temperature control in summer. The difference remained significant in the GEE model including respondents' age and gender. The trend was similar for other rooms and also during winter in the case buildings, whereas an opposite trend was seen among respondents in the control buildings.

3.4.3 Indoor environmental quality

Table 29 shows results from IEQ variables, mostly related to dampness and mould, odours, lighting, and noise. At the baseline, respondents from the control buildings reported significantly less frequently odours related to food, and daily noise disturbance related to traffic or industry as compared to the respondents from the case buildings. At the follow-up, the respondents from the case buildings reported odour related to tobacco smoke significantly less frequently as compared to respondents from control buildings.

Among the case group, reporting of odours appeared to become less frequent after retrofits. The group level differences were statistically significant for odours of tobacco, stuffiness, and sewage smell. The differences for stuffiness remained significant in the GEE model including respondents' age and gender. Also among this group, daily noise disturbance related to the dwelling and ventilation, plumbing, etc. systems appeared to become more frequent, whereas disturbance related to traffic or industry was reported significantly less frequently. These differences were also statistically significant in the GEE models including respondents' age and gender.

Table 29. Indoor environmental quality in Finland.

Indoor environmental quality	CASE 1st N	CASE 1st %	CASE 2nd N	CASE 2nd %	p	CONTROL 1st N	CONTROL 1st %	CONTROL 2nd N	CONTROL 2nd %	p
Condensation on windows										
Summer	24	12	22	14	0.60	7	23	3	27	0.75
Winter	75	37	52	32	0.36	14	45	7	64	0.29
No know water damage	151	77	123	79	0.48	24	77	9	82	0.74
No moisture or mould damage in the bedroom	184	100	151	100	0.37	26	93	9	100	0.56
Odours										
Food	46	25	25	17	0.07	1	3	2	18	0.11
Tobacco	**28**	**15**	**11**	**7**	**0.03**	**3**	**10**	**5**	**46**	**0.01**
Mould	3	2	1	1	0.41	1	4	1	9	0.48
Building materials	2	1	3	2	0.50	1	3	0	0	0.53
Stuffiness*	**33**	**19**	**12**	**8**	**0.01**	4	14	2	18	0.73
Sewage	**31**	**17**	**13**	**9**	**0.03**	4	13	2	18	0.70
Lighting defects										
In the dwelling	21	11	16	10	0.82	4	13	1	9	0.71
In the hallways	18	9	10	7	0.37	3	10	2	18	0.50
Outside	36	19	28	18	0.89	4	15	3	27	0.37
Daily noise disturbance related to										
The dwelling (occupants etc.)	12	6	17	12	0.08	4	14	2	18	0.76
Ventilation, plumbing, electrical systems, lifts, etc.	22	12	26	18	0.10	6	21	3	30	0.58
Neighbours	46	24	42	28	0.41	10	35	4	36	0.91
Traffic, industry etc.*	**52**	**28**	**26**	**18**	**0.03**	2	7	2	18	0.31

* Further analysed with GEEs

3.4.4 Satisfaction with housing and health symptoms

As indicated in Table 30, occupants from the control buildings were more satisfied with indoor air quality (IAQ) and maintenance of the building at the baseline, and they reported less upper respiratory symptoms and eye symptoms. They also related symptoms to home environment less often than the occupants from the case buildings. They missed days from work or school less frequently. At the follow-up, the differences between study and control buildings appeared to diminish.

Table 30. Satisfaction with housing and health symptoms in Finland.

Satisfaction with housing and health symptoms	CASE					CONTROL				
	1st		2nd		p	1st		2nd		p
	N	%	N	%		N	%	N	%	
Plans to move	57	28	32	20	0.07	8	26	6	55	0.08
Satisfied with dwelling	82	41	82	52	0.23	18	58	5	46	0.37
Satisfied with IAQ*	**42**	**22**	**65**	**41**	**0.00**	14	45	4	36	0.56
Satisfied with maintenance	**65**	**33**	**63**	**40**	**0.02**	12	41	4	36	0.56
Health symptoms[a]										
General symptoms	56	28	42	26	0.75	4	13	3	27	0.27
Upper respiratory symptoms*	**75**	**37**	**44**	**27**	**0.05**	6	19	3	27	0.58
Lower respiratory symptoms	45	22	23	14	0.06	3	10	1	9	0.96
Eye symptoms	64	32	43	27	0.32	**3**	**10**	**4**	**36**	**0.04**
Skin symptoms	60	30	42	26	0.46	9	29	4	36	0.65
Arthritis	51	25	45	28	0.54	6	19	2	18	0.93
Muscular pain	40	20	34	21	0.74	4	13	2	18	0.67
Diarrhea	7	3	4	3	0.59	2	7	1	9	0.77
Difficulties to sleep	46	23	37	23	0.94	7	23	3	27	0.75
Symptoms are related to home environment	60	34	55	37	0.53	**4**	**15**	**5**	**50**	**0.03**
Respiratory infections[b]*	**62**	**32**	**34**	**22**	**0.04**	8	26	3	27	0.92
Doctor visits	56	29	30	20	0.05	6	19	3	27	0.58
Antibiotics	58	30	34	23	0.10	6	19	3	27	0.58
Missed work or school	33	21	17	13	0.06	5	17	2	18	0.91

[a] Daily / weekly [b] within the last 12 months * Further analysed with GEEs

After retrofits, the respondents in the case buildings were significantly more frequently satisfied with IAQ and maintenance of the buildings than before retrofits, and they were less frequently planning to move, whereas an opposite trend was seen in the control buildings.

Respondents in the case buildings reported significantly less weekly upper respiratory symptoms and a similar trend was seen for lower respiratory symptoms. Reporting of respiratory infections, doctor visits and missed work or school days were also reduced. The differences with respect to satisfaction with IAQ and upper respiratory symptoms remained significant in the GEE models including age and gender.

3.4.5 Occupant diaries

Occupants filled a diary daily during a two-week period, as shown in Table 31. Most responses were from the case group. About 31-50% apartments had more than one occupant filling the diary. About half of the occupants reported not working during the weekdays.

Table 31. Diary information in Finland.

Diary information	Unit	CASE		CONTROL	
		1st	2nd	1st	2nd
Buildings	N	26	24	3	3
Apartments	N	125	84	14	10
Occupants [a]	N	2208	1404	20	14
Information received [b]	Days	1616	1024	271	181
Weekday	Days	26	24	200	129
Did you work today (on weekdays)?					
Yes	%	33	30	47	41
No, I did not work	%	57	62	42	53
No, I was sick	%	1	1	2	2
No, I had a day off	%	5	4	9	3
No, other reasons	%	4	3	1	1

a: Some apartments had two occupants reported the diary; b:
Partial diary data missed (less than 14 days).

Averaged time usage within 24 hours is presented in Figures 11 and 12. Occupants from the case group spent more time in public buildings during the weekdays, and outdoors during the weekends. The time spent home increased from the 1st to the 2nd measurement in both groups.

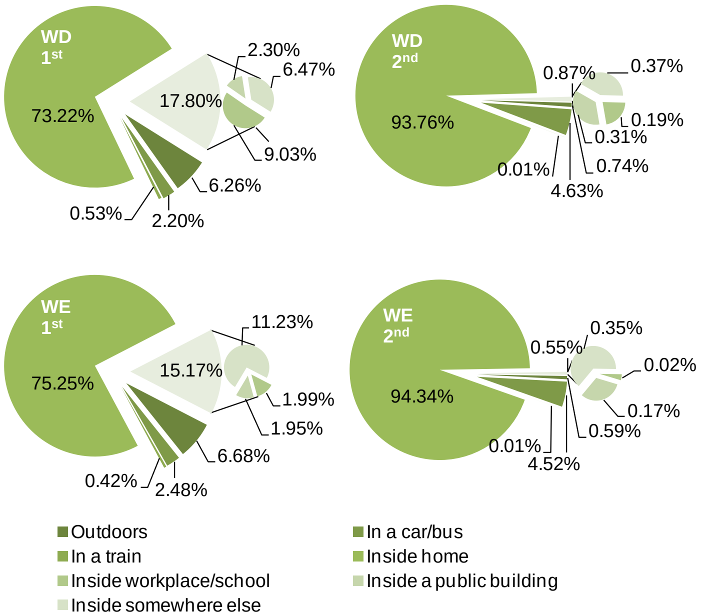

Figure 11. The percentage of time use for case group during the weekdays (WD) and weekends (WE) in Finland.

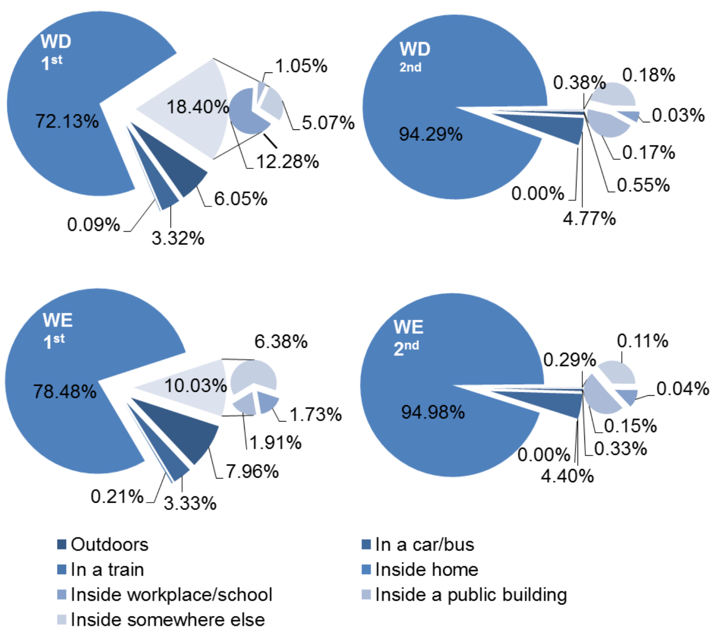

Figure 12. The percentage of time use for control group during the weekdays (WD) and weekends (WE) in Finland.

Usage of alternative methods for heating, ventilation and air conditioning is shown in Figure 13. In the case group, kitchen vent hood was used less frequently at the follow-up, possibly due to the upgraded ventilation systems. However, windows were open more frequently (up to 105 minutes per day) after retrofits.

In the control group, occupants opened windows for ventilation more frequently during the weekend than weekdays at the baseline, while the opposite trend was found at the follow-up. At the same time, increased usage of air humiditfiers and air purifiers were reported.

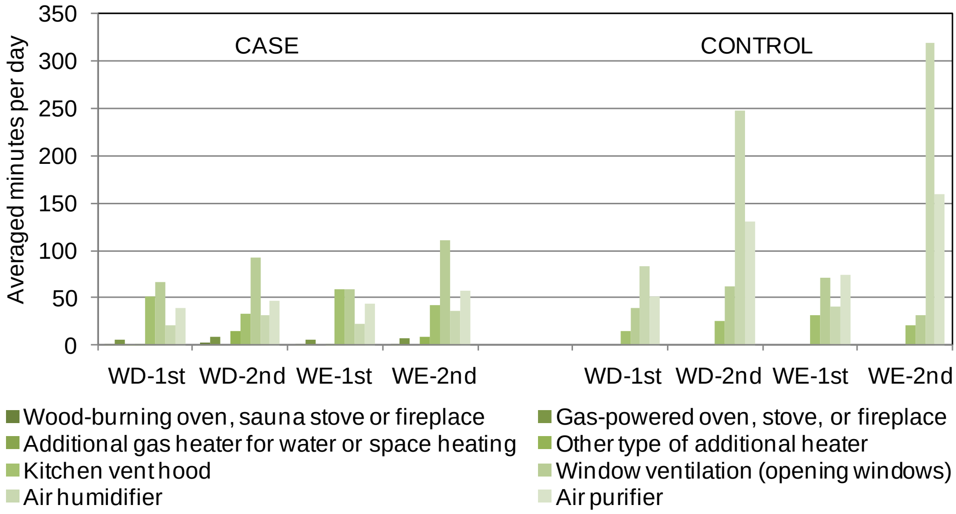

Figure 13 Usage of alternative methods for heating, ventilation and air conditioning during the weekdays (WD) and weekends (WE) in Finland.

During the two-week measurement periods, activities related to vacuum-cleaning, dusting, and sweeping remained similar in the case group (Figure 14). Occupants in the control group did more vacuum-cleaning during weekdays than weekends. Smoking was reported more frequently at the follow-up (2nd measurement) in both groups.

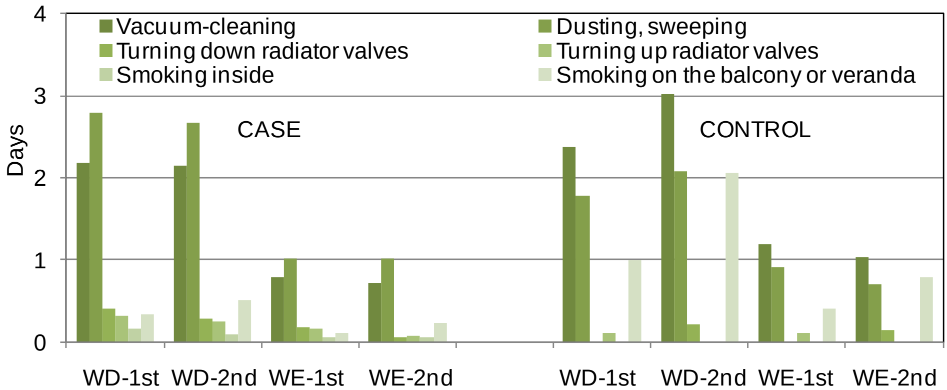

Figure 14. Activities during the weekdays (WD) and weekends (WE) in Finland.

Issues botheríng 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". The scores were averaged, and they were found relatively low in general, as shown in Figure 15. In the case group, noise outside the dwelling was reported by six occupants with score over 7, whereas four occupants reported too high indoor temperature, and two to three occupants reported odours inside dwelling, stuffiness or poor IAQ, and too low humidity before retrofits.

In the case group the average situation in terms of stuffiness or poor IAQ and draught was improved after retrofits. In the control group, too low indoor temperature and draught was reported more frequently.

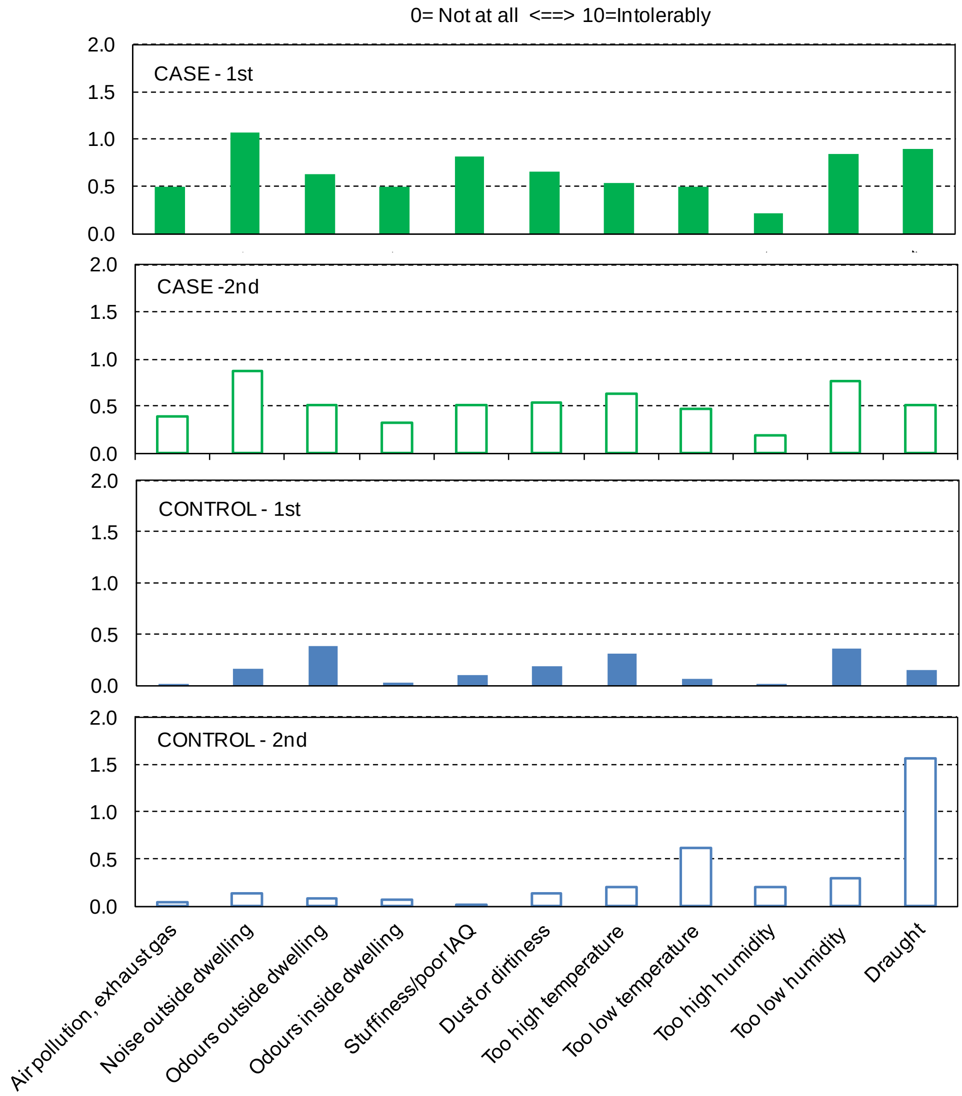

Figure 15. Averaged scores for issues bothering the occupants at home in Finland.

In the case group, most of the symptoms were reported less frequently after retrofits (Figure 16). Some symptoms, such as rash or skin symptoms, or joint pain/swelling were reported by a few individuals. The opposite trend was found in the control group, especially for rhinitis or cold or stuffy nose, sleeping problems, and joint pain or swelling.

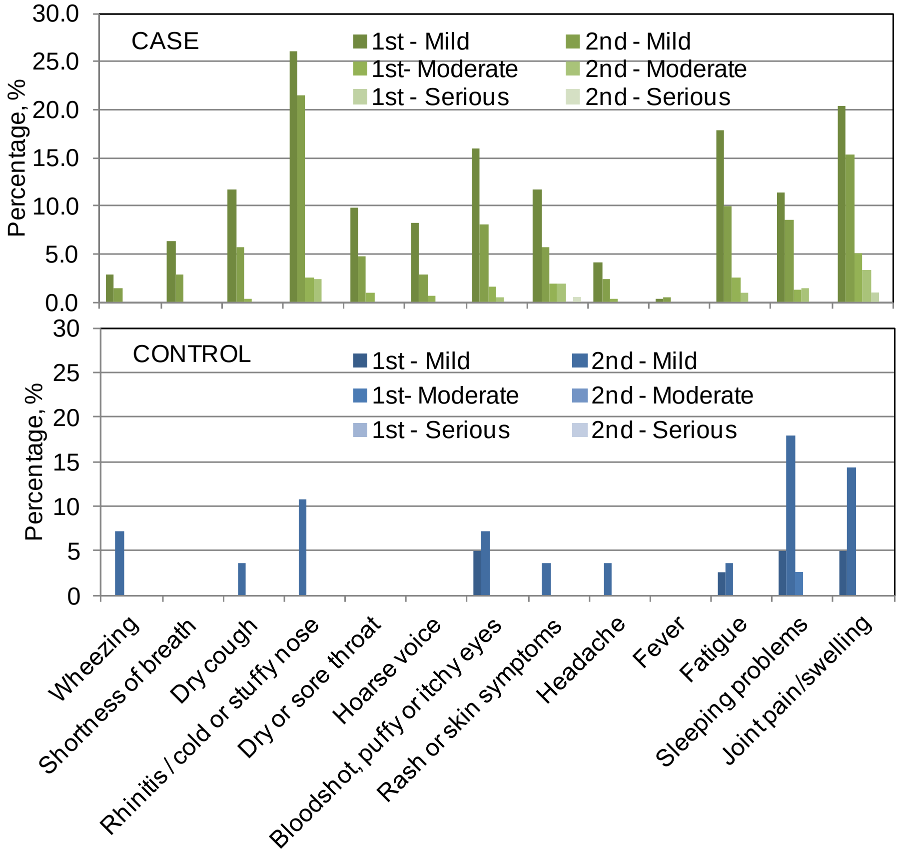

Figure 16. Percentage of occupants reporting symptoms in Finland.

Although the prevalence of self-reported symptoms was higher in the case group (as shown above), usage of medicines was not necessarily more frequent: in fact occupants in the control group reported more frequent usage of certain medicines, such as painkillers for joint or muscle pain, sleeping pills, asthma medications, and especially blood pressure medications (Figure 17).

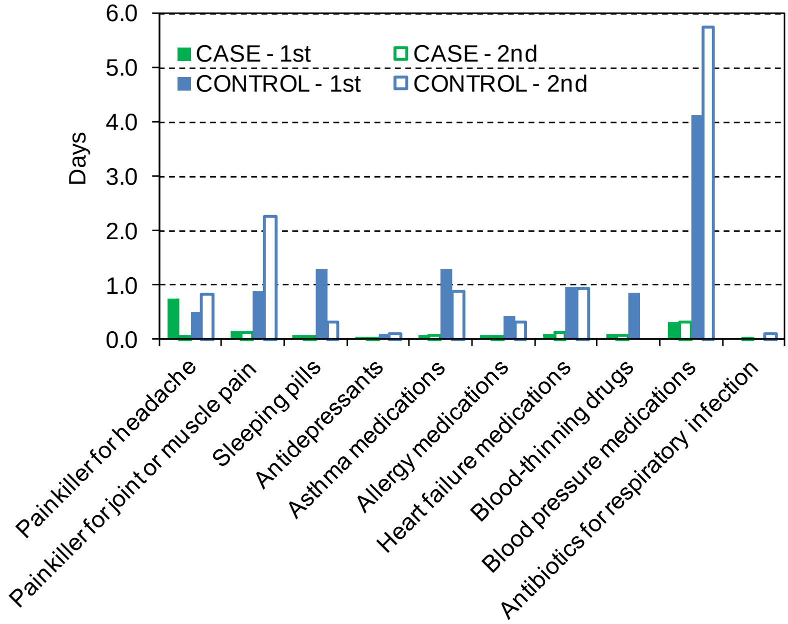

Figure 17. Number of days when medicines were taken during the two-week period in Finland.

Days that occupants felt like having a cold or the flue remained similar in the case group, and slightly decreased in the control group (Figure 18). The occupants smoked more frequently during the 2nd measurement, especially in the control group. Exposure to environmental tobacco smoke was slightly higher in the case group.

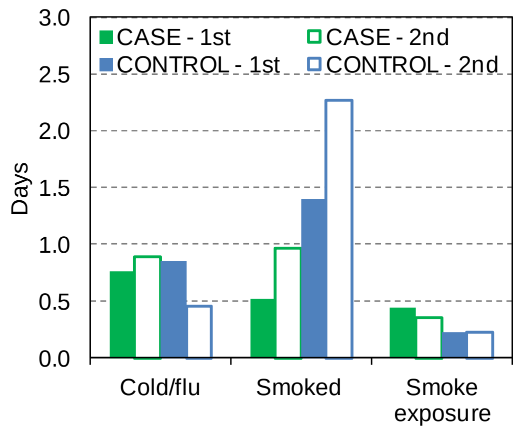

Figure 18. Days feeling like having a cold or the flue, smoked, or been exposed to environmental tobacco smoke in Finland.

Majority of occupants reported general health status as usual, seen in Figure 19. In the case group, “the slightly worse than usual” dropped by 2% after retrofits.

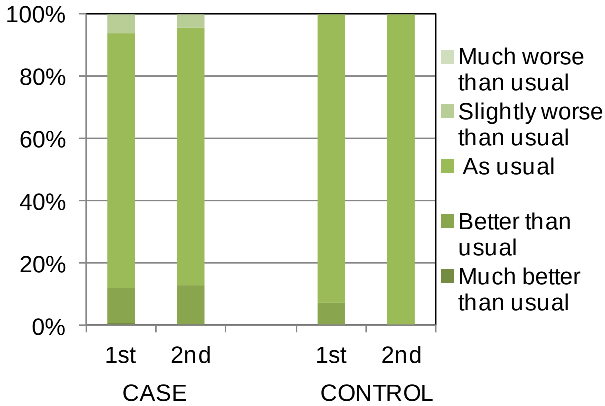

Figure 19. Occupants’ general health in Finland.

4. Results from Lithuania

4.1 Buildings and energy

4.1.1 Building characteristics

The final sample from Lithuania included 20 buildings (96 apartments). Characteristics of the recruited buildings are shown in Table 32. The agerage age of the buildings was 46 years and their average floor area is 3,520 m^2. Most of the buildings (95%) have district heating, and the remaining buildings have water circulating radiators or local central heating/fireplace. All buildings in Lithuania had natural ventilation (some buildings had mechanical exhaust equipment in the kitchen and bathroom).

Table 32. Characteristics of the recruited buildings in Lithuania.

Parameters	N	Percent, %	Average	SD
No. of buildings	20	100	-	-
No. of apartments	20	100	46	26
No. of floors	20	100	6	4
Building age, year	20	100	40	15
Building area, m^2	16	80	3520	1554
District heating	20	95	-	-
Ventilation system				
Mechanical	20	0	-	-
Natural	20	100	-	-

4.1.2 Retrofit activities

Figure 20 shows the different levels of retrofit activities, categorized into "focused" (N=2) and "deep" (N=13) energy retrofits (see section 3.1.2 for definitions). The change of ventialtion system refers to the cleaning of ventilation shafts and installation of new fans in the attics.

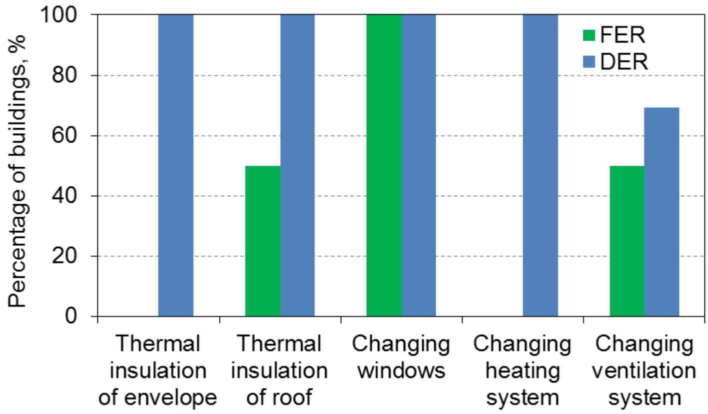

Figure 20. The percentage of buildings with different types of retrofits in Lithuania (FER: focused energy retrofits; DER: deep energy retrofits).

4.1.3 Energy efficiency and sources

Calculations made after retrofitting the case buildings revealed that the reduction of energy consumption varied from 30 to 60 % in buildings with district heating (12 buildings). Two of these buildings had installed solar panels, which helped to reduce energy consumption by approximately 56% in both cases. Three case buildings had individual space heating system (gas boiler), and after retrofitting activities their energy consumption decreased by approximately 40%. An average of 10% reduction in the heating energy consumption was observed in partially retrofitted buildings as compared to the situation before retrofit.

4.2 Building investigations

4.2.1 Air pressure differences and air change rate

Table 33 presents pressure differences between indoors and both staircase and outdoors. There appears to be a lot of variation in the pressure differences, especially between indoors and outdoors. Pressure difference is strongly depended on the local climate (wind, indoor/outdoor temperature difference) at the time of the measurement, especially if the apartments have natural ventilation.

Table 34 presents calculated ACR, which are a bit lower after retrofits in the case buildings. The ACRs are also lower in the control buildings based on the 2nd measurement. Ventilation rates in naturally ventilated buildings are based on pressure differences, especially based on temperature difference between indoors and outdoors (so-called stack effect). Also the pressure differences in both case and control buildings were lower at the follow-up (2nd measurement).

Table 33. Pressure differences (∆P) between indoors and both staircase and outdoors in Lithuania.

Pressure Pa	CASE_Natural				CONTROL_Natural			
	1st	1st	2nd	2nd	1st	1st	2nd	2nd
	Staircase	Outdoor	Staircase	Outdoor	Staircase	Outdoor	Staircase	Outdoor
N	71	59	56	55	24	22	8	5
Average	-2.1	-4.0	-0.1	-2.8	-3.1	-6.3	-2.4	-0.8
SD	1.9	4.6	3.1	6.7	3.8	6.8	2.1	3.4
Median	-1.9	-2.5	-0.5	-2.2	-1.4	-4.1	-1.7	-1.6
5th	-5.2	-14.3	-2.8	-15.3	-10.5	-14.8	-5.9	-4.9
95th	-0.2	-0.4	5.3	7.0	0.5	-0.8	-0.4	3.4

Table 34. Air change rates (ACR) in Lithuania.

ACR, 1/h	CASE		CONTROL	
	1st	2nd	1st	2nd
N	72	55	23	8
Average	0.38	0.32	0.40	0.28
SD	0.27	0.24	0.23	0.13
Median	0.33	0.27	0.38	0.25
5th	0.06	0.05	0.08	0.10
95th	0.88	0.79	0.73	0.45

4.2.2 Thermal index

Table 35 presents thermal indexes based one-time surface temperature, and indoor and outdoor temperature measurement data.

Table 35. Thermal index (TI) in Lithuania.

TI	Case		Control	
	1st	2nd	1st	2nd
N	71	58	23	7
Average	69.4	77.4	69.4	73.9
SD	9.3	6.2	5.5	5.6
Median	69.7	77.1*	69.9	74.9
5th	55.0	67.8	61.3	66.9
95th	84.5	88.9	75.9	80.7

The thermal index is significantly higher after retrofits in the case buildings. It is also higher in the control buildings at the follow-up (2nd measurement), but the difference was smaller.

4.3 Environmental measurements and sampling

4.3.1 Thermal conditions

Table 36 presents results related to indoor and outdoor T and RH. In the case buildings, indoor conditions (Tc, Tw, RHc, RHw) showed significant differences after retrofits. The percent of time with low Tw (< 18°C) decreased by 28% in the case group as compared to 10 % in the control group.

Table 36. Indoor and outdoor temperature and relative humidity (%) in Lithuania.

Stat-istics	Tw, °C				Tc, °C				Outdoor T, °C			
	CASE		CONTROL		CASE		CONTROL		CASE		CONTROL	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
N	66	55	23	8	68	57	23	8	68	57	23	8
Ave	19.5	20.4	20.0	21.2	17.7	19.1	18.5	19.9	-0.7	2.0	0.9	9.3
SD	1.8	1.3	1.1	1.5	2.2	1.9	2.1	1.9	4.7	3.3	4.5	2.2
Med	19.5	20.4*	19.9	21.1	18.0	19.4*	18.8	20.4	-2.3	1.3*	3.0	9.4*
5th	16.3	18.4	18.5	19.1	13.3	15.9	14.6	17.0	-6.3	-2.9	-6.0	6.0
95th	22.3	22.4	21.6	23.1	20.8	21.5	21.1	21.7	8.2	7.4	5.3	11.4
	RHw, %				RHc, %				RHo, %			
N	66	55	23	8	68	57	23	8	68	57	23	8
Ave	43.4	48.7	43.9	46.8	48.7	52.1	48.2	50.8	75.9	76.7	75.0	66.7
SD	10.7	8.8	7.5	6.2	11.3	9.7	8.3	7.9	7.1	6.3	4.0	2.3
Med	43.6	48.3*	42.2	47.9	47.7	51.9	45.6	52.9	77.9	75.9	73.9	65.9*
5th	27.5	34.2	34.9	37.8	33.7	37.1	37.5	38.5	63.2	65.0	69.9	64.8
95th	64.0	64.0	55.8	53.9	68.9	68.5	58.8	59.3	85.4	85.8	81.1	70.4

*p<0.05 based on Mann-Whitney U Test (paired samples)

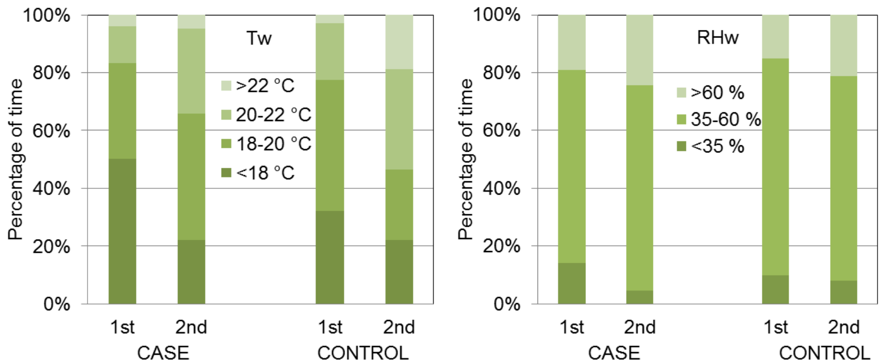

Figure 21. Percentages of time for different indoor temperature and relative humiditycategories in Lithuania.

As shown in Table 37, the continuous “thermal indexes” (TIc) values were generally higher than thermal index values calculated using coldest surface temperature (see Table 35). In the case buildings, the average values were slightly increased (Figure 22). In the control buildings, the average values were decreased, and the values varied widely during the 2nd measurement, possibly due to small sample size (N=8).

Table 37. Continuous “thermal index” (TIc) in Lithuania.

TIc	CASE		CONTROL	
	1st	2nd	1st	2nd
N	66	55	23	8
Average	91.5	92.7	92.7	86.6
SD	7.9	7.5	6.6	10.6
Median	93.7	93.9	95.5	87.4
5th	75.2	83.4	80.8	71.1
95th	99.9	99.4	98.9	96.6

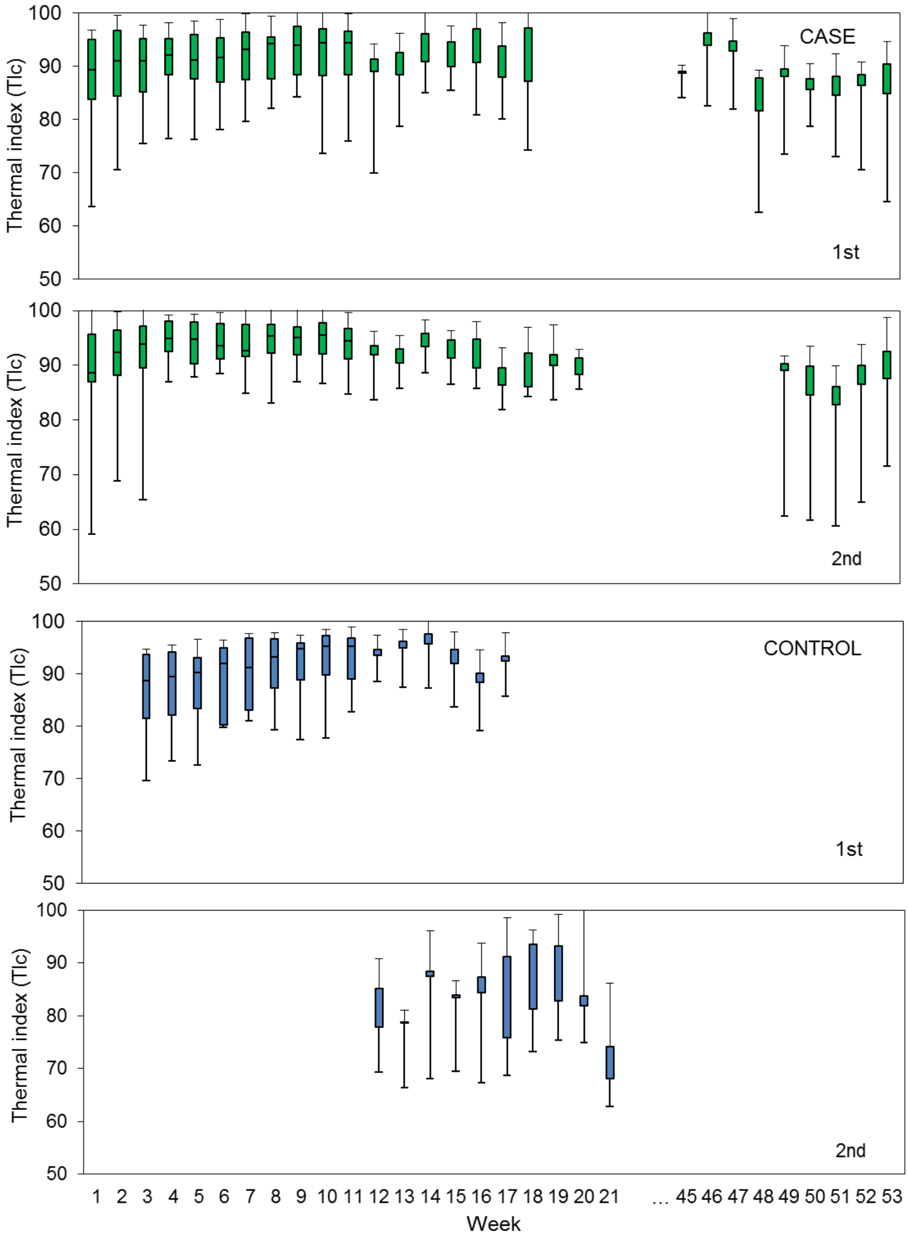

Figure 22. Continuous “thermal index” (TIc) by calendar week in Lithuania (n⩾ 5 included).

4.3.2 Carbon dioxide

In the case buildings, CO_2 levels were slightly higher after retrofits, but the difference was not statistically significant (Table 38).

Table 38. Carbon dioxide (CO_2) concentrations in Lithuania.

CO_2,	CASE		CONTROL	
ppm	1st	2nd	1st	2nd
N	66	57	22	8
Average	1018	1097	1053	936
SD	411	473	310	320
Median	957	993	1013	1002
5th	507	547	602	515
95th	1856	1868	1498	1284

The variations were considerably high between apartments. The percentage of time with CO_2 levels exceeding 1000ppm, 1200ppm, 1500ppm was increased by 6 to 9% in the case buildings after retrofits, whereas there was an average of 5% decrease in the control buildings at the same time (Figure 23).

The ACRs during the night time were calculated based on CO_2 concentrations. The median ACRs were relatively low in the case buildings and no significant differences were found (Table 39). ACRs in the control buildings varied widely due to small sample size at the follow-up (2nd measurement).

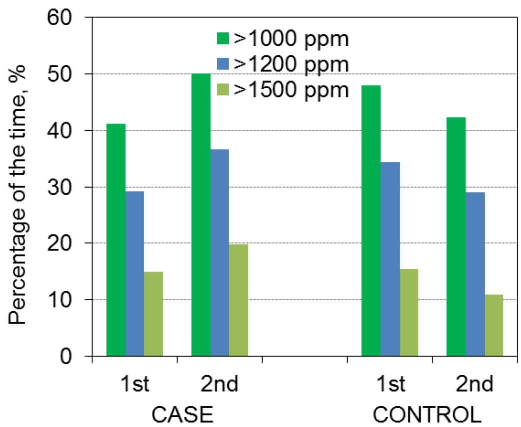

Figure 23. The percentage of time with CO_2 concentrations exceeded levels of 1000ppm, 1200ppm and1500ppm in Lithuania.

Table 39. Air change rate based on night time CO_2 concentrations in Lithuania.

ACR, 1/h	CASE		CONTROL	
	1st	2nd	1st	2nd
N	39	33	16	5
Average	0.36	0.27	0.54	0.79
SD	0.33	0.22	0.85	0.85
Med	0.24	0.21	0.27	0.49
5th	0.1	0.1	0.08	0.22
95th	0.72	0.54	1.72	1.96

4.3.3 Particulate matter

Table 40 shows $PM_{2.5}$ and PM_{10} levels in Lithuanian apartments. Average values are below limits set by WHO and national legislation. At the same time, 95th percentile indoor PM concentrations are exceeding threshold. Based on the average values, there was no statistically significant differences before and after retrofits. Statistically significant changes in outdoor concentrations were associated with stronger outdoor sources, potentially due to a low temperature and increased fuel burning for heating. However, this increase did not seem to affect indoor PM levels.

The distribution of I/O ratios in Lithuanian appartments is log-normal, with the medians of 0.63 (PM2.5) and 0.8 (PM10), which indicates that the activities of inhabitants are most likely contributing to the IAQ in at least 50% of apartments (Table 41). The mean is affected by high values of I/O reaching 5.45 for PM10. This may be related to a variety of activities, including cooking, cleaning, intensive walking etc. The median I/O is insignificantly smaller for PM2.5 but larger for PM10 in retrofitted appartments as compared to baseline, while the control buildings do not follow similar trend. The decreased I/O ratio for PM2.5 could indicate tighter building envelope resulting in decreased penetration of outdoor particles.

Median value for PM2.5 decay rate in retrofitted buildings is 0.25, that is, the PM2.5 concentration is reduced by 25% of its initial value during one hour period (Table 42). This results is consistent with air change rate estimations, suggesting that decay rates and subsequent removal of PM are smaller in naturally ventilated buildings than in mechanically ventilated buildings. Very low PM2.5 background concentrations were registered, with a median slightly smaller after retrofits, while the opposite was observed for the control buildings. Based on the PM2.5/PM10 ratio, more than half of the particles were PM2.5, and the ratio decreased after retrofits, although the decrease is not statistically significant. This decrease could indicate a tighter building envelope and lower penetration of fine aerosol from outdoors.

Table 40. Indoor and outdoor PM levels in Lithuania.

PM, µg/m³	IN				OUT			
	CASE		CONTROL		CASE		CONTROL	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
				PM2.5				
N	71	55	22	8	64	40	21	6
Ave	12.44	12.75	8.84	5.44	21.01	19.76	17.75	9.00
SD	14.71	14.50	5.05	1.85	15.80	6.88	9.92	2.11
Med	9.17	9.87	6.64	5.38	18.11	20.48	15.85	9.39
5th	2.81	4.52	2.86	3.29	2.98	9.83	6.90	6.26
95th	26.95	23.70	16.77	8.22	48.93	29.61	37.21	11.25
				PM10				
N	71	55	22	8	64	40	21	6
Ave	22.44	30.44	20.18	17.39	34.26	30.06	26.77	17.72
SD	19.76	25.75	15.42	6.09	33.78	15.24	11.35	4.87
Med	18.50	24.79	17.82	18.27	25.99	29.18	29.59	16.67
5th	6.67	7.99	5.70	8.88	5.05	13.97	10.71	12.37
95th	47.59	77.35	37.92	25.03	81.94	46.28	41.92	24.23

*p<0.05 based on Mann-Whitney U Test (paired samples)

Table 41. Indoor and outdoor PM ratios in Lithuania.

I/O	PM2.5				PM10			
	CASE		CONTROL		CASE		CONTROL	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
N	64	40	20	6	64	40	20	6
Ave	1.31	0.87	0.67	0.88	1.6	1.14	1.06	1.37
SD	2.62	1.22	0.39	0.28	2.42	1.14	1.05	0.57
Med	0.63	0.57	0.63	0.99	0.80	0.87	0.84	1.34

5th	0.15	0.28	0.19	0.53	0.15	0.34	0.15	0.67
95th	2.83	1.91	1.45	1.17	5.45	4.16	1.95	2.05

Table 42. PM2.5 indicators in Lithuania.

Statistics	Decay rate, 1/h				Background concentrations, µg/m^3			
	CASE		CONTROL		CASE		CONTROL	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
N	71	54	22	8	71	55	22	8
Ave	0.31	0.28	0.42	0.32	7.4	7.54	4.25	3.42
SD	0.19	0.16	0.25	0.16	9.32	10.58	3.37	1.69
Med	0.25	0.23	0.39	0.24	4.72	5.49	4	2.62
5th	0.13	0.09	0.13	0.16	1.45	2.65	1.2	2.24
95th	0.68	0.57	0.68	0.56	19.49	15.97	7.99	6.23
	PM2.5/PM10 ratio							
N	71	55	22	8				
Ave	0.62	0.57	0.59	0.41				
SD	0.18	0.18	0.13	0.12				
Med	0.64	0.55	0.57	0.43*				
5th	0.32	0.28	0.41	0.27				
95th	0.86	0.86	0.78	0.58				

*p<0.05 based on Mann-Whitney U Test (paired data)

4.3.4 Carbon monoxide

In Lithuania, twenty eight apartments had low (below the guideline) CO concentrations at the baseline, and four out of 29 apartments had levels exceeding the guideline (2.43 ppm) after retrofits.

4.3.5 Gaseous pollutants

Concentrations of formaldehyde (CH_2O), VOCs (BTEX), and nitrogen dioxide (NO_2) are shown in Table 43. The maximum level of CH_2O was 72 µg m^{-3}. The concentrations were significantly higher during the follow-up (2nd measurement) in both groups. Concentrations of BTEX were right-skewed with the maximum concentration of 135 µgm^{-3}. After retrofits, BTEX concentrations were slightly higher in the case buildigns, but the difference was not statistically significant. Concenrations of NO_2 were significantly decreased in the control buildings.

Table 43. Concentrations of gaseous pollutants in Lithuania.

Gaseous pollutants, µg/m^3	CH_2O				BTEX			
	CASE		CONTROL		CASE		COTROL	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
N	71	57	24	8	71	55	24	8
Ave	25.5	31	16.2	33	26.6	24.5	11.4	16
SD	10.6	13.4	6.1	10.9	27.3	12.9	12.4	23.4
Med	24.1	28*	16.5	32.9*	16	19.4	7.3	7.7
5th	10.3	13	9	16.6	5.6	10.7	2	6.1
95th	44.9	57.8	24	43.9	84.7	46.8	32.4	51.7
	NO_2							
N	71	57	22	8				
Ave	13.7	13.8	15	13.1				
SD	8.1	7.9	7.1	5.3				
Med	11.9	11.7	16	13.8*				
5th	4.2	3.9	4.4	5.7				
95th	28.4	29.6	25.2	20				

*$p<0.05$ based on Mann Whitney's test (paired samples)

4.3.6 Radon

After retrofits, the concentrations were significantly higher in the case buildings (Table 44). One apartment had over 100 Bq/m^3 during both measurements. Concentrations were also slightly higher in the control buildings, but not as much.

Table 44. Radon concentrations.

Radon, Bq/m^3	CASE 1st	CASE 2nd	CONTROL 1st	CONTROL 2nd
N	33	31	12	4
Average	32	44	21	17
SD	25	27	17	6
Median	28	38*	14	18
5th	10	43	4	18
95th	72	78	48	22

*p<0.05 based on Mann Whitney's test (paired samples)

4.3.7 Fungi and bacteria in settled dust

Microbial content in settled dust, including *Cladosporium herbarum (*Cherb), *Penicillium spp./Aspergillus spp./Paecilomyces variotii* (PenAsp), Gram-positive and Gram-negative bacteria, and total fungi are presented in Table 45.

Table 45. Content of selected fungi and bacteria in settled dust in Lithuania.

Microbial content Cell/(m^2*day)	Cherb				PenAsp			
	Case		Control		Case		Control	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
N	69	51	22	5	69	51	22	5
Average	661	307	240	5022	140111	33711	34711	85451
SD	1531	510	332	8802	836368	69849	54676	167108
Median	109	172*	126	1742	9630	7596*	11378	15288
5th	8	27	19	345	304	549	1387	2135
95th	2991	1099	794	16957	267758	184305	160155	311178
	Grampos				Gramneg			
N	69	51	22	5	69	51	22	5
Average	72526	113755	62459	164147	94940	93485	82822	87299
SD	112520	229354	60367	174897	241914	173015	85546	87536
Median	21288	31868*	42436	156662	32672	26154*	58889	40688*
5th	69	1059	1618	10896	91	3071	2450	18035
95th	346446	667206	157361	392279	303198	435248	267006	202466

	Total fungi			
N	69	51	22	5
Average	24659	7209	7266	30549
SD	128666	13867	10411	40112
Median	2147	1960*	3712	11706
5th	139	169	338	1942
95th	52179	40629	35076	85690

*p<0.05 based on Mann Whitney's test (paired samples)

After retrofits, concentrations of Cherb and gram positive bacteria were significantly higher, whereas concentrations of PenAsp, total fungi, and gam negative bacterial were lower in the case buildings. Similar trends were seen in the control buildings for Cherb and gram positive bacteria (higher) as well as gram negative bacteria (lower), however, it is difficult to draw any conclusions from control buildings due to small sample size at the follow-up (N=5).

4.3.8 Mineral fibers

Surface concentration/density of mineral fibres (fiber/cm^2) was calculated for 20 buildings at the baseline and for 14 buildings at the follow-up (Table 46). Statistically significant difference was observed in the case buildings after retrofits. Similar trend was also seen for the control buildings. No minerals fibers were seen in 35% (25 from 71) and 13% (6 from 48) of apartments in the case buildings before and after retrofits. In the control buildings, no mineral fibers were seen in 42% (10 out of 42) and 17% (1 out of 6) of apartments at the baseline (1st measurement) and follow-up (2nd measurement), respectively.

Table 46. Surface concentrations of mineral fiber in Lithuania.

Mineral fiber, fiber/cm^2	Case		Control	
	1st	2nd	1st	2nd
N	71	48	24	6
Average	1.04	1.52*	1.03	1.87
SD	1.10	1.00	1.24	1.54
Median	1.12	1.12	1.12	1.69
5th	0.00	0.00	0.00	0.28
95th	2.25	3.37	3.37	3.93

*p<0.05 based on Mann Whitney's test (paired samples)

4.4 Occupant surveys

Information on occupants' background and behaviour, housing characteristics, thermal condition and perceived health and wellbeing was collected directly from the occupants. A total of 60 occupants from 96 apartments (response rate 63%) answered to the questionnaire at the baseline (1st measurement), and 27 occupants from 65 apartments (response rate 42%) answered at the follow-up (2nd measurement). None of the occupants from control buildings responded to the questionnaire at the follow-up.

4.4.1 Background characteristics

Table 47 shows some background characteristics.

Table 47. Questionnaire respondents' background characteristics in Lithuania.

Background characteristics	CASE 1st N	CASE 1st %	CASE 2nd N	CASE 2nd %	p	CONTROL 1st N	CONTROL 1st %	p[a]
Gender, female	32	67	21	78	0.31	5	56	0.52
Smoking in the dwelling, never	12	24	4	15	0.37	1	11	0.40
Furry pets	23	51	10	40	0.37	**1**	**11**	**0.03**
Exercising several days per week								
Near dwelling	17	47	5	25	0.41	4	57	0.16
On the way to work	6	27	0	0	0.12	2	50	0.63
Elsewhere	4	24	3	23	0.56	1	20	0.29
Percent of income spent for housing					0.51			0.75
< 15 %	1	2	0	0		0	0	
16–25%	5	11	7	29		1	14	
26-35%	11	24	5	21		3	43	
36–50%	11	24	4	17		2	29	
51–65%	10	22	4	17		0	0	
> 65 %	8	17	4	17		1	14	
Tenure status					0.17			**0.04**
Own	48	96	23	89		0	0	
Rent	1	2	0	0		**7**	**78**	
Other[b]	1	2	3	12		2	22	
Balcony	28	55	11	41	0.23	6	67	0.51
Covered balcony	30	59	15	56	0.78	6	67	0.66
Mechanical exhaust	**21**	**41**	**4**	**15**	**0.02**	2	22	0.28
Mechanical supply	9	18	3	11	0.45	0	0	0.17
Trickle vents	13	26	8	30	0.70	5	56	0.07
Wood burning fire place / oven	2	4	1	4	0.96	0	0	0.55
Sauna	0	0	0	0	-	0	0	-
	Mean	SD	Mean	SD	p	Mean	SD	p
Age mean	53.7	14.7	59.2	14.4	0.12	55.2	13.4	0.77
Years lived in the current dwelling	22.8	17.3	28.8	12.3	0.18	22.9	8.5	0.99
Number of persons in the dwelling								
Adults (18-65 yrs)	1.9	0.9	1.8	0.8	0.82	1.8	1.2	0.80
Children (7-17 yrs)	0.8	0.8	1.2	0.4	0.29	0.4	0.5	0.18
Children (<7 yrs)	0.8	0.8	1.0	0.0	0.73	**0.1**	**0.4**	**0.03**

[a]Compared to the case group at the baseline (1st questionnaire)
[b]includes: employers' housing, right of residence apartment, and others

P-values shown in the tables are referring to the statistical testing of group level differences between 1st and 2nd measurements using chi-square test. The test does not take into account the dependency between the samples. Therefore, the test results are only used for screening purposes. Where significant differences were found on the group level, the results were further analysed using General Estimating Equations (GEEs).

We also tested the differences between the case and control buildings using chi-square test, but these results should be treated with caution due to small number of respondents from control buildings. The respondents in the control buildings were significantly more often tenants, and had less children living in their apartments. The respondents from the case buildings reported smaller proportion of apartments having mechanical exhaust after retrofits, which is appears to be more corresponding to the actual situation (most buildings had natural ventilation).

4.4.2 Thermal conditions

Results related to occupant self-reported thermal conditions are shown in Table 48. Occupants from the control buildings reported significantly more draught during summer as compared to the occupants from the case buildings at the baseline (1^{st} questionnaire). In the case buildings, the respondents reported significantly higher indoor temperatures during heating season after retrofits as compared to the situation before retrofits. Reporting suitable warm winter temperatures increased and the differences remained significant in the GEE model including respondents' age and gender. Similarly, reporting too cold winter temperatures decreased. Occupants' attempts to adjust thermostats increased, which appeared to be related to that before retrofits adjusting thermostats was not possible in many cases.

4.4.3 Indoor environmental quality

Table 49 shows results from IEQ variables, mostly related to dampness and mould, odours, lighting, and noise. At the baseline, respondents from the control buildings reported odours related to mould significantly less frequently than the respondents from the case buildings. After retrofits, the respondents from the case buildings reported less daily disturbance related to the dwelling and traffic as compared to the situation before retrofits, and the differences with respect to traffic noise was statistically significant in the GEE model including respondents' age and gender.

Table 48. Thermal conditions in Lithuania.

Thermal conditions	CASE 1st N	CASE 1st %	CASE 2nd N	CASE 2nd %	p	CONTROL 1st N	CONTROL 1st %	p[a]
Typical temperature during heating season					**0.01**			0.46
<18°C	**13**	**28**	**0**	**0**		4	57	
18-20°C	**25**	**53**	**18**	**67**		2	29	
20-22°C	**8**	**17**	**9**	**33**		1	14	
22-24°C	1	2	0	0		0	0	
>24°C	0	0	0	0		0	0	
Thermal conditions in summer								
Suitable warm	23	45	15	56	0.38	4	44	0.97
Too cold	6	12	0	0	0.06	0	0	0.28
Too hot	13	26	9	33	0.46	4	44	0.25
Draughty	2	4	1	4	0.96	**4**	**44**	**0.00**
Cold floor surfaces etc.	5	10	0	0	0.09	0	0	0.33
Thermal conditions in winter								
Suitable warm*	**16**	**31**	**21**	**78**	**0.00**	4	44	0.44
Too cold	**18**	**35**	**0**	**0**	**0.01**	4	44	0.60
Too hot	4	8	0	0	0.14	0	0	0.38
Draughty	1	2	0	0	0.46	1	11	0.16
Cold floor surfaces etc.	17	33	3	11	0.03	2	22	0.51
Open windows daily in kitchen for temperature control								
Summer	46	90	25	93	0.73	9	100	0.33
Winter	34	67	17	63	0.74	4	44	0.20
Open windows daily in bedroom for temperature control								
Summer	44	86	26	96	0.16	9	100	0.24
Winter	34	67	17	63	0.74	4	44	0.20
Open windows daily in living room for temperature control								
Summer	38	75	23	85	0.28	8	89	0.35
Winter	25	49	12	44	0.70	4	44	0.80
Did not attempt to adjust thermostats in the past 12 mo.[b]	**38**	**83**	**10**	**44**	**0.00**	7	100	0.23
[b]Inc. not possible to adjust	17	**37**	**0**	**0**				
Adjusted colder	2	4	2	9				
Adjusted warmer	2	4	2	9				
Adjusted both colder and warmer	4	9	9	39				

[a]Compared to the case group at the baseline (1st questionnaire) * Further analysed with GEEs

Table 49. Indoor environmental quality in Lithuania.

Indoor environmental quality	CASE 1st N	CASE 1st %	CASE 2nd N	CASE 2nd %	p	CONTROL 1st N	CONTROL 1st %	p[a]
Condensation on windows								
Summer	9	18	7	26	0.39	2	22	0.74
Winter	40	78	24	89	0.25	7	78	0.97
No know water damage	35	75	22	82	0.81	5	63	0.74
No moisture or mould damage in the bedroom	27	59	19	83	0.13	4	80	0.37
Odours								
Food	18	49	2	54	0.75	1	25	0.37
Tobacco	4	15	1	10	0.70	3	43	0.10
Mould	3	13	1	14	0.93	**3**	**60**	**0.02**
Building materials	1	5	1	13	0.91	0	0	0.68
Stuffiness	4	19	1	13	0.68	2	40	0.32
Sewage	5	19	3	25	0.64	2	50	0.16
Lighting defects								
In the dwelling	1	2	0	0	0.42	0	0	0.67
In the hallways	2	5	2	8	0.71	0	0	0.50
Outside	21	50	10	40	0.43	2	25	0.19
Daily noise disturbance related to								
The dwelling (occupants etc.)	4	13	0	0	0.10	1	17	0.53
Ventilation, plumbing, electrical systems, lifts, etc.	2	7	0	0	0.18	1	20	0.39
Neighbours	10	26	3	13	0.19	2	33	0.72
Traffic, industry etc.*	19	49	6	26	0.08	4	57	0.68

[a]Compared to the case group at the baseline (1st questionnaire)
* Further analysed with GEEs

4.4.4 Satisfaction with housing and health symptoms

As indicated in Table 50, respondents from the control buildings reported muscular pain and difficulties to sleep more frequently than the respondents from the case buildings. After retrofits, the respondents from the case buildings were significantly more frequently satisfied with IAQ than before retrofits. Reporting of respiratory infections decreased, but the differences were not statistically significant.

Table 50. Satisfaction with housing and health symptoms in Lithuania.

Satisfaction with housing and health symptoms	CASE 1st N	CASE 1st %	CASE 2nd N	CASE 2nd %	p	CONTROL 1st N	CONTROL 1st %	p[a]
Plans to move	7	14	2	7	0.41	0	0	0.24
Satisfied with dwelling	9	19	9	35	0.26	2	22	0.20
Satisfied with IAQ*	**9**	**20**	**9**	**33**	**0.03**	1	13	0.62
Satisfied with maintenance	7	18	10	37	0.11	1	11	0.20
Health symptoms[b]								
General symptoms	9	18	7	26	0.39	3	33	0.28
Upper respiratory symptoms	5	10	1	4	0.34	3	33	0.06
Lower respiratory symptoms	3	6	1	4	0.68	1	11	0.56
Eye symptoms	9	18	5	19	0.92	3	33	0.28
Skin symptoms	5	10	1	4	0.34	2	22	0.29
Arthritis	9	18	6	22	0.63	4	44	0.09
Muscular pain	2	4	4	15	0.09	**3**	**33**	**0.00**
Diarrhea	0	0	0	0	-	0	0	-
Difficulties to sleep	7	14	6	22	0.34	**5**	**56**	**0.00**
Symptoms are related to home environment	10	27	6	27	0.98	0	0	0.18
Respiratory infections[c]*	14	31	3	12	0.07	3	38	0.72
Doctor visits	9	28	3	14	0.21	1	13	0.36
Antibiotics	9	24	5	21	0.75	1	13	0.47
Missed work or school	7	24	3	15	0.44	1	13	0.47

[a]Compared to the case group at the baseline (1st questionnaire)
[b] Daily / weekly [c] within the last 12 months * Further analysed with GEEs

4.4.5 Occupant diaries

Table 51 presents the information received from occupants. Most responses were from the case group, and there were no responses from the control group during the follow-up (2nd measurement). During the weekdays, about half occupants (49-53%) did not work in the case group, whereas the percentage was only 17% in the control group at the baseline.

In the case group, occupants spent slightly more time at home during weekends, and inside a public building during weekdays (Figure 23). The patterns were quite similar between weekdays and weekdays after retrofits.

Table 51. Diary information in Lithuania.

Diary information	Unit	Case 1st	Case 2nd	Control 1st
Buildings	N	14	12	5
Apartments	N	40	21	14
Information received [a]	Days	506	208	186
Weekday	Days	365	149	134
Did you work today (weekday)?				
Yes	%	40	48	72
No, I do not work	%	1	0	6
No, I was sick	%	2	0	1
No, I had a day off	%	4	3	4
No, other reasons	%	53	49	17

a: Partial diary data missed (less than 14 days).

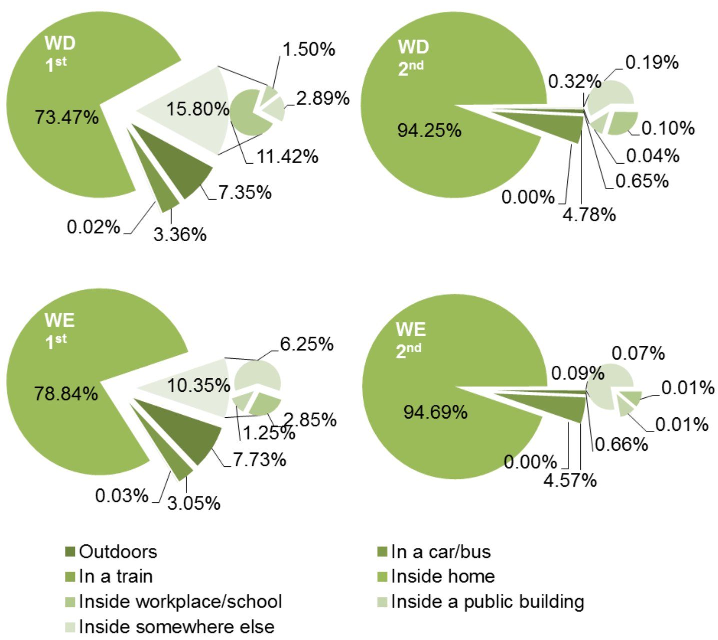

Figure 23. The percentage of time use for case group during the weekdays (WD) and weekends (WE) in Lithuania.

Averaged time use within 24 hours for each occupant in the control group is presented in Figure 24. Occupants spent more time at home during the weekends, as well as outdoors.

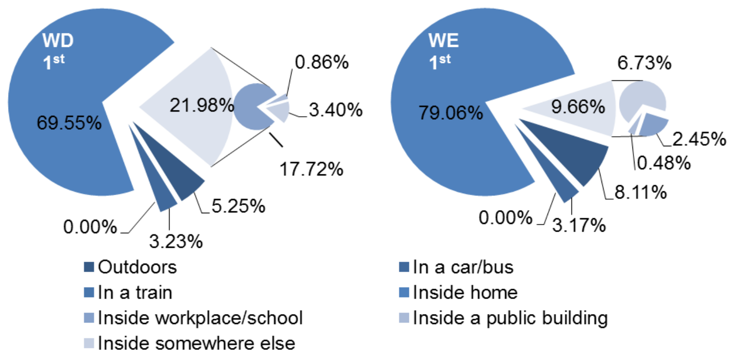

Figure 24. The percentage of time use for control group during the weekdays (WD) and weekends (WE) in Lithuania.

Usage of alternative methods for heating, ventilation and air conditioning is shown in Figure 25. In general, the usage levels were higher during the weekends than on weekdays. In the case group, the use of additional heater decreased after retrofits, as well as use of kitchen vent hood and opening windows. However, usage of gas-power oven, stove, or fireplace was slightly increased.

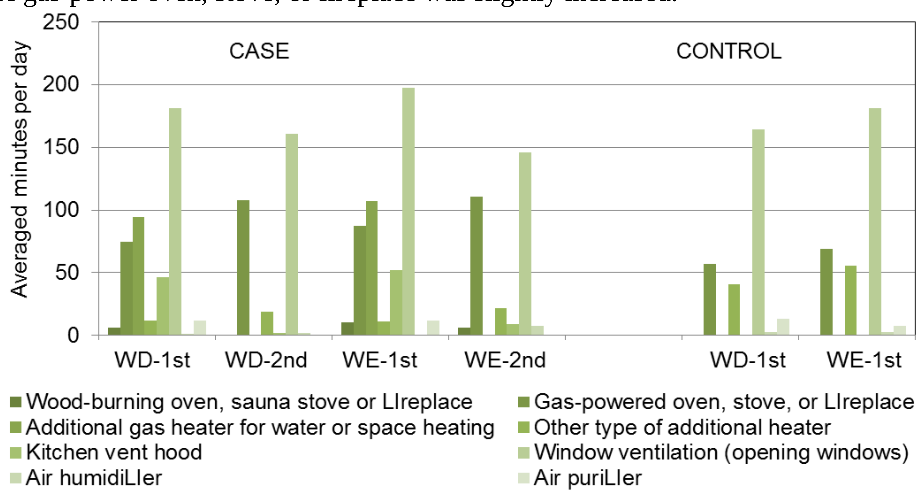

Figure 25. Usage of alternative methods for heating, ventilation and air conditioning during the weekdays (WD) and weekends (WE) in Lithuania.

During the weekdays, occupants reported frequent cleaning actions, e.g., vacuum-cleaning, dusting and sweeping (Figure 26) at the baseline. The pattern remained similar after retrofits. Interestingly, adjusting radiator valves (either up or down) was reported less frequently after retrofits.

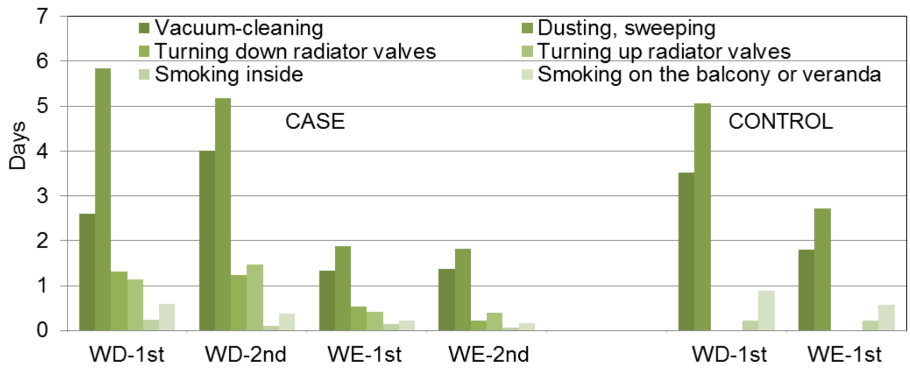

Figure 26. Activities during the weekdays (WD) and weekends (WE) in Lithuania.

Using the scale from 0 to 10, four occupants from the case group reported noise from outside, low temperature, and too high humidity with a score ≥8 (Figure 27). However, the situation appeared to be improved in most of the cases after retrofits. Too low temperate was reported more frequently in the control group (score up to 7 by four occupants), as well as too high humidity at the baseline.

In the case group, mild to moderate fatigue, sleeping problems and joint pain/swelling were reported, and the symptoms were improved after retrofits up to 9% (Figure 28). Other symptoms, such as dry cough, hoarse voice, bloodshot, buffy or itchy eyes, rash or skin symptoms, headache, and fever, were reported more frequently after retrofits. In the control group, 32% and 7% of the occupants reported mild and moderate fatigue, respectively. Over 10% reported mild health symptoms, such as rhinitis / cold or stuffy nose, sleeping problems and joint pain/swelling.

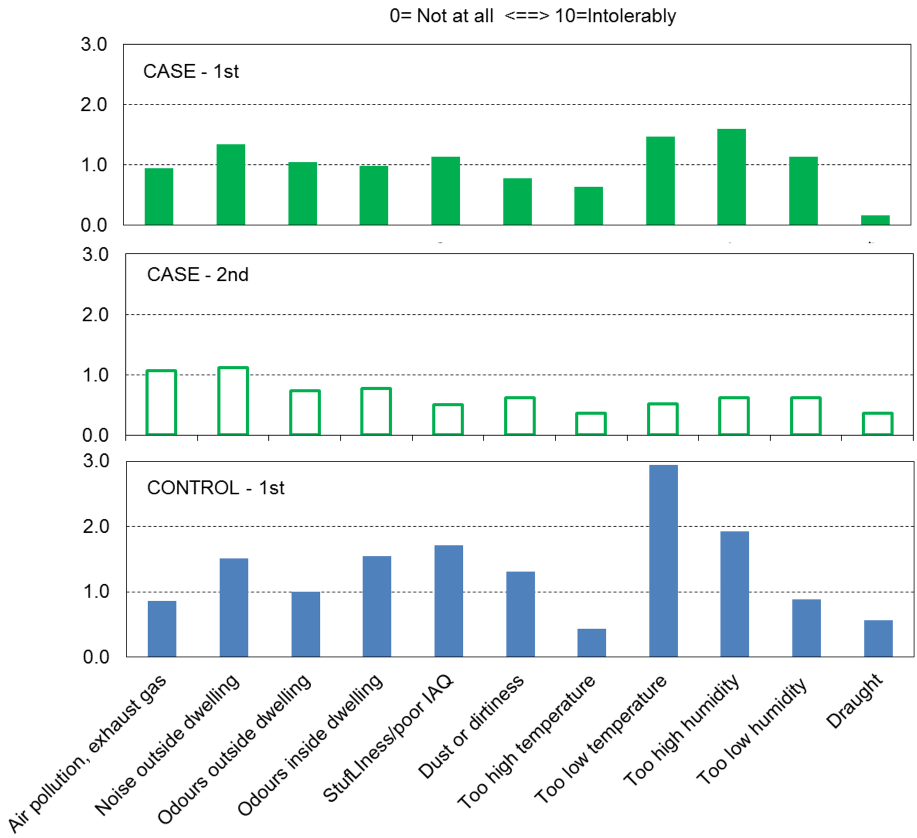

Figure 27. Averaged scores for issues bothering the occupants at home in Lithuania.

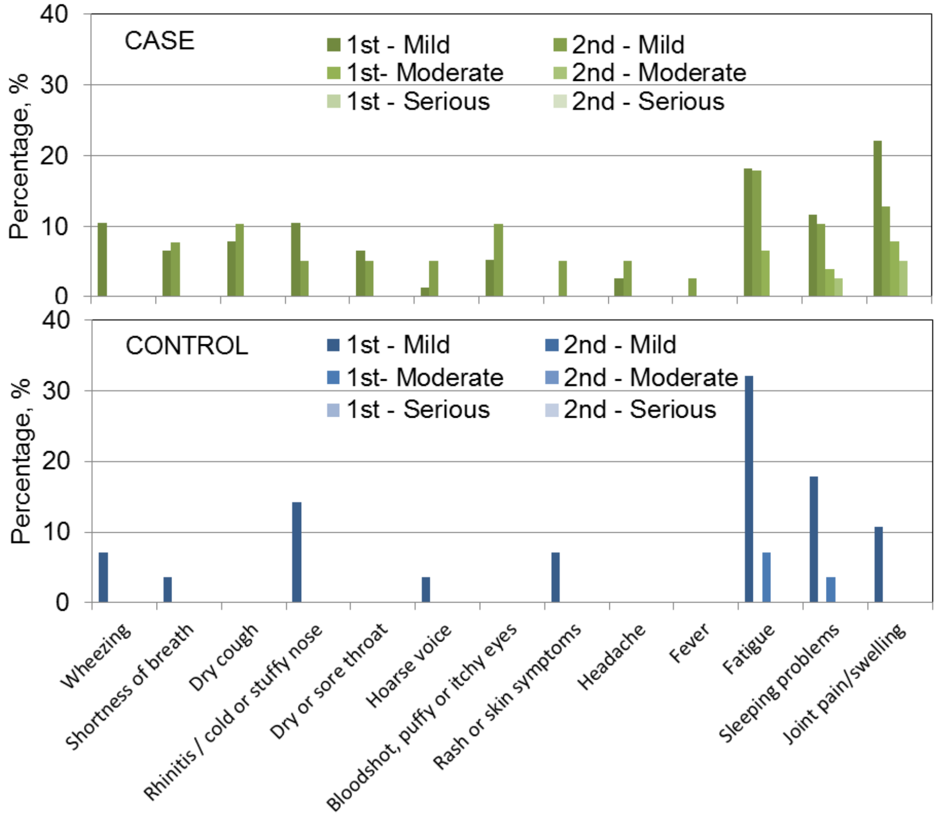

Figure 28. Percentage of occupants reporting symptoms in Lithuania

In the case group, frequently used medications included blood pressure mediations, blood-thinning medicine, and sleeping pills (Figure 29). Some occupants reported similar medicine usage in the control group. After retrofits, painkiller usage for headache was reported less reguently in the case group.

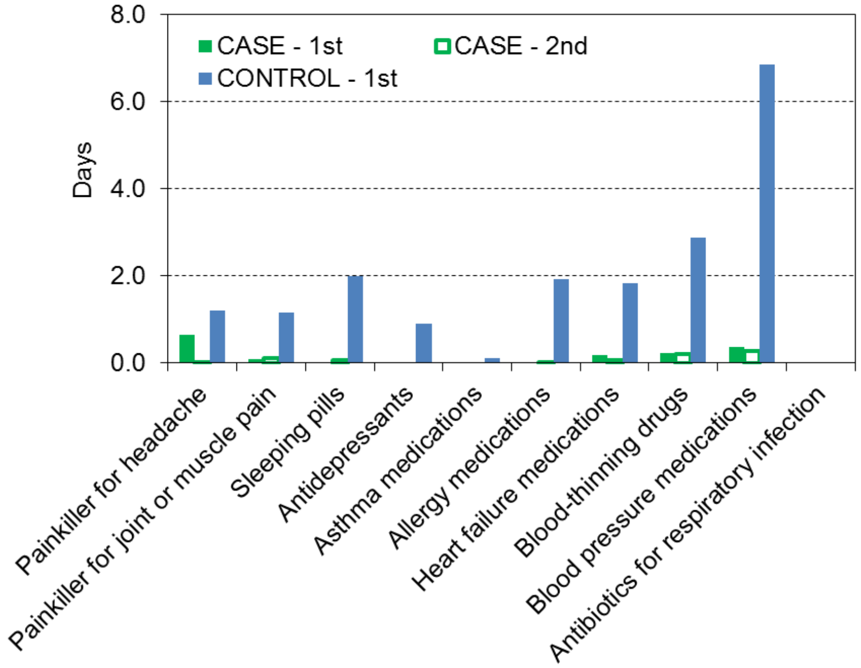

Figure 29. Number of days when medicines were taken during the two-week period in Lithuania.

Most of the occupants stated their health status as usual. About 10% of the occupants reported better than usual health status, and 4% slightly worse than usual in both groups (Figure 30). In the case group, the general health was slightly worse (2% drop in better than usual and 4% increase in slightly worse) after retrofits.

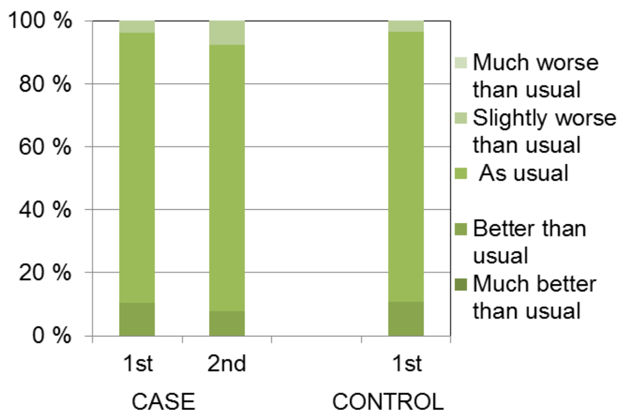

Figure 30. Occupants' general health in Lithuania.

At the baseline, occupants reported having a cold or the flu more frequently in the control group than in the case group, while exposure to environmental tobacco smoke was slightly higher in the case group (Figure 31).

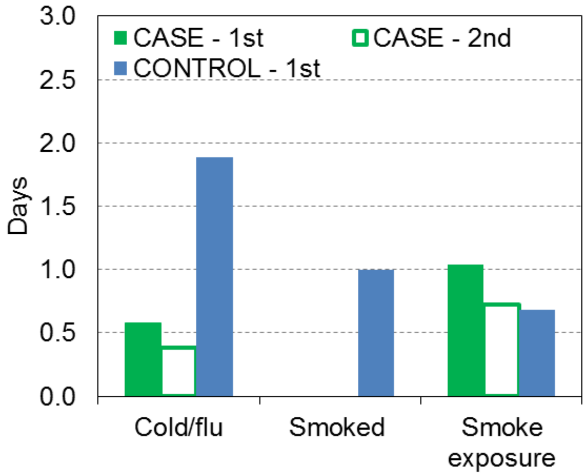

Figure 31. Days feeling like having a cold or the flue, smoked or been exposed to environmental tobacco smoke in Lithuania.

5 Additional cases

Additional case studies were performed in multi-family buildings in Finland, Latvia, Estonia and UK. In addition, data were collected from set of single-family houses (11 houses in Lithuania) and public buildings (data from Finnish schools). The main goal was to test the assessment protocol in other European countries and buildings types.

Prior to the data collection, field technicians in Latvia, Estonia and UK were trained during a 2-day period, including in-class sessions and on-site training. During the training, the field technicians were given instruction about the protocol, use of different instruments, as well as data collection and handling. Hands-on training was conducted in selected case study buildings. After the training, the field technicians continued data collection on their own.

5.1 Additional case studies in Finland

In Finland, we tested the protocol in one semi-detached house (one apartments) and in one row house (seven apartments). Overall, the results were comparable to those obtained from the case buildings, however, the results are not representative due to small sample size (Table 52).

Table 52. IAQ measurement results from Finnish semi-detached and a row houses.

Gaseous pollutants	CH_2O [µg/m^3]		BTEX [µg/m^3]		NO_2 [µg/m^3]	
	1st	2nd	1st	2nd	1st	2nd
N	8	7	7	7	8	7
Ave	59.3	31.7	9.2	12.4	5.1	5.0
SD	25.7	12.0	5.3	10.2	3.2	2.4
Med	57.1	33.3	6.6	7.9	4.0	4.5
5th	25.6	14.2	5.9	4.6	2.4	3.0
95th	88.8	44.4	17.7	28.4	10.4	8.6

We also gathered and further analysed data from school buildings. In schools, our focus has been in ventilation and thermal conditions, which have a great influence on school buildings energy concumption and operational cost. Inadequate ventilation and thermal comfort has also been associated with students' heath and academic performance (e.g. [47, 48]).

The first set of data came from ten school buildings located in eastern Finland, including eight elementary and secondary schools, one high school, and one special school. Data included 1) continuous measurements of IEQ parameters; 2) health questionnaire data from students; and 3) tests measuring attention and cognitive performance. IEQ measurements were performed using continuous, almost real time measurements of IEQ parameters including T, RH, CO_2, and gVOC[49]. In addition, real time water, electricity, and heat energy consumption data were collected from schools where it was technically possible, considering buildings' various ages and technical conditions. All data were collected using the internet, and have been reported elsewhere [50]. An analysis related to energy consumption in school buildings has been also published recently[51].

During the data collection, school principals and technical staff responsible for the school building maintenance were provided an access to the user interface (protected by user IDs), where they could view the data concerning their school. Subsequent work involved development of open assessment framework for school buildings, which could provide anonymous data open for public. Although the open assessment framework needs to be futher developed, the preliminary experiences are promising in terms of that with modern technology, it is relatively easy to monitor energy consumption and IEQ (almost) real time. Majority of the data can be can be collected via the internet, and it can also be made easlily accessible. Utilizing the avalaible data researchers may learn more about the relationships between energy consumption, IEQ, health, and performance. However, once openly accessible, these data can also be utilized to obtain more immediate benefits, for example: municipality can compare school buildings and focus on areas in need; school personnel can be alerted to conserve energy, enhance ventilation, improve hygiene, etc.; parents and other stakeholders can find information about the schools, their performance, and IEQ. Ideally, measurement and control systems will evolve so that the operation of buildings can be automatically optimized to reach maximum performance in terms of sustainable, healthy, and productive indoor environments.

Second set of data came from a nation wide data collection conducted in 2007-2008[52]. In the latest study, we focused on measurement data related to ventilation and thermal conditions collected from 60 elementary schools [53]. It was found that ventilation rates per student were below national standard (6 l/s per person) in 58% of the 108 classrooms studied. The standard was not met in any of the classrooms with natural (passive stack) ventilation or with mechanical exhaust only: in these schools ventilation systems may need adjusting, maintenance, or upgrading. In addition, ventilation rate adjustment should be done to accommodate the maximum number of students at any time. Adequate ventilation was also related to thermal comfort and appearred to associate with mathematics test results similar to other recent studies, which emphasizes the importance of meeting the standards.

Based on the results related to learning outcomes, this study did not indicate a need to increase the ventilation rate above the current standard in Finnish schools. However, further studies with more schools and longer follow-up periods are recommended for more in-depth assessment. Potential to reduce ventilation rates in schools (and other building types) should also be considered for energy conservation purposes, however, it would require more information about the actual indoor air pollutants, as ventilation is merely an indicator of IAQ. Future studies could benefit from utilizing multi-pollutant assessment to thoroughly characterize IAQ in schools, which would improve understanding of the children's exposure to indoor air pollutants and most effective ways to reduce these exposures. Such studies have also been useful in terms of developing strategies (such as source control) of prevention of adverse health consequences in for children in schools[54, 55].

5.2 Additional case studies in Lithuania

Eleven single-family low energy buildings (A class) located in Lithuania (Kaunas and Vilnius regions) were selected as additional cases. The average age of the buildings was two years. All buildings had installed mechanical ventilation (recuperative) system which was operating all the time. Floor area of buildings varied between 100-210 m^2, with number of occupants from 2 to 5. Two buildings were not fully equipped and were unoccupied during the measurement period, which occurred during the months of April-July 2014.

As described in Chapter 2, ambient T and RH were recorded during one month period. Two loggers were used per building (cold and warm spots). The measured gaseous pollutants indoors included CO_2, CO, NO_2, VOCs (BTEX), and CH_2O. Sampling duration of CO/CO_2 concentrations in each building was one week (7 days measurement) with one minute resolution. VOCs, CH_2O, and NO_2 were measured by passive sampling methods. Housing questionnaires were designed for gathering the information concerning building construction characteristics and occupant activities during measurement period. The main data from questionnaires used in this study included background building information (age of a dwelling, building materials, ventilation and heating system, typical number of occupants, etc.)

Relative humidity values fell within the comfort range as defined by the Lithuanian guidelines (35-60%). However, the thermal conditions were not always comfortable or within guidelines (18-22 °C). The absolute maximum registered temperature exceeded 25°C in eight of the eleven tested low energy buildings. CO_2 levels were mostly within recommended values, the mean concentration was 670±237 ppm, while the median values ranged from 436 ppm to 1101 ppm (Table 53). In most cases, increased CO_2 concentrations were observed during the nigh-time.

The concentrations of formaldehyde ranged from 3.3 to 53.2 μg/m^3, with overall measured mean value of 30.8±13.5 μg/m^3. None of investigated single-family buildings exceeded WHO guideline value of 100 μg/m^3. However, the Lithuanian national standard limit daily value of 10 μg/m^3 was exceeded in all occupied buildings, indicating very conservative national guidelines. The largest influence on the relative high formaldehyde concentrations was related to materials used for surfaces or furniture.

With respect to BTEX, the concentrations varied greatly among measured single-family buildings (from 1.9 to 877.9 μg/m^3) with the mean value of 91.5±261.4 μg/m^3. In eight out of eleven buildings BTEX concentrations did not exceeded 10μg/m^3. However, in recently constructed buildings where recent painting and varnishing of walls, floor and stairs took place, BTEX concentrations varied from 66.4 to 877.9 μg/m^3, indicating harmful living conditions.

The concentrations of NO_2 ranged from 1.3 to 5.7 μg/m^3, with the mean of 3.8±1.6 μg/m^3. The investigated buildings did not have indoor combustion sources and were located in the suburb area with no major outdoor traffic, corresponding with lower indoor NO_2 concentrations.

Table 53. IAQ measurement results from Lithuanian single family homes.

Gaseous pollutants	Lithuania			
	CO_2 [ppm]	CH_2O [μg/m^3]	BTEX [μg/m^3]	NO_2 [μg/m^3]
N	11	11	11	11
Ave	670	30.8	91.5	3.8
SD	237	13.5	261.4	1.6
Med	632	30.8	7.0	3.6
5th	430	10.6	3.5	1.5
95th	1057	47.4	472.1	5.7

5.3 Additional cases studies in Estonia

Three multi-family buildings from Tallinn, Estonia were selected as additional cases. Two buildings (5 and 9 storeys) were controls (no retrofits took place) and one was assessd after completion of retrofit activities (5 storey building, retrofit finished in 2014). All buildings were situated near busy roads. The average age of the buildings was about 40 years (built before 1986). Large-panel concrete and bricks were used as construction materials. These type of buildings (common in all Baltic countries) are known for their leaky envelope, low thermal insulation, unbalanced heating, and natural ventilation systems. Eight apartments were measured in the control buildings with average occupancy of 3-4 persons per apartment, while two apartments were measured in the retrofitted building with two persons per apartment.

Measurements included both thermal comfort parameters (T and RH) and gaseous pollutants (CO, CO_2, NO_2, VOCs (BTEX), CH_2O, and radon). As described in Chapter 2, ambient T and RH were recorded with data loggers. T and RH measurements continued for 7 to 11 consecutive days in the control buildings, and from October, 2013 to February, 2015 in the retrofitted building (additional T and RH loggers were used for prolonged measurements). Gaseous pollutants were measured by passive sampling methods for 7 to 11 consecutive days (Table 54).

In the control buildings, only in three apartments from seven RH values fell within the comfort range as defined by the Estonian guidelines (25-45% during winter), while three were below (20-24%) and one above (50%) the national guidelines. In the retrofitted building, RH levels were within guidelines (44% in both apartments). According to national guidelines, indoor T should stay around 22±3 °C during the heating season, and all investigated apartments fell within this range. Average T varied between 22.0-22.5 °C in the retrofitted and 20.1-24.4 °C in the control buildings, respectively. CO_2 levels were mostly within recommended guidelines: the mean concentration was 799±454 ppm in the control buildings and 740±133 ppm in the retrofitted buildings. Higher CO_2 concentrations in the control buildings could be related to the higher occupancy during the measurement period.

Concentrations of CH_2O ranged from 7.3 to 25.7 μg/m^3, with overall mean value of 16.8±6.8 μg/m^3 in the control buildings. CH_2O concentrations were lower in the retrofitted building with overall mean value of 7.0±0.8 μg/m^3. WHO guideline value (100 μg/m^3) was not exceeded in any of the measured buildings. Slightly different pattern was observed with respect to BTEX levels. The concentrations were found higher in the retrofitted building with mean value of 24.5±0.1 μg/m^3, whereas mean BTEX concentration was 18.1±5.1 μg/m^3 in the control building. NO_2 concentrations were also higher in the retrofitted building (mean 10.9±1.5 μg/m^3) than in the control buildings (mean 6.1±2.6 μg/m^3). However, it is not possible to draw any strong conclusions due to a relatively small sample size.

Table 54. IAQ measurement results from Estonian multifamily buildings.

Gaseous pollutants	Estonia			
	CO_2 [ppm]	CH_2O [μg/m^3]	BTEX [μg/m^3]	NO_2 [μg/m^3]
N	9	9	9	10
Ave	787	14.7	13.4	7.1
SD	410	7.3	4.3	3.1
Med	725	15.2	12.9	6.8
5th	406	6.8	7.7	3.6
95th	1351	24.7	19.4	11.4

5.4 Additional cases studies in Latvia

Two retrofitted multifamily buildings and two control buildings from Cesis, Latvia were selected as additional cases. Both case buildings were four storey buildings (36 apartments), built in 1972 and 1974. Additional comparison with respect to the type of ventilation system was performed between case buildings, since mechanical ventilation was installed in one of retrofitted buildings, while the other one had originally designed natural ventilation.

Measurements were divided in two parts: one month and one week campaign. During one month (March-April 2014) air flow velocity and temperature were measured in both air circuits before and after heat recovery unit (HRU), and T, RH, and CO_2 were measured in two apartments. One week (April 2014) measurement campaign included T, RH, CO_2, VOCs (BTEX), CH_2O, and radon monitoring in five apartments of each building. However, VOCs, formaldehyde, and radon samplers were lost during the handling process.

Mechanical ventilation operated well during the warmer days. However, a large difference between supply and exhaust air before and after HRU was observed during the coldest period. During the measurement period (March-April, 2014) an average thermal efficiency from the supply side was 77% (range 71– 86%).

Temperature measurements revealed that the heating system was not fully adjusted, there was too large temperature distribution between different apartments (one below 20 °C, another above 22 °C) within the same building. The average temperature decrease during air transfer from air handling unit to ground floor was 1.1 °C (max 3.2 °C).

In both retrofitted buildings CO_2 concentrations varied from 500 to 2500 ppm, being most of the time over 1000 ppm, which is recommended maximum concentration in Latvia. During the measurements, air-handling unit was working on a mode corresponding to air exchange rate of 0.18 h^{-1} (measured 0.17 h^{-1}). Results from building with natural ventilation system indicated comfortable CO_2 levels as well, indicating that windows were periodically opened to get fresh air by residents.

To compare planned and gained results, energy consumption corrections using heating degree-days were made. Energy consumption was assessed not as low as it was expected: before retrofit consumption was 152 kwh/m^2, after retrofit 98 kwh/m^2 (36% reduction), whereas planned consumption was 71 kwh/m^2 (53% reduction).

5.5 Additional cases studies in UK

In UK, case studies were planned in both single-family and multi-family buildings, and pre-renovation measurements were started in the spring of 2014. However, these measurements were not successful due to occupants tampering with the equipment. A possible reason for unsuccessful data collection could be related to that the field techs were affiliated with the housing company (building owner).

It may be beneficial for the overall success of IEQ assessments that they are conducted by independent assessors with suitable training and work experience. The assessors should liaise with both building owners and the occupants so that necessary background information can be collected and measurements and sampling conducted as planned. This way, the confidentiality requirements can be addressed and the participating occupants can be provided apartment level results of the assessment, whereas building level results can be reported to the building owner (without revealing the results from the individual apartments).

6 Assessment protocol

Several European surveys indicate that quality of housing, health, and satisfaction with the dwelling are correlated and interact in complex ways [56-58]. Divergence between objective measurements and subjective evaluations has been identified [56], and it is not readily know which one gives more valuable information in terms of occupant health and wellbeing.

INSULAtE-protocol includes both objective and subjective indictors, namely 1) building-related assessment for issues relevant to energy efficiency and buildings; 2) indoor environment, including thermal conditions and IAQ; and 3) occupants' health and satisfaction with indoor environment (including thermal conditions, IAQ, acoustics / noise, and lighting).

The assessment is ideally performed both before and after major retrofitting and/or renovation activities, and it could also be used to complement energy audits. Utilizing the protocol for the previously mentioned purposes could yield the following benefits:

- Assessment conducted before energy retrofits or large scale renovations would give valuable information for the designers about the needs and possibilities for improving IEQ, which could result in added value for the investment.
- Assessment conducted after energy retrofits or large scale renovations would provide assurance for that that IEQ is at an appropriate level and fulfilling the recommendations.
- Assessment conducted as a part of an energy audit would yield a more comprehensive knowledge about the condition and performance of the building, including both energy and IEQ.

A list of primary items included in the assessment is presented in Table 55. They have been used to develop indicators. In the following paragraps, each part of the assessment is presented in more detail.

Table 55. Primary items for IEQ assessment

1. Building-related	Energy efficiency	1. Energy sources 2. Energy consumption 3. Thermal resistance values of the building envelope 4. Thermal resistance values of windows and doors 5. Air tightness of the building envelope 6. Heating system 7. Ventilation (and possible heat recovery) system
	Structure	8. Temperature (indoor/outdoor, measurement) 9. Relative humidity(indoor/outdoor, measurement) 10. Absolute humidity / moisture gain 11. Surface temperature 12. Thermal index (TI, calculated) 13. Ventilation rate 14. Pressure difference across building envelope
2. Indoor environment	Exposure	15. Particulate matter (PM_{10}, $PM_{2.5}$) 16. Carbon dioxide (CO_2) 17. Carbon monoxide (CO) 18. Nitrogen dioxide (NO_2) 19. Formaldehyde (CH_2O) 20. Volatile Organic Compounds (VOCs) 21. Radon 22. Microbial content of settled dust 23. Mineral fibers
	Comfort	24. Dwelling space 25. Typical indoor temperature (occupied zone) 26. Lighting of the living environment 27. Noise nuisance
	Occupant behaviour	28. Related to ventilation, e.g. kitchen vent 29. Adjust the thermostat of the radiator valves 30. Opening windows/doors for ventilation purposes
3. Health and wellbeing	Satisfaction	31. Dwelling / building 32. Maintenance 33. Indoor air 34. Quality of life
	Health	35. Health symptoms 36. Missing days from work or school
	Confounding factors	37. Socio-economic factors, e.g. age, marital status 38. Living habits, e.g. smoking, physical exercise 39. Exposure to pets, ETS, etc.

6.1 Building-related assessment

The protocol covers energy efficiency and structures, including energy consumption and sources, thermal insulation and air tightness of the building envelope, thermal properties of windows and doors, heating, ventilation and air conditioning systems, and external shadowing. Following measurements are used to complement the assessment: air pressure and air flow measurements, surface temperature measurements, and long-term monitoring of temperature and relative humidity. Based on the information gathered, the following indicators are proposed (Table 56):

Table 56. Indicators proposed

Indicator	Method[1]	Unit	Notes
Metered and non-metered energy consumption	Information from building owners / house managers	kWh/ m^3/a	Weather corrections as applicable
Thermal insulation of the building envelope (external walls, floors, windows, doors)	U-values (design values)		
Air tightness of building envelope	Blower door testing	1/h	Reference values for new buildings are not necessarily applicable, pre-post retrofit comparison may provide useful information in some cases. Thermographic camera viewing simultaneously could locate leaky spots.
Thermal index	Surface temperature measurements		Indoor and outdoor T needed
Percent overheating	Long term monitoring	%	Time above recommended T
Percent too cold	Long term monitoring	%	Time below recommended T
Percent too high RH	Long term RH monitoring	%	Time above recommended RH
Percent too low RH	Long term RH monitoring	%	Time below recommended RH
Indoor moisture gain	T and RH monitoring	g/m^3	Indoor and outdoor T and RH needed
ΔP	Pressure difference measurements	Pa	Designed vs. measured, need for adjusting ventilation
Air change rate	Air flow measurements	1/h	Designed vs. measured, need for adjusting ventilation
External shadowing	Observations		Ways to improve

[1] Many of these methods are already used in typical building assessments and energy audits or data already exists (e.g. in design documents)

6.2 Indoor environmental quality

Indoor environmental quality (IEQ) is influenced by thermal conditions, indoor air pollutants (such as particles, microbes, chemical impurities, and radon), and visual and aural comfort. Indoor environmental exposure indicators are mainly composed of objective measurements, which are usually covered by regulations, standards, and policies. INSULAtE-protocol includes the following parameters: PM_{10}, $PM_{2.5}$, CO_2, CO, NO_2, CH_2O, VOCs, radon, microbial content of settled dust, and mineral fibres. Based on the results following indicators are proposed (Table 57). They are recommended to be used selectively (as needed based on expert opinion).

Table 57. Measurement proposed

Indicator	Method	Unit	Notes
Maximum CO_2	>24h measurement; under normal occupancy	ppm	Additional information on ventilation adequacy
PM10 I/O ratio	>24h measurement		
PM2.5 I/O ratio	>24h measurement		
CO	>24h measurement		In cases where combustion sources are present
NO_2	Passive sampling	$\mu g/m^3$	Could provide additional information about (mainly outdoor) sources of pollutants
CH_2O	Passive sampling	$\mu g/m^3$	Could provide additional information about (mainly indoor) sources of pollutants
VOCs (BTEX)	Passive sampling	$\mu g/m^3$	Could provide additional information about (mainly indoor) sources of pollutants
Radon	As recommended by national authorities	Bq/m^3	Recommended for buildings (for instance ground floor apartments) that are suspected to have high radon levels or if unknow
Microbial content of settled dust	Passive sampling	Cells / m^2/d	Currently only for research purposes
Mineral fibres	Passive sampling	Fiber/c m^2	Could be used if high levels of fibres are suspected

6.3 Occupants' satisfaction and health

Subjective perception of occupants is also considered an important factor from the point of view of housing and health. In the INSULAtE-protocol, information about occupants' background and behavior, housing characteristics, and satisfaction with indoor environmental quality is collected directly from the occupants. The information is collected by questionnaire, which is less covered by regulations or standards. Data from national survey is used for a reference.

The subjective views from the occupants represent their individual attitudes on how satisfied the respondents are to their housing, which in turn affect their well-being and behaviour. This information also helps to understand the results from objective measurements more comprehensively, and could be incorporated to assessment of buildings undergoing energy retrofits or large scale renovations as well as to complement energy audits (Table 58). It is recommended that in such cases the questionnaires are distributed and collected by independent assessors (not by the representative of the buildings owner or housing association). Interpretation of the results should be done cautiously: small sample size or low response rate may result in biased results which are not representative on the building level.

Table 58. Items in the occupants' questionnaire that have been associated with housing health and satisfaction also in buildings undergoing energy retrofits. Numbers refer to the original questionnaire (see Appendix C)

Question	Choises
19. What are the temperature conditions like in your dwelling? You may choose more than one option - In summer - In winter	Suitably warm / Too cold / Too warm / Draughty / Cold floor surfaces, etc.
17. Do you keep a room window open for ventilation or temperature regulation? You may choose more than one option. - In summer - In winter	Daily or almost daily / Less frequently / Never / Not possible
How satisfied are you with - 5. your present dwelling/building - 15. quality of the indoor air in your dwelling - 11. building maintenance and repairs that have been carried out	Satisfied / Fairly satisfied / Rather unsatisfied / Unsatisfied / No opinion / Cannot tell
27. Are there unpleasant odours present in your dwelling or in the immediate surroundings and what are they associated with? You may choose more than one option. - General stuffines - Sewer odour	No harmful odours / In the dwelling / Elsewhere in building indoor areas / Outdoors
25. Which of the following cause daily/almost daily noise nuisance in your dwelling? - Noise from the building's ventilation, plumbing, electrical systems, lifts, etc. - Noise from the surrounding areas (traffic, industry, etc.)	Noise nuisance daily or almost daily / No or infrequent noise nuisance
24. Are there any deficiencies in the lighting of your living environment? - Interior lighting of the dwelling - Interior lighting of the building (staircases, storage areas, etc.)	Sufficient / Not sufficient

In addition to occupants' satisfaction, our questionnaire included items related to occupants' health. These questions are not recommended to be used in the assessments of individual buildings (unless required by health authorities). However, housing and health surveys could be useful on a larger scale national, regional, or in some cases, local assessments, to follow-up trends and evaluate effects of certain policies on housing and health conditions. The questions include general health status, which is an important indicator related to overall well-being. The other health related questions self-assessed mainly included respiratory tract infections, resulting visits to a doctor, use of medication, or absences from work or schools. Missing days from school or work due to health issues/symptoms could be used to estimate the cost of lost productivity, and evaluate the social and economic burden. Information on health symptoms and the frequency they associated with housing environment were also collected, but their interpretation is more challenging. Further analyses are needed to study the associations between health symptoms and objective indoor environmental quality parameters.

Lifestyle related behaviours, such as smoking habits and physical exercise, are significantly associated with health status. Also other background information (such as age, gender, marital status, and socio-economical status) are needed to better understand the health status and the self-assessed quality of life of the occupants in large scale surveys, and how they may be associated with the living environment independently from the background variables / confounding factors. Ethical issues need to be carefully considered as a part of each survey.

As a part of the insulate protocol, we also tested occupant diaries (see Appendix C). While the information gathered may help to provide additional information about indoor environmental quality and how it relates to occupant behaviour, the method needs to be further developed.

Drawing conclusions based on questionnaire data requires careful analyses and interpretation. Occupant self-reporting is subjective and prone to reporting bias. There are, however, some ways to increase objectivity: e.g. using questions that specifically ask about issues that can be validated, such as doctor diagnosed diseases, emergency room visits, and missed work/school days due to illness. In addition, occupant responses can be linked with objective measurements.

Due to numerous factors that influence human health and well-being, a large enough sample size is needed to draw conclusions about the empirical relationships between housing conditions and occupant health. The required sample size is primarily based on the need to have sufficient statistical power, so that one can be reasonably confident to detect an effect of a given size. There are many methodological difficulties inherent in assessing the health effects of housing that need to be carefully considered. For example, response and follow up rates in studies are often low, which can limit the possibility to draw conclusions and generalize the results.

On the group level, our sample size appears to be sufficient to detect relatively large differences (>10-20% difference in the prevalence values) between the sub-samples. However, group level comparisons may be inconclusive, as there are many confounding factors that have to be taken into consideration. Therefore, our sample size may be limited for drawing definite conclusions on the potential effects of energy retrofits on occupant health, but the data could be used to develop tools to follow-up effects of national programmes and policies aiming to improve energy efficiency of buildings, particularly in terms of occupants' satisfaction. Future analyses will provide additional information about associations between occupants' self-reported and measured IEQ, which could be used for validation purposes.

6.4 Reporting the results for building owners and occupants

A part of the assessment protocol is reporting the results of the assessment for building owners and occupants. Report for occupants includes results from their own apartment and their interpretation. The interpretation of the results is largely based on national guidelines and reference values (i.e. varies by country). Report for the building owners includes summaries of results from all IEQ measurements without identifying any individual apartment.

Examples of the reports used in this project are presended in Appendix D.The examples represent a randomly selected Finnish case building. Based on user consulations and feedback, simpler report formats with visual information were preferred. Therefore, alternative report formats were developed during the course of the project, presented as Appendix D4. However, this report formats have not been tested in the real case buildings, and particularly the report format for building owner should be further developed.

6.5 Summary

Table 59 summarises measurement parameters in the case and control buildings.

In Finland, significant differences after retrofits were seen in RH, CH_2O, BETEX, and microbial content of settled dust. Relative humidity as well as bacterial levels were similarly changed in the control building indicating the effect of outdoor conditions or temporal variation. Concentrations of CH_2O as well as levels of fungi were significantly lower after the retrofits, whereas BETEX levels were increased: similar trends but weaker were seen in the control buidings. Occupant satisfaction with the dwelling and IAQ, perceived odours, daily noise disturbance related to traffic or industry, as well as respiratory symptoms and missed work or school days could be related to the retrofits, although further studies are needed to verify the associations. All of these issues were improved after retrofits. Occupant responses concurred with the objective measurements in thermal conditions since no changes were observed in either one. An opposite trend was seen in reporting noise disturbance related to plumbing, ventilation, electrical systems etc., which increased by 6 %, but this change was not statistically significant.

In Lithuania, significant differences after retrofits were seen in indoor T, RH, CH_2O, radon, and microbial content of settled dust. However similar changes were observed in the control buildings, and in addition, smaller sample size limits the possibility to draw definite conclusions on the group level. CO_2 levels were slightly higher after retrofits, which could indicate decreased ventilation in some cases, although average ACH remained on the same level. Occupants satisfaction with the dwelling, IAQ and thermal conditions improved, and daily noise disturbance related to traffic or industry decreased, which could be related to the retrofits.

Table 59. Summary of measured parameters in case and control buildings.

Parameter, unit	CASE		CONTROL	
	1st N; median	2nd[1] N; median	1st N; median	2. st N; median
Finland				
Tw[2], °C	163; 23.0	101; 22.7	30; 22.0	21; 22.4
TI	143; 49.6	101; 59.9	8; 56.5	7; 51.1
RHw[2], %	169; 29.0	102; 30.2*	30; 18.0	21; 24.0*
Moisture gain, g m^{-3}	135; 1.0	101; 1.0	8; 1.5	7; 1.2
ACR, h^{-1}				
Mechanical ventilation	119; 0.4	70; 0.4	10; 0.6	8; 0.4
Natural ventilation	11; 0.2	8; 0.2	-	-
CO_2, ppm	129; 651	80; 617	11; 633	9; 546
$PM_{2.5}$, I/O	136; 0.9	96; 0.9	16; 0.8	11; 1.1
PM_{10}, I/O	136; 1.0	96; 1.3	16; 1.3	11; 0.8
NO_2, µg m^{-3}	145; 6.2	104; 6.0	16; 3.9	13; 4.9
CH_2O, µg m^{-3}	140; 18.2	103; 16.4*	16; 15.9	13; 13.5
BETEX, µg m^{-3}	132; 6.5	102; 9.1*	16; 5.4	13; 7.0
Radon, Bq m^{-3}	132; 60	88; 50	13; 40	12; 40
Bacteria, gram+, cells/m^2/d	83; 6498	56; 1363*	11; 6727	10; 1569*
Bacteria, gram-, cells/m^2/d	83; 7944	56; 1386*	11; 5602	10; 1816*
Fungi, cells/m^2/d	83; 477	56; 97*	11; 148	10; 138*
Fibres, cm^{-2}	121; 0.0	62; 0.0	16; 0.0	11; 0.0
Lithuania				
Tw[2], °C	66; 19.5	55; 20.4*	23; 19.9	8; 21.1
TI	71; 69.7	58; 77.1	23; 69.9	7; 74.9
RHw[2], %	66; 43.6	55; 48.3*	23; 42.2	8; 47.9
Moisture gain, g m^{-3}				
ACR, h^{-1} (Natural ventilation)	72; 0.3	55; 0.3	23; 0.4	8; 0.3
CO_2, ppm	66; 957	57; 993	22; 1013	8; 1002
$PM_{2.5}$, I/O	64; 0.6	40; 0.6	20; 0.6	6; 1.0
PM_{10}, I/O	64; 0.8	40; 0.9	20; 0.8	6; 1.3
NO_2, µg m^{-3}	71; 11.9	57; 11.7	22; 16.0	8; 13.8*
CH_2O, µg m^{-3}	71; 24.1	57; 28.0*	24; 16.5	8; 32.9*
BETEX, µg m^{-3}	71; 16.0	55; 19.4	24; 7.3	8; 7.7
Radon, Bq m^{-3}	33; 28	31; 38*	12; 14	4; 18
Bacteria, gram+, cells/m^2/d	69; 21288	51; 31868*	22; 42436	5; 156662
Bacteria, gram-, cells/m^2/d	69; 32672	51; 26154*	22; 58889	5; 40688*
Fungi, cells/m^2/d	69; 2147	51; 1960*	22; 3712	5; 11706
Fibres, cm^{-2}	71; 1.12	48; 1.12	24; 1.12	6; 1.69

[1] After retrofits [2] Occupied zone *$p < 0.05$ based on Mann-Whitney U-test (paired samples)

Overal, the situation (usually about one year) after retrofits appears similar or slightly better than at the baseline. However, it should be noted that while the average or median values are used to detect differences in the samples pre and post retrofits, there are values on both side of the averages, i.e. in some cases the situation could have improved and in some cases worsened. Analyzing these data further could yield valuable information about possible ways to improve IEQ and success of the retrofits in general. It should also be noted that long-term effects have not been assessed so far.

7 Conclusions and recommendations

7.1 Conclusions

A comprehensive protocol was developed for assessment of the impacts of improving energy efficiency of multifamily buildings on indoor environmental quality and health. The protocol was tested in more than three countries and limited testing was conducted also in some other building types.

Based on both objective measurements and subjective evaluations before and after energy retrofits, the group level effects of improved energy efficiency on IEQ and occupant health appeared to be mainly positive. After retrofits, the average temperatures remained unchanged in Finland, while thermal conditions were significantly improved in Lithuania. Ventilation rates appeared were improved in Finnish case buildings, but remained similar or decreased in Lithuanian case buildings. In some cases, the significance of indoor sources of pollutants appeared to increase after retrofits. Occupant satisfaction with indoor environmental quality was mostly increased. However, follow up was done for about one year after the retrofits, and the long-term effects could not be studied.

The project results can be used to develop guidance and support the implementation of the EPBD. Specifically, we have developed indicators that can be used for assessment of IEQ in connection with energy retrofits and large scale renovations as well as to complement energy audits. The large database collected as a part of the project can be used as a reference for as long as nationally representative databases does not exist.

On the level of individual apartment, the assessment protocol can be mainly used to ensure that IEQ fulfils the national (or international) guidelines. On the building level, the assessment could be used to provide useful information and support decisions and planning of retrofitting and renovation actitities and to give a more comprehensive picture of the condition and performance of the building, possibly complementing energy audit and certificates. On the national level, similar surveys could be used to assess the effects of national policies and programmes. Many countries do not have objective baseline information about the condition of their building stock and IEQ: for example, assessment of thermal conditions and ventilation on a national scale also provides information about over-heating / cooling issues, which are closely linked to energy consumption: simple adjustments could help to save significant amount of energy and also improve IEQ. On the EU level, at least some of the indicators could be imcorporated in the existing surveys and databases (e.g. Eurostat, ENHIS).

7.2 Recommendations

It is recommended that the large datasets collected will be further analysed and the information disseminated as a part of After-Life communication plan. Further analyses are expected to provide information related to the associations between different paramenters, including IEQ and occupant health.

Some of the measurement tools used also need further developing: for example microbial analyses were carried out from settled dust with qPCR methods which is currently mostly used for research purposes. Occupant diaries appeared to provide useful information about occupant behaviour that could also be related to energy consumption, but the method has not been validated.

We recommend that international guideline or reference values are developed for most important IEQ factors. Currently many factors only have national (if any) guidelines, which makes it more difficult to assess the effects of EU-level policies and programmes.

We also recommend that a basic IEQ assessment is included in building energy audits. As a minimum, thermal conditions and ventilation adequacy should be assessed, not only from the point of view of energy consumption, but also from the point of view of IEQ. The basic assessment could be extended based on initial observations and/or feedback from the buiding occupants. Reporting format related to IEQ assessment should be further developed pertaining to the international guideline and reference values. Training of energy auditors should cover relevant IEQ issues.

Given that the European building stock will go through major changes starting in the next few years due to EPBD requirements, it is recommended that guidance and tools for follow-up of the effects will be further developed, to fully utilize the potential for improving the quality of the housing stock, while also reducing its carbon footprint.

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List of Appendixes

A Building owner related SOPs and material

1. Contact/communication with the building owner
2. Contact letter for house managers
3. Notice board
4. Energy+building related information
5. House manager inquiry

B Field study related SOPs and material

1. Collection of building related data
2. T/RH logger set-up
3. PM measurements
4. SOP, PM measurement
5. Passive sampling instructions
6. Passive sampling, VOC, NO_2
7. RAM NO_2 instructions
8. Fibre sampling
9. SOP for fibres wipe
10. SOP for fibres, tape
11. Radon sampling (STUK)
12. SOP for settled dust
13. Fieldform, dust
14. SOP SDB vacuuming
15. Check-list, measurement
16. Sampling log sheets

C Building occupants related SOPs and material

1. Delivery and collection of occupant questionnaires and diaries
2. Information letter, willingness to participate and questionnaire
3. Notice for study participant
4. Instructions for occupants
5. Housing and health survey
6. Housing and health diary
7. Thank you -letter

D Reporting of results

1. Result letter to occupant
2. Result letter to house manager
3. Report format 2.0

Appendix A – Building owner related SOPs and material

1. Contact/communication with the building owner

Purpose

To describe material needed and procedure for contacting building owner or house manager in order to recruit possible case buildings, select case buildings, and prepare for field studies in the selected buildings.

Definitions

Building owner is the owner of the building, for instance in case of rental building, it can be a rental building company (VVO, SATO, TA-yhtymä, AVARA-Suomi) or municipality (Tampere/VTS, Helsinki/Stadin asunnot, Espoo/ Espoon Kruunu, Vantaa/VAV Asunnot, Heinola, etc.). In a case where the occupants own their apartment, the building owner can be a housing corporation (contact person: chairman of housing corporation). Decisions of renovation, etc. are made by the building owners. House manager is an individual or an organization responsible for practical operations of the building, stays in contact with occupants, and holds all technical information concerning structures, renovation operations, energy efficiency, etc.

Material

- Short description of the studies (brochure and cover letter, App. A2)
- Questions of basic information (of buildings) (App. A3)

1. Basic information of the building: age, area, number of apartments, doorsteps and storeys, balconies, ownership of building (own/rented apartments)
2. Heat distribution system, ventilation system
3. Planned renovation: actions and timetable

Procedure

1. Contacting building owner/house manager by phone or email.

2. Sending “Short description of the studies” (App.A2) and “Questions of basic information to contact person” (App. A6).

3. Choosing the case buildings (based on criteria). Criteria for choosing case building (most important first):

- Timetable: renovation scheduleObject (at least one) of the planned renovation action is to improve energy efficiency: e.g. improving thermal insulation of external walls (and roof)
- A proper plan, including building condition assessment, has been performed
- Age of the building (e.g. built between 1960-1993 in Lithuania; 1960-1980 in Finland)
- The renovation actions are limited to couple of actions (1 to 2): Improving thermal insulation of windows (and doors), improving air infiltration systems, improving air tightness of building frame, improving heating and ventilation systems
- At least most of the apartments have a balcony
- The energy used for heating can be distinguished from total energy used (domestic electrics, real estate electrics), building has district heating (commonly used in Finnish suburban multi-storey buildings)

4. If possible, house manager distributes information and material (App. C2) to occupants

5. Detailed study plan: timetable, actions

- collecting detailed material: design documents, structural details, energy consumption information (App. A6)
- possibility to use master key for entry apartments (requires approval from the occupants, App. C2)
- ventilation system should be switched on when measuring air flows (normally the system could be on only few hours in morning and in the afternoon)

2. INSULAtE Contact letter for house manager

INSULAtE

Improving Energy Efficiency of Housing Stock: Impacts on Indoor Environmental Quality and Public Health in Europe

Case study buildings are needed for Energy efficiency and indoor environmental quality- research

The 5-year research project (brochure attached), co-financed by EU Life+ funding is looking for case study buildings. Target buildings are multi-family apartment buildings with planned energy retrofits (e.g. improving thermal insulation of envelope) during 2011 or 2012.

Different kind of measurements concerning indoor air conditions and environmental quality will be performed in approximately five apartments of each building. Measurements will be performed before and after renovation. Also occupants will be asked to participate in questionnaires / interviews. The apartments and occupants for the measurements will be chosen among volunteers.

Additional information about the building, such as structures, energy consumption and renovations, will be collected from the house managers.

In the first phase we ask you to list possible case study buildings from your ownership in the attached form. The final selection of the buildings will be done based on the building type, renovation methods, and renovation schedule. After that we will contact you for arranging further actions.

We will ask you (house manager/ property maintenance) help in contacting occupants of the selected buildings. We wish that you can deliver questionnaires to each apartment, where we also ask occupant's interest to participate in the measurements. Also the collection of the questionnaires could be arranged through you. If the occupants agree, part of the visits in the apartments (installing/removing measurements devices) can be done using master key while occupants are not present. In such case, we would need property maintenance's help.

The research results concerning each building(s) (excluding results concerning occupant's health) will be delivered to the owner of the building. The final analysis and reporting will be done on group level, where single buildings or occupants cannot be identified.

Please fill the attached form and return it by xx.xx.201x either by email (address xxx.aaa @tut.fi or by mail (address ….).

More information: N.N….

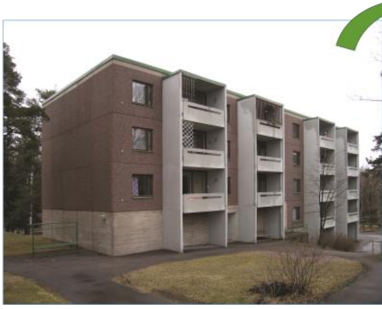
Attachments: Brochure of the research project
Form of possible case study buildings

3. Notice board

Improving Energy Efficiency of Housing Stock: Impacts on Indoor Environmental Quality and Public Health in Europe (INSULAtE)

Housing and health surveys and indoor measurements will be performed in this building as a part of the INSULAtE project during ___ / ___ / _____ – ___ / ___ / _____.

Additional information concerning the study can be found in the material delivered to each residence and on the project website www.insulateproject.eu



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NATIONAL INSTITUTE FOR HEALTH AND WELFARE

KAUNAS UNIVERSITY OF TECHNOLOGY

TAMPERE UNIVERSITY OF TECHNOLOGY

4. Energy+building related information

Name or address of the building:__________________________________

	Before retrofit	After retrofit
Energy consumption, yearly (from energy consumption report, energy audit,…)		
Heating energy consumption (kWh/build-m^2)		
Electricity consumption(kWh/build-m^2)		
Use of water, yearly (m^3, m^3/build-m^2 or m^3/occup)		

Structures (from energy audit, old blue prints,…), if available		
U-value of outer walls (W/m^2 K)		
U-value of roofs (W/m^2 K)		
U-value of floors (W/m^2 K)		
U-value of windows (W/m^2 K)		
U-value of doors (W/m^2 K)		
Ventilation on maximum power (hours per day)		
Ventilation on maximum power, times		
Set value of indoor temperature (^oC)		

Energy certificate		
ET- or E-value (specify which one)		
Energy consumption based on ET- or E-value calculation kWh/gross-m^2/year (specify which one)		

5. INSULAtE House manager inquiry

Basic information of case buildings

Name, address	Age of building	Area of building, m^2	Volume of building, m^3	Number of floors	Number of stairs	Number of apartments	Energy class (energy certification)	Has building received public renovation support of loan, what and where	Code (will be given later)
1.									
2.									

Basic information of case buildings **Name, address**	Renovation budget, €	Heating system of building	Air change system of building (natural, mechanical supply/exhaust)	Previosly renovation history	Code
1.					
2.					

Basic information of renovation

Name, address	Starting date of renovation	Ending date of renovation	Thermal insulation of envelope	Changing windows	Thermal insulation of roof	Changing heating system	Changing ventilation system	Other renovations, Footnotes	
			Renovation methods (mark x)						
1.									
2.									

Contact information, footnotes

Name, address	Are apartments occupated during renovation?	Do apartments have balconies?	Contact person, house manager	Contact person, occupant society (if contacts to occupants through this)	Footnotes about renovation etc.	
1.						
2.						

Other information:

Name of the responsible person:

Appendix B – Field study related SOPs and material

1. Collection of building related data: measurement instruments, checklists etc.

Purpose

To describe methods for structural measurements and assessment.

Definitions

- T, Temperature
- RH, relative humidity

Material

- Equipment

1. T+RH loggers, indoor and outdoor (see equipment for further information)
2. T+RH meters (see equipment for further information)
3. Surface temperature meter (see equipment for further information)
4. Air flow meter, anemometer (see equipment for further information)
5. Air pressure difference meter (see equipment for further information)
6. Check-list and measurement logs
7. Timetable agreed by occupants and house manager, contact information etc.
8. List of information from building owner/house manager (also under D6)[[2]]
9. Basic information (first contact with owner/manager)
10. Details of building (from design documents): structures (envelope, U-values), total area and volume of heated building space, etc.
11. Energy (annual) consumption of the building: divided to energy used for heating, electric energy for apartments, energy used to warming water, etc.
12. Detailed renovation plan and schedule, including condition assessment done before renovation planning.

Procedure

Check-list/log sheet, see: http://heande.opasnet.org/wiki/File:Stuctural_measurements.pdf

1. Installing T+RH loggers, indoors and outdoors

Examples for placing loggers, see: http://heande.opasnet.org/wiki/File:Field_measuring_points.pdf The loggers must be pre-programmed for logging T+RH values once a hour. The measurement starts by pushing some bottom (manual). Take a photo where you put the loggers and also take a photo when you pick them up (check if the placement has been changed, which should be considered in data analysis).

Indoor T+RH loggers

Two loggers are set for each apartment. One logger is placed on the floor facing outdoor wall, representing the coldest spot of the apartment, indicated surface temperature measurements ot thermographic camera imaging. If there are small children or pets living in the apartment, the logger should be placed a bit higher or at least the logger should be fasten, for instance hanging on the wall socket. The other logger is placed in the middle of the room, at the height of about 1 m, for example on the table. The loggers can be placed in the same room, but not necessarily (consult with the occupant). Give instructions to the occupant about the loggers: loggers should be kept primarily at the same place (can be moved during cleaning, etc.), display shows values of T and RH, ask to contact researcher in a case of malfunction (low battery),.

2. Measuring T+RH, indoor and outdoor

(the meter can be included into some other meter (surface temperature, air flow meter, air pressure difference)

Outdoor temperature and relative humidity

Measure and record outdoor T+RH at least when entering the building and when leaving the building or placing the meter inside balcony when entering the apartment and record before leaving the apartment (meter needs time to stabilise).

Indoor T+RH

Measure and record indoor T+RH of each the apartment at the height of about 1.1 m, i.e. occupied zone.

3. Measuring surface temperatures

Record maximum and minimum surface temperature in each room. Point floor/wall, wall/roof connections and outer wall edges as well as window and door connections in order to find max and min values. Or you can use thermographic camera if it is available by following instructions of the camera.

4. Measuring air flow (air change rate)

If the apartment has a natural ventilation system, it is not usually possible to measure air flow (ventilation) rates. Also it is not possible to measure air flow rates from the kitchen vent hood. Air flows can be measured from exhaust or supply ventilation vents.

Before measurements, find out the ventilation system. If there is a mechanical ventilation system, ask the building manager to make sure the system is on normally used speed.

Measure and record air flows for each exhaust and supply air vents. Use adequate air flow cone for different sized air channels to canalize air flow (if the diameter is other than 100 mm). Measure the area of the channel and the airflow can be read directly [m^3/s].

5. Measuring air pressure difference

Try to measure both highest and lowest story apartments. If there is a mailbox on the door, it is possible to measure air pressure difference between the apartment and stairwell. Also measure air pressure difference between outdoors and indoors in one room per apartment (usually through balcony door). Measurement step by step:

1) Open the window (or mailbox or balcony door)

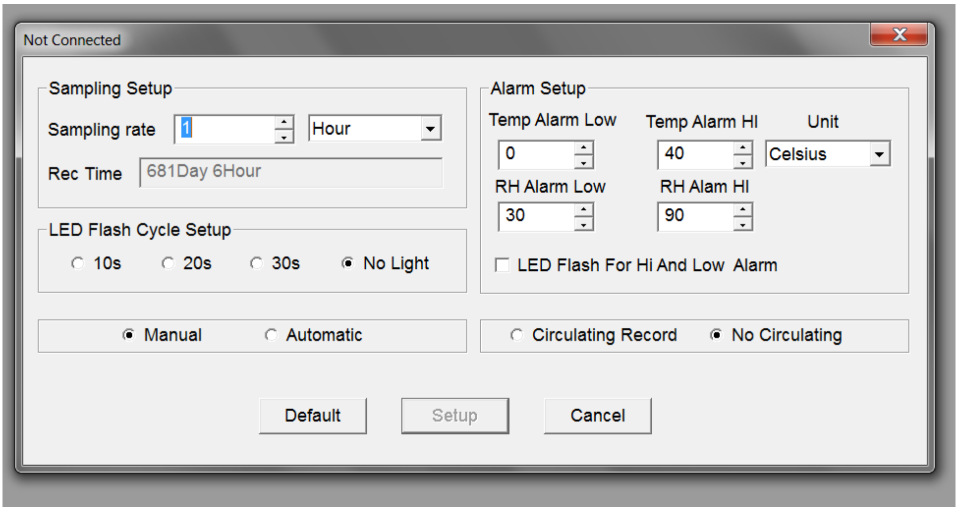
2) Place the measuring tube to the other side

3) Close the window (or mailbox or balcony door) carefully without blocking air flow through the tube. If closing the window blocks air flow, leave the window slightly open and use removable masking tape to tighten the gap)

4) Measure air pressure differences for a few minutes and record the average value (if it’s a windy day) (manual).

2. T/RH logger set-up

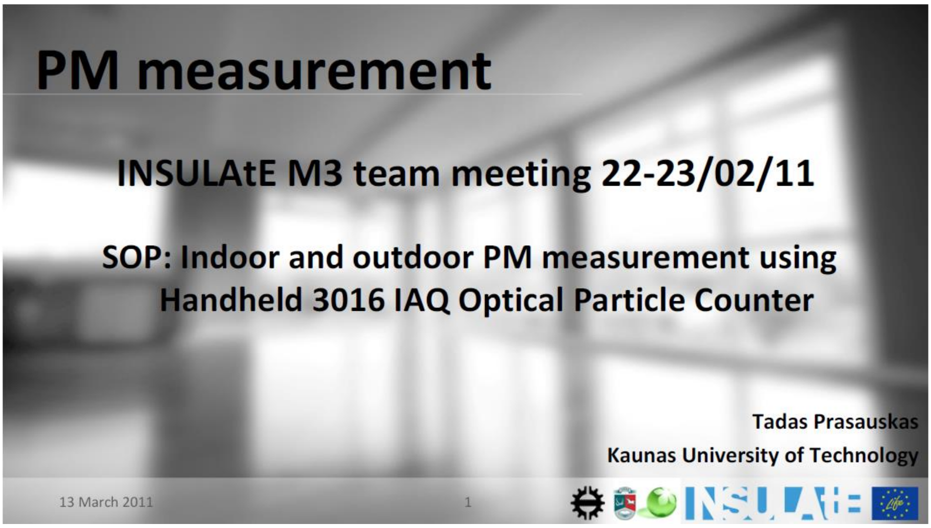
T+RH logger (CEM DT-172) setup for INSULAtE field measurements

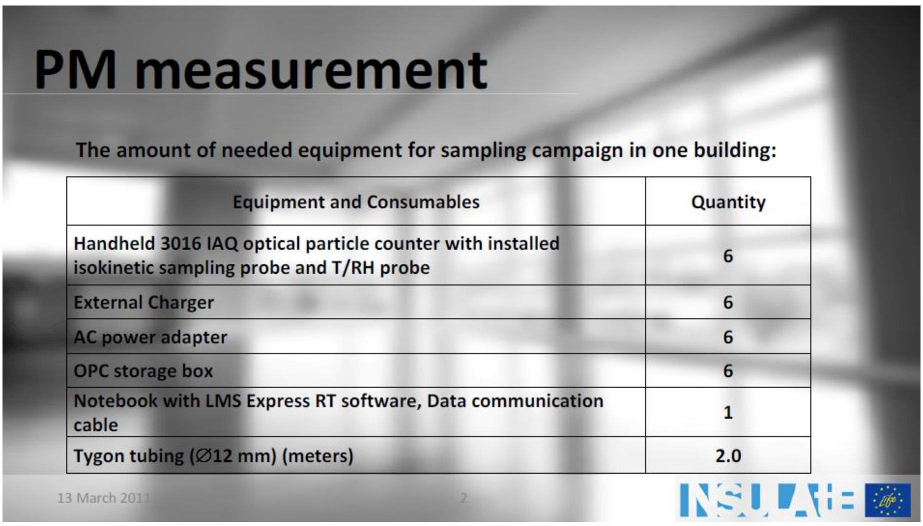


3. PM measurements

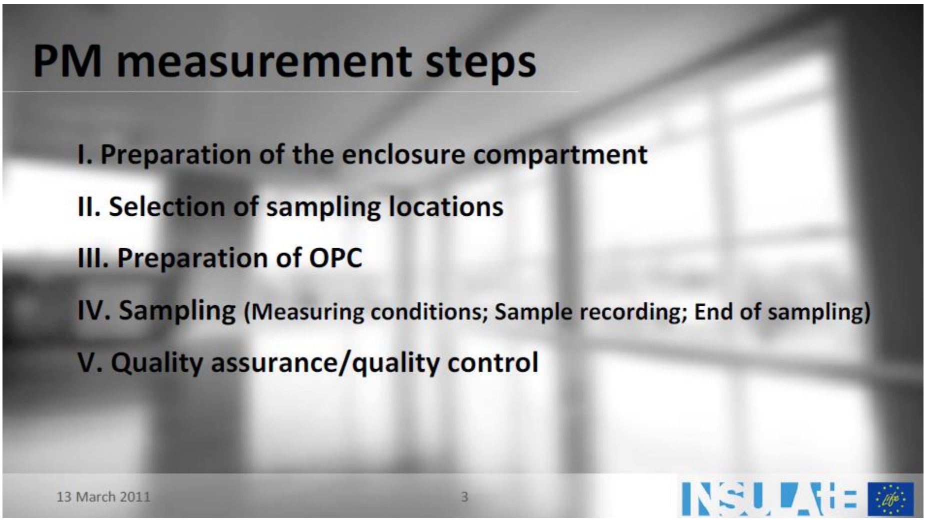
STANDARD OPERATING PROCEDURE

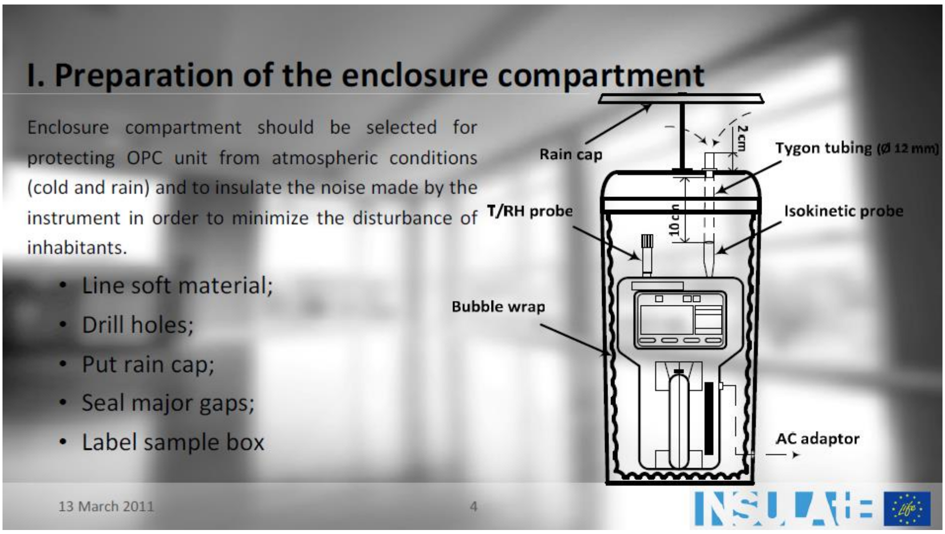
Indoor and outdoor PM measurement using Handheld 3016 IAQ Optical Particle Counter

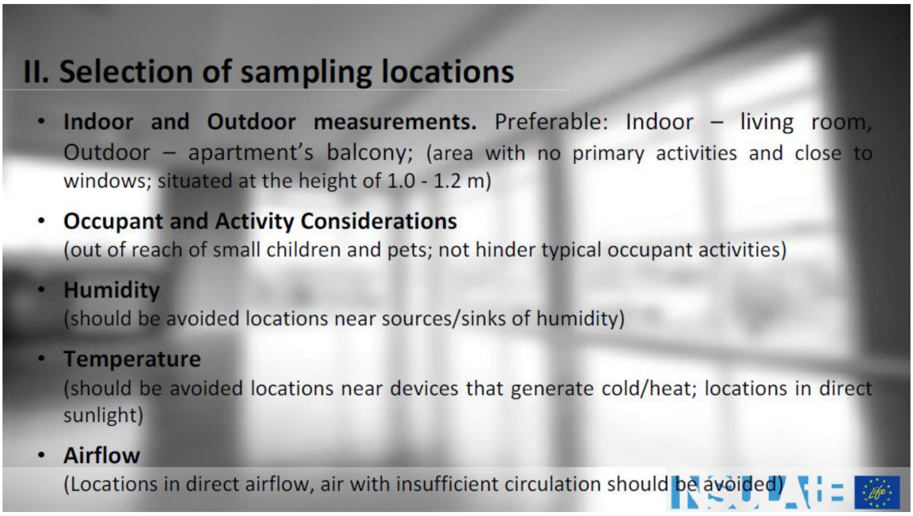


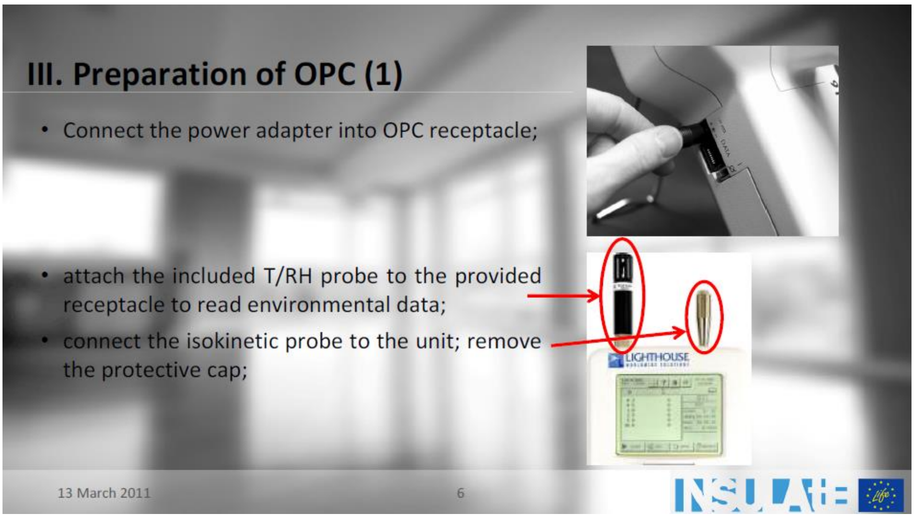


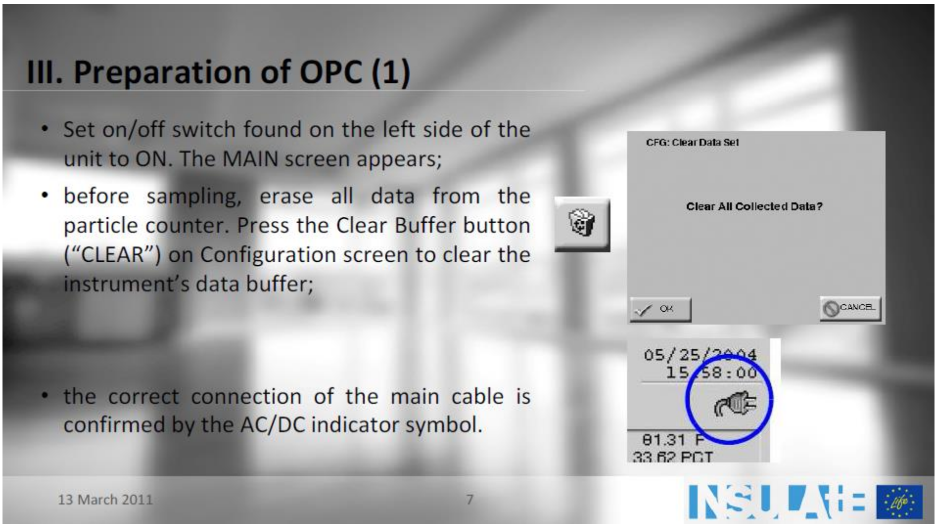
Equipment and Consumables	Quantity
Handheld 3016 IAQ optical particle counter with installed isokinetic sampling probe and T/RH probe	6
External Charger	6
AC power adapter	6
OPC storage box	6
Notebook with LMS Express RT software, Data communication cable	1
Tygon tubing (∅12 mm) (meters)	2.0

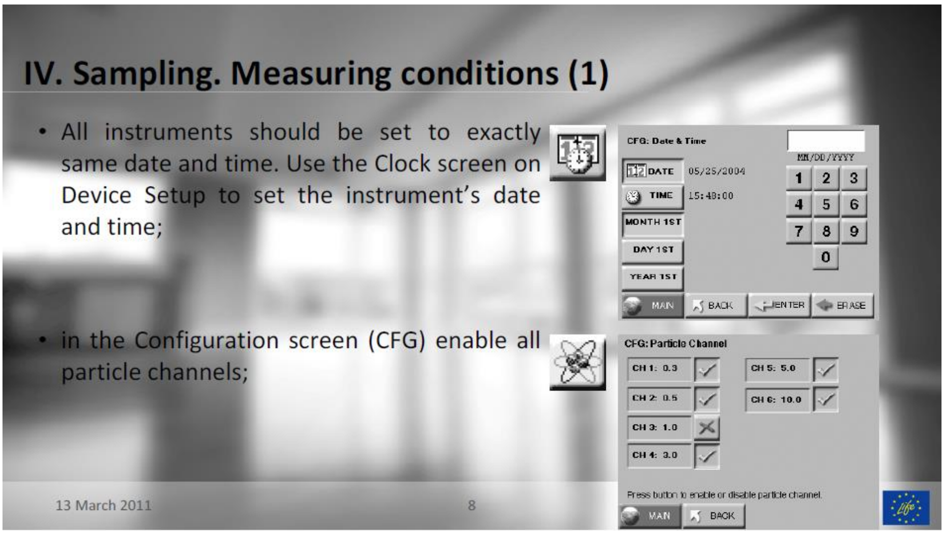

PM measurement steps
I. Preparation of the enclosure compartment
II. Selection of sampling locations
III. Preparation of OPC
IV. Sampling (Measuring conditions; Sample recording; End of sampling)
V. Quality assurance/quality control
13 March 2011
3
INSULAtE

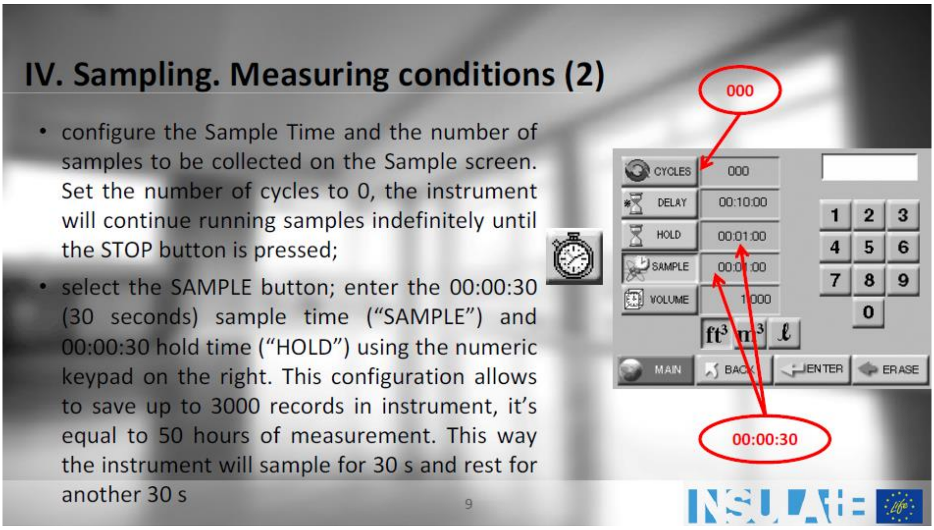

I. Preparation of the enclosure compartment
Enclosure compartment should be selected for protecting OPC unit from atmospheric conditions (cold and rain) and to insulate the noise made by the instrument in order to minimize the disturbance of inhabitants.
• Line soft material;
• Drill holes;
• Put rain cap;
• Seal major gaps;
• Label sample box
Rain cap
2cm
Tygon tubing (Ø 12 mm)
T/RH probe
10cm
Isokinetic probe
Bubble wrap
AC adaptor
13 March 2011
4
INSULAtE

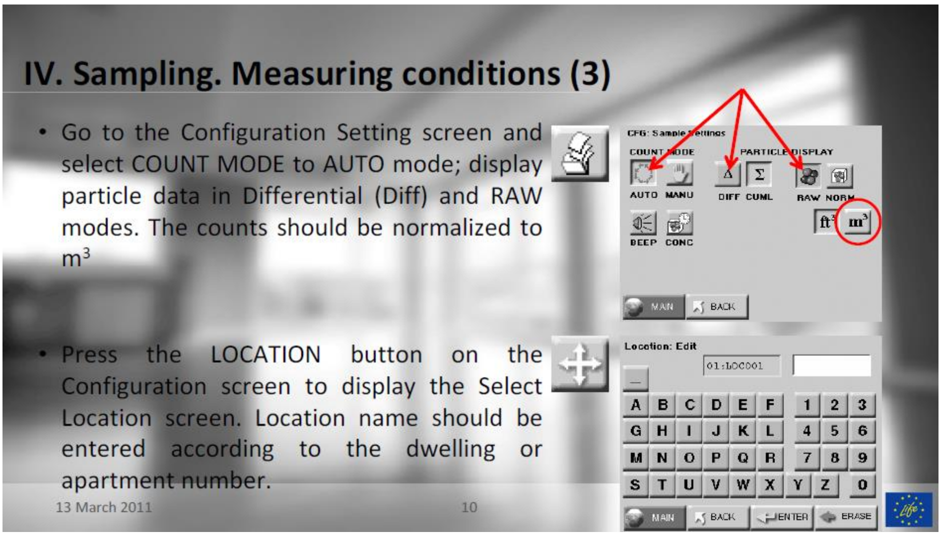

II. Selection of sampling locations
• Indoor and Outdoor measurements. Preferable: Indoor – living room, Outdoor – apartment's balcony; (area with no primary activities and close to windows; situated at the height of 1.0 - 1.2 m)
• Occupant and Activity Considerations
(out of reach of small children and pets; not hinder typical occupant activities)
• Humidity
(should be avoided locations near sources/sinks of humidity)
• Temperature
(should be avoided locations near devices that generate cold/heat; locations in direct sunlight)
• Airflow
(Locations in direct airflow, air with insufficient circulation should be avoided)

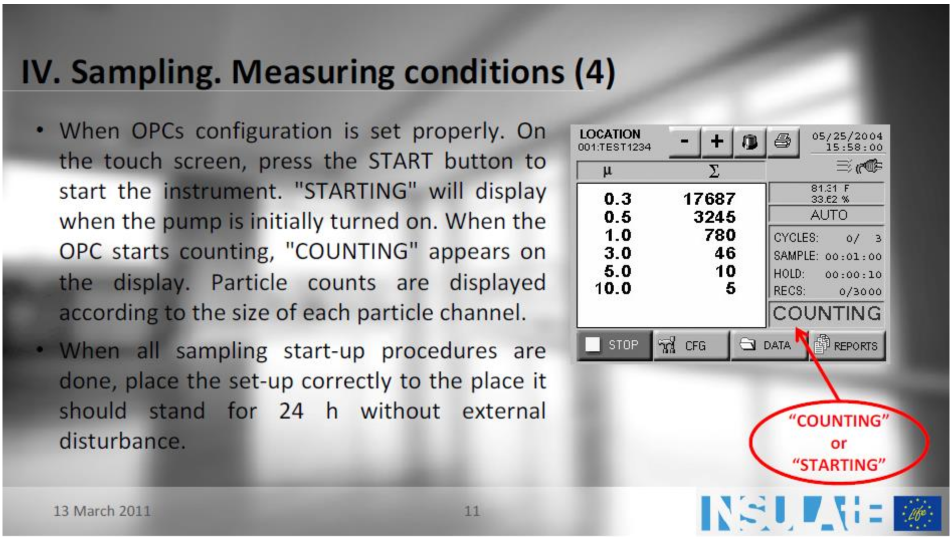

III. Preparation of OPC (1)
• Connect the power adapter into OPC receptacle;
• attach the included T/RH probe to the provided receptacle to read environmental data;
• connect the isokinetic probe to the unit; remove the protective cap;
LIGHTHOUSE
13 March 2011
6

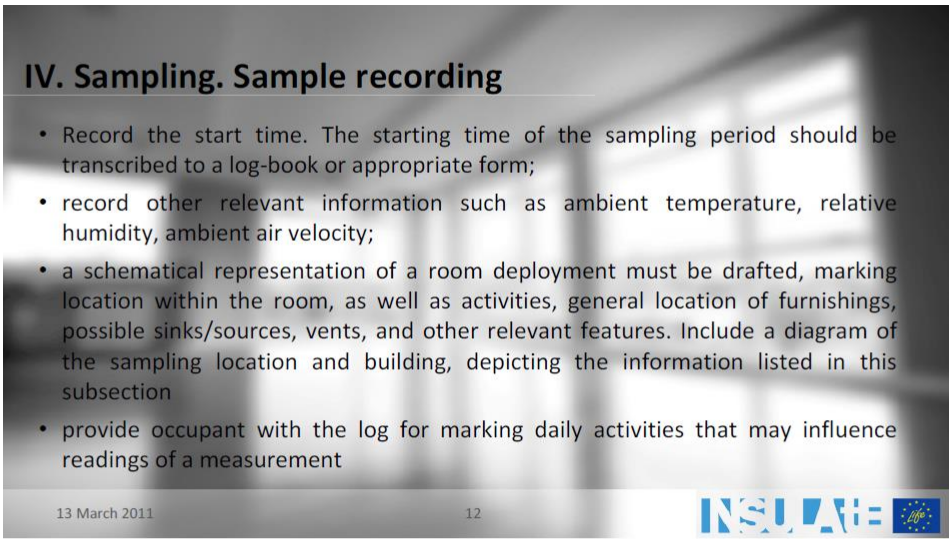

III. Preparation of OPC (1)
• Set on/off switch found on the left side of the unit to ON. The MAIN screen appears;
• before sampling, erase all data from the particle counter. Press the Clear Buffer button ("CLEAR") on Configuration screen to clear the instrument's data buffer;
• the correct connection of the main cable is confirmed by the AC/DC indicator symbol.
CFG: Clear Data Set
Clear All Collected Data?
OK
CANCEL
05/25/2004
15:58:00
81.31 F
33.62 PCT
13 March 2011
7
INSULAtE

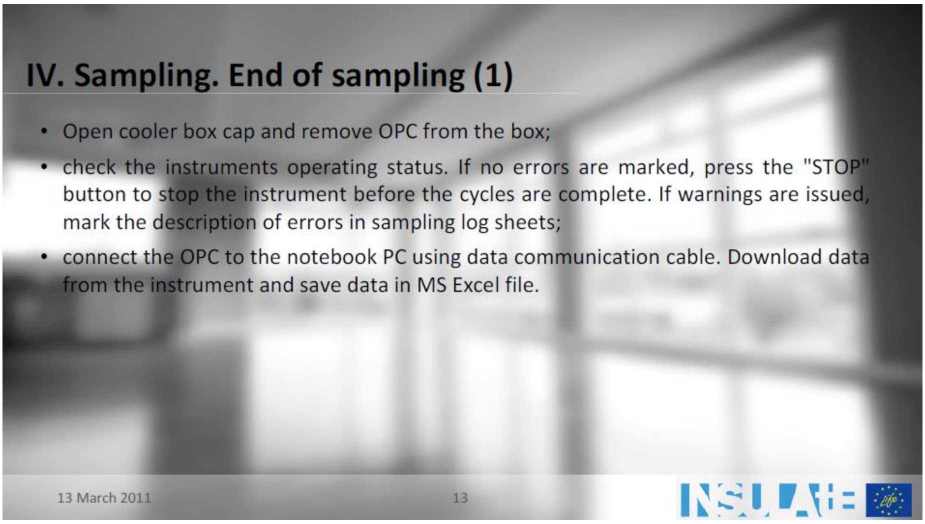

IV. Sampling. Measuring conditions (1)
• All instruments should be set to exactly same date and time. Use the Clock screen on Device Setup to set the instrument's date and time;
• in the Configuration screen (CFG) enable all particle channels;
CFG: Date & Time
MM/DD/YYYY
DATE 05/25/2004
TIME 15:48:00
MONTH 1ST
DAY 1ST
YEAR 1ST
MAIN
BACK
ENTER
ERASE
CFG: Particle Channel
CH 1: 0.3
CH 2: 0.5
CH 3: 1.0
CH 4: 3.0
CH 5: 5.0
CH 6: 10.0
Press button to enable or disable particle channel.
13 March 2011
8

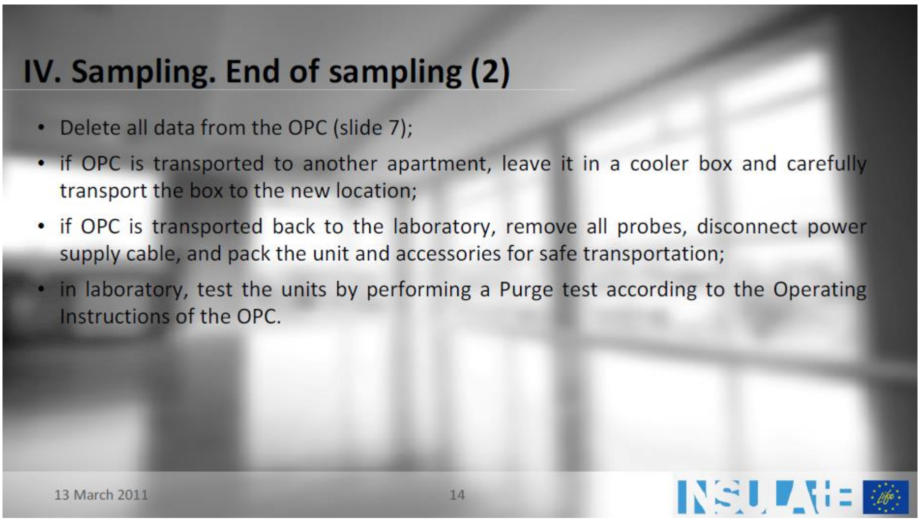

IV. Sampling. Measuring conditions (2)
• configure the Sample Time and the number of samples to be collected on the Sample screen. Set the number of cycles to 0, the instrument will continue running samples indefinitely until the STOP button is pressed;
• select the SAMPLE button; enter the 00:00:30 (30 seconds) sample time ("SAMPLE") and 00:00:30 hold time ("HOLD") using the numeric keypad on the right. This configuration allows to save up to 3000 records in instrument, it's equal to 50 hours of measurement. This way the instrument will sample for 30 s and rest for another 30 s
000
CYCLES
000
DELAY
00:10:00
HOLD
00:01:00
SAMPLE
VOLUME
MAIN
BACK
ENTER
ERASE
00:00:30
9

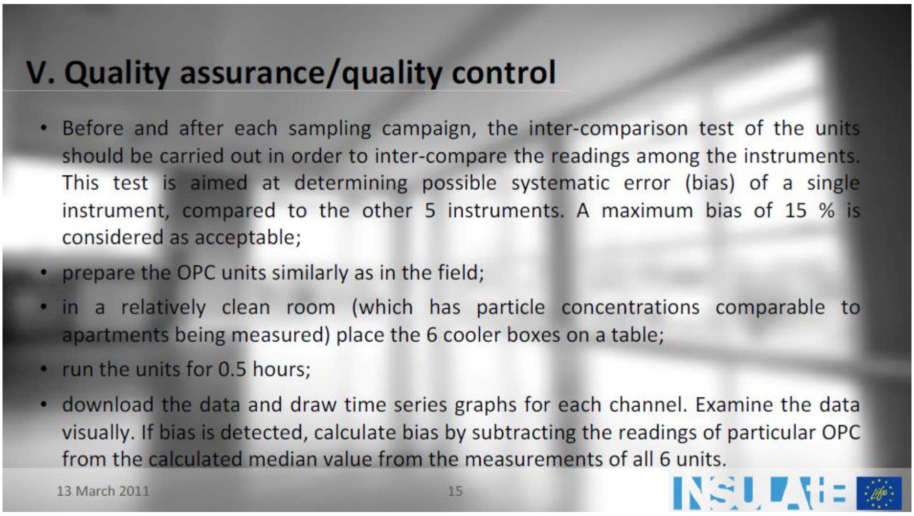

IV. Sampling. Measuring conditions (3)
• Go to the Configuration Setting screen and select COUNT MODE to AUTO mode; display particle data in Differential (Diff) and RAW modes. The counts should be normalized to m3
• Press the LOCATION button on the Configuration screen to display the Select Location screen. Location name should be entered according to the dwelling or apartment number.
AUTO MANU
DIFF CUML
RAW NORM
BEEP CONC
MAIN
BACK
Location: Edit
01:LOC001
ENTER
ERASE
13 March 2011
10


IV. Sampling. Measuring conditions (4)
• When OPCs configuration is set properly. On the touch screen, press the START button to start the instrument. "STARTING" will display when the pump is initially turned on. When the OPC starts counting, "COUNTING" appears on the display. Particle counts are displayed according to the size of each particle channel.
• When all sampling start-up procedures are done, place the set-up correctly to the place it should stand for 24 h without external disturbance.
LOCATION
001:TEST1234
05/25/2004
15:58:00
µ
Σ
0.3 17687
0.5 3245
1.0 780
3.0 46
5.0 10
10.0 5
AUTO
CYCLES: 0/ 3
SAMPLE: 00:01:00
HOLD: 00:00:10
RECS: 0/3000
COUNTING
STOP
CFG
DATA
REPORTS
"COUNTING" or "STARTING"
13 March 2011
11
INSULAtE


IV. Sampling. Sample recording
• Record the start time. The starting time of the sampling period should be transcribed to a log-book or appropriate form;
• record other relevant information such as ambient temperature, relative humidity, ambient air velocity;
• a schematical representation of a room deployment must be drafted, marking location within the room, as well as activities, general location of furnishings, possible sinks/sources, vents, and other relevant features. Include a diagram of the sampling location and building, depicting the information listed in this subsection
• provide occupant with the log for marking daily activities that may influence readings of a measurement
13 March 2011
12
INSULAtE


IV. Sampling. End of sampling (1)
• Open cooler box cap and remove OPC from the box;
• check the instruments operating status. If no errors are marked, press the "STOP" button to stop the instrument before the cycles are complete. If warnings are issued, mark the description of errors in sampling log sheets;
• connect the OPC to the notebook PC using data communication cable. Download data from the instrument and save data in MS Excel file.
13 March 2011
13


IV. Sampling. End of sampling (2)
• Delete all data from the OPC (slide 7);
• if OPC is transported to another apartment, leave it in a cooler box and carefully transport the box to the new location;
• if OPC is transported back to the laboratory, remove all probes, disconnect power supply cable, and pack the unit and accessories for safe transportation;
• in laboratory, test the units by performing a Purge test according to the Operating Instructions of the OPC.
13 March 2011
14


V. Quality assurance/quality control
• Before and after each sampling campaign, the inter-comparison test of the units should be carried out in order to inter-compare the readings among the instruments. This test is aimed at determining possible systematic error (bias) of a single instrument, compared to the other 5 instruments. A maximum bias of 15 % is considered as acceptable;
• prepare the OPC units similarly as in the field;
• in a relatively clean room (which has particle concentrations comparable to apartments being measured) place the 6 cooler boxes on a table;
• run the units for 0.5 hours;
• download the data and draw time series graphs for each channel. Examine the data visually. If bias is detected, calculate bias by subtracting the readings of particular OPC from the calculated median value from the measurements of all 6 units.
13 March 2011
15

4. SOP, PM measurement

INSULAtE

STANDARD OPERATING PROCEDURE

Indoor and outdoor PM measurement using

Handheld 3016 IAQ Optical Particle Counter

SUMMARY:

This standard operating procedure describes PM measurement in multifamily buildings using the Lighthouse Handheld 3016 IAQ Optical Particle Counter (Further referred to as OPC).

Sampling locations: One particle counter should be set indoors of the apartment, if possible in the living room (OPC should be located at the same location during entire measurement time). Another OPC should be set outdoors; the most preferable place is the apartment's balcony.

Sampling time: Sampling duration in one apartment should be at least 24 hours (full day measurement), with a 1-minute resolution for both indoor and outdoor PM measurements. Equipment to be used: Handheld 3016 IAQ optical particle counters, isokinetic sample probes, temperature/relative humidity probes, external battery chargers, AC power adapters, enclosure compartments, Tygon tubing (Ø12 mm), Notebook PC with LMS Express RT software, data communication cable.

A. EQUIPMENT

1. Equipment description:

1.1. The **HANDHELD 3016 IAQ** must be six particle-size channels (0.3, 0.5, 1.0, 2.5, 5.0 and 10.0 :m particle fraction simultaneous sampling) starting at 0.3 microns with a flow of 0.1 CFM and a touch screen interface. The unit should be programmed to calculate PM1, PM2.5 and PM10 fractions concentrations. Data storage capacity should be up to 3000 sample records, including particle and environmental data, plus location and time. Environmental Sensors: Temperature/Relative Humidity Probe: 0-50°C ± 0.5°C, 15-90% ±2%. Each of the units should be labeled by assigning them subsequent numbers, such as “OPC#1”.

1.2. **LMS Express RT** software should be used to download collected data from the instrument, collect real time data, save data for historical review, and have advanced reporting with standard reports. Special data cable is needed to connect the OPC to a notebook PC, running on MS Windows XP or newer operating system.

1.3. **External Battery Charger with AC power adapter** are utilized to constantly keep instrument in a charged state, in order to avoid battery drainage and operation failure.

1.4. **Enclosure compartment** must be used to enclose the OPC unit with the aim to protect it from environmental stress as well as to protect the environment from the noise produced by the pump of the OPC unit. Specially prepared cooler box may be utilized for this purpose, as described in chapter A.2.

1.5. **Isokinetic sampling probe** and Tygon tubing (Ø12 mm) are joined to form sampling inlet

for the UPC unit.

The amount of equipment units for sampling campaign at one building is summarized in a Table 1.

Table 1. The amount of needed equipment for sampling campaign in one building

Equipment and Consumables	Quantity
Handheld 3016 IAQ optical particle counter with installed isokinetic sampling probe and T/RH probe	6
External Battery Charger	6
AC power adapter	6
OPC storage box	6
Notebook with LMS Express RT software, Data communication cable	1
Tygon tubing, (Ø12 mm) (meters)	2.0

2. <u>Preparation of the enclosure compartment:</u>

2.1. A cooler box the volume of (>0.025 m^3), internal height of (>0.4 m), internal width of >0.2 m. Should be selected for protecting OPC unit from atmospheric conditions (cold and rain) and to insulate the noise made by the instrument in order to minimize the disturbance of inhabitants. The cooler box should be modified for enclosing the OPC unit according to a drawing presented in Fig. 1.

2.2. If needed, line soft material (e.g. bubble wrap) inside of the boxes to prevent damaging of the equipment and to improve sound insulation.

2.3. Drill one hole for Tygon tubing in the top cover of the box of similar or smaller diameter to an external diameter of Tygon tubing. Another hole should be drilled for power cable in a lower part of a cooler box wall.

2.4. For outdoor measurements rain cap may be installed to protect the enclosure from rain drops.

2.5. Seal major gaps to minimize the penetration of noise. On the other hand, the air pumped by OPC should be discharged from the box without major pressure drop in order to prevent the pump from the box.

2.6. Each of the sampling boxes should be labeled by assigning them subsequent numbers, such as “Box#1”.

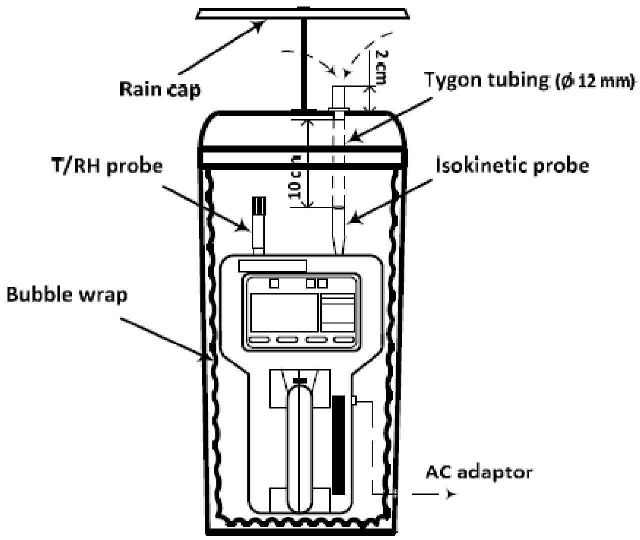


Fig. 1. Cross-section of cooler boxed used as an enclose compartment for the PM measurement unit.

B. SELECTION OF MEASUREMENT LOCATIONS

1. **Positioning of samplers in an apartment**. One OPC should be set indoors of the apartment, if possible in the living room, close-by to the other sampling devices. Another OPC should be set outdoors; the most preferable place would be the apartment's balcony.

   The indoor OPC should be positioned in the area with no primary activities (e.g. TV, computer or other working equipment, which generates and attracts particulate matter) and close to windows (because of outdoor environment influence and formation of draughts). The sampling enclosure should be positioned so that the inlet would be situated at the height of 1-1.2 m from the floor surface. The sampler should be placed in a location that is both unobstructed and representative of the actual used area of the room.

2. **Occupant and Activity Considerations –** The samplers should be placed out of reach of small children and pets; the location should not hinder typical occupant activities. The sampler should not be placed near suspected

sources/sinks. The sampler location should be discussed with the occupant(s). The location should not interfere with normal occupant activities.

3. **Humidity** – Locations near water basins, tubs, showers, stoves, washers, driers, humidifiers/dehumidifiers, or other known sources/sinks of humidity should be avoided.
4. **Temperature –** Locations near furnaces, vents, sinks, tubs, showers, electric lights, air conditioners, or other devices that may directly or indirectly generate heat/cold should be avoided. Locations in direct sunlight or near seasonal or short-term variations from weather should be avoided.
5. **Airflow** – Locations in direct airflow, such as near ventilation vents, appliance fan vents, and computer cooling fans, should be avoided. Areas with a known air-flow due to pressure differentials between rooms should be avoided. Air with insufficient circulation to provide a representative atmosphere to the sampler should be avoided.

C. MEASUREMENT

1. Double-check that all necessary equipment for indoor/outdoor PM measurement is collected before leaving laboratory. Transport the equipment in dedicated and well-maintained tool-boxes.
2. Choose correct sampling location for placing the set-up (see above “sampling locations”).
3. Preparation of OPC:
    - 3.1. Refer to the OPC manual to correctly perform actions described in the following steps.
    - 3.2. Connect the power adapter into OPC receptacle.
    - 3.3. Connect the isocinetic probe to the unit; remove the protective cap. **NOTE:** The protective cap must be placed on the isokinetic probe during transportation of the unit.
    - 3.4. Attach the included Temperature/Relative Humidity probe to the provided receptacle to read environmental data (in this case, the inside T/RH of cooler box will be measured. This will be useful to analyze to check the

operating conditions for the OPC unit (too hot/too cold)).

4. Set on/off switch found on the left side of the unit to ON. The MAIN screen appears.
5. Before sampling, erase all data from the particle counter. Press the Clear Buffer button (“CLEAR”) on Configuration screen to clear the instrument’s data buffer.
6. The correct connection of the mains cable is confirmed by the AC/DC indicator symbol.
7. Set identical measuring conditions for both indoor and outdoor particle counters:
    7.1. All instruments should be set to exactly same date and time. Use the Clock screen on Device Setup to set the instrument’s date and time.
    7.2. In the Configuration screen (CFG) enable all particle channels.
    7.3. Configure the Sample Time and the number of samples to be collected on the Sample screen. Set the number of samples to 0, the instrument will continue running samples indefinitely until the STOP button is pressed.
    7.4. Select the SAMPLE button; enter the 00:00:30 (30 seconds) sample time (“SAMPLE”) and 00:00:30 hold time (“HOLD”) using the numeric keypad on the right. This configuration allows to save up to 3000 records in instrument, it’s equal to 50 hours of measurement. This way the instrument will sample for 30 s and rest for another 30 s.
    7.5. Go to the Configuration Setting screen and select COUNT MODE to AUTO mode; display particle data in Differential (Diff) and RAW modes. The counts should be normalized to m^3.
    7.6. Press the LOCATION button on the Configuration screen to display the Select Location screen. Location name should be entered according to the dwelling or apartment number.
8. When OPCs configuration is set properly. On the touch screen, press the START button to start the instrument. "STARTING" will display when the pump is initially turned on. When the OPC starts counting, "COUNTING" appears on the display. Particle counts are displayed according to the size of each particle channel.

9. Put working OPCs into the cooler box and make sure that they stand firm on the bottom of the cooler box.
10. Connect isokinetic probe with Tygon tube. Place cooler box cap on the top so that the end of the tube would be sticking out (few centimeters straight tube).
11. Seal all remaining box gaps to minimize the sound effect of the particle counter (if needed).
12. When all sampling start-up procedures are done, place the set-up correctly to the place it should stand for 24 h without external disturbance.
13. Fill out the sampling log:

    13.1. Record the start time. The starting time of the sampling period should be transcribed to a log-book or appropriate form.

    13.2. Record other relevant information such as ambient temperature, relative humidity, ambient air velocity.

    13.3. A schematical representation of a room deployment must be drafted, marking location within the room, as well as activities, general location of furnishings, possible sinks/sources, vents, and other relevant features. Include a diagram of the sampling location and building, depicting the information listed in this subsection.

    13.4. Provide occupant with the log for marking daily activities that may influence readings of a measurement.

D. END OF SAMPLING

1. Open cooler box cap and remove OPC from the box.
2. Check the instruments operating status. If no errors are marked, press the "STOP" button to stop the instrument before the cycles are complete. If warnings are issued, mark the description of errors in sampling log sheets.
3. Connect the OPC to the notebook PC using data communication cable. Download data from the instrument and save data in MS Excel file. The file should be named as follows: <OPC ID#>_<Building#>_<Apt#>_<Date of measurement DD/MM/YYYY>, and stored in a folder named by a building number. For example, OPC1_B2_A4_12/03/2011.xls stored in folder

Building1.

4. Delete all data from the OPC (see point C.6.).
5. If OPC is transported to another apartment, leave it in a cooler box and carefully transport the box to the new location.
6. If OPC is transported back to the laboratory, remove all probes, disconnect power supply cable, and pack the unit and accessories for safe transportation.
7. In laboratory, test the units by performing a Purge test according to the Operating Instructions of the OPC.

E. QUALITY ASSURANCE/QUALITY CONTROL

1. The OPC units must be checked and maintained according to manufacturer's recommendations.
2. Before and after each sampling campaign, the inter-comparison test of the units should be carried out in order to inter-compare the readings among the instruments. This test is aimed at determining possible systematic error (bias) of a single instrument, compared to the other 5 instruments. A maximum bias of 15 % is considered as acceptable.
   - 2.1 Prepare the OPC units similarly as in the field (steps C. 1 - 13)
   - 2.2 In a relatively clean room (which has particle concentrations comparable to apartments being measured) place the 6 cooler boxes on a table. The room should not contain major aerosol sources nearby. The room should not also be affected by excessive air flow movements due to strong forced ventilation.
   - 2.3 Run the units for 0.5 hours.
   - 2.4 Download the data and draw time series graphs for each channel. Examine the data visually. If bias is detected, calculate bias by subtracting the readings of particular OPC from the calculated median value from the measurements of all 6 units. If the bias is larger than 15% at any point of 30 measurements, actions needed to be taken to resolve the reasons of bias to occur.

5. Passive sampling instructions

GRADKO (NO_2):

Storage:

- Before and after sampling store the sampler in a refrigerator, for example in a Minigrip-bag or similar (polyethylene)

Sampling outdoors:

- Place the ID-tag on the backside of the sampler
- Fix the shelter to a suitable place
- Fix the sampler under the shelter (pre positioned Velcro® spots on sampler)
- Remove the black cap from the sampler
- After sampling replace the black cap, remove the sampler form the shelter and put the sampler in a Minigrip-bag or similar

Sampling indoors:

- Place the ID-tag on the backside of the sampler
- Put a double-sided adhesive tape to the backside of the sampler
- Place the sampler to a vertical surface
- OR hang it up with a clip
- Remove the black cap from the sampler
- After sampling replace the black cap and put the sampler in a Minigrip-bag or similar

RADIELLO (VOCs and aldehydes):

Storage:

- Before the sampling store the sampler in room temperature, away from the sunlight (in the dark)
- After sampling store it in a cool place

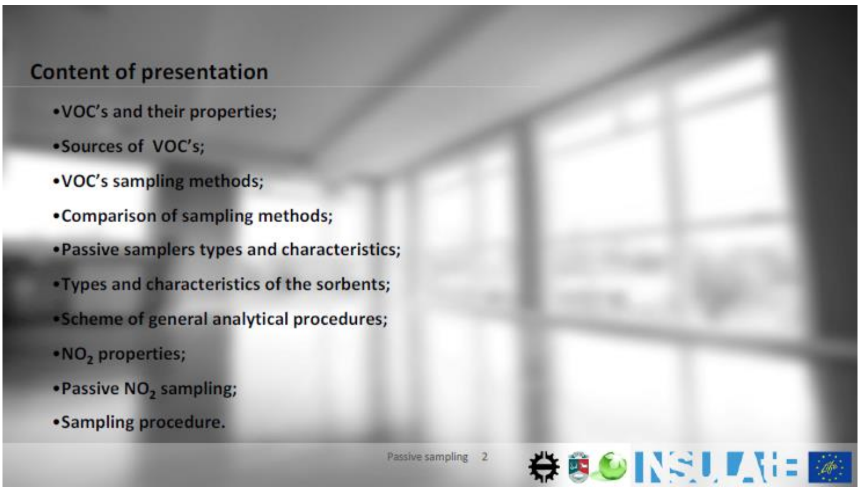
Sampling (VOC sampler code 130, white diffusive bodies code 120)**:**

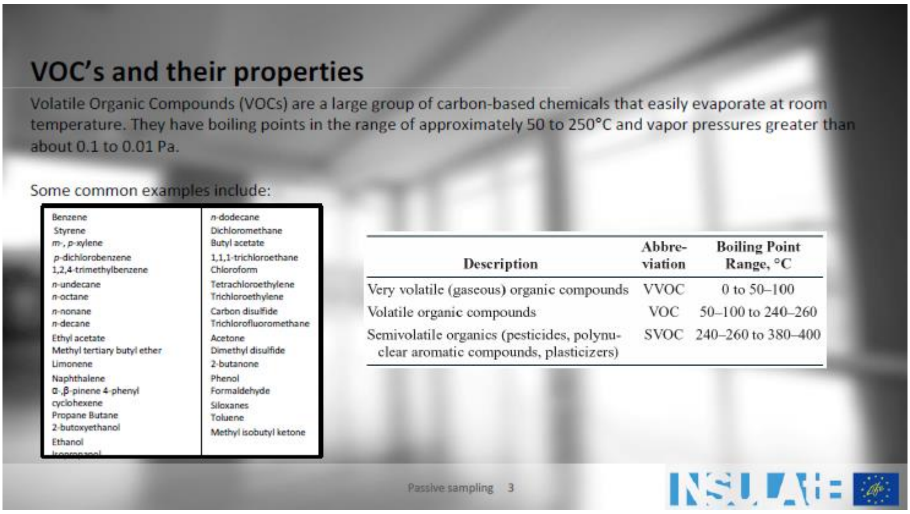
- Open the plastic bag and slide the sampler to the white diffusive body
- Do not touch the sampler (with your hands)
- Keep the glass/plastic tube and cap in the original bag
- NOTE! When the sampler is placed right it is completely inside the white diffusive body. If the sampler is partially visible, tap the diffusive body gently so that the sampler slides completely inside the body.
- Keep the diffusive body in upright position while screwing it firmly to the supporting plate.
- Mark down the starting date and time.

- Place the supporting plate to the sampling location.
- After sampling remove the diffusive body from the supporting plate, slide the sampler into the tube and close it with the cap.
- Mark the tube with the label (that has the ID code, starting date and time and the ending date and time)
- Store it in a cool place, where there are no VOC emitting materials present.

6. Passive sampling, VOC, NO_2

STANDARD OPERATING PROCEDURE
Passive VOC and NO_2 sampling





VOC's and their properties

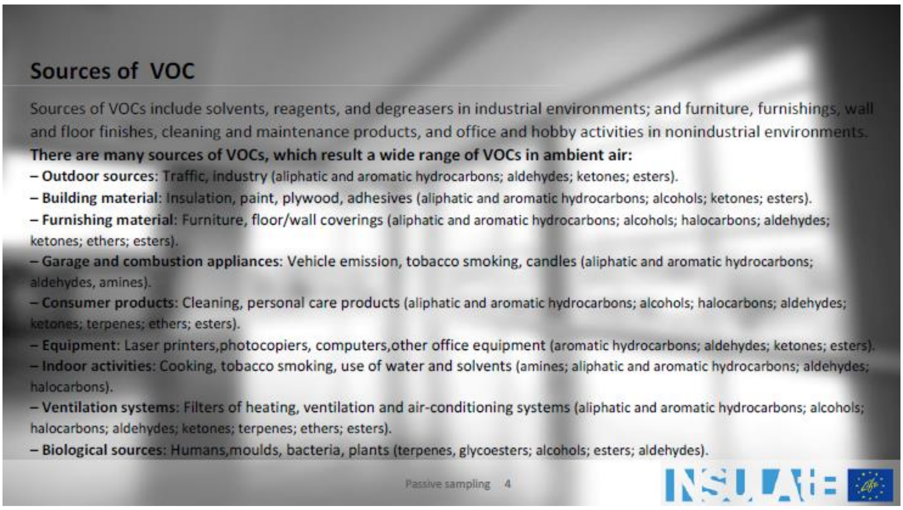
Volatile Organic Compounds (VOCs) are a large group of carbon-based chemicals that easily evaporate at room temperature. They have boiling points in the range of approximately 50 to 250°C and vapor pressures greater than about 0.1 to 0.01 Pa.

Some common examples include:

Benzene	*n*-dodecane
Styrene	Dichloromethane
m-, *p*-xylene	Butyl acetate
p-dichlorobenzene	1,1,1-trichloroethane
1,2,4-trimethylbenzene	Chloroform
n-undecane	Tetrachloroethylene
n-octane	Trichloroethylene
n-nonane	Carbon disulfide
n-decane	Trichlorofluoromethane
Ethyl acetate	Acetone
Methyl tertiary butyl ether	Dimethyl disulfide
Limonene	2-butanone
Naphthalene	Phenol
α-,β-pinene 4-phenyl	Formaldehyde
cyclohexene	Siloxanes
Propane Butane	Toluene
2-butoxyethanol	Methyl isobutyl ketone
Ethanol	
Isopropanol	

Description	Abbre-viation	Boiling Point Range, °C
Very volatile (gaseous) organic compounds	VVOC	0 to 50–100
Volatile organic compounds	VOC	50–100 to 240–260
Semivolatile organics (pesticides, polynuclear aromatic compounds, plasticizers)	SVOC	240–260 to 380–400

Passive sampling 3



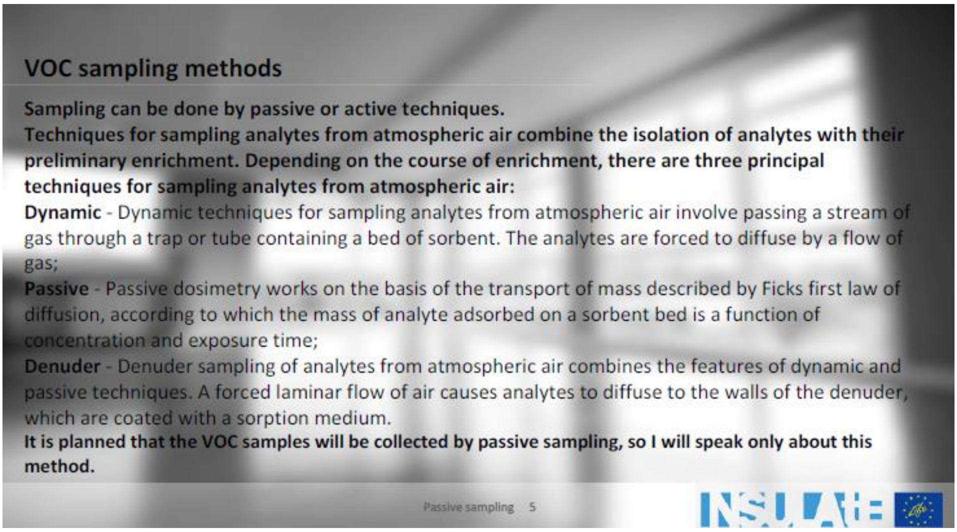
Sources of VOC

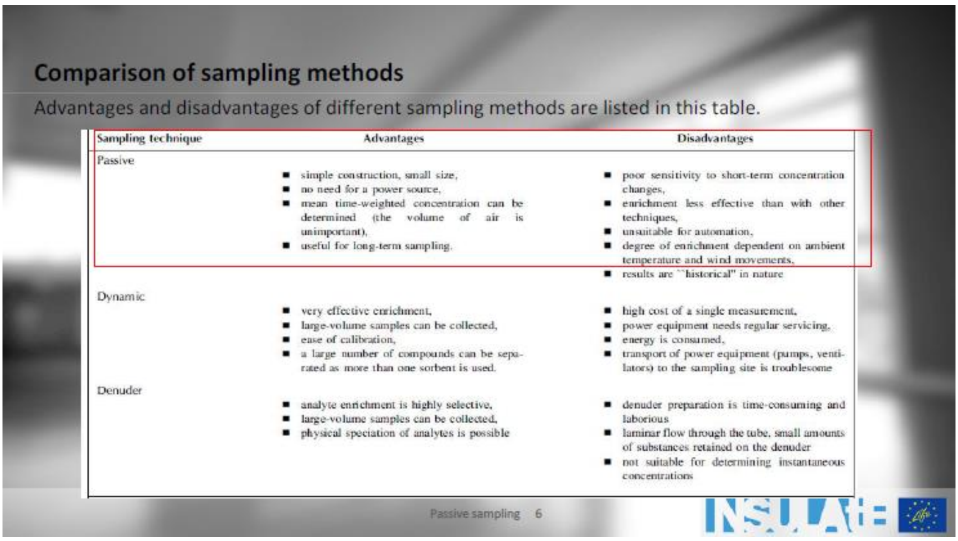
Sources of VOCs include solvents, reagents, and degreasers in industrial environments; and furniture, furnishings, wall and floor finishes, cleaning and maintenance products, and office and hobby activities in nonindustrial environments.

There are many sources of VOCs, which result a wide range of VOCs in ambient air:

– **Outdoor sources**: Traffic, industry (aliphatic and aromatic hydrocarbons; aldehydes; ketones; esters).
– **Building material**: Insulation, paint, plywood, adhesives (aliphatic and aromatic hydrocarbons; alcohols; ketones; esters).
– **Furnishing material**: Furniture, floor/wall coverings (aliphatic and aromatic hydrocarbons; alcohols; halocarbons; aldehydes; ketones; ethers; esters).
– **Garage and combustion appliances**: Vehicle emission, tobacco smoking, candles (aliphatic and aromatic hydrocarbons; aldehydes, amines).
– **Consumer products**: Cleaning, personal care products (aliphatic and aromatic hydrocarbons; alcohols; halocarbons; aldehydes; ketones; terpenes; ethers; esters).
– **Equipment**: Laser printers,photocopiers, computers,other office equipment (aromatic hydrocarbons; aldehydes; ketones; esters).
– **Indoor activities**: Cooking, tobacco smoking, use of water and solvents (amines; aliphatic and aromatic hydrocarbons; aldehydes; halocarbons).
– **Ventilation systems**: Filters of heating, ventilation and air-conditioning systems (aliphatic and aromatic hydrocarbons; alcohols; halocarbons; aldehydes; ketones; terpenes; ethers; esters).
– **Biological sources**: Humans,moulds, bacteria, plants (terpenes, glycoesters; alcohols; esters; aldehydes).

Passive sampling 4





Sampling technique	Advantages	Disadvantages
Passive	▪ simple construction, small size, ▪ no need for a power source, ▪ mean time-weighted concentration can be determined (the volume of air is unimportant), ▪ useful for long-term sampling.	▪ poor sensitivity to short-term concentration changes, ▪ enrichment less effective than with other techniques, ▪ unsuitable for automation, ▪ degree of enrichment dependent on ambient temperature and wind movements, ▪ results are ``historical" in nature
Dynamic	▪ very effective enrichment, ▪ large-volume samples can be collected, ▪ ease of calibration, ▪ a large number of compounds can be sepa-rated as more than one sorbent is used.	▪ high cost of a single measurement, ▪ power equipment needs regular servicing, ▪ energy is consumed, ▪ transport of power equipment (pumps, venti-lators) to the sampling site is troublesome
Denuder	▪ analyte enrichment is highly selective, ▪ large-volume samples can be collected, ▪ physical speciation of analytes is possible	▪ denuder preparation is time-consuming and laborious ▪ laminar flow through the tube, small amounts of substances retained on the denuder ▪ not suitable for determining instantaneous concentrations

Passive samplers types and characteristics

Diffusive sampler — a device that is capable of collecting gases and vapors from an atmosphere at rates controlled by gaseous diffusion through a static air layer (boundary layer) or permeation through a membrane, but which does not involve the active movement of air through the sampler.

There are two basic configurations of passive samplers:
Axial diffusive sampler — a tube-form device with precisely controlled dimensions that samples gaseous organic chemicals in air diffusively through one end of the tube onto the sorbent surface held inside the tube at a fixed distance from the sampling end.
Radial diffusive sampler — a tube form device which allows controlled diffusive sampling around the walls of the sampler; that is, parallel to the radius. The sampling center of a radial diffusive sampler for thermal desorption, typically comprises sorbent contained in a fine (for example, 400-mesh) gauze cylinder.

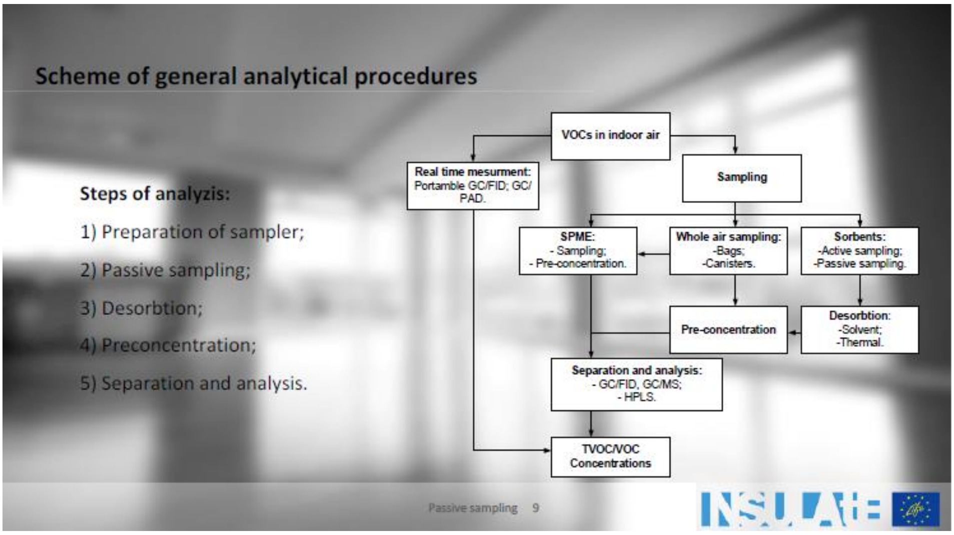
Passive sampling 7

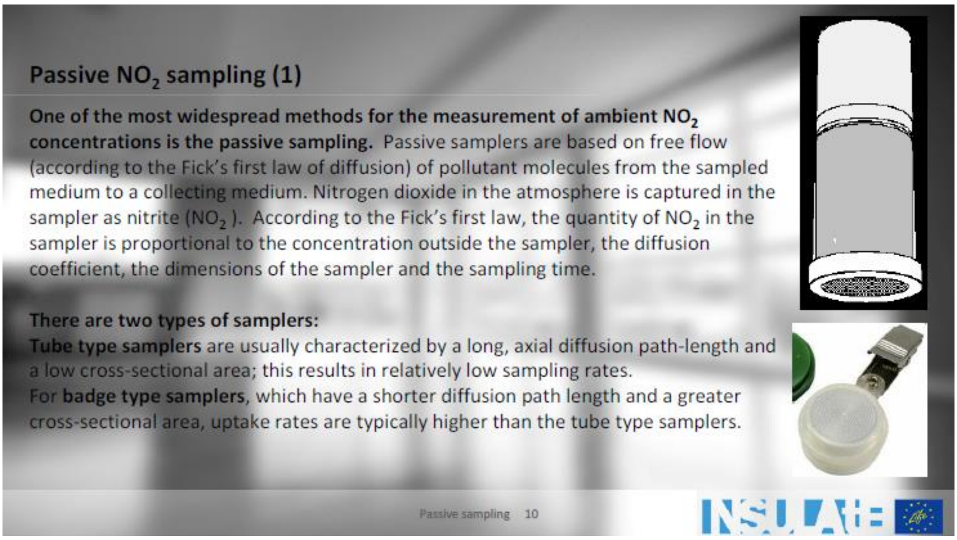
Types and characteristics of the sorbents

It is used a wide range of sorbents, which have different characteristics and analytical techniques. In this case, Tenax sorbent will be used.

Type	Structure	Surface area (m^2/g)	Products	Desorption	Compounds tested (Starting at b.p.)	Polarity	Thermal stability	Water affinity
Inorganic	Silica gels	1–30	Volasphere, Florisil	Solvent	PCBs, pesticides	High	~400°C	High
	Molecular sieves	500–800		Solvent	Permanent gases	High	<400°C	High
	Aluminum oxides	~300	Alumina F1	Solvent	Hydrocarbons	High	300°C	High
Carbon based	Activated Charcoal	800–1200		Solvent	Non-polar and slightly polar VOCs (>50°C)	Medium	>400°C	High
	Carbon molecular Sieves	400–1200	Carbosieve, Ambersorb, Spherocarb Carboxen	Solvent/ Thermal	Non-polar and slightly polar VOCs (>– 80°C)	Low	>400°C	Low–medium
	Graphitized carbon blacks	12–100	Carbotrap, Carbopack, Carbograph	Thermal	Non-polar VOCs (>60°C)	Low	>400°C	Low
Porous polymers	Styrene, divinylbenzene or polyvinylpyrrolidone polymers	300–800	Porapak Q/N, Chromosorb 106/102,	Thermal/ solvent	Non-polar and moderately polar VOCs (>40°C)	Variable	<250°C	Low
	Phenylphenylen oxide polymers	20–35	Tenax	Thermal	Non-polar VOCs (>60°C)	Low	<350°C	Low
	PU-Foams			Solvent	Pesticides	Low	<200°C	Low

Passive sampling 8


Scheme of general analytical procedures
Steps of analyzis:
1) Preparation of sampler;
2) Passive sampling;
3) Desorbtion;
4) Preconcentration;
5) Separation and analysis.
VOCs in indoor air
Real time mesurment: Portamble GC/FID; GC/PAD.
Sampling
SPME: - Sampling; - Pre-concentration.
Whole air sampling: -Bags; -Canisters.
Sorbents: -Active sampling; -Passive sampling.
Pre-concentration
Desorbtion: -Solvent; -Thermal.
Separation and analysis: - GC/FID, GC/MS; - HPLS.
TVOC/VOC Concentrations
Passive sampling 9


Passive NO2 sampling (1)
One of the most widespread methods for the measurement of ambient NO2 concentrations is the passive sampling. Passive samplers are based on free flow (according to the Fick's first law of diffusion) of pollutant molecules from the sampled medium to a collecting medium. Nitrogen dioxide in the atmosphere is captured in the sampler as nitrite (NO2). According to the Fick's first law, the quantity of NO2 in the sampler is proportional to the concentration outside the sampler, the diffusion coefficient, the dimensions of the sampler and the sampling time.
There are two types of samplers:
Tube type samplers are usually characterized by a long, axial diffusion path-length and a low cross-sectional area; this results in relatively low sampling rates.
For badge type samplers, which have a shorter diffusion path length and a greater cross-sectional area, uptake rates are typically higher than the tube type samplers.
Passive sampling 10

Passive NO_2 sampling (2)

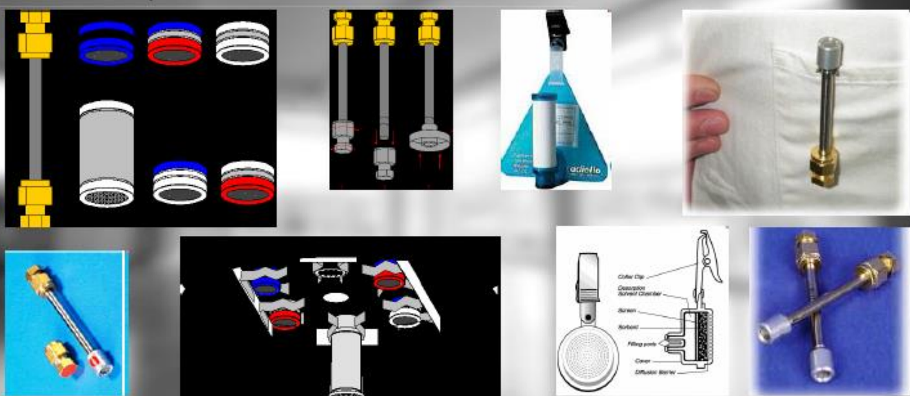
Different types of NO_2 passive samplers have been described with the variations regarding dimensions, materials, diffusion barriers and absorbents. Many of these passive samplers are commercially available.

Sampler type	Sampler material	Dimensions L(cm)×A(cm^2)	Inlet	Absorbent	Theoretical sampling rate (ml/min)	Precision (±%)	Overall Uncertainty (±%)	Detection limit
Palmes Type diffusion tube[a]	Acrylic[b]	7.1×0.95[b]	Open[b]	TEA[b]	1.23	6[c]	11.8[c]	1 μg/m^3[c] (1 week)
Ferm Badge[a, d]	Polypropylene	1.0×3.14	Steel grid and teflon membrane	KI/NaAsO$_2$NaI/ NaOH	29	3.9	15	0.10 μg/m^3 (1 month)
Willems Badge[e]	–	0.2×5.31	PTFE membrane	NaI/NaOH	245	–	–	–
Ogawa Badge[a]	–	0.6×0.79[f]	Open[f]	TEA[f]	12.10	<5[g]	–	25 μg/m^3[f] (1 h)
Radiello Radial symmetry sampler[a]	Microporous HDPE[h]	4.0×1.30[e]	Cylindrical Synthesised micro-porous polyethylene[e]	TEA[h]	0.2 ppb/min[e]	–	11.9[h]	2 μg/m^3[h] (1 week)
Krochmal Badge[i]	Black stained polythene	1.0×4.91	Polypropylene membrane	TEA	45.30	6	10	0.50 μg/m^3 (1 month)
Yanagisawa Badge[j]	Polypropylene	0.5×9.88	Hydrophobic fluorine containing polymer filter paper	TEA	182.40	4.8	20	124.80 μg/m^3 (1 h)
Analyst Badge[a]	Glass[k]	2.54×3.27[k]	Stainless steel screen[k]	Na$_2$CO$_3$/glycerine[k]	12.30	<5[k]	20[k]	2 μg/m^3 (1 week)
Passive sampler in this study	Glass	3.98×1.13	Stainless steel screen	TEA	2.63	8.8	7.9	1.99 μg/m^3 (1 week)

Passive sampling 11

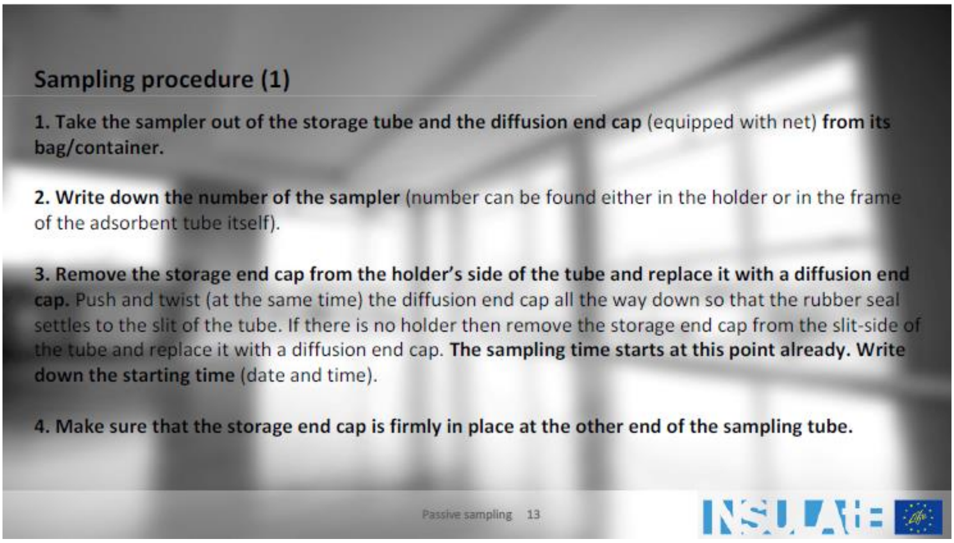
INSULAtE

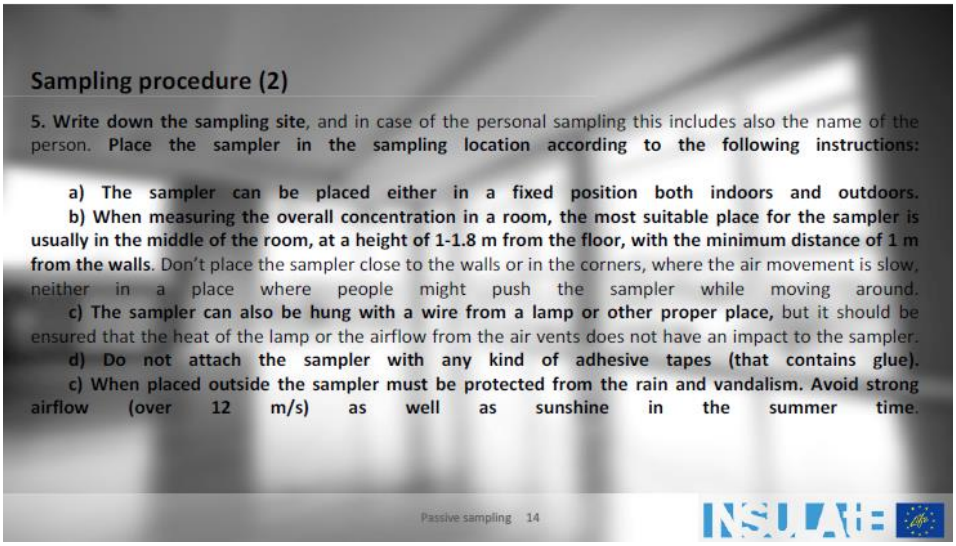
Passive samplers

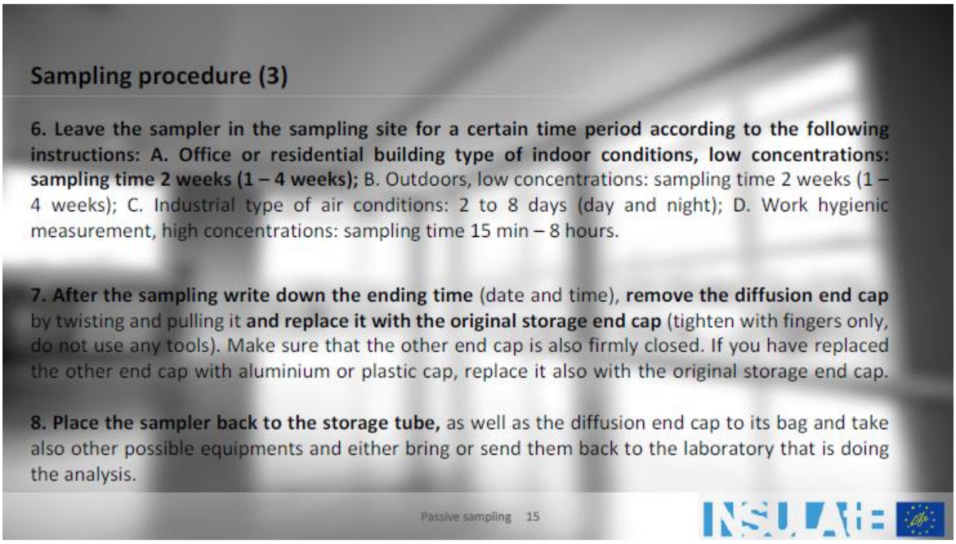


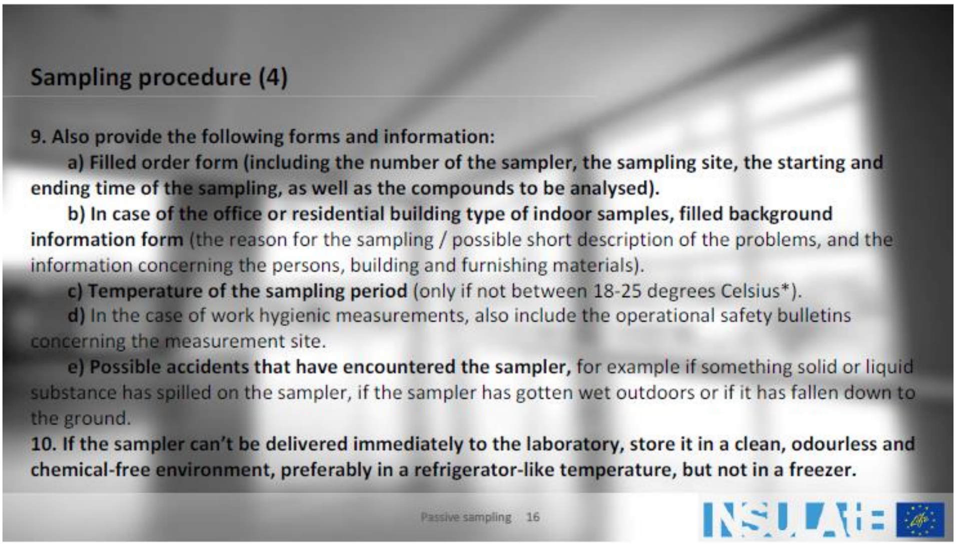
Passive sampling 12

INSULAtE


Sampling procedure (1)
1. Take the sampler out of the storage tube and the diffusion end cap (equipped with net) from its bag/container.
2. Write down the number of the sampler (number can be found either in the holder or in the frame of the adsorbent tube itself).
3. Remove the storage end cap from the holder's side of the tube and replace it with a diffusion end cap. Push and twist (at the same time) the diffusion end cap all the way down so that the rubber seal settles to the slit of the tube. If there is no holder then remove the storage end cap from the slit-side of the tube and replace it with a diffusion end cap. The sampling time starts at this point already. Write down the starting time (date and time).
4. Make sure that the storage end cap is firmly in place at the other end of the sampling tube.
Passive sampling 13
INSULAtE


Sampling procedure (2)
5. Write down the sampling site, and in case of the personal sampling this includes also the name of the person. Place the sampler in the sampling location according to the following instructions:
a) The sampler can be placed either in a fixed position both indoors and outdoors.
b) When measuring the overall concentration in a room, the most suitable place for the sampler is usually in the middle of the room, at a height of 1-1.8 m from the floor, with the minimum distance of 1 m from the walls. Don't place the sampler close to the walls or in the corners, where the air movement is slow, neither in a place where people might push the sampler while moving around.
c) The sampler can also be hung with a wire from a lamp or other proper place, but it should be ensured that the heat of the lamp or the airflow from the air vents does not have an impact to the sampler.
d) Do not attach the sampler with any kind of adhesive tapes (that contains glue).
c) When placed outside the sampler must be protected from the rain and vandalism. Avoid strong airflow (over 12 m/s) as well as sunshine in the summer time.
Passive sampling 14
INSULAtE


Sampling procedure (3)
6. Leave the sampler in the sampling site for a certain time period according to the following instructions: A. Office or residential building type of indoor conditions, low concentrations: sampling time 2 weeks (1 – 4 weeks); B. Outdoors, low concentrations: sampling time 2 weeks (1 – 4 weeks); C. Industrial type of air conditions: 2 to 8 days (day and night); D. Work hygienic measurement, high concentrations: sampling time 15 min – 8 hours.
7. After the sampling write down the ending time (date and time), remove the diffusion end cap by twisting and pulling it and replace it with the original storage end cap (tighten with fingers only, do not use any tools). Make sure that the other end cap is also firmly closed. If you have replaced the other end cap with aluminium or plastic cap, replace it also with the original storage end cap.
8. Place the sampler back to the storage tube, as well as the diffusion end cap to its bag and take also other possible equipments and either bring or send them back to the laboratory that is doing the analysis.
Passive sampling 15


Sampling procedure (4)
9. Also provide the following forms and information:
a) Filled order form (including the number of the sampler, the sampling site, the starting and ending time of the sampling, as well as the compounds to be analysed).
b) In case of the office or residential building type of indoor samples, filled background information form (the reason for the sampling / possible short description of the problems, and the information concerning the persons, building and furnishing materials).
c) Temperature of the sampling period (only if not between 18-25 degrees Celsius*).
d) In the case of work hygienic measurements, also include the operational safety bulletins concerning the measurement site.
e) Possible accidents that have encountered the sampler, for example if something solid or liquid substance has spilled on the sampler, if the sampler has gotten wet outdoors or if it has fallen down to the ground.
10. If the sampler can't be delivered immediately to the laboratory, store it in a clean, odourless and chemical-free environment, preferably in a refrigerator-like temperature, but not in a freezer.
Passive sampling 16

7. RAM NO_2 instructions

Nitrogen Dioxide RAM Instructions
Shelf life: This monitor has a shelf life of 6 months.

RAM storage:

1. New samplers should be stored in a polyethylene bag or similar and kept in a refrigerator. One sampler should be used as a blank – the cap should NOT be removed and it should be left in the refrigerator during the sampling period.

2. Exposed samplers should be stored under the same conditions as 1. The samplers should be returned for laboratory analysis within 2-3 weeks of completion of sampling.

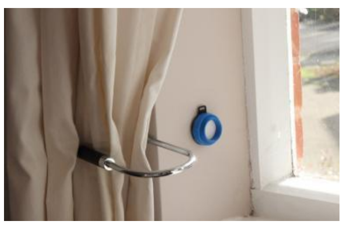
Sampling sites: The RAM should not be placed in any form of recess (to avoid the possibility of sampling stagnant air). To avoid sampling in an area of higher than usual turbulence, RAMs should not be located on the corner of a building.

Exposure:

External Ambient Air Sampling e.g. Roadside

1. Apply sample identifier in oblong space at the of the back of sampler
2. Fix shelter on to a suitable post using cable ties
3. Fix sampler into shelter using pre positioned Velcro® spots on sampler
4. Remove cap from sampler and store in a safe place
5. Expose sampler for required period i.e. 1 hour to 168 hours dependant on environment being sampled.
6. At the end of the exposure period, replace cap, remove sampler from shelter. Label the sampler with the barcode label provided, and affix the corresponding number label to the exposure sheet.

Indoor Air Sampling



1. Apply sample identifier in oblong space at the back of sampler.
2. Apply double-sided adhesive tape or Blu-tack® to

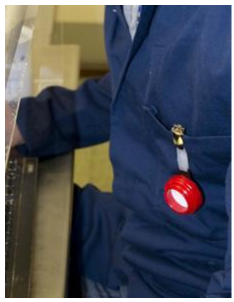
back of sampler

3. Fix sampler to vertical surface
4. Remove cap from sampler and store in a safe place
5. Expose sampler for required period i.e. 1 hour to 24 hours dependant on environment being sampled

6. At the end of the exposure period, replace cap. Label the sampler with the barcode label provided, and affix the corresponding number label to the exposure sheet.

Personal Sampling

1. Apply sample identifier in oblong space at back of the sampler
2. Using the attached slot tab , fit pocket strap on to sampler
3. Fit sampler to coat lapel or pocket.



4. Expose sampler for required period i.e. 1 hour to 8 hours dependant environment being sampled.

5. At the end of the exposure period, replace cap. Label the sampler with the barcode label provided, and affix the corresponding number label to the exposure sheet.

Returning monitors: RAMs should be returned as soon as possible after exposure and must be returned within 3 weeks. Fill in exposure data record sheet including **exposure time**. RAMs should be returned in a sealed container, such as the plastic bag that they are received in.

Return address:
Gradko International Ltd, St Martins House, 77 Wales Street, Winchester, Hampshire, SO23 0RH. **Tel:** +44 (0) 1962 860 331
Email: diffusion@gradko.com or enquiries@gradkolab.com

8. Fibre sampling

STANDARD OPERATING PROCEDURE
Sampling of fibres

Sampling of fibres with wiping method

- Collecting samples with wiping method enables to analyse the composition of the dust
- Samples from such places that <u>are regularly cleaned</u>
- Dust should settle down for two weeks before the sampling

1/4

Sampling procedure

- Get plastic bags sized 1 or 2 litres (for example Minigrip).
- Turn the plastic bag inside out and place your hand inside it (picture below).

2/4

Sampling procedure

- Wipe the surfaces of the sampling site or the inner surface of the air duct with the plastic bag. The electricity of the bag will collect the dust particles.
- After sampling: turn the plastic bag outside in and close it properly.
- Mark the plastic bags with sample number and write down the sampling sites.
- Fill out the order form and send/mail it together with the sample/s to the lab

3/4

Notes

- Use at least one plastic bag per sampling site (for example room).
- However, surface and air duct samples that are collected from the same sampling site (room) should be collected in separate bags.
- Lot of dust is needed for this sampling!

4/4

Sampling of fibres with a tape-method

- Gel tape
- Recommended settling time for the dust is two weeks
- But in INSULAtE:
  - First tape sample after 1 week
  - Second sample after 2 months

  -> Comparing, which sampling time is better

  -> No extra visits to the location this way

1/8

- During the first visit to the location: place two empty Petri dish plates to the sampling site surface (dust settles in the plate)
- When visiting the site after one week: take a tape sample of the other plate
- When visiting the site after 60 days: take a tape sample of the remaining plate

2/8

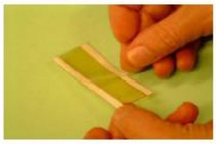
Sampling procedure

- Before the sampling:

  Store the tapes (in aluminium bag) in a refrigerator.

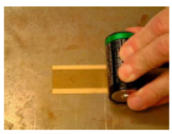
3/8

- At the sampling site:
  Open the aluminium bag, take the tape out of the bag and remove the cover foil right before the sampling. The cover foil can then be disposed.



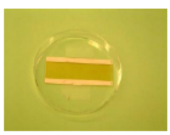
4/8

- Place the tape on the sampling surface so that the gel side (of which the cover foil was removed) is facing the surface
- Press the tape for example with a battery or other similar tool and roll it back and forth at the same time. The purpose is to press the gel so that it fills in all the pores in the surface that can contain mineral fibres. Too strong a force is not an issue.



5/8

- Carefully remove the tape from the surface
- Attach it to the Petri dish using a normal tape (attach the normal tape to the white areas of the sampling tape). The gel side (from which the cover foil was removed) must be facing up!



6/8

- Close the Petri dish with the lid and secure it with normal tape. Mark the plate with the sample number.

- Fill out the order form and send it to the lab together with the sample/s.

7/8

Notes

- If too much dust on the surface: tape sample will be hard to analyse

-> Use wipe-method

- Asbestos can only be analysed from the wipe sample, NOT from the tape sample

-> price ~ 136 euros / sample

8/8

10. SOP for fibres, wipe

STANDARD OPERATING PROCEDURE
Sampling of fibres with wipe method

Finnish Institute of Occupational Health

Sampling of dust (fibres) with wiping method

Collecting samples with wiping method enables to analyse the composition of the dust in such cases where the cleanliness of the indoor air is doubted for example if people are having symptoms. The sampling procedure is recommended to be carried out so that the samples are taken on the surfaces of the sampling site as well as from the fresh air ducts. In that way it is easier to detect the source of the problem.

The surface dust sample should be taken from such places that are regularly cleaned, for example from the work desks. Do not take the sample from a place that might have collected settled dust for many years, for example from upper surfaces that are hard to reach. The dust should settle down for two weeks before the sampling (do not clean-up during this two week period).

Sampling procedure (both for surface and fresh air duct dust samples)

1) Get plastic bags sized 1 or 2 litres (for example Minigrip).

2) Turn the plastic bag inside out and place your hand inside it (picture below).

3) Wipe the surfaces of the sampling site or the inner surface of the air duct with the plastic bag. The electricity of the bag will collect the dust particles.

4) Now turn the plastic bag outside in and close it properly.

5) Use at least one plastic bag per sampling site (for example room). However, surface and air duct samples that are collected from the same sampling site (room) should be collected in separate bags.

6) Mark the plastic bags with sample number and write down the sampling sites.

7) Fill out the order form and send/mail it together with the sample/s to the lab.

(SOP made by Finnish Institute for Occupational Health)

11. SOP for fibres, tape

STANDARD OPERATING PROCEDURE
Sampling of fibres with tape method

Finnish Institute of Occupational Health

Sampling of fibres with a tape-method

The occurrence of man-made mineral fibres (glass fibres, rock wool, glass wool) in indoor air is estimated with a gel tape samples taken from the surfaces. The gel tape collects the dust that has settled on the surface studied, the recommended settling time for the dust is two weeks.

Sampling strategy

Clean the sampling surface two weeks before the sampling time. Do not clean-up during this two week period.

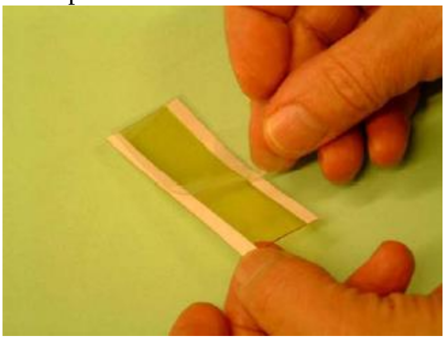
If this arrangement is not possible, take the sample from a place that is regularly cleaned, for example from a worktable. Do not take the sample from a place that might have collected settled dust for many years, for example from upper surfaces that are hard to reach. Also do not take the sample right after cleaning.

NOTE! Gel tape method is only to be used for detecting the number of industrial mineral fibres. The type of the fibres (whether they are fibreglass, mineral wool or glass wool) can not be detected with this method. This method can not be used for detecting asbestos, mould spores or other particles either.

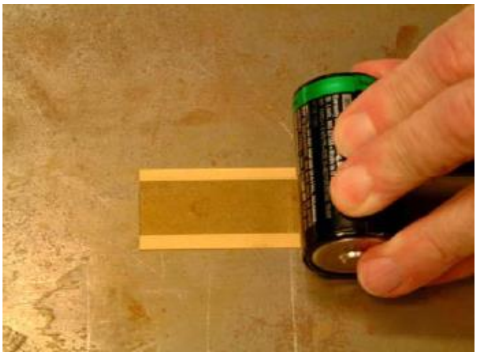
Sampling procedure

1) Store the tapes (in aluminium bag) in a refrigerator.

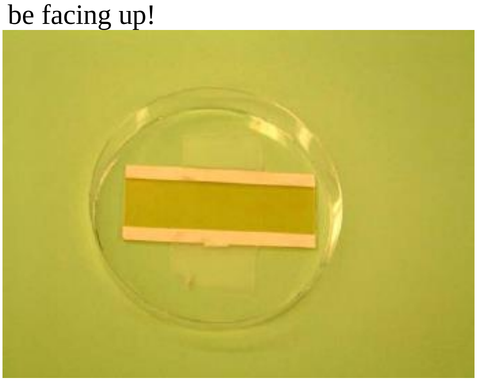
2) At the sampling site, open the aluminium bag, take the tape out of the bag and remove the cover foil right before the sampling. The cover foil can then be disposed.



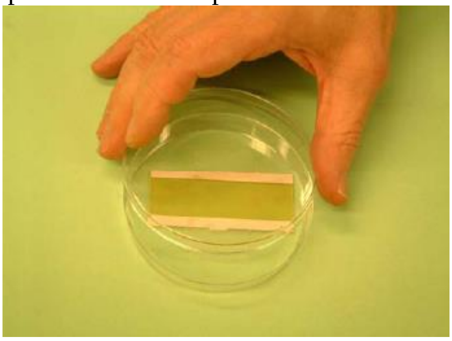
3) Place the tape on the sampling surface so that the gel side (of which the cover foil was removed) is facing the surface and press the tape for example with a battery or other similar tool and roll it back and forth at the same time. The purpose is to press the gel so that it fills in all the pores in the surface that can contain mineral fibres. Too strong a force is not an issue.



4) Carefully remove the tape from the surface and attach it to the Petri dish using a normal tape (attach the normal tape to the white areas of the sampling tape). The gel side (from which the cover foil was removed) must be facing up!



5) Close the Petri dish with the lid and secure it with normal tape. Mark the plate with the sample number.



6) Fill out the order form and either send or bring it to TTL together with the sample/s.

Analysis

Over 20 µm long industrial mineral fibres are counted from the sample by using a light microscope. The result is reported using a unit: number of fibres per cm^2. If the number of fibres exceeds 100 fibres per cm^2 the result is reported: over 100 fibres per cm^2. The lowest reported number of fibres (detection limit) is 0.1 fibres per cm^2.

Interpretation of the results

The guidance level for the fibre count when using the settling period of two weeks is 0.2 fibres per cm^2. When the guidance level is exceeded it is necessary to find out the fibre sources and the possibilities to reduce the fibre concentrations.

References

Harju R., Tuovila H., Riala R., Kovanen K., Laamanen J., Tossavainen A. (2006). Ilmanvaihtolaitteiden hiukkaspäästöt työtiloihin, Sisäilmastoseminaari 2006, SIY raportti 24, s. 165–170.

12. Radon sampling (STUK)

STANDARD OPERATING PROCEDURE
Radon sampling (STUK)

- Recommended sampling time: at least 2 months, between November 1st - April 30th
- 2 samplers per apartment (if apartment is very small, use one sampler only)
- Sampler contains polycarbonatemembrane

Sampling procedure

- Take the sampler from the plastic bag, DO NOT open the sampler!
- Place the samplers for example in the bookshelf (number side down).
- Height: about 1 meter from the floor level.
- Mark down the sampling period and the sampling sites (to the form that came with the sampler).

Notes

- Place the sampler/s away from the front door, windows, fresh-air vents and fireplaces.
- Do not place the sampler on a concrete- or stone surface.

13. SOP for settled dust

SAMPLING OF SETTLED DUST WITH BOXES IN INSULATE STUDY

1. Purpose

This protocol describes the material needed and the methods used to perform the settled dust sampling with boxes. Settled dust sampling is assumed to represent an integrated sample of airborne particles over the sampling time. The samplers will be distributed and collected back by the field workers. The sampling will happen passively and the sampling period will be 8 weeks. Sampling in the apartments will be performed both, before and after renovation. Ideally, sampling for microbes is performed in the winter/heating season. It is essential that before/after sampling is done during the same season, ideally, during the same months in following years. However, the microbial sampling will follow the general sampling schedule in the study.

2. Definitions

SDB	Settled dust sampler (settled dust box), the box used for collecting the settled dust
Documentation sheet	documentation sheet, on which relevant information like apartment ID, sampling period, sampling location in the room etc., and the sample codes must be noted
Sample suspension	the dust sample vacuumed from the box and suspended into dilution buffer
Local study center	the participating study center

3. Materials

2 SDBs per apartment (including 2 field blanks per apartment building), i.e. on average 12 SDBs per apartment building
blueprint, building plans etc. showing the plan for distribution of samplers in the apartment building and in each apartment
predefined ID-code stickers
blank stickers
hanging devices for fixing the boxes to the wall, if needed (double sided tape, pins, …)
measuring tape
documentation sheet
pens

tape

4. Procedure

Precautions

To minimize contamination from other sources, it is requested:

- storage of the unfolded SDBs prior to sampling: dry, clean place; covered in the plastic foil sent with the SDBs
- to keep the sampling boxes closed until sampling;
- to minimize touching the boxes, particularly the inner side, (use gloves);
- after sampling to close the boxes carefully with slow movements, so that the dust will not disperse
- to keep boxes all the time "face up" and to transport the boxes carefully to the lab
- store assembled SDBs after sampling until further processing under dry and clean conditions (preferably in plastic bags)

Time of sampling

Samples will be collected at two time points, before and after renovation of the buildings; the SDB sampling will follow the general sampling schedule in Insulate. Settled dust should be ideally collected during the winter/heating season, to reduce input from outdoor sources on the microbial determinations. Also, sampling in one building before and after renovation should be done during same season, ideally same months in the year.

The sampling duration will be 8 weeks.

Selection of the room for SDB sampling

The passive collection of dust for determination of microbial agents should be performed in the living room in each apartment. Living room is the room where the family typically spends their evenings. Ideally, the living room will be the room in which most of the determinations (also chemical/physical) in Insulate are performed. If for some reason the passive dust sampling can not be performed in the living room, sampling can alternatively be performed in the bed room. Rooms such as toilets, bathrooms, kitchens, etc. are excluded for sampling.

Sampling/sampling location

All SDBs required for one apartment building are prepared in the lab or equivalent room prior to the field work. The SDBs should be folded/assembled using gloves. Close the SDBs and store under dry and clean conditions (preferably in plastic bags). Transport the SDBs in plastic bags to the field – keep boxes dry and clean.

Two SDBs will be distributed in each apartment included in the study in the selected room; ideally, the two samplers are located just next to each other. An ID-sticker containing the Insulate sample code will be attached on the side of each box. The box will be opened and the samplers will be located at the height of at least 1.0 m and max. 2,3 m on a shelf or a cupboard, which is in an undisturbed place (not close to doors, windows, ventilation, or active sampling devices). An absolute minimum of 0,5 m distance from the ceiling, better at least 1 m should be kept (to the sampling area in the box) to allow settling of dust. The samplers should not be located near lamps or computers producing heat. The sampler should not be located on a fireplace if it is used. If no shelf etc. is available the samplers will be attached to the wall with double-sided tape.

The location code, the location of the samplers in the room, sampler ID and date etc. will be recorded onto the documentation sheet.

After 8 weeks, each sampler will be carefully closed with the lid. The closing is done with slow movements so that dust will not disperse. All openings of the box are closed with covering-tape from the outside. All the observations on objects in the boxes, damages, etc. will be recorded onto the documentation sheet.

The samplers will be transported carefully, in plastic bags, face up to the laboratory of the local study center.

Field blanks

In each apartment building two SDB field blanks will be placed in one randomly selected apartment. The SDB is assembled/folded and closed together with the other SDBs prior to the field work. All openings of the box are closed with covering-tape from the outside. The SDB is transported to the building and placed along with two other SDBs in a selected location. However, **do not open the field blank SDB** and keep it closed for the entire sampling duration. This field blank is registered in the field form.

At the end of sampling, collect and treat the field blank along with the other SDBs.

Storage of the samples

The closed SDB-samplers will be stored as such at **room temperature** until further treatment, which is the "vacuuming" of the dust from the box. The storage place needs to be dry and clean; the boxes are to be stored in plastic bags to avoid additional contamination. The sampled boxes should be stored as such for **a maximum of 6 weeks prior to further treatment.**

The vacuuming of dust from the settled dust sampler (SDB)

The samples should be treated very carefully to ensure that no dust will disperse. All the glass ware and other materials that is used should be sterile. Samples should be handled by using gloves. The settled dust sample collected with a collection box

(SDB) will be vacuumed from the box onto a filter (1 SDB to 1 filter) and from there, the dust will be suspended with dilution solution and freezed. The vacuuming must happen in a clean room on a table.

Materials needed per sample:
* 1 filter casette (Zefon, 37mm 3PC, 0.45µm MCE; order no. 7345MCE)
* 1 filter (Zefon, Filter 37mm, 45µm, MCE, plain white; order no FMCE4537)
* 1 support pad (Zefon, PAD, cellulose, 37mm, oder no. FSP37)
* Sterile tweezers
* A pump (suction ~10 l/min) + clean plastic hoses + metal or other adaptor (if available; adaptor not obligatory)

Detailed instructions on vacuuming of dust from SDBs are provided in the photoprotocol "Insulate_Photoprotocol_SDBvacuuming".

Preparing the vacuuming: Attach clean plastic hoses into inlet and exhaust of the pump. For each sample (one SDB) at least one sterile filter should be provided. The support pad will be placed on the bottom of the filter casette (next cassette outlet), the filter will be placed on top of the support pad and the filter casette will be closed. Also the caps on the cassettes should be closed. Bring the SDB to be treated on the table. Mark the cassette with the corresponding sample ID.

The vacuuming: The cap at the bottom of the casette will be opened and attached with the hose that is connected to the **inlet** of the pump. Carefully open the SDB. Open the cap also at the lid (next casette inlet) and start the pump. Start vacuuming the dust from the box. Vacuum the dust from the box throroughly (spot-by-spot creating of short vacuum cleans the SDB most efficiently). When all the dust has been vacuumed, turn the casette upwards so that no dust will fall off when turning off the pump. Disconnect hose from cassette, close cassette inlet and outlet, and switch off the pump.

Shipment of filter casettes to the analysing laboratory at THL:
Shipment of the filter casettes should be done using courier service to guarantee shipment within one week from the local study center to THL. Shipment should be organised **within four weeks after sample collection**, so that the filter cassettes containing the dust are received at THL within 5 weeks after end of the sampling period. Inform THL well ahead in time before up-coming shipments – the samples need to be processed further at THL and this works needs to be scheduled.
Proper packaging need to be provided to guarantee dry and save transportation. Care need to be taken to close the inlet and outlet on the filter cassette properly. Each filter cassettes should be stored in a separate plastic bag (eg. minigrip mini). Use

filling material to avoid free movement of the filter casettes in the shipment box. Shipment should be done at room temperature – no cooling/ice is needed.

Performed centrally at THL:

The extraction of the dust and freezing: Open the filter cassette in the middle, move with the tweezers the filter into the sterile decanter, place filter with dust ”face down” on the bottom and mark the decanter with the sample ID. Sample will be extracted with 5 ml dilution buffer, which is partly used for rinsing the dust from both parts of the cassette into the decanter. Pipette the rest of the 5 ml on the filter in decanter. Close decanter with parafilm. Put the sample first for 15 min in a ultrasonic bath and then for another 15 min on a shaker (approx. 600 rpm). After shaking remove the filter, transfer the sample solution from the decanter in the sterile 15mL plastic tube (sample ID!) and freeze the sample at -20 ºC.

Materials needed only at THL (processing of samples from this point forward is done centrally at THL):

100 ml Decanter (big enough to place filter even on bottom)
* Dilution buffer
1-5 ml Finn-pipet
1-5 ml sterile pipet tips
Sterile tweezers
1 sterile 15 mL plastic tube (eg. Greiner or similar)
ID-code stickers

* marked items are provided by THL

Dilution buffer

Reagents:
1 l deionsized water
0.04 g KH_2PO_4,
0.25g $MgSO_4 \times 7H_2O$
0.008 g NaOH
0.2 ml Tween 80 detergent'

Store in 5±3°C maximum 6 months in a bottle

Re-use of filter cassettes: The filter cassettes should be re-used after washing with water, dipping in methanol and drying (eg. over night). THL will provide 30 filter cassettes per center, which should be a sufficient number to cover one day of vacuuming SDBs without the need to wash the cassettes in between.

14. Fieldform, dust

Insulate: Exposure assessment 1 Field form dust sampling

Building: ______________________________ **Building ID[1]:** ______

Address: ______________________________ **Insulate Study phase**:

Insulate Apartment code[2] : _____________

Floor[3]: ____________

all kind of stuff concerning the apartment, like orientation, how many residents, etc.

Real apartment number[4]: ______________

Sample collection start – Date[5]: ______________(dd.mm.yyyy)

Sample collection start – field worker(s)[6]: ______________________________

Sample collection end – Date[7]: ______________(dd.mm.yyyy)

Sample collection end – field worker(s)[8]: ______________________________

Additional information:

[1] 2-digit apartment building ID (ww)
[2] 2-digit Insulate apartment ID (10-99) yy
[3] 0 … ground floor; 1 … 1st floor; 2 … 2nd floor; -1 … basement; etc
[4] eg apartment number used in the address
[5] Date when the exposure assessment was started (ie. placing of SDB)
[6] Field worker who started the exposure assessment
[7] Date when the exposure assessment was ended (ie. collection of SDB)
[8] Field worker who finalized the exposure assessment

Sample code[9] ww x yy zz	**Sample type**	**Sampling location in the room**[10]	**Sampling height [cm]**[11]	**Remaining height to ceiling [cm]**[12]	**Distance to closest disturbance source [cm]**[13]	**Additional information**[14]
. 10	SDB_1					
. 11	SDB_2					
. 12	SDB[15] field blank					
. 13	SDB field blank					

[9] Pre-fill; 7 digit code: ww … buildin ID; x … phase; yy … apartment ID; zz … sample ID
[10] descriptive, from entering the door; eg. cupboard left of the entrance
[11] height in which the SDB sampler is placed in the room (sampling area)
[12] distance from sampling area of SDB to the ceiling
[13] distance of SDB to closest air flow disturbance source, if <2 meters; e.g. HVAC intake/outlet, entrance door, windows that are opened regularly, etc. (specify under 14)
[14] descriptive; eg. objects on/in SDB; sample lost; if an air flow disturbance source was near the sampling location (<2m), specify which one; etc.
[15] Field blank for SDBs will be done with 2 SDBs at 1 location per each apartment building

LOCATION SKETCH INDICATING PLACEMENT OF SAMPLERS

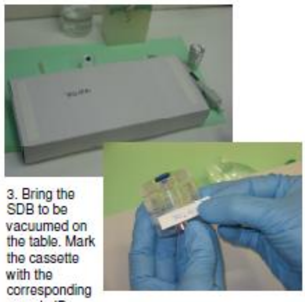
Hand-drawn sketch of the location; in the sketch, indicate location of samplers (SDB, EDC), locations of sampling (VFD, MS/SD), entrance door, windows, ventilation intake/outtake (if any), etc.

15. Protocol, SDB vacuuming

The vacuuming of dust from the settled dust sampler (SDB)

1. Materials needed per sample: filter cassette pre-loaded (or: filter cassette, 1 filter, 1 support pad); sterile tweezers, a pump + clean plastic hoses, ID-code stickers and sterile gloves.

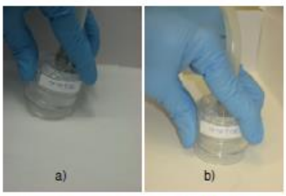
2. Attach clean plastic hoses into inlet and exhaust of the pump.



3. Bring the SDB to be vacuumed on the table. Mark the cassette with the corresponding sample ID.

4. Open the cap at the bottom of the cassette (outlet). Attach the cassette to the hose that is connected to the inlet of the pump. Use metal or other adapter if available - otherwise provide a tight and stable connection between hose and cassette (support with fingers - see 7b).

5. Open the SDB carefully. Open also the cap at the lid of the cassette (inlet). When starting the pump, start vacuuming of the dust in the SDB immediately.



6. Thoroughly vacuum all the dust from the total bottom-area of the box. Apply two techniques:
a) first, vacuum the whole area with only one side of the cassette touching the box and the other side slightly lifted (1-2 mm). Most of the dust will be collected that way. For dust remaining in the box:
b) Spot-by-spot, create short vacuum by placing the the whole cassette on the box-bottom; vacuum one spot, detach and move to next spot. This very effectively collects the remaining dust.

7. When all the dust has been vacuumed, turn the cassette upwards so that no dust will fall off when turning off the pump. Remove the hose, close the inlet and outlet caps of the cassette, and switch off the pump.

16. Check-list for measurements

When setting up samples and monitoring		**Equipment needed:**	
1. OPCs (1 placed in the living room and 1 outside)	☐	1a. OPC-counter, probes 1b. AC power adapter, extension cable 1c. cooler box, bubble wrap, rain cap 1d. For outdoor sampling: ropes, weight, …. (find out beforehand if there is a balcony)	☐ ☐ ☐ ☐
2. CO, CO_2-monitor (1 placed in the living room)	☐	2a. CO, CO_2-counter	☐
3. Fibre sampling (1 wipe, 1 tape, placed in the living room)	☐	3a. Petri dishes 3b. Masking tape (for marking sampling area)	☐ ☐
4. VOC, aldehyde, NO_2 sampers (one each placed in the living room)	☐	4a. Samplers 4b. Threads, clothespins, etc. for hanging	☐ ☐
5. Settled dust (2 boxes placed in the living room (1.2...2.5 m height, on a shelf or cupboard etc.), not close to doors, windows, ventilation, lamps or computers etc. producing heat) + 1 closed box /building (field blank)	☐	5a. Cardboard boxes (2) 5b. Cotton cloves 5c. Double sided tape, pins for hanging	☐ ☐ ☐
6. Radon sampler (1 placed in the living room)	☐	6a. Radon sample	☐
7. T+RH loggers (placed in the bedroom and living room, cold spot and living area)	☐	7a. Loggers (2) 7b. Threads for hanging	☐ ☐
8. Air pressure measurements	☐	8. Air pressure meter, tubes	☐
9. Air change/flow measurements	☐	9. Air flow meter, cone	☐
10. Surface temperature measurements	☐	10. Surface temperature meter or thermographic camera	☐
When picking up samples and equipment		**Equipment needed:**	
1. OPCs (after 1 day)	☐	1a. Notebook (+ LMS RT)	☐
2. CO, CO_2-monitors (after 1 day)	☐	2a. Notebook	☐

3. Fibre samples (wipe, tape, after 2 weeks)	☐	3a. Gel tape 3b. Plastic bags (Minigrip, 1or 2 liters) 3c. Rubber gloves	☐ ☐ ☐
4. VOC, aldehyde, NO_2 samples (after 2 weeks)	☐	4a. Storage tubes and end caps	☐
5. Settled dust (2 months)	☐	5a. Cotton cloves 5b. Large plastic bag (garbage bag)	☐ ☐
6. Radon (2 months)	☐	6a. Sampling form 6b. Delivering envelope	☐ ☐
7. T+RH loggers (2 months), when picking up dust and radon samples	☐	7a. Notebook with data downloading software 7b. Batteries (LS 14250, 3,6 V) for replacements	☐
Other material:			
1. Health questionnaire forms 2. Blueprint etc. showing the plan for distribution of samplers 3. Predefined ID-code stickers 4. Blank stickers 5. Measuring tape		6. Documentation sheet 7. Pens 8. All kinds of tapes 9. Camera 10. Scissors 11. Ladder	
Possible extra measurements in some case buildings: 1. Thermographic camera: take picture outside the building in the morning after cold night when sun has not started to warm envelope.			

17. Sampling log sheets

INSULAtE sampling log sheet No. 1																			
BUILDING INVESTIGATION - OUTDOOR T, RH, THERMOVISION																			
Sample ID																**Time [hr: min]**	**Value Temp. (°C, %)**	**RH (°C, %)**	**Notes, weather conditions (sunny, clowdy, windy etc)**
Country	**Building**		**Apt.**	**Site**		**Type**		**Sampler**		**Day**		**Month**		**Year**					
1	0	1	0	0	1	0	1	0	1	0	7	1	2	1	1				
																		Measure the outdoor temperature and RH when entering and leaving the apartment	
																		Tip: leave one T+RH logger in balcony for the time your visit apartment for measuring	
Measurement Site identification: Outdoors North Face - 01, Outdoors East Face - 02, Outdoors West Face - 03, Outdoors South Face - 04 **Identification of the type of measurement:** BI T+RH outdoor - 01, BI O thermovision – 02																			

INSULAtE sampling log sheet No. 1

BUILDING INVESTIGATION - INDOOR T, RH, THERMOVISION

Sample ID																Time [hr: min]	Value Temp. °C	Value RH %	Notes (position in a room, etc)
Country	Building		Apt.	Site		Type		Sampler		Day		Month		Year					
1	0	1	1	0	6	0	4	0	1	0	7	1	2	1	1				
																			Tip: leave the T+RH logger for a while to hallway to measure overall average

Measurement Site identification: Kitchen - 06, Master bedroom - 11
Identification of the type of measurement: BI T indoor - 04, BI RH indoor - 05, BI thermovision indoor - 10

INSULAtE sampling log sheet No.																					
LONG-TERM INDOOR TEMPERATURE AND RELATIVE HUMIDITY																					
Sample ID																**Start date [dd/mm/yy]**	**Start Time [hr:min]**	**End Time [dd/mm/yy]**	**End Time [hr:min]**	**Value Temp., RH (°C, %)**	**Notes (position in a room, etc)**
Country	**Building**		**Apt.**	**Site**		**Type**		**Sampler**		**Day**		**Month**		**Year**							
1	0	1	1	1	1	0	6	0	1	0	7	1	2	1	1						
																					Tip: measure first the surface temperatures to find coldest spot to place 1 logger

Measurement Site identification: Living room - 09, Master bedroom - 11
Identification of the type of measurement: BI T/RH indoor loggers – 06

INSULAtE sampling log sheet No.

BUILDING INVESTIGATION - AIR FLOW

Sample ID																Time [hr:min]	Diameter of inlet mm	Value Flow m/s	Value Temp. ^{o}C	Notes (position in a room, etc)
Country	Building		Apt.	Site		Type		Sampler		Day		Month		Year						
1	0	1	1	0	6	0	7	0	1	0	7	1	2	1	1					
																				Note: be sure that the ventilation is on!

Measurement Site identification: Kitchen - 06, Bathroom - 07, clothroom - 15
Identification of the type of measurement: BI air flow - 07

INSULAtE sampling log sheet No.

BUILDING INVESTIGATION - PRESSURE DIFFERENCE

Sample ID																Time [hr:min]	Level or Height from ground m	Value Pressure Pa	Value Temp. °C	Notes (position in a room, etc)
Country	Building		Apt.	Site		Type		Sampler		Day		Month		Year						
1	0	1	1	1	0	0	8	0	1	0	7	1	2	1	1					

Measurement Site identification: Living room - 09, Hallway - 10, Master bedroom - 11, Bedroom#1 - 12, Bedroom#2 - 13, Bedroom#3 - 14
Identification of the type of measurement: BI pressure difference – 08

<table>
<tr><td colspan="20">INSULAtE sampling log sheet No.</td></tr>
<tr><td colspan="20">BUILDING INVESTIGATION - SURFACE TEMPERATURE</td></tr>
<tr><td colspan="16">Sample ID</td><td rowspan="2">Time
[hr:min]</td><td>Value</td><td>Value</td><td rowspan="2">Notes (position in a room, etc)</td></tr>
<tr><td>Country</td><td colspan="2">Building</td><td>Apt.</td><td colspan="2">Site</td><td colspan="2">Type</td><td colspan="2">Sampler</td><td colspan="2">Day</td><td colspan="2">Month</td><td colspan="2">Year</td><td>Min Temp. °C</td><td>Max Temp. °C</td></tr>
<tr><td>1</td><td>0</td><td>1</td><td>1</td><td></td><td></td><td>0</td><td>9</td><td>0</td><td>1</td><td>2</td><td>2</td><td>1</td><td>1</td><td>1</td><td>1</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="20">Measurement Site identification: Kitchen - 06, Bathroom - 07, Toilet - 08, Living room - 09, Hallway - 10, Master bedroom - 11, Bedroom#1 - 12, Bedroom#2 - 13, Bedroom#3 - 14
Identification of the type of measurement: BI surface temperature - 09</td></tr>
</table>

INSULAtE sampling log sheet No.

LONG-TERM CO/CO_2 SAMPLING

Sample ID																Start date [dd/mm/yy]	Start time [hr:min]	End date [dd/mm/yy]	End time [hr:min]	Sampling duration [days]	Notes (Balcony/window, etc)
Country	Building		Apt.	Site		Type		Sampler		Day		Month		Year							
1	0	1	1			1	1	0	1	2	2	1	1	1	1						

Measurement Site identification: Kitchen - 06, Bathroom - 07, Toilet - 08, Living room - 09, Hallway - 10, Master bedroom - 11, Bedroom#1 - 12, Bedroom#2 - 13, Bedroom#3 - 14
Identification of the type of measurement: Long Term I CO/CO2 – 11

INSULAtE sampling log sheet No.

SHORT-TERM CO/CO_2 SAMPLING

Sample ID									Start date [dd/mm/yy]	Start time [hr: min]	End date [dd/mm/yy]	End time [hr: min]	Sampling duration [h]	Mean 24-h value		Notes (Balcony/window, etc)
Country	Building	Apt.	Site	Type	Sampler	Day	Month	Year						CO, ppm	CO_2, ppm	
1	0 1	1	0 9	1 2	0 2	0 7	1 2	1 1								

Measurement Site identification: Living room - 09
Identification of the type of measurement: Short Term CO/CO2 - 12

INSULAtE sampling log sheet No.

ACTIVE PM SAMPLING

Sample ID																**Start date [dd/mm/yy]**	**Start time [hr:min]**	**End date [dd/mm/yy]**	**End time [hr:min]**	**Sampling duration [h]**	**Mean 24-h value**		**Notes (Position in a room, Balcony/window, etc) Distance to ventilation intake/exhaust or other major disturbance factors**
Country	**Building**		**Apt.**	**Site**		**Type**		**Sampler**		**Day**		**Month**		**Year**							**PM2.5, µg/m3**	**PM 10, µg/m3**	
1	0	1	1	0	5	1	3	0	1	0	7	1	2	1	1								

Measurement Site identification: Outdoor North Face - 01, Outdoor East Face - 02, Outdoor West Face - 03, Outdoor South Face - 04, Balcony - 05, Living room - 09
Identification of the type of measurement: Particulate Matter – 13

INSULAtE sampling log sheet No.

SETTLED DUST

Sample ID																						
Country	**Building**		**Apt.**	**Site**		**Type**		**Sampler**		**Day**		**Month**		**Year**		**Start date [dd/mm/yy]**	**Start time [hr:min]**	**End date [dd/mm/yy]**	**End time [hr:min]**	**Sampling duration [days]**	**Sampler place. Height, m**	**Notes (position in a room, top of cupboard, on shelve, etc.) Distance to ventilation intake/exhaust or other major disturbance factors**
1	0	1	1	0	9	1	4	0	1	0	7	1	2	1	1							

Measurement Site identification: Living room - 09, Master bedroom - 11, Bedroom#1 - 12, Bedroom#2 - 13, Bedroom#3 - 14
Identification of the type of measurement: Settled dust sample - 14

INSULAtE sampling log sheet No.

SETTLED FIBRES (TAPE+WIPING)

Sample ID																Start date [dd/mm/yy]	Start time [hr:min]	End date [dd/mm/yy]	End time [hr:min]	Sampling duration [days]	Value fibres/ cm^3	Notes (Position in a room, etc)
Country	Building		Apt.	Site		Type		Sampler		Day		Month		Year								
1	0	1	1	0	9	1	5	0	1	0	7	1	2	1	1							

Measurement Site identification: Living room - 09, Master bedroom - 11, Bedroom#1 - 12, Bedroom#2 - 13, Bedroom#3 - 14
Identification of the type of measurement: Settled Fibres tape - 15, Settled Fibres wipe - 16

INSULAtE sampling log sheet No.

GASES AND VAPOURS

Sample ID																**Start date [dd/mm/yy]**	**Start time [hr:min]**	**End date [dd/mm/yy]**	**End time [hr:min]**	**Sampling duration [h]**	**Value ng/m³**	**Notes (Position in a room, etc) Name of gases and vapours**
Country	**Building**		**Apt.**	**Site**		**Type**		**Sampler**		**Day**		**Month**		**Year**								
1	0	1	1	0	9	1	7	0	1	2	2	1	1	1	1							

Measurement Site identification: Living room - 09, Master bedroom - 11, Bedroom#1 - 12, Bedroom#2 - 13, Bedroom#3 - 14
Identification of the type of measurement: VOC - 17, Formaldehyde - 18, NOx - 19

<table>
<tr><td colspan="23">INSULAtE sampling log sheet No.</td></tr>
<tr><td colspan="23">RADON</td></tr>
<tr><td colspan="16">Sample ID</td><td rowspan="2">Start date

[dd/mm/yy]</td><td rowspan="2">Start time

[hr:min]</td><td rowspan="2">End date

[dd/mm/yy]</td><td rowspan="2">End time

[hr:min]</td><td rowspan="2">Sampling duration

[days]</td><td rowspan="2">Value

Bq/m³</td><td rowspan="2">Notes (position in a room, radon internal SN, etc)

E-PERM Electret number!!!</td></tr>
<tr><td>Country</td><td colspan="2">Building</td><td>Apt.</td><td colspan="2">Site</td><td colspan="2">Type</td><td colspan="2">Sampler</td><td colspan="2">Day</td><td colspan="2">Month</td><td colspan="2">Year</td></tr>
<tr><td>1</td><td>0</td><td>1</td><td>1</td><td>0</td><td>9</td><td>2</td><td>0</td><td>0</td><td>1</td><td>0</td><td>7</td><td>1</td><td>2</td><td>1</td><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="23">Measurement Site identification: Living room - 09, Master bedroom - 11, Bedroom#1 - 12, Bedroom#2 - 13, Bedroom#3 - 14
Identification of the type of measurement: Radon – 20</td></tr>
</table>

I		II		III		IV		V		VI		VII	VIII	IX
Country identification		Building No.		Apartment identification		Measurement Site identification		Identification of the type of measurement		Sampler Number		Day	Month	Year
Finland	1		01	Outdoor	0	Outdoors North Face	01	BI T outdoor	01	BI O T/RH	01	01	01	11
Lithuania	2		50		9	Outdoors East Face	02	BI RH outdoor	02		02	31	12	15
Other	3					Outdoors West Face	03	BI O thermovision	03	BI I Loggers T/RH	01			
						Outdoors South Face	04	BI T indoor short term	04		02			
						Balcony	05	BI RH indoor short term	05	Airflow	01			
						Kitchen	06	BI T/RH indoor loggers	06		02			
						Bathroom	07	BI air flow	07	Pressure diff	01			
						Toilet	08	BI pressure diff.,	08		02			
						Living room	09	BI surface temp.,	09	Surface Temperature	01			
						Hallway	10	BI thermovision indoor	10		02			

Master bedroom	11	Long Term CO/CO_2	11	Thermovision	01
Bedroom #1	12	Short Term CO/CO_2	12		02
Bedroom #2	13	Particulate Matter	13	Long term CO/CO_2	01
Bedroom #3	14	Settled dust sample	14		02
Blank sample	00	Settled Fibres tape	15	Short term CO/CO_2	01
		Settled Fibres wipe	16		06
		Passive sampler VOC	17	PM OPC	01
		Passive sampler Formaldehyde	18		09
		Passive sampler Nox	19	Settled dust	01
		Radon	20		02
				Fibres Tape	01
					02
				Fibres Wipe	01
					02

Outdoor Temp measurement in Finland, Building 2,

Apartment 3, at north face of the building, with a sampler No. 1, on
November 5th, 2011

1-02-3-01-01-01-051111

VOC measurement in Lithuania, Building 12, Apartment 5, in living room, sampler No. 1, on March 2nd, 2012

2-12-5-09-17-01-020312

VOC	01
	02
Formaldehyde	01
	02
NOx	01
	02
Radon	01
	02

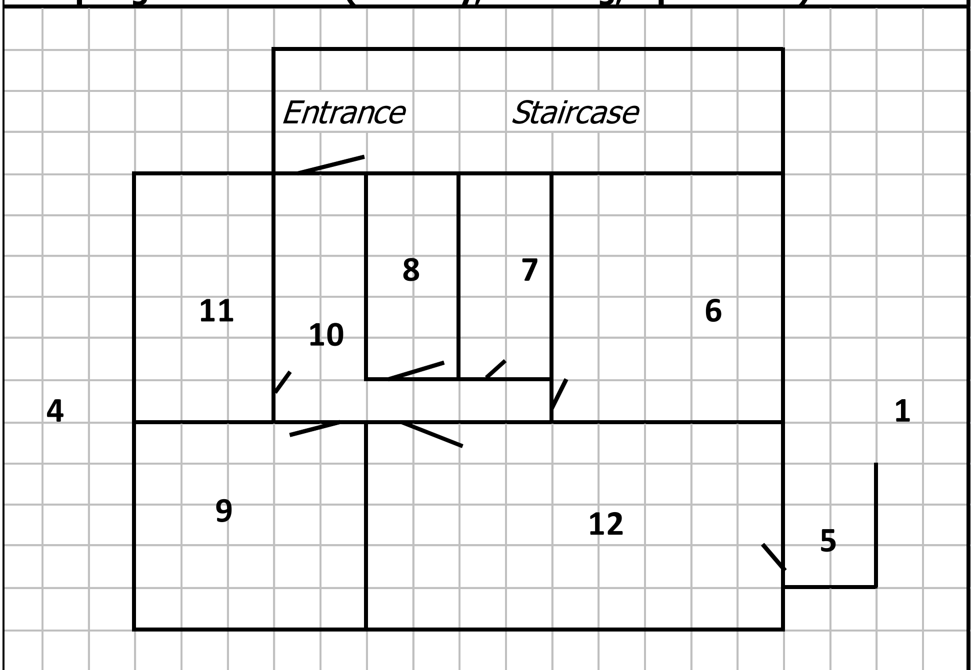
Equipment location in apartment
Sampling date:
Sampling location ID: (Country, Building, Apartment)
Notes: Outdoors North Face - 1, Outdoors East Face - 2, Outdoors West Face - 3, Outdoors South Face - 4, Balcony - 5, Kitchen - 6, Bathroom - 7, Toilet - 8, Living room - 9, Hallway -10, Master bedroom - 11, Bedroom #1 - 12, Bedroom #2 - 13, Bedroom #3 - 14.

INSULAtE sampling log sheet

Equipment location in apartment

Sampling date:

Sampling location ID: (Country, Building, Apartment)



Notes: Outdoors North Face - 1, Outdoors East Face - 2, Outdoors West Face - 3, Outdoors South Face - 4, Balcony - 5, Kitchen - 6, Bathroom - 7, Toilet - 8,
Living room - 9, Hallway -10, Master bedroom - 11, Bedroom #1 - 12, Bedroom #2 - 13, Bedroom #3 - 14.

Appendix C – Building occupants related SOPs and material

1. Delivery and collection of occupant questionnaires and diaries

Purpose

To describe material needed and procedure for delivery and collection of occupant questionnaires and diaries

Material

- A contact letter to the occupants
- Information-brochure
- Occupant "willingness to participate" - form to be send together with the contact letter
- Preliminary questionnaire
    - Occupant contact information as detailed as possible (name, address, phone number, best time to reach by phone or by person)
    - Basic information of the apartment: size of apartment, number of rooms, number of occupants (age distribution: adults/children)
    - Special questions: pets, small children (information should be known in order to planning placement/ shielding of measuring equipment and for entering apartment)
    - also inquiring permission for building investigators to enter the apartment with a masterkey (for leaving and picking measuring equipment, when occupants are not at home)

- Questionnaire/diary forms
- Pre-paid and addressed return envelope

Procedure

- The questionnaires and diaries should be filled at the same time by the occupants of each case building
- The exact schedule depends on the on-site investigation / measurement schedule
    - Pre-retrofit questionnaires to be filled before the investigations
    - Post-retrofit questionnaires to be filled before collection of the measurements instruments and/or post-retrofit measurements

Prior to delivery of the survey material (questionnaire forms and instructions) to the occupants

- Decide when occupants should answer the questionnaire and fill in the diary (week, starting from Monday)
- Contact the occupants about 2 weeks before the questionnaire and diary should be filled
    - Arrange for delivery and collection time and method:

1. delivery directly to the occupants or to their mailbox or
2. collection by a researcher or
3. by mail

- Delivery of the questionnaire and diary to occupants as agreed with the occupants
- Collection the questionnaire and diary as agreed with the occupants

- Based on preliminary questionnaire and willingness to participate forms, 5 apartments / building will be selected for the measurements (if more volunteer than needed). Criteria for choosing apartments for the study (most important first):
    - The occupants volunteer to participate the study
    - The selected apartments in one building are located different point of compass (north/south), building height (upper lever, lower level) and building width (corner, middle)
    - The selected apartments in one building include different sizes (living area per occupant varies)
- The subsequent home-visits will be scheduled together with the house manager and the participating occupants

2. Information letter, willingness to participate

Dear Sir/Madam, occupant of [address] [date]

Indoor environmental quality is influenced by ventilation, thermal conditions, indoor air pollutants such as particles, microbes, chemical impurities and radon, noise and lighting. Your building has been selected to participate in INSULAtE* -project, which investigates the impacts of building renovation on the indoor environmental quality.

The project includes investigations and measurements in buildings undergoing renovations in 2 – 3 EU countries. From Finland, project partners include the National Institute for Health and Welfare (THL), coordinating the project and being responsible for health surveys, and Tampere University of Technology responsible for building related studies. From Lithuania, Kaunas University of Technology is responsible for exposure assessment. The project is a part of the European Commission's "Environment Life+" program.

Information on indoor air quality and health issues will be gathered by measurements and occupant interviews. Small measurement devices set in the apartments will monitor parameters such as temperature, relative humidity, air change rate, particles, organic compounds, nitrogen oxides, carbon monoxide and dioxide, aldehydes, radon and mineral fibres. The occupants' perceptions on indoor air quality and health will be examined by questionnaires and interviews.

We hope that you will participate in the project. Please contact the researcher [name] by phone or email (contact information below). You can also sign up by filling the enclosed form and returning it by mail by [date] (with the reply envelope, post-free).

It is voluntary to participate and no costs will fall upon the occupants. If you choose to participate, you will receive a package of coffee or tea as a gift.

If you require any further information before signing up, please contact:

Researcher [name]
[National Insitute for Health and Welfare (THL) / Tampere university of technology / Kaunas university of technology]
phone, email

Improving energy efficiency of housing stock: impacts on indoor environmental quality and public health in Europe (INSULAtE)

National Institute for Health and Welfare
Tampere University of Technology
Kaunas University of Technology

I __________________________ have been asked to participate in the above-mentioned project whose purpose is to demonstrate the effects of energy efficiency improvements of residential buildings on indoor environmental quality and health. I have familiarized myself with the written study description and I have had an opportunity to pose questions about it. I have been given sufficient information about my rights, the purpose of the study, its execution and the benefits and risks of the study.

I understand that my participation is voluntary. I am aware that I may reverse my consent at any point without announcing a reason and the rescission will not affect my treatment in any way. I know that my information will be handled confidentially and they will not be turned over to outsiders. I know that if I abort my participation in the study there will be no new information collected about me, but information and measurement results that have been collected earlier will be used in the way according to the study.

a. I agree to participate in the survey (including filling out the questionnaire form and diary for the duration of two weeks, questionnaire will be posted later)

Yes ____ No ____

b. I agree to indoor air measurements performed in my apartment and I will answer to the questions next page

Yes ____ No ____

_______________________ ________________________
Name of study participant Address of study participant

_______________________ ________________________
Date Signature

______________________ ___________ _______________________
Name of researcher Date Signature
(Will be filled out by the receiver of the consent)

Please answer the following questions, if you agree to indoor air measurements:

a. Information about the apartment and occupants:

(If there are more volunteers to participate in the measurements than we need, the measured apartments will be chosen representative to the building and its apartments and occupants.)

Size of the apartment: ______**room** + ______**kitchen** + ______**sauna**, ________**m2**

Occupants: _____adults, ______children, of which _____________are under school age

b. Other information for planning and scheduling measurements:

There **are**______ /_________ **are no** domestic animals (pets) in my apartment, which

animals____________________

There is______ /_________ is **no** balcony in my apartment

The balcony **has** ________**glazed windows** / ____________does not **have glazed windows**

I agree that the researchers can visit measuring sites using master key while I am not at home. All visits will be arranged with the researchers.

Yes ____ **No** ____

c. Contact information for arranging measurements:

Name: ____

I want that I will be contacted by:

____phone, phone number: ________________________, _____ in day time, ______in evening

____email, email address: ____

3. Notice for study participant

NOTICE FOR STUDY PARTICIPANT
x.x.201x

Dear Recipient,

The joint project of the National Institute for Health and Welfare (THL), Tampere University of Technology (TUT), Finland, and Kaunas University of Technology (KTU) aims to demonstrate the effects of energy efficiency improvements of residential buildings on indoor environmental quality and health. The project is funded by the European Union LIFE+ programme.

Information that is gathered from the occupants is an essential part of the project. Information will be collected with interviews / questionnaires and housing health diaries. We hope that You will take part in the study.

We kindly ask one adult from your household to fill out the attached questionnaire or to enrol for an interview, which will be based on the questionnaire and carried out over the phone. Alternatively you may also fill out the questionnaire via the internet. We ask you to enrol for the potential phone interview within one week to our researcher xxx, whose contact information can be found in the bottom of the next page. She may also provide you with more information about the possibility of responding via the internet.

In addition, we ask all the adults of your household to fill in the attached housing health diary for a period of two weeks starting from Monday. If needed, you may ask for more diaries to be delivered in case that you have more than two adult members in the household. **The diary includes questions concerning symptoms, time consumption, and activities. Each participant should fill out a two sided one-page form once a day for the duration of two weeks.**

Furthermore, there will be measurements taken in some of the apartments of your residential building (relative humidity of indoor air, temperature, carbon dioxide, and particle concentrations) and environmental samples will be gathered to examine chemical and microbiological factors and fibres. Selection of the apartments to be measured will be based on volunteering and done so that they represent different floors and compass points.

If you are willing to take part in the survey and/or measurements, we kindly ask you to return the questionnaire, housing health diary, and the consent form inside the attached return envelope to the locked mailbox that is situated near your main entrance or by mail (postal fees have been paid). We hope that you will add your contact information on the questionnaire so we may contact you if needed.

Participation in the project is voluntary. Participation will be useful, as it will help us examine the data of the effects of energy efficiency improvements of residential buildings on the quality and healthiness of indoor environment on a national level.

There is additional information about the study that we hope you will familiarize yourself with on the reverse side of the paper.

Improving energy efficiency of housing stock: impacts on indoor environmental quality and public health in Europe

Your residential building has been chosen as a case building in a project to demonstrate **effects of energy efficiency improvements of residential buildings on indoor environmental quality and health.** An essential part of the project is the residential study in which you will hopefully participate in.

You have an opportunity to ask questions about the project (contact information in the bottom of the page).

Progress of the study

The study information will be gathered using the attached questionnaire/survey forms and housing health diaries. Only information concerning health received from the study participants themselves will be added to the study material. The Research Ethics Committee of xxxhas evaluated the research plan and given a supportive statement of it.

Benefits and risks related to the study

One package of coffee or tea per household can be given as a reward of study participation, and participation will not cause any risks. By taking part in the study You will have a chance to receive information about the conditions of your apartment, and about housing health in general.

Confidentiality, information processing and storage

All the information received from you and the study results will be handled confidentially according to procedure provided by the Personal Data File Act. Individual participants will be given a code and information will be stored in the coded form. The results will be analysed on a group level in a way that no individual person can be identified. Information will not be shared with persons outside the project. The final results will be reported on a group level and identifying individual participants will be impossible. All documents will be permanently stored according to the filing regulation ofxxx.

Voluntariness

Participating in the study is completely voluntary.

Announcing the study results

The aim is to publish the results as group results in national and international publications. The results will also be announced to the general public.

Additional information

Persons in charge of the project: Professor Dainius Martuzevicius (KTU), Researcher Virpi Leivo (TUT), and Senior Researcher Ulla Haverinen-Shaughnessy (THL).

We are pleased to answer any questions you might have concerning the study.

Study contact person:

researcher xxx

phone e-mail:

NATIONAL INSTITUTE FOR HEALTH AND WELFARE

ktu 1922 kaunas university of technology

TAMPERE UNIVERSITY OF TECHNOLOGY

4. Instructions for occupants

Energy efficiency and indoor environmental quality –research

Instructions for occupants concerning measurements in the apartment

Different kinds of indoor environmental quality measurements will be performed in your apartment. The duration of these measurements varies between one day to about one year. Same measurements will be done before and after building retrofits. The measurements have been planned to cause as little inconvenience as possible and they do not prevent normal living.

In the following, we give information about the measurements as well as some instructions. The measurements are presented starting from the short-term measurements. The exact placement of measuring devices can be negotiated with occupants.

1. Fine particle counter, CO_2-measurement, duration about 24 hours

Particle counter is placed in a soundproof box. It requires electricity, energy consumption is xx kWh during the measuring period. While the counter is slightly buzzing, it will placed for instance in the living room (not to bedroom).	

2. VOC, aldehyde, NO_x –samplers, duration 7 days

Different samplers measuring indoor air pollutants are freely hanged in such a place that allows air circulation. Avoid using aerosols (for instance hair spray, air fresheners) in the immediate proximity of the samplers.	

3. Fiber particle collectors, duration 7 days

Plastic bowl (petri dish) placed on the table or a shelf and an area will be marked on the surface, where dust is allowed to settle during the measuring period. The dust should not be wiped and the the bowl should not be moved.	

4. Microbes, settled dust, radon, duration 2 months

Two cardboard boxes are placed on a shelf or attached on the wall where dust is allowed to settle during the sampling period. The boxes should be left undisturbed. Also a radon sampler could be placed on the shelf.	 	

5. **Indoor air temperature and relative humidity (RH) measurement, duration max one year.**

Loggers measuring temperatures and RH are placed on two locations (near floor level and on a table or a self). Try to keep loggers approximately in their original places; you can temporary move them for instance during cleaning.	

Return the following form to the researchers when they come to collect measuring devices after 2-month period.

Background information about changes which could affect on measurements:

At the measuring period	Yes	No
New furniture has been brought to the apartment		
There are new pets in the apartment		
Interior materials have been changed (e.g. painting, new wallpaper, etc.)		
Water damage has occurred in the apartment		
Measuring devices have been damaged or disturbed		
Other, what?		

Information about the measurements:

NN

5. Housing and health survey

ID CODE:

Improving energy efficiency of housing stock: impacts on indoor environmental quality and public health in Europe

Housing and health survey

Welcome to a survey geared to mapping your indoor environmental quality and health! First we are going to ask you for some background information. Such questions are asked in order to be able to analyse the group level data gathered. The results of the survey will be handled with absolute confidentiality so that no information given by individual respondents can be identified. Your answers will take 10-20 minutes of your time.
Instructions: Tick correct option(s) or write your answer in the appropriate space.

RESPONDENT'S INFORMATION

Name of housing association			
Forename of respondent		Surname	
Number and street			
Post code		Post office	
E-mail address			

<u>LIVING ENVIRONMENT AND BUILDING</u>

1. How many years have you been living in your present dwelling? Indicate in years______

2. What is the form of occupancy for your dwelling?

- ☐ Rental flat in a tenement building
- ☐ Rental flat in a housing association building
- ☐ Owner-occupied flat/house

- ☐ Dwelling provided by the employer
- ☐ Right-of-residency apartment
- ☐ Other, please specify ____

3. Which of the following facilities are found in your dwelling? You may choose more than one option.

- ☐ Balcony
- ☐ Glass-enclosed balcony
- ☐ Central heating
- ☐ Mechanical exhaust ventilation
- ☐ Mechanical support ventilation
- ☐ Fresh air vents in bedrooms
- ☐ Air humidifier
- ☐ Air purifier
- ☐ Unvented gas heater
- ☐ Gas stove
- ☐ Fireplace/wood burning oven
- ☐ Kitchen vent hood
- ☐ Sauna

4. Do you find your dwelling spacious enough?

- ☐ No
- ☐ Yes

5. How satisfied are you with your present dwelling/building?

- ☐ Satisfied
- ☐ Fairly satisfied
- ☐ Rather unsatisfied
- ☐ Unsatisfied
- ☐ No opinion / Cannot tell

6. If you are planning to move to another dwelling within the next 12 months, why? You may choose more than one option. If you do not plan to move, mark the first option.

- ☐ I am not planning to move

- ☐ My dwelling is too small
- ☐ My dwelling is too large
- ☐ Condition of dwelling (e.g., excessive need for repair)
- ☐ Dwelling does not meet my needs otherwise
- ☐ We want to move to another residential area
- ☐ Financial reasons

☐ Other reasons, please specify

____

7. Which of the following types have been used for interior lining on the walls of the rooms in your dwelling (bedrooms/living room/kitchen)? Choose 1-3 most common options.

☐ Natural wood/panel
☐ Painted wood/panel
☐ Painted brick/concrete/stone/stucco
☐ Unpainted brick/concrete/stone/stucco
☐ Painted wallboard (wood fibre, gypsum, chipboard, etc.)
☐ Papered wallboard (wood fibre, gypsum, chipboard, etc.)
☐ Papered stone/concrete, etc.
☐ Do not know
☐ Other, please specify ____

8. Which of the following coverings have been used on the floors of the rooms in your dwelling? Choose 1-3 most common options.

☐ Wood/parquet
☐ Laminate
☐ Ceramic tile/clinker/natural stone
☐ Plastic membrane/tile
☐ Linoleum
☐ Wall-to-wall carpet
☐ Do not know
☐ Other, please specify ____

9. What kind of windows have you got in your dwelling?

☐ Single pane
☐ Double pane
☐ Triple pane
☐ Quadruple pane
☐ Do not know
☐ Other, please specify ____

10. Have the following renovations been performed in your building? "Renovation" in this context means a relatively extensive and separate project for repairing or replacing the building's existing structures, components, fixtures, accessories, systems and equipment (e.g., exterior walls, balconies, windows as well as heating, water-distribution and sewer systems).

	No	Yes,	Yes, during	Yes, more	Do not

		during the past 12 months	the past 5 years	than 5 years ago	know
Roof repair or new roof					
Façade renovation (additional thermal insulation, etc.)					
Drainage repair					
Pipework renovation					
Ventilation system repair / changes					
Heating system repair / changes					
Balcony renovation					
Window renovation / changes					
Lift renovation / addition					
Bathroom renovation					
Kitchen renovation					
Other*					

***What other renovation work has been performed if any?** ____

12. How satisfied are you with the building maintenance and repairs that have been carried out?

- ☐ Satisfied
- ☐ Fairly satisfied
- ☐ Rather unsatisfied
- ☐ Unsatisfied
- ☐ No opinion / Cannot tell

HYGIENE

12. In the water supply for your household, have there been any interruptions during the past 12 months for any of the following reasons?

	No	**Yes**	**Do not know**
System failure			
Freezing			
Dryness			
Interruptions due to repair work			
Other reason*			

***Other reason, please specify ________ ________________**

13. Have you got pets in your home?

	No	**Yes, indoors**	**Yes, but not indoors**
Dogs, cats, guinea pigs, birds, etc.			
Aquarium or terrarium animals (fishes, turtles, lizards, snakes, etc.)			
Other animals*			

***Other animals, please specify____**

14. Have you seen any signs of pests (live or dead insects or rodents, gnaw marks, excrement, etc.)? You may choose more than one option.

	No	**Yes, indoors**	**Yes, in the courtyard area**
Rodents (mice, rats, etc.)			
Insects (furniture beetles, cockroaches, carpenter ants, etc.)			

PHYSICAL, BIOLOGICAL AND CHEMICAL CONDITIONS

15. How satisfied are you with the quality of the indoor air in your dwelling?

- ☐ Satisfied
- ☐ Fairly satisfied
- ☐ Rather unsatisfied
- ☐ Unsatisfied
- ☐ No opinion / Cannot tell

16. In your opinion, have any of the following indoor air factors in your dwelling caused inconvenience or harm during the past 12 months?

	Never	Sometimes	Every week	Almost daily
Too high a room temperature				
Too low a room temperature				
Too high humidity (moist air)				
Too low humidity (dry air)				
Stuffiness/poor quality of indoor air				
Mould odour or visible mould growth				
Other unpleasant odour				
Noise				
Dust or dirtiness				
Static electricity charge				
Other*				

Other, please specify ____

17. Do you keep a room window open for ventilation or temperature regulation? You may choose more than one option.

	In summer			In winter			Not possible
	Daily/ almost daily	Less freque ntly	Nev er	Daily/al most daily	Less freque ntly	Ne ver	
Kitchen							
Bedroom(s)							
Living room							
Bathroom							
Other area*							

***Other area, please specify**_____________________________

18. What is the typical indoor temperature in your dwelling during the heating season?

- ☐ Under 18 degrees Celsius
- ☐ 18-20 degrees Celsius
- ☐ 20-22 degrees Celsius
- ☐ 22-24 degrees Celsius

☐ Over 24 degrees Celsius

19. What are the temperature conditions like in your dwelling? You may choose more than one option.

	Suitably warm	Too cold	Too warm	Draughty	Cold floor surfaces, etc.
In summer					
In winter					

20. During the past 12 months, have you tried to adjust the thermostat of the radiator valves yourself?

☐ No
☐ Yes, downwards (colder)
☐ Yes, upwards (warmer)
☐ Not possible

21. Is there moisture condensation present on the windows of your dwelling?

	Daily/almost daily	Weekly	Less frequently	Never
In summer				
In winter				

22. Has there been serious water damage in your dwelling (pipe leaks, etc.) involving the soaking of large areas/building components by large volumes of water?

☐ No
☐ Yes, during the past 12 months
☐ Yes, more than 12 months ago
☐ Do not know

23. At present, is there any moisture or mould damage in the main living space of your dwelling, and what is the location and extent of the damage?

	No damage	Point-sized	Localised (under 1 m^2 and limited to one area/building component)	Extensive (over 1 m^2 or covers several areas/building components)
Kitchen				

Bedroom(s)				
Living room				
Bathroom				
Other living space*				

***Please specify____**

24. Are there any deficiencies in the lighting of your living environment?

	Sufficient	Not sufficient
Interior lighting of the dwelling		
Interior lighting of the building (staircases, storage areas, etc.)		
Lighting of the courtyard area (passage ways, parking spaces)		
Street and general lighting in the area		
Other location*		

***Other location, please specify?_____________________________________**

25. Which of the following cause daily/almost daily noise nuisance in your dwelling?

	Noise nuisance daily/almost daily	No or infrequent noise nuisance
Noise from your own dwelling: music, household appliances, etc.)		
Noise from the building's ventilation, plumbing, electrical systems, lifts, etc.		
Noise from the immediate surroundings (neighbour dwelling, yard, etc.)		
Noise from the surrounding areas (traffic, industry, etc.)		

26. Does anyone smoke indoors in your dwelling?

- ☐ Never
- ☐ Daily/almost daily
- ☐ Occasionally

27. Are there unpleasant odours present in your dwelling or in the immediate surroundings and what are they associated with? You may choose more than one option.

	No harmful odours	**In the dwelling**	**Elsewhere in building indoor areas**	**Outdoors**
Food odours				
Cigarette smoke				
Mould odour				
Construction materials				
General stuffiness				
Sewer odour				
Smoke odour				
Farming odours				
Industrial odours				
Odours from traffic				
Waste treatment				
Other odours*				

*Other odours, please specify________________________________

28. Are there asbestos-containing materials in your building?

- ☐ No
- ☐ Yes, in living areas
- ☐ Yes, but not within the dwelling
- ☐ Do not know

29. Are there elevated radon concentrations in your dwelling (i.e., concentrations exceeding the 400 Bq/m^3 reference value or, if your dwelling was built after 1992, exceeding 200 Bq/m^3)?

- ☐ No
- ☐ Yes
- ☐ Do not know

WELL-BEING AND HEALTH

30. How has your general health been during the past 12 months?

- ☐ Good
- ☐ Fairly good
- ☐ Satisfactory
- ☐ Rather poor
- ☐ Poor
- ☐ No opinion / Cannot tell

31. During the past 12 months, have you had respiratory tract infections (such as ear infection, sinusitis or bronchitis), resulting in visits to a doctor, courses of antibiotics or absences from work or school?

	No	Yes
Had respiratory tract infections		
Visited doctor for respiratory tract infections		
Prescribed antibiotics		
Absences from work or school due to respiratory tract infections		

32. During the past 12 months, which of the following symptoms have you had and how often?

	Daily/almost daily	Weekly	Monthly or less frequently	Never
General symptoms (headache, fatigue, difficulties concentrating)				
Upper respiratory tract symptoms (stuffy nose, head cold, dry or sore throat)				
Lower respiratory tract symptoms (shortness of breath, cough, sputum production)				
Eye symptoms (itching, dryness, sensation of a foreign body in the eye)				
Rash or skin symptoms (reddening of the skin, dry skin, itching)				
Joint pain or swelling				

Muscle pain				
Diarrhoea				
Sleeping problems				

33. Do you think that the above-mentioned symptoms (question 32) are associated with a certain building or environment?

	No	Yes
Home		
Workplace		
Other location*		

*Other location, please specify ______________________________

34. Has you doctor ever stated that you have any of the following illnesses and which year were they diagnosed?

	No	Yes	When diagnosed (year)?
Arterial hypertension			
Heart failure			
Diabetes			
Cancer			
Rheumatoid arthritis			
Other articular disease			
Epilepsy			
Migraine			
Depression			
Other mental disorder			
Insomnia			
Asthma			
Allergy to house dust mites			
Pollen allergy			
Allergy to domestic animals			
Mould allergy			
Other chronic disease, please specify*			
Other long-lasting illness**			

***Other chronic disease, please specify __________________________**
****Other long-lasting illness, please specify ________________________________**

35. Have you received continuous medication for the above-mentioned illnesses and has there been any change in the medication during the past 12 months?

	Medication increased	Medication reduced	No medication/medication unchanged
Arterial hypertension			
Heart failure			
Diabetes			
Cancer			
Rheumatoid arthritis			
Other articular disease			
Epilepsy			
Migraine			
Depression			
Other mental disorder			
Insomnia			
Asthma			
Allergy to dust mites			
Pollen allergy			
Allergy to domestic animals			
Mould allergy			
Other chronic disease			
Other long-lasting illness			

36. Approximately how many times have you visited a doctor during the past 12 months? (Visits to a dentist excluded.) Enter 0 if you haven't made a single visit. _____ times

37. Approximately how many days have you been hospitalised during the past 12 months?_____ days

38. Approximately how many whole days have you been absent from work or unable to perform your regular tasks during the past 12 months? _____ days

39. Assuming that the best working capacity you have ever had would score 10 on a scale of 0 to 10, what score would you give to your present working capacity? (0=totally unable to work, 10=best working capacity). Score of _____

40. Are you taking physical exercise (such as walking, jogging, bike riding, or fitness training) at least half an hour per day?

	Yes, several times a week	Yes, approximately once a week	Less often than once a week	Never
In the living environment or close to it				
While going to and from school or work				
In other location				

41. How many hours do you sleep on the average: at night?_____hours during a 24-hour period? _____hours

42. How good do you think your present life as a whole, or your quality of life, has been during the past month (30 days)? Rate your quality of life by circling from among the numbers below the number that best describes your quality of life. The worst possible quality of life is reflected by 0 and the best possible by 10.

0	1	2	3	4	5	6	7	8	9	10
Worst										Best

BACKGROUND

43. Gender of respondent
- ☐ Female
- ☐ Male

44. Age of respondent ___________ years

45. Mother tongue of respondent
- ☐ English
- ☐ Finnish
- ☐ Lithuanian
- ☐ Russia
- ☐ Swedish
- ☐ Other, please specify_________________

46. Year of education after primary school __________years

47. Do you smoke or have you smoked in the past?
- ☐ No, I have never smoked
- ☐ No, I quit smoking within the past 12 months
- ☐ No, I quit smoking more than 12 months ago
- ☐ Yes, I smoke currently

48. What portion of your combined monthly pretax household income do you spend on dwelling costs? (In this context, "dwelling costs" means rent, maintenance fee, loans/loan expenses, heating, electricity and water, waste management, etc.)
- ☐ Under 15%
- ☐ 16 - 25%
- ☐ 26 - 35%
- ☐ 36 - 50%
- ☐ 51 - 65%
- ☐ Over 65%

49. Including yourself, how many people live permanently in your dwelling? (Indicate the number of occupants by age group.)

Elderly (aged 65 and over) __________________
Adults (aged between 18 and 65)__________________
Children aged 7 to 17 __________________
Children under the age of 7__________________

THANK YOU FOR YOUR TIME!

6. Housing and health diary

ID CODE:

Improving energy efficiency of housing stock: impacts on indoor environmental quality and public health in Europe

(INSULAtE)

Housing and health diary

Name: ________________________

Address: _________________________

Instructions:

- The diary covers two weeks (14 days).
- There are ten questions to be answered for each day (on one sheet meant to be completed on both sides).
- Please start completing the diary Monday evening. Complete the diary every day (weekdays and weekends) in the evening.
- Please write the date and time at the top of each page (new day).
- Answer the following questions related to the previous 24-hour period.
- Write your answer in the appropriate box.
- For questions with more than one option for answering, circle the number corresponding to the correct option or mark the box ☒. Do not mark more than one option with ☒ unless otherwise instructed for the question concerned.
- Some questions also ask for a more detailed explanation. In that case, write a brief explanation in the appropriate space.
- In the case of a so-called scale question, circle the number of you answer. Let’s assume that it measures the extent to which the noise outside your dwelling bothers you. Zero means that the noise does not bother you at all and ten means that it bothers you unbearably.
- Completing the diary shouldn’t take more than 5 minutes of your time each day.
- Once you have completed the whole diary (after 14 days – the last page), return the diary to us in the enclosed return envelope.

Thank you!

DATE: ___ / ___ / 201_ (Day 1) **Time:** ___ : ___

1. <u>During the past 24 hours</u>, how many hours and minutes did you spend in the following places?

	hours	**min**
Outdoors		
In a car or a bus		
In a train		
Inside your home		
Inside your workplace or school		
Inside a public building (library, townhall offices, sports hall, etc.)		
Inside somewhere else		
Total	24	00

2. <u>During the past 24 hours</u>, how many hours and minutes were the following devices and installations used in your home? (write zero if not used at all)

	hours	**min**
Wood-burning oven, sauna stove or fireplace (usage time)		
Gas-powered oven, stove, or fireplace		
Additional gas heater for water or space heating		
Other type of additional heater		
Kitchen vent hood		
Window ventilation (opening windows)		
Air humidifier		
Air purifier		

3. <u>During the past 24 hours</u>, did the following action take place in your home?

	No	Yes
Vacuum-cleaning	☐	☐
Dusting, sweeping	☐	☐
Turning down radiator valves	☐	☐
Turning up radiator valves	☐	☐
Smoking inside	☐	☐
Smoking on the balcony or veranda (in the immediate vicinity of the dwelling)	☐	☐

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

	0 - Not at all				**←→**						**Intolerably - 1**
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:____________________

---

5. During the past 24 hours, how would you rate your general health?

☐ Much better than usual
☐ Better than usual
☐ As usual
☐ Slightly worse than usual
☐ Much worse than usual

6. During the past 24 hours, have you had any of the following symptoms? Please choose one option for each symptom.

	No	**Mild**	**Moderate**	**Serious**
Wheezing	☐	☐	☐	☐
Shortness of breath	☐	☐	☐	☐
Dry cough	☐	☐	☐	☐
Rhinitis / cold or stuffy nose	☐	☐	☐	☐
Dry or sore throat	☐	☐	☐	☐
Hoarse voice	☐	☐	☐	☐
Bloodshot, puffy or itchy eyes	☐	☐	☐	☐
Rash or skin symptoms	☐	☐	☐	☐
Headache	☐	☐	☐	☐
Fever	☐	☐	☐	☐
Fatigue	☐	☐	☐	☐
Sleeping problems	☐	☐	☐	☐
Joint pain/swelling	☐	☐	☐	☐

7. During the past 24 hours, have you taken the following medicines?

	No	**Yes**
Painkiller for headache	☐	☐

Painkiller for joint or muscle pain	☐	☐
Sleeping pills	☐	☐
Antidepressants	☐	☐
Asthma medications	☐	☐
Allergy medications	☐	☐
Heart failure medications	☐	☐
Blood-thinning drugs	☐	☐
Blood pressure medications	☐	☐
Antibiotics for respiratory infection	☐	☐
Other medicines, please specify____________________	☐	☐

8. During the past 24 hours, did you feel like having a cold or the flu?

- ☐ No
- ☐ Yes

9. During the past 24 hours, have you smoked or been subjected to environmental tobacco smoke exposure?

- ☐ No
- ☐ Yes, I have smoked myself
- ☐ Yes, I have been subjected to tobacco smoke from other people

10. Did you work today?

- ☐ Yes
- ☐ No, because I do not work
- ☐ No, because I was sick
- ☐ No, because I had a day off today
- ☐ No, because of other reasons.

7. INSULAtE thank you -letter

Thank you for participating in the study called ”Improving energy efficiency of housing stock: impacts on indoor environmental quality and public health in Europe”!

We will do the corresponding measurements / questionnaire surveys in your apartment building after the retrofit. We hope that you will participate to them as well. We will contact you later on concerning these investigations.

The main goal of the study is to assess the effects of energy efficiency improvements of residential buildings on indoor environmental quality and health. The project is co-financed by the EU LIFE+ program.

If you have any questions regarding this study, please do not hesitate to contact us.

Contact information:

Common questions,
researcher xx, THL
phone: xx
email: firstname.lastname@thl.fi

Questions related to the questionnaire and diary,
researcher xx, THL
phone: xx
email: firstname.lastname@thl.fi

Questions related to the measurements,
researcher xx, TTY
phone: xx
email: firstname.lastname@tut.fi

Ulla Haverinen-Shaughnessy
National Institute for Health and Welfare (THL)

Virpi Leivo
Tampere University of Technology

Appendix D – Reporting of results

1. INSULAtE Result letter to occupant, pre and post

Dear occupant at [address],

You participated in the INSULAtE-project, which studies the effects of energy retrofits on indoor environmental quality. Below you will find a summary of the measurements carried out in your dwelling before and after the retrofit.

- Before the retrofit average indoor temperature was x°C (range: x–x°C) in the living room and x°C (range: x–x°C) in the bedroom; and after the retrofit x°C (range: x–x°C) in the living room and x°C (range: x–x°C) in the bedroom. Housing health guidelines (2003), issued by the Finnish Ministry of Social Affairs and Health (available in Finnish at: http://pre20090115.stm.fi/pr1063357766490/passthru.pdf) define indoor temperature of 21°C as good and indoor temperature of 18°C as adequate. When the heating is on, the indoor temperature should not exceed 23–24°C.
- Thermal index describing the temperature at single point in the junction of the interior wall and the exterior wall was xx before and xx after the retrofit. According to Housing health guidelines (2003), adequate thermal index is ≥61 and good is ≥65.
- Before the retrofit relative humidity was on average x % (range x– x %) in the living room and x% (range x– x %) in the bedroom. After the retrofit the relative humidity was on average x% (range x– x %) in the living room, and x% (range x– x %) in the bedroom. According to Housing health guidelines (2003), relative humidity should be about 20–60%. Occasionally the range cannot be reached due to climatic factors, which then cannot be considered a health risk if other perquisites for healthy living conditions are met.
- Before the retrofit carbon dioxide concentration was on average xx ppm, ranging between x and x ppm; and after retrofit xx ppm, ranging between x and x ppm. Housing health guidelines (2003) maintain that ventilation is not in compliance with the Finnish Health Protection Act if carbon dioxide concentration in indoor air exceeds 1500 ppm. Adequate carbon dioxide concentration is about 1200 ppm.
- Carbon monoxide concentration was x ppm before and x ppm after the retrofit. According to Housing health guidelines (2003) the upper limit for carbon monoxide concentration is 6.9 ppm.

- Based on a two-month measurement period, radon concentration was xx Bq/m^3 before and xx Bq/m^3 after the retrofit. According to Housing health guidelines (2003), annual mean radon concentration should not exceed 400 Bq/m^3.
- Formaldehyde concentration in indoor air was xx µg/m^3 before and xx µg/m^3 after the retrofit. According to Housing health guidelines (2003), indoor formaldehyde concentration should not exceed 100 µg/m^3.
- Indoor air in your dwelling was also tested for some other pollutants, but these measurements were conducted solely for research purposes.

Summary

The results indicate that during the measurement period, indoor air quality in your dwelling with regard to indoor temperature, relative humidity, carbon dioxide, carbon monoxide, radon, and formaldehyde complied with the levels defined in Housing health guidelines (2003). However, it should be noted that the measurements were not necessarily carried out in accordance with the guidelines.

Sincerely yours,
INSULAtE Research Group

2. INSULAtE Result letter to house manager

Dear representative of [address],

Your building has participated in INSULAtE-project, as a part of which indoor environmental quality was assessed in x apartments on two occasions. Attached is a summary of the measurement results before and before and after energy retrofits. We have send result letters for building occupants regarding the results of their individual apartments.

Kind regards,

Researcher xx

National Institute for Health and Welfare

P.O. Box 95, 70701 Kuopio

email: xx(at)thl.fi

puh. xx

http://www.insulateproject.eu/

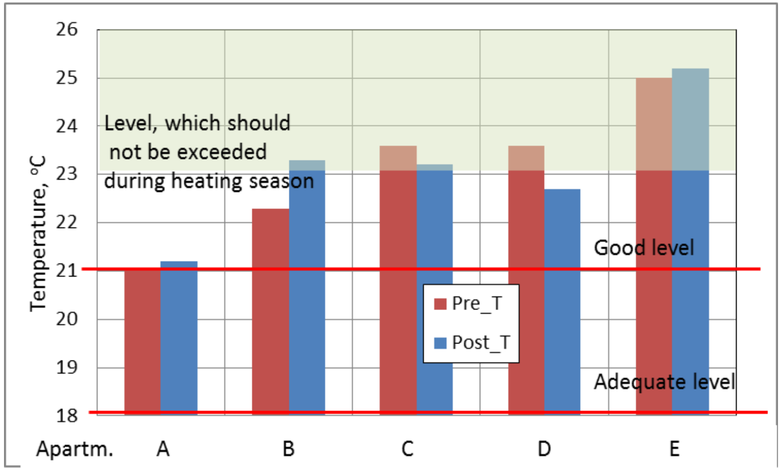
http://www.thl.fi/fi/tutkimus-ja-asiantuntijatyo/hankkeet-ja-ohjelmat/hankkeet/28407

[Address of the case building] property participated INSULAtE-project, part of which selected indoor environmental quality parameters were measured

Five apartments were measured both before and after renovation. Please see below a short summary of the measurement results.

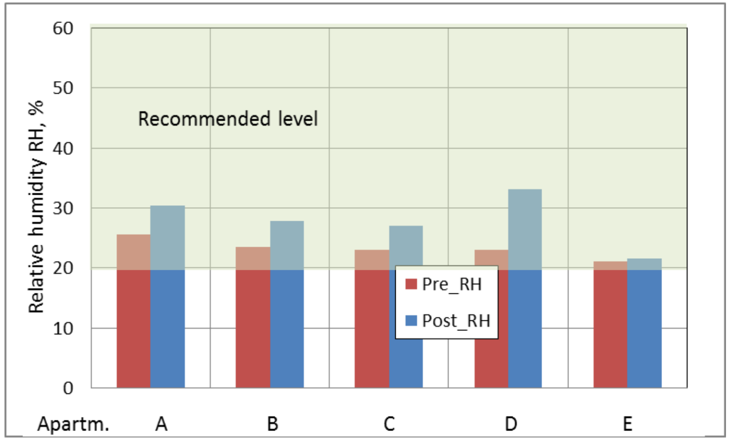
In the results "Pre" means result of measurement before repair and "Post" after repair.

Indoor temperature:



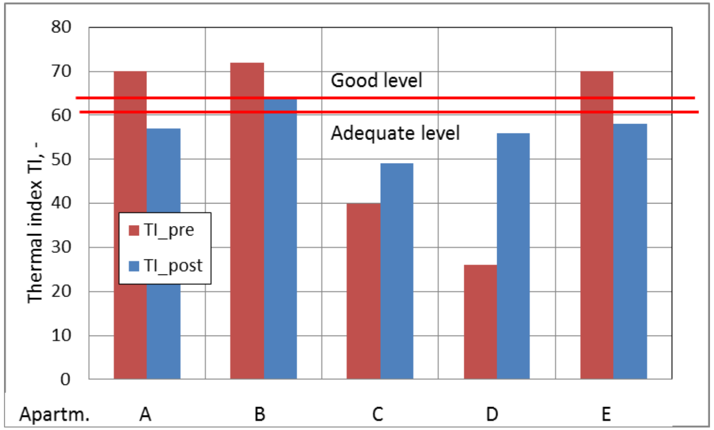
According to Finnish Housing Health Guidelines (2003) good indoor temperature is 21 °C and adequate is 18 °C. Indoor temperature should not exceed 23–24 °C during heating season.

Indoor relative humidity:

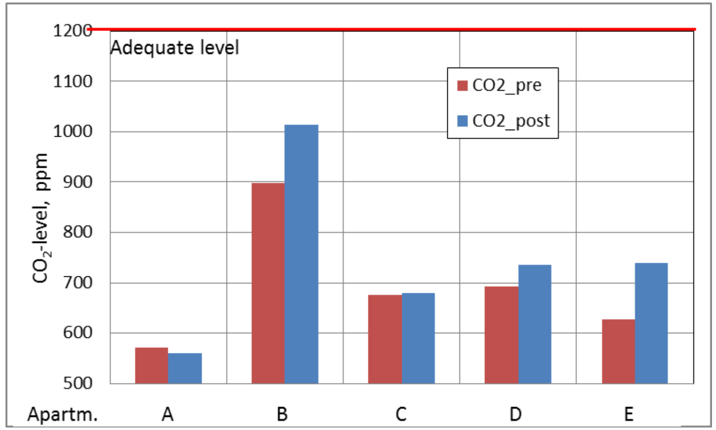


Indoor relative humidity should be approximately 20–60 %, but reaching that is not always possibility for example due to climatic reason. Exceeding of these values cannot be regarded as health hazard, if other indoor conditions are healthy.

Thermal Index:



Carbon dioxide, CO2:

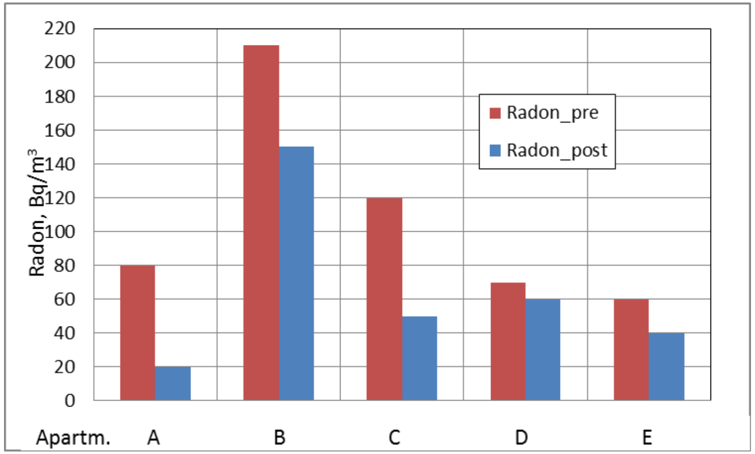


Thermal index illustrate coldest spot temperature of external wall surface. According to Finnish Housing Health Guidelines (2003) thermal index ≥ 61 is adequate and ≥ 65 is good.

Ventilation does not fulfill requirements of Health Protection Act, if indoor air level of carbon dioxide exceeds 1 500 ppm. Indoor air carbon dioxide level 1200 ppm can be considered adequate.

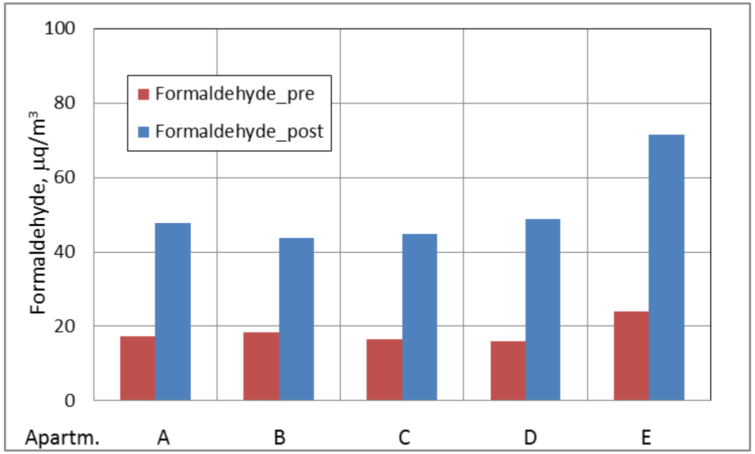
There was no carbon monoxide observed in any apartments within the detection limits.

Radon:



According to Finnish Housing Health Guidelines (2003) average-annual level of radon should not exceed 400 Bq/m3.

Formaldehyde:



Indoor air formaldehyde concentration should not exceed 100 μg/m3.

In addition to, levels of some other pollutants were measured, but these results are meant only for research use.

Thank you for participating in the project,

INSULAtE-project group

3. INSULAtE Report format 2.0

Indoor environmental quality assessment for [address], Apartment A Report 05-10-2015/1A

This report consists of results from assessment of indoor environmental quality (IEQ) parameters conducted using a protocol developed in INSULAtE –project*. For more information on how to interpret the results, visit www.insulateproject.eu.

Parameter [unit]	Result		Interpretation based on Housing health guidelines (2003), issued by the Finnish Ministry of Social Affairs and Health (available in Finnish at: http://pre20090115.stm.fi/pr1063357766490/passthru.pdf)
	Before retrofit	After retrofit	
T [^oC]	24	24	Good temperature (T) is 21 °C ja satisfactory temperature is 18 °C. When the heating is on, the indoor temperature should not exceed 23–24°C.
RH [%]	32	32	Relative humidity (RH) should be about 20–60% Deviations from these levels should not be regarded as a health risk if other health-related conditions in the dwelling are fulfilled.
TI	60	71	Thermal index (TI) is adequate at ≥61 and good at ≥65.
CO [ppm]	1543	1246	ventilation is not in compliance with the Finnish Health Protection Act if carbon dioxide (CO_2) concentration in indoor air exceeds 1500 ppm. Adequate CO_2 concentration is about 1200 ppm.
CO_2 [ppm]	0	0	Carbon monoxide (CO) concentration should not exceed 8 mg/m^3 (6.9 ppm).
Radon [Bq/m^3]	100	70	Annual mean radon concentration should not exceed 400 Bq/m^3.
CH_2O[µg/m^3]	22	21	Indoor formaldehyde (CH_2O) concentration should not exceed 100 µg/m^3.

Color codes

	T [^oC]	RH [%]	TI	CO_2 [ppm]	CO [ppm]	CH_2O [µg/m^3]	Radon [Bq/m^3]
Good	$18 \le T \le 21$	20–60	≥ 65	< 1 200		< 50	< 200
Satisfactory	$21 < T \le 24$		≥ 61	1 200-1 500		< 100	< 400
Poor	T < 18, T > 24			> 1 500	> 6.9		

Indoor environmental quality assessment for [address] Report 05-10-2015/1

	Before retrofit							After retrofit							Comments
Measurement	T	RH	TI	CO_2	CO	Radon	CH_2O	T	RH	TI	CO_2	CO	Radon	CH_2O	Measurement protocol: www.insulateproject.eu
A															
B								-	-	-	-	-	-	-	
C															
D															
Total	4	4	4	4	4	4	4	3	3	3	3	3	3	3	Rooms measured
Satisfactory N	2	4	2	3	4	4	4	1	3	2	3	3	3	3	
%	50	100	50	75	100	100	100	33	100	67	100	100	100	100	% Meeting recommended

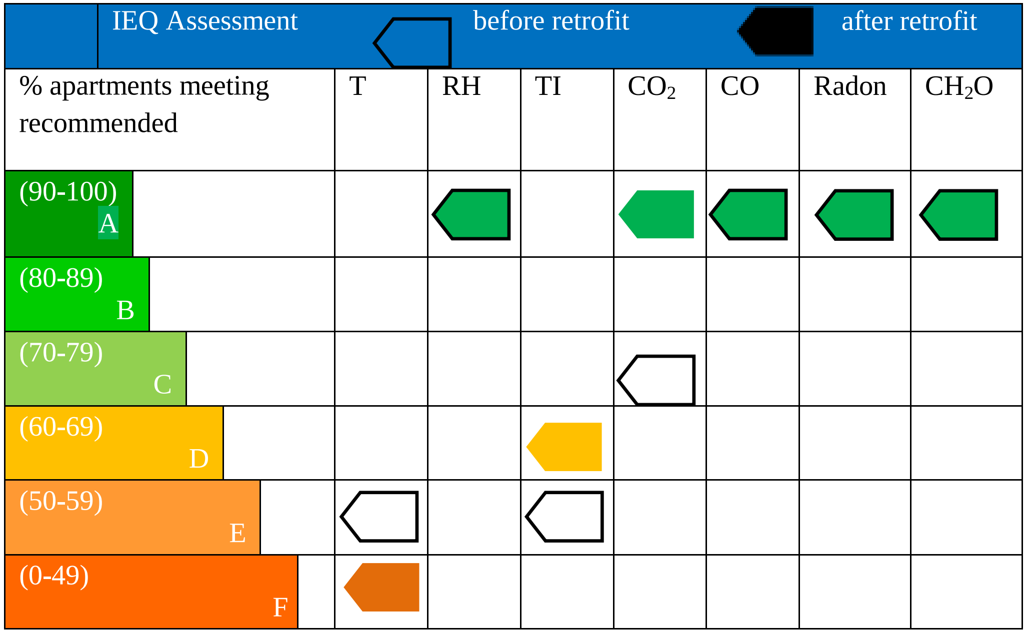
’F’: measurement failed; ’-’: not measured

Colour codes

	T [°C]	RH [%]	TI	CO_2 [ppm]	CO [ppm]	CH_2O [µg/m^3]	Radon [Bq/m^3]
Good	$18 \leq T \leq 21$	20–60	≥ 65	< 1 200		< 50	< 200
Satisfactory	$21 < T \leq 24$		≥ 61	1 200-1 500		< 100	< 400
Poor	T < 18, T > 24			> 1 500	> 6.9		

Indoor Environmental Quality, summary for [address] Report 05-10-2015/1

This report consists of results from assessment of indoor environmental quality (IEQ) parameters conducted using a protocol developed in INSULAtE –project*. For more information on how to interpret the results, visit www.insulateproject.eu.



Interpretation of the results is based on the following recommendations (Housing Health Guidelines 2003):

- During the heating season, indoor temperature (T) should not exceed 23–24 °C. Indoor temperature below 18 °C can cause adverse health effects.
- Relative humidity (RH) should be 20-60%. Occasionally the range cannot be reached due to climatic factors, which cannot be considered a health risk if other perquisites for healthy living conditions are met.
- An adequate level of thermal index (TI) is ≥ 61 and a good level is ≥ 65.
- In case carbon dioxide (CO_2) concentrations are exceeding 2 700 mg/m^3 (1 500 ppm), the ventilation has to be increased. (Satisfactory CO_2 level is 1 200 ppm.)
- Instantaneous carbon monoxide (CO) concentration should not exceed 6.9 ppm.
- An average-annual level of radon should not exceed 400 Bq/m3.
- Formaldehyde (CH_2O) concentration should not exceed 100 ug/m^3.

Administrative information:	*Technical information:*	*Notes:*
Address: Street x,	*Year constructed/renovated 19xx/2013*	
70xxx Kuopio Finland	*Mechanical exhaust*	
Number of apartments/rooms assessed:	*Total floor area x m2*	