Interim report

# Renovair

## Verkennend onderzoek naar de binnenmilieukwaliteit in gebouwen na (energie-efficiënte) renovaties

## Explorative study on the quality of the indoor environment in buildings after (energy-efficient) renovations

Final Report

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## UITGEBREIDE SAMENVATTING

De uitvoering en handhaving van de richtlijn voor energieprestatie van gebouwen (EPBD, 2010) heeft gezorgd voor de ontwikkeling van een beleid met maatregelen om het energieverbruik van gebouwen terug te dringen. Dit heeft echter ook geleid tot een aantal uitdagingen die moeten worden aangepakt, zoals de impact van de hoge energie-efficiëntie op de kwaliteit van het binnenklimaat in gebouwen, zonder afbreuk te doen aan het comfort, de gezondheid en de productiviteit van hun bewoners. Als gevolg daarvan, startte de Vlaamse overheid (LINE en VEA) in 2012 de Clean Air Low Energy studie op, waarin de binnenluchtkwaliteit in energie-efficiënte, nieuwbouw huizen en scholen werd bepaald en vergeleken met de meer traditionele gebouwen in deze regio. Hoewel de eindresultaten van dit onderzoek wezen op een neutraal, en in sommige gevallen positief effect op de binnenmilieukwaliteit (IAQ), bleek alsnog een aanzienlijk aantal gezondheidsklachten in Vlaanderen gerelateerd te zijn aan renovaties en verbouwingen van de binnenomgevingomgevingen (Huislabo AZG 2008-2015).

De Renovair studie werd opgestart in 2014, met als doel om de impact van energie-efficiënte renovaties op de binnenmilieukwaliteit in huizen en scholen te beoordelen, met inbegrip van maatregelen ter verbetering van het binnenmilieu. De volgende onderzoeksvragen werden geformuleerd:

- Beïnvloeden energiebesparende renovaties de binnenluchtkwaliteit en is er een relatie tussen de impact op de binnenluchtkwaliteit en de effectiviteit van een renovatie?
- Heeft de installatie van een hogere efficiëntie luchtfiltratie invloed op verkeersgerelateerde binnenluchtkwaliteit veroorzaakt?

De tweede doelstelling werd beoordeeld in een deelonderzoek van Renovair, gericht op het effect van de luchtfiltratie op het binnenmilieu van scholen. De resultaten van dit deelonderzoek zijn gerapporteerd "Verkennend onderzoek naar de kwaliteit van het binnenmilieu in gebouwen na (energiezuinige) renovaties; Air Filtration. Eindrapport, juli 2015", in het kader van JOAQUIN (www.joaquin.eu). De resultaten van Renovair hebben tot doel om gerichte aanbevelingen voor het beleid inzake energie-efficiënte renovaties en luchtfiltratie te formuleren. De bestudeerde gevallen in dit project zijn daarom zodanig geselecteerd dat de resultaten op relatief kleine schaal, kunnen worden geëxtrapoleerd naar de rest van Vlaanderen. Studiegebieden werden geselecteerd op voorwaarde dat zij representatief zijn voor de huidige en toekomstige trends van de Vlaamse gebouwenpatrimonium.

De Renovair studie werd opgestart met de volgende doelstellingen:

1) Het genereren van representatieve gegevens over het binnenmilieu voor- en na de uitvoering van energiebesparende renovaties, met als doel om de gevolgen van specifieke vernieuwingen op het binnenmilieu in kaart te brengen en de kritische aspecten of kennishiaten te identificeren;
2) Het genereren van gegevens over het binnenmilieu na de uitvoering van energiebesparende renovaties, om een database op te stellen die de binnenluchtkwaliteit in gerenoveerde gebouwen kan toetsen aan de deze van energie-efficiënte nieuwbouw woningen (Clean Air Low Energy, LNE 2013) en aan het gemiddelde binnenmilieu in een Vlaamse woning (Toezicht op de gezondheid van de klachtvrije woningen, AZG 2012).
3) Bestuderen welk hoe binnenmilieu-polluenten uitgestoten door specifieke bouwmaterialen, zich gedragen na verloop van tijd.
4) Het verzamelen van aandachtspunten om, binnen het kader van het renovatiepact 2015-2050 (waarbij de verhoging van de renovatiegraad van ons Vlaams woningpatrimonium en de

energieprestatie ervan geoptimaliseerd wordt tot het bijna-energieneutraal niveau), eveneens gezonde woningen te creëren.

Renovair is een pilootstudie, waarbij in een relatief kleine steekproef zowel chemische, microbiologische als fysieke kenmerken van de luchtdichtheid van het gebouw, de ventilatie en de oppervlaktetemperatuur bepaald worden. De auteurs zijn zich bewust van de beperkingen die er zijn bij dit onderzoeksopzet, waardoor resultaten statistisch beschouwd kunnen worden. In plaats daarvan worden de gegevens gerapporteerd en geanalyseerd op een beschrijvende manier. Een vooraf gedefinieerde set van selectiecriteria werd toegepast om gevallen te selecteren, die representatief zijn voor de huidige en toekomstige gebouwentrends en zo kunnen worden geëxtrapoleerd naar de rest van Vlaanderen.

De impact van energie-efficiënte renovaties op IAQ en de mogelijke relatie met de doeltreffendheid ervan, werden bestudeerd in 17 gebouwen, waarbinnen 7 verschillende 'renovatie-types' uitgevoerd werden. Alle renovatie-types, geselecteerd in Renovair, zijn representatief voor de energie-efficiënte maatregelen die het meest frequent uitgevoerd worden in de Vlaamse gebouwen (bijvoorbeeld aangemoedigd door de overheid door middel van financiële compensaties).

De bestudeerde renovaties zijn: vervanging van ramen, aanbrengen van vloerisolatie, muur-behandelingen tegen opstijgend vocht, de installatie van een mechanisch ventilatiesysteem, uitvoeren van gevelisolatie, vervangen van de luchtfilter, evenals grondigere energiebeparende renovaties, die bestaan uit een aantal van de hier opgesomde afzonderlijke renovatie-initiatieven bestaan. Per renovatie type werden ten minste twee gevallen (d.w.z. twee gebouwen) onderzocht, waarvan ten minste één geval zowel voor en na renovatie onderzocht werd.

Bij de karakterisering van het binnenmilieu werd kwaliteit van zowel de binnen- als de buitenlucht bepaald, en werd de hoeveelheid schimmels en bacteriën in stof bepaald. Daarnaast werden oppervlaktetemperaturen bepaald, en werden luchtdichtheid en ventilatiedebieten gemeten. Een grondig onderzoek naar het welzijn en het comfort van de bewoners van het gebouw, maakte ook deel uit van dit onderzoek. De metingen na de renovaties werden telkens pas 6 maanden na de renovatie uitgevoerd. Indien er werd vastgesteld dat er een risico was op een aanzienlijke of specifieke emissie uit gebruikte bouwmaterialen, dan werd er een specifieke IAQ beoordeling uitgevoerdéén week na de renovatie.

Algemeen kan opgemerkt worden dat in de binnenmilieus voornamelijk aldehyden (formaldehyde, acetaldehyde en in mindere mate de somparameter "andere aldehyden") in aanzienlijk hogere concentraties gemeten werden meer dan 6 maanden na de uitvoering van de energiebesparende renovaties. Deze bevinding geeft aan dat meer dan 6 maanden nadat de renovatie-activiteit plaatsvond, de emissies afkomstig van het gebruik van bouwmaterialen, nog steeds aanwezig zijn. De gemiddelde hoeveelheid vluchtige organische stoffen (VOS) binnenshuis bleek hoger in absolute concentraties, maar niet in binnen/buiten-verhoudingen en de gemiddelde $CO_2$ binnenshuis bleek vergelijkbaar vóór en na de renovaties, wat aangeeft dat er geen meetbare impact was op de algemene gebouwverluchting. In sommige individuele gevallen werd echter het tegenovergestelde gevonden.

Volgens een kleine een meer diepgaande kwalitatieve analyse van 4 Renovair cases met betrekking tot de bouwmateriaalkeuze, bleken voornamelijk TVOS en formaldehyde, en in mindere mate benzeen, in de binnenlucht toe te nemen naarmate minder initiatieven voor de selectie van lage-VOS emitterende bouwmaterialen genomen werden door de gebouwegenaar of architect.

Wat betreft binnenshuiscomfort, bleek een online bevraging van belangrijke indicatoren voor gezondheidsklachten gerelateerd aan het binnenmilieu, niet op een grote impact te wijzen. De energie-efficiënte renovaties beïnvloedden echter duidelijk de U-waarden (warmte-transfer coëfficiënten) van de onderzochte woningen op een positieve manier.

Voor de meeste van de onderzochte gebouwen, kan een relatie tussen binnenluchtkwaliteit en ventilatie karakteristieken (luchtdichtheid en luchtdebiet) worden opgemerkt. Ook bij deze energie-efficiënte renovaties worden hogere concentraties aan vluchtige organische stoffen (VOS) en $PM_{2.5}$ in de buitenlucht, weerspiegeld in het binnenmilieu. De installatie van meer geïsoleerde ramen beïnvloedde de binnenluchtkwaliteit of de luchtdichtheid van het gebouw niet en een type ventilatiesysteem A (natuurlijke ventilatie) leidde niet tot lagere $CO_2$ concentraties binnenshuis in vergelijking met een niet-geventileerde woning. De installatie van vloerisolatie leidde tot hogere TVOS en formaldehyde-concentraties na de renovatie, en verhoogde ook de vloertemperatuur met 3°C. Binnen een week na het installeren van de PUR vloerisolatie werden er sporen van dimethylbenzylamine -een katalysator voor schuimvorming- gedetecteerd in de woonkamer. Muurbehandelingen tegen opstijgend vocht bleken de VOS-concentraties binnenshuis (ten gevolge van verhoogde TVOS concentraties, sporen van epoxysilanen) te verhogen minder dan een week na de installatie ervan, en na een periode van 6 maanden werden opnieuw lagere concentraties gedetecteerd. In één van deze woningen bereikte TVOS een concentratieniveau dat volgens de “German Indoor Air Guide” gerangschikt is als “mag niet worden overschreden in kamers voor langdurig verblijf” (1-3 mg/m³), 6 maanden na de renovatie daalden de concentratie opnieuw tot niveaus, die door diezelfde instelling gecategoriseerd wordt als 'ideale omstandigheden'. Slechts in één van de twee onderzochte gevallen bleek het vocht in wanden verminderd te zijn. Onderzoek naar diepgaande renovaties illustreerde de impact van een onafgewerkte renovatie op het binnenmilieu ($PM_{2.5}$, TVOS en aldehyden). Er werd ook aangetoond dat in een aantal gevallen koudebruggen, die al aanwezig waren vóór de renovatie, nog steeds aanwezig zijn na de grondige renovatie, en dat onafgewerkte vernieuwingen (afwerking) de luchtdichtheid van het gebouw beïnvloeden. De installatie van een mechanisch ventilatiesysteem type D, leidde tot lagere $CO_2$-concentratie en een lagere relatieve vochtigheid in de woning. Ook de binnen / buiten-verhouding van $PM_{2.5}$ en TVOS bleken lager. Bij het vervangen van een bevuilde luchtfilter in een school, bleek geen van de gekwantificeerde luchtverontreinigende stoffen in deze studie te wijzigen in concentratie. Het luchtdebiet bleek wel te verhogen na installatie van de nieuwe filter. Mogelijk beïnvloedt het uitschakelen van het ventilatiesysteem, gecombineerd met de opening van de ramen tijdens de pauzes de binnenluchtkwaliteit in deze klaslokalen, zowel voor als na de filterwissel.

Op basis van deze indicatieve bevindingen, heeft de NAV aanvullende infobladen ontwikkeld met praktische richtlijnen voor professionals in de bouw. Deze fiches zullen worden toegevoegd aan de map 'Bouw Gezond'. De 3 nieuwe infobladen richten zich op de thema's: (1) Materialen, (2) Ventilatie en (3) Opdrachtgever. Bovendien hebben de resultaten van de studie geleid tot de formulering van de volgende beleidsaanbevelingen:

**Aanbevelingen voor het milieubeleid en andere entiteiten**

- Behandelingen tegen opstijgend vocht (zie fiche)

Een correcte installatie en gebruik van materialen tegen opstijgend vocht in muren beïnvloedt de luchtkwaliteit in een slechts tijdelijke en beperkte manier; een onjuiste installatie kan TVOS concentraties van enkele mg/m³ veroorzaken die het binnenmilieu maanden tot jaren kan beïnvloeden. Behandeling tegen opstijgend vocht zijn een vaak voorkomende renovatie en er is behoefte aan meer kennis over de technische achtergrond van dit probleem. Deze kennis zou het mogelijk maken om praktische richtlijnen te formuleren met als doel onjuiste installaties te voorkomen. Een karakterisering van de uitstoot bij verschillende installatie-wijzen van hetzelfde product in eenzelfde muur, kan hierbij waardevolle inzichten leveren.

Een technische keuring van de installatie (cfr. BUtgb) kan hierbij zinvol zijn, doch mogelijk praktisch niet haalbaar.

- Herstel van koudebruggen

Volgens de Renovair data, worden koudebruggen, aanwezig vóór de renovatie, in sommige gevallen meer uitgesproken aangetroffen na de renovatie. Een vergelijkbare bevinding werd gemeld in het Finse "Mould and Moisture programme". In een nieuw decreet (2016) van de Sociale Zaken en Volksgezondheid Ministerie in Finland biedt de overheid de mogelijkheid aan voor het uitvoeren van een professionele huisinspectie (een persoon die aangesteld met kwalificaties volgens de eisen van de overheid) in huizen met gezondheidsrisico's. Aan de hand daarvan worden aanbevelingen geformuleerd voor een geschikte renovatie, met het oog op het wegwerken van koudebruggen, in privéwoningen (http://uutiset.hometalkoot.fi/en/home.html).

- Onderhoud en ontwerp van ventilatiesystemen op school:
    - Standaard afmetingen van luchtfilters worden aanbevolen: de afmetingen van bepaalde ventilatiesystemen wijken af van de standaardimensies, hierdoor blijven deze filters duurder te zijn in gebruik. Dit beïnvloedt niet alleen de onderhoudskosten van het ventilatiesysteem, maar het beperkt ook het aanbod van filterleveranciers tot de leverancier van het ventilatiesysteem (niet alle leveranciers bieden filterafmetingen die afwijken van de norm.
    - Een schatting van de onderhoudskosten voor mechanische ventilatie als criterium bij aanbestedingen: de geschatte kosten van nieuwe filters (van de benodigde afmetingen), eventuele reiniging/onderhoud van ventilatiekanalen of warmterecuperatiesysteem, en de kosten van de technische ondersteuning moeten beschouwd worden als een doorslaggevend evaluatiecriterium tijdens de ontwerpfase van een schoolgebouw. Uit Renovair bleek dat de meeste scholen beperkt of zelfs niet bewust zijn van de handelingen die nodig zijn voor een goed onderhoud van het ventilatiesysteem en de mogelijke kosten ervan.
    - Een basisopleiding in 'Onderhoud ventilatiesysteem' voor een aantal medewerkers van een school wanneer een schoolgebouw in gebruik wordt genomen. Daarbij wordt de werking en het onderhoud van een ventilatiesysteem aangeleerd. Een eenvoudige en gemakkelijk toegankelijk instructie over 'Onderhoud ventilatiesysteem' kan nuttig zijn (in het algemeen is het 'As Built'-dossier is te uitgebreid en te technisch om een eenvoudig gebruik door medewerkers van de school mogelijk te maken).
    - Er is behoefte aan meer kennis en een duidelijke communicatie over hoe en wanneer een grondige reiniging van een mechanisch ventilatiesysteem (met inbegrip van warmte-recuperatie en ventilatiekanalen) wordt aanbevolen. Er is de noodzaak om op een objectieve manier te definiëren wat aanvaardbaar is en wat niet. De beschikbare wetenschappelijke literatuur bevat tegenstrijdige informatie over de effectiviteit van reiniging van de leidingen (Zuraimi, 2010). Reinigingsspecialisten schatten de hoeveelheid stof in (uitgedrukt in $g/m^2$) op basis van een visueel onderzoek, rekening houdend met de verschillende erkende methodes. Deze methodes kunnen echter aanleiding geven tot afwijkende resultaten en conclusies, zoals beschreven door Lavoie et al. 2011. Op basis van deze schatting wordt vervolgens aangeraden of het reinigen van de leidingen nodig is.
- Het gebruik van grofstof filters (G-type) in combinatie met fijne filters (F-type)
    - Alle scholen die in aanmerking voor Renovair bleken F-type filtratie te gebruiken, zonder voorfiltratie door middel van een G-type (grof stoffilter). G-type filters zijn aanzienlijk

goedkoper dan F-type filters. Het gebruik van een G-type filter voor voorfiltratie van grotere deeltjes (zoals pollen) zou verstopping van de F-type filter kunnen beperken en zal de drukval kunnen verminderen, hierdoor zal het energieverbruik van het ventilatiesysteem dalen en zal ook de levensduur van de filter verhogen.

- Het ontwerp van ventilatiesystemen:
  - Ingenieurs wordt aanbevolen om ventilatiesystemen te ontwikkelen die relatief eenvoudig onderhouden kunnen worden, wat ook inhoudt dat de technische ruimtes gemakkelijk toegankelijk zouden moeten zijn. In het bijzonder voor scholen, is dit van groot belang.
  - Isolatie van muren, gevels, vloeren en ramen kunnen aanzienlijke invloed hebben op de luchtdichtheid van gebouwen en hebben dus een invloed op de binnenluchtkwaliteit. De gebruikers van het gebouw moeten worden geïnformeerd over de gevolgen en de noodzaak van de aanpassing van hun ventilatiegedrag aan de nieuwe omstandigheden.
- initiatieven voor het selecteren van lage VOS-emissie materialen leiden tot een directe verbetering van de binnenluchtkwaliteit.

**Aanbevelingen met betrekking tot de relatie tussen binnen- en buitenmilieu (luchtfiltratie)**

- Zowel de F7- en F9-luchtfilters leiden tot een aanzienlijke vermindering van buiten luchtvervuiling binnenshuis, en worden beiden aanbevolen voor gebruik.
- De efficiëntie van F9-luchtfiltratie bleek significant beter voor $PM_{2.5}$, $PM_1$ en deeltjes <0,3 µm, 'black carbon' en ultrafijn stof. Echter, wanneer het regressiemodel ingevuld wordt met realistische concentratieniveaus voor de buitenlucht, blijkt het verschil tussen de geschatte binnenluchtconcentratie minder dan 1 µg/m³ voor $PM_1$ (bijvoorbeeld bij een hypothetische buitenconcentratie van 20 µg/m³ $PM_1$ zou de berekende concentratie in een klaslokaal 3,92 µg/m³ bedragen met F7-luchtfiltratie en 2,35 µg/m³ met F9).
- De effectiviteit van F9-luchtfiltersysteem is het meest uitgesproken voor $PM_{2.5}$, de reductie van buitenconcentraties binnenshuis zijn kleiner voor 'black carbon' en UFP: voorspelde indoor UFP bij F9 vs. F7 in vergelijking met buitenlucht UFP (-79% vs -69 %), BC (-65% vs -49%) en verschillende PM fracties (bijv $PM_{2.5}$ -87% vs -82%)
- Luchtfiltratie op school is het minst doeltreffend voor $PM_{10}$ en TSP, omdat het voorkomen in de klas voornamelijk het gevolg is van opwaaiend stof. Grondig poetsen kan $PM_{10}$ en TSP in klaslokalen reduceren.
- Het gebruik van een G-type filter voor voorfiltratie van grove deeltjes zou verstopping van het F-type filter met grof materiaal kunnen beperken, het kan de drukval verminderen, waardoor het energieverbruik van het ventilatiesysteem vermindert en de levensduur verlengd wordt.
- Er is behoefte aan meer kennis over de doeltreffendheid van luchtfilters met actieve kool om de blootstelling aan verkeersgerelateerde gassen in het binnenmilieu te verminderen - de monstergrootte van Renovair was te klein om doorslaggevende aanbevelingen te formuleren rond dit aspect.

  Belangrijke te onderzoeken aspecten: Wanneer is de actieve kool verzadigd? Welke buitenconcentratie kan beschouwd worden als grenswaarden of beslissingsboom voor de installatie van luchtzuivering door middel van actieve kool? Is het corrigerende effect vergelijkbaar met het plaatsen van de luchttoevoer op een afstand van de verkeersemissies? Beïnvloeden verschillende mogelijke installaties de effectiviteit?
- Er is behoefte aan objectieve aanbevelingen over luchtfiltratie voor scholen op hotspot-locaties. Er is nood aan een definitie van 'wanneer' er behoefte is aan luchtfiltratie. Welk type van de luchtfiltratie is aan te bevelen? Een studie, met een gelijktijdige evaluatie en

vergelijking van het effect van actieve luchtreiniging (met F7, F9 of F7 + actieve kool) op het voorkomen van verkeersgerelateerde luchtvervuiling binnen is nodig. Het is hierbij belangrijk dat de klaslokalen een gelijkaardige inrichting hebben, met vergelijkbare bronnen en de daaruit voortvloeiende IAQ, met hetzelfde ventilatiesysteem en luchttoevoer. Het is wel noodzakelijk dat elk klaslokaal dan een afzonderlijke luchttoevoer heeft om zo een gerichte vergelijking en objectieve beoordeling mogelijk maken.

**Aanbevelingen met betrekking tot de gevolgen van renovaties**

- Muur behandelingen tegen opstijgend vocht

Zie ‘Aanbevelingen voor het milieubeleid en andere entiteiten’

- Herstel van koudebruggen

Volgens de Renovair gegevens, worden koudebruggen aanwezig vóór de renovatie in sommige gevallen meer uitgesproken teruggevonden na de renovatie.

De luchtdichtheid rond de schrijnwerkerij in gevels werd benadrukt als een belangrijk aspect bij renovaties. Oudere voordeuren en garages toonden warmteverliezen rond de frames. Het is belangrijk om de algemene kennis hierrond bij verbouwers te verhogen (bijvoorbeeld door het aspect op te nemen in subsidies of door verplichte follow-up van renovatie-planning door een deskundige). Een vergelijkbare bevinding werd gemeld in het Finse ‘Mould and Moisture programme’. In een nieuw decreet (REF) van de Sociale Zaken en Volksgezondheid Ministerie in Finland biedt de overheid de mogelijkheid voor het uitvoeren van een professionele woninginspectie (persoon aangesteld met kwalificaties die vastgelegd worden door de overheid) in huizen met gezondheidsrisico’s. Aan de hand daarvan worden aanbevelingen geformuleerd voor een geschikte renovatie van de privéwoning.

(http://uutiset.hometalkoot.fi/en/home.html) .

- Doorgedreven initiatieven voor het selecteren van lage VOS-emissiematerialen leiden tot een directe verbetering van de binnenluchtkwaliteit wat betreft VOS en formaldehyde. Er is behoefte aan richtlijnen en hulpmiddelen voor het bouwprofessionelen en burgers voor het selecteren van lage VOS-emitterende bouwmaterialen. De tabel voor bouwmateriaal selectie in de map 'Bouw Gezond' voor bouwprofessionals, is hierbij een zeer nuttig hulpmiddel. Echter, regelmatige updates van deze tool zijn nodig, omdat productemissies en product labels een toenemende marketingwaarde hebben en het gebruik ervan door fabrikanten groeit snel.
- De beperkte bereidheid van installateurs, aannemers, architecten of eigenaars van gebouwen om mee te werken aan het Renovair onderzoek naar de installatie van PU-isolatieschuim, heeft mogelijk te maken met een soort van angst onder de gebruikers. Deze bevinding kan ook wijzen op een behoefte aan transparante en betrouwbare informatie en communicatie over mogelijke risico's, maar ook over de voordelen van de installatie.
- Op basis van literatuuronderzoek van WP1, kunnen de risico's die samenhangen met een combinatie van renovaties worden beperkt door het opnemen van toekomstige renovatiefasen in de technische uitvoering van eerdere renovatie. Bijvoorbeeld voor muurisolatie en vervanging van ramen, wordt dit principe al in het subsidiebeleid geïntegreerd (door het verstrekken van grotere subsidies wanneer beide interventies worden uitgevoerd binnen 12 maanden na elkaar). Een uitbreiding van dit principe (bijv. Combinatie van isolatiemaatregelen met het installeren van een ventilatiesysteem), en ook meer uitgebreide technische vereisten voor het ontvangen van subsidies kunnen een interessante stimulans zijn om de kwaliteit van toekomstige renovatieprojecten te verhogen.
- De comfortbevraging die uitgevoerd werd in Renovair, duidde op een lichte verlaging van de gezondheidsklachten, en minder symptomen na de energie-efficiente renovaties. Door het

relatief klein aantal respondenten in Renovair, kon geen significant effect vastgesteld worden. Echter, het uitbreiden van het aantal respondenten tot bijvoorbeeld particulieren die de overheidssubsidie voor energie-efficiënt renoveren aanvragen, zou een statistische analyse van de gevevens toelaten.

## EXTENDED SUMMARY


The implementation and enforcement of the Energy Performance of Buildings Directive (EPBD, 2010) has introduced the development of policies and measures to reduce the energy use of buildings. This has however also led to a number of challenges that need to be addressed, in terms of the impact of high energy performance of the quality of the indoor climate of buildings, without compromising the comfort, health and productivity of their occupants. As a consequence, the Flemish government (LNE and VEA) have initiated in 2012 the Clean Air Low Energy study, in which the Indoor Air quality (IAQ) of energy-efficient, new built houses and schools was assessed and compared to the more traditional building stock in this region. Even though the outcomes of this study indicated a neutral, in some cases even positive effect on the indoor environmental quality (IEQ), a considerable number of IAQ related health complaints in Flanders was found to be related to renovations and refurbishments of indoor environments (…., AZG 2012).

The Renovair study was initiated in 2014, in order to assess the impact of energy-efficient renovations on the IEQ of houses and schools in Flanders, including measures to improve the indoor environment. The following research questions were formulated:

- Do Energy efficiënt renovations affect IAQ and is there any relation between the impact on IAQ and the effectiveness of a renovation?
- Does the installation of higher efficientcy air filtration affect the IAQ caused by vehicular emissions?

The second objective was assessed in one particular part of Renovair, focussed on the effect of air filtration on the indoor environment in schools. The outcomes of this part of the project have been reported in 'Explorative study on the quality of the indoor environment in buildings after (energy-efficient) renovations; Air Filtration. Final Report, July 2015', in the context of JOAQUIN (www.joaquin.eu). Outcomes of Renovair are intended to lead to targetted policy recommendations on energy-efficient renovations and air filtration. The cases studied in this project have been selected in such a way that the outcomes, which are obtained on a relatively small scale, can be extrapolated to the rest of Flanders. Sites were selected on condition that they are representative for current and future trends of the Flemish building stock.

The Renovair study was initated with the following objectives:

1) Generating representative data for Flanders on indoor environments pre and post energy-efficient renovations, in order to explore the impact of specific renovations on the indoor environment, identify critical aspects and knowledge gaps;
2) Generating data on indoor environments post energy-efficient renovations, in order to create a database on the IEQ in renovated buildings that can then be evaluated against indoor environments of newly built energy-efficient buildings (the Clean Air Low Energy Study, LNE 2013) as well as the average Flemish indoor environment in a dwelling (Surveillance of health complaint-free houses, AZG 2012).
3) Exploring the impact of time on the decay of indoor pollutants after the use of new, specific building materials

Renovair is a pilot study, in which a relatively small sample size is characterised very deeply, chemically, microbiologically, physically as well as in terms of the building enveloppe's air tightness, ventilation and surface termperature. The authors are aware of limitations that are related to this study design, which includes the fact that none of the study outcomes' significance can be assessed. Instead, the data are reported and analysed in a descriptive way. A pre-defined set of selection criteria was applied in order to select cases, that are representative for the current and future building trends, and can be extrapolated to the rest of Flanders.

The impact of energy-efficiënt renovations on IEQ and the potential relation with its effectiveness, were studied in 17 indoor locations, where 7 different renovation types were executed. All renovation types selected for Renovair, are representative energy-efficient measures in the Flemish building stock (e.g. encouraged by the government by means of financial compensations).

The studied renovations include: window upgrades, floor insulation, wall treatments against rising damp, the installation of a mechanical ventilation system, façade insulations, air filter replacements as well as initiatives of more thorough energy-efficiënt renovations, which consist of several of the individual renovation initiatives. For each renovation type, at least two cases (i.e. two buildings) were studied, of which at least one case was studied pre and post renovation.

The IEQ assessment included an IAQ assessment indoors as well as outdoors, a study of the microbial content of settled dust, a study of surface temperatures, an assessment of air tightness and ventilation rates, and a thorough survey on indoor well-being and comfort of building occupants. Post renovation assessments took only place 6 months after the renovations. In case a risk for a considerable or a specific emission from used building materials was assumed, a dedicated IAQ assessment was organised within one week after the renovation.

In general mainly indoor aldehydes (formaldehyde, acetaldehydes and to a lesser extent the sum parameter other aldehydes) were found in considerably higher indoor levels more than 6 months after the renovation activity took place. This finding indicates that more than 6 months after the renovation activity took place, emissions originating from the indoor use of building materials are still present indoors. Average indoor TVOC was found to be higher in absolute concentrations, but not in I/O ratios and average indoor $CO_2$ was found to be similar before and after the renovations, indicating no measurable deterioration of building ventilation. In some individual cases however, the opposite was found. According to a small qualitative study of 4 Renovair cases on building material selection, mainly indoor TVOC and formaldehyde, and to a lesser extent indoor benzene, were found to increase with decreasing amount of initiatives for selecting low VOC-emitting building materials. In terms of indoor comfort, the administration of an auto questionnaire to assess the impact of known important predictors on the outcome of health complaints due to presence in an indoor environment is not suggestive of a large impact of the renovation status. The energy-efficient renovations clearly affected the U-values (heath transfer coefficients) of the studied houses in a positive way.

For most of the studied cases, a relation between IAQ and ventilation characteristics (air tightness and ventilation rate) can be noticed in the Renovair dataset. Outdoor levels of volatile organic compounds (VOCs) and $PM_{2.5}$ are reflected in the corresponding indoor concentration. The installation of more insulated windows didn't affect the IAQ, or the building air tightness, and a ventilation system type A (natural ventilation) didn't lead to reduced indoor $CO_2$ levels compared to a non-mechanically ventilated house. The installation of floor insulation led to increased TVOC and formaldehyde levels post renovation, but also raised the floor temperature with 3°C. Within a week after installing the PUR floor insulations traces of dimethylbenzylamine, a catalyst for foam formation, were detected in the living room. Wall treatment against rising damp was found to affect indoor VOCs (increased TVOC level, traces of epoxy silanes) at differing levels less than a week after the installation and was found at reduced indoor levels again 6 months after the installation. In one house TVOC concentration levels reached a level that is ranked according to the German Indoor Air Guide values as 'should not be exceeded in rooms for long-term residence' (1-3 mg/m³), 6 months after the renovation the concentration levels decreased until levels, classified by the same institution as 'ideal conditions'. Only in one of the two studied cases moisture in walls was found to be decreased. Studied thorough renovations demonstrated the impact of unfinished renovation initiatives in IAQ (PM2.5, TVOC and aldehydes). It was found in some cases that cold spots present before the renovation, were still present after the thorough renovation and unfinished renovations (finishing works) also affected air tightness of the building. The installation of a mechanical ventilation system type D, led to reduced indoor $CO_2$ and relative humidity after the renovation; also the indoor/outdoor ratio of $PM_{2.5}$ and TVOC were found to be reduced. When replacing a contaminated air filter in a school, none of the quantified air pollutants in Renovair was found to be deteriorated before and after the intervention. The ventilation rate was found to be increased with the new filter, and possibly the impact of shutting down the ventilation system and opening of windows during breaks impacted on the IAQ.

Based on the indicative findings that were reported in Renovair, the Flemish Architect's Council has formulated additional data sheets with practical guidance for building professionals, that can be added to the 'Bouw Gezond' map. The 3 new data sheets focus on the topics: (1) Materials, (2) Ventilation and (3) Client. Furthermore, the study outcomes led to the formulation of the following policy recommendations:

#### RECOMMENDATIONS FOR ENVIRONMENTAL POLICY AND OTHER ENTITIES

- Wall treatments against rising damp

  A correct installation and use of materials against rising damp in walls affects the indoor air quality in an only temporary and limited way; an incorrect installation may cause indoor TVOC levels of several mg/m³, and affects the indoor environment in an adverse way during several months to years. Treatments against rising damp are a very common a renovation type and there is a need for more knowledge about the technical background of this issue. This knowledge would then allow the formulation of practical guidelines to prevent incorrect installations. A characterisation of emissions from different application modes of the same product in the same wall, can contribute to the understanding of this aspect.

  - A technical approval of the installation (cfr. BUtgb) could be useful.

- Repair of cold bridges

  According to the Renovair data, cold bridges present before the renovation are found to be more pronounced post renovation in some cases. A similar finding was reported in the Finland 'Mould and Moisture programme'. In a new Decree (REF) set by the Social Affairs and Health Ministry in Finland, the government offers the possibility for a professional house inspection (person with qualifications according to requirements set by the government) in houses with health hazards, who formulates recommendations for a suitable renovation of the private dwelling (http://uutiset.hometalkoot.fi/en/home.html) .

- Maintenance of ventilation systems at school

  - Standard dimensions of air filters are recommended: ventilation system brands may use dimensions that differ from standard dimensions, which are found to be more expensive. This not only affects the maintenance costs of the ventilation system, it also limits purchasing filters at different suppliers (not all suppliers offer filter dimensions different from the standard ones).

  - An estimate of the maintenance costs for mechanical ventilation as a criterion in calls for tenders: the estimated cost of new filters (of the needed dimensions), possible cleaning of ventilation ducts or heat recovery system as well as the cost of technical support should be considered as a decisive criterion in the design phase of a school building. Renovair revealed that most schools are only limited or even not aware of the actions that are needed for a correct maintenance of the ventilation system and the possible costs that would imply.

  - A basic training in 'ventilation system maintenance' for several staff members of a school is recommended when a school building is taken into use. Doing so, knowledge about the operation and maintenance of a ventilation system will maintain in the school. A basic and easily accessible instruction on 'ventilation system maintenance' can be useful (in general, the As Built file is too extensive and too technical to allow an easy use by school staff).

- There is a need for more knowledge and a clear communication on how and when a thorough cleaning of a mechanical ventilation system (including heat exchange and ventilation ducts) is recommended. There is a need to define in an objective way what is acceptable and what is not. In open literature contradictory information about the effectiveness of duct cleaning can be found (Zuraimi, 2010). Professional cleaners estimate the amount of dust (expressed in g/m²) based on a visual inspection with respect to the various recognized methods, that may have variable outcomes as reported by Lavoie et al. 2011. Based on this estimation it is then recommend whether duct cleaning is needed.

- The use of coarse filters (G-type) in combination with fine filters (F-type)
    - All schools that have been considered for Renovair used F-type filtration, without pre-filtration by means of a G-type (coarse dust filter). G-type filters are considerably less costly than F-type filters. The use of a G-type filter for pre-filtration of coarse particles would limit clogging of the F-type filter with coarse material, would reduce the pressure drop, would therefore reduce the energy consumption of the ventilation system and would also increase the life span of the filter.
    - The design of ventilation systems:

      Engineers are recommended to design ventilation systems that are relatively easily accessible for maintenance, which also implies easily accessible technical rooms. Especially for schools, this should be an item of considerable importance.

- Subsequent insulations of walls, façades, floors and windows may considerably affect the building's air tightness, and therefore affect the IAQ. Building users should be informed about the consequences and the need for adapting their ventilation behaviour to the new circumstances.

- Thorough initiatives for selecting low VOC emission materials lead to a direct improvement of the IAQ.

#### Recommendations on the relation between indoor and outdoor environment (air filtration)

- Both F7 and F9 air filtration lead to a considerable reduction of outdoor air pollutants indoors, and are both recommended to be used.

- The efficiency of F9 air filtration was found to be significantly better for $PM_{2.5}$, $PM_1$ and particles < 0.3 µm, black carbon and UFP. However, recalculated to representative air concentrations, the difference between the estimated resulting indoor air concentration is less than 1 µg/m³ for $PM_1$ (e.g. a hypothetical outdoor $PM_1$ concentration of 20 µg/m³ would e.g. lead to indoor levels of 3.92 µg/m³ with F7 air filtration and 2.35 µg/m³ with F9).

- The effectiveness of F9 air filtration is most pronounced for $PM_{2.5}$, reduction of the outdoor levels indoors are smaller for black carbon and UFP: predicted indoor levels for F9 vs. F7 compared to outdoors for UFP (-79% vs. -69%), BC (-65% vs. -49%) and various PM fractions (e.g. $PM_{2.5}$ -87% vs. -82%)

- Air filtration is least effective for $PM_{10}$ and TSP, because their indoor occurrence mainly results from resuspendation of settled dust. Cleaning can lower indoor $PM_{10}$ and TSP.
  - The use of a G-type filter for pre-filtration of coarse particles would limit clogging of the F-type filter with coarse material, would reduce the pressure drop, would therefore reduce the energy use of the ventilation system and would increase the life span of the filter.
- There is a need for more knowledge about the effectiveness of activated charcoal air filters to reduce indoor exposure to traffic related gaseous compounds - the sample size of Renovair was too small to formulate decisive recommendations on this aspect. Important parameters to be studied: When is the activated charcoal saturated? Which outdoor concentration can be considered as a threshold to recommend air cleaning by means of activated charcoal? Is the remedial impact comparable to placing the air intake at a distance from traffic sources? Do different set-ups affect the effectiveness in a different way?
- There is a need for objective recommendations about air filtration for schools at hotspot locations. There is a need to define 'when' there is a need for air filtration? Which type of air filtration is recommended? A dedicated study, with a simultaneous evaluation and comparison the impact of active air cleaning (using F7, F9 or F7+ activated charcoal), on the indoor occurrence of traffic related air pollution indoors is needed to assess this information. The most important aspect would here be that the rooms have a similar set-up, with comparable sources and resulting IAQ, have the same ventilation system and air flow, but have a separate air intake which would allow a targeted comparison and evaluation.

#### RECOMMENDATIONS ON THE IMPACT OF RENOVATIONS

- Wall treatments against rising damp

  A correct installation and use of materials against rising damp in walls affects the indoor air quality only in a temporary and limited way; an incorrect installation may cause indoor TVOC levels of several mg/m³, and affects the indoor environment in an adverse way during several months to years. Treatments against rising damp are a very common a renovation type and there is a need for more knowledge on the technical background of this issue. This knowledge would then allow the formulation of practical guidelines to prevent incorrect installations.

  - A technical approval of the installation (cfr. BUtgb) could be useful.

- Repair of cold bridges

  According to the Renovair data, cold bridges present before the renovation are in some cases found to be more pronounced post renovation. The air tightness around the joinery in the façades was a point of particular interest in the thorough renovation cases. Older front doors and garages clearly showed heat losses around the frames. The awareness for this phenomenon could be raised (e.g. by incorporating it in subsidies or by mandatory follow-up of renovation planning by an expert). A similar finding was reported in the Finland 'Mould and Moisture programme'. In a new Decree (REF) set by the Social Affairs and Health Ministry in Finland, the government offers the possibility for a professional house inspection (person with qualifications according to requirements set by the government) in houses with health hazards, who formulates recommendations for a suitable renovation of the private dwelling (http://uutiset.hometalkoot.fi/en/home.html) .

- Thorough initiatives for selecting low VOC emission materials lead to a direct improvement of the IAQ in terms of indoor TVOC and formaldehyde. There is a need for guidelines and tools for building professionals and citizens for selecting low VOC-emitting building materials. The table for building material selection in the map 'Bouw Gezond' for building professionals is a very useful tool in this context. However, regular updates of this tool are needed, because product emissions and product labels have an increasing marketing value and their use by product manufacturers is expanding rapidly.
- The limited willingness of installers, contractors, architects or building owners to allow an air quality assessment after installing PU insulation foam that was experienced in Renovair, might indicate some kind of anxiety amongst users. This finding might therefore indicate a need for transparent and reliable information and communication on potential risks but also on the benefits of the installation.
- Based on literature review from WP1, the risks associated with combination renovations can be limited by incorporating future renovation phases in the technical execution of earlier renovation. For example for wall insulation and replacing windows, this principle is already integrated in the subsidies policy (by providing larger subsidies when both interventions are executed within 12 months from each other). An extension of this principle (e.g. combination of insulation measures with installing a ventilation system) as well as more elaborate technical requirements for receiving subsidies could be interesting to increase the quality of future renovation projects.
- The small scale survey on health and comfort indicated a slight improvement in health complaints, and a lower expected symptom score after the energy-efficient renovations. Because of relatively small number of respondents, no significant effect could he registered. By expanding the number of respondents to e.g. citizens who request a (partial) refunding of their renovation expenses from the government, would allow a statistical analysis of the dataset.

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| | |
|---|---|
| VOCs | Volatile Organic Compounds |
| IAQ | Indoor Air Quality |
| TVOC | Total Volatile Organic Compounds |
| PM | Particulate Matter |
| EPB | Energy Performance of Buildings |
| HVAC | Heating, Ventilation and Air Conditioning |
| BUTGB | Belgische Unie voor de technische goedkeuring in de bouw |
| IEQ | Indoor Environmental Quality |

# CHAPTER 1 INTRODUCTION

The overall objective of this project, as described in the project proposal, concerns an explorative study of the indoor air quality in buildings (residences and schools), that have been subjected to energy-efficient renovations, including measures to improve the indoor environment. One specific part of the project aimed at assessing the impact of air filtration on the indoor environment in schools. The outcomes of this part of the project have been reported in 'Explorative study on the quality of the indoor environment in buildings after (energy-efficient) renovations; Air Filtration. Final Report, July 2015', in the context of JOAQUIN (www.joaquin.eu).

Results and conclusions of the here reported exploratory research on the impact of energy-efficient renovations on the indoor environment, are intended to lead to targetted policy recommendations on energy-efficient renovations and air filtration. The cases studied in this project have been selected in such a way that the outcomes, which are obtained on a relatively small scale, can be extrapolated to the rest of Flanders. Sites were selected on condition that they are representative for current and future trends of the Flemish building stock. For the execution of the air filtration part of the study, a maximum agreement with objectives will be respected, because of its integration in this study.

This report of 'Work Package 3' aims at processing, reporting and interpreting the study results with respect to its initial objectives.

## 1.1. THE RENOVAIR DATABASE

The Renovair database is build-up with the intention of:

4) Generating representative data for Flanders on indoor environments pre and post energy-efficient renovations, in order to explore the impact of specific renovations on the indoor environment.
5) Generating data on indoor environments post energy-efficient renovations, in order to create a database on the Indoor Environmental Quality (IEQ) in renovated buildings that can then be evaluated against indoor environments of newly built energy-efficient buildings (the Clean Air Low Energy Study, LNE 2013) as well as the average Flemisch indoor environment in a dwelling (Surveillance of health complaint-free houses, AZG 2012).
6) Exploring the impact of time on the decay of indoor pollutants after the use of new, specific building materials

Table 1 shows an overview of the 17 studied renovations, indicating whether the indoor environmental characterisation of the Renovair study took place post renovation or pre as well as post renovation. Cases with measurements within less than 6 months after the renovation are indicated as well. The table also classifies the different studied renovation cases into 'renovation types', which are then characterised by similar energy-efifcient renovation objectives. The renovation types are assigned by the letters A to G. The following data analysis will respect this classification.

*Table 1 Overview of the studied renovations, before and/or after renovation activities*

| ***Type of renovation*** | ***No.*** | ***Renovation activity*** | ***pre renovation*** | ***< 6 months*** | ***post renovation*** |
|---|---|---|---|---|---|
| A | 1 | Upgrade windows – case 1 | X | | X |
| A | 2 | Upgrade windows – case 2 | | | X |
| B | 3 | Floor insulation – case 1 | X | X | X |
| B | 4 | Floor insulation – case 2 | X | | X |
| C | 5 | Rising damp – case 1 | X | X | X |
| C | 6 | Rising damp – case 2 | X | X | X |
| D | 7 | Combi/thorough – case 1 | | | X |
| D | 8 | Combi/thorough – case 2 | | | X |
| D | 9 | Combi/thorough – case 3 | | | X |
| D | 10 | Combi/thorough – case 4 | | | X |
| D | 11 | Combi/thorough – case 5 | X | | X |
| E | 12 | Mechanical ventilation – case 1 | X | | X |
| E | 13 | Mechanical ventilation – case 2 | X | | X |
| F | 14 | Air filter replacement – case 1 | X | X | |
| F | 15 | Air filter replacement – case 2 | X | X | |
| G | 16 | Façade insulation – case 1 | X | | X |
| G | 17 | Façade insulation – case 2 | | | X |

## 1.2. Strategy for data analysis

The data-analysis will consist of two evaluations:

### 1.2.1. General evaluation of the impact of renovations on indoor environmental parameters

The use of (new) building materials when performing energy-efficient building renovations, and the changes that it induces on building ventilation, insulation and air tightness, may considerably impact on the indoor environment.

In this overall data analysis, environmental parameters collected pre and post the different types of all renovations that were studied in this project, are compared and evaluated in order to assess any impact on the indoor environment, that can be related to the activity of energy-efficient renovations in general. The main focus of this descriptive analysis is put on indoor chemical, microbiological parameters, as well as indoor comfort.

This analysis will be described in CHAPTER 2.

### 1.2.2. Evaluation of the effectiveness and impact of specific renovations on the indoor environment

Each energy-efficient renovation induces the use of specific building materials, at specific places inside or outside the building. The impact on the indoor environment may therefore differ between the different types of renovation that are studied in Renovair.

This analysis of every type of renovation (types defined as listed in Table 1) will consist of a stepwise approach:

1) a comparison of the situation pre and post renovation (available for at least one case per renovation type that is considered),

2) an overall evaluation of the situation post renovation for this type of renovation (including a comparison with existing data and databases, with identification of outliers and risks, and a comparison to guidelines and standards)
3) an evaluation of the effectiveness of this type of renovation

This analysis will be described in CHAPTER 3.

The outcomes of this data-processing will lead to the formulation of policy recommendations and the identification of possibilities for valorisations, reported in CHAPTER 4.

# CHAPTER 2 THE IMPACT OF RENOVATIONS ON ENVIRONMENTAL PARAMETERS

Energy-efficient renovations induce the use of (new) building materials which may introduce emissions of various volatile organic compounds (VOCs) and aldehydes in indoor environments. The potential improvements in building ventilation, insulation and air tightness that it induces, may also considerably impact the indoor environment.

In this overall data-analysis, indoor environmental parameters before and after all the types of renovations that were studied in Renovair, are compared and evaluated. The objective of this analysis is to assess any impact on the indoor environment, that can be related to the activity of energy-efficient renovations in general. The main focus of this descriptive analysis is put on indoor chemical, microbiological parameters, as well as indoor comfort.

## 2.1. IMPACT OF RENOVATIONS IN TERMS OF IAQ

### 2.1.1. GENERAL EVALUATION OF IAQ AFTER RENOVATIONS

To evaluate the impact of renovations on the IAQ in the studied buildings, the average, minimal and maximal indoor and outdoor levels that were measured in those cases where IAQ was assessed pre and post renovation, are illustrated in Table 2. Because IAQ is well-known to be partly determined by outdoor air, respective indoor/outdoor ratio’s (I/O-ratio) are visualised in Figure 1.

*Table 2 $PM_{2.5}$, $CO_2$, temperature, TVOC, and aldehydes pre and post renovation*

| | | *pre renovation* | | *post renovation (> 6 months)* | |
|---|---|---|---|---|---|
| | | *IN* | *OUT* | *IN* | *OUT* |
| $PM_{2.5}$ [µg/m³] | average | 20,7 | 15,5 | 64,7 | 51,2 |
| | min | 8,5 | 4,4 | 5,8 | 10,1 |
| | max | 82,6 | 28,2 | 248 | 106 |
| $CO_2$ [ppm] | average | 654 | 476 | 665 | 488 |
| | min | 522 | 405 | 505 | 407 |
| | max | 1055 | 536 | 932 | 554 |
| temperature [°C] | average | 17,7 | 7,9 | 19,8 | 12,0 |
| | min | 12,8 | 2,9 | 13,5 | 4,1 |
| | max | 21,4 | 15,4 | 23,1 | 15,9 |
| TVOC [µg/m³] | average | 258 | 69,7 | 420 | 99,4 |
| | min | 53 | 13 | 101 | 31 |
| | max | 788 | 171 | 1660 | 165 |
| formaldehyde [µg/m³] | average | 19,0 | 1,8 | 27,9 | 1,9 |
| | min | 0,5 | 0,5 | 2,5 | 0,3 |
| | max | 38 | 2,6 | 82,5 | 3,3 |
| *continuation* | | | | | |

| | | *pre renovation* | | *post renovation (> 6 months)* | |
|---|---|---|---|---|---|
| | | *IN* | *OUT* | *IN* | *OUT* |
| *Table* 2 | | | | | |
| acetaldehyde [µg/m³] | average | 2,7 | 0,3 | 3,3 | 0,5 |
| | min | 0,1 | 0,01 | 0,8 | 0,01 |
| | max | 11,9 | 0,5 | 6,0 | 3,2 |
| total other aldehydes [µg/m³] | average | 10,1 | 3,1 | 10,2 | 5,7 |
| | min | 0,2 | 0,4 | 0,8 | 0,4 |
| | max | 55 | 6 | 38 | 19 |

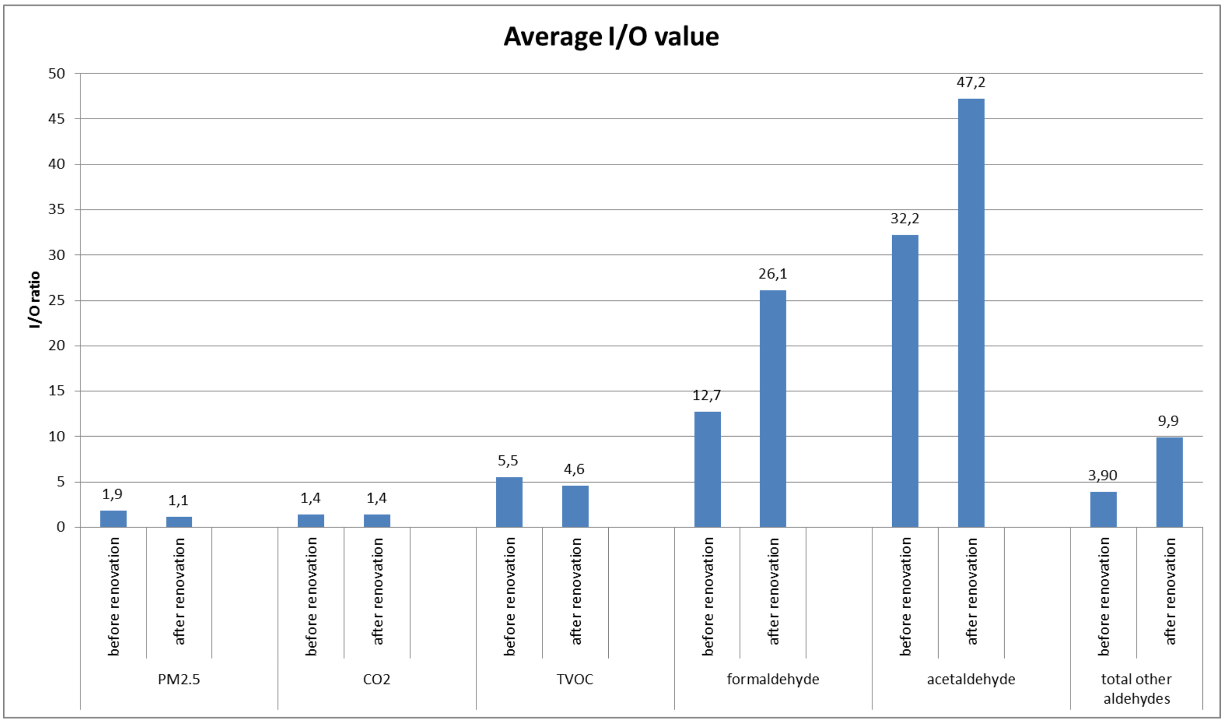



*Figure 1 Average I/O ratio's before and more than 6 months after the renovation*

In general, average indoor temperatures we found to moderately increase after the renovation (increase from 17,7°C to 19,8°C), in terms of average, minimal and maximal levels, which is likely to result from a better building insulation after the renovation because average outdoor temperatures of both phases were comparable (e.g. maximum 15,4°C pre renovation and maximum 15,9°C post renovation).

Even though indoor $CO_2$ was expected to potentially increase as a result of enhancing the dwelling air tightness, the average indoor $CO_2$, quantified as a measure for building ventilation, air tightness and occupation, was found to be unchanged in most of the houses. In some individual houses however, it was found to increase after the renovation (see further).

TVOC I/O ratios are comparable pre and post renovations, but in general indoor levels were found to be higher after the renovations (e.g. on average 258 ± 248 µg/m³ before renovations and 420 ± 418 after renovations). Indoor concentrations of quantified VOCs were however, on average, not all found in higher indoor concentrations after the renovation (Figure 2).

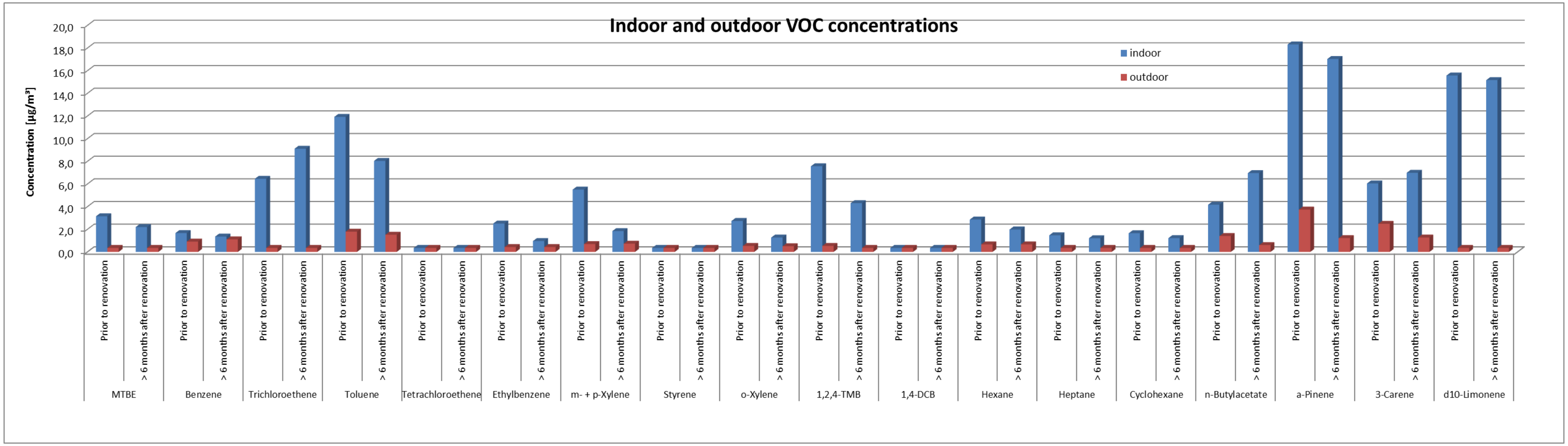



*Figure 2 Average indoor and outdoor VOC concentrations, before and after the renovations*

Considerably higher I/O ratios were found for formaldehyde, acetaldehyde and other aldehydes, even though, after the renovations least pronounced for the latter group of compounds (see Figure 1). Indoor formaldehyde levels reached concentrations up to 82 µg/m³ post renovation.

There are few general observations that can be interpreted from this study with respect to microbial levels so far. Bacterial, fungal and yeast levels were determined from settled particulate matter collected on a standardized surface (petri dishes) over a standardized collection period (1 week?), using cultivation based methods. Samples were collected from 7 cases pre and 14 cases post renovation, with in most cases two samples per each case being collected, in some cases one. Bacterial levels were generally factor 10 higher compared to fungal levels, as could be expected. Yeasts were rarely detected. Very similar fungal and bacterial median levels were found pre and post renovation (2 and 3 spores per cm² settling surface, for fungi; and 11 and 15 spores per cm2settling surface for bacteria, respectively). Differences between median levels pre and post are small and may well be due to the small and uneven sample size for before and after intervention cases. Case 3 showed clearly elevated fungal and bacterial levels in the pre renovation situation compared to all other samples; this case needs to be further explored in order to try to interpret this finding (eg. via presence/absence of pets, unusual occupancy levels, seasonal effect, etc.). In addition, elevated level (>75$^{th}$ percentile) pre renovation were found in house 9 and 13 in one sample each. Post renovation, case 3 still showed elevated fungal and bacterial levels; in addition, houses 1,5,8,13,14,16 showed slightly higher levels in either or both fungal and bacterial parameters. As mentioned above, it would require further investigation why for these homes microbial levels were elevated, as a number of factors may impact microbial measurements.

Only 6 interventions where a pre and post situation was measured, can be compared (houses 3,11,12,13,14,15). There are no clear effects of the intervention on bacterial or fungal levels observed in these cases, with the exception of No 3 (floor insulation, house 1, living room). There the pre intervention situation indicated elevated bacterial and fungal levels, which were reduced almost 40 fold for bacteria and almost 100 fold for fungi post renovation. This is interesting, however, given this is a single finding and due to lack of information of other determinants of microbial levels (eg. season of sampling, presence or absence of pets, occupancy, etc.) it cannot be concluded whether this reduction was due to the renovation or any other presence or absence of a determinant of microbial levels. Post renovation values for both fungi and bacteria in this house 3 were still higher compared to most of the other home microbial levels, indicating that the intervention was only partly successful with respect to microbial contamination.
For case 14 (air filter replacement, case 1) we observed somewhat elevated levels post intervention. Also this finding is difficult to interpret, but could theoretically imply elevated fungal levels post intervention due to the cleaning activities.

### 2.1.2. EVALUATION OF IAQ AFTER RENOVATIONS WITH ATTENTION TO LOW EMISSION MATERIALS

#### → Objective

This qualitative additional data analysis was organised to evaluate whether (1) building owners consciously take initiatives for selecting low emission building materials, and (2) if they do so, whether the IAQ in these houses is found to be ‘better’ than the IAQ in an average Flemish house. The here reported data should be considered indicative, and cannot be considered as qualitative data.

The objective of this analysis called for clear and easily accessible IAQ targets for building renovations, which building owners and architects could use to set goals for a renovation. Since for now no easily accessible or applicable IAQ targets are available for architects and house owners, we assume that by taking initiatives such as selecting low-emission building materials in order to create a healthy IAQ, house owners aim at creating an indoor environment that is more healthy than the IAQ of an average Belgian (Flemish) house. The IAQ of a general Flemish house has been quantified, based on a database on the occurrence of chemical air pollutants in 450 Flemish houses (*Surveillance of health complaint-free houses, AZG 2012*), including terraced, detached houses and apartments, representative for the current building stock thus including traditional, renovated, refurbished as well as energy-efficient houses, equally distributed over all provinces and outdoor environments (rural, urban, urban centre).

→ **Strategy**

In order to evaluate the impact of initiatives of house owners to create a healthier IAQ on the indoor environment, houses of 4 participants of the Renovair project were studied more in detail. This implied that the building owners, and architects of these 4 Renovair cases were interviewed, with a focus on their objectives and goals in building material selection, and the initiatives for material selection that resulted from this approach. Their initiatives for a (more) healthy IAQ, the outcomes of the IAQ assessment in their house as well as an evaluation hereof are summarized in Table 3.

Even though more than 18 chemical indoor parameters are assessed in the Renovair study, this targeted analysis focusses on the most referred parameters for renovations, refurbishments and new building materials, namely benzene (included in the WHO Guidelines for Indoor Air Quality, that recommends 'No safe level of exposure'), TVOC (total volatile organic compounds, a recognized indicator for indoor air sensory irritation, Mølhave 2003[1]), and formaldehyde (included in the WHO Guidelines for Indoor Air Quality, that recommends a 30-minute average concentration of 0.1 mg/m³).

→ **Conclusion**

Besides the applicable EU regulations, Belgium has only limited regulations that restrict building material emissions, and has no mandatory product label that applies for all building products that are available on the Belgian market. The current product policy to limit VOC emissions was introduced in January 2015 (RD 8th of May 2014) and applies to (only) flooring materials and adhesives available on the Belgian market. It restricts emissions of VOCs and aldehydes; however it does not impose emission testing of the building materials as such.

Interviews of the house owners pointed out that for the choice of all materials different from flooring materials and adhesives, house owners and architects typically consult the EPB regulation, material labels or guides such as the VIBE (website Flemish Institute for Bio-Ecological Construction and Living) or the NIBE (Dutch Institute for Building Biology and Ecology) environmental classification for building materials. These tools assist them to select materials, based on information such as the embodied energy of construction materials and environmental impacts. Whenever possible, house owners tried to re-use materials and elements in situ or from other sources (e.g. re-use of bricks and terrace tiles, doors, wood to make new stairs), also avoiding construction waste in that way. For none of the cases, quantitative targets have been set to reduce

1 Mølhave L. Organic compounds as indicators of air pollution. Indoor Air. 2003;13 Suppl 6:12-9.

construction waste. Interviews indicated that the offer of low VOC-emission materials on the Belgian market is difficult to overview, and so far bio-ecological materials are rewarding alternative materials that are low VOC-emitting. Bio-ecological materials in general don't contain solvents, and therefore don't contribute to indoor VOC or aldehyde emissions. It should be noted that bio-ecological materials potentially emit biocides or microbial contaminations, which are generally not included in emission evaluation schedules and product labels (Koivula et al. 2005), and are therefore not necessarily more healthy materials.

Table 3 ranks the studied renovation cases in order of decreasing amount of initiatives for creating a healthy indoor air. The table's third column describes the initiatives, in terms of material selection, that building owners took to create a healthier IAQ in their house. In the next columns, the assessed IAQ is evaluated towards the set IAQ targets.

According to this evaluation, mainly indoor TVOC and formaldehyde, and to a lesser extent indoor benzene, are found to increase with decreasing amount of initiatives for selecting low VOC-emitting building materials. It has to be noticed that the relatively high indoor TVOC and benzene levels in case 16 have been identified pre as well as post renovation. Even though they originate from a local indoor source (vehicle emissions), the indoor levels post renovation were found to be higher than pre renovation, as a result of increased air tightness and insufficient ventilation.

*Table 3 Overview of IAQ targets, initiatives of house owners to create a more healthy IAQ, outcomes of the IAQ assessment*

| Case | IAQ Target | Initiatives to create a healthy IAQ | IAQ assessment (>6m) | Evaluation |
|---|---|---|---|---|
| Case 7 | **Benzene**<br>1.54 ± 2.09 µg/m³<br>P75: 1.6 µg/m³<br>**TVOC**<br>443 ± 604 µg/m³<br>P75: 458 µg/m³<br>**Formaldehyde**<br>26.6 ± 17.4 µg/m³<br>P75: 31.0 µg/m³ | **Thorough initiatives for a healthy IAQ:** pressed wood with low formaldehyde emissions, avoidance of glued materials, initiatives to limit use of synthetic materials, natural and ecological paint (water-based) for indoor finishing, no pre-treated straw, loam walls, laminate flooring. Natural ventilation (type A). | **Benzene**<br>1.30 µg/m³<br>(outdoor: 1.18 µg/m³)<br>**TVOC**<br>104 µg/m³<br>(outdoor: 139 µg/m³)<br>**Formaldehyde**<br>13.3 µg/m³<br>(outdoor: 1.99 µg/m³) | - Indoor benzene can be considered equal to outdoor levels (measurement error), indicating that its indoor occurrence results from outdoor levels and no additional indoor sources are present.<br>- Indoor TVOC is lower than outdoor levels, indicating no indoor sources, indoor TVOC is significantly lower than P75 of the average Flemish house.<br>- Indoor formaldehyde is lower than representative Flemish house levels, yet exceeding levels of case 7b (possibly related to laminate flooring). |
| Case 10 | **Benzene**<br>1.54 ± 2.09 µg/m³<br>P75: 1.6 µg/m³<br>**TVOC**<br>443 ± 604 µg/m³<br>P75: 458 µg/m³<br>**Formaldehyde**<br>26.6 ± 17.4 µg/m³<br>P75: 31.0 µg/m³ | **Several initiatives for a healthy IAQ:** Pressed wood with low formaldehyde emissions, plaster fibre boards, minimized PU use (NIBE classification), ecological paint for indoor finishing, loam walls, wooden floors, massif passive building. Mechanical ventilation type D. | **Benzene**<br>0.89 µg/m³<br>(outdoor: 0.81 µg/m³)<br>**TVOC**<br>215 µg/m³<br>(outdoor: 136 µg/m³)<br>**Formaldehyde**<br>2.49 µg/m³<br>(outdoor: 1.11 µg/m³) | - Indoor benzene is equal to outdoor levels, indicating that its indoor occurrence results from outdoor levels and no additional indoor sources are present.<br>- Indoor TVOC is exceeding outdoor levels, indicating the presence of indoor sources, yet indoor levels are lower than P75 of the average Flemish house<br>- Formaldehyde levels significantly lower than P75 if the average Flemish house (outdoor levels are typically lower than indoor levels) |
| Case 16 | **Benzene**<br>1.54 ± 2.09 µg/m³<br>P75: 1.6 µg/m³<br>**TVOC**<br>443 ± 604 µg/m³<br>P75: 458 µg/m³<br>**Formaldehyde**<br>26.6 ± 17.4 µg/m³<br>P75: 31.0 µg/m³ | **Limited initiatives for a healthy IAQ**: Selection of low-emission materials if materials easily accessible, e.g. kitchen based on pressed straw. No mechanical ventilation system | **Benzene**<br>2.14 µg/m³<br>(outdoor 0.75 µg/m³)<br>**TVOC**<br>1660 µg/m³<br>(outdoor 165 µg/m³)<br>**Formaldehyde**<br>25,5 µg/m³<br>(outdoor 1.4 µg/m³) | - Indoor benzene is exceeding outdoor levels, indicating the presence of additional indoor sources of benzene, could be related to the building materials used or related to a specific sources present indoors, exceeding P75 of the average Flemish house.<br>- Indoor TVOC is significantly higher than outdoor levels, indicating indoor sources that could be related to the building materials used. Indoor TVOC is considerably exceeding P75 of the average Flemish house.<br>- Indoor formaldehyde exceeds outdoor levels, indicating the presence of indoor sources. Indoor levels are lower than representative Flemish house levels. |
| Case 8 | **Benzene**<br>1.54 ± 2.09 µg/m³<br>P75: 1.6 µg/m³<br>**TVOC**<br>443 ± 604 µg/m³<br>P75: 458 µg/m³<br>**Formaldehyde**<br>26.6 ± 17.4 µg/m³<br>P75: 31.0 µg/m³ | **No specific initiatives for healthy IAQ:** (house owner not aware of building material emissions). Wall insulations with PU, covered with impermeable metal foils, floor insulation with PU, roof insulation with glass fibre boards, resin treatment of walls against damp, glued tiles. Mechanical ventilation type D. | **Benzene**<br>2.67 µg/m³<br>(outdoor: 1.34 µg/m³)<br>**TVOC**<br>398 µg/m³<br>(outdoor: 172 µg/m³)<br>**Formaldehyde**<br>18.2 µg/m³<br>(outdoor: 3.07 µg/m³) | - Indoor benzene is exceeding outdoor levels, indicating the presence of additional indoor sources of benzene, could be related to the building materials used. Significantly exceeding P75 of the average Flemish house.<br>- Indoor TVOC is higher than outdoor levels, indicating indoor sources that could be related to the building materials used. Indoor TVOC is almost equalizing P75 (measurement error) of the average Flemish house.<br>- Indoor formaldehyde exceeds outdoor levels, indicating the presence of indoor sources. Indoor levels are lower than representative Flemish house levels. |

## 2.2. IMPACT OF RENOVATIONS IN TERMS OF INDOOR COMFORT

It has been shown that a variety of specific health complaints that people may experience can be related to the type of buildings (with their specific characteristics) they occupy. In office buildings, these problems are often designated as examples of the so-called Sick Building Syndrome (SBS).
SBS is mainly characterized by one or more non-specific symptoms of the skin, mucous membranes, airways and the central nervous system. The symptoms arise when people are present in the indoor environment which they identify as the cause of their health symptoms, and disappear when they leave this environment.
Most times it is very difficult to find the cause of the symptoms. It is certain that the origin is multifactorial: chemical, microbiological and physical (climatological) factors play a role, but also characteristics of the environment, personal, psychosocial and organizational aspects yield an important impact on the resulting health complaints.
Provikmo developed and validated a Dutch/French auto questionnaire that can be used not only to document people's opinions on all these contributing factors, but also to classify building types as low, mediocre or high risk environments for health complaints, based on the questionnaire responses of the people that occupy them (Geens *et al.*, 2012).

The auto questionnaire consists of five important sections: personal factors, environmental (non-thermal) factors, thermal factors, psychosocial factors and a variety of unspecified health complaints of the eyes, nose, throat, upper and lower airways, skin and central nervous system. The combined response to this last mentioned section -containing more than twenty relevant health-related items- is considered as the main outcome, which we will further referred to as the symptom risk score (SRS).
The questionnaire was validated with a sample of 450 randomly chosen Flemish office workers in 2012. Results of this questionnaire are believed to be representative for normal office personnel in Flanders, without excessive complaints about their indoor working environment. A multiple linear regression model was constructed to model the symptom risk score with predictors from the four other sections of the questionnaire. The final model incorporates gender and known allergic history (personal factors), noise, air quality and lighting complaints (environmental factors), temperature complaints (head/hands) and draught complaints (neck/back) (thermal factors) as well as satisfaction (work/family balance and stress, psychosocial factors) as significant predictors in explaining the variability in the symptom risk score.

In a last step, cut-off values dividing the symptom risk score distribution into a low (56% of all scores), mediocre (33% of all scores) and high score (11% of all scores) group, were derived.

The Provikmo questionnaire was adapted for use in the Renovair project, with the specific purpose to compare health complaints of residents, before and after renovation of their home living environment. Only minor changes (home/office terminology) had to be made to the questionnaire items. A basic summary on the number of respondents is provided in Table 1: at the time of this report, 32 responses were collected: 13 before and 19 after renovation.

*Table 4: Summary of the responses to the auto questionnaire*

| ***No.*** [a] | ***Before*** | ***During*** | ***After*** | ***Total*** |
|---|---|---|---|---|
| 1 | | | 3 | 3 |
| 2 | | | 2 | 2 |
| 3 | 2 | | 1 | 3 |
| 5 | 2 | | 2 | 4 |
| 6 | 2 | 1 | 1 | 3(/4) |
| 7 | | | 1 | 1 |
| 8 | | | 2 | 2 |
| 9 | 1 | | | 1 |
| 10 | | | 2 | 2 |
| 11 | 1 | | 1 | 2 |
| 12 | 1 | | | 1 |
| 13 | 2 | | 2 | 4 |
| 16 | 2 | | 2 | 4 |
| | **13** | **1** | **19** | **32(/33)** |

[a]: 4 and 9 are the same building, only the results for No. 9 are shown, work in NO. 14 and 15 still ongoing

The symptom risk scores for all respondents at each time point were calculated and categorised as low, mediocre or high, according to the Provikmo model. These exploratory results are displayed in Figure 3: there does not seem to be any clear effect of "renovation" on the overall health complaints in the present study sample (left). This is confirmed with Fisher's exact probability test (no difference in the distribution of scores across the three categories before and after renovation, $p=0.999$). If the distribution is compared with the benchmark population from the Provikmo study ($n=450$), again, no significant difference is observed ($Chi^2 = 1.39$, $df = 2$, $p=0.499$).

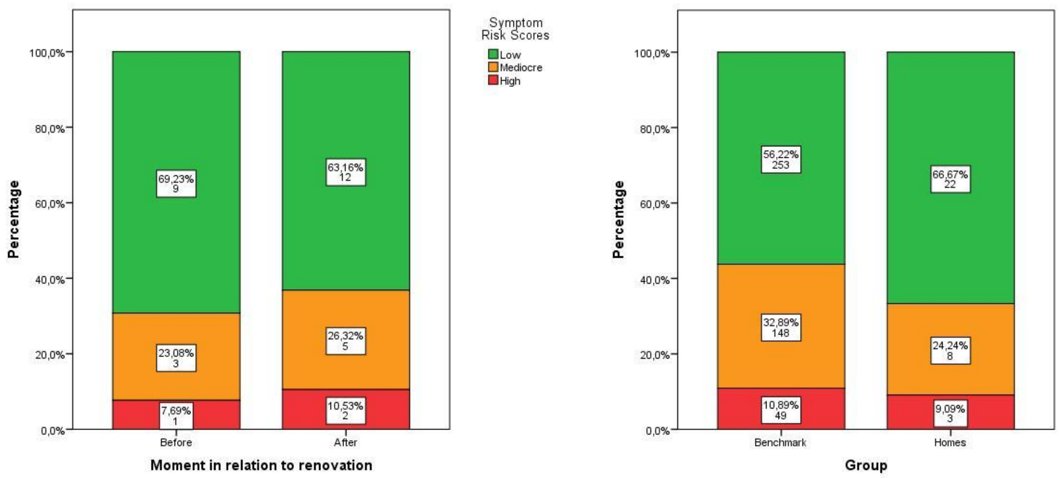



*Figure 3 Symptom Risk Score distribution in relation to the moment of renovation (before/after)(left) as well as to the benchmark that was originally used to validate the questionnaire (right).*

The health complaints however are only a small portion of the information obtained with the questionnaire. The questionnaire was designed to explain health complaints using a group of non-health complaint predictors. Thus: another important question arises: do we expect a lower amount of health complaints using the information from personal, environmental, thermal and psychosocial factors, after the renovation?

The results of this analysis are shown in Figure 4. The mean symptom risk score (directly calculated from the questionnaire) before and after renovation does not seem to differ (blue) but the calculated symptom risk score with the model however, is suggestive of an improvement after renovation (green). The results of this preliminary analysis are confirmed in a mixed models approach using the respondent as random effect and the moment (before/after renovation) as primary fixed effect of interest. Variances were estimated as between respondents and within respondents (18 of the 32 responses were in fact repeated measurements from 9 persons that participated in the questionnaire before as well as after renovation). A significant variance in intercepts between the respondents' predicted symptom risk scores is shown: after renovation, the prediction is on average 2,42 units lower (t=4.288,df=9.786,p=0.002). The reason why this significant difference is not observed in Figure 3 (the error bars still overlap) is the fact that the confidence intervals are not corrected for the portion of repeated measurements in the data. Since only part of results is paired, neither paired nor independent samples t-tests are appropriate in this case.

Table 5 shows a comparison of response proportions per predictor (or other informative variable) between the current study and the benchmark population before and after renovation within the current study population.

We learn that the current study population resembles the benchmark population quite good. Only one significant difference arises that might explain any difference found in symptom risk score: the current population has a higher proportion of respondents that indicate that they have a known allergy (which could explain a higher symptom risk score). For information purposes, the time using a visual display unit (desktop, laptop, tablet, smartphone, …) is also shown. The benchmark (office) population has a higher usage time, which seems quite reasonable to expect since during office hours this parameter is expected to be higher than during leisure time at home. However: in our model, VDU time does not have a significant impact on the outcome of health complaints.

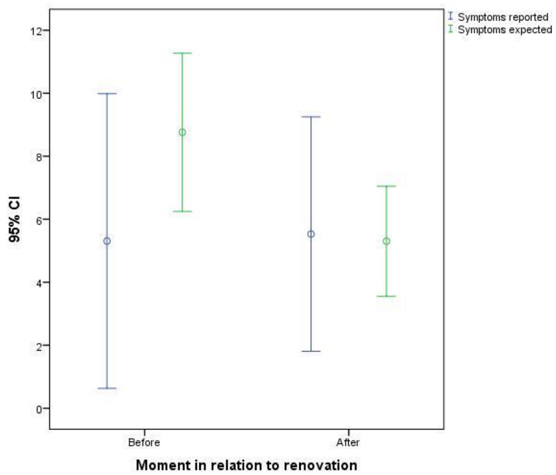



*Figure 4 Reported (blue) versus expected (green) symptoms*

*Table 5 Comparison of response proportions per predictor between the current study and a benchmark population as well as before and after renovation*

| | | Study group | | | | | | | Time in relation to renovation | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Benchmark | | Homes | | | | | Before | | After | | | | |
| Predictor | Category | Count | % / mean | Count | % / mean | *statistic* [d] | *df* | *p* | Count | % / mean | Count | % / | *Statistic* [d] | *df* | *p* |
| Gender | Female | 215 | 47,8% | 13 | 39,4% | *0,867* | *1* | *0,352* | 6 | 46,2% | 7 | 36,8% | *0,277* | *1* | *0,598* |
| | Male | 235 | 52,2% | 20 | 60,6% | | | | 7 | 53,8% | 12 | 63,2% | | | |
| Smoker [c] | Current smoker | 77 | 17,1% | 3 | 9,1% | *4,035* | *2* | *0,133* | 1 | 7,7% | 1 | 5,3% | *1,073* | *2* | *0,585* [a,b] |
| | Never smoked | 261 | 58,0% | 25 | 75,8% | | | | 11 | 84,6% | 14 | 73,7% | | | |
| | Quitted smoking | 112 | 24,9% | 5 | 15,2% | | | | 1 | 7,7% | 4 | 21,1% | | | |
| Allergy | No known allergy | 328 | 72,9% | 17 | 51,5% | *6,882* | *1* | *0,009* | 5 | 38,5% | 12 | 63,2% | *1,89* | *1* | *0,169* |
| | Known allergy | 122 | 27,1% | 16 | 48,5% | | | | 8 | 61,5% | 7 | 36,8% | | | |
| Age [c] | Age (year) | 450 | 40,1 | 33 | 38,3 | *0,983* | *480* | *0,326* | 13 | 39,5 | 19 | 37,8 | *0,404* | *30* | *0,689* |
| Seniority [c] | Seniority (year) | 450 | 7,3 | 33 | 8,1 | *-0,643* | *458* | *0,521* | 13 | 7,4 | 19 | 9,0 | *-0,553* | *30* | *0,584* |
| VDU time [c] | VDU time (hours) | 450 | 6,2 | 33 | 2,2 | *15,925* | *49* | *<0,001* | 13 | 2,1 | 19 | 2,2 | *0,313* | *30* | *0,756* |
| Satisfaction (work/family balance, stress) | (Very) dissatisfied | 67 | 14,9% | 2 | 6,1% | *3,147* | *2* | *0,207* | 2 | 15,4% | 0 | 0,0% | *3,149* | *2* | *0,207* [a,b] |
| | Neutral | 185 | 41,1% | 18 | 54,5% | | | | 6 | 46,2% | 11 | 57,9% | | | |
| | (Very) satisfied | 198 | 44,0% | 13 | 39,4% | | | | 5 | 38,5% | 8 | 42,1% | | | |
| Temperature complaints (head and hands) | Neutral | 233 | 51,8% | 21 | 63,6% | *3,824* | *2* | *0,148* | 7 | 53,8% | 14 | 73,7% | *2,289* | *2* | *0,318* [a,b] |
| | Somewhat too cold/hot | 151 | 33,6% | 11 | 33,3% | | | | 5 | 38,5% | 5 | 26,3% | | | |
| | (Much) too cold/hot | 66 | 14,7% | 1 | 3,0% | | | | 1 | 7,7% | 0 | 0,0% | | | |
| Draught complaints (neck and back) | Neutral | 310 | 68,9% | 26 | 78,8% | *2,71* | *2* | *0,258* | 9 | 69,2% | 16 | 84,2% | *1,013* | *1* | *0,314* [a,b] |
| | Somewhat | 111 | 24,7% | 7 | 21,2% | | | | 4 | 30,8% | 3 | 15,8% | | | |
| | (Much) too much | 29 | 6,4% | 0 | 0,0% | | | | 0 | 0,0% | 0 | 0,0% | | | |
| Noise | No complaints | 363 | 80,7% | 24 | 72,7% | *2,88* | *2* | *,237* | 10 | 76,9% | 14 | 73,7% | *4,362* | *2* | *0,113* [a,b] |
| | Slight complaints | 41 | 9,1% | 6 | 18,2% | | | | 1 | 7,7% | 5 | 26,3% | | | |
| | Heavy complaints | 46 | 10,2% | 3 | 9,1% | | | | 2 | 15,4% | 0 | 0,0% | | | |
| Air quality and lighting | No complaints | 219 | 48,7% | 17 | 51,5% | *0,189* | *2* | *0,91* | 5 | 38,5% | 12 | 63,2% | *2,443* | *2* | *0,295* [a] |
| | Slight complaints | 64 | 14,2% | 5 | 15,2% | | | | 2 | 15,4% | 3 | 15,8% | | | |
| | Heavy complaints | 167 | 37,1% | 11 | 33,3% | | | | 6 | 46,2% | 4 | 21,1% | | | |
| Health complaints (symptom risk score) [c] | Low | 253 | 56,2% | 22 | 66,7% | *1,393* | *2* | *0,498* | 9 | 69,2% | 12 | 63,2% | *0,142* | *2* | *0,932* [a] |
| | Mediocre | 148 | 32,9% | 8 | 24,2% | | | | 3 | 23,1% | 5 | 26,3% | | | |
| | High | 49 | 10,9% | 3 | 9,1% | | | | 1 | 7,7% | 2 | 10,5% | | | |

[a] More than 20% of cells in this sub table have expected cell counts less than 5. Chi-square results may be invalid, [b] The minimum expected cell count in this sub table is less than one. Chi-square results may be invalid, [c] These variables are shown for information purposes only and are not significant predictors for explaining health symptoms according to our model, [d] chi$^2$ statistic except for age, seniority, VDU time, for which the t-statistic is shown

From the right part of Table 5, we also learn that no major differences arise before and after renovation. This is again quite reasonable since the same people are expected to occupy their same home before and after renovation and some important parameters are not affected by the renovation (gender, smoker, allergy, age, seniority, VDU time, satisfaction). Some variation is noticed since not all people filled out the questionnaire before and after renovation (not all the observations were paired).
All (non-significant) changes in percentages across categories after renovation however point in the direction of a lower expected symptom risk score according to our model. Unfortunately, this is not observed in the pattern of health complaints itself, but it might explain why overall, a slight improvement in health complaints would be expected.

However, we have to be careful in not over interpreting the results of the current study: the study population is small in relation to the group on which the original model was built. These small numbers are also reflected in the counting of cases that fell into certain response categories. When frequencies are below five or even zero, chi² tests may be invalid. Last but not least: the questionnaire was slightly adapted for use in a home setting without a possibility for prior validation. Results should in any case be regarded as indicative and as triggers for further study.

## 2.3. Impact of renovations on moisture in walls and thermography

In most cases, the lower zones of (some of) the façades contain more moisture than the top of the external walls. This is caused by rainwater splashing on the nearby ground surfaces. In the following text, this phenomenon will not be addressed anymore, since there is no relation with the studied renovation scenarios.

## 2.4. The impact of renovations on the K- and E- level

The Flemish EPB regulations impose targets on the energy performance level ('E-peil') of all newly built dwellings, as well as performance targets for some individual components, such as maximum heat transfer coefficients (U- values) for building enclosures. In case of renovations, only works requiring a building permit are subject to the EPB regulations. Buildings undergoing major renovations works are subject to performance targets at the building level, although less stringent than those imposed on newly constructed buildings.

In practice, the renovation works implemented in all the Renovair case studies can be carried out without having to obtain a building permit. This is for example the case for window renovations, as long as the dimensions of the facade openings remain the same. If the works are not subject to a building permit, the interventions are only subject to rules on the performance of individual components - or no regulatory targets at all.

Dwelling 1 is taken as an example to illustrate this principle. The EPB regulations state that the heat transfer coefficient of glazing can attain maximum 1.1 W/m²/K for windows which are replaced during the renovation works (in case of a dwelling obtaining a building permit in 2016). Building owners are not forced to replace all windows, hence the maximum set by the regulations only affects the windows which are effectively been renovated. The walls, HVAC installations, etc. are not part of the renovation plans, so as long as the renovation is not considered as a major (or 'thorough') renovation, no targets are imposed on these components, and neither on the energy performance level of the building as a whole.

In order to calculate the U-values of constructions prior and after the renovation measures, some assumptions had to be made. For materials of which the properties are not exactly known, defaults from the EPB calculation procedure are assumed (Transmissie referentie document 2014). For unknown insulation materials, average values from the Belgian EPBD website (EPB productgegevens) are used (since they are more in accordance with execution practice) and reported as assumptions in Table 6. Although they are not legally binding for the renovated buildings, Table 7 displays the performance targets of the EPB regulations for 2016 to be able to compare the obtained results with current standards for new buildings.

Treatments against rising damp could have an effect on the heat transfer in a building, but this is not accounted for in the simplified steady state U-value. Therefore, this renovation type (type C) as well as the mechanical ventilation (type E), duct cleaning cases (type F) and their corresponding intervention segments in the combination cases (type D) are considered not relevant in the U-value calculations. The results of the heat transfer coefficient assessment are reported in Table 6.

*Table 6: U-value results for each studied case*

| nr | Renovation activity | Assumptions | U-value before renovation | U-value after renovation | EPB standard |
|---|---|---|---|---|---|
| 1 | Upgrade windows – case 1 | | $U_{glass}$ = 2.90 W/m²K | $U_{glass}$ = 1.10 W/m²K | $U_{g,max}$ = 1.1 W/m²K |
| 2 | Upgrade windows – case 2 | $U_{glass}$ of older double glazing = 2.80 W/m²K | $U_{glass}$ = 2.80 W/m²K | $U_{glass}$ = 1.10 W/m²K | $U_{g,max}$ = 1.1 W/m²K |
| 3 | Floor insulation – case 1 | $\lambda_{PUR\_sprayed}$ = 0.029 W/mK<br>Thickness insulation layer = 0.07 m<br>Floor on top of well-ventilated crawlspace | $U_{floor}$ = 2.15 W/m²K | $U_{floor}$ = 0.35 W/m²K | $U_{floor,max}$ = 0.24 W/m²K |
| 4 | Floor insulation – case 2 | no data could be obtained from the home owner | | | $U_{floor,max}$ = 0.24 W/m²K |
| 5 | Rising damp – case 1 | not applicable | | | |
| 6 | Rising damp – case 2 | not applicable | | | |
| 7 | Combi/thorough – case 1 | Non-ventilated cavity | $U_{wall\_inner}$ = 1.25 W/m²K | $U_{wall\_inner}$ = 0.46 W/m²K | $U_{wall\_inner,max}$ = none (*) |
| | | other interventions: no data received from the home owner yet | | | |
| 8 | Combi/thorough – case 2 | $\lambda_{PUR\_plates}$ = 0.023 W/mK | $U_{wall\_outer}$ = 1.27 W/m²K | $U_{wall\_outer}$ = 0.24 W/m²K | $U_{wall\_outer,max}$ = 0.24 W/m²K (*) |
| | | other interventions: no data received from the home owner yet | | | |
| 9 | Combi/thorough – case 3 | no data could be obtained from the home owner | | | |
| 10 | Combi/thorough – case 4 | Data retrieved from architect | $U_{floor\_ground}$ = 2.69 W/m²K<br>$U_{floor\_cellar}$ = 2.22 W/m²K<br>$U_{roof}$ = 1.03 W/m²K<br>$U_{wall\_outer}$ = 2.14 W/m²K<br>$U_{wall\_inner}$ = 3.08 W/m²K | $U_{floor}$ = 0.13 W/m²K<br>$U_{floor\_cellar}$ = 0.25 W/m²K<br>$U_{roof}$ = 0.14 W/m²K<br>$U_{wall\_outer}$ = 0.30 W/m²K<br>$U_{wall\_inner}$ = 0.42 W/m²K | $U_{floor,max}$ = 0.24 W/m²K<br>$U_{roof,max}$ = 0.24 W/m²K<br>$U_{wall\_outer,max}$ = 0.24 W/m²K (*)<br>$U_{wall\_inner,max}$ = none (*) |
| 11 | Combi/thorough – case 5 | owner will be sending data later | | | |
| 12 | Mechanical ventilation – case 1 | not applicable | | | |
| 13 | Mechanical ventilation – case 2 | not applicable | | | |
| 14 | Duct cleaning – case 1 | not applicable | | | |
| 15 | Duct cleaning – case 1 | not applicable | | | |
| 16 | Façade insulation – case 2 | Thickness insulation layer = 0.05 m | $U_{wall\_cavity}$ =1.46 W/m²K | $U_{wall\_cavity}$ = 0.50 W/m²K | $U_{wall\_cavity,max}$ = 0.55 W/m²K (*) |
| 17 | Façade insulation – case 1 | Thickness insulation layer = 0.05 m | $U_{wall\_cavity}$ =1.76 W/m²K | $U_{wall\_cavity}$ = 0.53 W/m²K | $U_{wall\_cavity,max}$ = 0.55 W/m²K (*) |

(*) for an external wall which is renovated an subject to EPB regulations, the U value which has to be targeted depends on the application of insulation:

- application at outer side: $U_{wall\_outer,max}$ = 0.24 W/m²K
- cavity wall insulation: $U_{wall\_cavity,max}$ = 0.55 W/m²K
- insulation application at the inner side of the construction ($U_{wall\_inner,max}$): no legal requirements

*Table 7 Maximum allowed U-values from EPB regulations 2016*[2]

**MAXIMAAL TOELAATBARE U-WAARDEN**

| Constructiedeel | | $U_{max}$ (W/m²K) |
|---|---|---|
| 1 | SCHEIDINGSCONSTRUCTIES DIE HET BESCHERMD VOLUME OMHULLEN, met uitzondering van de scheidingsconstructies die de scheiding vormen met een aanpalend beschermd volume | |
| 1.1 | TRANSPARANTE SCHEIDINGSCONSTRUCTIES, met uitzondering van deuren en poorten (zie 1.3), lichte gevels (zie 1.4), glasbouwstenen (zie 1.5) en scheidingsconstructies andere dan glas (zie 1.6) | 1.5 en $U_{g,max}$ = 1.1 |
| 1.2 | OPAKE SCHEIDINGSCONSTRUCTIES, met uitzondering van deuren en poorten (zie 1.3) en lichte gevels (zie 1.4) | |
| 1.2.1 | daken en plafonds | 0.24 |
| 1.2.2 | muren niet in contact met de grond, met uitzondering van de muren bedoeld in 1.2.4 | |
| 1.2.3 | muren in contact met de grond | 0.24 |
| 1.2.4 | verticale en hellende scheidingsconstructies in contact met een kruipruimte of met een kelder buiten het beschermd volume | |
| 1.2.5 | vloeren in contact met de buitenomgeving | |
| 1.2.6 | andere vloeren (vloeren op volle grond, boven een kruipruimte of boven een kelder buiten het beschermd volume, ingegraven keldervloeren) | |
| 1.3 | DEUREN EN POORTEN (met inbegrip van kader) | 2.0 |
| 1.4 | GORDIJNGEVELS (volgens prEN 13947) | 2.0 en $U_{g,max}$ = 1.1 |
| 1.5 | GLASBOUWSTENEN | 2.0 |
| 1.6 | TRANSPARANTE SCHEIDINGSCONSTRUCTIES ANDERE DAN GLAS, met uitzondering van deuren en poorten (zie 1.3) en lichte gevels (zie 1.4) | 2.0 en $U_{tp,max}$ = 1.4 |
| 2 | SCHEIDINGSCONSTRUCTIES TUSSEN TWEE BESCHERMDE VOLUMES OP AANGRENZENDE PERCELEN | 0.6 |
| 3 | VOLGENDE OPAKE SCHEIDINGSCONSTRUCTIES BINNEN HET BESCHERMD VOLUME OF PALEND AAN EEN BESTAAND BESCHERMD VOLUME OP EIGEN PERCEEL, met uitzondering van deuren en poorten (zie 1.3): | |
| 3.1 | TUSSEN APARTE WOONEENHEDEN | 1.0 |
| 3.2 | TUSSEN WOONEENHEDEN EN GEMEENSCHAPPELIJKE RUIMTEN (trappenhuis, inkomhal, gangen, ...) | |
| 3.3 | TUSSEN WOONEENHEDEN EN RUIMTEN MET EEN NIET-RESIDENTIËLE BESTEMMING | |
| 3.4 | TUSSEN RUIMTEN MET EEN INDUSTRIËLE BESTEMMING EN RUIMTEN MET EEN NIET-INDUSTRIËLE BESTEMMING | |
| 4 | NA-ISOLEREN VAN BESTAANDE SCHEIDINGSCONSTRUCTIES DIE HET BESCHERMD VOLUME OMHULLEN | |
| 4.1 | OPAKE CONSTRUCTIES met uitzondering van de scheidingsconstructies die de scheiding vormen met een aanpalend beschermd volume | |
| 4.1.1 | BESTAANDE DAKEN EN PLAFONDS MET NA-ISOLATIE tussen of aan de buitenzijde van de draagconstructie in contact met de buitenomgeving of een AOR | 0.24 |
| 4.1.2 | BESTAANDE MUREN MET NA-ISOLATIE aan de buitenzijde van de bestaande constructie in contact met de buitenomgeving | |
| 4.1.3 | BESTAANDE SPOUWMUREN MET NAVULLING, in contact met de buitenomgeving of een AOR (enkel voor ingrijpende energetische renovatie van residentiële gebouwen) | 0.55 |
| 4.1.4 | BESTAANDE MUREN MET NA-ISOLATIE aan de binnenzijde van de bestaande constructie | |
| 4.1.5 | BESTAANDE VLOEREN MET NA-ISOLATIE aan de buitenzijde van de bestaande constructie in contact met de buitenomgeving | 0.24 |

*Ten hoogste 2 % van de totale oppervlakte van alle scheidingsconstructies die het beschermde volume omhullen, zoals vermeld onder 1.1 t/m 1.6, mag afwijken van deze eisen.*

[2] http://www2.vlaanderen.be/economie/energiesparen/epb/doc/epbuwaarden2016.pdf

## 2.5. CONCLUSION

Due to the sample size no statistical analysis of the dataset is possible, which leads to a purely descriptive sample analysis. In general mainly indoor aldehydes (formaldehyde, acetaldehydes and to a lesser extent the sum parameter other aldehydes) were found in considerably higher indoor levels more than 6 months after the renovation activity took place. This finding indicates that more than 6 months after the renovation activity took place, emissions originating from the indoor use of building materials are still present indoors. A similar conclusion was reported by Chi et al. (2016) who states that during the first 12 months after decorating, the indoor pollution is mainly 'decoration pollution', characterised by increased TVOC and aldehyde levels, after the frist 12 months but before 24 months, the indoor pollution can be called 'transition pollution (both decoration materials and human activities affect the IAQ), and 24 months after the decoration, its transits to 'consumption pollution', such as combustion sources. Average indoor TVOC was found to be higher in absolute concentrations, but not in I/O ratios and average indoor $CO_2$ (when comparing the same house and same amount of building occupants) was found to be similar before and after the renovations, indicating no measurable deterioration of building ventilation. In some individual cases however, the opposite was found which will be further described in CHAPTER 3.

In terms of indoor comfort, the administration of an auto questionnaire to assess the impact of known important predictors on the outcome of health complaints due to presence in an indoor environment is not suggestive of a large impact of the renovation status. The study sample is too small to be confident in the outcome of statistical tests and consists of paired as well as unpaired samples, which impedes the choice for an easy test. Further dividing the study sample into the different types of renovations will make it even more difficult to explore assumptions with a statistical approach. Therefore we conclude that it is more appropriate to stick to descriptive analyses in the remaining part of the report.

# CHAPTER 3 EVALUATION OF THE EFFECTIVENESS AND IMPACT OF SPECIFIC RENOVATIONS

Every energy-efficient renovation induces the use of specific building materials, at specific places in a building. The impact on the indoor environment may therefore differ between the different types of renovation that were studied in Renovair.

In this chapter, each of the 7 renovation types (upgrade windows, floor insulation, rising damp, combi/thorough, mechanical ventilation, air filter replacement, and façade insulation) is therefore considered and analysed separately in a descriptive way. The size of this Renovair database does not allow any statistical analysis, however, a descriptive study of the collected data will lead to a detailed and broad screening of the impact of the renovations. For every type of renovation (types defined as listed in Table 1) the same stepwise approach is followed, including:

1) a description of the studied cases within each renovation type,
2) a comparison of the situation pre and post renovation (available for at least one case per renovation type that is considered),
3) an overall evaluation of the situation post renovation for this type of renovation (including a comparison with existing data and databases, with identification of outliers and risks, and a comparison to guidelines and standards)
4) an evaluation of the effectiveness of this type of renovation

## 3.1. The impact of window upgrades on the indoor environment (renovation type A)

### 3.1.1. The studied cases

The impact of window upgrades on the indoor environment was studied in two houses. Both detached houses are constructed around 1990, and are situated in a rural environment. Both residences have an insulated roof and insulated floorings, and have a new heating installation.

Whilst case 1 (house no. 1) has façade insulation as well as a ventilation system type A (natural ventilation), case 2 (house no. 2) has no insulated walls and no mechanical ventilation system or trickle ventilators.

In both residences, the renovation activities were performed by contractors, only case 2 was guided by an architect.

*Figure 5 IAQ assessment*

### 3.1.2. Comparison of the situation before and after the renovation

The IAQ (chemically and microbiologically) in these two cases was only studied after the renovation. Ventilation, moisture in walls and thermography was performed in case 1 (House no. 1)

In terms of ventilation, case 1 has only natural ventilation, consequently only the air tightness of the building was measured before and after the renovation. Two alternative conditions were measured. The volume of the dwelling was estimated using the cadastral map.

- For the first variation the attic trapdoor was opened, because the attic is part of the protected volume (case 1a). This corresponds to the official measurement protocol.
- For the second variation the attic trapdoor was closed (case 1b). This corresponds better to the actual use case.

In this dwelling, before the renovation, it was not possible to execute the depressurization test in the b condition, so only the pressurization test was taken into account. Taking into account the inaccuracy on a blower door measurement, no significant difference was found pre and post renovation (see Figure 6).

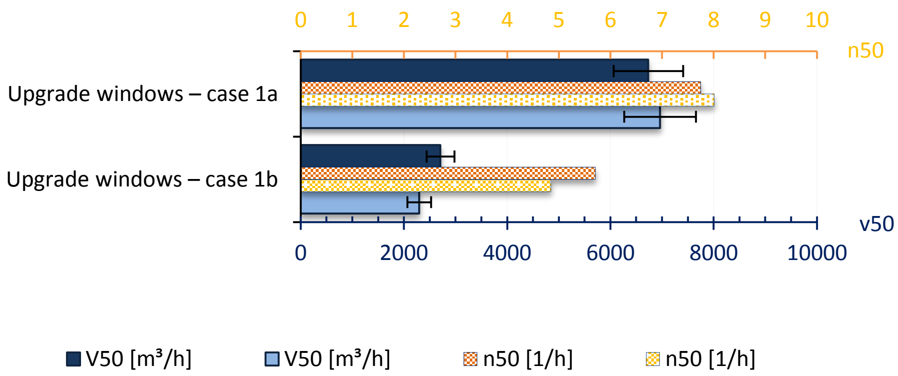



*Figure 6: Air flow rate [m³/h] at 50Pa before and after the renovation. Two variations were measured: attic trapdoor opened and attic trapdoor closed.*

In terms of moisture in walls and thermography, no relevant difference could be detected between the moisture in walls and thermography before and after renovation regarding surface temperatures on windows (measured on matte tape on renovated windows at rear façade). In fact in this case, where the walls were already insulated when this study was performed, the window sill was detected as a thermal bridge, both before and after the renovation

In terms of indoor comfort, a before – after comparison of indoor comfort questionnaire results is not possible since no responses were collected prior to renovation.

### 3.1.3. Evaluation of the situation after the renovation

**→ Indoor air quality**

Even though case 1 has a ventilation system (system A), higher indoor $CO_2$ concentrations as well as relative humidity were characterised compared to case 2, which has no ventilation system (Table 8), indicating a presumably higher air tightness of the building envelope in case 1 (confirmed further). Outdoor $PM_{2.5}$ is reflected in the IAQ for both dwellings, which results in the higher indoor concentrations in case 1.

Indoor TVOC and formaldehyde are also found to be higher in the house with highest indoor $CO_2$ levels (case 1). However the TVOC increment compared to outdoor levels is highest in case 2 (I/O .9 in house 1, compared to 6.8 in house 2). Acetaldehyde concentrations in both houses are similar (Table 9).

*Table 8 Physical indoor environment characteristics (window upgrades)*

| | Type of renovation | Prior to renovation | | < 6 months after renovation | | > 6 months after renovation | |
|---|---|---|---|---|---|---|---|
| | | IN | OUT | IN | OUT | IN | OUT |
| $CO_2$ [ppm] | Upgrade windows – case 1 | | | | | 847 | 477 |
| | Upgrade windows – case 2 | | | | | 522 | 511 |
| Temperature [°C] | Upgrade windows – case 1 | | | | | 22,1 | 15,9 |
| | Upgrade windows – case 2 | | | | | 23,1 | |
| Relative Humidity [%] | Upgrade windows – case 1 | | | | | 57,3 | - |
| | Upgrade windows – case 2 | | | | | 31,2 | - |

*Table 9 Chemical indoor environmental characteristics (window upgrades)*

| | Type of renovation | Prior to renovation | | < 6 months after renovation | | > 6 months after renovation | |
|---|---|---|---|---|---|---|---|
| | | IN | OUT | IN | OUT | IN | OUT |
| $PM_{2.5}$ [µg/m³] | Upgrade windows – case 1 | | | | | 104 | 87,7 |
| | Upgrade windows – case 2 | | | | | 22,7 | 36,7 |
| TVOC [µg/m³] | Upgrade windows – case 1 | | | | | 692 | 140 |
| | Upgrade windows – case 2 | | | | | 397 | 59 |
| formaldehyde [µg/m³] | Upgrade windows – case 1 | | | | | 53,56 | 0,50 |
| | Upgrade windows – case 2 | | | | | 10,62 | 1,66 |
| acetaldehyde [µg/m³] | Upgrade windows – case 1 | | | | | 3,43 | 0,07 |
| | Upgrade windows – case 2 | | | | | 3,12 | 0,09 |
| total other aldehydes [µg/m³] | Upgrade windows – case 1 | | | | | 38,44 | 0,40 |
| | Upgrade windows – case 2 | | | | | 1,28 | 1,31 |

Indoor TVOC concentrations exceed the guideline value that is currently recommended in the Flemish Indoor Environment Decree (Indoor TVOC < 200 µg/m³, Flemish Indoor Environment Decree of 11th of June 2004). For TVOC case 2 is in agreement with the German TVOC Indoor Guide Values for ideal TVOC conditions in indoor environments (recommended to be between 200-300 µg/m³). However, in case 1, the concentration of 692 µg/m³ is closer to the concentration range of 1000-3000 µg/m³, which is representative for a concentration range that should not be exceeded in rooms intended for longer stays. For formaldehyde, case 1 exceeds the guideline value that is currently recommended in the Flemish Indoor Environment Decree (indoor formaldehyde < 10 µg/m³) as well as the French indoor guideline value of 10 µg/m³ on an annual basis. The Surveillance of Health Complaint-free houses reported P75 concentration of 31 µg/m³.

### → Ventilation

In terms of ventilation, case 1 has only natural ventilation, consequently only the air tightness of the building was measured before and after the renovation. Two alternative conditions were measured. The volume of the dwelling was estimated using the cadastral map.

- For the first variation the attic trapdoor was opened, because the attic is part of the protected volume (case 1a). This corresponds to the official measurement protocol.
- For the second variation the attic trapdoor was closed (case 1b). This corresponds better to the actual use case.

In this dwelling, before the renovation, it was not possible to execute the depressurization test in the b condition, so only the pressurization test was taken into account. Taking into account the inaccuracy on a blower door measurement, no significant difference was found pre and post renovation (see Figure 6).

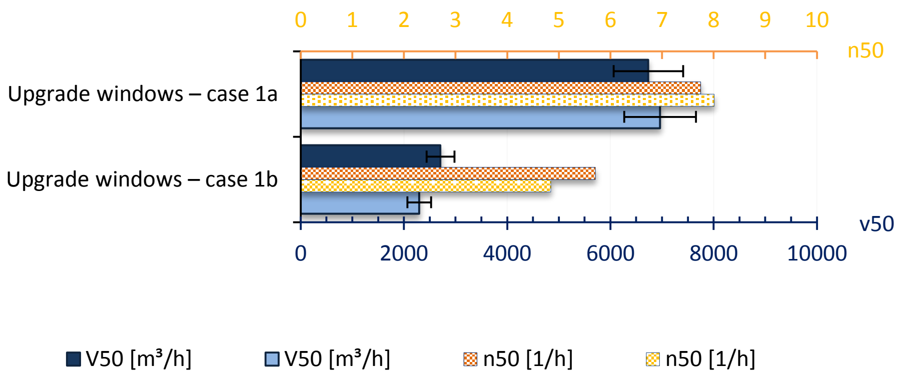



*Figure 7: Air flow rate [m³/h] at 50Pa before and after the renovation. Two variations were measured: attic trapdoor opened and attic trapdoor closed.*

### → Moisture in walls and thermography

In both cases (dwelling 1 and 2), the surface temperatures on windows were found to be low (much lower than indoor temperatures), meaning that the windows are well insulated. In case 2 (where the walls were not insulated) condensation occurred on the interior side of the glazing in the rooms that were occupied during the night before the measurement. In Interim Report 1, condensation on the walls was identified as a risk, however the condensation in case 2 appeared on the window surfaces themselves. No other humidity problems were detected during the walk-through survey of this case.

### → Indoor comfort

After renovation, for only one out of five respondents, a mediocre result is seen. This is acceptable since according to our model it is considered "normal" that up to 33% of all building residents exhibit some slight complaints attributed to the indoor environment. No specific comments were made by the respondents for this renovation type. To our opinion, it is not feasible to make an in depth comparison in terms of well-being of the responses for this renovation type with all other responses.

#### 3.1.4. Evaluation of the effectiveness of upgrading windows

To our opinion, it is not possible to infer any conclusions about the technical effectiveness in terms of well-being due to the small size of the study population and the fact that no responses could be gathered before the intervention.

Both cases upgraded their windows from older to modern double glazing, has improving the heat transfer coefficients of the glazing. Although there was no obligation, both cases comply with the EPB regulations for new buildings (which is a demand for receiving subsidies for this intervention).

In the studied cases, it was noticed that cold bridges present before the renovations are maintained after the renovations. Based on the outcomes it can be presumed that the objective of energy-saving has been obtained in both cases, and the assumed increase of indoor comfort could not be quantified. The risk of creating new cold bridges was not noticed in these cases, however, it was noticed that cold bridges present before the renovation are maintained after the renovation.

### 3.2. The impact of floor insulation on the indoor environment (renovation type B)

#### 3.2.1. The studied cases

Both houses that were studied to assess the impact of floor insulation on the indoor environment, were constructed between 1950 and 1960. Case 1 (House no. 3) is a terraced dwelling, whilst Case 2 (House no. 4) is a detached house.

Case 1 is equipped with a mechanical ventilation system with controlled exhaust air (ventilation type C), and has no roof-, window-, or façade insulation; the studied floor insulation is the first insulating initiative in this house.

Case 2 on the contrary has insulated windows, façade- and roof insulation, but no mechanical ventilation system; the installation of floor insulation is a final step of a thorough energy-efficient renovation of the house.

The floor insulations using PU foam were executed by contractors, and renovations were not guided by an architect.

#### 3.2.2. Comparison of the situation before and after the renovation

**→ Indoor air quality**

In the case 2, after the measurements less than 6 months after the renovation (the second house visit), the house owner didn't allow further measurements, which resulted in missing values for the measurement more than 6 months post renovation, for case 2 (House no. 4). This comparison of the situation before the renovation with the situation more than 6 months after the renovation, can only be made for case 1.

In case 1 (house no. 3), as expected no impact could be quantified on indoor $CO_2$, relative humidity or temperature (see Table 10). It should be noted that in neither of both studied cases, the heating system was working whilst the pre renovation measurements took place. Indoor TVOC, formaldehyde and acetaldehyde have increased post renovation. The increased aldehyde emissions are however more likely to be resulting from building materials, different from PU insulations, that were used indoors, since no scientific publication reports on aldehyde emissions from PU foam.

The increase of indoor $PM_{2.5}$ is a direct consequence of indoor generated dust from (other) renovation activities that were still ongoing during fieldwork due to a delay of the renovation activities (Table 11).

*Table 10 Physical indoor environment characteristics (floor insulations)*

| | Type of renovation | Prior to renovation | | < 6 months after renovation | | > 6 months after renovation | |
|---|---|---|---|---|---|---|---|
| | | IN | OUT | IN | OUT | IN | OUT |
| $CO_2$ [ppm] | Floor insulation – case 1 | 537 | 483* | | | 697 | 483* |
| | Floor insulation – case 2 | 651 | 531 | | | - | - |
| Temperature [°C] | Floor insulation – case 1 | 12,8 | 5,6 | | | 21,1 | 14,5 |
| | Floor insulation – case 2 | 13,5 | 7,4 | | | - | - |
| Relative Humidity [%] | Floor insulation – case 1 | 59,6 | - | | | 64,7 | - |
| | Floor insulation – case 2 | 67,3 | 86,3 | | | - | - |

*Table 11 Chemical indoor environmental characteristics (floor insulations)*

| Type of renovation | | Prior to renovation | | < 6 months after renovation | | > 6 months after renovation | |
|---|---|---|---|---|---|---|---|
| | | IN | OUT | IN | OUT | IN | OUT |
| $PM_{2.5}$ [µg/m³] | Floor insulation - case 1 | 82,6 | 9,3 | | | 192 | 106 |
| | Floor insulation - case 2 | 16,3 | 27,8 | | | - | - |
| TVOC [µg/m³] | Floor insulation - case 1 | 53 | 135 | | | 302 | 138 |
| | Floor insulation - case 2 | 788 | 61 | 255 | - | - | - |
| formaldehyde [µg/m³] | Floor insulation - case 1 | 0,5 | 2,3 | | | 30,56 | 3,34 |
| | Floor insulation - case 2 | 14,7 | 0,8 | | | - | - |
| acetaldehyde [µg/m³] | Floor insulation - case 1 | 0,06 | 0,10 | | | 1,25 | 0,50 |
| | Floor insulation - case 2 | 1,10 | 0,04 | | | - | - |
| total other aldehydes [µg/m³] | Floor insulation - case 1 | 0,24 | 5,1 | | | 16,45 | 12,08 |
| | Floor insulation - case 2 | 5,23 | 0,4 | | | - | - |

→ **Ventilation**

No case before and after is available.

→ **Moisture in walls and thermography**

In case 2 (house no. 4), the IR surface temperature measurements are only performed after the renovation works have been carried out, in order to check the quality. In case 1 (House no. 3), a distinct difference in surface temperature of the floor could be detected (from 3°C below indoor air temperature before renovation to equal to indoor air temperature after renovation).

The results before and after renovation are considered to be normal. No specific comments were made by the respondents for this renovation type.

#### 3.2.3. EVALUATION OF THE SITUATION AFTER THE RENOVATION

**→ Indoor air quality**

A screening of VOCs and isocyanates, within one week after the installation of the floor insulation in case 2 (house no. 4), did not indicate elevated indoor levels of these compounds, except for a catalyst:

- An isocyanate quantification according to MDHS 25/3 for the determination of organic isocyanates in air, using 1-(2-methoxyphenyl)piperazine coated glass fibre filters reported 2,4-toluylendiisocyanate, 2,6-toluylendiisocyanate, diphenylmethan-4,4'-diisocyanate, and 1,6-hexamethylendiisocyanate in 3 locations of the insulated flooring in concentration levels below the detection limit of 0.01 mg/m³. Note that only a selection of isocyanates was measured – possibly other isocyanates, not measured here, have been emitted.
- A screening of indoor VOCs has led to concentrations below the detection limit of 1 µg/m³ for the major part of the VOCs listed in Table 12. N,N-dimethyl-benzenemethanamine, or dimethylbenzylamine, the highest concentrated VOC that was determined, is likely to originate from the PU flooring, as it is known to be used as a catalyst in the formation of PU foam. In a ppt presentation 'SPF crawl space insulation: Impact on indoor air quality', Havermans et al. (2013, TNO) reported living room concentrations of 0.5 µg/m³ and crawl space concentrations of 216 µg/m³ 6 days after the PU application. Compared to these concentrations, the concentrations quantified in the Renovair study are low, however the living room concentration is higher than the one reported by Havermans et al (2013).

*Table 12 VOC screening less than 6 months post installation of a PU flooring*

| VOC compound | Concentration [µg/m³] |
|---|---|
| 1-butanole | < 1,0 |
| Benzene | 1,0 |
| pentanal | < 1,0 |
| heptane | < 1,0 |
| methylisibutylketone | < 1,0 |
| toluene | < 1,0 |
| hexanal | 1,7 |
| n-butylacetate | < 1,0 |
| tetrachloorethene | < 1,0 |
| furfural | < 1,0 |
| ethylbenzene | < 1,0 |
| p+m-xylene | < 1,0 |
| heptanal | < 1,0 |
| styrene | < 1,0 |
| butylglycol | < 1,0 |
| o-xylene | < 1,0 |
| cyclohexanon | < 1,0 |
| alfa-pinene | < 1,0 |
| fenol | < 1,0 |

| | |
|---|---|
| 1,3,5-Trimethylbenzene | < 1,0 |
| beta-pinene | < 1,0 |
| octanal | < 1,0 |
| 1,2,4-trimethylbenzene | < 1,0 |
| 3-carene | < 1,0 |
| 2-ethyl-1-hexanol | 1,1 |
| 1,4-dichloorbenzene | < 1,0 |
| 1,2,3-Trimethylbenzene | < 1,0 |
| limonene | 1,1 |
| 1-methyl-2-pyrrolidon | < 1,0 |
| 1,2-dichloorbenzene | < 1,0 |
| undecane | 1,8 |
| nonanal | 3,3 |
| butyldiglycol | < 1,0 |
| n-dodecane | < 1,0 |
| decanal | 3,3 |
| n-tetradecane | < 1,0 |
| Decane* | 3,9 |
| **N,N-dimethyl-benzenemethanamine*** | **12** |
| Nonanal* | 2,6 |
| Decanal* | 2,8 |

** semi-quantitative*

### → Ventilation

The measured air leakage rates are shown in Table 13. The measurement for case 1 was performed during the renovation phase. All the cracks were sealed, but in the summer of 2016 a ventilation system (type C) will still be installed. The volume of the dwelling was estimated using the cadastral map to estimate the air change rate per hour. As for type 1, the airtightness is in line with contemporary standard construction. Underfloor insulation is deemed to have a minimal effect on the overall airtightness of the dwelling.

*Table 13 Air flow rate and air changes per hour at 50Pa for the two cases*

| | Type of renovation | pre renovation | | | post renovation (> 6 months) | | |
|---|---|---|---|---|---|---|---|
| | | Under pressure | Over pressure | Average | Under pressure | Over pressure | Average |
| $V_{50}$ [m³/h] | Floor insulation – case 1 | | | | 2328 | 2267 | 2297.5 |
| | Floor insulation – case 2 | | | | | | |
| $n_{50}$ [1/h] | Floor insulation – case 1 | | | | 6.1 | 4.5 | 5.3 |
| | Floor insulation – case 2 | | | | | | |

### → Moisture in walls and thermography

In Interim Report 1, thermal bridges appearing at the junctions with other construction elements (e.g. interior walls) were identified as a risk when placing floor insulation. In this study, no thermal bridges were detected in neither of both dwellings

To our opinion, it not feasible to make an in depth comparison in terms of well-being of the responses for this renovation type with all other responses.

#### 3.2.4. EVALUATION OF THE EFFECTIVENESS OF FLOOR INSULATIONS

In Case 1 (house 3), the U-value of the floor drastically decreased (to 16% of the original U-value) after installation of the floor insulation, confirming the benefit that was aimed for by the house owners when performing this renovation type. The renovation intervention is not in compliance with the EPB regulations (which was not an obligation), which is often not feasible due to height restrictions for the floor composition.

As suggested in the initial objectives and benefits resulting from this renovation type, energy-savings will result from this intervention, but a (temporary) impact on IAQ was quantified.

To our opinion, it is not possible to infer any conclusions about the technical effectiveness in terms of well-being due to the small size of the study population.

### 3.3. THE IMPACT OF TREATMENTS AGAINST RISING DAMP ON THE INDOOR ENVIRONMENT (RENOVATION TYPE C)

#### 3.3.1. THE STUDIED CASES

Two houses with treatments against rising damp were studied in Renovair: in case 1 (house no. 5) the detached house is constructed in 1967, whilst case 2 (house no. 6), a semi-detached house, is constructed in 1925. Both houses have floor- and roof insulation, and a new heating installation. Case 1 has façade insulation, and case 2 has upgraded windows.

None of the cases has a mechanical ventilation system.

#### 3.3.2. COMPARISON OF THE SITUATION BEFORE AND AFTER THE RENOVATION

In terms of indoor $CO_2$, temperature and relative humidity, no difference can be identified pre and post renovation (Table 14). In both houses indoor $PM_{2.5}$ has increased after the renovation, however, the outdoor concentrations indicate that this is most likely resulting from higher outdoor concentrations during the second sampling week (post renovation), see Table 14.

*Table 14 Physical indoor environment characteristics (rising damp)*

| | Type of renovation | Prior to renovation | | < 6 months after renovation | | > 6 months after renovation | |
|---|---|---|---|---|---|---|---|
| | | IN | OUT | IN | OUT | IN | OUT |
| $CO_2$ [ppm] | Rising damp – case 1 | 532 | 536 | | | 549 | 439 |
| | Rising damp – case 2 | 552 | 414 | | | 521 | 477 |
| Temperature [°C] | Rising damp – case 1 | 18,9 | 7,8 | | | 20,3 | 15,2 |
| | Rising damp – case 2 | 16,3 | 2,9 | | | 21,3 | 15,7 |
| Relative Humidity [%] | Rising damp – case 1 | 53,6 | - | | | 56,5 | 69,2 |
| | Rising damp – case 2 | 54,7 | - | | | 49,4 | - |

Post renovation, approximately one week after treating the walls against rising damp, a temporary increase of TVOC was noticed in both cases: whilst in case 1 the indoor TVOC concentration raised in tenfold, in case 2 the concentration doubled. After 6 months, the indoor TVOC concentration decreased again to 3 times the initial TVOC level in case 1 and it equalized the initial concentration in case 2. A visualisation of this evolution is illustrated in Figure 8.

Even though indoor aldehydes increased post renovation, these augmentations are small, and not likely to be related to be related to the renovation activity that took place.

*Table 15 Chemical indoor environmental characteristics (rising damp)*

| Type of renovation | | Prior to renovation | | < 6 months after renovation | | > 6 months after renovation | |
|---|---|---|---|---|---|---|---|
| | | IN | OUT | IN | OUT | IN | OUT |
| $PM_{2.5}$ [µg/m³] | Rising damp – case 1 | 8,8 | 15,8 | | | 58,4 | 52,2 |
| | Rising damp – case 2 | 10,8 | 16,6 | | | 72,3 | 97,1 |
| TVOC [µg/m³] | Rising damp – case 1 | 124 | 62 | 1187 | | 410 | 129 |
| | Rising damp – case 2 | 123 | 13 | 219 | | 150 | 31 |
| formaldehyde [µg/m³] | Rising damp – case 1 | 12,8 | 0,5 | | | 23,51 | 2,60 |
| | Rising damp – case 2 | 18,4 | 2,0 | | | 14,93 | 2,35 |
| acetaldehyde [µg/m³] | Rising damp – case 1 | 1,89 | 0,01 | | | 5,96 | 0,25 |
| | Rising damp – case 2 | 11,93 | 0,35 | | | 5,74 | 0,50 |
| total other aldehydes [µg/m³] | Rising damp – case 1 | 2,36 | 1,1 | | | 8,76 | 8,21 |
| | Rising damp – case 2 | 4,44 | 3,1 | | | 4,62 | 8,79 |

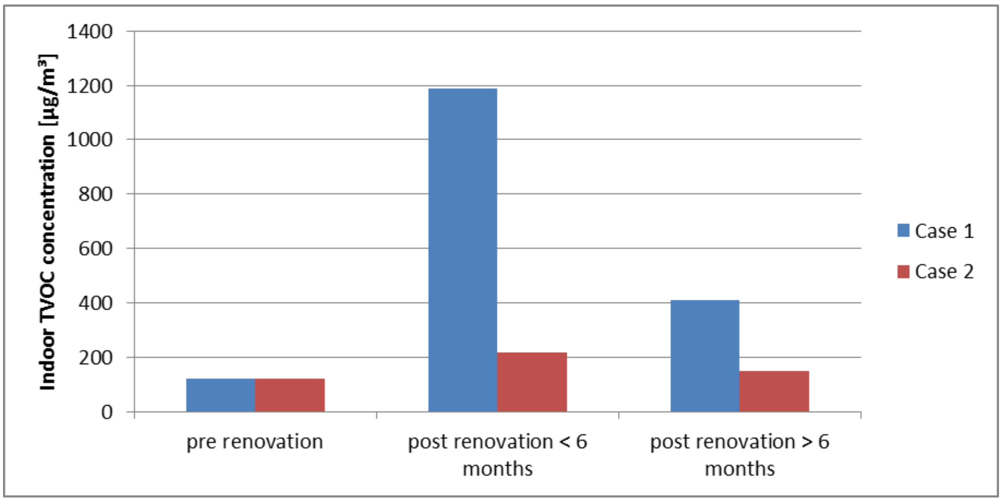



*Figure 8 Indoor TVOC concentration decay after wall treatment against rising damp*

A more detailed analysis of 18 indoor VOCs, quantified by means of passive samplers, doesn't highlight the increase of any of these organic compounds.

However, a screening of indoor VOCs, collected by means of active sampling, (1) confirms the indoor concentrations that were quantified using passive samplers, and (2) indicates the presence of certain 'unidentified' organic compounds in higher concentration levels, as well as expoxysilanes, likely to be resulting from the indoor use of products against rising damp in walls, containing exopy resins.

*Table 16 Quantified VOCs pre and post treatment against rising damp, in µg/m³*

| | | Pre renovation | post renovation < 6 months | post renovation > 6 months |
|---|---|---|---|---|
| MTBE | Case 1 | < 0,35 | < 0,35 | < 0,35 |
| | Case 2 | < 0,35 | < 0,35 | < 0,35 |
| Benzene | Case 1 | 1,35 | 0,72 | 0,33 |
| | Case 2 | 1,66 | 1,82 | 0,43 |
| Trichloroethene | Case 1 | 12,50 | 2,93 | 5,75 |
| | Case 2 | 0,41 | 0,61 | < 0,35 |
| Toluene | Case 1 | 7,36 | 2,36 | 3,69 |
| | Case 2 | 2,00 | 2,42 | 1,01 |
| Tetrachloroethene | Case 1 | < 0,35 | < 0,35 | < 0,35 |
| | Case 2 | < 0,35 | < 0,35 | < 0,35 |
| Ethylbenzene | Case 1 | 1,37 | 0,50 | 0,75 |
| | Case 2 | < 0,35 | 0,48 | < 0,35 |
| m- + p-Xylene | Case 1 | 4,55 | 1,46 | 2,21 |
| | Case 2 | 0,85 | 0,76 | 0,60 |
| Styrene | Case 1 | < 0,35 | < 0,35 | < 0,35 |
| | Case 2 | < 0,35 | < 0,35 | < 0,35 |
| o-Xylene | Case 1 | 1,64 | 0,55 | 0,80 |
| | Case 2 | 0,54 | < 0,35 | < 0,35 |
| 1,2,4-Trimethyl-benzene | Case 1 | 2,07 | 0,74 | 1,10 |
| | Case 2 | < 0,35 | < 0,35 | < 0,35 |
| '1,4-Dichloro-benzene | Case 1 | < 0,35 | < 0,35 | < 0,35 |
| | Case 2 | < 0,35 | < 0,35 | < 0,35 |
| Hexane | Case 1 | 0,70 | 0,40 | 0,57 |
| | Case 2 | 1,41 | 1,37 | < 0,35 |
| Heptane | Case 1 | 0,64 | < 0,35 | 0,65 |
| | Case 2 | 1,09 | 7,12 | < 0,35 |
| Cyclohexane | Case 1 | 0,68 | < 0,35 | 1,07 |
| | Case 2 | 1,02 | 1,89 | < 0,35 |
| n-Butylacetate | Case 1 | 8,22 | 3,51 | 1,43 |
| | Case 2 | 5,29 | 0,59 | 1,79 |
| a-Pinene | Case 1 | 4,94 | 1,75 | 3,61 |
| | Case 2 | 15,2 | 12,8 | 10,5 |
| 3-Carene | Case 1 | 1,45 | 0,68 | 1,61 |
| | Case 2 | 10,1 | 9,01 | 7,66 |
| d10-Limonene | Case 1 | 20,5 | 26,7 | 9,23 |
| | Case 2 | 5,48 | 21,5 | 9,53 |

*Table 17 Screening of indoor VOCs less than 6 months after wall treatments against rising damp, in µg/m³*

| | Case 1 (House no. 5) | Case 2 (House no. 6) |
|---|---|---|
| 1-butanol | < 1,0 | **1,9** |
| Benzeen | **2,2** | **2,0** |
| pentanal | < 1,0 | < 1,0 |
| heptaan | < 1,0 | **1,4** |
| methylisibutylketon | < 1,0 | < 1,0 |
| tolueen | **5,4** | **4,0** |
| hexanal | **1,3** | **3,1** |
| n-butylacetaat | **2,2** | < 1,0 |
| tetrachlooretheen | < 1,0 | < 1,0 |
| furfural | < 1,0 | < 1,0 |
| ethylbenzeen | < 1,0 | < 1,0 |
| p+m-xyleen | **3,6** | **1,1** |
| heptanal | < 1,0 | **0,9** |
| styreen | < 1,0 | < 1,0 |
| butylglycol | < 1,0 | < 1,0 |
| o-xyleen | < 1,0 | < 1,0 |
| cyclohexanon | < 1,0 | < 1,0 |
| alfa-pineen | **1,4** | **6,6** |
| fenol | < 1,0 | < 1,0 |
| 1,3,5-Trimethylbenzeen | < 1,0 | < 1,0 |
| beta-pineen | < 1,0 | < 1,0 |
| octanal | **2,2** | **1,7** |
| 1,2,4-trimethylbenzeen | < 1,0 | **1,1** |
| 3-careen | < 1,0 | **5,2** |
| 2-ethyl-1-hexanol | < 1,0 | **1,5** |
| 1,4-dichloorbenzeen | < 1,0 | < 1,0 |
| 1,2,3-Trimethylbenzeen | < 1,0 | < 1,0 |
| limoneen | **30** | **3,9** |
| 1-methyl-2-pyrrolidon | < 1,0 | < 1,0 |
| 1,2-dichloorbenzeen | < 1,0 | < 1,0 |
| undecaan | **2,0** | **1,4** |
| nonanal | **3,2** | **3,5** |
| butyldiglycol | < 1,0 | **1,6** |
| n-dodecaan | < 1,0 | < 1,0 |
| decanal | **3,4** | **3,8** |
| n-tetradecaan | < 1,0 | **1,4** |
| trichloorethyleen | **4,6** | - |
| unidentified/1* | **5,5** | - |
| unidentified/2* | **36** | - |
| unidentified/3* | **137** | - |

| | Case 1 (House no. 5) | Case 2 (House no. 6) |
|---|---|---|
| *continuation of Table 17* | | |
| propyleenglycol* | - | **4,5** |
| di-ethoxymethaan* | - | **5,1** |
| 4-chloro-3-methylfenol* | - | **8,3** |
| tri-ethoxypentylsilaan* | **29** | **75** |
| dodecyltri-ethoxysilaan* | **22** | **11** |

** semi-quantitative*

→ **Ventilation**

For both cases the air tightness of the building was measured before and after the renovation. The volume of the two dwellings was estimated using the cadastral map. Taking into account the inaccuracy on a blower door measurement, in the first case no significant change in leakage level was observed. For the second case the air leakage rate increased, which indicates a lower air tightness of the building after the renovation, but again the significance of the effect is small.

*Figure 9: Air flow rate and air change rate per hour at 50Pa before and after the renovation for the two cases*

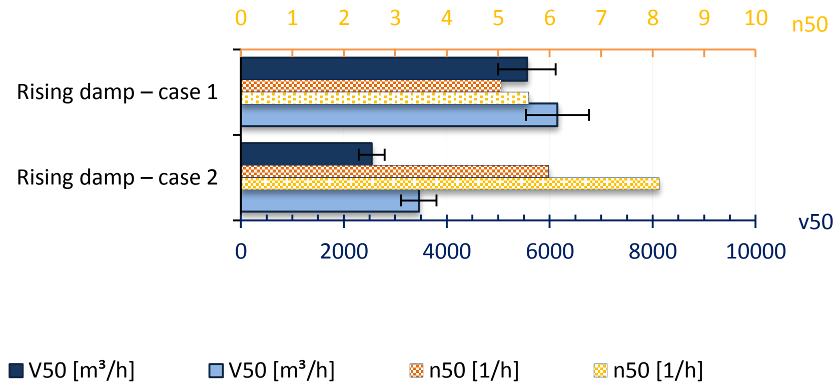



*Table 18 Air flow rate and air changes per hour at 50Pa for the two cases*

| | Type of renovation | pre renovation | | | post renovation (> 6 months) | | |
|---|---|---|---|---|---|---|---|
| | | Under pressure | Over pressure | Average | Under pressure | Over pressure | Average |
| $V_{50}$ [m³/h] | Rising damp – case 1 | 5229 | 5890 | 5559.5 | 6837 | 5461 | 6149 |
| | Rising damp – case 2 | 2432 | 2649 | 2540.5 | 3938 | 2973 | 3456 |
| $n_{50}$ [1/h] | Rising damp – case 1 | 4.8 | 5.4 | 5.1 | 6.2 | 5.0 | 5.6 |
| | Rising damp – case 2 | 5.7 | 6.2 | 6.0 | 9.3 | 7.0 | 8.1 |

→ **Moisture in walls and thermography**

In case 2 (house no. 5), no improvement on the humidity levels of the interior kitchen walls was detected. In case 2 (house nr 6), the interventions to prevent rising damp effectively resulted in lower humidity levels of the interior walls at ground level.

→ **Indoor comfort**

For renovation type C, 3 paired results are available; in the situation before, all three scores are low, but after renovation, two results are falling into the higher categories. However, no specific complaints were found referring to odour perception which might have resulted from a treatment witch chemical products against rising damp. The responses are not suggestive of a decrease in perception of well-being that could be attributed to the renovation type. The results before and after renovation are considered to be normal. No specific comments were made by the respondents for this renovation type.

### 3.3.3. EVALUATION OF THE SITUATION AFTER THE RENOVATION

→ **Indoor Air Quality**

Both cases studied to explore the impact of treatments against rising damp in walls, demonstrate a temporary increase of TVOC directly after the renovation, followed by a decrease of indoor TVOC, in one case until the initial TVOC concentration was reached. This finding illustrates a successful and correct installation and use of the materials, in which the augmentation of emissions indoors remains temporary and limited.

Open literature is available on incorrect installations of epoxy binders, in which elevated indoor VOC levels up to several milligrams (a.o. of linande, benzene, toluene) have been reported (Rella et al. 2014). In Flanders, examples of incorrect wall treatment against rising damp are available as well (Huislabo AZG, 2011-2015). A comparison of the Renovair data with these data confirms the correct installation and use of the materials in Renovair (illustrated in Table 11).

*Table 19: Indoor VOC concentrations post wall treatment against rising damp (in µg/m³)*

| | *Health Complaint House 1** | | | *Health Complaint House 2** | | *Renovair Case 1* | | *Renovair Case 2* | | *Median reference value*** | *P75 reference value*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *<< 6 m* | *6 m* | *12 m* | *<< 6 m* | *6 m* | *<< 6 m* | *6 m* | *<< 6 m* | *6 m* | | |
| MTBE | < 0,2 | < 0,2 | < 0,2 | 22 | 0,4 | < 0,35 | < 0,35 | < 0,35 | < 0,35 | 0,3 | 0,6 |
| Benzene | 0,3 | 1,0 | 0,6 | 7,5 | 1,3 | 0,7 | 0,3 | 1,8 | 0,4 | 1 | 1,7 |
| Toluene | 3,8 | 3,8 | 4,5 | 100 | 3 | 2,4 | 3,7 | 2,4 | 1,0 | 5,1 | 11,1 |
| Tetrachloroethene | < 0,2 | < 0,2 | 0,3 | <DL | < 0,1 | < 0,35 | < 0,35 | < 0,35 | < 0,35 | 0,1 | 0,2 |
| Ethylbenzene | 0,7 | 0,4 | 0,3 | 5,7 | 0,3 | 0,5 | 0,7 | 0,5 | < 0,35 | 0,7 | 1,2 |
| m- + p-Xylene | 2,51 | 1,41 | 1 | 19 | 0,8 | 1,5 | 2,2 | 0,8 | 0,6 | 1,6 | 3,3 |
| o-Xylene | 1,1 | 0,9 | 0,7 | 6,4 | 0,2 | 0,6 | 0,8 | < 0,35 | < 0,35 | 0,6 | 1,2 |

| | *Health Complaint House 1** | | | *Health Complaint House 2** | | *Renovair Case 1* | | *Renovair Case 2* | | *Median reference value*** | *P75 reference value*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *<< 6 m* | *6 m* | *12 m* | *<< 6 m* | *6 m* | *<< 6 m* | *6 m* | *<< 6 m* | *6 m* | | |
| 1,2,4-TMB | 0,5 | 0,7 | 1,3 | 18 | < 0,1 | 0,7 | 1,1 | < 0,35 | < 0,35 | - | - |
| Pentane | 0,4 | 2,3 | 4,2 | 27 | 2,0 | - | - | - | - | 1,1 | 2,9 |
| Hexane | 1,6 | < 0,20 | 0,4 | 17 | 0,7 | 0,4 | 0,6 | 1,4 | < 0,35 | 1 | 1,8 |
| Heptane | 16,9 | 0,3 | 0,4 | 9,1 | 2,3 | < 0,35 | 0,6 | 7,1 | < 0,35 | 0,9 | 2,1 |
| Cyclohexane | 3,7 | < 0,20 | < 0,20 | 3,3 | 0,3 | < 0,35 | 1,1 | 1,9 | < 0,35 | 0,7 | 1,7 |
| a-Pinene | n.a. | 15 | 1,5 | 3,8 | | 1,7 | 3,6 | 12,8 | 10,5 | 3,6 | 8,2 |
| d10-Limonene | n.a. | < 0,20 | 17,9 | 7,3 | | 26,7 | 9,2 | 21,5 | 9,5 | 13,2 | 29,7 |
| n-Butylacetate | n.a. | 0,4 | 1,4 | 0,8 | | 3,5 | 1,4 | 0,6 | 1,8 | 1,4 | 2,8 |
| TVOC | 6.640 | 14.600 | 12.500 | 6.330 | 345 | 1.190 | 410 | 219 | 150 | 337 | 463 |
| C10-C14 * | n.a. | 13.800 | 12.200 | 2.880 | 314 | - | - | - | - | | |

* Huislabo, AZG 2011-2015
** Surveillance Health Complaint-free houses, AZG 2008-2012

In this table it can be noticed that in both health complaint houses indoor TVOC levels up to 14,6 mg/m³ and 6,3 mg/m³ respectively were quantified. A temporary increased ventilation and heating was found to be effective in health complaint house 2, whilst the same remedial actions appeared to be not effective in health complaint house 1. Indoor TVOC and VOC concentrations in the studied Renovair cases were considerably lower, indicating that in these houses a correct installation and use of the building materials was applied. Even though indoor levels in Renovair case 1 temporary exceeded 1000 µg/m³, 6 months after the installation the indoor concentrations had decreased up to levels that equalize or are lower than the median (337 µg/m³) as well as the P75 (463 µg/m³) reference concentration quantified in 'the Surveillance of Health Complaint-free houses'. The reference concentrations were determined based on a large scale IAQ assessment in a set of 450 health complaint free Flemish houses (Surveillance of health compliant-free houses, 2012, Public Health Service, Flemish Government).

In case 1, the TVOC concentration that was quantified shortly after the wall treatment, is in the German Indoor Air Guide value range of 1-3 mg/m³, defined as 'should not be exceeded in rooms intended for long-term residence'. 6 months after the renovation, the indoor concentrations had decreased until the range, that is defined in the German Indoor Air Guide values as being ideal indoor TVOC concentrations. The indoor TVOC levels in case 2 have been in accordance with the ideal conditions during the whole renovation process. In both health complaint houses on the contrary, the measured TVOC concentrations were in the range that according to the German Indoor Guide values are 'reasonable for daily stays on a short term', defined by a concentration range of 10-25 mg/m³.

### → **Ventilation**

No case before and after is available.

→ **Moisture in walls and thermography**

In case 1 (House no. 5), the interior kitchen walls contained a high level of humidity even after the renovation, while in case 2 (House 6) the humidity levels at the interior walls are clearly lower.

To our opinion, it not feasible to make an in depth comparison in terms of well-being of the responses for this renovation type with all other responses.

#### 3.3.4. EVALUATION OF THE EFFECTIVENESS OF TREATMENTS AGAINST RISING DAMP

To our opinion, it is not possible to infer any conclusions about the technical effectiveness in terms of well-being. What could however be noticed is that, even when the materials are correctly used, a temporary deterioration of the IAQ can occur, which is then found to improve within 6 months post renovation. It is noticed that the highest indoor TVOC concentrations were measured in the houses where wall treatment against rising damp appeared to be least effective. Based on this small dataset, a coincidence cannot be excluded here.

### 3.4. THE IMPACT OF THOROUGH RENOVATIONS ON THE INDOOR ENVIRONMENT (RENOVATION TYPE D)

#### 3.4.1. THE STUDIED CASES

In total 5 different cases of thorough renovations were studied in Renovair, of which one was studied before and after these renovations. The other 4 cases were only studied after the renovation. The studied cases contain houses constructed between 1933 and 1972, including 2 semi-detached houses, 2 detached houses and one terraced house (the latter house was studied before and after the renovation took place).

In case 1, case 1, case 3, and case 4, the thorough energy-efficient renovation included an upgrade of windows, façade insulation, roof as well as floor insulation and the installation of a new heating system. Cases 2 and 4 applied a treatment against rising damp and have a mechanical ventilation system type D, whilst both initiatives were not applied in cases 1 and 3.

An overview of the residences' locations is shown in Table 20.

*Table 20 Overview of the studied thorough renovation cases*

| nr | Renovation activity | Construction date | Environment | Type | Construction |
|---|---|---|---|---|---|
| 7 | Combi/thorough – case 1 | 1972 | urban | semi-detached | bricks |
| 8 | Combi/thorough – case 2 | 1933 | rural | detached | bricks |
| 9 | Combi/thorough – case 3 | 1952 | urban | detached | bricks |
| 10 | Combi/thorough – case 4 | 1850 | urban | semi-detached | bricks |
| 11 | Combi/thorough – case 5 | 1960 | urban | terraced | bricks |

Cases 1 and 2 (House no. 7 and 8) have been renovated in phases, spread over a time frame of 3 years maximum. Cases 3 to 5 (Houses 9 until 11) have been renovated in a shorter period of time, with renovation durations of less than 1 year.

In case 5 (House no. 11) mechanical ventilation system D was already installed before the measurements took place. The studied renovations included an upgrade of windows, façade insulation, roof insulation as well as floor insulation.

### 3.4.2. COMPARISON OF THE SITUATION BEFORE AND AFTER THE RENOVATION

**→ Indoor Air Quality**

The situation before and after the renovation was evaluated in case 5 (House no. 11) from the combi/thorough renovation cases. In terms of indoor $CO_2$, temperature and relative humidity, no difference between the initial and post renovation was quantified, as reported in Table 21.

*Table 21 Physical indoor environment characteristics (thorough renovations)*

| | Type of renovation | Prior to renovation | | < 6 months after renovation | | > 6 months after renovation | |
|---|---|---|---|---|---|---|---|
| | | IN | OUT | IN | OUT | IN | OUT |
| $CO_2$ [ppm] | Combi/thorough – case 1 | | | | | - | 483* |
| | Combi/thorough – case 2 | | | | | 505 | 407 |
| | Combi/thorough – case 3 | | | | | 651 | 531 |
| | Combi/thorough – case 4 | | | | | 657 | 510 |
| | Combi/thorough – case 5 | 800 | 483* | | | 721 | 483* |
| Temperature [°C] | Combi/thorough – case 1 | | | | | 19 | - |
| | Combi/thorough – case 2 | | | | | 18 | 4,1 |
| | Combi/thorough – case 3 | | | | | 13,5 | 7,4 |
| | Combi/thorough – case 4 | | | | | 22,2 | 14,5 |
| | Combi/thorough – case 5 | 21,4 | - | | | 19,2 | 12,3 |
| Relative Humidity [%] | Combi/thorough – case 1 | | | | | 44,5 | - |
| | Combi/thorough – case 2 | | | | | 49,8 | - |
| | Combi/thorough – case 3 | | | | | 67,3 | 86,3 |
| | Combi/thorough – case 4 | | | | | 62,3 | 77,8 |
| | Combi/thorough – case 5 | 58,4 | - | | | 64,5 | - |

Post renovation, indoor $PM_{2.5}$ (250 µg/m³), TVOC (212 µg/m³) and total other aldehydes (13 µg/m³) were found to be increased (Table 11) compared to the initial conditions for case 5, most likely resulting from renovation works that were still ongoing at the time of the air quality assessment (the construction works were delayed). For $PM_{2.5}$ and TVOC, it should however be noticed that outdoor levels were higher at the time of the measurement 6 months post renovations, compared to the situation before the renovation, which also must have contributed to the higher indoor concentrations post renovation.

*Table 22 Chemical indoor environmental characteristics (thorough renovations)*

| Type of renovation | | Prior to renovation | | < 6 months after renovation | | > 6 months after renovation | |
|---|---|---|---|---|---|---|---|
| | | IN | OUT | IN | OUT | IN | OUT |
| $PM_{2.5}$ [µg/m³] | Combi/thorough – case 1 | | | | | 22 | 30,1 |
| | Combi/thorough – case 2 | | | | | 19,6 | 24,1 |
| | Combi/thorough – case 3 | | | | | 16,3 | 27,8 |
| | Combi/thorough – case 4 | | | | | 5,8 | 20,3 |
| | Combi/thorough – case 5 | 8,9 | 11,2 | | | 248 | 57,2 |
| TVOC [µg/m³] | Combi/thorough – case 1 | | | | | 101 | 47 |
| | Combi/thorough – case 2 | | | | | 352 | 85 |
| | Combi/thorough – case 3 | | | | | 788 | 61 |
| | Combi/thorough – case 4 | | | | | 178 | 51 |
| | Combi/thorough – case 5 | 63 | 24 | | | 212 | 129 |
| formaldehyde [µg/m³] | Combi/thorough – case 1 | | | | | 13,29 | 1,99 |
| | Combi/thorough – case 2 | | | | | 18,22 | 3,07 |
| | Combi/thorough – case 3 | | | | | 14,71 | 0,76 |
| | Combi/thorough – case 4 | | | | | 82,54 | 2,49 |
| | Combi/thorough – case 5 | 29,3 | 2,6 | | | 30,69 | 0,31 |
| acetaldehyde [µg/m³] | Combi/thorough – case 1 | | | | | 3,95 | 0,12 |
| | Combi/thorough – case 2 | | | | | 5,37 | 0,09 |
| | Combi/thorough – case 3 | | | | | 1,10 | 0,04 |
| | Combi/thorough – case 4 | | | | | 0,82 | 3,17 |
| | Combi/thorough – case 5 | 0,91 | 0,50 | | | 3,03 | 0,50 |
| total other aldehydes [µg/m³] | Combi/thorough – case 1 | | | | | 11,63 | 3,09 |
| | Combi/thorough – case 2 | | | | | 7,49 | 4,59 |
| | Combi/thorough – case 3 | | | | | 5,23 | 0,41 |
| | Combi/thorough – case 4 | | | | | 0,84 | 18,80 |
| | Combi/thorough – case 5 | 5,72 | 2,2 | | | 12,73 | 4,28 |

A more detailed exploration of VOC components, shown in Table 23, doesn't indicate the increase of any of the quantified VOCs after the renovation activity.

*Table 23 Quantified VOCs pre and post a thorough renovation, expressed in µg/m³*

| | *Prior to renovation* | | *< 6 months after renovation* | | *> 6 months after renovation* | |
|---|---|---|---|---|---|---|
| | IN | OUT | IN | OUT | IN | OUT |
| MTBE | < 0,35 | < 0,35 | | | < 0,35 | < 0,35 |
| Benzene | 0,73 | 0,47 | | | 0,54 | < 0,35 |
| Trichloroethene | < 0,35 | < 0,35 | | | < 0,35 | < 0,35 |
| Toluene | 2,93 | 7,88 | | | 2,47 | 0,59 |
| Tetrachloroethene | < 0,35 | < 0,35 | | | < 0,35 | < 0,35 |
| Ethylbenzene | < 0,35 | 1,07 | | | < 0,35 | < 0,35 |
| m- + p-Xylene | 0,82 | 4,27 | | | 0,66 | < 0,35 |
| Styrene | < 0,35 | < 0,35 | | | < 0,35 | < 0,35 |
| o-Xylene | < 0,35 | 2,31 | | | < 0,35 | < 0,35 |
| 1,2,4-Trimethyl-benzene | 0,61 | 1,45 | | | 0,53 | < 0,35 |
| 1,4-Dichloro-benzene | < 0,35 | < 0,35 | | | < 0,35 | < 0,35 |
| Hexane | 0,60 | 0,56 | | | 0,55 | < 0,35 |
| Heptane | 0,81 | 1,32 | | | < 0,35 | < 0,35 |
| Cyclohexane | < 0,35 | < 0,35 | | | < 0,35 | < 0,35 |
| n-Butylacetate | 1,36 | 3,82 | | | < 0,35 | < 0,35 |
| a-Pinene | 2,35 | 10,0 | | | < 0,35 | < 0,35 |
| 3-Carene | 0,77 | 4,13 | | | < 0,35 | < 0,35 |
| d10-Limonene | 2,42 | 19,3 | | | < 0,35 | < 0,35 |

### → Ventilation

No case before and after is available.

### → Moisture in walls and thermography

In case 5 (House no. 11), thermal bridges were detected (e.g. ring girder at the base of the sloped roof in front and rear façade) both before and after the renovation. These thermal bridges became more pronounced after the renovation (although part of that phenomenon is caused by higher air temperature difference between interior and exterior).

### → Comfort

Again, it is very difficult to make a before – after comparison since only one response was available for this type before renovation. This single result was intermediary before renovation and remained in the same category after renovation. Two respondents commented that their house was uninhabitable before renovation and that this was the reason why they could not participate in the questionnaire before renovation. Cases 1, 4 and 5 were renovated with guidance of an architect, the other renovations were not.

### 3.4.3. EVALUATION OF THE SITUATION AFTER THE RENOVATION

→ **Indoor Air Quality**

Even though case 1 (House nr 7) and case 3 (House nr 9) have no mechanical ventilation system (all other thorough renovation cases have a controlled air intake and exhaust), no distinct difference between indoor $CO_2$ can be noticed – note that $CO_2$ data are missing for case 1. In case 2 (House nr 8), where the mechanical ventilation system has a recirculation function, no distinct difference with the other cases could be identified. $CO_2$ time profiles all clearly reflect the presence and absence of building occupants during the time of the measurements. Because $CO_2$ measurements were performed in the living room, the lowest indoor $CO_2$ of the day is detected early in the morning, and peak concentrations are found before occupants leave the house. The 5 studied cases had a comparable amount of 3 tot 4 occupants; each with employed adults, except for case 3 (House 9), where the average occupancy was 1-2 occupants.

Indoor $PM_{2.5}$ concentrations in all 5 cases are low (below 20 µg/m³), except in case 5 where increased indoor levels are likely to be related to (1) higher outdoor concentrations during the post renovation measurements, and (2) renovation activities that were still ongoing when collecting the post renovation data (a delayed renovation schedule).

Indoor TVOC in the thoroughly renovated houses are all but one found to be below the P75 (463 µg/m³) as well as median concentration (337 µg/m³) that was determined as a reference value for health complaint-free houses in Flanders (Surveillance of health compliant-free houses, 2012, Public Health Service, Flemish Government). In case 3 (House no. 9) the highest indoor TVOC concentration of all Renovair measurements 6 months post renovation is detected (788 µg/m³), whilst corresponding outdoor levels were low (60 µg/m³). Even though the quantified VOCs in this house (listed in Table 24) don't occur in elevated concentrations, a screening of the chromatogram learned that higher alkanes (decane, 4-methyldecane, undecane,…) were the major contributors to the high TVOC concentration in this houses, most probably resulting from the use of building materials such as floor adhesives, wood stain or floor finishing. The measured $CO_2$ concentration in this house at a relatively low occupancy (1-2 occupants), is clearly not a good indicator for TVOC concentration in this case of low building occupancy.

Table 24 gives an overview of quantified VOCs post renovation in the 5 studied cases. Benzene levels equalling the Flemish IAQ guideline value of 2 µg/m³, were quantified in case 2, but are likely to result from the outdoor levels which approximate the same concentration. The highest toluene and xylene concentrations were measured in case 5, in which renovation activities were still ongoing. The elevated pinene, limonene and careen concentrations in cases 3, 4 and 5 were likely to be related to the use of cleaning agents or air fresheners indoors.

*Table 24 Quantified VOCs post thorough renovations, expressed in µg/m³*

| Number | Type of renovation | Prior to renovation | < 6 months after renovation | > 6 months after renovation |
|---|---|---|---|---|
| **MTBE** | Combi/thorough – case 1 | | | < 0,35 |
| | Combi/thorough – case 2 | | | < 0,35 |
| | Combi/thorough – case 3 | | | 0,60 |
| | Combi/thorough – case 4 | | | < 0,35 |

| Number | Type of renovation | Prior to renovation | < 6 months after renovation | > 6 months after renovation |
|---|---|---|---|---|
| | Combi/thorough – case 5 | < 0,35 | | < 0,35 |
| **benzene** | Combi/thorough – case 1 | | | 1,20 |
| | Combi/thorough – case 2 | | | 2,69 |
| | Combi/thorough – case 3 | | | 1,84 |
| | Combi/thorough – case 4 | | | 0,71 |
| | Combi/thorough – case 5 | 0,73 | | 0,47 |
| **Trichloroethene** | Combi/thorough – case 1 | | | 2,59 |
| | Combi/thorough – case 2 | | | < 0,35 |
| | Combi/thorough – case 3 | | | < 0,35 |
| | Combi/thorough – case 4 | | | < 0,35 |
| | Combi/thorough – case 5 | < 0,35 | | < 0,35 |
| **Toluene** | Combi/thorough – case 1 | | | 2,75 |
| | Combi/thorough – case 2 | | | 2,86 |
| | Combi/thorough – case 3 | | | 4,87 |
| | Combi/thorough – case 4 | | | 2,55 |
| | Combi/thorough – case 5 | 2,93 | | 7,88 |
| **Tetrachloroethene** | Combi/thorough – case 1 | | | < 0,35 |
| | Combi/thorough – case 2 | | | < 0,35 |
| | Combi/thorough – case 3 | | | < 0,35 |
| | Combi/thorough – case 4 | | | < 0,35 |
| | Combi/thorough – case 5 | < 0,35 | | < 0,35 |
| **Ethylbenzene** | Combi/thorough – case 1 | | | < 0,35 |
| | Combi/thorough – case 2 | | | < 0,35 |
| | Combi/thorough – case 3 | | | 0,55 |
| | Combi/thorough – case 4 | | | 0,60 |
| | Combi/thorough – case 5 | < 0,35 | | 1,07 |
| **m- + p-Xylene** | Combi/thorough – case 1 | | | 0,67 |
| | Combi/thorough – case 2 | | | 0,79 |
| | Combi/thorough – case 3 | | | 1,39 |
| | Combi/thorough – case 4 | | | 1,13 |
| | Combi/thorough – case 5 | 0,82 | | 4,27 |
| **Styrene** | Combi/thorough – case 1 | | | < 0,35 |
| | Combi/thorough – case 2 | | | < 0,35 |
| | Combi/thorough – case 3 | | | < 0,35 |
| | Combi/thorough – case 4 | | | < 0,35 |
| | Combi/thorough – case 5 | < 0,35 | | < 0,35 |
| **o-Xylene** | Combi/thorough – case 1 | | | 0,49 |
| | Combi/thorough – case 2 | | | 0,70 |
| | Combi/thorough – case 3 | | | 0,57 |
| | Combi/thorough – case 4 | | | 0,65 |
| | Combi/thorough – case 5 | < 0,35 | | 2,31 |
| **1,2,4-Trimethyl-benzene** | Combi/thorough – case 1 | | | 0,60 |
| | Combi/thorough – case 2 | | | < 0,35 |
| | Combi/thorough – case 3 | | | < 0,35 |
| | Combi/thorough – case 4 | | | 0,67 |

| Number | Type of renovation | | | |
|---|---|---|---|---|
| | | Prior to renovation | < 6 months after renovation | > 6 months after renovation |
| | Combi/thorough – case 5 | 0,61 | | 1,45 |
| '1,4-Dichloro-benzene | Combi/thorough – case 1 | | | < 0,35 |
| | Combi/thorough – case 2 | | | < 0,35 |
| | Combi/thorough – case 3 | | | < 0,35 |
| | Combi/thorough – case 4 | | | < 0,35 |
| | Combi/thorough – case 5 | < 0,35 | | < 0,35 |
| Hexane | Combi/thorough – case 1 | | | 0,64 |
| | Combi/thorough – case 2 | | | 1,60 |
| | Combi/thorough – case 3 | | | 1,56 |
| | Combi/thorough – case 4 | | | 0,63 |
| | Combi/thorough – case 5 | 0,60 | | 0,56 |
| Heptane | Combi/thorough – case 1 | | | 0,48 |
| | Combi/thorough – case 2 | | | 0,93 |
| | Combi/thorough – case 3 | | | 0,51 |
| | Combi/thorough – case 4 | | | 0,49 |
| | Combi/thorough – case 5 | 0,81 | | 1,32 |
| Cyclohexane | Combi/thorough – case 1 | | | 0,59 |
| | Combi/thorough – case 2 | | | 0,96 |
| | Combi/thorough – case 3 | | | 0,51 |
| | Combi/thorough – case 4 | | | 0,50 |
| | Combi/thorough – case 5 | < 0,35 | | < 0,35 |
| n-Butylacetate | Combi/thorough – case 1 | | | 0,53 |
| | Combi/thorough – case 2 | | | 1,66 |
| | Combi/thorough – case 3 | | | 0,69 |
| | Combi/thorough – case 4 | | | 1,18 |
| | Combi/thorough – case 5 | 1,36 | | 3,82 |
| a-Pinene | Combi/thorough – case 1 | | | 7,92 |
| | Combi/thorough – case 2 | | | 28,6 |
| | Combi/thorough – case 3 | | | 23,6 |
| | Combi/thorough – case 4 | | | 6,31 |
| | Combi/thorough – case 5 | 2,35 | | 10,0 |
| 3-Carene | Combi/thorough – case 1 | | | 2,48 |
| | Combi/thorough – case 2 | | | 12,8 |
| | Combi/thorough – case 3 | | | 18,6 |
| | Combi/thorough – case 4 | | | 2,28 |
| | Combi/thorough – case 5 | 0,77 | | 4,13 |
| d10-Limonene | Combi/thorough – case 1 | | | 39,7 |
| | Combi/thorough – case 2 | | | 32,0 |
| | Combi/thorough – case 3 | | | 6,04 |
| | Combi/thorough – case 4 | | | 15,8 |
| | Combi/thorough – case 5 | 2,42 | | 19,3 |

→ **Ventilation**

The measured air leakage rates are shown in Table 25. For case 1, case 2, case3 and case 5 the volume of the dwelling was estimated using the cadastral map to estimate the air change rate per hour. For case 4 the volume was obtained from a certificate of the Blower door test.

Compared to the other renovation types, lower values for the air leakage rate could be observed after the renovation (case 1, case 4). In the future, the air tightness of case 1 will probably be further improved as the door-wall interfaces still need to be finished and the skirting boards still have to be placed. Taking this into account, cases 1 and 4 approach the requirements for passive standard air tightness ($n_{50}$ = 0.6) and can be characterised as very airtight compared to the other dwellings in the study.

*Table 25 Air flow rate and air changes per hour at 50Pa for the five cases*

| | Type of renovation | pre renovation | | | post renovation (> 6 months) | | |
|---|---|---|---|---|---|---|---|
| | | Under pressure | Over pressure | Average | Under pressure | Over pressure | Average |
| $V_{50}$ [m³/h] | Combi/thorough – case 1 | | | | 1894 | 2047 | 1970.5 |
| | Combi/thorough – case 2 | | | | 3846 | 4058 | 3952 |
| | Combi/thorough – case 3 | | | | | | |
| | Combi/thorough – case 4 | | | | 202 | 187 | 194.5 |
| | Combi/thorough – case 5 | 4339 | 3701 | 4020 | | | |
| $n_{50}$ [1/h] | Combi/thorough – case 1 | | | | 1.4 | 1.5 | 1.5 |
| | Combi/thorough – case 2 | | | | 7.4 | 7.8 | 7.6 |
| | Combi/thorough – case 3 | | | | | | |
| | Combi/thorough – case 4 | | | | 0.7 | 0.7 | 0.7 |
| | Combi/thorough – case 5 | 4339 | 3701 | 4020 | | | |

For case 2, case 3 and case 4 the ventilation system was already in operation. The air flow rate of the ventilation system was measured by using a Flowfinder. Results are listed in Table 26. In case of a renovation (expansion or partial reconstruction) only newly created rooms have to fulfil the requirements. Because it is not known whether the rooms were new or not, these values are only used as reference. (values in brackets Table 26). Furthermore, it is not possible for all rooms to evaluate the measured air flow rate to existing guidelines and standards because the floor area is not available.
Note:

- In case 2 it was not possible to install an outlet vent in the toilet. Therefore, a flow-through was created from the toilet to the bathroom, which is not conform the requirements.
- In some cases the measured flow rate can deviate from the real flow rate because the supply or outlet was difficult to access (*Figure 10*). This is the case in case 3 and case 4 (bathroom), leading to quite low air flow rates, far beneath the recommended or required values.

*Table 26 Overview of the type of ventilation (A/B/C/D) and ventilation rate[m³/h] for case 2-4*

| | System | *Space* | **flow rate [m³/h]** |
|---|---|---|---|
| | | | **> 6 months after renovation** |

| Type of renovation | | | | nominal | maximum | auto |
|---|---|---|---|---|---|---|
| Combi/thorough – case 2 | D | Entrance /bureau [* - min 25] | supply | 18 | 38 | 18 |
| | | Living room [* - min 75] | supply | 20 | 42 | 22 |
| | | Kitchen | outlet | 28 [50] | 64 [50] | 28 [50] |
| | | Laundry room | exhaust | 21 [50] | 36 [50] | 19 [50] |
| | | Bathroom | exhaust | 26 [50] | 59 [50] | 25 [50] |
| | | Toilet (*Note) | flow through | 4 [25] | 2 [25] | 4 [25] |
| | | Bedroom (at stairs) [* - min 25] | supply | 51 | 105 | 49 |
| | | Bedroom [* - min 25] | supply | 31 | 65 | 30 |
| | | hallway | outlet | 19 | 51 | 22 |
| Combi/thorough – case 3 | B | Ground Floor - living 1 (side wall) | supply | 9 | | |
| | | Ground Floor - living 2 (façade) | supply | 7 | | |
| | | Ground Floor - dressing | supply | 6 | | |
| | | Second Floor - Bedroom 1 (back) | supply | 14 [* - min 25] | | |
| | | Second Floor - Bedroom 2 (façade) | supply | 10 [* - min 25] | | |
| Combi/thorough – case 4 | D | Ground Floor- Bureau left | supply | 30 [* - min 25] | | |
| | | Ground Floor- Bureau right | supply | 30 [* - min 25] | | |
| | | Ground Floor-Bureau Outlet | exhaust | 25 | | |
| | | Second Floor - Living room | supply | 47 [* - min. 75] | | |
| | | Third Floor – Bad room | exhaust | 40 [50] | | |
| | | Third Floor - Bedroom | inlet | 44 [* - min 25] | | |
| | | Fourth Floor - Kitchen | exhaust | 59 [50] | | |
| | | Fifth Floor - Bedroom | inlet | 39 [* - min 25] | | |
| | | Fifth Floor - technical facilities | exhaust | 29 | | |

* Related to floor area 3,6 $m^3/h.m^2$

*Figure 10: Sometimes the supply or exhaust outlet was difficult to access, leading to errors in the measurement of the air flow rate.*

In general, except for Case 3, the measured air flow rates are more or less in accordance with the requirements. In Case 3 they are far below the requirements and have virtually no impact on the airflow in the dwelling.

→ **Moisture in walls and thermography**

Heat leakages around the joinery parts in the façades are present in most of the studied cases (garage in case 2, front door in house 7, 9, and 11), probably caused by air leakages.

Thermal bridges (window lintels in house 7 and 8, and ring girder in house 11) are visible in the thermograms. These thermal bridges appear slightly in the cases which are renovated in phases (house 7 and 8) and more distinct in case 11 which was renovated in a shorter time period.

In house 7, the front façade is insulated while the rear façade is not (although this was initially planned but not yet in place). However the difference between the surface temperatures of both façades is limited. In house 9, the original façades (especially the front façade) display some limited surface temperature differences. Moisture measurements don't reveal problems, so the source of this small temperature differences cannot be pinpointed.

Other surface temperature deviations are low compared to temperature conditions during the measurements.

After renovation, for only one out of six respondents, an intermediate result is seen. This is acceptable since according to our model it is considered as "normal" that up to 33% of all building residents exhibit some slight complaints attributed to the indoor environment. To our opinion, it not feasible to make an in depth comparison in terms of well-being of the responses for this renovation type with all other responses.

#### 3.4.4. EVALUATION OF THE EFFECTIVENESS OF THOROUGH RENOVATIONS

Compared to other renovation types, a thorough renovation makes it easier to improve the air tightness of the building. (Not possible to relate this to the demand or mind-set of the owner or to the type of interventions). Therefore, lower values for the air leakage rate could be observed. (case 1, case 4).

In House 10, a large number of different technical solutions were combined depending on the exact location of the building enclosure component. For the heat transfer coefficient assessment, the component with the highest U-value after the intervention will be reported (e.g. the side façades have a higher U-value than the front façade, due to lower thickness of the outer insulation). For house 9, no data regarding building component compositions could be retrieved from the home owners.

The heat transfer coefficients of all parts of the thorough renovation cases, were drastically improved. None of the studied cases were obliged to be in compliance with the EPB regulations. The included window and insulated roof upgrades however were for all cases in compliance, while the façade insulation was only in some cases in compliance. The upgraded floor insulation was for all cases not in compliance (similar to effectiveness of renovation type B).

To our opinion, it is not possible to infer any conclusions about the technical effectiveness in terms of well-being due.

## 3.5. THE IMPACT OF THE INSTALLATION OF MECHANICAL VENTILATION ON THE INDOOR ENVIRONMENT (RENOVATION TYPE E)

### 3.5.1. THE STUDIED CASES

Both houses in which the impact of the installation of a mechanical ventilation system is studied, are detached houses. Case 1 (house 12) was constructed in 1959, and case 2 (House 13) was built in 1969. Both houses have insulated floor, roof and façades as well as upgraded windows.

In case 1 (house 12) a type C-like mechanical ventilation with trickle ventilators and controlled exhaust was installed, in case 2 (house 13) a mechanical ventilation type D, with controlled air intake and exhaust was installed.

### 3.5.2. COMPARISON OF THE SITUATION BEFORE AND AFTER THE RENOVATION

According to Table 27 a clear improvement of the house ventilation in terms of indoor $CO_2$ (decrease of the weekly average concentration from 1055 ppm to 638 ppm) and relative humidity (decease of the weekly average relative humidity of 74 % to 49%) is quantified in case 2, whilst in case 1 no clear difference can be noticed. Note that in case 1 the measurements pre renovation already led to acceptable indoor $CO_2$ concentrations, of 584 ppm.

*Table 27 Physical indoor environment characteristics (mechanical ventilation)*

| | Type of renovation | Prior to renovation | | < 6 months after renovation | | > 6 months after renovation | |
|---|---|---|---|---|---|---|---|
| | | IN | OUT | IN | OUT | IN | OUT |
| $CO_2$ [ppm] | Mechanical ventilation – case 1 | 584 | 481 | | | 740 | 554 |
| | Mechanical ventilation – case 2 | 1055 | 491 | | | 638 | 483* |
| Temperature [°C] | Mechanical ventilation – case 1 | 21,1 | 10,1 | | | 21 | 13,9 |
| | Mechanical ventilation – case 2 | 19,3 | 15,4 | | | 16,4 | 7,2 |
| Relative Humidity [%] | Mechanical ventilation – case 1 | 58 | - | | | 63,8 | - |
| | Mechanical ventilation – case 2 | 74,2 | 76,4 | | | 49,6 | - |

The increased ventilation rate or the effect of air filtration, which both can result from the installation of a ventilation system, are not reflected in the absolute indoor concentrations post renovation (Table 28) because of the higher background (outdoor) $PM_{2.5}$ post renovation in both cases. However, in terms of Indoor/Outdoor ratios, the impact of air cleaning and increased ventilation rate can be noticed: in case 2 the I/O ratio of 1.9 pre renovation decreased to 0.9 post renovation. In case 1, this ratio remained the same pre and post renovation (I/O: 0.8).

An improvement of the indoor environment was found for indoor TVOC, which in both cases decreased to values below 200 µg/m³ although the outdoor background TVOC concentrations augmented post renovations. In terms of TVOC I/O ratio, case 1 demonstrated a decrease from 7.2 to 1.8 and in case 2 the ratio decreased from 8.3 to 1.2. Indoor formaldehyde and total other aldehydes improved mainly in case 2, where a clear improvement of the ventilation rates was also reflected in indoor $CO_2$.

*Table 28 Chemical indoor environmental characteristics (mechanical ventilation)*

| Type of renovation | | Prior to renovation | | < 6 months after renovation | | > 6 months after renovation | |
|---|---|---|---|---|---|---|---|
| | | IN | OUT | IN | OUT | IN | OUT |
| $PM_{2.5}$ [µg/m³] | Mechanical ventilation – case 1 | 9,2 | 10,8 | | | 31 | 37,8 |
| | Mechanical ventilation – case 2 | 8,5 | 4,4 | | | 9,1 | 10,1 |
| TVOC [µg/m³] | Mechanical ventilation – case 1 | 412 | 57 | | | 189 | 106 |
| | Mechanical ventilation – case 2 | 296 | 36 | | | 188 | 152 |
| formaldehyde [µg/m³] | Mechanical ventilation – case 1 | 22,4 | 1,3 | | | 32,7 | 2,6 |
| | Mechanical ventilation – case 2 | 38,2 | 2,6 | | | 12,1 | 1,8 |
| acetaldehyde [µg/m³] | Mechanical ventilation – case 1 | 2,21 | 0,13 | | | 2,2 | 0,5 |
| | Mechanical ventilation – case 2 | 0,25 | 0,50 | | | 4,3 | 0,4 |
| total other aldehydes [µg/m³] | Mechanical ventilation – case 1 | 3,14 | 4,3 | | | 6,6 | 4,1 |
| | Mechanical ventilation – case 2 | 54,5 | 5,5 | | | 9,8 | 5,6 |

In general, the highest concentrated indoor VOCs in Renovair have been quantified in case 1 of this renovation type (House no. 12). Because for most of the organic compounds, similar concentration levels were determined before and after the renovation, their common source doesn't result from this renovation activity. Corresponding outdoor levels were however found to be low. Even though the house is situated at more than 30 m from a major road, and its garage is not used for the car, VOCs that occurred at increased indoor levels all relate to gasoline, combustion or solvents. Amongst others, toluene (48.3 µg/m³ pre and 39.7 µg/m³ post renovation), benzene (3.4 µg/m³ pre and 3.2 µg/m³ post renovation), MTBE (4.0 µg/m³ pre and 3.2 µg/m³ post renovation), 1,2,4-trimethylbenzene (20.2 µg/m³ pre and 7,1 µg/m³ post renovation) occurred in increased concentrations.

### → Ventilation

Results are shown on *Figure 11*. In the first case two variations were measured. For the first variation the attic trapdoor was opened (case 1a), because the attic is part of the protected volume. For the second variation the attic trapdoor was closed (case 1b). The volume of the two dwellings was estimated using the cadastral map to estimate the air change rate per hour. For both cases, an increase in the air leakage rate was noticed after renovation. However, taking into account an inaccuracy of 10% on a blower door measurement, no valid conclusion could be drawn for the air leakage rate before and after the renovation.

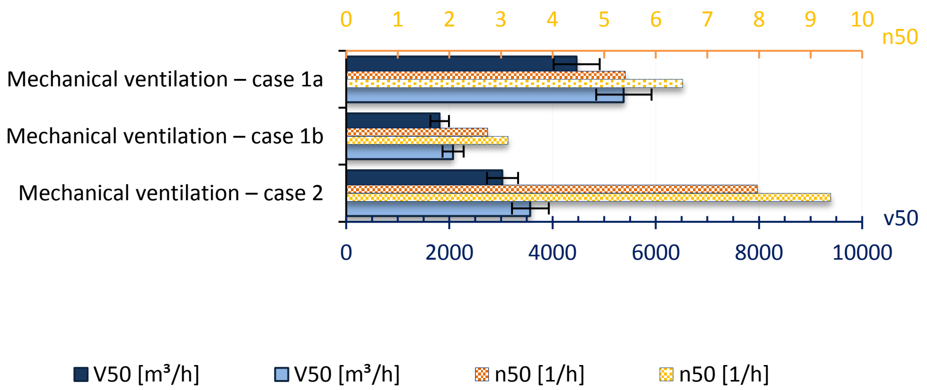



*Figure 11: Air flow rate at 50Pa for the two cases.*

In the first case a ventilation system C-like was installed, while in the second a ventilation system D was installed. For both cases the nominal values were larger than the advised or required minimum ventilation rate.

Note:

- In case 1 it was not possible to measure the ventilation rate for the bedrooms because it was too difficult to reach the vent.

*Table 29 : Air flow rate and air change rate per hour at 50Pa for the two cases*

| | Type of renovation | pre renovation | | | post renovation (> 6 months) | | |
|---|---|---|---|---|---|---|---|
| | | Under pressure | Over pressure | Average | Under pressure | Over pressure | Average |
| $V_{50}$ [m³/h] | Mechanical ventilation – case 1a | 4476 | 4453 | 4464.5 | 6430 | 4331 | 5380.5 |
| | Mechanical ventilation – case 1b | - | 1810 | 1810 | 2325 | 1818 | 2071.5 |
| | Mechanical ventilation – | 2843 | 3216 | 3029.5 | 3350 | 3788 | 3569 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | case 2 | | | | | | |
| $n_{50}$ [m³/h] | Mechanical ventilation – case 1a | 5.4 | 5.4 | 5.4 | 7.8* | 5.2 | 6.5 |
| | Mechanical ventilation – case 1b | - | 2.7 | 2.7 | 3.5 | 2.8 | 9.4 |
| | Mechanical ventilation – case 2 | 7.5 | 8.5 | 8 | 8.8 | 10 | 16 |

*(*) The result of this measurement is questioned, as it deviates from the other measurements of the air tightness from this dwelling.*

*Table 30 Overview of the type of ventilation (C-like/D) and ventilation rate[m³/h] for both cases*

| | System | *Space* | | flow rate [m³/h]** > 6 months after renovation | |
|---|---|---|---|---|---|
| | | | | **Normal (optional)** | **nominal** |
| Mechanical ventilation – case 1 | C-like | Laundry room | exhaust | 18 | 59 [25] |
| | | Kitchen | exhaust | 23 | 68 [50] |
| | | Toilet ground floor | exhaust | 7 | 25 [25] |
| | | Hallway | | 8 | 34 |
| | | Toilet first floor | exhaust | 4 | 29 [25] |
| | | Bedroom | exhaust | Not possible to measure | |
| | | Bathroom | exhaust | 36 | 36 [50] |
| Mechanical ventilation – case 2 | D | Living room | supply | 30 | 55 [* - min 75] |
| | | Living room (at window) | supply | 39 | 63 [* - min 25] |
| | | Kitchen 1 | exhaust | 30 | 58 [50] |
| | | Kitchen 2 (corner) | exhaust | 33 | 59 [50] |
| | | Bedroom | supply | 34 | 65 [* - min 25] |
| | | Bathroom | exhaust | 36 | 70 [* - min 50] |
| | | Bedroom | supply | 32 | 55 [* - min 25] |
| | | Toilet | exhaust | 25 | 44 [* - min 25] |

* Related to floor area 3,6 m³/h.m²

### → Moisture in walls and thermography

No changes occurred in surface temperature analysis between before and after renovation. In case 2 (house 13), the elevated moisture levels in the cellar walls were not present any more during the measurement after the renovation. Based on this limited measurement campaign, it cannot be concluded that the moisture problem in case 2 is definitively solved. Installing a ventilation system in the dwelling will probably has no or a very limited effect on the air replenishment in the cellar. The differences in moisture levels could also be due to seasonal changes in humidity and temperature levels (pre renovation more elevated relative humidity was measured inside and outside case 2; post renovation the indoor level was lower as well).

For this type of renovation, only 2 paired results are available; in the situation before, one score was high, one was low. After renovation, the high score remained high and the low score became higher. However, no specific complaints were found referring to air quality which might have resulted from an upgrade of the ventilation system. Specific comments made were: slight experience of draught due to the presence of ventilation air grids and noise due to the presence of the National Airport. The presence of the National Airport was however not reflected in the outdoor air quality measurements at this house.

#### 3.5.3. EVALUATION OF THE SITUATION AFTER THE RENOVATION

**→ IAQ (chem, microbio)**

See 3.5.2

**→ Ventilation**

See 3.5.2

**→ Moisture in walls and thermography**

Thermal bridges (window lintels in case 12 and window sills and doorsteps in case 13) are clear on the thermographic images of both cases (both have insulated walls).

To our opinion, it not feasible to make an in depth comparison in terms of well-being of the responses for this renovation type with all other responses.

#### 3.5.4. EVALUATION OF THE EFFECTIVENESS OF MECHANICAL VENTILATION INSTALLATION

To our opinion, it is not possible to infer any conclusions about the technical effectiveness in terms of well-being.

### 3.6. THE IMPACT OF AIR FILTER REPLACEMENT ON THE INDOOR ENVIRONMENT (RENOVATION TYPE F)

#### 3.6.1. THE STUDIED CASES

The impact of this basic initiative of ventilation system maintenance was studied in two classrooms of one school. The school was constructed in 2011, and is mechanically ventilated with a controlled air intake and exhaust, using a $CO_2$ demand-controlled system. The school participated in an IAQ study organised by LNE and VEA in 2012 (Clean Air Low Energy study).

The air filters, F7-type, of the mechanical ventilation system have not been replaced at the recommended maintenance frequency until now (i.e. filter replacement every 6 months). This intervention study therefore implied the IEQ assessment pre and post filter replacement. The IEQ assessment was performed in two classrooms: the first classroom hosts pupils aged 7-8 years old, the second classroom hosts pupils aged 10-11 years old. Figure 12 illustrates the playground and classroom environments.

*Figure 12 Indoor and outdoor sampling locations in classroom 1*

### 3.6.2. COMPARISON OF THE SITUATION BEFORE AND AFTER THE RENOVATION

According to Table 31 in the two studied classrooms, $PM_{2.5}$, TVOC, formaldehyde, acetaldehyde and total other aldehyde concentrations can be considered comparable pre and post filter replacement. Moderately higher indoor $PM_{2.5}$ concentrations in one of the classrooms (case 1) after replacing the air filter, are most probably related to the increased outdoor levels during the second sampling week. $PM_{2.5}$ I/O ratios of 0,6 and 0,2 before the filter replacement, and of 0,8 and 0,43 confirm these comparable indoor conditions in terms of the listed air pollutants. Ratios of formaldehyde, acetaldehyde and total other aldehydes exceed unity as expected, however, the exceedance remains unchanged after replacing the air filters by new ones. Figure 13 shows the comparable I/O ratios before and after air filter replacements.

For case 14 (air filter replacement, case 1) we observed somewhat elevated levels post intervention. Also this finding is difficult to interpret, but could theoretically imply elevated fungal levels post intervention due to the cleaning activities.

*Table 31 Overview of IAQ before and after filter replacement (in µg/m³)*

| Type of renovation | | Prior to renovation | | < 6 months after renovation | | > 6 months after renovation | |
|---|---|---|---|---|---|---|---|
| | | IN | OUT | IN | OUT | IN | OUT |
| $PM_{2.5}$ [µg/m³] | Air filter replacement – case 1 | 47,2 | 77 | | | 106 | 132 |
| | Air filter replacement – case 2 | 19,2 | 77 | | | 57 | 132 |
| TVOC [µg/m³] | Air filter replacement – case 1 | 66 | 239 | | | 152 | 264 |
| | Air filter replacement – case 2 | 150 | 239 | | | 308 | 264 |
| formaldehyde [µg/m³] | Air filter replacement – case 1 | 13,3 | 3,0 | | | 18,6 | 3,7 |
| | Air filter replacement – case 2 | 10,2 | 3,0 | | | 15,5 | 3,7 |
| acetaldehyde [µg/m³] | Air filter replacement – case 1 | 4,37 | 0,60 | | | 8,41 | 1,25 |
| | Air filter replacement – case 2 | 2,71 | 0,60 | | | 5,72 | 1,25 |
| total other aldehydes [µg/m³] | Air filter replacement – case 1 | 6,97 | 5,7 | | | 7,13 | 2,58 |
| | Air filter replacement – case 2 | 3,4 | 5,7 | | | 5,29 | 2,58 |

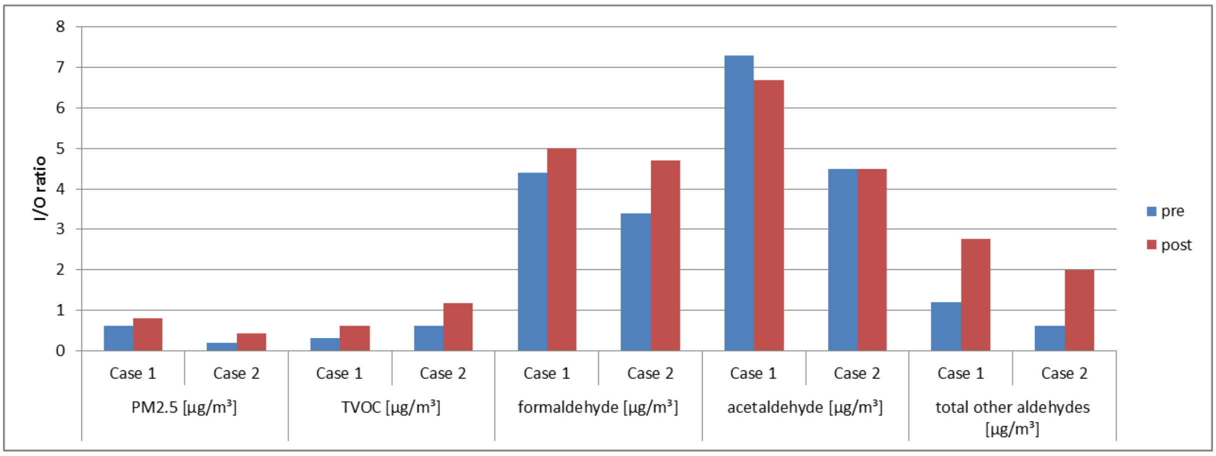



*Figure 13 I/O ratio's pre and post air filter replacement in classrooms*

All other VOCs that have been quantified in both classrooms, occurred in concentrations that represented outdoor conditions or indoor emissions related to the specificity of the classroom. E.g. indoor benzene was more increased indoors post filter replacement (2,0 µg/m³ in case 1 and 2,17 in case 2) than before the intervention (0,68 µg/m³ and 0,72 µg/m³respectively), which is confirmed by the corresponding outdoor concentrations of 0,68 µg/m³ before the intervention and 2,4 µg/m³ after the intervention. In case of local indoor classroom influences, one of the two classrooms was characterized by a moderately elevated indoor concentration during both sampling weeks. Only limonene was found in higher concentrations after the filter replacement (pre filter replacement case 1 and case 2: 8,5 µg/m³, after filter replacement case 1 17,5 µg/m³ and case 2 12 µg/m³). However, the fact that this was found in both classrooms indicates a relation to a cleaning activity that took place inside both classrooms at the time of the second sampling campaign.

### 3.6.3. EVALUATION OF THE SITUATION AFTER THE RENOVATION

#### → Indoor Air Quality

Compared to existing school IAQ data in Flanders (Table 33), the overall concentration levels in the two studied classrooms are within the same range, except for butylacetate, limonene, $PM_{2.5}$ and $CO_2$. Butylacetate, reported to be emitted by lacquers, inks, coatings, and adhesives, but also from various fruits (WHO, 2005), was found to be more elevated in one classroom (case 1) both before and after the intervention, and thus is likely to be related to the classroom indoor environment. The elevated indoor $PM_{2.5}$ concentration is likely to be related to the outdoor conditions, since at this school the outdoor levels were amongst the highest of the Renovair dataset. The elevated outdoor levels are less reflected in the second classroom (Case 2), which is likely to be related to window opening during lunchbreaks (teachers have reported that during the lunch break the ventilation system is turned off and windows are opened).

Contrary to the expectations, in both classrooms indoor $CO_2$ was as elevated as the levels that were measured in the non-mechanically ventilated classrooms, mostly after the intervention. The highest average indoor $CO_2$ levels was measured in Case 2, which is in agreement with the ventilation characterisations.

→ **Ventilation**

Results of the blower door measurements are shown at Table 32. Although the two class rooms are nearly the same, a large difference in air tightness was measured. Unlike case 1 (classroom 2), case 2 (classroom 5) is located under a pitched roof, separated by a false ceiling. Consequently the measured volume is much larger than the volume of the class room.

*Table 32 Air flow rate and air changes per hour at 50Pa for the two cases*

| | Type of renovation | pre renovation | | | post renovation (> 6 months) | | |
|---|---|---|---|---|---|---|---|
| | | Under pressure | Over pressure | Average | Under pressure | Over pressure | Average |
| $V_{50}$ [m³/h] | Duct cleaning – classroom 1 | | | | 982 | 1045 | 1013 |
| | Duct cleaning – classroom 2 | | | | 4239 | 6140 | 5190 |
| $n_{50}$ [1/h] | Duct cleaning – classroom 1 | | | | 6.4 | 6.8 | 6.6 |
| | Duct cleaning – classroom 2 | | | | 27.7 | 40.1 | 33.9 |

The air leakage in the space above the suspended ceiling is hard to trace. Nevertheless, the overall airtightness of case 2 is far worse than that of case 1. The duct cleaning, however, does not affect the airtightness.

*Table 33 Overview of the IAQ data pre and post intervention in both classrooms, compared to existing Flemish school IAQ data*

| Compound | Renovair Case 1 - pre filter replacement | Renovair case 2 pre filter replacement | Renovair Case 1 post filter replacement | Renovair Case 2 post filter replacement | Clean air Low Energy schools | | | | BiBa | |
|---|---|---|---|---|---|---|---|---|---|---|
| in µg/m³ | | | | | Average ± stdev | Min-max | P25 | P75 | Average ± stdev | Min-max |
| MTBE | < 0,35 | < 0,35 | 0,49 | 0,49 | 0,14 ± 0,10 | 0,10 - 0,41 | 0,1 | 0,1 | 0.36 ± 0.46 | 0.02 – 3.22 |
| Benzene | 0,68 | 0,72 | 2,05 | 2,17 | 0,98 ± 0,57 | 0,10 - 2,02 | 0,6 | 1,28 | 1.41 ± 0.88 | 0.44 – 4.0 |
| Trichloroethene | < 0,35 | < 0,35 | < 0,35 | < 0,35 | 0,10 ± 0,00 | 0,10 - 0,10 | 0,1 | 0,1 | | |
| Toluene | 1,37 | 2,39 | 2,08 | 4,96 | 3,13 ± 2,68 | 0,94 - 10,90 | 1,38 | 4,15 | 3.49 ± 4.82 | 0.91 – 40.4 |
| Tetrachloroethene | < 0,35 | < 0,35 | < 0,35 | < 0,35 | 0,10 ± 0,00 | 0,10 - 0,10 | 0,1 | 0,1 | 0.37 ± 0.44 | 0.10 – 2.16 |
| Ethylbenzene | < 0,35 | < 0,35 | < 0,35 | < 0,35 | 0,43 ± 0,34 | 0,10 - 1,67 | 0,24 | 0,49 | 1.74 ± 4.36 | 0.17 – 36.2 |
| m- + p-Xylene | < 0,35 | < 0,35 | 0,72 | 0,93 | 1,12 ± 1,11 | 0,29 - 5,70 | 0,52 | 1,28 | 4.88 ± 6.79 | 0.61 - 166 |
| Styrene | < 0,35 | < 0,35 | < 0,35 | < 0,35 | 0,11 ± 0,04 | 0,10 - 0,29 | 0,1 | 0,1 | | |
| o-Xylene | < 0,35 | < 0,35 | < 0,35 | < 0,35 | 0,41 ± 0,44 | 0,10 - 2,10 | 0,15 | 0,59 | 1.08 ± 1.16 | 0.20 – 26.6 |
| 1,2,4-Trimethylbenzene | < 0,35 | < 0,35 | < 0,35 | 1,30 | 1,65 ± 4,41 | 0,21 - 23,0 | 0,33 | 0,87 | 5.3 ± 19.9 | 0.34 - 178 |
| 1,4-Dichlorobenzene | < 0,35 | < 0,35 | < 0,35 | < 0,35 | 0,15 ± 0,06 | 0,10 - 0,23 | 0,1 | 0,21 | | |
| tVOC | 66 | 150 | 152 | 308 | 318 ± 193 | 184 – 1175 | 239 | 314 | 238 ± 164 | 18 – 1126 |
| Hexane | 0,72 | 0,71 | 1,99 | 2,29 | 0,84 ± 0,63 | 0,28 - 2,38 | 0,39 | 0,95 | | |
| Heptane | 1,21 | < 0,35 | 1,90 | 1,06 | 0,93 ± 1,33 | 0,10 - 5,50 | 0,25 | 0,68 | | |
| Cyclohexane | < 0,35 | < 0,35 | 0,83 | 1,07 | 5,65 ± 14,03 | 0,24 - 72 | 0,47 | 4,7 | | |
| n-Butylacetate | 4,76 | 1,61 | 8,42 | 1,96 | 2,15 ± 2,03 | 0,20 - 8,50 | 1,05 | 2,26 | | |
| alfa-Pinene | < 0,35 | < 0,35 | < 0,35 | < 0,35 | 4,27 ± 7,06 | 0,10 -34,00 | 1,19 | 3,7 | | |
| 3-Carene | < 0,35 | < 0,35 | < 0,35 | < 0,35 | 1,79 ± 1,98 | 0,21 - 6,50 | 0,48 | 2,73 | | |
| d10-Limonene | 8,59 | 8,52 | 17,48 | 12,02 | 6,06 ± 6,46 | 0,50 - 20,30 | 1,12 | 11,2 | | |
| Formaldehyde | 13,3 | 10,2 | 18,60 | 15,50 | 16,9 ± 6,8 | 5,0 - 28,8 | 11,2 | 23,4 | 26.0 ± 13 | 6.3 - 71 |
| Acetaldehyde | 4,37 | 2,71 | 8,41 | 5,72 | 8,5 ± 1,7 | 6,3 - 12,5 | 7,3 | 9,6 | 5.40 ± 1,84 | 2.2 - 12,0 |
| Total other aldehydes | 6,97 | 3,42 | 7,13 | 5,29 | 14,02 ± 6,02 | 3,90 - 24,0 | 9,25 | 18,15 | 33.0 ± 15.0 | 8.7 – 78.0 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $PM_{2.5}$ | 47,2 | 19,2 | 106 | 57 | 30 ± 17 | mei/66 | 20 | 36 | 23.2 ± 13.9 | 4.1 – 59.5 |
| **in ppm** | | | | | | | | | | |
| $CO_2$ (24h) | 624 | | 862 | 1390 | 480 ± 96 | 308 - 716 | | | 933 ± 394 | 408 - 2683 |
| I/O $PM_{2.5}$ | 0,6 | 0,2 | 0,8 | 0,4 | 0.88 ± 0.65 | | | | 1.25 ± 1.08 | |
| Temperature [°C] | 19,7 | | 20,6 | 18,7 | 20,5 ± 1,5 | 18,1 - 23,2 | 19,4 | 21,8 | 19 ± 2 | 14 - 24 |
| Relative humidity [%] | 34,5 | | 32,7 | 42,5 | 39,2 ± 13,9 | 15,5 -59,0 | 32,5 | 52,5 | 43 ± 11 | 29 -87 |


*Figure 14: Location of the two cases. Case 2 is located under the pitched roof.*

The air flow rate of the ventilation system was only measured in the normal operating mode.
Each classroom has one exhaust and one supply, both located near the ceiling. Measured values are shown at Table 34. Note: During lunch break, the windows were opened and the ventilation system was not in operation.

*Table 34 Air flow rate and air changes per hour at 50Pa for the two cases*

| | System | *Space* | | **flow rate [m³/h]** | |
|---|---|---|---|---|---|
| | | | | **Pre filter** | **Post filter** |
| Type of renovation | | | | | |
| Filter replacement – Case 1 | D | Classroom 2 – first floor | supply | 219 | 222 |
| | | | exhaust | 249 | 257 |
| Filter replacement – case 2 | D | Classroom 5 – first floor | supply | 227 | 253 |
| | | | exhaust | 213 | 239 |

As can be expected, the total ventilation flow rate is slightly higher after the filter change.

### → Moisture in walls and thermography

Due to time pressure (because of the end of winter time and thus good circumstances for the thermographic assessments), the surface temperature measurements were carried out before the renovation. The replacement of the air filter however doesn't have an effect on the energy losses through the building envelope, thus making this analysis in compliance with the measurement plan.

On the thermographic images, the ventilation outlets in the façade cause some striking warmer areas. Other surface temperature deviations are insignificant compared to temperature conditions during the measurements.

→ **Indoor Comfort: Overview of the momentary indoor comfort survey**

### 3.6.4. RESPONSE AND DESCRIPTIVE STATISTICS

The momentary indoor comfort survey was administered to at least 30 pupils and 1 or 2 teachers (Table 35) and had to be filled out 3 times a week (Monday morning, Wednesday noon, Friday afternoon) during the 3 subsequent weeks. The first two weeks the existing filter was used, the last week, a clean filter was introduced into the ventilation system. This should have resulted in 9 repeated measurements per participant. The number of pupils was counted by means of their name in combination with their classnumber. However, 27 questionnaires were returned without names or classnumbers, making it impossible to connect their results to a specific pupil and thus impairing a repeated measures analysis.
In total, 165 questionnaires were collected, yielding a total response rate of 61%.

*Table 35 Amount of teachers and pupils per school that was asked to fill out the questionnaire*

| | School 1 | School 2 |
|---|---|---|
| **Amount of teachers** | 1 | 1 |
| **Amount of pupils** | 17 | 13 |

The questionnaire consisted out of two parts. A first set of ten questions (Q1- Q10) could be summarized as “How did you feel while being in the classroom the last few days?”, a second set of ten questions (Q12-Q21) as “How did you like your classroom environment the last few days?”. The underlying idea for these two blocks is that as well perceived health complaints (symptoms) as perceived quality of the environment are important determinants for the overall well-being of individuals. Both question blocks are concluded with a more general question of overall satisfaction (Q11 and Q22).
The 7-point scaling system used is the one proposed by Gao *et al.* 2014. In the present study, the letter codes were replaced with numbers, and explanatory drawings were added to make the questionnaire more easy to understand for younger children. A score of 1 represents always the best situation, a score of 7 the worst. A score of 4 can be interpreted as neutral.

A summary of mean answer scores per school (one classroom per school) for each question during the 3 weeks of the study is given in Table 36.

### 3.6.5. PHC AND PQE SCALES

The internal consistency of the two blocks of the questionnaire was checked in a previous phase of the project using cronbach’s alpha measure. Cronbach’s alpha for the perceived health complaints block was 0,864, for the perceived quality of the environment block 0,802. Both values are well above a generally accepted quality limit for research questionnaires of 0,7. The conclusion was that the different item scores per block could be added up to be summarized in two new parameters being the perceived health complaints (PHC) and the perceived quality of the environment (PQE).
The indoor comfort in the classrooms is described by means of the perceived health complaints (PHC) and perceived quality of the environment (PQE) scales. In an exploratory phase, the effect of the filter condition (existing dirty versus new clean filter) on both scales is analysed by means of boxplots (Figure 15). It can clearly be noticed that the distributions are heavily right-skewed. In order to reduce this deviation from normality, a logtransformation was used.

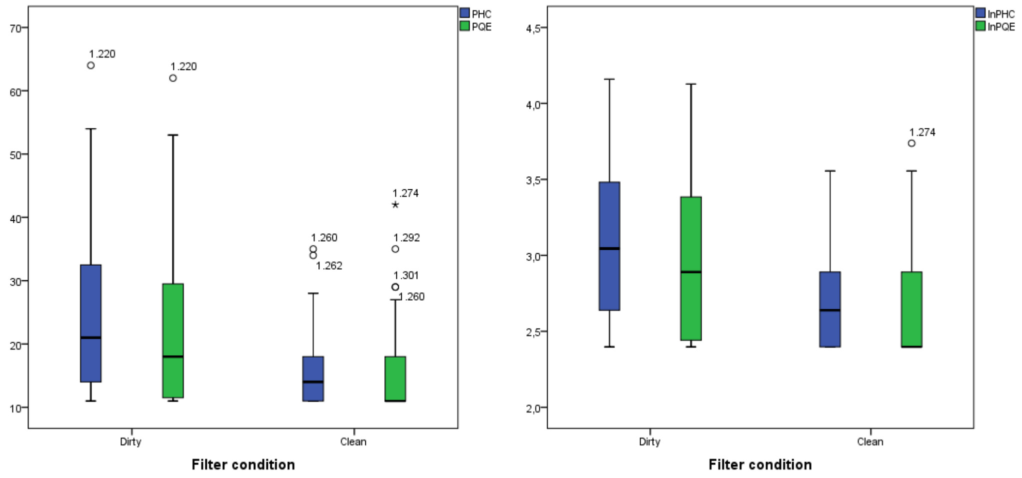



*Figure 15 Boxplots of the original and log-transformed PHC and PQE scales.*

Hereafter, the impact of filter upgrade on both transformed scales was examined using an analysis of variance.

The effect of the filter upgrade was found to be significant on both lnPHC ($F(1,159)=28,169, p<0,001$) and lnPQE($F(1,154)=15,730, p<0,001$).

From these results we can assume that there exists a small but significant effect of introducing a clean filter into the ventilation system on perceived health complaints and on perceived quality of the environment.

*Table 36 Mean perception of symptoms and quality of the environment in the different schools per week of the study; a score of 1 represents a very high degree of satisfaction, 7 a very high degree of dissatisfaction*

| **Classroom** | **Filtration** | **Week** | **Ik had geen verstopte neus (Q1)** | **Ik was niet moe (Q2)** | **Ik had geen pijn aan mijn hoofd (Q3)** | **Ik had geen droge lippen (Q4)** | **Ik was niet ziek (Q5)** | **Mijn ogen prikten of jeukten niet (Q6)** | **Ik was niet draaierig of misselijk (Q7)** | **Ik had geen keelpijn of moest niet hoesten** | **Mijn huid jeukte niet (Q9)** | **Ik had zin om actief mee te werken (Q10)** | ***Ik was tevreden in de klas (Q11)*** | **Ik had het niet te koud (Q12)** | **Het rook fris en aangenaam (Q13)** | **Er was niet teveel lawaai (Q14)** | **Ik voelde geen tocht (Q15)** | **Er was genoeg licht (Q16)** | **De lucht was niet te vochtig (Q17)** | **Ik had het niet te warm (Q18)** | **De luchtkwaliteit was goed (Q19)** | **Er was geen storend licht (Q20)** | **De lucht was niet te droog (Q21)** | ***Ik vond het fijn om in de klas te zijn (Q22)*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | old filter | 1 | 2,73 | 3,73 | 2,75 | 3,68 | 1,65 | 2,47 | 1,75 | 2,98 | 2,26 | 2,65 | 2,25 | 2,63 | 2,1 | 3,64 | 1,62 | 1,2 | 1,72 | 2,95 | 2,15 | 2,56 | 3,1 | 2,13 |
| | old filter | 2 | 2,66 | 2,45 | 2,48 | 2,17 | 1,17 | 1,62 | 1,69 | 1,83 | 1,41 | 1,97 | 1,48 | 1,59 | 1,83 | 1,93 | 1,41 | 1,1 | 1,31 | 2,48 | 1,45 | 1,59 | 1,86 | 2,41 |
| | new filter | 3 | 1,39 | 1,89 | 2,04 | 1,44 | 1,43 | 1,21 | 1,21 | 1,57 | 1,21 | 1,86 | 1,07 | 1,18 | 1,25 | 1,71 | 1 | 1,11 | 1,25 | 2,21 | 1,11 | 1,32 | 1,14 | 2,18 |
| **2** | old filter | 1 | 2,46 | 2,92 | 2,38 | 3,15 | 3,08 | 2,15 | 1,92 | 3,15 | 2,23 | 2,46 | 2,23 | 2,69 | 2,15 | 2,77 | 2,58 | 1,54 | 2 | 2,46 | 2,85 | 1,85 | 3,15 | 2,31 |
| | old filter | 2 | 2,26 | 1,91 | 2,09 | 2,35 | 2,48 | 1,7 | 2,04 | 2,43 | 1,52 | 1,96 | 1,61 | 2,13 | 1,39 | 2,26 | 1,57 | 1,13 | 1,87 | 1,52 | 2 | 1,7 | 1,7 | 1,5 |
| | new filter | 3 | 1,65 | 1,55 | 1,19 | 1,74 | 1,26 | 1,42 | 1,16 | 1,77 | 1,42 | 1,16 | 1,19 | 1,19 | 1,48 | 1,75 | 1,34 | 1,31 | 1,38 | 1,94 | 1,22 | 1,22 | 1,69 | 1,31 |

## 3.7. THE IMPACT OF FAÇADE INSULATION ON THE INDOOR ENVIRONMENT (RENOVATION TYPE G)

### 3.7.1. THE STUDIED CASES

Whilst case 1 is located in a woody environment, case 2 is located in a more rural area. In both cases, window, floor and roof insulations were yet applied before the measurements were performed. By means of cavity insulation the walls were insulated.

### 3.7.2. COMPARISON OF THE SITUATION BEFORE AND AFTER THE RENOVATION

**→ Indoor Air Quality**

In this case of façade insulation, the situation after the intervention was characterised by higher indoor $CO_2$ concentration, increased temperatures as well as increased relative humidity (Table 37). Each of these parameters indicates increased air tightness without increasing the building ventilation by means of aeration (no mechanical ventilation system present).

*Table 37 Physical indoor environment characteristics (façade insulation)*

| | Type of renovation | Prior to renovation | | < 6 months after renovation | | > 6 months after renovation | |
|---|---|---|---|---|---|---|---|
| | | IN | OUT | IN | OUT | IN | OUT |
| $CO_2$ [ppm] | façade insulation – case 1 | 522 | 405 | | | 932 | 483* |
| | façade insulation – case 2 | | | | | 1118 | 483* |
| Temperature [°C] | façade insulation – case 1 | 18 | 6,3 | | | 20,2 | 11 |
| | façade insulation – case 2 | | | | | 18,6 | 2,8 |
| Relative Humidity [%] | façade insulation – case 1 | 46,7 | - | | | 60,4 | - |
| | façade insulation – case 2 | | | | | 49,4 | - |

The more increased indoor $PM_{2.5}$ concentration post renovation is most likely related to the more elevated outdoor concentration during this second sampling period. In spite of the woody environment, background concentrations may be elevated because of e.g. dominant wind directions (data lacking in this study). Before, but even more after the renovation, indoor TVOC levels reached considerably high indoor concentrations, up to 1660 µg/m³; according the German Indoor Guide values classify as 'should not be exceeded in rooms intended for long-term residence'. Also indoor formaldehyde was found in higher indoor concentrations after the renovation. In the first place, both increases are likely to be related to an increased building airtightness after the renovation, whilst remaining the same ventilation habits as before the renovation.

*Table 38 Overview of IAQ before and after façade insulation (in µg/m³)*

| Type of renovation | | Prior to renovation | | < 6 months after renovation | | > 6 months after renovation | |
|---|---|---|---|---|---|---|---|
| | | IN | OUT | IN | OUT | IN | OUT |
| $PM_{2.5}$ [µg/m³] | façade insulation – case 1 | 20,4 | 28,2 | | | 40,2 | 77,9 |
| | façade insulation – case 2 | | | | | 90,3 | 188 |
| TVOC [µg/m³] | façade insulation – case 1 | 204 | 171 | | | 1660 | 165 |
| | façade insulation – case 2 | | | | | 684 | 211 |
| formaldehyde [µg/m³] | façade insulation – case 1 | 15,8 | 2,2 | | | 25,55 | 1,41 |
| | façade insulation – case 2 | | | | | 31,58 | 1,77 |
| acetaldehyde [µg/m³] | façade insulation – case 1 | 3,2 | 0,5 | | | 2,8 | 0,0 |
| | façade insulation – case 2 | | | | | 19,73 | 0,17 |
| total other aldehydes [µg/m³] | façade insulation – case 1 | 5,1 | 3,5 | | | 8,13 | 2,15 |
| | façade insulation – case 2 | | | | | 4,46 | 2,03 |

The more detailed analysis of indoor VOCs in case 1 (Table 39) revealed increased levels of vehicular emissions inside the house, mainly after the renovation. Additional information learned that these emissions can be attributed to the storage of a motor cycle, in an area nearby the living area. In the more airtight and less ventilated situation of case 1, these emissions are more accumulated indoors and resulted in the higher indoor TVOC.

*Table 39 Quantification of VOCs both in case 1 and case 2*

| | Prior to renovation | | < 6 months after renovation | | > 6 months after renovation | |
|---|---|---|---|---|---|---|
| | IN | OUT | IN | OUT | IN | OUT |
| MTBE | 4,85 | < 0,35 | | | 4,85 | < 0,35 |
| Benzene | 2,43 | 1,12 | | | 2,14 | 0,75 |
| Trichloroethene | < 0,35 | < 0,35 | | | < 0,35 | < 0,35 |
| Toluene | 22,97 | 1,00 | | | 23,12 | 1,49 |
| Tetrachloroethene | < 0,35 | < 0,35 | | | < 0,35 | < 0,35 |
| Ethylbenzene | 0,91 | < 0,35 | | | 1,53 | < 0,35 |
| m- + p-Xylene | 2,40 | 0,45 | | | 2,73 | 0,78 |
| Styrene | < 0,35 | < 0,35 | | | 6,62 | < 0,35 |
| o-Xylene | 1,66 | < 0,35 | | | 1,78 | < 0,35 |
| 1,2,4-Trimethyl-benzene | 7,33 | < 0,35 | | | 8,08 | < 0,35 |
| '1,4-Dichloro-benzene | < 0,35 | < 0,35 | | | < 0,35 | < 0,35 |
| Hexane | 5,86 | 0,46 | | | 5,96 | 0,64 |
| Heptane | 2,40 | < 0,35 | | | 2,24 | < 0,35 |
| Cyclohexane | 1,83 | < 0,35 | | | 1,44 | < 0,35 |
| n-Butylacetate | 0,92 | < 0,35 | | | 0,69 | < 0,35 |
| a-Pinene | 8,45 | 3,74 | | | 7,02 | 1,22 |
| 3-Carene | 3,46 | 2,48 | | | 5,34 | 1,27 |
| d10-Limonene | 10,4 | < 0,35 | | | 27,4 | < 0,35 |

After the renovation, in case 2 (house 17) considerably high indoor $PM_{2.5}$ is most probably related to the elevated outdoor levels (188 µg/m³). Indoor TVOC is moderately higher than the rest of the dataset, and according to the German Indoor Air Guide values, this level is exceeding 'ideal conditions', but is still not high enough to be ranked in the second category. Both formaldehyde, acetaldehyde and total aldehyde levels are representative for post renovation levels.

The quantification of individual VOC compounds confirmed the increased indoor VOC levels in case 1. In case 2 the elevated limonene concentration, related to indoor use of fragrances, was the second highest of the dataset.

*Table 40 overview of VOCs quantified after façade insulations*

| | Case 1 (house 16) | | Case 2 (House 17) | |
|---|---|---|---|---|
| | > 6 months after renovation | | > 6 months after renovation | |
| | IN | OUT | IN | OUT |
| MTBE | 4,85 | < 0,35 | 2,07 | 1,81 |
| Benzene | 2,14 | 0,75 | 1,25 | 1,29 |
| Trichloroethene | < 0,35 | < 0,35 | < 0,35 | < 0,35 |
| Toluene | 23,12 | 1,49 | 7,92 | 3,76 |
| Tetrachloroethene | < 0,35 | < 0,35 | < 0,35 | < 0,35 |
| Ethylbenzene | 1,53 | < 0,35 | 0,89 | 0,71 |
| m- + p-Xylene | 2,73 | 0,78 | 2,72 | 2,05 |
| Styrene | 6,62 | < 0,35 | < 0,35 | < 0,35 |
| o-Xylene | 1,78 | < 0,35 | 1,44 | 0,78 |
| 1,2,4-Trimethyl-benzene | 8,08 | < 0,35 | 5,68 | 0,87 |
| '1,4-Dichloro-benzene | < 0,35 | < 0,35 | < 0,35 | < 0,35 |
| Hexane | 5,96 | 0,64 | 1,12 | 1,00 |
| Heptane | 2,24 | < 0,35 | 1,68 | 0,49 |
| Cyclohexane | 1,44 | < 0,35 | 1,35 | < 0,35 |
| n-Butylacetate | 0,69 | < 0,35 | 6,17 | 0,60 |
| a-Pinene | 7,02 | 1,22 | 7,96 | < 0,35 |
| 3-Carene | 5,34 | 1,27 | 1,44 | < 0,35 |
| d10-Limonene | 27,4 | < 0,35 | 36,84 | < 0,35 |

→ **Ventilation**

*Table 41 Air flow rate and air changes per hour at 50Pa for the two cases*

| | Type of renovation | pre renovation | | | post renovation (> 6 months) | | |
|---|---|---|---|---|---|---|---|
| | | Under pressure | Over pressure | Average | Under pressure | Over pressure | Average |
| $V_{50}$ [m³/h] | Façade insulation - case 1 | | | | 1736 | 2005 | 1870.5 |
| | Façade insulation - case 2 | | | | | | |
| $n_{50}$ [1/h] | Façade insulation - case 1 | | | | 2.5 | 2.9 | 2.7 |
| | Façade insulation - case 2 | | | | | | |

Case 1 has no ventilation system, except an exhaust in the bathroom, operated by a switch (no sensor). The flow rate was measured at 25m³/h.

→ **Moisture in walls and thermography**

In House 16 (case 1), the thermal bridges formed by the window lintels, are visible both before and after the renovation. The other limited differences in surface temperatures from the measurements before the renovation, are less apparent after the renovation.

In Interim Report 1, thermal bridges appearing at the junctions in the façades (e.g. window lintels) were identified as a possible risk when placing façade insulation. In this study, heat leakages at the window lintels were prominent in case 1 (house 16) but not present in case 2 (house 17). In house 17, heat leakages around the doors in the façades are present, probably caused by air leakages. Other surface temperature deviations are low compared to temperature conditions during the measurements.

#### 3.7.3. EVALUATION OF THE EFFECTIVENESS OF FAÇADE INSULATION

Both cases insulated their façades by placing cavity insulation, thus improving the heat transfer coefficients of the façades. Both cavities were filled with 5 cm of insulation (the minimum thickness for technical feasibility). Although there was no obligation, both cases comply with the EPB regulations for post-insulation of cavity walls (and with the requirements of maximum thermal conductivity of the applied insulation material for receiving subsidies).

# CHAPTER 4 VALORISATION AND POLICY RECOMMENDATIONS

Based on the outcomes of both parts Renovair study, the study of the impact of energy-efficient renovations on the indoor environment as well as the impact of filter upgrades on the indoor environment, valorisations and policy recommendations have been formulated.

## 4.1. Policy recommendations

### 4.1.1. Recommendations for environmental policy and other entities

- Wall treatments against rising damp

  A correct installation and use of materials against rising damp in walls affects the indoor air quality in an only temporary and limited way; an incorrect installation may cause indoor TVOC levels of several mg/m³, and affects the indoor environment in an adverse way during several months to years. Treatments against rising damp are a very common a renovation type and there is a need for more knowledge about the technical background of this issue. This knowledge would then allow the formulation of practical guidelines to prevent incorrect installations. A characterisation of emissions from different application modes of the same product in the same wall, can contribute to the understanding of this aspect.

  - A technical approval of the installation (cfr. BUtgb) could be useful.

- Repair of cold bridges

  According to the Renovair data, cold bridges present before the renovation are found to be more pronounced post renovation in some cases. A similar finding was reported in the Finland 'Mould and Moisture programme'. In a new Decree (REF) set by the Social Affairs and Health Ministry in Finland, the government offers the possibility for a professional house inspection (person with qualifications according to requirements set by the government) in houses with health hazards, who formulates recommendations for a suitable renovation of the private dwelling (http://uutiset.hometalkoot.fi/en/home.html) .

- Maintenance of ventilation systems at school

  - Standard dimensions of air filters are recommended: ventilation system brands may use dimensions that differ from standard dimensions, which are found to be more expensive. This not only affects the maintenance costs of the ventilation system, it also limits purchasing filters at different suppliers (not all suppliers offer filter dimensions different from the standard ones).

  - An estimate of the maintenance costs for mechanical ventilation as a criterion in calls for tenders: the estimated cost of new filters (of the needed dimensions), possible cleaning of ventilation ducts or heat recovery system as well as the cost of technical support should be considered as a decisive criterion in the design phase of a school building. Renovair revealed that most schools are only limited or even not aware of the actions that are needed for a correct maintenance of the ventilation system and the possible costs that would imply.

- A basic training in 'ventilation system maintenance' for several staff members of a school is recommended when a school building is taken into use. Doing so, knowledge about the operation and maintenance of a ventilation system will maintain in the school. A basic and easily accessible instruction on 'ventilation system maintenance' can be useful (in general, the As Built file is too extensive and too technical to allow an easy use by school staff).
- There is a need for more knowledge and a clear communication on how and when a thorough cleaning of a mechanical ventilation system (including heat exchange and ventilation ducts) is recommended. There is an need to define in an objective way what is acceptable and what is not. In open literature contradictory information about the effectiveness of duct cleaning can be found (Zuraimi, 2010). Professional cleaners estimate the amount of dust (expressed in $g/m^2$) based on a visual inspection with respect to the various recognized methods, that may have variable outcomes as reported by Lavoie et al. 2011. Based on this estimation it is then recommend whether duct cleaning is needed. The use of coarse filters (G-type) in combination with fine filters (F-type)
  - All schools that have been considered for Renovair used F-type filtration, without pre-filtration by means of a G-type (coarse dust filter). G-type filters are considerably less costly than F-type filters. The use of a G-type filter for pre-filtration of coarse particles would limit clogging of the F-type filter with coarse material, would reduce the pressure drop, would therefore reduce the energy consumption of the ventilation system and would also increase the life span of the filter.
- The design of ventilation systems:

  Engineers are recommended to design ventilation systems that are relatively easily accessible for maintenance, which also implies easily accessible technical rooms. Especially for schools, this should be an item of considerable importance.

- Subsequent insulations of walls, façades, floors and windows may considerably affect the building's air tightness, and therefore affect the IAQ. Building users should be informed about the consequences and the need for adapting their ventilation behaviour to the new circumstances.
- Thorough initiatives for selecting low VOC emission materials lead to a direct improvement of the IAQ.

#### 4.1.2. Recommendations on the relation between indoor and outdoor environment (air filtration)

- Both F7 and F9 air filtration lead to a considerable reduction of outdoor air pollutants indoors, and are both recommended to be used.
- The efficiency of F9 air filtration was found to be significantly better for $PM_{2.5}$, $PM_1$ and particles < 0.3 µm, black carbon and UFP. However, recalculated to representative air concentrations, the difference between the estimated resulting indoor air concentration is less than 1 µg/m³ for $PM_1$ (e.g. a hypothetical outdoor $PM_1$ concentration of 20 µg/m³ would e.g. lead to indoor levels of 3.92 µg/m³ with F7 air filtration and 2.35 µg/m³ with F9).
- The effectiveness of F9 air filtration is most pronounced for $PM_{2.5}$, reduction of the outdoor levels indoors are smaller for black carbon and UFP: predicted indoor levels for F9 vs. F7 compared to outdoors for UFP (-79% vs. -69%), BC (-65% vs. -49%) and various

PM fractions (e.g. $PM_{2.5}$ -87% vs. -82%)

- Air filtration is least effective for $PM_{10}$ and TSP, because their indoor occurrence mainly results from resuspendation of settled dust. Cleaning can lower indoor $PM_{10}$ and TSP.
  - The use of a G-type filter for pre-filtration of coarse particles would limit clogging of the F-type filter with coarse material, would reduce the pressure drop, would therefore reduce the energy use of the ventilation system and would increase the life span of the filter.
- There is a need for more knowledge about the effectiveness of activated charcoal air filters to reduce indoor exposure to traffic related gaseous compounds - the sample size of Renovair was too small to formulate decisive recommendations on this aspect. Important parameters to be studied: When is the activated charcoal saturated? Which outdoor concentration can be considered as a threshold to recommend air cleaning by means of activated charcoal? Is the remedial impact comparable to placing the air intake at a distance from traffic sources? Do different set-ups affect the effectiveness in a different way?
- There is a need for objective recommendations about air filtration for schools at hotspot locations. There is a need to define 'when' there is a need for air filtration? Which type of air filtration is recommended? A dedicated study, with a simultaneous evaluation and comparison the impact of active air cleaning (using F7, F9 or F7+ activated charcoal), on the indoor occurrence of traffic related air pollution indoors is needed to assess this information. The most important aspect would here be that the rooms have a similar set-up, with comparable sources and resulting IAQ, have the same ventilation system and air flow, but have a separate air intake which would allow a targeted comparison and evaluation.

#### 4.1.3. Recommendations on the impact of renovations

- Wall treatments against rising damp

  A correct installation and use of materials against rising damp in walls affects the indoor air quality only in a temporary and limited way; an incorrect installation may cause indoor TVOC levels of several mg/m³, and affects the indoor environment in an adverse way during several months to years. Treatments against rising damp are a very common a renovation type and there is a need for more knowledge on the technical background of this issue. This knowledge would then allow the formulation of practical guidelines to prevent incorrect installations.

  - A technical approval of the installation (cfr. BUtgb) could be useful.

- Repair of cold bridges

  According to the Renovair data, cold bridges present before the renovation are in some cases found to be more pronounced post renovation. The air tightness around the joinery in the façades was a point of particular interest in the thorough renovation cases. Older front doors and garages clearly showed heat losses around the frames. The awareness for this phenomenon could be raised (e.g. by incorporating it in subsidies, or by mandatory follow-up of renovation planning by an expert). A similar finding was reported in the Finland 'Mould and Moisture programme'. In a new Decree (REF) set by the Social Affairs and Health Ministry in Finland, the government offers the possibility for a professional house inspection (person with qualifications according to requirements set by the government) in houses with health hazards, who formulates recommendations for a suitable renovation of the private dwelling (http://uutiset.hometalkoot.fi/en/home.html) .

- Thorough initiatives for selecting low VOC emission materials lead to a direct improvement of the IAQ in terms of indoor TVOC and formaldehyde. There is a need for guidelines and tools for building professionals and citizens for selecting low VOC-emitting building materials. The table for building material selection in the map 'Bouw Gezond' for building professionals, is a very useful tool in this context. However, regular updates of this tool are needed, because product emissions and product labels have an increasing marketing value and their use by product manufacturers is expanding rapidly.
- The limited willingness of installers, contractors, architects or building owners to allow an air quality assessment after installing PU insulation foam that was experienced in Renovair, might indicate some kind of anxiety amongst users. This finding might therefore indicate a need for transparent and reliable information and communication on potential risks but also on the benefits of the installation.
- Based on literature review from WP1, the risks associated with combination renovations can be limited by incorporating future renovation phases in the technical execution of earlier renovation. For example for wall insulation and replacing windows, this principle is already integrated in the subsidies policy (by providing larger subsidies when both interventions are executed within 12 months from each other). An extension of this principle (e.g. combination of insulation measures with installing a ventilation system) as well as more elaborate technical requirements for receiving subsidies could be interesting to increase the quality of future renovation projects.
- In only 6 of the reported cases we have pre and post intervention data on microbial levels to compare and conclude on an impact of the interventions. There are some interesting findings as to the changes of microbial levels potentially due to certain interventions (floor insulation, case 3: incomplete reduction of microbial levels; duct cleaning, case 11: increase of fungal levels). However, microbial contamination can have multiple sources, such as occupancy, season of sampling, pet keeping, and many more, and thus – based on the data provided by this study, we cannot conclude whether these changes are due to the intervention actions or other, confounding factors. These are aspects well worth further exploring, in a study with sufficient numbers of indoor environments that undergo specific interventions and relate these interventions to microbial levels.
- The small scale survey on health and comfort indicated a slight improvement in health complaints, and a lower expected symptom score after the energy-efficient renovations. Because of relatively small number of respondents, no significant effect could he registered. By expanding the number of respondents to e.g. citizens who request a (partial) refunding of their renovation expenses from the government, would allow a statistical analysis of the dataset.

## 4.2. POSSIBILITIES FOR VALIORISATION

'Bouw Gezond' is a communication initiative that was initiated by LNE in 2012, targeted to building professionals, such as architects, construction engineers and building contractors. It consists of a map, in which summarising data sheets with guidance on creating a healthy indoor environment are collected. The current topics included in the map are 1. Guidance of the client, 2. Design of the building envelope, 3. Ventilation, 4. Other techniques (heating, …), 5. Materials, 6. Construction site coordination, 7. Other themes.

Based on the indicative findings that were reported in Renovair, the Flemish Architect's Council has formulated additional data sheets with practical guidance for building professionals, which will be added to the 'Bouw Gezond' map. The 3 new data sheets focus on the topics: (1) Materials, (2) Ventilation and (3) Client, and are added below.

## Materialen - 8

# Impact op het binnenklimaat bij injecteren van muren bij opstijgend vocht

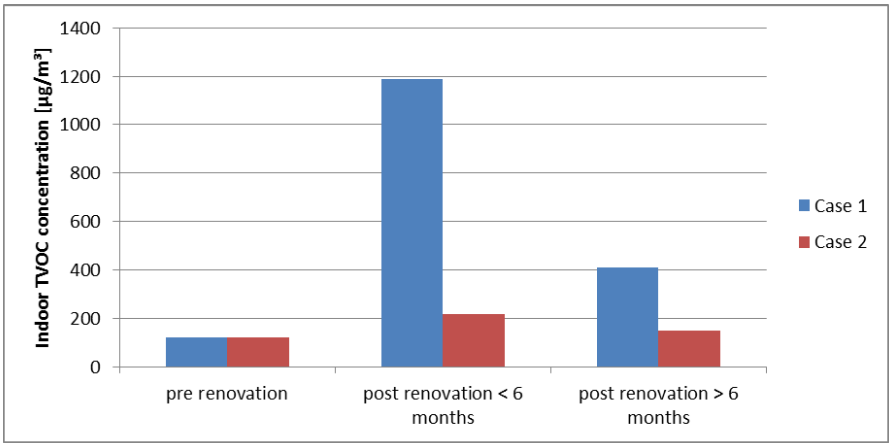
*Uit verkennend onderzoek naar de binnenluchtkwaliteit in woningen na renovatie werd bij een beperkt aantal cases vastgesteld dat de binnenluchtkwaliteit door meerdere factoren kan worden beïnvloed. Een degelijke uitvoering blijkt hierbij van groot belang.*

| | | |
|---|---|---|
| CASE-STUDIES | Achtergrond Case 1:<br>- vrijstaande woning;<br>- naoorlogse constructie;<br>- vloer- en dakisolatie;<br>- gevelisolatie;<br>- nieuwe verwarmingsinstallatie;<br>- geen ventilatiesysteem. | Achtergrond Case 2:<br>- halfopen bebouwing;<br>- vooroorlogse constructie;<br>- vloer- en dakisolatie;<br>- ramen vervangen;<br>- nieuwe verwarmingsinstallatie;<br>- geen ventilatiesysteem. |

| **Impact injecteren muren op de fysische karakteristieken** | |
|---|---|
| **$CO_2$ (ppm) - temperatuur (°C) - relatieve vochtigheid (%)** | |
| | |
| PRE - POST RENOVATIE | In deze beperkte studie werd minimaal tot geen verschil vastgesteld tussen voor en na renovatie voor de $CO_2$-concentratie, temperatuur en relatieve vochtigheid in het binnenklimaat. |

| **Impact injecteren muren op de chemische karakteristieken** | |
|---|---|
| **$PM_{2,5}$ (µg/m³)** | |
| Wat? | De afkorting PM staat voor 'Particulate Matter'. Het betreft de concentratie van fijn stof waarvan de luchtdeeltjes een aerodynamische diameter kleiner dan 2,5 µm hebben. Fijn stof komt in de omgevingslucht via uitstoot van verbrandingsprocessen in het verkeer, landbouw en industrie. De toxiciteit wordt zowel door de concentratie, de grootte, de vorm van de deeltjes als de chemische bestanddelen die zich aan het fijn stof hechten bepaald. |
| Impact? | Geen grote verschillen werden vastgesteld tussen de situatie voor en na de injectie van de muren in deze woningen zonder luchtzuivering. De concentratie van fijn stof in de buitenlucht heeft een grotere impact op de concentratie in het binnenmilieu dan het injecteren van de muren. |

| **TVOC (µg/m³)** | |
|---|---|
| Wat? | TVOC is de afkorting voor "Total Volatile Organic Compounds" en geeft een beeld van het totaal aan vluchtige organische stoffen in het binnenmilieu. De term omvat een groep koolwaterstoffen die gemakkelijk verdampen en in de omgevingslucht terecht komen. Er zijn niet toxische en toxische VOCs in onze omgeving aanwezig. Algemeen wordt TVOC beschouwd als een doeltreffende indicator voor zintuiglijke irritatie, waardoor de parameter een efficiënte indicator is voor de kwaliteit van het binnenmilieu. |
| Impact? | Bij het injecteren van muren tegen opstijgend vocht bleek een tijdelijke stijging van de concentratie TVOC kort na de ingreep. Na 6 maanden daalde de concentratie TVOC tot een lager niveau. |




*Figuur: TVOC concentratie in het binnenklimaat bij het injecteren van muren tegen opstijgend vocht*

| | |
|---|---|
| AANDACHT | De verhoging van de concentratie aan TVOC na 6 maanden kan gedeeltelijk verklaard worden door organische stoffen die vrijkomen bij de injectie van muren tegen opstijgend vocht, zoals epoxysilaan (door injecteren van epoxy hars). Deze polluenten zijn minder vluchtig en blijven nog lange tijd (tot 1,5 jaar) in het binnenklimaat aanwezig, zelfs bij verluchten na de ingreep.<br>Eerder onderzoek wijst uit dat de concentratie hoger is bij ingrepen waar de injectie niet afdoende was of niet correct werd uitgevoerd. In die situaties kunnen de concentraties oplopen tot een 10-voud van de normale omstandigheden. |

| **Aldehydes en ketonen (µg/m³)** | | |
|---|---|---|
| Wat? | Aldehydes (zoals bv. formaldehyde) zijn eveneens vluchtige stoffen, die uitgestoten worden door een brede waaier van bouwmaterialen. Er zijn verschillende soorten met een gelijkaardige structuur. De meeste hebben een sterke geur en komen voor in lijm, hars, sprays, parfum en verbrandingsgassen. Hoe hoger de temperatuur en luchtvochtigheid, hoe sneller aldehyden uit bouwmaterialen vrijkomen. | |
| | *Soort aldehyde* | *gebruikt in/komt vrij uit* |
| | Acetaldehyde | Grondstof chemische industrie<br>Sigarettenrook<br>afbraakproduct alcohol |
| | Aceton (keton) | Oplosmiddel |
| | Formaldehyde | Hars en lijm in bouwmaterialen<br>Schoonmaakmiddelen<br>Geurverfrissers |
| | Glutaaraldehyde | Desinfectie en sterilisatiemiddel<br>Balsemen<br>Fixeren van weefsels |
| Impact? | Een verwaarloosbare stijging werd vastgesteld na de ingreep, welke bovendien moeilijk kan worden toegeschreven aan het injecteren van muren. | |

**Referenties**

VITO, Renovair, Verkennend onderzoek naar de binnenmilieukwaliteit in woongebouwen na (energie-efficiënte) renovaties, 2015.
[www.gezondheidenmilieu.be](http://www.gezondheidenmilieu.be)

**Ventilatie - 21**

## Kies de juiste luchtfiltering - Scholen

*In een mechanisch balansventilatiesysteem zijn de filters een belangrijk aspect voor de goede werking van het systeem en de luchtkwaliteit. Hoe beter (of fijner) de filter, hoe beter... is niet noodzakelijk terecht.*
*Voor scholen is dit zeker een aandachtspunt. Deze fiche formuleert enkele aandachtspunten bij het vervangen of keuze van filters in scholen.*

| **Type meest voorkomende filters en hun efficiëntie** | | | | | |
|---|---|---|---|---|---|
| Stoffen | Sigarettenrook | | Sporen | | |
| | Gas | Bacteriën | | | Pollen |
| | Huisstof (fijn stof) | | | | |
| deeltjesgrootte (µm) | 0,1 | 0,5 | 1 | 5 | 10 |
| Filterklasse | *percentage gefilterde deeltjes (%)* | | | | |
| G3 | - | *0 - 5* | *5 - 15* | *35 - 70* | *70 - 85* |
| G4 | - | *5 - 15* | *15 - 35* | *60 - 90* | *85 - 98* |
| M5 | *0 - 10* | *15 - 30* | *30 - 50* | *90 - 99* | *> 98* |
| M6 | *5 - 15* | *20 - 40* | *50 - 65* | *95 - 99* | *> 99* |
| F7 | *25 - 35* | *60 - 75* | *85 - 95* | *> 99* | *> 99* |
| F8 | *35 - 45* | *80 - 90* | *95 - 98* | *> 99* | *> 99* |
| F9 | *45 - 60* | *90 - 95* | *> 98* | *> 99* | *> 99* |

| **Aandachtspunten bij scholen** | |
|---|---|
| Opstelling installatie: | De opstelling van het ventilatiesysteem wordt nog steeds onderschat. Ook in scholen moet de plaats van de installatie op eenvoudige wijze toegankelijk zijn. |
| Aanbeveling: | Voorzie een voldoende grote ruimte (informeer bij de constructeur) voor de installatie, maak deze eenvoudig toegankelijk (bv. trap i.p.v. ladder, deur i.p.v. luik) en voorzie plaats voor onderhoud (uittrekken van filters).<br>Informeer het schoolpersoneel om de ruimte niet als opslagplaats te gebruiken. |
| Informatie gebruiker: | Vaak ontbreekt de kennis bij het personeel van een school over de noodzaak van het onderhoud van de installatie. "Wanneer moet er controle gebeuren, wat moet er vervangen worden en wat moet er besteld worden?" |
| Aanbeveling: | Zorg voor eenvoudig onderhoud via kennis en (bondige) informatie: sensibiliseer het schoolbestuur en -personeel over de te nemen maatregelen voor onderhoud, en voorzie eventueel een korte opleiding of eenvoudige instructie over het type, termijn en belang van het vervangen van filters en onderhoud. |

| | |
|---|---|
| Onderhoud filters: | Regelmatig vervangen van vervuilde filters is noodzakelijk. Vervuilde filters kunnen leiden tot een verhoogd drukverlies, een stijging van de energieconsumptie van de ventilatoren, een daling van de luchtdebieten en een stijging aan gezondheidsklachten.<br>Soms wordt met afwijkende afmetingen van filters gewerkt, waardoor deze bij een beperkt aantal leveranciers kunnen besteld worden of op maat gemaakt dienen te worden (dit kan de kosten voor onderhoud opdrijven). |
| Aanbeveling: | Controleer of laat de filters controleren op regelmatige basis. Vervang vervuilde filters tijdig (om de 6 - 12 maanden of sneller bij zichtbare of gekende verontreiniging). Zie ook fiche Klant 2.<br>Zorg voor duidelijke specificaties van de filters of kies bij plaatsing voor een type toestel met filters met standaardafmetingen. |
| Keuze filters: | Een fijnere filter (F9 i.p.v. F7) zorgt niet noodzakelijk voor een betere luchtkwaliteit, gezien deze slechts een matige werking heeft bij grote concentraties fijn stof in de buitenlucht.<br>Een betere/fijnere filter blijkt een positieve invloed te hebben op gezondheidsklachten in scholen. |
| Aanbeveling: | Overweeg eerder een F7 in combinatie met een groffilter (G3-G4) boven een F9-filter. Een groffilter geplaatst voor de fijnfilter zal de grovere deeltjes (zoals pollen) uit de lucht filteren en de levensduur van de fijnfilter verlengen. Een filter met actieve kool kan zorgen voor een lager niveau aan vluchtige organische stoffen (bv. afkomstig van verkeersuitstoot) in het binnenmilieu. |

**Afkortingen**

| | |
|---|---|
| *G* | *Groffilter* |
| *M* | *Medium filter* |
| *F* | *Fijnfilter* |

**Referentiedocument en meer informatie**

*VITO, Renovair, Verkennend onderzoek naar de binnenmilieukwaliteit in gebouwen na (energie-efficiënte) renovaties.*

*WTCB, Ventilatiegids, http://www.wtcb.be/homepage/download.cfm?dtype=publ&doc=Ventilatiegids%20woningen.pdf*

**Klant - 5**

## Impact van energie-efficiënte renovaties op het binnenmilieu

*Uit een verkennend onderzoek over het binnenmilieu (soms) voor en na renovatie van woningen, (VITO) werden een aantal renovatie-maatregelen en hun impact op het binnenmilieu onderzocht. We sommen de bevindingen hieronder op.*

| Maatregel 1: Opwaarderen van de ramen | | |
|---|---|---|
| *Impact op* | *binnenluchtkwaliteit :* | Een redelijke concentratie van voornamelijk formaldehyde, maar ook TVOC, RV, $CO_2$ en formaldehyde werd vastgesteld bij een verbeterde luchtdichtheid, zelfs met ventilatie (systeem A). |
| | *luchtdichtheid/ventilatie :* | Merkbare verbetering. |
| | *koudebruggen/vocht in de muren :* | Niet langer condensatie op de binnenzijde van het glas.<br>Geen vaststelling van vochtproblemen na renovatie tijdens de studie.<br>Bestaande koudebruggen blijven aanwezig. |
| | *ervaren comfort :* | Geen opmerkingen gemaakt door de bewoners. |
| | *energiebesparing :* | Duidelijk verbetering van de U-waarde t.p.v. het schrijnwerk. |

| Maatregel 2: Plaatsen van vloerisolatie (in situ PUR) | | |
|---|---|---|
| *Impact op* | *binnenluchtkwaliteit :* | Geen merkbare invloed op $CO_2$, temperatuur en RV. De concentratie aan TVOC en formaldehyde stijgen na renovatie door toepassing van bouwmaterialen tijdens renovatie.<br>Een week na de toepassing van de isolatie werd een verwaarloosbare stijging gemeten van de VOC specifiek afkomstig van de PU. |
| | *koudebruggen/vocht in de muren :* | Hogere oppervlaktetemperatuur t.p.v. de vloer.<br>Risico op koudebruggen, maar er werden geen vastgesteld in de studie. |
| | *ervaren comfort :* | Geen opmerkingen gemaakt door de bewoners. |
| | *energiebesparing :* | Aanzienlijke verbetering van de U-waarde van de vloer. |

| Maatregel 3: Injecteren van muren tegen opstijgend vocht | | |
|---|---|---|
| *Impact op* | *binnenluchtkwaliteit :* | Tijdelijke stijging van TVOC door de toegepaste producten van de ingreep. Bij correcte toepassing materialen en uitvoering blijft de stijging beperkt en tijdelijk. |
| | *koudebruggen/vocht in de muren :* | Bij correcte uitvoering opvallend lagere vochtigheid in de muren. |

| Maatregel 4: Plaatsen mechanisch ventilatiesysteem | | |
|---|---|---|
| *Impact op* | *binnenluchtkwaliteit :* | Verbetering niveau $CO_2$ en RV in het binnenmilieu.<br>Verlaagde concentratie TVOC t.o.v. voor de renovatie. |

| | | |
|---|---|---|
| | *koudebruggen/vocht in de muren :* | Geen merkbare invloed. |
| | *ervaren comfort :* | Binnentredende geluiden uit de buitenomgeving en lichte tocht resulterend uit de plaatsing werden opgegeven. |

| **Maatregel 5: Grondige renovatie (gecombineerde ingrepen)** | | |
|---|---|---|
| *Impact op* | *binnenluchtkwaliteit :* | Verhoging van TVOC (voornamelijk afkomstig van de vloerafwerking), maar binnen de grenzen om gezondheidsklachten te voorkomen. |
| | *luchtdichtheid/ventilatie :* | Duidelijk verbeterde luchtdichtheid van de woningen na renovatie.<br>Laag luchtdebiet werd vastgesteld na plaatsing van ventilatie. |
| | *koudebruggen/vocht in de muren :* | Meer geprononceerde (bestaande) koudebruggen, maar verwaarloosbare invloed op de oppervlaktetemperatuur. |
| | *energiebesparing :* | Drastische verbetering van de U-waarde op alle gerenoveerde oppervlaktes. |

| **Aandachtspunten:** | |
|---|---|
| Beperking studie: | De bevindingen zijn gebaseerd op een verkennend onderzoek met een beperkt aantal woningen in Vlaanderen (gevalstudies). Hoewel de studie onderbouwd werd met wetenschappelijke literatuur, kan bijkomend onderzoek de representativiteit van deze conclusies bevestigen en de impact op de bewoners identificeren. |
| Keuze materiaal: | Energie-efficiënte renovaties worden over het algemeen uitgevoerd met materialen waaruit mogelijk vluchtige organische stoffen (VOC) kunnen vrijkomen. Wanneer tijdens een renovatie bewust wordt gekozen voor materialen met lage VOC-emissie, blijken zowel formaldehyde als TVOC (totale concentratie vluchtige organische stoffen) in het binnenmilieu lager te liggen. Toch blijft het raadzaam te informeren naar stoffen die mogelijk kunnen vrijkomen uit bio-ecologische materialen (bv. biociden en microbiologische polluenten) en steeds goed te verluchten na renovatie. (Zie ook fiche materialen 2) |

**Afkortingen**

| | |
|---|---|
| *RV* | *Relatieve Vochtigheid: bij voorkeur tussen 30 - 70%.* |
| *VOC (of VOS)* | *Vluchtige Organische Stoffen: stoffen die kunnen vrijkomen uit bouwmaterialen.* |
| *TVOC* | *De concentratie aan Totaal Vluchtige Organische Stoffen.* |

**Referenties**

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