Eindrapport

Clean Air, Low Energy – *Schone Lucht, Lage Energie*

Exploratory research on the quality of the indoor environment in energy-efficient buildings: the influence of outdoor environment and ventilation

Verkennend onderzoek naar de binnenmilieukwaliteit van duurzame gebouwen: invloed van buitenmilieu en ventilatie

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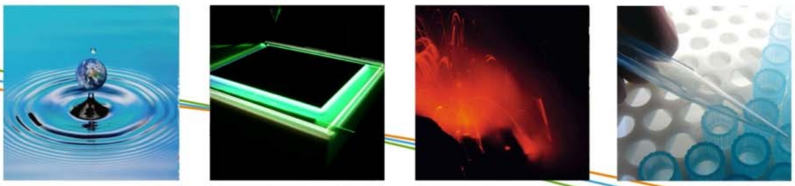

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Clean Air Low Energy Samenvatting

Dit verkennend onderzoek had als doel de karakterisatie van de binnenluchtkwaliteit in energie-efficiënte gebouwen (woningen en scholen). Fysische, chemische en biologische parameters werden gemeten om te bestuderen of het binnenmilieu in dergelijke gebouwen verschillend is van dat in niet-energie-efficiënte gebouwen. Bijzondere aandacht werd besteed aan de invloed van buitenmilieu en van ventilatiesystemen op het binnenmilieu.

Het ontwerpen van energie-efficiënte gebouwen is synoniem voor een verminderd energieverbruik, beschouwd over de gehele levenscyclus van het gebouw. Efficiënte strategieën om het energieverbruik te verminderen zijn onder meer een betere gebouwisolatie en een sterkere luchtdichtheid. Hierdoor blijft gegenereerde warmte binnen de gebouwschil en wordt de warmtevraag beperkt, wat een positieve invloed heeft op het energieverbruik. Een verhoogde luchtdichtheid in nieuwbouwwoningen en -scholen brengt echter ook een verminderde gebouwverluchting via openingen en scheuren in de gebouwschil met zich mee. Omdat voldoende verluchting onmisbaar is om een gezond binnenmilieu te creëren en te behouden, is in dit type gebouwen een ventilatiesysteem noodzakelijk. Een deels of volledig mechanisch systeem is wenselijk, want mechanische ventilatiesystemen bieden het voordeel van een gecontroleerde gebouwventilatie. De verantwoordelijkheid voor een correct gebruik en onderhoud ligt echter bij de eigenaar/gebruiker van het gebouw. Hierdoor worden gebouwgebruikers of bewoners verantwoordelijk voor het creëren en het onderhouden van een gezond binnenmilieu.

In dit verkennend onderzoek Schone Lucht Lage Energie, wordt de **binnenluchtkwaliteit bepaald in 51 lage-energie gebouwen in Vlaanderen, waarvan 25 woningen en 26 klaslokalen. Elk gebouw is uitgerust met een mechanisch ventilatiesysteem (zowel gecontroleerde toe- en afvoer van lucht als gecontroleerde afvoer van lucht met toevoer via ventilatieroosters werden opgenomen in deze studie)**. Het binnenmilieu werd telkens chemisch, fysisch en microbiologisch gekarakteriseerd, terwijl ook de energieperformantie en de gebouwschil van elk gebouw bestudeerd werd.

In de eerste fase van het project werd de gedetailleerde meetstrategie vastgelegd. Deze werd gebaseerd op literatuur met betrekking tot (inter)nationale studies, welke verwerkt werd in een review over onderzoek naar “oorzaak-gevolg-oplossing” in energie-efficiënte gebouwen. Deze review omvat voordelen en knelpunten, gerapporteerd over energie-efficiënte, mechanisch geventileerde gebouwen. Het binnenmilieu, en de invloed van het buitenmilieu hierop, werden ook opgenomen in deze literatuurstudie. Als resultaat werden relevante chemische, fysische en biologische parameters van het binnen- en buitenmilieu vastgelegd in het meetplan voor het Schone Lucht Lage Energie veldwerk. Binnen deze set parameters werden de parameters, gebaseerd op de literatuurstudie, opgedeeld in (1) prioritaire selectiecriteria voor gebouwen, (2) parameters die ter plaatse gemeten moeten worden, of (3) parameters die opgenomen moeten worden in een bevraging naar de gebouwkarakteristieken.

Daarnaast werd uit het literatuuronderzoek ook besloten dat deze Schone Lucht, Lage Energie de eerste studie in zijn soort is, die de interactie tussen chemische, fysische en biologische binnen/buiten parameters en (1) gebouwschil karakteristieken, zoals luchtdichtheid en totaal ventilatievoud, (2) ventilatiesysteem-karakteristieken, zoals ventilatiesysteemtype en warmterecuperatiesysteem en (3) geluidshinder, ten gevolge van het ventilatiesysteem en het buitenmilieu, nader bestudeert.

In de tweede fase van het onderzoek werden 51 gebouwen, 25 woningen en 26 klaslokalen, geselecteerd in Vlaanderen. Deze selectie gebeurde door middel van een mailing en een aankondiging op relevante websites. Gebouweigenaars konden zich kandidaatstellen voor

deelname aan dit onderzoek via een registratiedocument. Dit document bevatte relevante informatie over de woning/school karakteristieken (o.a. luchtdichtheid, gebouwschil en details van het ventilatiesysteem) die gebruikt werden bij de woning- en schoolselectie. Alle gekozen meetplaatsen zijn daarom gekarakteriseerd door combinaties van gebouwschil en ventilatiesystemen, die representatief zijn voor huidige en toekomstige trends in het gebouwpatrimonium van Vlaanderen. Daarom maakten passiefgebouwen alsook lage-energie gebouwen met gecontroleerde lucht toe- en afvoer en gecontroleerde luchtafvoer met toevoer via ventilatieroosters, deel uit van dit onderzoek.

Tijdens de meetcampagne werd het binnenmilieu zowel chemisch, fysisch als biologisch gekarakteriseerd in de energie-efficiënte gebouwen. Dit hield in: een fysico-chemische analyse van het binnen- en het buitenmilieu, een kwantificatie van biologische contaminanten in de binnenlucht en in de corresponderende buitenlucht, een meting van geluidshinder ten gevolge van ventilatie (zowel door het ventilatiesysteem als door de buitenomgeving) en de meting van de doeltreffendheid van het ventilatiesysteem ten opzichte van de theoretische ventilatie en luchtinfiltratie. De volgende parameters werden gemeten: 18 VOS componenten, TVOS, formaldehyde, acetaldehyde, totaal andere aldehydes, $PM_{2.5}$, CO_2, tocht, temperatuur, relatieve vochtigheid, bacteriën en schimmels in lucht en in depositiestof, het totaal ventilatievoud, de luchtdichtheid en geluidshinder.

Deze brede dataset werd vervolgens geanalyseerd op de onderlinge relaties tussen de gekarakteriseerde parameters in de verschillende omgevingen. De volgende vragen werden naar voren geschoven bij deze analyse:

> *Heeft een ventilatiesysteem een invloed op de binnenluchtkwaliteit?*
> *Heeft de luchtdichtheid een invloed op de binnenluchtkwaliteit?*
> *Heeft het totaal ventilatievoud een invloed op de binnenluchtkwaliteit?*
> *Heeft geluidshinder een invloed op de gebouwventilatie en is er een indicatie van een indirect verband met binnenluchtkwaliteit?*

Scholen

Algemeen werd besloten voor **Schone Lucht Lage Energie scholen** dat de fysico-chemische kwaliteit van de binnenlucht in energie-efficiënte, mechanisch geventileerde klaslokalen beter of gelijk is aan deze die typisch gemeten wordt in traditionele klaslokalen (dit zijn klaslokalen waarbij de verluchting plaatsvindt door het openen van ramen). Voornamelijk voor CO_2, $PM_{2.5}$ en de I/O ratio van $PM_{2.5}$, worden aanzienlijk lagere concentraties waargenomen in de Schone Lucht Lage Energie klaslokalen.

Voor deze dataset werd vastgesteld dat de luchtdichtheid van een gebouw de binnenluchtkwaliteit niet lijkt te beïnvloeden. Over het algemeen werd dus geen afname van de binnenluchtkwaliteit waargenomen in sterk luchtdichte klaslokalen. Het type mechanisch ventilatiesysteem (gecontroleerde lucht toe- en afvoer of gecontroleerde luchtafvoer met toevoer via ventilatieroosters) en het totale ventilatievoud van het klaslokaal bleken echter wel fysico-chemische en biologische karakteristieken van de klaslokalen te beïnvloeden. In het bijzonder wanneer de binnenluchtkwaliteit vergeleken werd met voorgaande studies met lagere ventilatievouden, werd een duidelijke verbetering van het binnenmilieu waargenomen.

In de bestudeerde klaslokalen bleek CO_2 onafhankelijk van het type mechanisch ventilatiesysteem. Klaslokalen met een mechanisch gecontroleerde lucht toe- en afvoer hadden verminderde $PM_{2.5}$ in de instromende lucht, wat leidde tot lagere binnenconcentraties en verminderde $PM_{2.5}$ en I/O verhoudingen ten opzichte van zowel klaslokalen uitgerust met ventilatieroosters en mechanische luchtafvoer als klaslokalen zonder mechanisch ventilatiesysteem. Het verhoogde totale ventilatievoud in klaslokalen met een ventilatiesysteem D in deze dataset leidde slechts tot matig gereduceerde concentraties TVOS, bepaalde individuele VOS, formaldehyde, totaal andere aldehyden en relatieve vochtigheid in deze klaslokalen ten opzichte van de andere lokalen.

In klaslokalen met ventilatieroosters en mechanische afvoer werd een matige toename van tocht (gemeten als windsnelheid) waargenomen ten opzichte van de klaslokalen uitgerust met ventilatiesysteem type D. Hierbij dient opgemerkt te worden dat in de BiBa-studie (Onderzoek naar de luchtkwaliteit in traditioneel gebouwde klaslokalen, 2010), 25 van de 90 bestudeerde klaslokalen uitgerust waren met ventilatieroosters (zonder gecontroleerde luchtafvoer); slechts 64% hiervan gebruikte echter de ventilatieroosters tijdens de uitvoering van het veldwerk. Hoewel de parameter ‘tocht’ niet gekwantificeerd werd tijdens dat onderzoek, werd deze parameter in de bijhorende vragenlijst wel vermeld door de klastitularis als de oorzaak voor het afsluiten van de ventilatieroosters.

Het totaal ventilatievoud, herberekend volgens IDA klassen, waarbij het totaal aantal aanwezige leerlingen in de klas in rekening gebracht wordt, toonde een goede overeenstemming met CO_2, $PM_{2.5}$, formaldehyde, en in mindere mate met de tolueen concentraties. Klaslokalen uit hogere IDA-klassen hadden verhoogde concentraties van de opgesomde polluenten. Hierbij dient vermeld te worden dat in vergelijking met NBN EN 13779, voor elke IDA-klasse lagere CO_2 niveaus worden gemeten dan de aanbevolen concentraties op basis van het ventilatievoud per leerling. Dit wijst op een zekere discrepantie in deze dataset, tussen de methodes die gebruikt worden om IDA-klasses toe te kennen aan klaslokalen: (1) door berekening van ‘het totaal ventilatievoud per leerling’ en (2) door berekening van ‘het verschil tussen binnen en buiten CO_2 niveaus’.

Het verband tussen de binnenluchtconcentraties en de IDA-klassen (luchttoevoer per persoon), is sterk in lijn met de recent gerapporteerde conclusies van het EU project HEALTHVENT (December 2012). Deze studie had tot doel om ventilatierichtlijnen te formuleren, gebaseerd op gezondheid, voor niet-industriële gebouwen in Europa (kantoren, woningen, scholen, en kinderdagverblijven). Deze richtlijnen streven ernaar om de rol van ventilatie te verzoenen met (1) een gezonde kwaliteit van het binnenmilieu, door mensen te beschermen die het grootste deel van hun leven binnenshuis doorbrengen, en (2) door tezelfdertijd de nood aan een meer efficiënt energieverbruik voor comfort in gebouwen na te streven. Het resultaat van deze studie geeft aan dat een toevoer van 7-8l/sec/pers voldoende is om significante gezondheidsproblemen te vermijden, indien men niet over verdere informatie beschikt, met betrekking tot dit gebouw en de polluenten die erin voorkomen. Een minimaal gezondheidsgebaseerd ventilatievoud van 4l/sec/pers kan echter aangeraden worden, indien alle mogelijke initiatieven voor broncontrole gegarandeerd kunnen worden. Dit impliceert: een goede buitenluchtkwaliteit (Wereld Gezondheids Organisatie-richtlijnen), laag-emitterende materialen en producten en geen andere binnenbronnen dan de gebruikers/bewoners zelf. Voor meer informatie: http://www.healthvent.byg.dtu.dk/. Aangezien in geen enkele van de bestudeerde klaslokalen in Schone Lucht, Lage Energie enige actie tot broncontrole ondernomen werd, is het aangeraden ventilatievoud volgens HEALTHVENT gelijk aan 7-8l/sec/pers, wat dan volgens NBN EN 13779 vertaald wordt in IDA3 of beter.

Woningen

Algemeen werd voor **Schone Lucht, Lage Energie woningen** besloten dat de fysico-chemische kwaliteit van de binnenlucht in energie-efficiënte, mechanisch geventileerde woningen, matig verbeterde ten opzichte van traditionele woningen (d.w.z. geventileerd via opening van ramen, geen mechanisch ventilatiesysteem). De sterkste verbetering werd vastgesteld voor CO_2 in de woningen, voor de andere gemeten componenten werden minder uitgesproken verbeteringen van de luchtkwaliteit waargenomen.

In woningen bleek het grootste deel van de gemeten fysico-chemische componenten onafhankelijk van het mechanisch ventilatiesysteem of van de gebouwluchtdichtheid. Algemeen kan besloten worden dat er geen degradatie van de binnenmilieukwaliteit waargenomen werd bij een toenemende luchtdichtheid. Enkel in woningen, gekarakteriseerd door het hoogste totaal ventilatievoud (gelijk of groter dan 0.5ACH), werden opmerkelijk lagere binnenconcentraties van CO_2, VOCs, TVOC en in mindere mate aldehyden waargenomen, ten opzichte van de woningen met een lager totaal ventilatievoud. Er werd geen significant verschil waargenomen in de concentraties van de bestudeerde componenten tussen woningen met de twee mechanische ventilatiesysteemtypes.

Het verband tussen het binnenmilieu en het totaal ventilatievoud of het type ventilatiesysteem komt minder frequent voor en is minder uitgesproken in Schone Lucht, Lage Energie woningen, ten opzichte van Schone Lucht, Lage Energie klaslokalen. Deze vaststelling kan toegeschreven worden aan: (1) het feit dat de groep Schone Lucht, Lage Energie klaslokalen duidelijk homogener is dan de groep woningen, als gevolg van de grotere variëteit en het frequenter voorkomen van binnenbronnen in woningen; (2) het feit dat bij het toekennen van de IDA klassen een herberekening van het ventilatievoud per klaslokaal werd uitgevoerd, waarbij rekening gehouden wordt met het aantal leerlingen aanwezig in de klas. Deze ‘IDA-klasse’-parameter van een klaslokaal blijkt beter geassocieerd te zijn met het binnenmilieu van dat lokaal dan het totale ventilatievoud van een gehele woning (niet omgerekend naar het aanwezige aantal aanwezigen, wegens te variabel gedurende de dagen) ten opzichte van de luchtkwaliteit in de woonkamer ervan.

Alhoewel een betere tot gelijke luchtkwaliteit aangetroffen wordt terwijl de geïnstalleerde maximale debieten de ontwerpdebieten niet halen, zijn deze resultaten niet direct aan elkaar gekoppeld. Het ontwerpdebiet wordt verondersteld een goede luchtkwaliteit te voorzien bij volledige bezetting van de ontwerpcondities en zonder luchttoevoer via kieren en openingen. Deze volledige bezetting en afwezigheid van lekken zijn echter niet de condities waaronder deze stalen werden verzameld.

Voor biologische binnenluchtkwaliteit wijst de meerderheid, doch niet alle wetenschappelijke literatuur op een positieve, d.i. reducerende, impact (1) van mechanische ventilatie met filtratie van toevoerlucht en (2) van een hoger ventilatievoud op schimmels, en in mindere mate, op bacteriën in de binnenlucht. Algemeen wordt aangenomen dat dit positief effect het gevolg is van de verwijdering van fijn stof, inclusief microben, door filtratie van inkomende buitenlucht en door het verwijderen van deeltjes via uitgaande lucht. Er werd echter nog nooit een systematische vergelijking gemaakt binnen energie-efficiënte gebouwen, waarbij zoals in deze studie woningen met mechanische luchtafvoer en ventilatieroosters beschouwd worden ten opzichte van woningen met gecontroleerde toe- en afvoerlucht. De bevindingen van Schone Lucht Lage Energie spreken dit concept in zekere zin tegen, voornamelijk voor bacteriën in de binnenlucht, en dit in het bijzonder voor klaslokalen. In klaslokalen met ventilatiesysteem D werden verhoogde concentraties bacteriën aangetroffen ten opzichte van type C; een lichte trend naar lagere hoeveelheden bacteriën en schimmels in klaslokalen met een lager debiet per leerling werd waargenomen.

Het is onmogelijk om uit dit onderzoek te besluiten of deze bevindingen wijzen op een werkelijk effect van gebouwtype op microbiële parameters van de binnenlucht, dan wel dat ze het gevolg zijn van de redelijk kleine dataset - uit eerder onderzoek is immers gebleken dat kleine datasets gevoelig zijn voor de welgekende variabiliteit van korte-termijn actieve luchtmetingen bij aanwezigheid van sterke bronnen van bacteriën en schimmels - of misschien het gevolg zijn van een ondoeltreffend onderhoud van ventilatiesystemen in deze dataset. Verder, aangezien er voor België/Vlaanderen geen informatie ter beschikking is over achtergrondniveaus van microbiële parameters van klachten-vrije woningen en scholen, kunnen de verzamelde gegevens niet geëvalueerd worden ten opzichte van data uit traditionele, niet-mechanische geventileerde woningen en scholen in vergelijkbare omgevingen en omstandigheden.

De gezondheidsimpact van een verhoogde concentratie bacteriën in binnenlucht is nog niet duidelijk. Toch zijn de resultaten van deze studie erg waardevol en geven ze aanleiding voor verder onderzoek, om de indicaties die in deze studie aangegeven worden verder op te helderen.

De volgende beleidsaanbevelingen en valorisatie mogelijkheden werden geformuleerd:

1. Op gebied van chemische, fysische en biologische karakterisatie

- In energie-efficiënte, mechanisch geventileerde (zowel systeem C met verluchtingsroosters met gecontroleerde luchtafvoer, als systeem D met gecontroleerde toe- en afvoer lucht) gebouwen komen de meeste chemische componenten op gelijkaardige, ietwat lagere concentratieniveaus voor, in vergelijking met traditionele gebouwen (zonder een mechanisch ventilatiesysteem). Mechanisch geventileerde gebouwen zijn duidelijk doeltreffender geventileerd dan traditionele gebouwen. Deze bevinding wijst erop dat in voldoende geventileerde gebouwen nog lagere binnenluchtconcentraties van polluenten verkregen zouden kunnen worden, indien een doeltreffende bron-reductiestrategie toegepast zou worden. Richtlijnen over het gebruik van laag-emitterende bouwmaterialen en consumentenproducten, productlabels of regelgeving over materiaalemissies kunnen van grote betekenis zijn om deze doelstelling te bereiken.

- Er is een gebrek aan referentiewaarden met betrekking tot het voorkomen van schimmels en bacteriën in klachtenvrije, traditionele woningen en scholen in België en Vlaanderen. Ook het onderlinge verband tussen chemische, fysische en biologische karakteristieken en het voorkomen hiervan in traditionele, nieuwbouw en gerenoveerde gebouwen zou meer in detail bestudeerd moeten worden.

- Het is onduidelijk in hoeverre een constante luchtstroom in mechanisch geventileerde klaslokalen een invloed kan uitoefenen op het in resuspensie blijven van opgewaaid stof, zodat het bezinken van bacteriën en schimmels op oppervlakten vermindert. Om dit fenomeen meer in detail te bestuderen is een diepgaandere analyse nodig, die noodzakelijkerwijs bestaat uit een aanzienlijk groter aantal stalen en gelijke groepen van mechanisch geventileerde en niet-mechanische geventileerde klaslokalen.

- Voor klaslokalen is het IDA-classificatiesysteem een zeer geschikte indicator voor de aanwezigheid van chemische en fysische contaminanten in het binnenmilieu ($PM_{2.5}$, CO_2, tolueen en formaldehyde). De binnenconcentraties van deze componenten vertonen de tendens om toe te nemen met de IDA-klassenummer. Bacteriën in de binnenlucht blijken echter antigecorreleerd te zijn aan de IDA-klassenummer in deze dataset. Zoals eerder vermeld in deze paragraaf is meer onderzoek naar het (samen) voorkomen van de verschillende componenten nodig (zoals reeds vermeld kunnen de gerapporteerde concentratieniveaus beïnvloed zijn door specifieke karakteristieken in de bestudeerde klaslokalen in Clean Air, Low Energy).

- De bestudeerde gebouwen in Clean Air Low Energy zijn nieuwbouwconstructies. Aangezien renovaties tegenwoordig en ook in de toekomst in Vlaanderen nog veel frequenter zullen plaatsvinden, en omdat renovaties vaak complexe combinaties van bestaande en vernieuwde gebouwelementen impliceren, is het belangrijk om deze zelfde set parameters te bestuderen in gerenoveerde gebouwen en deze te vergelijken met de gegevens uit deze dataset. Een interessant aspect van deze oefening, kan zijn om de impact van particuliere initiatieven van gebouweigenaars, te vergelijken met renovaties begeleid door een architect.

- Het is niet voor de hand liggend om de enige momenteel beschikbare passiefschool in Vlaanderen te beschouwen als representatief voor alle passief scholen die momenteel gebouwd worden in Vlaanderen. Omdat de bestudeerde passief school een gesloten instelling is, hadden niet alle klaslokalen een typische klaslokaalinrichting. Zo was bijvoorbeeld één klaslokaal ingericht als keuken, en was een ander klaslokaal uitgerust met een winkel. Het is niet uitgesloten dat specifieke producten aanwezig in deze lokalen de binnenmilieumetingen beïnvloed hebben, in het bijzonder de biologische karakterisatie. Deze conclusie moet alsnog beschouwd worden als hypothetisch, meer onderzoek naar het binnenmilieu in passief school-klaslokalen met een typische inrichting is nodig.

- In verder onderzoek kan het zinvol zijn om het niveau van detail van de metingen nog te verhogen. Zo kan bijvoorbeeld het noteren van het eigenlijke aantal aanwezigen, de eigenlijke ventilatie, luchtdichtheid en luchtkwaliteit, op een kleinere tijdsresolutie leiden tot extra inzichten, in het bijzonder met betrekking tot de effecten van vraaggestuurde ventilatiesystemen. De kosten, en de inbreuk op de privacy van de bewoners om deze informatie te verkrijgen, kunnen dit voorstel echter tegenwerken.

2. Op gebied van ventilatiesystemen

- Sensibiliseren en informeren over het gebruik en onderhoud van een ventilatiesysteem, gericht op scholen en woningen, is noodzakelijk (uit dit onderzoek blijkt dat ventilatiesystemen vaak gebruikt worden op een te laag debiet en dat ze zelfs uitgeschakeld worden in klaslokalen) aangezien het merendeel van de gebruikers niet op de hoogte blijkt te zijn van de impact en de functie van het ventilatiesysteem. Meer specifiek voor scholen lijkt begeleiding bij het uitstippelen van een doeltreffende onderhoudsstrategie, gericht op de verschillende actoren aanwezig op school (de directie, de preventieadviseurs, de leerkrachten, het onderhoudspersoneel en externe poetsdiensten) nuttig. De ontwikkeling van een code van goede praktijk voor het gebruik van ventilatiesystemen op school kan hierbij een doeltreffend actiepunt zijn (cfr. Code van goede praktijk voor ventilatiesystemen in residentiële gebouwen, WTCB)

- Aanbevelingen over de juiste dimensionering van ventilatiesystemen, om te voorkomen dat het dagdagelijks functioneert in de hoogste stand (dit verhoogt de waarschijnlijkheid op geluidshinder) om een voldoende ventilatievoud in functie van het aantal aanwezigen te verkrijgen. Informeren en sensibiliseren van relevante actoren bij het dimensioneren van het ventilatiesysteem, zoals fabrikanten, installateurs en architecten, die kunnen bijdragen tot de preventie van ondergedimensioneerde ventilatiesystemen, is hierbij nodig.

- Een kwaliteitsgarantie voor ventilatiesystemen zal een toegevoegde waarde opleveren voor kwaliteit van het binnenmilieu: een opgelegde keuring is hiervoor aangewezen. De resultaten van dit onderzoek tonen, in overeenstemming met vorige studies, aan dat het ontwerpdebiet zoals gespecificeerd in de standaarden niet gehaald wordt in de meeste situaties. Uit voorgaand onderzoek blijkt dat dit toegeschreven wordt aan het simultaan voorkomen van een onvolledig/ontbrekend ontwerp en een gebrek aan kwaliteitscontrole bij de installatie. Momenteel is dit mogelijk omdat een keuring onbestaand is, en de prestatie van het systeem daardoor nooit gecontroleerd wordt. Het is aanbevolen een keuringsrapport te verplichten

- Ondanks de tekortkomingen die vastgesteld worden bij de geteste ventilatiesystemen, wordt een voldoende binnenluchtkwaliteit gemeten. Deze vaststelling demonstreert de noodzaak om de bediening van het ventilatiesysteem of de automatische bediening ervan goed te begrijpen. Dit impliceert echter niet dat de ontwerpdebieten te hoog zijn. Meer onderzoek is nodig om na te gaan of een reductie van debieten werkelijk aanvaardbaar is. INDIEN deze verlaagd zouden kunnen worden, is een diepgaande inspectie van de eigenlijke debieten van het ventilatiesysteem noodzakelijk, want dan zal er minder marge zijn voor afwijkingen.

- Toevoer- en afvoerdebieten hoeven niet in balans te zijn volgens de standaard. Dit leidt tot een aantal interpretatieproblemen met betrekking tot warmterecuperatie en tot een lager totaal ventilatievoud. Dit kan verholpen worden door bijvoorbeeld richtlijnen te formuleren waarin het toe- of afvoerontwerpdebiet in elk specifiek project (welke van de twee de laagste is) verhoogd moet worden om de totale ontwerpdebieten gelijk te stellen voor toevoer en afvoer.

- Er is nood aan meer aandacht voor geluidshinder geproduceerd door ventilatiesystemen (of geluid afkomstig van buiten dat binnen treedt via openstaande ventilatieroosters). De resultaten duiden op een risico voor verlaagdeventilatiedebieten door geluidshinder, in het bijzonder in slaapkamers uitgerust met mechanische luchttoevoer (systeem D). Dit kan op zijn beurt leiden tot een minder goede binnenluchtkwaliteit. Architecten en installateurs moeten goed geïnformeerd zijn over het belang van het gebruik van geluidsbeperkende maatregelen, zoals geluidsdempers in kanalen of ventilatieeenheden met lagere geluidsproductie, om zowel akoestisch comfort als een goede binnenluchtkwaliteit te verzekeren.

- Deze studieresultaten duiden op een mogelijk probleem ten gevolge van geluidshinder in scholen opgebouwd uit modulaire eenheden, uitgerust met een mechanisch ventilatiesysteem. Meerdere gevalsstudies zijn nodig om te onderzoeken of het nodig is om het concept van mechanische ventilatie in dit type scholen te herbekijken.

- Architecten moeten bewust gemaakt worden van de geluidshinder die met waarschijnlijkheid geïnduceerd wordt in slaapkamers of woonkamers van ‘open plan’ projecten (met natuurlijke toevoer, systeem C) ten gevolge van de mechanische luchtextractie in aangrenzende badkamers of keukens. Extra geluidsbeperkende maatregelen, zoals dempers in de eindkanalen moeten in zo’n geval voorzien worden.

- Conclusies met betrekking tot de doeltreffendheid van onderhoudsinitiatieven van ventilatiesystemen kunnen niet geformuleerd worden op basis van deze dataset. Hiervoor is een aanvullende gedetailleerde vragenlijst over het laatste onderhoud, en hoe en wanneer dit uitgevoerd werd, nodig. Ondanks het feit dat dergelijk onderzoek geen deel uitmaakt van Clean Air Low Energy, zou dit een waardevol aanvullend onderzoeksprogramma zijn.

- Aangezien alle hier bestudeerde constructies gebouwd zijn na 2006 en de meerderheid van de gebouwen slechts sinds 3 tot 4 jaar in gebruik is, kan de lange-termijn invloed van verouderde ventilatiesystemen en van de onderhoudsinitiatieven van gebouweigenaars of schoolgebouw verantwoordelijken, niet opgenomen worden in deze studie. Een opvolgstudie in deze gebouwen, na 5 tot 10 jaar gebruik van het ventilatiesysteem, kan waardevolle onderzoeksinformatie opleveren, waarin de doeltreffendheid van het ventilatiesysteem, en de invloed hiervan op microbiële en chemische contaminatie van het binnenmilieu bestudeerd kan worden.

3. Op gebied van gebouwschil

- De binnenluchtkwaliteit van energie-efficiënte woningen en scholen uit dit onderzoek bleek licht verbeterd of gelijk aan deze die vastgesteld werd in traditionele gebouwen (zonder mechanisch ventilatiesysteem) met een zelfde functie. Er is dus geen indicatie dat het bouwen van energie-efficiënte gebouwen nadelige effecten op binnenluchtkwaliteit of menselijke gezondheid zou veroorzaken.

- Een zeer luchtdicht gebouw impliceert niet noodzakelijk een slechtere luchtkwaliteit

- Het verhogen van de luchtdichtheid van een gebouwschil (beperken van scheuren en kleine openingen, verzegelen van ramen, …) kan een zeer kostenefficiënte energiebesparende maatregel zijn. Dit kan door bijvoorbeeld kennisoverdracht naar ontwerpers en vakmensen. De gegevens van dit onderzoek tonen aan dat er bijvoorbeeld in de modulaire eenheden van scholen een verbetering mogelijk is op vlak van luchtdichtheid.

- Een lagere luchtdichtheid en een hoger totaal ventilatievoud van een klaslokaal leidt niet noodzakelijk tot een reductie van polluenten, typisch gevormd in het binnenmilieu zoals CO_2 en bacteriën. Afhankelijk van de plaats van de openingen en scheuren, is het mogelijk dat niet alle inkomende lucht afkomstig is van buiten (dit moet verder in detail bestudeerd worden).

- In geval van significante geluidshinder van buiten ($L_A > 60$ dB), moet de akoestische performantie van ventilatieroosters en andere ‘zwakkere’ façade elementen zoals ramen en rolluikkasten nauwgezet bestudeerd worden om te voorkomen dat gebruikers van het gebouw de roosters afsluiten wegens geluidshinder. In het bijzonder voor geluidshinder-gevoelige kamers (slaapkamers en klaslokalen) zijn akoestisch verbeterde roosters en akoestische beglazing (bijvoorbeeld asymmetrisch of gelamineerd) aangeraden. Architecten en hun cliënten moeten gesensibiliseerd worden over de nood aan een goed-gebalanceerde geluidsisolatie van akoestisch zwakke façade-elementen in functie van geluidshinder afkomstig van buiten, om het correct gebruik van ventilatieroosters en dus een voldoende luchtdebiet te verzekeren.

4. Warmtewisselaars

- Op basis van deze studie is er een indicatie dat een ventilatiesysteem D uitgerust met een bodemwarmtewisselaar, een risico voor verhoogde luchtconcentraties bacteriën met zich mee brengt. Hierbij moet benadrukt worden dat de grootte van deze dataset slechts toelaat om een indicatie vast te stellen. Dit is een aspect dat in verder onderzoek meer aandacht verdient.

- Andere warmterecuperatie opties, zoals de aardwarmtewisselaar, hercirculatie van lucht en de aanwezigheid van flexibele leidingen, wezen niet op een verschillende situatie ten opzichte van het ‘gewone’ ventilatiesysteem type D. Hierbij moet benadrukt worden dat de grootte van deze dataset slechts toelaat om een indicatie vast te stellen. Dit iseen aspect dat in verder onderzoek meer aandacht verdient.

Clean Air Low Energy Summary

The aim of this exploratory study was to assess the indoor air quality (IAQ) in energy-efficient buildings (EEBs), including homes and schools. Physical, chemical and biological parameters have been measured in order to determine whether indoor air in such buildings differs from non-energy-efficient buildings. The particular focus is on how the outdoor environment and ventilation systems affect on indoor parameters.

Designing energy-efficient buildings is synonym for a reduced energy use of the building, considered over its complete life cycle. Efficient strategies to reduce the energy consumption are, amongst others, a better building insulation and increased air tightness. Doing so, generated heat is kept inside of the building envelope, which leads to a positive effect on the energy consumption. Increased insulation and air tightness in newly built houses and schools, however, imply a limited air leakage through openings and cracks in the building envelope. Since sufficient building ventilation is indispensable to create and maintain a healthy indoor environment, these types of buildings need a ventilation system. A partly or fully mechanical ventilation system is in this case advisable, since ventilation systems offer the advantage of a controlled air exchange rate in the building. However, since the responsibility of a correct use and maintenance is in the hands of the users/occupants, building owners, and occupants become responsible for the creation and maintenance of a healthy indoor environment.

In this exploratory study, *Clean Air Low Energy*, the **indoor air quality of 51 indoor sites in low energy buildings, equipped with a mechanical ventilation system (controlled supply and exhaust air as well as trickle ventilators with controlled exhaust air) in Flanders** has been determined, in total in 25 houses and 26 classrooms. Each indoor environment was characterized chemically, physically and biologically; the energy performance and the building envelope of each indoor location are assessed as well.

In a first phase of the project, a detailed measuring strategy was designed, founded on open literature on (inter)national studies and on reviews concerning cause-consequence-solution research in energy-efficient ventilated buildings. Advantages as well as bottlenecks related to energy-efficient, ventilated buildings were included in this review. The indoor environment, and the influence of the outdoor environment on the indoor air were reviewed as well. As a result, indoor and outdoor chemical, physical and biological parameters were included in the measuring plan for Clean Air, Low Energy. Based on this review, (1) priority selection criteria for buildings were formulated and distinguished from (2) parameters to be measured on-site or (3) parameters to be included in a building-related questionnaire. Furthermore it was concluded that this study is the first in its kind to explore the interaction between chemical, physical and biological indoor/outdoor parameters and (1) building envelope characteristics, such as airtightness and total air change rate, (2) ventilation system characteristics, such as ventilation system type and heat recovery systems, and (3) noise nuisance, related to the ventilation system and the outdoor environment.

In the second phase 51 buildings, of which 25 houses and 26 classrooms in Flanders, Belgium were selected. Initiated by a mailing and by notification on relevant websites, a message was sent out to recruit relevant buildings for this research programme. House and school owners could volunteer for participation in the study by completing a registration file. This registration document contained relevant house/school characteristics that were used in the final house/school building selection. All selected indoor sites are characterized by combinations of building envelop and ventilation system type, that are representative for the current and future

trends in the building patrimony in Flanders. Therefore, passive buildings as well as low-energy buildings, and ventilation systems with controlled supply and exhaust air as well as systems with controlled exhaust and trickle ventilators were included in the study.

The sampling campaign focussed on the chemical, physical, and biological characterisation of the indoor environment in these energy-efficient buildings. This implies a physico-chemical analysis of the indoor environment as well as the corresponding outdoor air; the quantification of fungi and bacteria indoors and in the corresponding outdoor air, the measurements of noise nuisance due to building ventilation (both ventilation system-related and outdoor air-related) and the measurement of the effectiveness of the ventilation system in relation to the theoretical ventilation and air infiltration. The following parameters were quantified for each location: 18 VOC compounds, TVOC, formaldehyde, acetaldehyde, total other aldehydes, $PM_{2.5}$, CO_2, draught, temperature, relative humidity, total viable bacteria count and fungi in air and in deposited dust, total air change rate, air tightness, and noise nuisance.

This wide data set has been explored with the aim to study inter-relations between the characterized parameters in the different studied locations. The following questions were put forward in this analysis:

> *Does the ventilation system have an influence on the indoor air quality?*
> *Does building airtightness influence the indoor air quality?*
> *Does the total air change rate influence the indoor air quality?*
> *Does noise nuisance affect building ventilation and is there any indication of an indirect relation with indoor air quality?*

Schools

In general for **Clean Air Low Energy schools**, it was concluded that the physico-chemical quality of the indoor air in energy-efficient, mechanically ventilated classrooms is improved or equal to the indoor air quality typically monitored in traditional classrooms (i.e. ventilated through window opening). Mainly for CO_2, $PM_{2.5}$ and the I/O ration of $PM_{2.5}$, considerably lower levels have been registered in the Clean Air Low Energy classrooms.

In this dataset, airtightness didn't seem to influence the indoor air quality. Overall, no significant degradation of the indoor air quality with better building airtightness was observed. However, the type mechanical ventilation system, as well as the total air change rate, were indicated to be related to the physico-chemical as well as biological contaminants in the classrooms. Especially when the results for indoor air quality are compared to previous studies with lower air exchange rates, a clear improvement indoor air quality is observed.

According to this dataset, indoor CO_2 is not influenced by the mechanical ventilation system type. However, in the studied classrooms, mechanical ventilation systems with controlled supply and exhaust air tend to reduce $PM_{2.5}$ in incoming air, which leads to reduced indoor levels, as well as to reduced $PM_{2.5}$ I/O ration compared to classrooms with trickle ventilators and mechanical exhaust. The higher total air change rate in classrooms with a mechanical ventilation system D, is characterised by only moderately lower indoor TVOC, certain individual VOCs, formaldehyde, total other aldehyde levels as well as relative humidity inside these rooms.

A moderate increase of draught (air speed) was found in the studied classrooms with trickle ventilators and controlled air exhaust, compared to controlled supply and exhaust air. In the BiBa study (On the indoor air quality in traditionally built schools, 2010), 25 of the 90 studied classrooms were equipped with trickle ventilators (without controlled exhaust air); only 64% actually hereof actually used the trickle ventilation during the fieldwork. Although draught was not quantified in that study, it was mentioned by the teacher to be the main reason for closing the trickle ventilators.

The total air change rate of the classrooms, recalculated to IDA classes taking into account the total number of present pupils in the rooms, was fairly well associated with the indoor CO_2, $PM_{2.5}$, formaldehyde, and to a lesser extent toluene concentrations. In fact, a higher IDA class implied increased indoor levels of the latter listed compounds. It should be noted that compared to NBN EN 13779, for each IDA class considerably lower indoor CO_2 levels were measured than the recommended concentrations. This indicates that in this dataset a certain discrepancy was found between both methods to assign the IDA classes in schools, i.e. by calculating the 'total air change rate per pupil' and by 'the difference between indoor and outdoor CO_2 levels'.

The association between indoor air concentrations and IDA classes (thus air supply per person) is clearly in line with the recently reported conclusions of the EU project HEALTHVENT (December 2012), which aim was to develop health-based ventilation guidelines for non-industrial buildings in Europe (offices, homes, schools, nursery, homes and day-care centres). Those guidelines aim to clarify the role of ventilation on reconciling IAQ health based quality by (1) protecting people staying indoors most of their life time against air pollution risk factors, and (2) at the same time taking into account the need for having more efficient energy use for comfort in buildings. The outcomes of this study indicated that a provision of 7-8l/sec/pers is enough to avoid significant health problem when one doesn't know anything about building and pollutants. However, a minimal health based ventilation rate guideline of 4l/sec/pers would be advisable if all source control measures have been guaranteed: good outdoor air (World Health Organisation guidelines), clean materials and no other sources indoors but the occupants themselves. See http://www.healthvent.byg.dtu.dk/. Since in none of the studied classrooms any initiative on source control has been taken, the advisable ventilation rate according to HEALTHVENT would be 7-8l/sec/pers, which translated according to NBN EN 13779 equals IDA 3 or better.

Houses

In general for **Clean Air Low Energy residences**, it can be concluded that the physico-chemical quality of the indoor air in energy-efficient, mechanically ventilated houses was found to be moderately improved or equal to the indoor air quality monitored in traditional buildings (i.e. ventilated through window opening). The best improvement was found for indoor $CO_{2,}$ for other compounds less distinct improvements are found.

In residences, the majority of the measured physico-chemical compounds was found to be independent of the mechanical ventilation system or the building airtightness. Overall, no significant degradation of the indoor air quality with better building airtightness was observed. Only in houses that are characterised by the most elevated total air change rate (equal or larger than 0.5 ACH), remarkably lower indoor CO_2, VOCs, TVOC and to a lesser extend aldehydes were monitored in comparison to the other total air change rate levels. Overall, no significant differences in indoor air quality were observed between the 2 ventilation system types apart from differences in air change rate.

Clearly fewer and less apparent relationships between building total air change rate or ventilation system and the indoor environment were found in the Clean Air Low Energy houses, especially when compared to the classrooms. This finding was attributed to several reasons: (1) the group of Clean Air Low Energy classrooms is clearly more homogeneous than the group of residences as a result of the wider variety and higher abundance of indoor sources in residences; (2) the IDA class recalculation of the total air change rate per classroom to an air supply per child, present in that room, is indicated to be better associated to the indoor environment than the total air change rate of a whole house to the indoor air quality of its living room, not being recalculated to the amount of persons present throughout the sampling period. The bulk exposure to CO_2 for example will be located in the bedrooms. This relative independence of flow rate and pollutant concentrations that are mainly linked to indoor sources also suggests that these sources are in equilibrium conditions with the indoor environment.

Although good IAQ results are found while the installed maximum flow rates do not meet the design flow rate, these two results have no direct connection. The design flow rate is supposed to provide good IAQ in fully occupied design conditions and without air supply through leakage. This does not correspond to the occupancy and leakage levels in the measurement period.

Biological indoor air quality, the majority, but not all of the scientific literature points towards a positive, i.e. reducing impact of mechanical ventilation (with filtration of incoming air, compared to natural ventilation) and higher air exchanges on fungal and - to a lesser extent - bacterial levels in indoor air. The positive effect is generally believed to be due to removal of outdoor particles, including microbes, through filtration and due to removal of particles through exhaust air. However, no systematic comparisons have been made within energy efficient buildings, comparing as here for example mechanic exhaust to mechanic intake and exhaust systems. The findings in Clean Air Low Energy generally somewhat oppose these concepts, in particular with respect to bacteria in indoor air and in particular for schools. Higher bacterial levels were found in classrooms with ventilation type D compared to type C; a tendency towards lower bacterial and fungal levels in classrooms with lower air exchange rate was observed.

It is impossible to conclude from this study whether these findings actually indicate a real effect of building types under study on the microbial contaminants in the indoor air, or whether the results are not rather an effect of the very low sample size, susceptible towards the known variability in short-term active air samples, the presence of strong indoor sources of bacteria and fungi or maybe some cases of inadequate maintenance of the ventilation systems in the study schools. Also, since there is a lack of baseline level information on microbial contaminants in complaint-free houses and schools in Belgium, the data cannot be measured to levels in traditional, non-mechanically ventilated buildings. The health relevance of elevated bacterial levels in indoor air is unclear. However, the results of this study are certainly interesting and call for further research to clarify the indications obtained in Clean Air Low Energy.

The following valorisation possibilities and policy recommendations were formulated:

1. In the field of chemical – physical – biological characterisation
   - In energy-efficient, mechanically ventilated (trickle ventilators with controlled exhaust as well as controlled supply and exhaust air) buildings, most chemical compounds occur at similar or somewhat lower concentration levels compared to traditional buildings. Mechanically ventilated buildings are clearly more effectively ventilated than traditional buildings. This finding indicates that sufficiently ventilated buildings may be characterised by even more reduced indoor concentration levels if an efficient source reduction strategy would be implied. More guidance on the usage of low-emitting building materials and consumer products; labelling of products, or regulations on material emissions would be of considerable value to achieve this goal.

   - There is a lack of baseline information of viable fungi and bacteria in Belgium, Flanders, in complaint-free, traditional houses and schools. Also the interrelation between chemical/physical/biological characteristics and their behaviour in traditional, in newly built and in renovated buildings should be studied more in detail.

   - It is unclear in how far a constant airflow in mechanically ventilated classrooms may affect on keeping resuspended microbial material suspended in the air rather than supporting settling and deposition of bacteria and fungi on surfaces. In order to investigate more in depth into this issue, clearly higher number of samples and equal group sizes of mechanically ventilated and non-mechanically ventilated classrooms are necessary.

- In classrooms, IDA classes are a very appropriate indicator for chemical/physical contaminants in indoor air ($PM_{2.5}$, CO_2, toluene, formaldehyde). Indoor levels of these compounds tend to increase when moving to a higher IDA class. Viable bacteria seem to behave anti-correlated in this particular dataset. As listed in this paragraph, more research on the (co-)occurrence of the compounds in indoor air is needed (as specified earlier, the reported results may be influenced by specific characteristics of the studied classrooms).

- The buildings studied in Clean Air Low Energy are new built constructions. Since renovations are even more common today and in the future in our regions, and because renovations often imply a much more complex interplay between the existing and the renewed elements of the building, it is important to study this same set of parameters in renovated buildings and compare the indoor environment with this dataset. An interesting aspect of repeating a similar study like Clean Air Low Energy in renovated buildings, is the impact of individual initiatives of house owners, compared to renovations guided by an architect.

- It is difficult to consider the one passive school studied in Clean Air Low Energy as an indoor environment representative for all passive schools that are currently being built or will be built in Flanders. Because of the fact that the studied school was a closed rehabilitation institute, not all classrooms had a typical classroom setup in this case. For instance, the first classroom was a kitchen, the second had a shop inside. Specific products in these rooms may have biased the indoor environment, mainly its biological characterisation. However, since this conclusion should be reported as hypothetical, more research on the indoor environments of operational passive schools is needed.

- In future studies, it might be interesting to increase the level of detail of the measurements even more. Monitoring the actual amount of people present and the actual instantaneous ventilation, infiltration rates and air quality, might provide additional insights, especially concerning the effects of demand controlled ventilation systems. Associated costs and the intrusion of the privacy of the inhabitants might however hamper these research methods.

2. In the field of ventilation and ventilation systems

   - Sensibilisation and information on use and maintenance of the ventilation system, in schools as well as in residences, is needed (generally the ventilation system is used at a low set point; even shut-down effect in one classroom), since most of the users do not seem to be aware of the impact or functionality of their ventilation system. More specifically for schools, guidance on a good maintenance strategy, focussed on the different actors in a school (school principal, prevention advisors, teachers, school building cleaning personnel and external cleaning services) can be beneficial. The development of a code of good practice for ventilation systems in schools could in this case be a suitable action (cfr. Code of good practice for ventilation systems in residential buildings, WTCB).

- Recommendations on a correct dimensioning of a ventilation system, with the aim to prevent a day-to-day operation in the highest position (which implies potentially more noise nuisance) to achieve a sufficient ventilation rate as a function of the typical amount of occupants. Informing or sensibilisation of relevant actors in the dimensioning of a ventilation system, such as manufacturers of ventilation systems, installers and architects, may contribute to the prevention us under-dimensioned ventilation systems.

- Quality assurance for ventilation systems would imply an added value to the quality of the indoor environment: commissioning is necessary since this study, in accordance with others, demonstrates that the design flow rates specified in the standards are not met in a majority of cases. This can be traced back to simultaneous occurrence of inadequate or absent design and a lack of quality control during installation, allowed to exist by the fact that commissioning is virtually non-existent and the performance of the system is therefore never checked. It is recommended that a commissioning report becomes mandatory.

- The relatively good indoor air quality that was found in spite of all shortcomings of the ventilation systems clearly demonstrates the necessity of either good understanding of the control of the ventilation system or automated control. This, however, does not imply that the design flow rates are too high. Further research is needed to assess if a reduction of the legally required flow rates is really acceptable. IF these requirements would be lowered, a thorough inspection of the actual flow rates of the ventilation system is essential, because there will be less margin.

- Supply and exhaust flow rates in the standard are not balanced, leading to a number of interpretation problems for heat recovery ventilation and generally lower total air change rates for exhaust ventilation. This could be addressed by specifying e.g. in guidelines that the total design flow rates for supply and exhaust should be equal. The supply or exhaust design flow rates in each specific project (which ever of both is the lowest) should be increased to achieve equal total design flow rates for supply and exhaust.

- There is a need for more attention towards the noise produced by the ventilation system itself (or noise entering through the vents from outside the buildings. Results indicate an actual risk of ventilation flow rates being lowered because of noise nuisance, especially in bedrooms with mechanical air supply (system D), which may in turn result in poor IAQ. Architects and installers have to be well informed about the interest of sound reducing measures such as duct silencers and ventilation units with low noise production, to ensure both acoustic comfort and indoor air quality.

- The study indicates a possibly major problem of noise nuisance in modular unit schools due to mechanical ventilation system. More case studies have to be examined to point out a possible need to reconsider the concept of mechanical ventilation in this type of school building.

- Architects have to be made aware of the noise nuisance that is likely to occur in bedrooms or living rooms in ‘open plan’ projects (with natural air supply, system C) from mechanical air extraction in adjoining bathrooms or kitchens. Additional noise reducing measures such as mufflers in the end ducts have to be considered.

- There is an indication that system D with an earth-to-air heat exchanger risks to have more elevated indoor bacterial levels. Other options such as earth coupled heat exchangers with heat transfer fluid, recirculation of air and the presence of plastic ducts did not indicate differences to the 'regular' system D. It should be stressed that the magnitude of this dataset can only lead to an indication of an aspect that may need more attention in future research.

- Conclusions on the successfulness of maintenance initiatives of ventilation systems cannot be formulated based on this dataset. This would have implied additional detailed questionnaires on the last maintenance and how and when this has been performed. In spite of the fact that this kind of study was not part of Clean Air, Low Energy it would be a valuable additional research programme.

- Since all studied constructions were built after 2006 and the majority of the buildings is only in use since 3 to 4 years, the long-term influence of aging ventilation systems and the maintenance initiatives organised by house owners or school building responsibles, are not included in this study. It will however be valuable to organize a follow-up study in these buildings after 5 to 10 years usage of the ventilation system, including the effectiveness of the ventilation system, and its influence on indoor microbial and chemical contamination.

3. In the field of building Envelope characterisation

- The IAQ in energy-efficient, mechanically ventilated houses and schools was found to be moderately improved or equal to the indoor air quality monitored in traditional buildings. There is no indication that the trend towards energy efficient buildings will cause detrimental effects on IAQ and human health.

- A very airtight building does not necessarily imply a poor IAQ.

- Increasing the airtightness of building enclosures (reducing cracks and small openings, sealing windows,...) can be a very cost effective energy reduction measure and should be stimulated, e.g. by transferring knowledge to designers and craftsmen. The data in this study indicate that e.g. in the studied modular units improvement is possible on the level of airtightness.

- A lower airtightness and a higher total air change rate of classrooms don't necessarily lead to a decrease in pollutants typically formed indoors, such as CO_2 and bacteria. Depending on location of openings and cracks, not all incoming air may be originating from outdoors (needs more study)

- In case of significant outdoor noise levels ($L_A > 60$ dB), the acoustic performance of trickle ventilators and other 'weak' façade elements such as windows and roller shutter boxes has to studied carefully in order to prevent users from closing the trickle vents because of noise nuisance. Especially for noise sensitive rooms (bedrooms, classrooms) acoustically improved trickle vents and acoustic glazing (e.g. asymmetric or laminated) seem to be necessary. Architects and their clients have to be sensitized about the need of a well-balanced sound insulation of acoustically weak façade elements according to the outdoor noise exposure to ensure the use of trickle vents to supply sufficient air flow rates.

4. In the field of heat exchange system selection
    - The relation between the presence of an earth-to-air heat exchangers and indoor bacterial levels should be studied more in detail, in order to formulate a representative conclusion.

    - According to Clean Air Low Energy there is no indication for negative influences of other heat exchange systems on the indoor environment

Clean Air, Low Energy

Work Package 1: Measurement Strategy

“Exploratory research on the quality of the indoor environment in energy-efficient buildings: the influence of outdoor environment and ventilation”

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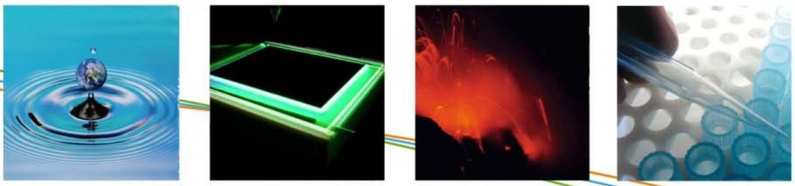

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LIST OF ACRONYMS

ACR	Air Change Rate
AER	Air Exchange Rate
CAV	Constant Air Volume
CO	Carbon monoxide
CO_2	Carbon dioxide
DCV	Demand-Controlled Ventilation
I/O ratio	Indoor/outdoor ratio
IAP	Indoor Air Pollution
IAQ	Indoor Air Quality
MVHR	Mechanical ventilation with Heat Recovery
NO_2	Nitrogen dioxide
O_3	Ozone
PEF	Peak Expiratory Flow
PFT	Perfluor carbon tracer
PMV	Predicted mean vote
PPD	Predicted percentage of dissatisfaction
RH	Relative Humidity
SAV	Seasonally Adapted Ventilation
EEBs	Energy-efficient buildings
SF6	Sulphur hexafluoride
SHS	Sick House Syndrome
SPL	Sound Pressure Level
STI	Speech Transmission Index
Temp	Temperature
TSP	Total Suspended Particles
VOC	Volatile organic compounds

CHAPTER 1 INTRODUCTION

The study to be conducted is an exploratory study on the indoor environment of energy-efficient buildings (EEBs). The overall aim is to assess the indoor air quality (IAQ) in energy-efficient buildings, including homes and schools; physical, chemical and biological parameters will be measured in order to determine, whether indoor air in such buildings differs from non-energy-efficient buildings. The overall study strategy follows the approach to determine various parameters in EEBs and compare the data generated in this study to data available from previous studies on non-energy-efficient buildings. The particular focus is on how the outdoor environment and ventilation systems affect on indoor parameters.

Designing energy-efficient buildings is synonym for a reduced energy use of the building, considered over its complete life cycle. Efficient strategies to reduce the energy consumption are, amongst others, a better building insulation and an increased air tightness. Doing so, generated heat is kept inside of the building envelope, which leads to a positive effect on the energy consumption.

Increased insulation and air tightness in newly built houses and schools, however, imply a limited air leakage through openings and cracks in the building envelope. Since sufficient building ventilation is indispensable to maintain a healthy indoor environment, these types of buildings need a ventilation system.

A partly or fully controlled mechanical ventilation system would be advisable, since ventilation systems offer the advantage of a controlled air exchange rate in the building. However, since the responsibility of a correct use and maintenance is in the hands of the users/occupants, building owners, and occupants become responsible for the creation and maintenance of a healthy indoor environment.

In this exploratory study, *Clean Air Low Energy*, the indoor air quality of 50 indoor sites - 25 houses and 25 schools/classrooms - in Flanders is determined. Each indoor environment is characterized chemically, physically and biologically; the energy performance and the building envelope are assessed as well. Mainly in the school monitoring part, the project’s name will be translated to *Schone Lucht Lage Energie*.

In agreement with LNE and VEA, the logo shown in Figure 1 has been designed in order to contribute to an efficient communication on the project to participants of the study – children as well as the inhabitants of the houses - to policy makers and to inhabitants, and school directions.

Figure 1: English and Dutch logo for the Clean Air, Low Energy study

Clean Air
Low Energy

Schone Lucht
Lage Energie

1.1. STRATEGY

1.1.1. PROJECT WORKPLAN

In a first phase (Work Package 1) a detailed measuring strategy is designed, founded on open literature on (inter)national studies and on reviews concerning cause-consequence-solution research in energy-efficient ventilated buildings. Advantages as well as bottlenecks related to energy-efficient, ventilated buildings, are included in this literature review. The indoor environment, and the influence of the outdoor environment on the indoor air is included as well. Therefore indoor and outdoor chemical, physical and biological parameters are included in the measuring plan.

Based on this review, (1) priority selection criteria for buildings are formulated and distinguished from (2) parameters to be measured on-site or (3) parameters to be included in a building-related questionnaire.

In the second phase (Work Package 2) in total 50 buildings, of which 25 houses and 25 schools/classrooms in Flanders, Belgium will be selected. These 50 buildings are characterized by combinations of building envelop and ventilation system type, that is representative for the current and future trends in the building patrimony in Flanders. Therefore, passive buildings as well as low-energy buildings (if available zero-energy buildings), and ventilation systems with controlled in-and outlet as well as systems with controlled outlets are included in the study.

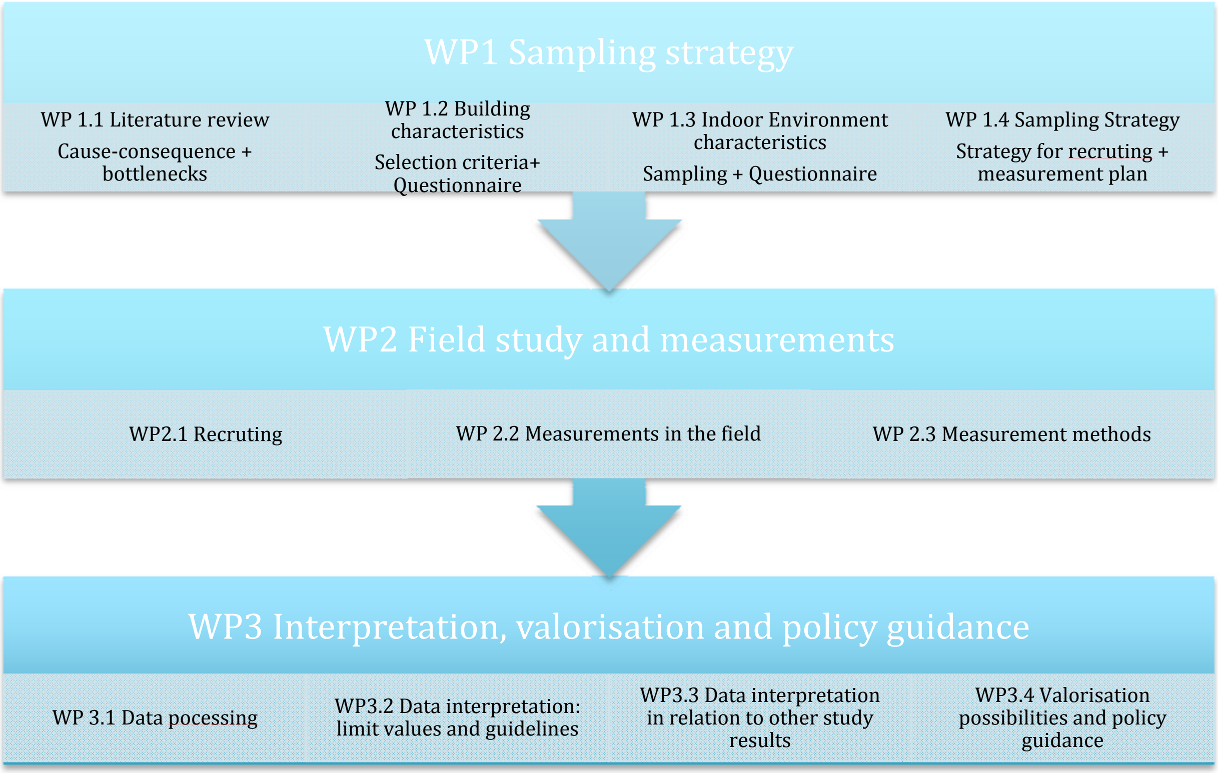
The sampling campaign focuses on the chemical, physical, and biological characterisation of the indoor environment in these energy-efficient buildings. This implies a physico-chemical analysis of the indoor environment as well as the corresponding outdoor air; the identification of fungi and bacteria inside the houses and the corresponding outdoor air, the measurements of noise nuisance due to building ventilation (both ventilation system-related and outdoor air-related) and the measurement of the effectiveness of the ventilation system in relation to the theoretical ventilation and air infiltration.

This large dataset will allow an exploratory comparison in the third work package (Work Package 3). In this step the indoor environments of passive, low-energy and traditional houses and schools in Flanders will be evaluated and compared, and different ventilation system types will be contrasted.

The indicative results of this research will lead to the formulation of policy options and guidance for environmental policy and other entities. Needs for further research, and practical guidelines for citizens will also result from this research. For this reason, in the building selection phase significant attention will be put on the possibility to extrapolate the data obtained from this relatively limited set of buildings, to the whole region of Flanders.

A schematic overview of the different work phases in Clean Air, Low Energy is shown in Figure 2.

Figure 2: Clean Air, Low Energy flowchart



1.1.2. MULTIDISCIPLINARY APPROACH

In order to achieve the workplan as presented in section 1.1.1, several scientific disciplines, all related to healthy energy-efficient building, are involved in this study. The various scientific disciplines and the respective research teams involved in *Clean Air, Low Energy* are listed in Table 1.

Table 1: Overview of the different scientific disciplines and responsible institutes

Discipline	**Involved team**
Chemical and physical contamination of the indoor and outdoor environment	VITO, Unit Environmental Risk and Health, team Air Quality Measurements
Biological contamination of the indoor environment	THL, National Institute for Health and Welfare, Department of Environmental Health, Environmental Microbiology Unit (Finland)
Noise Nuisance due to ventilation - Acoustics	WTCB, Technological Advice centre Acoustics.
Building Ventilation – ventilation systems	University of Ghent, Architecture and Urban Development, Building Physics and Installation techniques
Building insulation – Sustainability of buildings	VITO, Unit Transition Energy and Environment,

1.2. WP 1 INTERIM REPORT STRUCTURE

This first work package aims at the formulation of the most suitable sampling strategy to assess the indoor air quality in energy-efficient buildings (houses and schools), equipped with mechanical ventilation systems. The measurement strategy was determined in 3 phases:

Phase 1: An inventory of existing knowledge
Phase 2: The development of a strategy for building selection: recruitment & selection
Phase 3: The development of a detailed sampling strategy for the fieldwork

The sampling strategy will fit the conclusions and recommendations from relevant regional and (inter)national studies and will be based on knowledge reported in relevant scientific literature.

This report on ‘WP1 Sampling Strategy’ includes the literature review on current knowledge concerning the indoor environment in energy-efficient, energy-efficient buildings. Relevant studies are listed (CHAPTER 2) in a table format. The conclusions of this literature review will lead to the identification of building characteristics to be studied in *Clean Air, Low Energy* (CHAPTER 3). The literature review will also lead to the identification of the indoor characteristics, to be studied in *Clean Air, Low Energy* (CHAPTER 4). In the last chapter (CHAPTER 5) the conclusions and the final recommendations contribute to a detailed sampling strategy for *Clean Air, Low Energy*.

CHAPTER 2 LITERATURE REVIEW

2.1. RESEARCH STRATEGY

Relevant conclusions and outcomes, resulting from studies related to the characterization of the indoor environment, and to the influence of low-energy building and ventilation systems on the health of occupants on Flemish, Federal or European level, are included in this literature review. Also recent research results, reported in international, peer-reviewed journals are summarized in this review.

Doing so, the most important national and international conclusions and recommendations concerning cause-consequence in these characteristic indoor environments are collected. The result is reported in a table, including information on the health situation of occupants/building users, the indoor environment (indoor air quality, biological contaminants, noise nuisance, and outdoor environment), the building characteristics (ventilation systems, energy presentations, building envelope) and critical aspects (bottlenecks) and conclusions related to this building styles.

The following list of key words is used in the literature review:

Indoor (environment/air/air quality), energy-efficient (construction), passive (construction/building), energy-efficient (construction/building/design), low-energy (building/design), architecture, disturbance, comfort, background, level, grids, façade, speech, privacy, isolation, ventilation, ventilation systems/devices, green, health, noise, acoustics, outdoor environment, energy performance, building envelope, bottle necks (filter contamination, filter inefficiency, ventilation rate, usability of the ventilation system, maintenance, noise nuisance due to ventilation systems, noise nuisance due to outdoor environment, ventilation system types.

Furthermore the following search combinations gave most hits in a search on the Web of Science:

'ventilation and indoor quality', led to 1100 hits, and 'indoor air and ventilation system and chemical' led to 34 hits. It should be mentioned also that the combined search on 'Indoor air quality and low energy building', resulted in a very short list of publications.

2.2. LITERATURE REVIEW ON THE INDOOR ENVIRONMENT IN ENERGY-EFFICIENT BUILDINGS

Table 2 shows an extensive overview of relevant international literature in the indoor environment in energy-efficient, ventilated buildings. Table 3 gives an overview of finished and currently running relevant studies on aspects related to this topic.

Table 2: The most relevant publications concerning Physical, Chemical and Biological parameters in energy-efficient, mechanically ventilated buildings

	reference	study design?	location	chemical	physical	biological	acoustic	perceived IAQ	building envelope / type	energy performance	ventilation system	outdoor	health of occupants	bottle neck/conclusion
1	Aubin et al. 2011	Study on seasonal variation and intervention study investigating the impact of increased ventilation rates in different seasons on IAQ and the respiratory health of children	Canada	CO_2, NO_2, O_3, formaldehyde, benzene, toluene, hexanal, dichloromethane, tetrachloroethylene, a-pinene	temp, RH, SF6 AER and PFT AER,	airborne mould spores, settling mould spores, allergen samples in dust (not yet reported)	-	-	air tightness of the building (blower door)	-	the effect of increasing the ventilation rates: if ventilation rate < 0,3 h^{-1}, then ventilation rate is increased; comparison between seasons	-	-	seasonal variability: except for aldehydes, NO_2, O_3; all chemicals higher concentrated in winter/fall; intervention: average Canadian homes don't meet the nominal ventilation goal of 0,3/h; 85% of the houses don't meet this in winter time.
2	Bogers et al. 2011	A questionnaire based study on perceived air quality and subjective health in residences with mechanical air supply and exhaust ventilation and natural supply and mechanical exhaust systems	NL	-	-	-	-	perceived IAQ and subjective health	-	-	houses with mechanical air supply and exhaust versus natural air supply and mechanical exhaust	-	questionnaire on subjective health	lower perceived IAQ in mechanical supply and exhaust ventilation system; better perceived IAQ when natural air supply and mechanical exhaust
3	Breysse et al., 2011	investigation of resident health and building performance after rehabilitation of low-income housing according to green, energy-efficient techniques	USA	CO_2	radon	-	-	via questionnaire	low income housing, renovated according to green and healthy principles	energy use was reduced by 45 % over the one year post intervention period	after renovation: MV installed (no ventilation previously)		questionnaire: overall health, asthma, and not asthma-respiratory problems	significant improvements in overall health, asthma and not-asthma problems for adults and children
4	Dodoo et al., 2011	simulation study on the effect of heat recovery unit integration on the total primary energy use of residential buildings	Sweden	-	-	-	-	-	-	Passive house and conventional	Heat Recovery Ventilation	-	-	VHR systems can give substantial final energy reduction, but the primary energy benefit depends strongly on the type of heat supply system, and also on the amount of electricity used for VHR and the airtightness of buildings.
5	Raja et al. 2011	intervention study on the effect of the installation of a ventilation system with air filtration on the respiratory health in children	USA	VOCs, PM_{10}, CO, CO_2	temp, RH	-	-	-	-	-	comparison of bedroom with ventilation system turned on, ventilation system + filter (95% efficient PM removal), and ventilation system turned off.	-	pulmonary inflammation and PEF	statistical improvement of IAQ and pulmonary function with the unit running as compared with the placebo mode both with and without ventilation.
6	Stranger et al. 2011	comparison of the IAQ in 3 classrooms with different ventilation/aeration systems	B	$PM_{2.5}$, TVOC	temp, RH	-	-	-	-	-	first classroom equipped with heat recovery ventilation system and air supply filter, second is naturally ventilated with aeration surface $0,01\ m^2.m^{-3}$; third is naturally ventilated with aeration surface of $0,5\ m^2.m^{-3}$	-	-	IAQ in mechanically ventilated classroom better than aerated rooms; however in wintertime low indoor RH in ventilated room (< 30%)

7	Sundell et al., 2011	literature review investigation influence of ventilation on health	-	-	-	-	-	-	-	-	-	-	Non specific	Up to 25 l/s/pers of fresh air supply, a negative correlation is found between adverse health effects and ventilation rates
8	van Dijken et al. 2011	evaluation of the quality of ventilation systems (technical installation, maintenance and performance)	Nl	-	ventilation rates	-	installation noise levels	-	-	-	houses with balanced mechanical ventilation and houses with mechanical exhaust, built between 2006 and 2008; questionnaire on use and maintenance of the ventilation system	-	-	insufficient air supply and exhaust rates, improper construction of ductwork, insufficient control options and poor maintenance; overheating if no bypass section in installed as well as draught under the supply valves; wrong position of the ventilation unit, absence of properly installed silencers and improper construction of the duct work causes noise nuisance
9	Baird and Dykes, 2010	Post occupancy evaluations on 36 energy-efficient buildings in 11 different countries (Victoria university of Wellington, New Zealand)	Australia, Canada, D, India, Ir, Japan, Malaysia, New Zealand, Singapore, UK, USA	based on survey (other environmental factors: lighting, overall comfort, thermal comfort in winter, thermal comfort in summer)					commercial or institutional buildings	selected on basis of sustainability 'credentials' (LEED, BREEAM, CASBEE, Green Star Australia, Green Globes)	from full air conditioning through mixed-mode, to natural ventilation			despite high overall rating for interior environment of energy-efficient buildings , acoustic aspect scores less well. Strong correlation between overall perception of noise and perception of productivity and overall comfort
10	Briere, Bernard, 2010	Overview evolution of different ventilation systems according to applied building system in time (1900-…), referring to field study AIR-H " (see ref. AC.S.2)	F		condensations, draught	fungi	Equipment noise, sound insulation of façades				No ventilation, ventilation of individual rooms, overall natural ventilation, overall mechanical ventilation			Acoustical dysfuntions (façade insulation + equipments), 70% related to concept and workmanship, 22% to lack of maintenance or use, < 1% due to product/system dysfuntions. Problems related to IAQ remain predominant, reinforced air tightness leads to high sensitivity to equipment noise.
11	Haverinen-Shaughnessy et al., 2010	Cross-sectional study investigates the possible effect of low ventilation rates on academic achievement	USA	-	-	-	-	-	schools	-	-	-	-	School results are significantly influenced by the mean ventilation rate per pupil in the classroom
12	MacIntosh et al., 2010	modelling study, using multizone IAQ model to integrate data on ambient PM2.5, meteorology and ventilation and air cleaner configurations	-	$PM_{2.5}$	-	-	-	-	-	-	homes with natural ventilation (NV); homes with central AC with conventional filtration (AC CF) and homes with central AC with high efficiency in duct clears (AC high eff)	$PM_{2.5}$	-	median I/O ratios of 3 ventilation types: 0,57 (NV), 0,35 (AC CF) and 0,1 (AC high eff)

13	Madhavi et al. 2010	performance comparison of a passive and a low-energy building block	AU	CO2	temp, RH	-	-	thermal comfort assessed with PMV and PPD	passive building and low-energy building		passive building has a controlled ventilation; the low-energy building relies on user-operated natural ventilation (window opening)	-	-	performance on thermal comfort and IAQ contictions (CO_2) slightly better for passive house; a controlled ventilation system leads to lower indoor CO_2 concentrations , especially in cold periods and in multi-occupancy apartments
14	Noh et al., 2010	experimental study, PM levels measured at various ventilation rates and filter types in a residential housing		PM	-	-	-	-	residential housing with mechanical ventilation system	-	mechanical ventilation system with filter			appropriate combinations of filter type and ventilation rate was crucial for reducing PM levels indoor; inappropriate filters and rates leads to higher PM levels indoor compared to no mechanical ventilation
15	Paul et al. 2010	experiment in a test house (Tuskegee Healthy House) with mechanical induced fresh air ventilation.	USA	PM particle number	temp, RH, wall moisture	-	-	-	energy-efficient one-level test house		mechanical induced fresh air ventilation + HVAC system	-	-	fan 'on': RH, wall moisture and indoor PM increases; Fan 'off': RH, wall moisture an indoor PM decreases. In HVAC buildings: RH is low in winter time (dryness of skin, ..) ; in summer RH is high (humid and sweaty)
16	Viitanen et al., 2010	investigation of the susceptibility of building materials to mould if moisture exposure	Finland	-	RH	-	-	-	-	-	-	-	-	Proposed model makes it possible to evaluate the mold growth risk for different materials ifo. Humidity
17	Xu et al., 2010	intervention study: influence of air cleaning/ventilation unit in bedrooms of 30 asthmatic children: effect on health and IAQ		PM10, TVOC, CO, CO_2	-	-	-	-	bedrooms in participants dwellings (type: undefined)	-	HEPAiRx (3 AER per hour of outside air + 9 changes per hour of recirculated air, all over HEPA filter) units in bedrooms; average air exchange rate was 15,6 per hour	-	children with pre-existing asthma; significantly improvement of health outcomes (EBC nitrate, pH, PEF rate) on HEPAIRx operating status	2- fold lower PM 10 and TVOC concentrations when HEPAIRx system was operating; 20 % decrease in CO_2 levels
18	Zuraimi, 2010	literature review on the influence of duct cleanliness on indoor air quality	-	-	-	-	-	-	-	-	-	-	-	Existing evidence is insufficient to draw solid conclusions regarding positive impact of duct cleaning on IAQ, health benefits, cost savings and HVAC performance. Maintaining duct cleanliness has to be properly balanced by the probable generation of indoor pollution and potential health risks.
19	Bridger and George, 2009	Paper about HVAC mechanical systems and noise control as part of acoustics in green schools (in LEED Buildings)	USA	-	-	-	Calculation of SPL due to mechanical ventilation devices	-	Public buildings, Schools	Green Buildings (LEED)	mechanical ventilation devices			need for practical design methodologies and effective analysis tools for acoustical and mechanical engineers

20	Claeson et al., 2009	This work investigated perceived air quality and health effects from exposure to low to high levels of volatile organic compounds (VOCs) emitted from damp building materials and a mixture of moulds growing on the materials	-	VOC	-	-	-	PIAQ	-	-	-	-	Non specific	This study showed that exposure to high levels of VOC emitted from damp building materials and a mixture of mold may cause poor perceived air quality. It also indicated that stimulation of chemical warning systems (the nasal chemosensory part of the trigeminal system and the olfactory system) may enhance skin symptoms.
21	Coudriet, 2009	paper about various instances where energy-efficient building practices have degraded acoustical environment												with 'energy-efficient design' often: missing finishes, missing barriers, transom glazing, low pressure system and transfer air ducts, radiant heating, natural ventilation system, access flooring ... Implying ultra-low background noise, limited use of solid partitions, absence of common finishes --> poor acoustical conditions
22	Crump,2009	review report on IAQ in highly energy efficient homes												in UK, there have been no published studies on IAQ in highly energy efficient homes. There is a high need for more data on this topic.
23	Guigou-Carter et al., 2009	paper about effect of thermal retrofit on acoustic performance of a building from the 80s, based on prediction calculations (including the effect or air-inlets) - CSTB, France	F						apartment building 80's, 28 dwellings of different size, external walls 20 cm concrete with thermal lining (50 mm XPS+13 mm gypsum board), floor slabs 20 cm concrete.					The specific low-frequency sound reduction is in all cases above 30 dB. Including an air-inlet of performance 36 dB will generally reduce the façade sound insulation by 2 to 3 dB, while an air-inlet of performance 42 dB will generally reduce the façade sound insulation by 1 dB only
24	Maier et al. 2009	study on 22 identical houses in Germany, with 4 different ventilation strategies	D	CO_2	temperature			perceived thermal comfort	timber framed construction	energy consumption was measured	4 ventilation types: 1) natural, 2) ventilation system with air heating, 3) MVHR and 4) MV with single ventilators	-	comfort was measured	MVHR: 10 - 30 % lower energy consumption that other ventilation systems; MVHR: CO_2 concentrations 40 -50 % lower than with natural ventilation: perceived air quality was (very) good; no differences between systems; bottleneck: no other chemicals than CO_2 measured

25	McKell, Willmot, 2009	paper indicating achievable acoustic and ventilation performance with different ventilation strategies, calculations based on manufacturers' data and studies	Glasgow						facade containing elements comprising glass and masonry and a free area, standard bedroom size with a mid frequency reverberation time of 0.5 seconds		natural ventilation with partially opened windows (1), secondary glazed windows incorporating staggered openings (2) and trickle vents to provide background ventilation (3)			(1) : approximately 15 dB reduction, ventilation rate of 4 air changes per hour, not suitable for areas where the noise levels exceed 50 dB during the night, (2) : sound reduction of 26 dB to be expected, ventilation rate similar to (1), (3) : sound reduction of 31 dB, additional ventilation necessary
26	Roy, 2009	About the recurrent conflicts between recent trends in architectural design (open structures) or green design if buildings for sustainability and effect on speech privacy. Recommendations for architectural and acoustic design (LEED buildings)	USA	-	-	-	speech privacy (survey-wise)	-	Open plan spaces, closed spaces (offices, conference rooms, ...)	Green Buildings (LEED)	-	-	referring to research at UC Berkeley's Center for the Built Environment (post-occupancy IEQ evaluations, 400 buildings, 50000 respondents - 10% green buildings)	Acoustics = least satisfactory IEQ factor for all studies buildings, even slightly worse for green buildings (!) mainly focussing on lack of speech privacy (due to lack of insulation + absorption) (no measurements - only surveys)
27	Brager, L. Baker, 2008	describes the results of web-based surveys in 12 mixed-mode buildings, focuses on IEQ, compared to 358 other buildings with conventional air conditioning systems (University of California, Berkeley)	USA	air quality (occupant survey)	thermal comfort, lighting (occupant survey)	cleanliness (occupant survey)	speech privacy (occupant survey)	-	broad range of climates, building types, sizes and uses	-	mixed mode (combination of natural ventilation form operable windows an mechanical systems for air distribution and cooling) versus air-conditioning systems			mixed-mode buildings performing better compared to the overall building stock for thermal comfort and air quality; best performers in more moderate climates, newer, with radiant cooling or mechanical ventilation only, with high degrees of direct user control; overall lowest satisfaction scores for acoustics, only slightly better for mixed-mode buildings (no measurements - only surveys)
28	Brugman, 2008	Conclusions from several studies/researches on indoor climate in schools	the Netherlands						primary schools					3 bottle necks : IAQ during heating season, noise; control of temperature in rooms during summer period. CO_2 controlled ventilation with control of SPL

29	Versteeg, 2008	Article with conclusions from study "Lichtveld Buis & Partners" on indoor environment in primary schools ordered by. VROM, OCW, SZW en VWS – measurements + survey (part of research study AC.S.1)	60 primary schools (120 class rooms) in 30 different Dutch cities	Simultaneous registration of CO_2 –concentration, temperature and relative humidity (at least for 3 weeks)			Background noise level LAeq, reverberation time T60, speech intelligibility STI, characteristic façade insulation GA;k	IAQ during heating season and insufficient ventilation are seams to be hardest bottle neck: caused by human behaviour (draught, noise) + technical equipment (insufficient capacity), CO_2 concentration for rooms with system D seams lower ,			4 room types: natural in- and outlet by tilt- and turn windows, idem but with inlet ventilation grids in façade, system C and system D		Occupant survey	Besides air quality in heating season, other bottle necks: less controllable room temperature when no heating season, sound pollution due to outdoor noise (natural ventilation) leading to insufficient use of ventilation devices + equipment noise (mechanical ventilation). Most noise disturbance form mechanical in- and outlet. Room acoustics parameters (STI and reverb time) not related to ventilation system
30	Harm, 2008	Article base don report Health and Ventilation in 99 dwellings in Vathorst; research on relation between health complaints, indoor environment and dwelling characteristics (September 2007, GG Eemland)	The Netherlands	CO_2-concentration, draught and presence of van formaldehyde and VOS			SPL living room and most used bedroom (3 ventilation intensities) – more noise disturbance with balanced ventilation (though lower background noise)		Apartments, four, three and two façade dwellings built after 2000 (+/- 5 years old)	averaged EPC of 0.9	Type C (local natural inlet and central mechanical outlet), type D (central mechanical outlet and inlet with heat recuperation en sometimes bypass) only few dwellings where ventilation capacity meets prescriptions (15% for type D, 28% for type C)		Experienced noise disturbance seams to go with extreme tiredness and asthma (cause-consequence relation not clear), health complaints seam to be more related to balanced ventilation as to other indoor environment influences	Most important compaints for dwellings with system D (case group and matched group) are noise disturbance and draught from ventilation system, unpleasant smelling indoor air; faults in concept, material choices, execution and adjustment, expectations of habitant play an importent role in appreciation of indoor environment: more informed = less complaints. Link between balanced ventilation and health complaints inthis research can by a result of media attention (negative expectations – more attentive –more problems noticed))
31	Hodgson, 2008	occupant-satisfaction surveys and acoustical measurements in 6 green office buildings (University of British Colombia)	Canada	-	-	-	background noise level, reverberation time, STI, noise	-	mainly glass façades, sun shades and operable windows, mix of private and shared offices, open-office cubicles	-	one building studies with natural ventilation system	measurements made with quiet or noisy external source	-	inadequate noise isolation due to natural ventilation opening is a big problem, lack of speech privacy was found the biggest acoustical issue, next: HVAC noise, phone ringing, external noise, people moving and talking, office equipment, reverberation, mainly due to open office design, lack of absorption, ventilation openings in walls, floors, ceilings (= typical in Green buildings)

32	Palonen et al. 2008	assessment of thermal comfort, perceived IAQ and ventilation in 102 single family homes built since 1980	FIN	-	-	-	ventilation noise	perceived IAQ	single family houses, built since 1980	-	passive stack ventilation, mechanical exhaust ventilation and mechanical supply and exhaust ventilation with heat recovery; AER: 0.3 ACH (passive stack vent), 0.34 ACH mechanical exhaust; 0.41 mechanical supply and exhaust	-		1/3 of the homes: free of complaints; 20 %: at least 3 problems; most common problems: dustiness of surfaces and stuffy air, and ventilation noise related to the ventilation system. Measured ACR low compared with Finnish building regulation of 0.5 ach, with av. values of 0.30 ach for passive stack ventilation, 0.34 ach for mechanical exhaust and 0.41 ach for mechanical supply and exhaust ventilation
33	Howden-Chapman 2007	The study objective was to determine whether insulating existing houses increases indoor temperatures and improves occupants' wellbeing; community based, cluster, single blinded randomised study; intervention: installing ceiling insulation, draught stopping around windows and doors, ...	New Zealand	-	RH, Temp	self reported: musty smell, observed mould; measured: mould speciation, endotoxin, b-glucans, dust mite allergens (outcomes not reported in the results)	-						questionnaire, general practitioner visits	Bottleneck: few objective outcome measures; with respect to biologcial cont., only self-reported data on 'any mould'; Conclusions: insulating existing houses led to a significantly warmer, drier indoor environment and resulted in improved self reported health, self reported wheezing, days off school and work, visits to general practitioners as well as trend for fewer hospital admissions for respiratory conditions; statistically significant redcution of self-reported mould in intervention homes (aOR 0.24)
34	Khaleghi et al., 2007	pilot project at University of British Columbia, direct monitoring of ventilation, IAQ and acoustical conditions in 'green' and 'brown' buildings on ABC campus (3 buildings, 13 rooms) - investigation of correlation	Canada	(glass) fibre dust, PC, UPC, VOC concentration	-	-	background noise level, reverberation time, noise isolation	-	office spaces, small classrooms, large spaces with substantial acoustic treatment, large spaces with some acoustical treatment, with or without thermal slabs, 2 building concepts : 'brown' and 'green'	-	3 types: natural ventilation, displacement ventilation, forced-air ventilation (for ventilation and air conditioning)	next to campus roads, generally quiet external environments		resulting ventilation quality and noise levels inversely related, introduction of noise-control measures may adversely affect ventilation quality and IAQ; optimum building design = mechanical ventilation carefully selected amount, type and location of acoustical treatment
35	Ramalho et al. 2006; Kirchner et al. 2007	567 dwellings in FR	F	20 VOCs, CO, PM	radon and gamma radiation	allergens (dog, cat dust mite)	-	-	questionnaires recorded house characteristics	-	exhaust flow rate was measured	-	questionnaires recorded occupants allergic and respiratory symptoms	

36	Abbaszadeh et al., 2006	Discusses about the results of a IEQ survey for 160 'normal' office buildings compared to 21 'green/LEED' buildings (University of California, Berkeley)	USA, Canada, FIN	air quality (occupant survey)	thermal comfort, lighting (occupant survey)	cleaning, maintenance (occupant survey)	sound privacy, distracting noise from people's conversation, telephone rings (occupant survey)	in green buildings more satisfied occupants compared	office buildings (green, LEED en normal)	green/LEED buildings	-	-	occupant survey about IEQ, overal satisfaction with building and workspace	In green buildings more satisfied with air quality and thermal comfort, but more problems with lighting and acoustics because of open plan workspaces and cubicles ; need for innovative strategies providing optional spaces where quiet and privacy can be obtained when required (no measurements - only surveys)
37	Aizlewood 2006	In the frame of HOPE (Health Optimisation Protocol for Energy-efficient Buildings) cross-sectional study using building checklists and occupant questionnaires, and a detailed study of IAQ in a small number of home and office buildings.	UK	CO, CO, NO_2, O_3, PM10, PM2,5	temp	active air sampling for bacteria and fungi (1 stage impactor), house dust mites; assessed in multiple locations	-	via questionnaire	via questionnaire	via questionnaire	via questionnaire	-	comfort (questionnaires)	occupant health and comfort were not consistent with physical environmental measurements, indicating that perceived health and comfort was based on more than the physical parameters and cannot be fully explained by the measurements
38	Jarnstrom et al. 2006	8 residences constructed with low emitting materials; follow up of chemical IAQ after construction phase	FIN	TVOC, formaldehyde, ammonia	-	-	-	-	new buildings	-	natural ventilation or MV and exhaust systems; AER: 0.7 - 1.5 ACH	-	-	lowest concentration of chemicals was achieved in houses with MV and exhaust systems
39	Horn et al., 2006	study investigation influence of ventilation on demand on thermal comfort, air quality and energy conservation	D	CO_2	-	-	-	thermal comfort		Via quesitionnaire	demand-oriented supply with fresh air; split ventilation - shock ventilation	-	-	the split ventilation appeared to be superior to shock ventilation in terms of thermal comfort, air quality and energy conservation in residential homes
40	Leech et al., 2006	telephone-administered questionnaire in new homes - control homes (53) + 'case' homes (52) build according the R -2000 TM standard for energy efficient ventilation and construction practices	Canada	-	-	-	-	-	new homes - control homes (53) + 'case' homes (52) build according the R -2000 TM standard for energy efficient ventilation and construction			-	questionnaire for health status	in comparison with control homes, occupants of case homes (R 2000 -TM) reported more improvement over 2 years in throat irritation, cough, fatigue and irritability. Authors conclude that further research is required to determine if these perceived health effects relate to objective indoor air quality measures

41	Richardson, 2006	intervention study: upgrading social rental houses including wet central heating, on demand ventilation, double-glazed doors, cavity wall and roof/loft insulation	UK	particles 0.3 - 3 µm; particles 3 - 7 µg	RH, temp, wall to wall surface dampness	dust mite, microbial colonies	-	-	sounds constructions, semi-detached or terraced single family, 2 storey buildings with 3-4 bedrooms	-	before intervention: natural ventilation; after intervention: MV (on demand ventilation)	RH, temp, particles	self completed questionnaires on health status	changes in health outcome between intervention group (upgraded houses): not significant compared to control group: no significant changes in particles association indoor - outdoor. The housing upgrades increased bedroom temperatures in all houses. Other indoor environmental variables were not affected
42	Seppänen et al., 2006	Literature review investigation influence of ventilation on productivity	-	-	-	-	-	-	-	-	-	-	-	Typically 1-3 % of improvement in performance was found for each increase of 10 l/s/pers of ventilation rate, strong correlation up to 20 l/s/pers
43	Yoshino et al. 2006	investigation of IAQ in 60 houses where occupants were suspected of suffering symptoms caused by indoor pollution	Japan	TVOC, formaldehyde, toluene, ethylbenzene, xylene, p-dichlorobenzene	-	-	-	SHS	air tightness measured	-	AER measured	-	homes with people suffering from SHS (sick house syndrome)	concentrations of chemicals where higher in homes with high air tightnesss and low air exchange rate, and where there was new furniture or moth crystals used
44	Bornehag et al., 2005	study investigation influence of ventilation on allergic symptoms in children	Sweden	Passive tracer	-	-	-	-	-	-	-	-	Allergies	Lower ventilation rates were found in subgroup with allergic symptoms vs. healthy subgroup
45	Engvall et al, 2005	intervention study on 44 subjects: assessment impact of 'seasonally adapted ventilation' (i.e. 25 - 30 % reduction in ventilation flow during heating season	Scandinavia	CO_2	temp, RH	-	-	perceived IAQ measurement	multi-family building		mechanical ventilation: seasonally adapted ventilation (SAV) : shift from AER standard flow rate 0.5 - 0.8 ACH to reduced AER(0.4-0.5 ACH) during heating season	-	questionnaire on perception of odour, draught, temp , stuffy air	a significant increase of stuffy odour at reduced airflow, and the IAQ was perceived as poorer. Authors advice combined evaluation of energy saving measures with longitudinal evaluation of occupants reactions
46	Dimitroulopoulou et al,. 2005	37 homes in UK, built since 1995	UK	VOCs, NO_2, CO and formaldehyde (passive sampling 3d - 2weeks)	-	-	-	-	fan pressurisation test performed (air tightness)	all houses double glazed with trickle ventilators; all houses central heating with radiators	natural ventilation (in windows: trickle ventilators); in winter: 68 % of homes: AER < 0.5 ACH; in summer: 30 % homes: AER < 0.5 ACH	-	-	relationships between ventilation and concentration of pollutants were found
47	Isbell et al., 2005	simultaneous measurement of ventilation, benzene and toluene in residential indoor air of 2 homes	Alaska	benzene, toluene	-	-	-	-	detached dwellings, one air tight home with MV system (with heat exchanger) and one less air tight construction (natural ventilation)	-	one home with MV system (air-to-air heat exchangers); other house: unventilated	-	-	in home with MV: less transport of aromatic compounds from garage to living room than in unventilated house (source of aromatics: gasoline in attached garages)

48	Mysen et al. 2005	157 classrooms from 81 schools were inspected, the ventilating air volume and energy use has been analysed for 3 ventilation strategies	No	-	-	-	-	-	-	energy use	strategy 1: constant air volume (CAV); strategy 2: CO_2sensor based demand-controlled ventilation (DCV- CO_2); strategy 3: infrared occupancy sensor based demand-controlled ventilation (>DCV-IR)	-	-	DCV-CO2 and DCV-IR reduce the energy use due to ventilation in the average classroom to 38% and 51% respectively, compared to the CAV
49	Ubbels A., 2004	Users experiences with indoor environment in energy-efficient buildings (based on Rigo research 1996-2000 on the initiative of SEV-Novem) – large number of energy-efficient and energy-efficient exemplary projects in category of residential (15) and non-residential buildings	Nl											Not more complaints compared to regular dwellings – most complaints confirmed by measurements, causes : installation-technical defects, incorrect settings and insufficient capacity (also for regular dwellings). Need for information on applied techniques
50	Wargocki et al., 2002	Literature review comparing two experimental studies on the effect of ventilation rate on academic achievement	-	-	-	-	-	-	-	-	-	-	-	Both studies show that ventilation rate is significantly possitively related to academic achievement
51	Tuomainen, 2001	comparison of IAQ between 2 new flats; one constructed according Finnish classification system, and one according to normal, traditional practices	FIN	TVOC, limonene, toluene, formaldehyde, ammonia, TSP	-	fungal spores and bacteria with Andersen 6-stage impactor; cat, dog and house dust mite allergen	-	-	new flat (1997), "control" building: normal practice for design, construction and finishing materials; and new flat (1996), "case" building: design, construction and finishing materials: according to Finnish classification scheme (low emitting materials,...)	windows K-value 1.1 (case building) - 1.7 (control building)	"control" building: mechanical exhaust, ventilation rate (design value): 0,8/h; "case building": mechanical supply and exhaust, ventilation rate (design value): 1,7/h; heat recovery unit; glass fiber filter EU 7 class	-	-	lower conc. chemicals in flat type with MV type D comp compared to MV Type C ventilation system (largest differences for TVOC and ammonia);confounding factor: use of low emitting materials in case building compared to control building; lower levels of airborne fungi and bacteria in case buildings were influenced by the twofold higher ventilation rate and controlled supply air systems with filtration in the case building
52	Fisk, 2000	Literature review on the potential of productivity gains related to high ventilation rates	-	-	-	-	-	-	-	-	-	-	-	Productivity gains that are quantified and demonstrated could serve as a strong stimulus for energy efficiency measures that simultaneously improve the indoor environment.

53	Toftum et al., 1998	climate chamber study on the effect of humidity on thermal comfort	-	-	-	-	-	-	-	-	-	-	-	The model predicts that the relative air humidity may be close to 100% without causing much discomfort from humid skin among thermally neutral persons performing sedentary work.
54	Prowskiw 1992	IAQ monitoring in 20 detached bungalows: 16 constructed to R-2000TM standards (energy conservation standard), and 4 to conventional energy conservation standards	Canada	formaldehyde, PM, NO_2, CO_2	radon	-	-	-	homes constructed to R 2000 TM standards: tight building envelope with MV by a HRV	some homes: R 2000 TM energy conservation standard	all dwelling had some MV system, some only a bathroom exhaust fan	-	-	for formaldehyde: homes operated according to R-2000-TM ventilation standards had lower conc. than homes not complying to that standard; homeowners explained why they did not use the MV system: concerns about energy waste, noises and discomfort (cold draughts)
55	P.O. Fanger, 1988	Test subjects are exposed to the pollution produced by a single person under different ventilation rates	Denmark	-	-	-	-	PIAQ	-	-	-	-	-	The acceptability of air is correlated with bio effluents
56	Poupard et al., 2004	IAQ monitoring in 8 French school buildings. Measuments are compared with simultaneous outdoor sampling.	France	O_3, NO, NO_2, PM0.3-0.4, PM1.6-2.0	Temperature, humidity	-	-	-	School buildings of different ages		Both naturally and mechanically ventilated	O_3, NO, NO_2, PM0.3-0.4, PM1.6-2.0, Temperature, humidity	-	Air tightness is less accurate than air change rate, but has several other advantages for IAQ studies. The building air tightness has a great influence on the Indoor/Outdoor concentration ratios of Ozone. Paper discusses transformations that contaminants undergo after entering the building.
57	Hady et al., 2009	The relationship between health complaints, the quality of indoor air and housing characteristics in Vathorst	The Netherlands	CO_2, Formaldehyde	Temperature, humidity	-	-	-	Recently occupied dwellings		Mechanical exhaust ventilation versus full mechanical ventilation with heat recovery	-	-	Health complaints can be associated with shortcomings in the design, construction and maintenance of the HRV system.

Table 3: Overview of the most relevant regional, national and international studies

reference	Clean Air Low Energy of study	Country / Area	short description	indoor environment				building type		ventilation system	outdoor environ ment	health of occupants	bottle neck / Conclusion
				chemical	physical	biological	acoustic	building envelope	energy performance				
Caillou (still running)	Optivent	B	measurement of the performance of residential ventilation systems	-	-	-	ventilation components	-		C and D		-	Performance of most of the test cases is sub optimal
BBA binnenmilieu			measurement of the performance of residential ventilation systems	-	-	-	-	-		C and D		-	Performance in virtually all of the test cases is sub optimal
Haverinen-Shaughnessy et al. (still running) www.insulateproject.eu	INSULAtE*-project	FIN	Indoor environmental quality is influenced by ventilation, thermal conditions, noise, lighting, and indoor air pollutants such as particles, microbes, chemical impurities, and radon. INSULAtE*-project aims to demonstrate how energy improvements impact on these indoor environmental parameters, and to develop a protocol for assessment of the impacts	CO, CO_2, PM, NOx, VOC, Radon	T, RH	Microbes and microbials							Based on the information collected, impacts of renovation on energy consumption of the building will be assessed. In the apartments, impacts of renovation on thermal conditions, indoor air quality, and occupant health and wellbeing will be assessed
http://hope.epfl.ch/index.htm	HOPE	EU	Health Optimisation protocol for energy-efficient buildings: definition of energy-efficient building, an energy efficient building and an energy-efficient healthy building. Provides a protocol to assess the performance of a building with regard to health, comfort and energy-efficiency.	guidelines for CO_2, CO, NO_2, O_3, PM10, PM2,5				questionnaires on building characteristics, systems and use				health- and comfort related questionnaires	Assessment of target values for several chemical pollutants: CO_2, CO, NO_2, O_3, PM2,5, PM10. Assessment of an energy index to evaluate the energy efficiency (scaled good - medium - low). Databases and questionnaires
www.healthvent.eu	Healthvent	EU	The aim of the HealthVent project is to develop health-based ventilation guidelines. They will protect people in places like schools, nurseries, offices and homes against health problems caused by poor indoor air quality, and at the same time will ensure that energy is utilized efficiently.										
De Brouwere and Caillou,2009	Q-INTAIR	B	(national study) modelling of chemical concentrations in dwellings under various settings of building materials and related emissions, under various scenarios of ventilation types and design. Modelling taking into account 1-year dynamic meteorogical conditions in Belgium	TVOC, formaldehyde				$V50 = 3\ m^3/h.m^2$		Dstandard, Doccupancy, C	-	-	under equal conditions of house characteristics, material use: average indoor concentration to formaldehyde is 2 fold higher in home with MV type C compared to MV type D standard; average concentration to formaldehyde is about 20 -30 % higher in home with MV type D occupancy compared to MV type D standard.

http://www.smartenergyhome.eu/eng/vision.php	Energy Smart Home		Smart Energy Home aims to accelerate the uptake of energy-efficient, healthy homes that by integrating smart technology and solutions consume radically little resources while enhancing the quality of life. SEH is about providing a high quality, energy-efficient living experience without any radical increase in costs.								
http://www.beau.group.shef.ac.uk/?w=projects	EESH		Energy Efficient Social housing								
Woonkwaliteit Binnenmilieu in nieuwbouwwoningen, i.o.v. VROM-inspectie Regio Oos (Arnhem, NL)		Nl	Research on housing quality of indoor environment for new dwellings (78 projects, 154 dwellings): for instance ventilation devices, façade sound insulation, façade air tightness, users' instructions ventilation system, temperature exceedings and equipment noise. Checks: realised situation = permitted situation, compliance with Bouwbesluit	Measurements of air tightness, temperature exceedings, control of quality of execution cavity insulation with infrared shots (15 projects), EPC-calculations and field measures			Airborne and impact sound insulation, façade sound insulation, equipment noise	Newly built dwellings (subject to Bouwbesluit), 104 dwellings + 42 apartments	Control of in- and outlet capacity, users' manual (functioning, use, maintenance), 32% system D, 68% system D, other A and B		Aspects snot treated in Bouwbesluit such as equipment noise, users'manual ventilation and temperature exceedings, mostly do not meet the usual guidelines
Installations de ventilation dans l'existant – Enjeux et propositions d'amélioration à travers les diagnostics			Diagnosis of buildings(dwelling + service sector) and their equipment to improve the practice with respect to ventilation installations regarding energy performance, acoustics and air quality. Analysis of advantages and discomfort of different technologies regarding energy performance, IAQ, thermal and acoustic comfort.				see ref. AC.13				
http://www.euro.who.int/ t	The WHO Frankfurt housing intervention project	Germany	The WHO housing and health programme implemented a health-monitoring project in Germany. The project collected data before renovation work, and after renovation was carried out. In parallel, a control group of dwellings without interventions was used to collect additional data to identify changes caused by building rehabilitation in the intervention group. The main objective was to assess the impact of thermal insulation changes on indoor environments, and evaluate potential effects on residents' health.	VOCs	T, RH	dust samples determinations, self reported mould				questionnaire, exhaled NO, peak flow measurement	Preliminary conclusions: 1) thermal insulation measures have expected positive impact on indoor temp. and thermal comfort; 2) insulated dwellings may be more sensible to indoor humidity changes which in turn would enhance the relevance of ventilation and air exchange in order to reduce accumulation of indoor pollutants and mould growth; and 3) health constraints may be restricted to diseases such as asthma which make the individual person more vulnerable to the indoor conditions and contamination

La ventilation dans les écoles		USA, EU, F	Report based on newest technology articles from the CETIAT bulletins, on a state-of-the-art of the situations in North America, Europe and France, an inventory of causes and consequences of bad IAQ in schools					A Scandinavian study in 32 schools pointed out more problems in schools built with bricks than wooden constructions.				Numerous publications discuss the consequences of a poor IAQ : fatigue, sleepiness, concentration difficulties, irritations of eyes, skin, mucous membranes, dizziness, cough	Ventilation of classrooms is inadequate (ventilation rates, CO2 concentrations), exposure to pollution seems to be related to asthma attacks and other respiratory disorders, increase of air renewal flow rate, appropriate ventilation systems, choice of materials
www.hitea.eu	Health effects of indoor pollutants: integrating microbial, epidemiological and toxicological approaches (HITEA)	Europe	The HITEA School study is performed in three European countries, representing three different climatic regions: Spain, the Netherlands, and Finland. The overall aim of the study is to identify the role of indoor biological agents (relating to moisture damage and dampness issues in buildings) leading to short term respiratory and inflammatory health effects in pupils and teachers exposed to poor indoor air quality in schools across Europe. Such short term effects may potentially lead to chronic, long term respiratory, inflammatory and allergic health impacts among children. Cross-sectional as well as longitudinal study designs are applied.	PM2.5, NO_2/Nox, cleaning agents, CO_2 (continuous)	T, RH	various microbial parameters from settled dust (endotoxin, glucans, extracellular polysaccharide, various fungal and bacterial groups (qPCR), ergosterol, 3-OH fatty acids, muramic acid)	-	school buildings, different building types	-	mechanical and natural ventilation	outdoor contaminant levels are assessed	detailed cross sectional and longitudinal health assessments: questionnaire, symptom diary, lung function, exhaled NO, cytokines from blood and nasal lavage, exhaled breath condensate	
PREBAT: Performance de la ventilation et du bâti		Permanent observance of about thirty apartments on two sites of ventilation parameters such as flow rates, pressures, temperatures, humidity, CO_2 concentrations… and telemetry for almost two seasons (Villeurbanne, 14 residences - Paris, 80 residences)											

2.3. LITERATURE REVIEW CONCLUSIONS

None of the studies, cited in 2.2, reports on a combined assessment of physical, chemical, as well as biological pollutants, with a simultaneous characterization of the building envelope (air tightness, energy performance) and the ventilation system (efficiency, acoustics) by measurements.

In fact the studies included in paragraph 2.2 report on distinct aspects of this integral characterization of the indoor environment. They mostly study:

- The perception of the indoor environment in ventilated houses and schools
- Physical characterization of the indoor environment in various mechanically ventilated houses and schools
- A physical, chemical or biological characterization in (energy-efficient) buildings
- Monitoring campaigns on one of the physical, chemical or biological parameters and assessment of building related (ventilation system performance as well as energy efficiency) via questionnaire based research.

Therefore, none of the study results enables to conclude on a clear relationship between all parameters included in *Clean Air, Low Energy*. However, the urgent need for more knowledge on this integral, multidisciplinary approach, as proposed in *Clean Air, Low Energy*, and the interrelation between the different factors, has been concluded and emphasized by Crump (2009), stating that there is a dearth of information about the indoor air quality in highly energy efficient structures.

Finland is the EU country with the highest market penetration of mechanical supply and exhaust ventilation (Kurnitski and Seppanen, 2008); almost all new dwellings are fitted with MVHR systems. This was induced by changes in the Finnish regulation in 2003, which increased guideline ventilation rates from 4 to 6 l/s per person and required a minimum of 30% heat recovery from exhaust air. This regulation caused a change in the ventilation practice in Finland from primarily mechanical exhaust, to balanced supply and exhaust with heat recovery. Finland also has been reported to be one of the countries with the best IAQ in Europe, having the best isolated, energy efficient houses in the EU (Crump, 2010). The high indoor air quality in Finland will probably also be related to the Finnish M1 product label for building materials that led to a good market penetration of low-emitting materials and guaranties the use of these materials in new buildings (Kurnitski and Seppanen, 2008). The formulation of the emission tests for Finland has led to a remarkable reduction of material emissions. It has been noted that this might have consequences on the required airflow rates; however this has not yet fully been addressed. It was reported that in 2007, more than 1100 building material products and 100 clean ventilation products achieved the Finnish emission criteria. It is claimed that this suggests that the great majority of building materials currently available on the Finnish market is labelled. This statement is supported by Tuomainen (2001), who compared the IAQ of 2 new flats, of which one was constructed according to the Finnish classification system and the other one according to normal, traditional practices. They reported lower concentrations of TVOC, limonene, toluene, formaldehyde, ammonia and TSP in the flat with mechanical intake and exhaust and highlighted that the use of low-emitting building materials was a confounding factor. So Finland actually takes into account the 2 main prerequisites for good chemical IAQ in houses: (1) the installation of a good ventilation system, (2) the use of low emitting material (Crump, 2010).

Therefore, in a study like *Clean Air, Low Energy*, Finland should be considered as an example situation. However, it should be emphasized that the beneficial indoor environments in Finnish low-energy buildings might not or only to a limited extend, be transferable to our typical situation in Flanders, Belgium. The different Belgian climatic circumstances, the ventilation system suppliers and the individual responsibility for the maintenance of the ventilation systems, combined with fewer low-emitting building materials available on the market, might all impact on the quality of the indoor environment in ventilated energy-efficient buildings. This supports the high need for a study on the indoor environment of energy-efficient buildings in Belgium.

Several different types of research in this field can be distinguished in the literature overview, shown in Table 3. Controlled experiments have been performed. In these experiments as much as possible of the factors, potentially influencing the indoor environment, have been kept constant whilst only one or few parameters varied. These experiments have been performed in test houses (Paul et al. 2010) or in similarly constructed houses (Maier et al. 2009).

However, most of the reported information results from field studies or intervention studies. Data collection in both research strategies has been performed by measurements, by questionnaires or by a combination of both.

2.3.1. ON CHEMICAL AND PHYSICAL PARAMETERS IN INDOOR ENVIRONMENTS OF LOW-ENERGY BUILDINGS

The importance of noise nuisance in relation to the IAQ perception was confirmed by Khaleghi (2007) who concluded, based on field measurements in 13 rooms, that the ventilation quality is inversely proportional to the noise levels of the ventilation system. This study typically supports the (inverse) relation between indoor air quality and ventilation noise nuisance. According to this literature review however, no study has reported on the relation between noise nuisance and the energy-efficiency of a building. The relation between acoustic comfort (*room acoustic comfort*) and the sustainability of a building has been reported.

Other field studies have reported air pollutant levels in the indoor air of ventilated rooms. Several authors have reported lower indoor air concentration levels of various chemical pollutants, such as VOCs, aldehydes, and PM in mechanically ventilated rooms, especially if the system is equipped with an air cleaning unit, such as a filter unit (Aubin et al., 2011; Stranger et al., 2011; Raja 2011; Xu et al, 2010; Jarnsrom, 2006). In this context Noh et al. (2010) emphasized the importance of an appropriate combination of filter type and ventilation rate in order to efficiently reduce indoor PM. The risk of a reduced classroom relative humidity in wintertime was reported as a result of a case study in Belgian classrooms (Stranger et al., 2011) as well as in an experiment in a test house (Paul et al., 2010).

Improving the bedroom IAQ by installing a ventilation system equipped with a filter unit (95% of PM removal) during 14 weeks, significantly increased the pulmonary function of 20 American children aged between 5 and 16 (Raja et al. 2011). Xu et al. (2010) reported, besides an improvement of the indoor air quality, an improvement of the health outcomes of asthmatic children after installing the HEPAiRx system in their bedrooms.

Also in ventilated buildings a seasonal variation has been identified in the indoor air quality. Aubin et al. (2011) reported higher CO_2, and VOC concentrations in wintertime and fall. They also concluded that 85% of the studied mechanically ventilated houses doesn't reach the Canadian nominal ventilation goal of 0.3/h.

The basic aim of building ventilation is to remove/dilute emissions in the indoor air related to the presence of occupants: moisture, CO_2, and unpleasant odours (Crump et al. 2009). It is thus in the first place not focused on removing chemical pollution, arising from other indoor sources, such as building materials and furniture (this should be prevented by selecting low-emitting products). This might particularly impact on the indoor air quality in buildings with mechanical exhaust and those with mechanical intake and exhaust: whereas the system is designed to remove occupant related

IAP at the right moment, it might function less effectively to remove chemicals with a continuous source (when the source is independent on use: e.g. furniture, building materials,…).

2.3.2. ON BIOLOGICAL PARAMETERS IN INDOOR ENVIRONMENTS OF LOW-ENERGY BUILDINGS

A study conducted in 1350 households in seven low income communities in New Zealand looked at the effect of insulating existing houses on health inequality (Howden-Chapman 2007). The intervention in this community based, cluster, single blinded randomised study consisted of installation of a standard retrofit insulation package. Main outcome measures included indoor temperature and relative humidity, energy consumption, self reported health, wheezing, days off school and work, visits to general practitioners, and admissions to hospital. In terms of biologicals, several outcome measures were mentioned in the methods (mould speciation, mould mass, endotoxin, b-glucans, dust mite allergens), however, only self-reported mould was reported. The paper concluded that insulating existing houses led to a significantly warmer, drier indoor environment and resulted in improved self reported health, self reported wheezing, days off school and work, visits to general practitioners as well as trend for fewer hospital admissions for respiratory conditions. In terms of biological indoor contaminants, a statistically significant reduction of self-reported mould in homes after intervention was stated (aOR 0.24). Bottleneck in this study certainly was that only few objective outcome measures were included.

In another intervention study assessing the effect of thermal insulation on indoor climate parameters and occupants' health, the WHO housing and health programme implemented a health-monitoring project in cooperation with a large housing agency based in Germany (Braubach et al. 2008). The project collected data from 374 single family homes in the Frankfurt area in spring 2006 before renovation work, and re-contacted all households in spring 2007 after renovation was carried out. In parallel, a control group of dwellings without interventions was used to collect additional data to identify changes caused by building rehabilitation in the intervention group. The main objective was to assess the impact of thermal insulation changes on indoor environments, and evaluate potential effects on residents’ health. The data suggest that the intervention had little impact on visible mould, with more than 80% of surveyed dwellings not showing a change in mould status. When mould occurrence was analysed together with relative humidity in the dwellings, an increase in humidity was found to be potentially associated with both, and increase and decrease in mould, while the decrease of humidity levels was more clearly related to a reduction in visible mould. Interestingly, higher humidity lead to a strong increase in mould in the intervention dwellings, while this was not the case for control dwellings. Likewise, lower humidity was associated with a strong reduction in visible mould in the intervention dwellings only. In conclusion, well-insulated dwellings may react more sensitively to humidity changes than less well-insulated dwellings, and that mould could be a frequent consequence when humidity rises in well-insulated buildings.

In the absence of data on levels of indoor allergens, most importantly house dust mite allergen (*Der* pl), in energy-efficient buildings there is good documentation on the association between house dust mite levels and several indoor parameters considered highly important and frequently monitored in energy-efficient building. There is sufficient epidemiological data on the occurrence of house dust mites in dwellings that show a clear association between increased indoor air humidity and the increased occurrence and higher levels of house dust mites in floor and mattress dust, as reviewed by Korsgaard (1998). The author suggests that increased indoor air humidity due to sealing of the building envelope – as can be found in energy efficient houses as well as renovated older buildings – may be responsible for the fourfold increase in the occurrence of house dust mites in Danish dwellings. In turn, a reduction of indoor air humidity by controlled mechanical ventilation is suggested to reduce inhabitant exposure to house-dust mites. Note that this review was written 13 years ago, where the quality and performance status of 'energy-efficient houses' was certainly lower than today and where mechanical ventilation is many times implemented in energy efficient houses. Van Strien et al. (1994) have shown earlier that lower house dust mite allergen (*Der* pI) levels mattress dust samples from 516 dwellings in the Netherlands were found in homes with mechanical ventilation; higher *Der* pI levels were significantly associated with the absence of floor insulation and there was also a positive association found between relative humidity in the bedroom and *Der* pI concentrations in mattress and floor dust (similar findings were presented by Sundell et al. 1995). Wickens et al. (2001) conclude from their study in New Zealand homes that the presence of insulation is the single most important housing characteristic explaining the lower *Der* pI levels in carpeted living room floors.

Hirsch et al. (2000) report on changes in house-dust mite allergen and mold spores in apartment bedrooms after installation of insulated windows and central heating (replacing mostly single-oven coal stoves) in the Dresden area, Germany. Their results indicate that the intervention was followed by a decrease in air exchange rate and an increase in temperature and absolute humidity. Not surprisingly, also levels of house-dust mite allergen increased. Levels of viable *Cladosporium* spores in carpet dust were reduced statistically significant, relating to reduced outdoor contribution of indoor microbial content after installing well-insulated windows. Changes in *Penicillium*, *Alternaria* and *Aspergillus* (grown at 25 °C) in carpet and mattress dust and *Cladosporium* in mattress dust were not significant. Levels of thermo-tolerant *Aspergillus* spp. (grown at 37 °C) were found lower after renovation in the house dust samples; however an increase was noted for thermo-tolerant *Aspergillus fumigatus* in carpet floor dust.

Richardson et al. (2006) reported no statistically significant short-term changes in airborne viable microbes in bedroom and *Der* p1 concentration in bedroom mattress after a housing intervention including installation of wet central heating, on demand ventilation, double-glazed doors, cavity wall and roof/loft insulation in the Watcombe housing study conducted in the UK.

A comparison of air-conditioned versus naturally ventilated homes in the city of Honolulu (Kodama et al. 1986) identified differences in the indoor microbial content in the study buildings and also in relation to outdoor air. Levels of *Cladosporium* spp. – the most commonly occurring outdoor fungi - were lower in air-conditioned buildings, compared to naturally ventilated buildings and outside air. In contrast, *Aspergillus* spp. were clearly higher in air-conditioned buildings, indicating indoor source ort accumulation. Similarly, but even more pronounced, levels of Gram-positive cocci – representing the most common human derived bacteria, eg. staphylococci etc. – were found an order of magnitude higher in air-conditioned buildings compared to outdoor air and naturally ventilated buildings, which indicates that human derived microbes seem to accumulate in the AC buildings. Even though not directly relating to the topic of this review – 'energy-efficient buildings' – this study shall be mentioned here as probably one of the first ones to indicate the dynamics in indoor microbial content following a transition from naturally ventilated buildings to mechanically ventilated/air conditioned buildings.

The HOPE (Health Optimisation Protocol for Energy-efficient Buildings) project was conducted in order to prove that energy-efficient building can be both healthy and comfortable for their occupants. Following a general assessment based on questionnaire and checklist, more detailed measurements in a subset of homes and offices in the UK (Aizlewood et al. 2006) included indoor and outdoor air sampling for bacteria, fungi (using a single stage impactor) and house dust mite (*Der* p1 from vacuumed surface dust). The main overall conclusion was that occupant health and comfort were not consistent with environmental measurements, i.e. perceived health could not be fully explained by the measurements. With respect to biological agents, in particular bacterial levels were found to be in the higher concentration category in case of the two surveyed homes (including several flats). Bacterial levels were in the intermediate area for one office building and in the higher to very high concentration levels for the other office building, however, little data were provided to explain these results.

Tuomainen et al. (2001) report in a 3-year follow-up study in two blocks of flats – the case building being built for people with respiratory disease by following the instruction of the Finnish Classification of Indoor Climate, Construction and Finishing Materials, while the control building was built using conventional building technology. Up to one order of magnitude lower levels of airborne bacteria and fungi (samples via Andersen 6-stage impactor) in the case compared to the control flats were at least partly influenced by a twofold higher ventilation rate and the controlled supply air system with efficient filtration in the case buildings. As for indoor house dust mite (*Der* f1), cat (*Fel* d1) and dog (*Can* f1) allergens it was confirmed that prohibition against keeping furred pets retained the allergen levels low in case building, while the presence of pets in the control buildings cause increased allergen levels with a high variation. *Der* F1 allergen was found to be low in both building, attributable to low RH and no signs of water damage in both buildings.

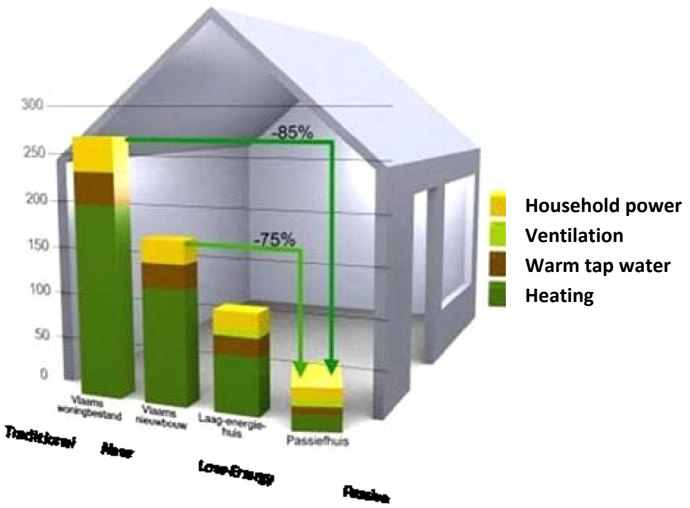
2.3.3. ON THE PERCEPTION OF THE INDOOR ENVIRONMENT

Besides physical, chemical, biological and acoustic measurements in indoor environments, an important aspect of health and wellbeing is the occupants' perception and satisfaction with the indoor environment, i.e. the perceived indoor air quality (Adan et al. 2007).

A typical questionnaire based field study on the perception of indoor environments, is reported by Bogers et al. (2011), where was concluded that buildings with mechanical air supply and exhaust are associated with a lower perceived IAQ, whilst a natural air intake combined with a mechanical exhaust control is associated with a better perceived IAQ. In the Netherlands, several other studies support this conclusion of dissatisfaction and lower perceived IAQ in various mechanically ventilated buildings (Van Dyken et al., 2011; Brugman et al, 2008; Versteeg et al. 2008; Harm et al. 2008). On the other hand, other surveys have reported contradictory conclusions, such as Hodgen (2008) who reported increased noise nuisance due to natural ventilation. Aizlewood reported in 2006 an inconsistency between the health situation of occupants and the IAQ in passive houses studied within the HOPE project. A study in passive (mechanical intake and exhaust) and low energy housing (in that study defined as naturally ventilated), lead to the conclusion that passive buildings are characterized by a better thermal comfort and lower CO_2 levels (Madhave et al. 2010). And also Abbaszadeh et al. (2006) reported that inhabitants of green buildings are more satisfied with the IAQ, although he stated that noise and lighting are critical factors in this type of building.

2.3.4. ON THE BUILDING ENVELOPE AND THE VENTILATION SYSTEM

Buildings account for about 40% of the total energy consumption in Europe. In order to reduce the dependency on fossil fuels and the related carbon dioxide emissions, the European commission and member states have set targets on the energy demand of newly constructed buildings. Former regulations by the Flemish government focused on insulation standards for roofs, walls, windows and floors. Within the framework of the European Energy Performance of Buildings Directive (EPBD) focus has shifted towards the total energy consumption of buildings, including ventilation losses, cooling energy and boiler efficiency (European Commission, 2002; 2010).



(source: Passive House Platform http://www.passiefhuisplatform.be)

Figure 3: Comparison of the final energy demands for the different types of buildings, available on the Belgian market

In the Belgian climate, space heating energy is the predominant factor of energy use in traditional houses and schools. In order to reduce the energy demand for space heating, heat losses should be minimized during cold periods. The conductive energy losses are minimized by applying building materials with low thermal conductivity such as thermal insulation materials and low energy glass with reduced thermal radiation losses. Another important factor in the energy balance of a building is the convective heat loss through ventilation and air infiltration. Reducing ventilation rates might sound beneficial for reducing the energy demand of a building, but can have a negative impact on the indoor air quality. As a consequence, the Flemish EPB regulation does not only cover the energy demand of buildings, but also imposes regulations on minimal ventilation rates (Wouters et al. 2008). These ventilation rates are supposed to induce a healthy indoor climate, but little or no scientific evidence is present. Technologies which limit the energy consumption due to ventilation, such as heat recovery ventilation, may even harm occupants' health if poorly designed, installed or maintained (Hardy et al. 2009).

In the pursuit of more energy efficient building concepts, ventilation and air infiltration play an important role. Many promising technologies have been developed, but the impact of these novel systems on IAQ is still poorly documented.

Concerning the energy-consumption of a ventilation system Mysen (2005) and Laverge (2011) reported the benefits of demand-controlled ventilation systems, based on infrared detection of occupants or based on CO_2, compared to a continuous running ventilation system.

Flückiger (1998) and many others commented on hygienic aspects of ground-coupled air systems. Instead of underground air tubes, an underground fluid network coupled to a heat exchanger is nowadays gaining popularity.

2.4. GENERAL CONCLUSION

In general it can be concluded that literature is not univocal on the influence of low-energy housing and mechanical ventilation systems on the indoor environment in schools and in houses. None of the reported studies has addressed all of the issues that will be studied in *Clean Air, Low Energy*.

Furthermore, in practice only few or even no studies on IAQ include aspects on energy demand or ventilation systems.

The ‘ideal’ measurement strategy to elucidate the difference between the various mechanical ventilation types would be a study in identical houses (design, use of construction materials, consumer products, etc…) with the only variable factor being the ventilation system. This type of study has been performed in the past, however only CO_2 was monitored (no other chemical pollutant).

The major part of the available literature concerns field studies and intervention studies. Although they only focus on distinct aspects of *Clean Air, Low Energy*, they allow an evaluation, and in necessary an optimisation of the measuring plan, proposed in the project description. This will be discussed more in detail in CHAPTER 4 Indoor characteristics; aspects to be studied.

CHAPTER 3 BUILDING CHARACTERISTICS; ASPECTS TO BE STUDIED

3.1. LOW ENERGY BUILDINGS

3.1.1. VENTILATION AND INFILTRATION

In well insulated buildings, the convective losses become relatively more important compared to conductive and radiative heat transfer, and may even account for the largest share of energy losses.

Simply reducing ventilation rates has a negative impact on IAQ, thus national and regional building regulations have imposed minimal ventilation rates for new buildings.

Architects and engineers try to design ventilation systems that limit the total heat loss by better controlling the ventilation rates, adopting demand controlled ventilation strategies, or increasing the temperature of the incoming air by heat exchangers. Air flows through cracks and small openings, account for a large share of the air intake in older (traditional) buildings. The air infiltration rate is not controllable, and varies depending on pressure differences, e.g. by wind forces and temperature gradients. In low energy buildings, this air infiltration is considered unwanted, because it surpluses the controlled ventilation needs, and thus imposes an extra heat demand for the building in cold periods. Furthermore, the infiltration through cracks may cause other problems such as draught and moisture risks. In conclusion, state of the art energy efficient buildings is mostly characterized by airtight building enclosures. Some standards for highly energy efficient buildings, such as the Passive House certification, impose a maximum level of air infiltration. A few EU countries even include airtightness requirements in their national energy regulations (2009, Erhorn et al.).

3.1.2. VENTILATION SYSTEMS

In order to control the airflow in and out of the building, any new building which has to comply with the Flemish EPB regulation has to be equipped with a dedicated ventilation system. The ventilation systems are grouped into 4 main categories:

A. Ventilation system A: natural air intake, natural air exhaust
B. Ventilation system B: mechanical (or 'forced') air intake, natural air exhaust
C. Ventilation system C: natural air intake, mechanical air exhaust
D. Ventilation system D: mechanical air intake, mechanical air exhaust

Ventilation system C is the most widespread type of ventilation system in Flanders, with an average market share of 65,31% in the new buildings of past 5 years (2011, VEA). The relatively low investment cost and ease of installation is probably the main reason for this high market share. Different companies have introduced demand controlled ventilation systems which adapt the ventilation rate based on humidity sensors or occupant presence detection in houses. In school buildings measurement of carbon dioxide is more common.

Ventilation system D is swiftly gaining popularity in new buildings: in 2006 9,93% of the new buildings was equipped with this system, in 2009 this market share has risen to 25,01% (2011, VEA). To our knowledge, a ventilation system D with demand control for domestic use is not yet on the market. Instead, most installations comprise a heat exchanger: the heat of the exhaust air is transferred to the fresh incoming air to reduce the heating demand. More advanced systems may include a ground-coupled heat exchanger which elevates (or lowers in summer time) the incoming air temperature to the nearly constant subsoil temperature. Ventilation system D is mostly equipped with a central air intake and thus requires air ducts to distribute the fresh air to the different rooms. Filters are used to clean the largest particles from the air stream before entering the ducts. These ducts, filters and the heat recovery unit impose a rather large pressure drop. Therefore buildings with ventilation system D with heat recovery ventilation must be very airtight, otherwise the induced air infiltration will severely degrade the efficiency of the heat recovery.

3.2. BUILDING CHARACTERISTICS

3.2.1. ENERGY PERFORMANCE

In this study, the indoor air quality of energy efficient buildings is investigated. Most energy saving measures, such as the application of additional thermal insulation materials, photovoltaic panels, condensing boilers or high efficiency glazing, aren’t expected to have an impact on the indoor air quality, apart from the thermal properties. Therefore, indicators of the total energy performance of a building such as calculated heating demand or the E-level (in Flemish EPB regulation) will not be used to group the buildings into different categories.

Instead, the eventual impact is expected to result from the ventilation and infiltration properties of the building. Ideally, the total amount of air exchange would be a criterion to divide the buildings under investigation into different categories. This is however not a constant value, and is amongst other factors heavily dependent on user behavior. Instead the building airtightness will be used to categorize the different buildings. This factor is not dependent on the behavior of the building occupants, but is a fixed value which shows the measured air permeability of the building skin. As stated before, airtightness is an important feature for most energy efficient homes. By reducing the air flow through cracks and openings, the total air exchange is limited to the controlled rates which are established by the ventilation system. This is beneficial for the energy performance of the building, especially for buildings with heat recovery ventilation. As a consequence, the rate of air exchange to maintain a healthy indoor environment now depends solely on the ventilation system. A low air permeability (very airtight building) indicates that the building is very dependent on the ventilation system, whereas in a building with a high permeability the building infiltration may contribute substantially to the total air exchange of the building.

A very airtight building cannot be obtained unless the designer pays special attention to the airtightness when designing construction details. Even so, the contractors have to alter their business-as-usual construction methods, in order to create airtight buildings (2010, Wei Pan). This extra work load is in present building practice only to be expected if the aim is to realize a very energy efficient building. Therefore, the building airtightness is expected to have a high correlation with the total energy efficiency of the building. The results of the calculated energy efficiency according to the Flemish EPB methodology (E-level and K-level) will be requested from each building participating in this study for later reference. This fact limits this survey to buildings for which the building permit was requested from January 2006 on. If the building is certified by the Flemish Passive House Organization (PHP, Passiefhuis Platform) additional documents are collected.

Passive houses/schools need to prove their high airtightness through a measurement in order to obtain a certification document. With a big fan, the building is pressurized or depressurized to measure the prevailing infiltration rate at a fixed pressure difference, often 50 Pa. For ordinary buildings, an airtightness measurement or 'blowerdoor-test' is seldom conducted. From 2006 till January 2011, only 3,86% of all buildings with a Flemish EPB-certificate had proven their airtightness. Presumably, most of these tests are conducted for low energy buildings, where owners want to gain some extra points on their EPB certificate, in order to gain subsidies or tax credits. The average measured v_{50} value for these buildings is 3,59 m^3/hm^2 (2011, VEA), which is considerably lower than the fairly high default value of 12 m^3/hm^2 in the Flemish EPB certification software. For this study, the n_{50} value will be used, which expresses the air changes per hour due to infiltration at a pressure difference of 50 Pa, instead of the v_{50} value used in EPB, which relates the air changes to the exposed area of the building envelope.

A building needs to obtain an infiltration rate $n_{50} \leq 0.6$ in order to obtain a passive house certificate. In this study buildings with an infiltration rate $n_{50} \leq 0.6$ will compose the category of 'very airtight' buildings. Buildings which comply to $0.6 < n_{50} \leq 2.5$ are considered 'moderately airtight'. The category of 'poorly airtight' buildings consists of buildings with an infiltration rate $n_{50} \geq 2.5$.

3.2.2. VENTILATION SYSTEMS

This exploratory study focuses on mechanically ventilated buildings, so buildings equipped with a ventilation system category A (fully naturally ventilated) will not be considered. For reference, naturally ventilated buildings in Flanders have been investigated in previous research projects (Surveillance of the health quality in Flemish residences, 2007-2008-2009-2010-2011, Flemish Agency for Care and Health/Vito; 2009, Biba Project, Environment, Nature and Energy Department/ Flemish Agency for Care and Health/VITO; 2007 FLIES Project Environment, Nature and Energy Department/VITO). Ventilation systems with mechanical air intake and natural air exhaust are rather seldom in Flanders: according to the Flemish Energy Agency a mere 0,44% of the new buildings subject to the EPB-regulations are equipped with this system, and this number is steadily declining (2011, VEA). Therefore buildings with ventilation system B will not be considered in this study.

When recruiting the buildings for the survey, the type of the ventilation system and possible options will be questioned. For ventilation system C (natural air intake, mechanical air exhaust), distinction is made between a traditional manually controlled system, and ventilation systems with demand controlled operation. For ventilation system D, the options are a system with or without heat recovery unit. The latter will be rarely present in a house, but may occur in schools.

Many alternative versions of ventilation system D are present in today's building stock. Although most of those versions are rare, these systems have promising benefits for large scale deployment in future low energy buildings, or may alternatively exhibit hazard for indoor air quality. Therefore attention will be paid to include some of these seldom used systems in this survey. Following properties are questioned before selecting the buildings of this survey:

- Presence of earth-to-air heat exchanger (earth tubes). During the visit of such a building, extra attention is paid to the possibilities of mould growth in the underground air ducts (1998, Flückiger et al.)
- Presence of ground coupled heat exchanger with a heat transfer fluid.
- Presence of a thermal recovery wheel. This system requires extra attention due to the possibility of contamination between fresh air and exhausted air (Roulet et al. 2002).

- Recirculation. Belgian regulations allow for partial recirculation of air from bedrooms, corridors,… to the living room in order to reduce the prescribed fresh air intake. Findings in (2011, RIVM) suggest that this may lead to a lower perception of IAQ by the building occupant.
- Presence of heating equipment within the ventilation system. In very low energy buildings, a limited extra heating of the incoming air may be sufficient for heating a building.

Furthermore the nature of the air ducts is questioned. Apart from the well known circular metal sheet ducts, smaller plastic ducts have gained significant popularity in dwellings. If possible, one or more buildings with rubbed plastic ducts will be investigated in this study, to preliminary assess the impact of this air distribution system on IAQ.

Many more aspects of the ventilation system are investigated during the measurement campaign after the building has been selected for this study. Properties such as installation brand, frequency of manually adjusting the ventilation rate, measured properties for the demand controlled systems, etc. will be questioned. These facts are potentially interesting when evaluating the measurements, but are not essential for the selection of the buildings and often require technical expertise of a research assistant. When investigation the acoustic properties of the ventilation system, attention will be paid to possible exterior noises (neighbors, traffic,…), and the location of the different components within the building.

3.2.3. BUILDING TYPOLOGY AND INTERIOR

In order to have a good mix of apartments, free standing houses, etc., the building typology is questioned beforehand.

The location of the building is also requested, as an urban environment differs greatly from a rural environment regarding outdoor air quality and noise levels. This may in return also affect the users control of the ventilation systems, e.g. shut down of the system because of smells or excessive noise.

Furthermore, there will be a differentiation in building method: heavy weight masonry buildings versus wood frame buildings. For schools, a third category of prefab ‘modular unit’ classrooms is added. These buildings behave different with regard to thermal comfort, and have distinguished acoustic properties which must be taken into consideration when investigating the acoustic performance of the ventilation system. The different materials may also have an impact on the indoor humidity levels and construction related contaminants. In newly constructed buildings, the relative humidity may be very high because of water which needs time to evacuate from the construction materials, and building materials may still have high emission levels of several contaminants. Therefore we exclude buildings from the survey if they aren’t inhabited for at least 12 months.

Interior finishes or furniture can also have an impact on building IAQ. These properties are not part of the selection process, but will be evaluated while visiting the houses or classrooms. Also the type of heating delivery system is recorded, as there are important differences with regard to internal air distribution and velocities between traditional hydraulic radiators, convectors, under floor heating systems and forced air heating.

In the case of a house, the presence of a cellar or garage integrated in the building is also noted, because these rooms may be the source of specific contaminants. During a visual inspection, it will be investigated how well these rooms are sealed off from the living compartments of the house. Inspectors will also describe the kitchen: whether or not it is integrated in the living room, whether the cooker uses gas or electricity (important according to (2007- GGD Eemland)), and whether the cooking hood is connected to the exterior of the building. An open cooking hood compromises the airtightness of a house, and therefore many owners of a low energy house opt for a re-circulating cooking hood, which filters the air and returns it to the kitchen environment.

3.2.4. OCCUPANTS

Building occupants have a major impact on the building IAQ, because they can decide on the ventilation rates of mechanical ventilation systems, and they are responsible for maintenance of its components. Furthermore, the building occupant has to a great extend impact on the contaminants which are released into the indoor air. To minimise the latter impact in this study, occupants are asked to avoid some activities (like vacuum cleaning during the measurement of biological contaminants or window opening during the blower door tests) during or shortly before the measurements, and buildings in which the occupants smoke or in which a wood burning stove is used are excluded from the survey.

The owners are asked to answer some simple questions regarding their control of the ventilation rates and window opening behaviour. In a limited number of indoor locations (2 residences en 2 schools/classrooms) the measurement period is repeated in the non-heating season to investigate the user behaviour more thoroughly.

The timely replacement of filters and possible cleaning of the air ducts is expected to have a major influence of IAQ. Therefore, owners will be questioned after their maintenance strategy, supplemented by a visual inspection of the condition of filters and ducts during the measurement campaign. If the house or apartment is not owned by the occupant, maintenance may become even more difficult, or completely overlooked by a lack of responsibility or knowledge. This aspect will be taken into account by comprising privately rented and public social houses in the building selection.

3.3. CRITERIA FOR BUILDING SELECTION AND QUESTIONNAIRE

The airtightness of the building is the main characteristic to categorise the buildings. We seek a balanced distribution of houses and schools in the three categories ‘very airtight’, ‘moderately airtight’ and ‘poorly airtight’. The infiltration rate of a building is not known until the airtightness is tested. The initial division of the buildings into the three categories is based on estimation for buildings without a test report, and may alter after the blowerdoor-test is performed.

In the previous paragraph many other building characteristics have been analyzed. Due to the limited amount of buildings under investigation in this exploratory study, it is not possible to include every combination of relevant building, occupant or ventilation characteristics in the survey. Instead, the buildings will be selected in order to have a wide range of different combinations, while still preserving a representative view on present and future technologies for low energy buildings.

The following tables (Table 4 and Table 5) indicate the three main building categories, and probable combinations of ventilation systems.

Table 4: Overview of dwelling characterisation

Dwelling category	Very airtight	Moderately airtight	Poorly airtight
Selection criterion	$n_{50} \le 0.6$	$0.6 < n_{50} \le 2.5$	$n_{50} \ge 2.5$
Expected ventilation system	D with heat recovery	(C) C demand controlled D with heat recovery	C C demand controlled (D with heat recovery)
Optional features	Earth-to-air heat exchanger Ground coupled heat exchanger with a heat transfer fluid Thermal recovery wheel Integrated heating Small plastic ducts		-

Table 5: Overview of school characterisation

School category	Very airtight	Moderately airtight	Poorly airtight
Selection criterion	$n_{50} \le 0.6$	$0.6 < n_{50} \le 2.5$	$n_{50} \ge 2.5$
Expected ventilation system	(D without heat recovery) D with heat recovery	(C) C demand controlled D without heat recovery D with heat recovery	C C demand controlled D without heat recovery
Optional features	Earth-to-air heat exchanger		-

The questionnaire (in Dutch) distributed to select possible buildings for the survey can be found in Annex 1. The questionnaire for building and ventilation characteristics during the measurement sessions can be found in Annex 2.

CHAPTER 4 INDOOR CHARACTERISTICS; ASPECTS TO BE STUDIED

Established protocols (eg Crump et al., 2002), international standards concerning indoor air quality measurements in the ISO 16000 series and study reports on (field)studies on IAQ should be taken into account as a guideline to define the parameters to be measured in an exploratory study of the air quality in energy efficient homes. These latter studies include regional monitoring campaigns (Surveillance of the health situation in Flemish residences (2007-2008-2009-2010-2011 Flemish Agency for Care and Health/Vito; 2009), BiBa on the indoor air quality in primary schools (2009, Environment, Nature and Energy Department/ Flemish Agency for Care and Health/VITO) and FLIES, the Flanders Indoor Exposure Study (2007, Environment, Nature and Energy Department/VITO as well as national and international surveys on the indoor air quality (Sinphonie 2010-2012 DG Sanco; INSULAte Finland, HITEA 2008-2013 FP7; WHO Frankfurt Housing intervention project 2008; HOPE EU 2005) as well as published research results (literature overview paragraph 2.2).

Based on these previously mentioned studies and the literature cited in paragraph 2.2, a set of parameters, relevant for the characterisation of the indoor environment in energy-efficient ventilated buildings, can be identified. The critical aspects and determining factors, linked to the occurrence of these parameters in energy-efficient buildings, will lead to a distribution of the parameters in two groups:

(1) parameters that should be monitored in the indoor micro-environments, and

(2) parameters that should be inventoried in a questionnaire.

The parameters, to be studied in order to characterize the indoor environment in energy-efficient buildings, can be subdivided in chemical, physical and biological parameters. They will be discussed separately in the following paragraphs.

According to Crump et al (2010), the association of any measurement with records of the occupants’ activities, including changes in the ventilation conditions, and the use of (consumer) products indoors, are of significant importance. Also information on the occupants’ understanding and undertaking maintenance of the system should be collected. The occupant’s perception of the indoor environment with respect to thermal comfort, perceived odour, and freshness of the air, and the occurrence of SBS symptoms should be undertaken. This note will be addressed in the next paragraphs as well.

4.1. CHEMICAL CHARACTERISTICS, ASPECTS TO BE STUDIED

We can distinguish indoor and/or outdoor generated chemical pollutants. For each pollutant, occurring in the literature review, the main source and/or the possibility to occur at concentration levels, influenced by the ventilation system, is indicated in Table 6. Furthermore, the table also indicates whether study results on the regional occurrence of these pollutants in traditional buildings are available.

In Table 6 it can be seen that several international publications report that TVOC, VOCs, aldehydes, CO_2 and PM2.5 are relevant compounds to study in the indoor environment of energy-efficient buildings. For these compounds, reference values on their occurrence in Belgian traditional houses and schools are available, which is necessary to evaluate the data collected in *Clean Air, Low Energy* with data collected in traditional buildings.

Table 6: Chemical parameters occurring indoors, and the possibility to occur at indoor levels, influenced by ventilation

Chemical compound	**Included in field studies in traditional buildings**	**Potential Source**	**Potentially influenced by ventilation**
TVOC	Surveillance of the health situation in Flemish buildings; BiBa; FLIES	traffic and indoor sources (building materials and consumer products) related	Aubin et al., 2011; Stranger et al. 2011; Raja et al. 2011; Xu, 2010 ; Jarnstorm et al. , 2006; Yoshino et al. 2006 ;
VOC (MTBE, benzene, trichloroethene, toluene, tetrachloroethene, ethylbenzene, xylene isomets, 1, 2, 4 trimethylbenzene, 1,4-dichlorobenzene)	Surveillance of the health situation in Flemish buildings; BiBa; FLIES	traffic and indoor sources (building materials and consumer products) related	Aubin et al., 2011; Raja et al. 2011 ; Yoshino et al. 2006 ; Dimitroupoulou et al. 2005
Aldehydes (total aldehydes, formaldehyde and acetaldehyde)	Surveillance of the health situation in Flemish buildings; BiBa; FLIES	building materials, consumer products, new furniture	Jarnstorm et al. , 2006; Yoshino et al. 2006 Dimitroupoulou et al. 2005
$PM_{2.5}$ (mass concentration) and PMx (time evolution)	Surveillance of the health situation in Flemish buildings; BiBa; FLIES	outdoor air, indoor generated	Stranger et al. 2011 ; MacIntoch et al. 2010 ; Noh et al., 2010 ; Paul et al. 2010 ;
PM_{10}		outdoor air, indoor generated	Raja et al. 2011
NO_2	Surveillance of the health situation in Flemish buildings	traffic, indoor combustion appliances	Aubin et al., 2011 Dimitroupoulou et al. 2005
O_3		(summer) outdoor air, specific sources	Aubin et al., 2011;
CO_2	Surveillance of the health situation in Flemish buildings; BiBa; FLIES	occupants	Raja et al. 2011 ; Breysse et al. 2011 ; Madhavi et al, 2010;
CO		combustion appliances	Raja et al. 2011 ;

PM10 was reported to be subject to the influence of ventilation as well, however, for research and exploratory aims, it is more interesting to give priority to smaller sized particles (inhalable size fraction) such as PM2.5. NO_2 has been reported to occur at lower indoor air levels in ventilated buildings. However, as a consequence of its close relation to the presence of gas stoves, the indoor levels are also related to the efficiency of the cooker hood. Furthermore, the use of NO_2 as an indication of the influence of traffic on the indoor air quality is not essential, since more accurate tracer compounds for traffic are part of the VOC compounds (such as MTBE) that will be assessed in the houses and the schools. Indoor O_3 is linked to specific indoor sources (such as printers or computers), but mostly highly depending on the ambient concentration levels, which on their turn therefore are known to be higher in summertime. Since the *Clean Air, Low Energy* field study will be organized during the heating season, O_3 will only be monitored during the seasonal variation case study (foreseen in 2 houses and 2 schools/classrooms). Since CO is related to disfunctioning combustion appliances, it is not included in this particular study, only few information has been reported on its occurrence in relation to ventilation systems.

Certain indoor contaminants, listed in Table 6, could be highly influenced by building related characteristics or by habits of or consumer products used by inhabitants. These include influences related to the outdoor environment, to indoor smoking or to new building materials. Therefore, a few selection criteria in relation to the chemical characterisation of the indoor environment are defined:

- We aim for an equal distribution between houses/schools in urban and rural environment
- There is no indoor smoking (nor by building occupants, nor by visitors) in any of the buildings, participating in *Clean Air, Low Energy*
- No major renovation activities have been organized in any of the buildings in the last 6 months, participating in *Clean Air, Low Energy*
- Buildings participating in *Clean Air, Low Energy* are older than 6 months.

Furthermore also smaller impacts on the indoor air quality can be expected, resulting from various indoor sources. This information is included in the *Clean Air, Low Energy* questionnaire, which is completed by the building occupants. The topics included are: recent (within the last 6 months) achievement of new furniture, recent (small) renovations (like room painting), odour nuisance, and the use of consumer products known to emit VOCs and/or aldehydes. In order to obtain a maximum comparability with existing regional studies in Flanders, the questionnaire for schools will be based on the 'BiBa' questionnaire (BiBa, 2009) and the questionnaire for residences will be based on the questionnaire from the study 'Surveillance of the health situation in Flemish buildings'.

4.2. PHYSICAL CHARACTERISTICS, ASPECTS TO BE STUDIED

Relevant physical parameters, listed in the literature overview in paragraph 2.2, are summarized in Table 1.

Table 7: Physical parameters occurring indoors, and the possibility to be subject to ventilation

Physical compound	In other field studies	Potential influence by ventilation
Temperature	Surveillance of the health situation in Flemish buildings; BiBa; FLIES	Aubin et al. 2011; Raja et al. 2011; Stranger et al. 2011; Madhavi et al., 2010 ; Paul et al. 2010; Maier et al. 2009 ; Versteeg 2008 ; Aizlewood 2006
Relative humidity	Surveillance of the health situation in Flemish buildings; BiBa; FLIES	Aubin et al. 2011; Raja et al. 2011; Stranger et al. 2011; Madhavi et al., 2010; Paul et al. 2010; Versteeg 2008 ;
Draught	Surveillance of the health situation in Flemish buildings	
Noise nuisance due to ventilation system	Optivent	Briere 2010 ; Harm 2008 ; Hodgson 2008 ; Palonen et al. 2008 ; Khaleghi et al. 2007 ;
Noise nuisance due to outdoor environment	Optivent	Versteeg 2008 ;
Ventilation rate	BiBa	Aubin et al. 2011; Van Dijken et al. 2011
Air leakage (air tightness)	SENVIVV study 1999	Aubin et al. 2011; Yoshino 2006; Dimitroupoupou et al. 2005
Wall moisture		Paul et al. 2010;

For the physical characteristics, listed Table 7 in reference values are available in traditional houses and/or schools in Flanders, Belgium. The relevance of the proposed parameters in a study on the characterisation of the indoor environment in energy-efficient buildings, is supported by sufficient literature. No reference values are available for wall moisture; however, this parameter will be included in the questionnaire (visual moisture damage present in the house/school?) for the indoor monitoring programme.

4.3. BIOLOGICAL CHARACTERISTICS, ASPECTS TO BE STUDIED

The study to be conducted is an exploratory study on the indoor environment of energy-efficient buildings (EEBs). The overall aim is to assess the indoor air quality (IAQ) in energy-efficient buildings, including homes and schools; physical, chemical and biological parameters will be measured in order to determine, whether indoor air in such buildings differs from non-energy-efficient buildings. The overall study strategy follows the approach to determine various parameters in EEBs and compare the data generated in this study to data available from previous studies on non-energy-efficient buildings. The particular focus is on how the outdoor environment and ventilation systems affects the indoor parameters Thus, the study question – specified for biological agents – could be formulated as follows: "*Do levels of biological/microbial agents in energy-efficient, mechanically ventilated buildings differ from ‘reference’, non-energy-efficient buildings and what is the influence of the outdoor environment on the indoor microbial content in energy-efficient buildings?*" By answering this questions one should be able to conclude on whether ventilation systems, additional insulation and other measures applied in EEBs, in contrast to non-energy-efficient buildings, affect on the indoor microbial levels in homes and schools.

The overall study strategy is pre-defined in this project and will be followed for all parameters measured, including biological/microbial agents. However, based on the literature review, the complementary assessment of microbial contaminants inside the ventilations systems of the 50 study locations would be a complex operation, with the likely results of contaminant levels that are only little comparable and difficult to interpret. Contrary to the above described objective, data on the microbial contamination of ventilation ducts cannot be evaluated based on their difference with ‘reference’, non-energy-efficient buildings or on their difference between the different ventilation system types. In a recent literature review (Peretti et al. 2011) it was concluded that no univocal way to effectively describe duct contamination has been developed so far. Available experimental work is not inter-comparable due to major differences in the data collection and analysis methodologies and furthermore, instrumentation is often adopted by the authors. The unequal distribution of dust on duct surfaces leads to a considerable variance and discrepancies in surface dust evaluation (Peretti et al. 2011, Holopainen et al.,2002a, Fransson et al., 1995). Therefore in ‘Clean Air, Low Energy’, it will be difficult to (1) obtain reproducible results and to (2) interpret and compare the results from different ventilation systems. E.g. a swap sample, collected in the air inlet of a system, which after analysis indicates no fungi, yeast or bacteria, does not naturally lead to the conclusion of a clean ventilation system. A microbial contamination may still be situated in another location in the ventilation system. A sound assessment on the microbial contamination of ventilation systems would require a dedicated study and considerable additional resources. On the other hand, in case of contaminated ventilation systems, microbes are likely to be present and measurable as elevated levels in indoor air; elevated microbial levels indeed would indicate the probability of a contaminated ventilation system. In order to maintain a maximal comparability of the results from ‘Clean Air, Low Energy’ with (national and international) existing studies, the biological characterisation of the indoor environment in this study will focus on the assessment of the indoor air quality.

In addition, there are certain definitions/limitations to be considered with respect to the feasibility of field work efforts and the sampling and analyses methods available at the partner responsible for conducting the sampling/analyses for biological agents. We therefore choose here to propose both, an 'ideal' sampling strategy (to be applied maybe in future, more extensive studies on these or related issues), as well as a sampling strategy feasible and applicable in the pre-defined framework of this project, considering available resources and methodologies.

4.3.1. 'IDEAL' SAMPLING STRATEGY FOR COMPARING BIOLOGICAL AGENTS IN ENERGY-EFFICIENT AND NON-ENERGY-EFFICIENT BUILDINGS

→ Sampling sites

As outlined above, the overall study strategy follows the approach to determine various parameters in EEBs and compare the data generated in this study to data available from previous studies on non-energy-efficient buildings. For the physical and chemical parameters to be measured, more or less standardized and comparable sampling and analysis methods are commonly used and will allow comparability to data generated in previous studies on non-energy-efficient buildings. For biological agents, sampling as well as analyses methods used in various studies vary widely and thus, direct comparison to existing data will be challenging. Considering this fact and the study question to be answered, i.e. "do levels of biological/microbial agents in energy-efficient buildings differ from 'reference', non-energy-efficient buildings", following a study design including both index (energy-efficient) and reference (non-energy-efficient) buildings would allow answering this question more accurately, rather than trying to compare newly generated data to existing data sets. Various building and other factors, such as geographical location and season, may affect on indoor biological levels and thus should be considered in choosing the study sites. Index and reference building pairs should be in close geographical vicinity to each other, sampled at the same season at least, preferably during same weeks/a month and be comparable with respect to building age, building type/use, and building frame/materials. Conditions of dampness/moisture damage/mould are important factors that may affect microbial levels indoors and thus such conditions need to be assessed prior to sampling campaigns; if such buildings are included, they should be equally included in index and reference buildings.

→ Timing of sampling campaigns and other general considerations

Outdoor air is a major source for the microbial content of indoor air; seasonal variation in indoor microbial levels has been described in various epidemiological and exploratory studies. In order to identify indoor sources of microbes and measuring the resulting levels, sampling is preferably done during the winter months (heating season), when outdoor contribution to indoor microbial levels is reduced (*Hyvärinen et al. 2001*). However, since the scope of this project includes also the contribution of outdoor air on the indoor air microbial content, a strict control for season is not necessary. Outdoor sampling will be conducted in parallel to indoor sampling campaigns, in order to assess this contribution. Nevertheless, in proposed index/reference design it will be important to conduct sampling campaigns in index and reference building pairs during the same season/months, as already outlined above.

Another common source of airborne microbes is occupancy and everyday activities in the buildings. A general decision on whether to conduct the indoor sampling campaigns during occupied or non-occupied situations will have to be made and to be followed in all sampling sites to guarantee comparability of results. In any case, during the short measurement time, occupants should be asked to avoid activities such as vacuuming, handling potentially mouldy (eg. cheese, sausage, bread, fruits) or unwashed food stuffs, plants or firewood, and opening windows or doors to the outside during or shortly before the sampling campaigns. When monitoring indoor environments using ventilation systems, it should be controlled that those are operating during sampling, as they are used in a normal living situation.

Pets represent another common source of indoor biological agents; again, if pets are present in an index building, the reference building should be matched with respect to pet keeping. All factors affecting microbial levels listed above added, as well as hobbies such as horse back riding, gardening etc. should be recorded and taken into account when considering the results.

→ Sampling strategy

Two different sampling approaches for biological agents in indoor air seem adequate to answer the scope of this project, i.e characterising the indoor environment of EEBs and compare this situation to non-energy-efficient buildings: sampling of bioaerosols (air sampling) and sampling of settled dust.

A) Sampling of bioaerosols:

Bioaerosol samples potentially relate best to actual human exposure situations, as only airborne, potentially inhalable compounds are collected. Several sampling methods are available for bioaerosols, being differentiated by different physical forces applied: inertial impaction (eg. Andersen impactor, Burkhard spore trap), centrifugal impaction (eg. Reuter Centrifugal samplers, cyclone samplers), liquid impingement (all-glass impingers, BioSampler), filtration (cassette filters, Button sampler) and gravitational settling (Willeke and Macher 1999, Reponen et al 2001). The selection of the method must be based on the aim of the measurement, the environment and the resources available (Hyvärinen PhD thesis 2002).

Typically conducted as short to medium term sampling campaigns (minutes to hours), all air sampling techniques have in common that they are heavily susceptible towards the known temporal changes in airborne concentrations of microbes. Exceptions here are long-term, high volume air samples, which, however, are very laborious and not commonly applied in field surveys.

Bioaerosol sampling directly onto agar plates using Andersen impactors are probably most commonly used and referred to in the existing literature. However, since sampling durations with Andersen impactors are typically in the range of minutes, this sampling approach requires repeated sampling in order to obtain meaningful data. Hyvärinen et al (2001) have studied the temporal and spatial variation of fungal concentrations of indoor air in two single-family homes using Andersen impactors (sampling duration 10 minutes, total sampling volume 283 L of air). Based on the between-rooms, within-day and within-season differences of concentrations of airborne, viable fungi the authors concluded that a one time measurement in one room over one season is not sufficient to characterize fungal levels in a residence. The authors calculate that sampling campaigns required to characterize the fungal concentration in a residence is 11, but mention that the sample size – relating to the precision of sampling – must also consider time efforts and costs. Samples are advisable to be taken in more than one room in a residence and in different times of a day. In any case, in parallel to indoor assessments, sampling of outdoor air with Andersen impactors need to be conducted in order to conclude on the outdoor contribution of indoor airborne, viable microbes.

Bioaerosol sampling via filtration using e.g. Button samplers can be conducted for a longer duration (e.g. 4 hours per day during occupancy, over 5 days of a week), which can circumvent the need for many repeated samples. Again, outdoor air samples would need to be taken in parallel to indoor assessments. However, the back-draw of such sampling approach is that a) filters get clotted after certain sampling duration and need to be exchanged; and b) the viability of spores is heavily compromised by extended periods of sampling and thus, cultivation based analyses methods are not advisable to be combined with longer term air samples. Analyses of such filter samples could be done using cultivation independent methodology (see below under Analyses of samples). This latter mentioned limitation, however, applies mostly only when using common polycarbonate filters and can be circumvented to a certain extent by using gelatine filters that maintain viability of spores better (ISO 16000-16).

B) Sampling of airborne, settled dust:

Dust settled on surfaces above floor level is considered a long term integrated sample of previously airborne material. Therefore, such sample is less prone to temporal variations of microbial concentrations indoors. One has to be aware, however, that with passive sampling all particles are not equally collected; larger particles may be overestimated and smaller underestimated. In addition, depending on the collection surface, resuspension may happen and during the long sampling period the open sampling area may be prone to disturbance by eg. cats and children. Different sampling approaches have been proposed, including sampling dust settled into settled dust boxes or onto electrostatic wipes (Noss et al 2008), both aiming at collecting dust over a defined period of time onto a defined surface area. Dust can be retrieved from these samplers and analysed using both, cultivation based as well as cultivation independent methodology. Back-draw here is that little data have been generated thus far for comparison. However, if using a proposed index/reference building approach, sampling of airborne settled dust could be considered an alternative sampling approach with certain advantages compared to other bioaerosol samples – but obviously also with limitations -, in order to answer the specific research question defined for this project.

→ Analyses of samples

Even though not being within the direct scope of this chapter, a few issues to be considered in the analyses of sample materials shall be mentioned here.

Cultivation based methods to determine viable spore counts of fungi and bacteria have been and are widely used in studies on microbes in indoor environments. While total spore counts give information on quantitative aspects of microbial levels, also qualitative aspects should be considered. Thus, differentiation in enumeration of different fungal genera (via microscopy) would be desirable. While total levels of microbes may be the comparable in different sampling sites, the qualitative content may vary considerably and may indicate ‘abnormal’ conditions with respect to indoor microbial pollutants (such as the presence of ‘indicator’ microbes in situations of dampness and moisture damage).

Recently, cultivation independent methods in analysing indoor sample materials have been introduced, in an effort to circumvent the limitation of selective/restricted coverage of the total microbial flora by cultivation based methods. Analyses of chemical markers and surrogates of microbial content are commonly applied in epidemiological surveys including indoor microbial exposures. These methods include measurement of endotoxin activity (via *Limulus* bioassay) and 3-hydroxy fatty acids of lipopolysaccharide (via gas chromatography/mass spectrometry (GC-MS)) as proxy for the presence of mainly Gram-negative bacteria; muramic acid (via GC-MS) as proxy of mainly Gram-positive bacteria; and of ergosterol (via GC-MS), β-glucans and fungal exo-polysaccharide (via immunoassays) as marker of fungal biomass. In addition to these, DNA-based methods, most prominently quantitative polymerase chain reaction (qPCR) is used to quantitatively assess the presence of DNA of different microbial groups at different specificity levels (species, genus, group specific), depending on the assay applied. Such methods will be widely used in the near future and are expected to strongly complement, if not replace analyses methods based on cultivation of microbes and may thus be considered in up-coming research.

In addition to microbes, allergens – and here most commonly house dust mite allergens - are commonly assessed in indoor environments as representing part of biological indoor pollutants. As increased levels in house dust mites have been frequently linked to conditions of elevated relative humidity in homes, a factor of concern also in energy-efficient building, measurement of house dust mite allergens from indoor dust could complement indoor assessment of microbes.

CHAPTER 5 DETAILED SAMPLING STRATEGY

The detailed sampling strategy to be applied in *Clean Air Low Energy* is summarized in this chapter. In this section the different measurement techniques which will be applied are presented and measuring programmes are adapted to be feasible within the proposed time frame and budgetary means of this exploratory research programme. Details on the sampling protocols for chemical, biological and physical measurements will in the first place aim for the generation of new data, comparable to data generated in previous research programmes. Therefore, the measurement site for sampling inside the house or the school might differ between chemical, biological and physical measurements.

5.1. SAMPLING STRATEGY FOR CHEMICAL PARAMETERS IN ENERGY-EFFICIENT BUILDINGS

The compounds listed in Table 8 will be assessed simultaneously in the indoor and corresponding outdoor environments. Samples will be collected at a distance of 1 meter from a wall, in the residences all samples will be collected in the living room; in the schools indoor samples will be collected in the classroom. Note that, in order to obtain data comparable to existing datasets on the indoor air quality in Flanders, Belgium, a different sampling time is selected in houses and schools.

Table 8: Measurement strategy for chemical parameters

Compound	Measurement technique	Sampling time	Sampling site
TVOC	Radiello passive sampler	Houses: 7 days Schools: 5 days	Houses: living room Schools: classroom Parallel outdoor
VOC (MTBE, benzene, trichloroethene, toluene, tetrachloroethene, ethylbenzene, xylene isomets, 1, 2, 4 trimethylbenzene, 1,4-dichlorobenzene)	Radiello passive sampler	Houses: 7 days Schools: 5 days	Houses: living room Schools: classroom Parallel outdoor
Aldehydes (total aldehydes, formaldehyde and acetaldehyde)	Umex passive sampler	Houses: 7 days Schools: 5 days	Houses: living room Schools: classroom Parallel outdoor
$PM_{2.5}$ (mass concentration)	MS&T Harvard type impactor	Houses: 7 days– 24h Schools: 5 days – teaching hours	Houses: living room Schools: classroom Parallel outdoor
PMx (time evolution)	Grimm optical PM monitoring	Houses: 7 days Schools: 5 days	
CO_2	Catec Klimabox + other	Houses: 7 days Schools: 5 days	Houses: living room + bedroom(s) Schools: classroom

5.2. SAMPLING STRATEGY FOR PHYSICAL PARAMETERS IN ENERGY-EFFICIENT BUILDINGS

The user satisfaction concerning the indoor environment, the thermal comfort and noise nuisance is assessed via the questionnaires. In classrooms, attention will be put to the sound privacy inside the rooms; this will be assessed via questionnaires.

Table 9: Measurement strategy for physical parameters

Compound	Measurement technique	Sampling time	Sampling site
Temperature	Catec Klimabox	Houses: 7 days Schools: 5 days	Houses: living room Schools: classroom Parallel outdoor
Relative humidity	Catec Klimabox	Houses: 7 days Schools: 5 days	Houses: living room Schools: classroom Parallel outdoor
Draught	e.g. OMNIPORT 20	Houses: 1h Schools: 1h	Houses: living room Schools: classroom
Noise nuisance due to ventilation system	Measurement installation noise, reverberation time and background noise levels Measurement of installation noise for different ventilation positions (normal rate, rate '2', and maximal rate), measurement of outdoor noise for rooms with natural air supply	Rooms with natural air supply: 1 hour (sampling time per measurement = min. 30s, max. 15') Rooms with mechanical air supply : 30 minutes (sampling time per measurement = min. 30 s)	Houses (8): living room, bedroom Schools (7): classrooms
Noise nuisance due to outdoor environment	Catec Klimabox	Houses: 7 days Schools: 5 days	Houses: living room Schools: classroom
Ventilation rate	CO_2 based Flowbox measurements	- (instantaneous measurement)	Houses: all vents Schools: all vents
Air leakage (air tightness)	Pressurization tests	- (instantaneous measurement, total time +- 1h)	Houses: front door (intervention in rest of dwelling) Schools: classroom door

5.3. ADAPTED SAMPLING STRATEGY FOR DETERMINING BIOLOGICAL AGENTS IN ENERGY-EFFICIENT BUILDINGS

5.3.1. GENERAL CONSIDERATIONS WITH RESPECT TO SAMPLING SITES AND TIMING OF SAMPLING

The overall study strategy follows, as discussed above, the approach to determine various parameters of the indoor air in energy-efficient buildings and compare the data generated in this study to data available from previous studies on non-energy-efficient buildings. It was also discussed that this will be challenging thing to do for biological agents. It is planned that sampling campaigns will be conducted in 15 homes and their gardens, as well as 5 schools and their playgrounds (15 classrooms), all of those categorized as 'energy-efficient buildings', but still including different building types, in particular with respect to ventilation systems in use. In fact the selection is performed as follows:

- Houses: 5 very airtight houses, 5 moderately airtight houses and 5 poorly airtight houses.
- Schools: 1 very airtight school (only one available in Flanders, 3 classrooms), 2 moderately airtight schools (6 classrooms) and 2 poorly airtight schools (6 classrooms).

As partly, this exploratory study also aims to look at differences in microbial levels between those different ventilation types, best possible comparability of the data generated within this study should be aimed at.

In the following we list a few factors that potentially influence indoor microbial levels and thus should be addressed when sampling is conducted at the sampling sites.

1) Dampness/moisture damage/visible mould growth: such conditions are frequently accompanied by elevated levels of fungal, bacterial and allergen (in particular house dust mite) loads indoors. Thus, the sampled homes and schools should be assessed prior to sampling for whether or not such conditions prevail in the buildings. This is ideally done by a walk through building inspections by a trained civil engineer; alternatively, a short questionnaire on these items could be addressed to the occupants (or school personnel in the case of schools), as done in many epidemiological studies aiming at linking (biological) indoor exposures and health.

2) As communicated earlier by the coordinator of this study, the sampling sites will be in relatively close geographical vicinity, which should allow comparability with respect to geographical variability of study buildings. Also the vegetation near sampling sites should be considered, ie. building next to park vs. building next to high way/urban surrounding.

3) General building factors, such as building age, building type/use, and building frame/materials should be recorded.

4) As communicated earlier by the coordinator of this study, sampling will be conducted during occupied hours. As everyday activity may influence microbial levels, effort should be put on that all the sampling sites are really occupied during sampling campaigns. Occupancy should be recorded. Within-day variation in levels of airborne fungi – possible due to activity patterns of occupants - has been described (*Hyvärinen et al. 2001*), which makes it advisable to aim at comparable activity in all sampling sites.

5) Occupants should be asked to avoid activities listed above such as vacuuming, handling unwashed food stuffs or firewood, and opening windows or doors to the outside during or shortly before the sampling campaigns (2 hour minimum).

6) When monitoring indoor environments using ventilation systems, it should be controlled that those are operating during sampling, as they are operating during normal use of buildings.

7) Pet keeping and the presence of pets during sampling campaigns should be recorded in addition to above mentioned factors.

5.3.2. SAMPLING STRATEGY AND SAMPLE ANALYSIS – FINAL MEASUREMENT STRATEGY

The sampling strategy in this project needs to be adapted to the resources and sampling/analyses methods available at the collaborator conducting the sampling and analyses of microbial samples, all in compliance with the project aims. Andersen impactor sampling will be used, followed by enumeration of total fungi+ yeasts (on DG18 agar medium) and total bacteria (on plate count agar). A sampling duration of 5 min, at 28.3 L/min flow rate (~150 L) is applied. In addition, surface swab samples are taken, again, followed by total enumeration of fungi, yeasts and bacteria.
The use of the Andersen impactor is preferred over other, simplified and more commercially used techniques, because of the following reasons:

- The Andersen impactor has been used on a worldwide scale, in various studies. The results have been reported and discussed in open literature. Using the same technique with a comparable method, guaranties a high comparability of the results from 'Clean Air, Low Energy' with other study results as well as an increased reliability of the outcomes.
- Sample collection on the 6 successive agar plates in the Andersen impactor guaranties a distribution of the collected particles over several impactor stages. This separated growth on the 6 plates leads to a more accurate count. Sample collection on one plate (using the commercial, simplified and cheaper method) on the other hand, may lead overloading of the medium. This overloading, results in overgrowing of different species, due to both fast and slow growth on one plate, which leads to decrease in the accuracy of the outcomes. Reducing the sampling time would reduce this risk of overgrowing, however it would significantly reduce the representativeness of the sample, due to high variability between air samples of short sampling times.

Following recommendations as concerns the sampling strategy:

- Andersen impactor samples are taken in two rooms of each residential home (additionally respecting the general considerations listed above).In school settings, samples are collected in at least two classrooms. Ideally, sampling would be repeated on a different day to confirm abnormal conditions, however, this is not feasible to be done in the scope of the current study. Outdoor samples are taken in parallel to each indoor assessment.

- Sampling duration is 5 minutes per sampling campaign; a total volume of ~150 L air should be sampled during this duration. The Andersen sampling has to be used at 28.3 L/min flow rate, otherwise the impaction is imperfect

- Samples are collected in the middle of the rooms in a height of 1 – 1.5 m. Control human activities as outlined under point 5 above.

- In order to allow maximum comparability to previously published studies, media used for fungi may include two non-selective media: 2% malt extract agar and dichloran glycerol agar (DG18), as recommended for detection of viable fungi (Samson et al 1994; see also ISO 16000-17)). Sabouraud agar medium should be used if the responsible collaborator is specialized on working only with this type of agar medium and also if resources are limited. Ideally, in that case the collaborator should provide reference datasets from reference homes/schools they have assessed earlier.

- As sampling is anticipated to span from September to May, the issue of seasonal variation needs to be addressed. This will be possible by relating the indoor air measurements with in parallel conducted outdoor air assessments.

- Ideally, enumeration of the main fungal genera would be approached from the agar plates after sampling in order to not only quantitatively, but also qualitatively describe the indoor microbial content to some extent.

- Swab sampling in this study, is considered to complement the bioaerosol sampling. However, swab samples should be taken from a defined area of a previously clean surface in a height of 1.5 to 2 m (eg. swab from a glass plate placed in the room on a shelve after one week).

This leads to the following overview of microbiological samples to be collected (Table 10).
Guidelines and questionnaires on the occupants' activities during the microbial sampling are formulated. They are inserted in Annex B.

Table 10 Measurement strategy for biological parameters

Compound	Measurement technique	Sampling time	Sampling site
Bioaerosol samples – fungi and yeast	Anderson 6-stage impactor	5 minutes total volume ~150L 28.3 L/min flow rate	15 Houses: living room, bedroom 15 classrooms Parallel outdoor
Bioaerosol samples – total bacteria	Anderson 6-stage impactor	5 minutes total volume ~150L 28.3 L/min flow rate	15 Houses: living room 15 classrooms Parallel outdoor
Settled dust sampling – fungi and yeast	Swap sampling	Not applicable - height of 1.5 to 2 m	Houses: living room, bedroom 15 classrooms
Settled dust sampling – total bacteria	Swap sampling	Not applicable - height of 1.5 to 2 m	Houses: living room, bedroom 15 classrooms

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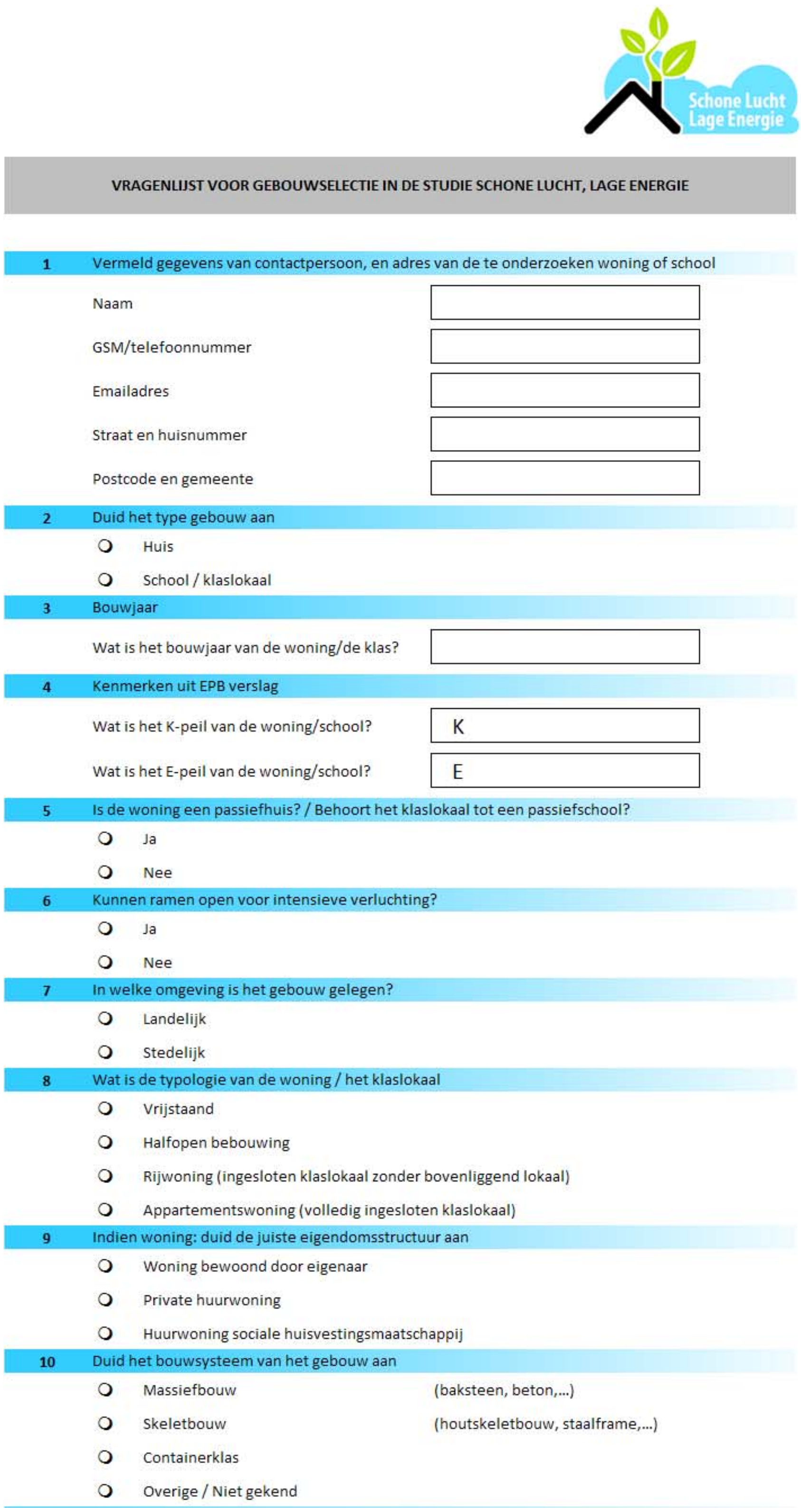
ANNEX A: QUESTIONNAIRE FOR RECRUITING

Part 1: Questionnaire for recruiting houses (and schools)



Schone Lucht Lage Energie

VRAGENLIJST VOOR GEBOUWSELECTIE IN DE STUDIE SCHONE LUCHT, LAGE ENERGIE

1 Vermeld gegevens van contactpersoon, en adres van de te onderzoeken woning of school

Naam

GSM/telefoonnummer

Emailadres

Straat en huisnummer

Postcode en gemeente

2 Duid het type gebouw aan

- ○ Huis
- ○ School / klaslokaal

3 Bouwjaar

Wat is het bouwjaar van de woning/de klas?

4 Kenmerken uit EPB verslag

Wat is het K-peil van de woning/school? K

Wat is het E-peil van de woning/school? E

5 Is de woning een passiefhuis? / Behoort het klaslokaal tot een passiefschool?

- ○ Ja
- ○ Nee

6 Kunnen ramen open voor intensieve verluchting?

- ○ Ja
- ○ Nee

7 In welke omgeving is het gebouw gelegen?

- ○ Landelijk
- ○ Stedelijk

8 Wat is de typologie van de woning / het klaslokaal

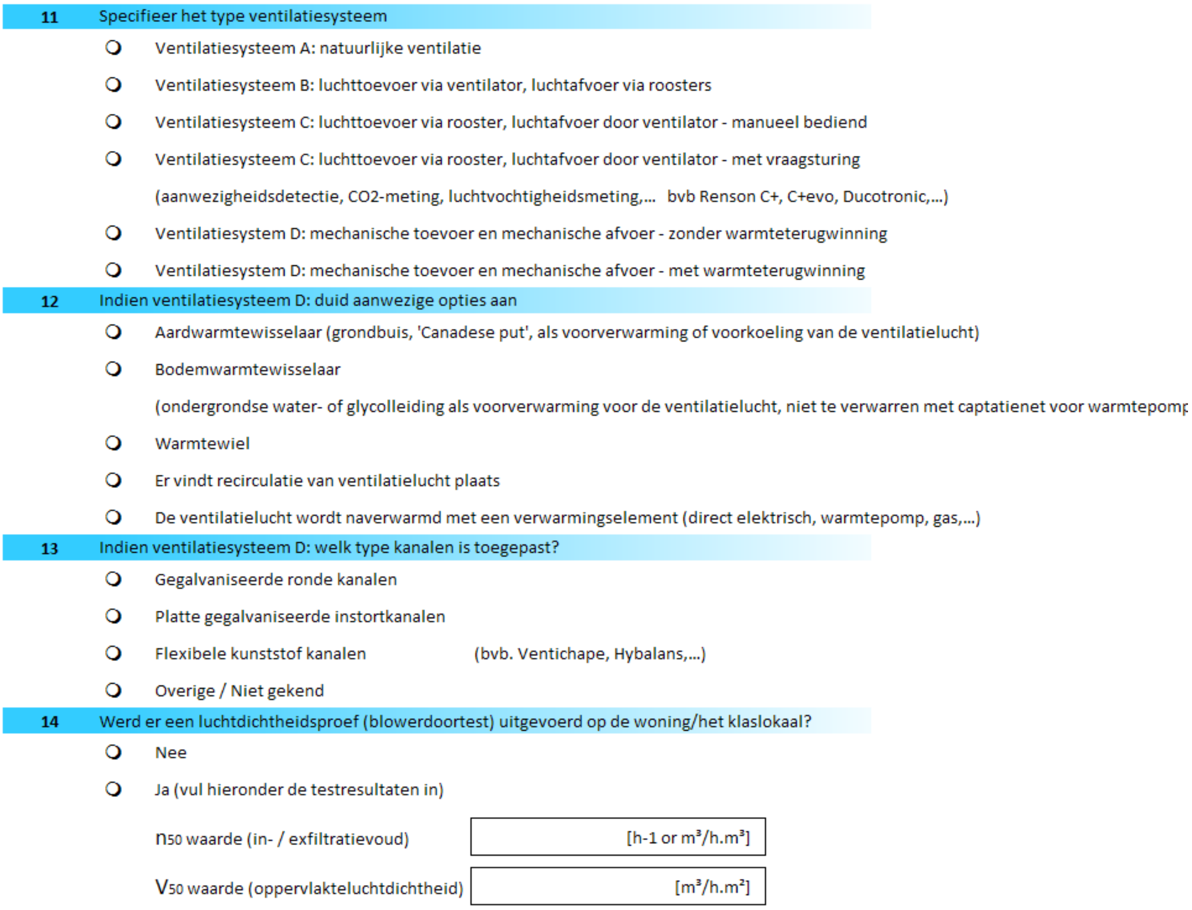
- ○ Vrijstaand
- ○ Halfopen bebouwing
- ○ Rijwoning (ingesloten klaslokaal zonder bovenliggend lokaal)
- ○ Appartementswoning (volledig ingesloten klaslokaal)

9 Indien woning: duid de juiste eigendomsstructuur aan

- ○ Woning bewoond door eigenaar
- ○ Private huurwoning
- ○ Huurwoning sociale huisvestingsmaatschappij

10 Duid het bouwsysteem van het gebouw aan

○ Massiefbouw	(baksteen, beton,...)
○ Skeletbouw	(houtskeletbouw, staalframe,...)
○ Containerklas	
○ Overige / Niet gekend	



11 Specifieer het type ventilatiesysteem

○ Ventilatiesysteem A: natuurlijke ventilatie

○ Ventilatiesysteem B: luchttoevoer via ventilator, luchtafvoer via roosters

○ Ventilatiesysteem C: luchttoevoer via rooster, luchtafvoer door ventilator - manueel bediend

○ Ventilatiesysteem C: luchttoevoer via rooster, luchtafvoer door ventilator - met vraagsturing

(aanwezigheidsdetectie, CO2-meting, luchtvochtigheidsmeting,... bvb Renson C+, C+evo, Ducotronic,...)

○ Ventilatiesystem D: mechanische toevoer en mechanische afvoer - zonder warmteterugwinning

○ Ventilatiesystem D: mechanische toevoer en mechanische afvoer - met warmteterugwinning

12 Indien ventilatiesysteem D: duid aanwezige opties aan

○ Aardwarmtewisselaar (grondbuis, 'Canadese put', als voorverwarming of voorkoeling van de ventilatielucht)

○ Bodemwarmtewisselaar

(ondergrondse water- of glycolleiding als voorverwarming voor de ventilatielucht, niet te verwarren met captatienet voor warmtepom

○ Warmtewiel

○ Er vindt recirculatie van ventilatielucht plaats

○ De ventilatielucht wordt naverwarmd met een verwarmingselement (direct elektrisch, warmtepomp, gas,...)

13 Indien ventilatiesysteem D: welk type kanalen is toegepast?

○ Gegalvaniseerde ronde kanalen

○ Platte gegalvaniseerde instortkanalen

○ Flexibele kunststof kanalen (bvb. Ventichape, Hybalans,...)

○ Overige / Niet gekend

14 Werd er een luchtdichtheidsproef (blowerdoortest) uitgevoerd op de woning/het klaslokaal?

○ Nee

○ Ja (vul hieronder de testresultaten in)

n_{50} waarde (in- / exfiltratievoud)	[h-1 or $m^3/h.m^3$]
V_{50} waarde (oppervlakteluchtdichtheid)	[$m^3/h.m^2$]

Part 2: Questionnaire for recruiting schools

VRAGENLIJST VOOR GEBOUWSELECTIE IN DE STUDIE SCHONE LUCHT, LAGE ENERGIE

1 Vermeld gegevens van contactpersoon, en adres van de te onderzoeken school

Naam van de school ☐

Straat en huisnummer ☐

Postcode en gemeente ☐

Naam van de contactpersoon (schooldirectie) ☐

GSM/telefoonnummer ☐

Emailadres ☐

2 Welk deel van het gebouw aan dat voldoet aan de Clean Air Low Energy voorwaarden?

○ De ganse school

○ Enkele klaslokalen Aantal lokalen : ☐

3 Welke onze onderwijsgraden volgen lessen in de energiezuinige klassen?

○ Kleuteronderwijs

○ Basisonderwijs

○ Secundair onderwijs

4 Bouwjaar

Wat is het bouwjaar van de E-zuinige klassen? ☐

5 Kenmerken uit EPB verslag

Wat is het K-peil van de energiezuinige klassen? K

Wat is het E-peil van de energiezuinige klassen? E

6 Behoort het klaslokaal (of klaslokalen) tot een passiefschool?

○ Ja

○ Nee

7 Kunnen ramen open voor intensieve verluchting?

○ Ja

○ Nee

8 In welke omgeving is het gebouw gelegen?

○ Landelijk

○ Stedelijk

9 Wat is de typologie van de nieuwbouw / de klaslokalen

○ Gelijkvloers

○ Hoogbouw

10 Duid het bouwsysteem van het gebouw aan

- ○ Massiefbouw (baksteen, beton,…)
- ○ Skeletbouw (houtskeletbouw, staalframe,…)
- ○ Modulair systeem
- ○ Overige / Niet gekend

11 Specifieer het type ventilatiesysteem

- ○ Ventilatiesysteem C: luchttoevoer via rooster, luchtafvoer door ventilator - manueel bediend
- ○ Ventilatiesysteem C: luchttoevoer via rooster, luchtafvoer door ventilator - met vraagsturing
  (aanwezigheidsdetectie, CO2-meting, luchtvochtigheidsmeting,… bvb Renson C+, C+evo, Ducotronic,…)
- ○ Ventilatiesystem D: mechanische toevoer en mechanische afvoer - zonder warmteterugwinning
- ○ Ventilatiesystem D: mechanische toevoer en mechanische afvoer - met warmteterugwinning

12 Indien ventilatiesysteem D: duid aanwezige opties aan

- ○ Aardwarmtewisselaar (grondbuis, 'Canadese put', als voorverwarming of voorkoeling van de ventilatielucht)
- ○ Bodemwarmtewisselaar
  (ondergrondse water- of glycolleiding als voorverwarming voor de ventilatielucht, niet te verwarren met captatienet voor warmtepomp
- ○ Warmtewiel
- ○ Er vindt recirculatie van ventilatielucht plaats
- ○ De ventilatielucht wordt naverwarmd met een verwarmingselement (direct elektrisch, warmtepomp, gas,…)

13 Op welke wijze wordt de luchttoevoer naar de geventileerde klassen geregeld?

- ○ Eén ventilator, voor verschillende klaslokalen
- ○ Eén ventilator per klaslokaal

14 Werd er een luchtdichtheidsproef (blowerdoortest) uitgevoerd op het klaslokaal?

- ○ Nee
- ○ Ja, op klaslokaalniveau (vul hieronder de testresultaten in)

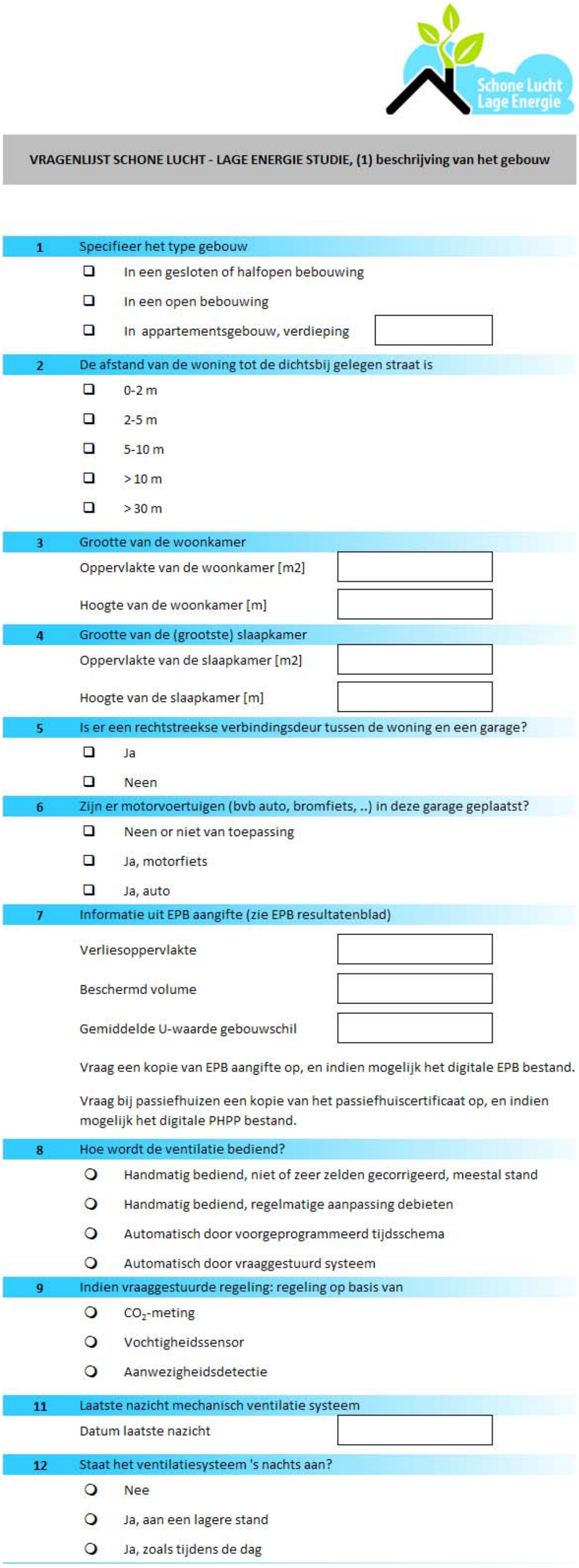
n_{50} waarde (in- / exfiltratievoud)	[h-1 or m^3/h.m^3]
V_{50} waarde (oppervlakteluchtdichtheid)	[m^3/h.m^2]

- ○ Ja, op schoolniveau (vul hieronder de testresultaten in)

n_{50} waarde (in- / exfiltratievoud)	[h-1 or m^3/h.m^3]
V_{50} waarde (oppervlakteluchtdichtheid)	[m^3/h.m^2]

ANNEX B: QUESTIONNAIRE FOR FIELDWORK

In the houses (part 1, part 2 and part 3)



Schone Lucht
Lage Energie

VRAGENLIJST SCHONE LUCHT - LAGE ENERGIE STUDIE, (1) beschrijving van het gebouw

1 Specifieer het type gebouw
- ☐ In een gesloten of halfopen bebouwing
- ☐ In een open bebouwing
- ☐ In appartementsgebouw, verdieping ☐

2 De afstand van de woning tot de dichtsbij gelegen straat is
- ☐ 0-2 m
- ☐ 2-5 m
- ☐ 5-10 m
- ☐ > 10 m
- ☐ > 30 m

3 Grootte van de woonkamer

Oppervlakte van de woonkamer [m2] ☐

Hoogte van de woonkamer [m] ☐

4 Grootte van de (grootste) slaapkamer

Oppervlakte van de slaapkamer [m2] ☐

Hoogte van de slaapkamer [m] ☐

5 Is er een rechtstreekse verbindingsdeur tussen de woning en een garage?
- ☐ Ja
- ☐ Neen

6 Zijn er motorvoertuigen (bvb auto, bromfiets, ..) in deze garage geplaatst?
- ☐ Neen or niet van toepassing
- ☐ Ja, motorfiets
- ☐ Ja, auto

7 Informatie uit EPB aangifte (zie EPB resultatenblad)

Verliesoppervlakte ☐

Beschermd volume ☐

Gemiddelde U-waarde gebouwschil ☐

Vraag een kopie van EPB aangifte op, en indien mogelijk het digitale EPB bestand.

Vraag bij passiefhuizen een kopie van het passiefhuiscertificaat op, en indien mogelijk het digitale PHPP bestand.

8 Hoe wordt de ventilatie bediend?
- ○ Handmatig bediend, niet of zeer zelden gecorrigeerd, meestal stand
- ○ Handmatig bediend, regelmatige aanpassing debieten
- ○ Automatisch door voorgeprogrammeerd tijdsschema
- ○ Automatisch door vraaggestuurd systeem

9 Indien vraaggestuurde regeling: regeling op basis van
- ○ CO_2-meting
- ○ Vochtigheidssensor
- ○ Aanwezigheidsdetectie

11 Laatste nazicht mechanisch ventilatie systeem

Datum laatste nazicht ☐

12 Staat het ventilatiesysteem 's nachts aan?
- ○ Nee
- ○ Ja, aan een lagere stand
- ○ Ja, zoals tijdens de dag

13 Ramen

☐ Ramen met dubbele beglazing

☐ Ramen met drievoudige beglazing

14 Is er een dampkap boven het fornuis?

○ Nee

○ Ja, met afvoer

○ Ja, met een eigen opvangsysteem (koolstoffilter)

15 Is er luchtkoeling ('airco') aanwezig?

○ Ja

○ Nee

16 Indien ventilatiesysteem C: Zijn de verluchtingsroosters zichtbaar bevuild?

Ventilatiesysteem C = verluchtingsroosters en mechanische afvoer van lucht

○ Ja

○ Neen

17 Indien ventilatiesysteem D: Is de luchttoevoermond zichtbaar bevuild?

Ventilatiesysteem D = mechanische aan- en afvoer van lucht in het klaslokaal

○ Ja

○ Neen

18 Indien ventilatiesysteem D: Specifieer het type filter in het systeem

Filtertype

19 Indien ventilatiesysteem D: Hoe vaak worden de filters vervangen?

○ Nooit (of nog nooit tot op heden)

○ Jaarlijks

○ 2x per jaar

○ Vaker dan 2x per jaar

20 Indien ventilatiesysteem D: Hoe vaak worden de kanalen gereinigd?

○ Nooit (of nog nooit tot op heden)

○ 2-jaarlijks

○ Jaarlijks

○ Vaker dan 1x per jaar

21 Indien ventilatiesysteem D: Is er een zomerbypass aanwezig in

○ Nee / onbekend

○ Ja, gedeeltelijke bypass

○ Ja, volledige bypass mogelijk

22 Welke van onderstaande materialen/producten komen voor in de woonkamer

Type vloerbekleding

○ vloertegels

○ tapijt

○ linoleum

○ andere:

Behandeling muren

○ geschilderd

○ behangpapier

○ vinylbehangpapier

○ andere:

Type plafond

○ welfsels bezet en geverfd

○ gyprocpanelen en geverfd

○ kunststofpanelen

○ houten panelen

○ andere:

Type gordijnen

○ stof (textiel)

○ kunststof (zonneblinden)

○ andere:

Wekelijks gebruikte producten in de woonkamer

○ reinigingsproducten

○ luchtverfrisser (spray, elektrisch, ..)

○ boenwasproducten

○ hobby: lijmen, verven, vernissen

○ andere:

Meubilair

○ vezelplaat

○ massief

○ kunststof

(sommige kunststoffen hebben houtpatroon)

○ andere materialen

23 Vraag een kopie van onderstaande documentatie op

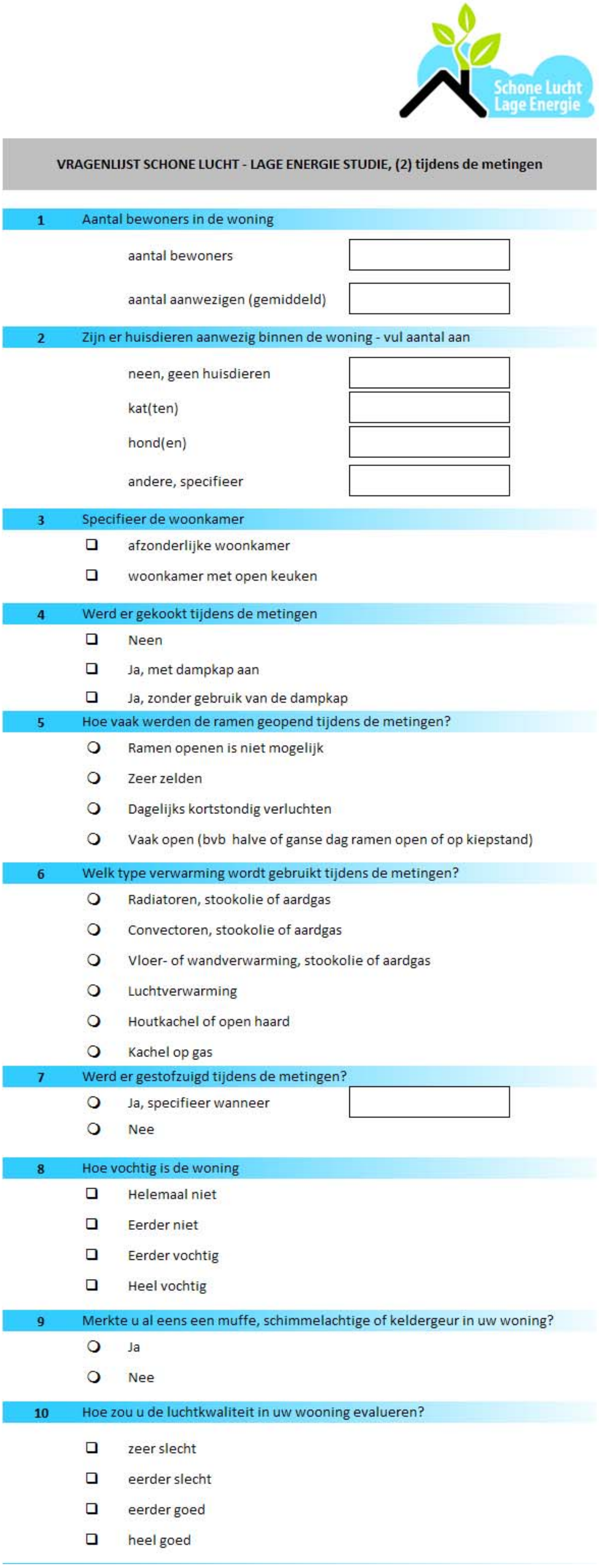
☐ Verslag EPB aangifte

☐ Digitale kopie van EPB bestand (indien mogelijk)

☐ Bij passiefhuis: Passiefhuiscertificaat

☐ Bij passiefhuis: digitala kopie van PHPP-berekening (indien mogelijk)

☐ Inregelrapport ventilatie (indien beschikbaar)



VRAGENLIJST SCHONE LUCHT - LAGE ENERGIE STUDIE, (2) tijdens de metingen

1 Aantal bewoners in de woning

aantal bewoners

aantal aanwezigen (gemiddeld)

2 Zijn er huisdieren aanwezig binnen de woning - vul aantal aan

neen, geen huisdieren

kat(ten)

hond(en)

andere, specifieer

3 Specifieer de woonkamer

☐ afzonderlijke woonkamer

☐ woonkamer met open keuken

4 Werd er gekookt tijdens de metingen

☐ Neen

☐ Ja, met dampkap aan

☐ Ja, zonder gebruik van de dampkap

5 Hoe vaak werden de ramen geopend tijdens de metingen?

○ Ramen openen is niet mogelijk

○ Zeer zelden

○ Dagelijks kortstondig verluchten

○ Vaak open (bvb halve of ganse dag ramen open of op kiepstand)

6 Welk type verwarming wordt gebruikt tijdens de metingen?

○ Radiatoren, stookolie of aardgas

○ Convectoren, stookolie of aardgas

○ Vloer- of wandverwarming, stookolie of aardgas

○ Luchtverwarming

○ Houtkachel of open haard

○ Kachel op gas

7 Werd er gestofzuigd tijdens de metingen?

○ Ja, specifieer wanneer

○ Nee

8 Hoe vochtig is de woning

☐ Helemaal niet

☐ Eerder niet

☐ Eerder vochtig

☐ Heel vochtig

9 Merkte u al eens een muffe, schimmelachtige of keldergeur in uw woning?

○ Ja

○ Nee

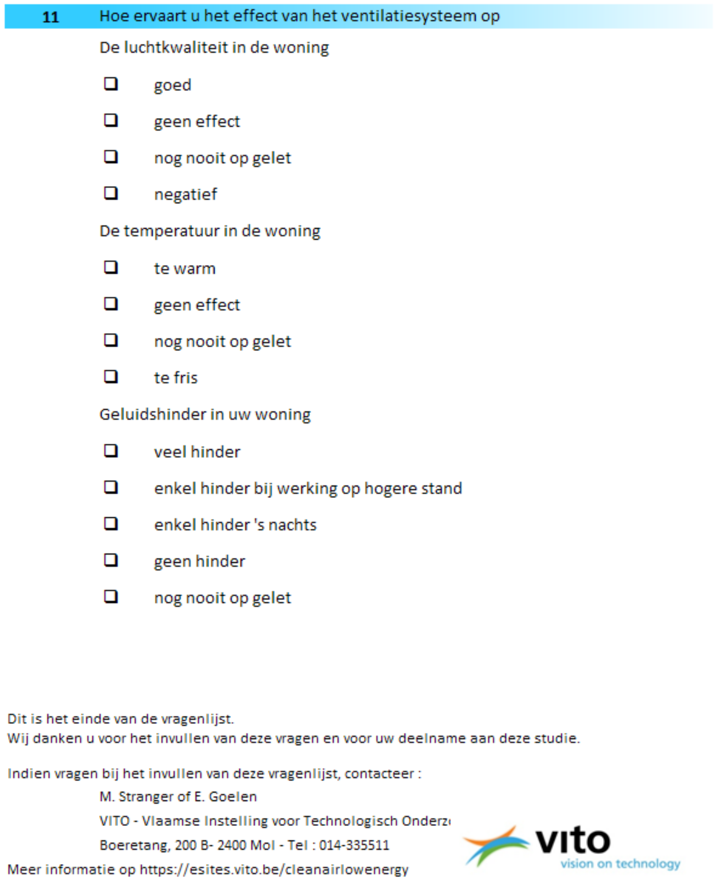
10 Hoe zou u de luchtkwaliteit in uw wooning evalueren?

☐ zeer slecht

☐ eerder slecht

☐ eerder goed

☐ heel goed



11 Hoe ervaart u het effect van het ventilatiesysteem op

De luchtkwaliteit in de woning

- ☐ goed
- ☐ geen effect
- ☐ nog nooit op gelet
- ☐ negatief

De temperatuur in de woning

- ☐ te warm
- ☐ geen effect
- ☐ nog nooit op gelet
- ☐ te fris

Geluidshinder in uw woning

- ☐ veel hinder
- ☐ enkel hinder bij werking op hogere stand
- ☐ enkel hinder 's nachts
- ☐ geen hinder
- ☐ nog nooit op gelet

Dit is het einde van de vragenlijst.
Wij danken u voor het invullen van deze vragen en voor uw deelname aan deze studie.

Indien vragen bij het invullen van deze vragenlijst, contacteer :
M. Stranger of E. Goelen
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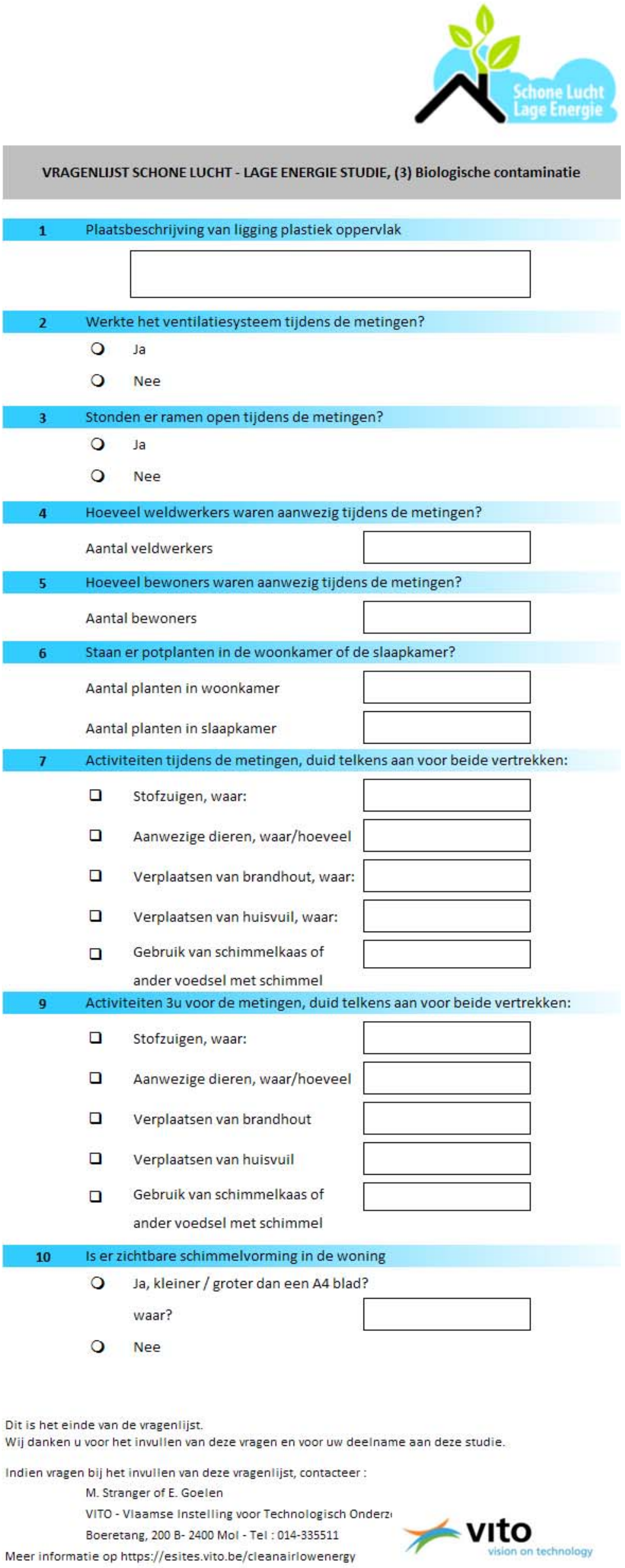
Boeretang, 200 B- 2400 Mol - Tel : 014-335511
Meer informatie op https://esites.vito.be/cleanairlowenergy



VRAGENLIJST SCHONE LUCHT - LAGE ENERGIE STUDIE, (3) Biologische contaminatie

1 Plaatsbeschrijving van ligging plastiek oppervlak

2 Werkte het ventilatiesysteem tijdens de metingen?

○ Ja

○ Nee

3 Stonden er ramen open tijdens de metingen?

○ Ja

○ Nee

4 Hoeveel weldwerkers waren aanwezig tijdens de metingen?

Aantal veldwerkers

5 Hoeveel bewoners waren aanwezig tijdens de metingen?

Aantal bewoners

6 Staan er potplanten in de woonkamer of de slaapkamer?

Aantal planten in woonkamer

Aantal planten in slaapkamer

7 Activiteiten tijdens de metingen, duid telkens aan voor beide vertrekken:

☐ Stofzuigen, waar:

☐ Aanwezige dieren, waar/hoeveel

☐ Verplaatsen van brandhout, waar:

☐ Verplaatsen van huisvuil, waar:

☐ Gebruik van schimmelkaas of ander voedsel met schimmel

9 Activiteiten 3u voor de metingen, duid telkens aan voor beide vertrekken:

☐ Stofzuigen, waar:

☐ Aanwezige dieren, waar/hoeveel

☐ Verplaatsen van brandhout

☐ Verplaatsen van huisvuil

☐ Gebruik van schimmelkaas of ander voedsel met schimmel

10 Is er zichtbare schimmelvorming in de woning

○ Ja, kleiner / groter dan een A4 blad?

waar?

○ Nee

Dit is het einde van de vragenlijst.
Wij danken u voor het invullen van deze vragen en voor uw deelname aan deze studie.

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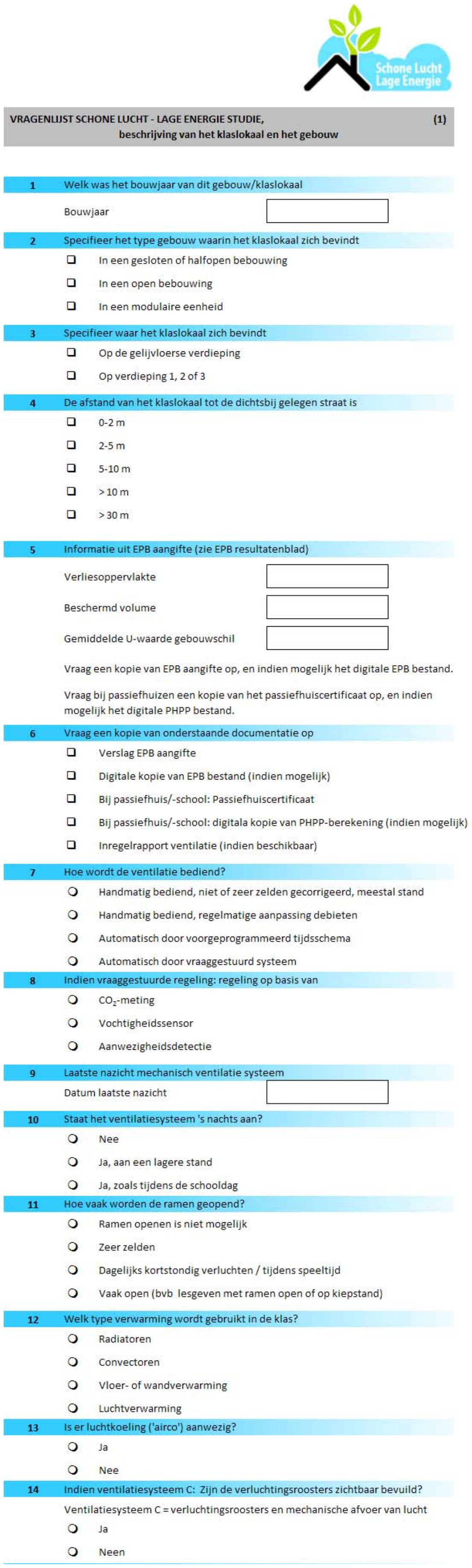


VRAGENLIJST SCHONE LUCHT - LAGE ENERGIE STUDIE, (1)
beschrijving van het klaslokaal en het gebouw

1 Welk was het bouwjaar van dit gebouw/klaslokaal

Bouwjaar

2 Specifieer het type gebouw waarin het klaslokaal zich bevindt

☐ In een gesloten of halfopen bebouwing
☐ In een open bebouwing
☐ In een modulaire eenheid

3 Specifieer waar het klaslokaal zich bevindt

☐ Op de gelijvloerse verdieping
☐ Op verdieping 1, 2 of 3

4 De afstand van het klaslokaal tot de dichtsbij gelegen straat is

☐ 0-2 m
☐ 2-5 m
☐ 5-10 m
☐ > 10 m
☐ > 30 m

5 Informatie uit EPB aangifte (zie EPB resultatenblad)

Verliesoppervlakte
Beschermd volume
Gemiddelde U-waarde gebouwschil

Vraag een kopie van EPB aangifte op, en indien mogelijk het digitale EPB bestand.

Vraag bij passiefhuizen een kopie van het passiefhuiscertificaat op, en indien mogelijk het digitale PHPP bestand.

6 Vraag een kopie van onderstaande documentatie op

☐ Verslag EPB aangifte
☐ Digitale kopie van EPB bestand (indien mogelijk)
☐ Bij passiefhuis/-school: Passiefhuiscertificaat
☐ Bij passiefhuis/-school: digitala kopie van PHPP-berekening (indien mogelijk)
☐ Inregelrapport ventilatie (indien beschikbaar)

7 Hoe wordt de ventilatie bediend?

○ Handmatig bediend, niet of zeer zelden gecorrigeerd, meestal stand
○ Handmatig bediend, regelmatige aanpassing debieten
○ Automatisch door voorgeprogrammeerd tijdsschema
○ Automatisch door vraaggestuurd systeem

8 Indien vraaggestuurde regeling: regeling op basis van

○ CO_2-meting
○ Vochtigheidssensor
○ Aanwezigheidsdetectie

9 Laatste nazicht mechanisch ventilatie systeem

Datum laatste nazicht

10 Staat het ventilatiesysteem 's nachts aan?

○ Nee
○ Ja, aan een lagere stand
○ Ja, zoals tijdens de schooldag

11 Hoe vaak worden de ramen geopend?

○ Ramen openen is niet mogelijk
○ Zeer zelden
○ Dagelijks kortstondig verluchten / tijdens speeltijd
○ Vaak open (bvb lesgeven met ramen open of op kiepstand)

12 Welk type verwarming wordt gebruikt in de klas?

○ Radiatoren
○ Convectoren
○ Vloer- of wandverwarming
○ Luchtverwarming

13 Is er luchtkoeling ('airco') aanwezig?

○ Ja
○ Nee

14 Indien ventilatiesysteem C: Zijn de verluchtingsroosters zichtbaar bevuild?

Ventilatiesysteem C = verluchtingsroosters en mechanische afvoer van lucht

○ Ja
○ Neen

15 Indien ventilatiesysteem D: Is de luchttoevoermond zichtbaar bevuild?

Ventilatiesysteem D = mechanische aan- en afvoer van lucht in het klaslokaal

○ Ja
○ Neen

16 Indien ventilatiesysteem D: Hoe vaak worden de filters vervangen?

○ Nooit (of nog nooit tot op heden)
○ Jaarlijks
○ 2x per jaar
○ Vaker dan 2x per jaar

17 Indien ventilatiesysteem D: Hoe vaak worden de kanalen gereinigd?

○ Nooit (of nog nooit tot op heden)
○ 2-jaarlijks
○ Jaarlijks
○ Vaker dan 1x per jaar

18 Indien ventilatiesysteem D: Is er een zomerbypass aanwezig in

○ Nee / onbekend
○ Ja, gedeeltelijke bypass
○ Ja, volledige bypass mogelijk

19 Welke van onderstaande materialen of producten komen voor in het klaslokaal

Type vloerbekleding
○ vloertegels
○ tapijt
○ linoleum
○ andere:

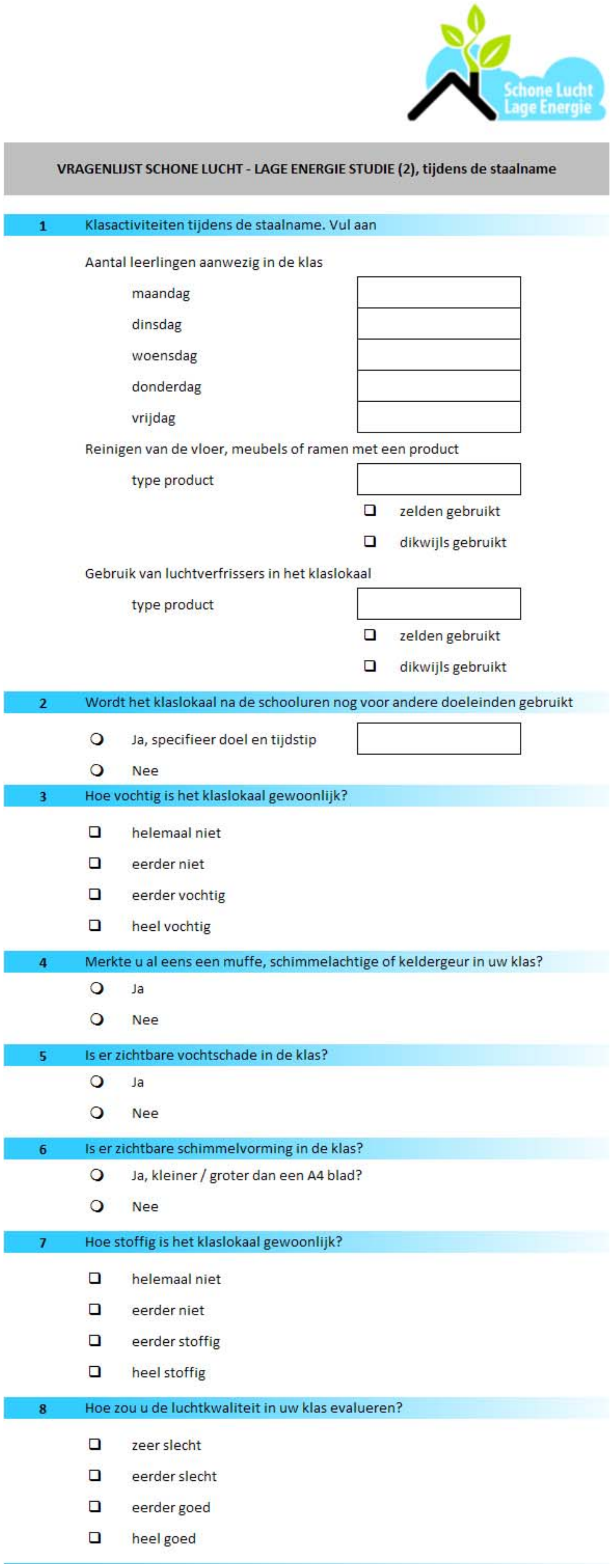
Behandeling muren
○ geschilderd
○ behangpapier
○ vinylbehangpapier
○ andere:

Type plafond
○ welfsels bezet en geverfd
○ gyprocpanelen en geverfd
○ kunststofpanelen
○ houten panelen
○ andere:

Type gordijnen
○ stof (textiel)
○ kunststof (zonneblinden)
○ andere:

Regelmatig gebruikte producten
○ vernis
○ verf
○ kleefmiddelen
○ bordstiften
○ schoolbordkrijt
○ andere:

Meubilair
○ vezelplaat
○ massief
○ kunststof
(sommige kunststoffen hebben houtpatroon)
○ andere materialen



VRAGENLIJST SCHONE LUCHT - LAGE ENERGIE STUDIE (2), tijdens de staalname

1 Klasactiviteiten tijdens de staalname. Vul aan

Aantal leerlingen aanwezig in de klas

maandag ☐
dinsdag ☐
woensdag ☐
donderdag ☐
vrijdag ☐

Reinigen van de vloer, meubels of ramen met een product

type product ☐

☐ zelden gebruikt
☐ dikwijls gebruikt

Gebruik van luchtverfrissers in het klaslokaal

type product ☐

☐ zelden gebruikt
☐ dikwijls gebruikt

2 Wordt het klaslokaal na de schooluren nog voor andere doeleinden gebruikt

○ Ja, specifieer doel en tijdstip ☐
○ Nee

3 Hoe vochtig is het klaslokaal gewoonlijk?

☐ helemaal niet
☐ eerder niet
☐ eerder vochtig
☐ heel vochtig

4 Merkte u al eens een muffe, schimmelachtige of keldergeur in uw klas?

○ Ja
○ Nee

5 Is er zichtbare vochtschade in de klas?

○ Ja
○ Nee

6 Is er zichtbare schimmelvorming in de klas?

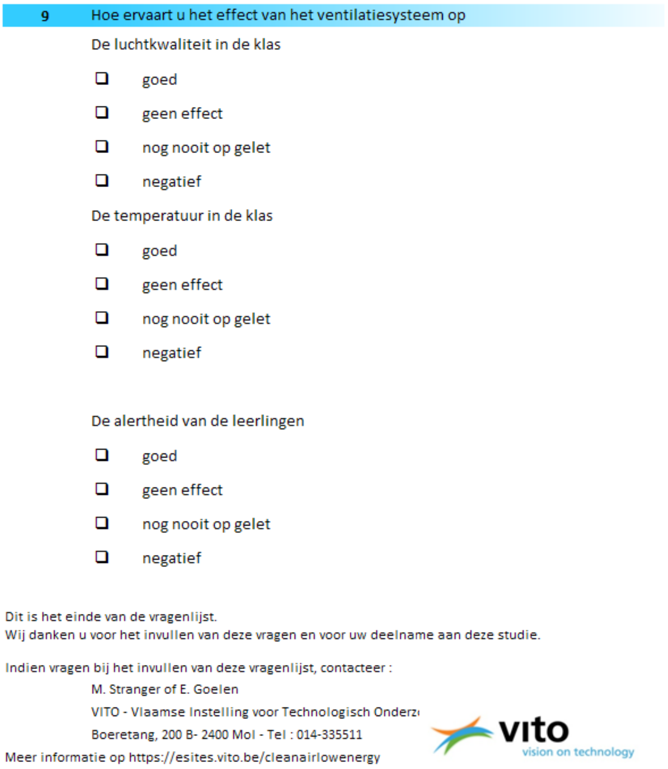
○ Ja, kleiner / groter dan een A4 blad?
○ Nee

7 Hoe stoffig is het klaslokaal gewoonlijk?

☐ helemaal niet
☐ eerder niet
☐ eerder stoffig
☐ heel stoffig

8 Hoe zou u de luchtkwaliteit in uw klas evalueren?

☐ zeer slecht
☐ eerder slecht
☐ eerder goed
☐ heel goed



9 Hoe ervaart u het effect van het ventilatiesysteem op

De luchtkwaliteit in de klas

- ☐ goed
- ☐ geen effect
- ☐ nog nooit op gelet
- ☐ negatief

De temperatuur in de klas

- ☐ goed
- ☐ geen effect
- ☐ nog nooit op gelet
- ☐ negatief

De alertheid van de leerlingen

- ☐ goed
- ☐ geen effect
- ☐ nog nooit op gelet
- ☐ negatief

Dit is het einde van de vragenlijst.
Wij danken u voor het invullen van deze vragen en voor uw deelname aan deze studie.

Indien vragen bij het invullen van deze vragenlijst, contacteer :
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Meer informatie op https://esites.vito.be/cleanairlowenergy

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BELANGRIJK – VRAAG GERICHT AAN DE DIRECTIE

Met het oog op sensibilisering en vergroten van de bekendheid van dit onderzoeksproject, plaatsen wij graag de coördinaten van uw school en foto’s van de meetapparatuur in de deelnemende klassen op onze projectwebsite http://wwwb.vito.be/flies.

Het is belangrijk te weten dat geen enkel bekomen resultaat gekoppeld zal worden aan de namen van deelnemende scholen.

Gelieve uw akkoord hiervoor op deze pagina te bevestigen.

Naam School: ____

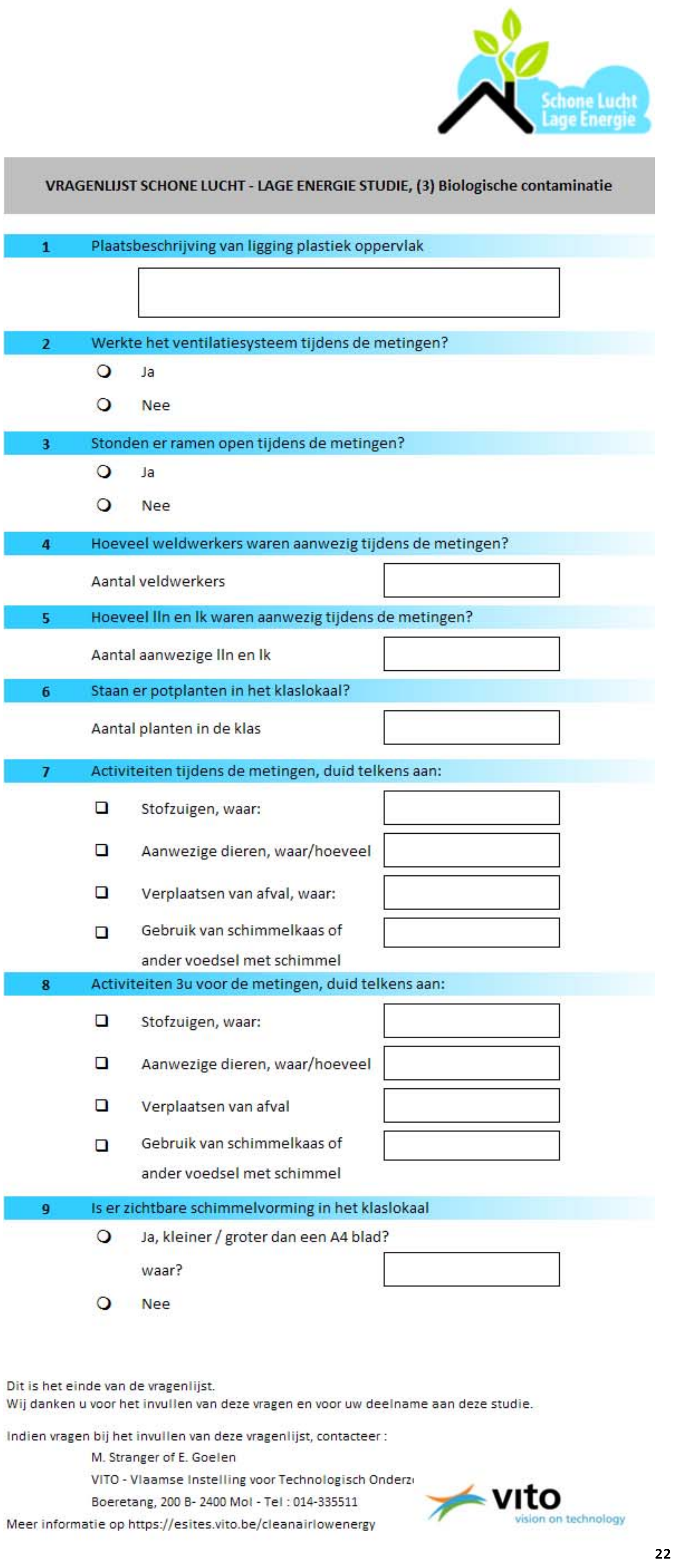
Adres School: ____

____

De directie gaat **akkoord** / **niet akkoord** met de vermelding van naam, adres en foto’s genomen op school en in de klassen op de website http://wwwb.vito.be/flies
(gelieve te schappen wat niet past)

naam + handtekening directie

Datum: ____



Schone Lucht Lage Energie

VRAGENLIJST SCHONE LUCHT - LAGE ENERGIE STUDIE, (3) Biologische contaminatie

1 Plaatsbeschrijving van ligging plastiek oppervlak

2 Werkte het ventilatiesysteem tijdens de metingen?

○ Ja

○ Nee

3 Stonden er ramen open tijdens de metingen?

○ Ja

○ Nee

4 Hoeveel weldwerkers waren aanwezig tijdens de metingen?

Aantal veldwerkers

5 Hoeveel lln en lk waren aanwezig tijdens de metingen?

Aantal aanwezige lln en lk

6 Staan er potplanten in het klaslokaal?

Aantal planten in de klas

7 Activiteiten tijdens de metingen, duid telkens aan:

☐ Stofzuigen, waar:

☐ Aanwezige dieren, waar/hoeveel

☐ Verplaatsen van afval, waar:

☐ Gebruik van schimmelkaas of ander voedsel met schimmel

8 Activiteiten 3u voor de metingen, duid telkens aan:

☐ Stofzuigen, waar:

☐ Aanwezige dieren, waar/hoeveel

☐ Verplaatsen van afval

☐ Gebruik van schimmelkaas of ander voedsel met schimmel

9 Is er zichtbare schimmelvorming in het klaslokaal

○ Ja, kleiner / groter dan een A4 blad?

waar?

○ Nee

Dit is het einde van de vragenlijst.
Wij danken u voor het invullen van deze vragen en voor uw deelname aan deze studie.

Indien vragen bij het invullen van deze vragenlijst, contacteer :
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Boeretang, 200 B- 2400 Mol - Tel : 014-335511
Meer informatie op https://esites.vito.be/cleanairlowenergy

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22

Clean Air, Low Energy

Work Package 2: Fieldwork and measurements

“Exploratory research on the quality of the indoor environment in energy-efficient buildings: the influence of outdoor environment and ventilation”

LNE/OL200900012/10034/M&G

Marianne Stranger[1], Françoise Geyskens[1], Rudi Swinnen[1], Lot Verbeke[1], David Poelmans[1], Francis Boonen[1], Joris Lauwers[1], Stijn Verbeke[2], Eddy Goelen[1],
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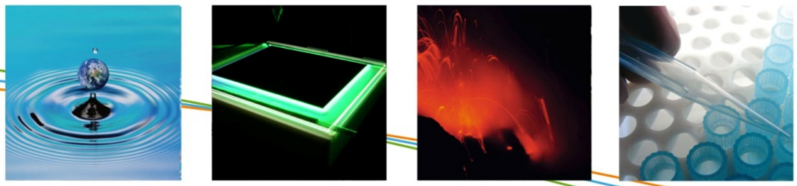
Jelle Laverge, Arnold Janssens,
Architecture and Urban Planning, Ghent University
Debby Wuyts, Bart Ingelaere,
Technological Advice centre Acoustics, WTCB

Study accomplished under the authority of LNE and VEA
2012/MRG/R/363

May 2012



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LIST OF ACRONYMS

ACR	Air Change Rate
AER	Air Exchange Rate
CAV	Constant Air Volume
CO	Carbon monoxide
CO_2	Carbon dioxide
DCV	Demand-Controlled Ventilation
I/O ratio	Indoor/outdoor ratio
IAP	Indoor Air Pollution
IAQ	Indoor Air Quality
MVHR	Mechanical ventilation with Heat Recovery
NO_2	Nitrogen dioxide
n50	Amount of air changes of a building volume in one hour, under a pressure of 50 Pa
O_3	Ozone
PEF	Peak Expiratory Flow
PFT	Perfluor carbon tracer
PMV	Predicted mean vote
PPD	Predicted percentage of dissatisfaction
RH	Relative Humidity
SAV	Seasonally Adapted Ventilation
EEBs	Energy-efficient buildings
SF6	Sulphur hexafluoride
SHS	Sick House Syndrome
SPL	Sound Pressure Level
STI	Speech Transmission Index
Temp	Temperature
TSP	Total Suspended Particles
V50	Leakage flow at 50 Pa, per m2 building envelope
VOC	Volatile organic compounds

CHAPTER 1 INTRODUCTION

In this exploratory study, *Clean Air Low Energy*, the indoor air quality of 51 indoor sites - 25 houses and 26 classrooms - in Flanders is determined. Each indoor environment is characterized chemically, physically and biologically; the energy performance and the building envelope are assessed as well. Mainly in the school monitoring part, the project's name will be translated to *Schone Lucht Lage Energie*.

1.1. STRATEGY

1.1.1. PROJECT WORKPLAN

In a first phase (Work Package 1) a detailed measuring strategy was designed, founded on open literature on (inter)national studies and on reviews concerning cause-consequence-solution research in energy-efficient ventilated buildings. Advantages as well as bottlenecks related to energy-efficient, ventilated buildings are included in this review. The indoor environment, and the influence of the outdoor environment on the indoor air is reviewed as well. Therefore indoor and outdoor chemical, physical and biological parameters are included in the measuring plan.

Based on this review, (1) priority selection criteria for buildings are formulated and distinguished from (2) parameters to be measured on-site or (3) parameters to be included in a building-related questionnaire.

In the second phase (Work Package 2) in total 51 buildings, of which 25 houses and 26 classrooms in Flanders, Belgium are selected. These 51 indoor sites are characterized by combinations of building envelop and ventilation system type, that is representative for the current and future trends in the building patrimony in Flanders. Therefore, passive buildings as well as low-energy buildings (if available zero-energy buildings), and ventilation systems with controlled in-and outlet as well as systems with controlled outlets are included in the study.

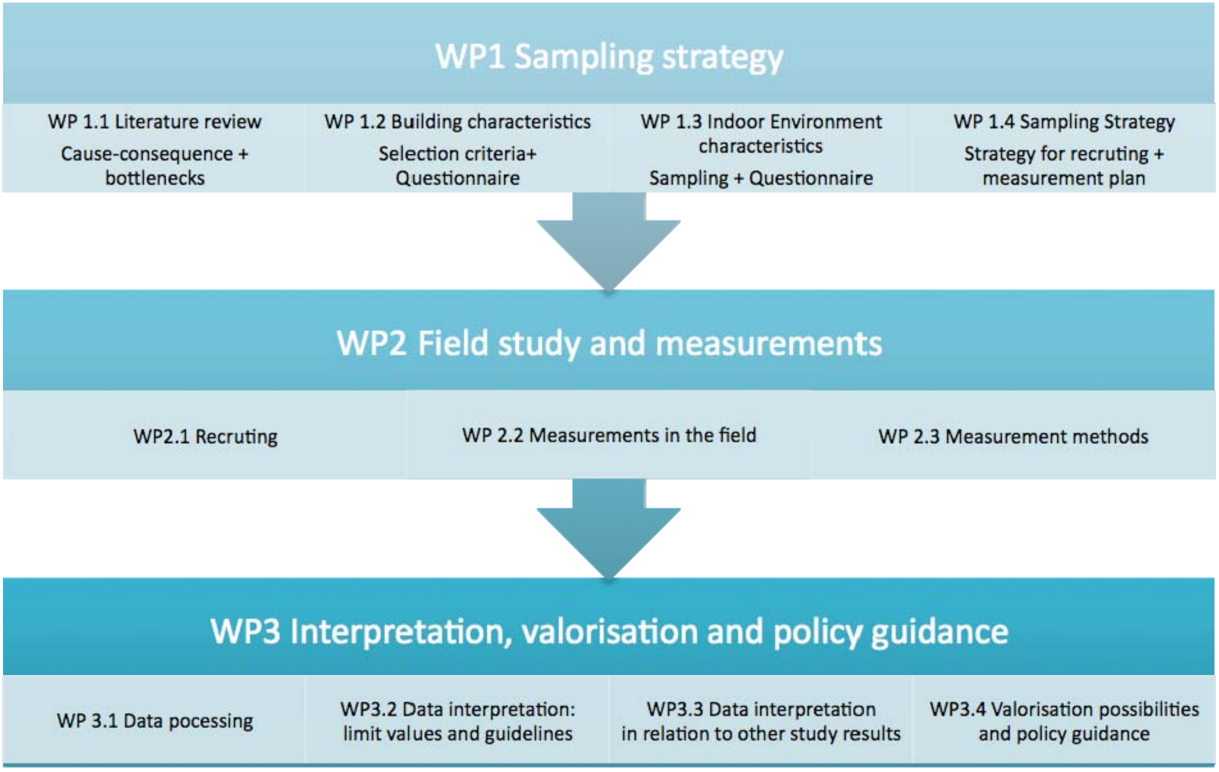
The sampling campaign focussed on the chemical, physical, and biological characterisation of the indoor environment in these energy-efficient buildings. This implies a physico-chemical analysis of the indoor environment as well as the corresponding outdoor air; the quantification of fungi and bacteria indoors and the corresponding outdoor air, the measurements of noise nuisance due to building ventilation (both ventilation system-related and outdoor air-related) and the measurement of the effectiveness of the ventilation system in relation to the theoretical ventilation and air infiltration.

This large dataset will allow an exploratory comparison in the third work package (Work Package 3). In this step the indoor environments of passive, low-energy and traditional houses and schools in Flanders will be evaluated and compared, and different ventilation system types will be contrasted.

The indicative results of this research will lead to the formulation of policy options and guidance for environmental policy and other entities. Needs for further research, and practical guidelines for citizens will also result from this research. For this reason, in the building selection phase significant attention will be put on the possibility to extrapolate the data obtained from this relatively limited set of buildings, to the whole region of Flanders.

A schematic overview of the different work phases in Clean Air, Low Energy is shown in Figure 1.

Figure 1: Clean Air, Low Energy flowchart



1.1.2. MULTIDISCIPLINARY APPROACH

In order to achieve the workplan as presented in section 1.1.1, several scientific disciplines, all related to healthy energy-efficient building, are involved in this study. The various scientific disciplines and the respective research teams involved in *Clean Air, Low Energy* are listed in Table 1.

Table 1: Overview of the different scientific disciplines and responsible institutes

Discipline	Involved team
Chemical and physical contamination of the indoor and outdoor environment	VITO, Unit Environmental Risk and Health, team Air Quality Measurements
Biological contamination of the indoor environment	THL, National Institute for Health and Welfare, Department of Environmental Health, Environmental Microbiology Unit (Finland)
Noise Nuisance due to ventilation - Acoustics	WTCB, Technological Advice centre Acoustics.
Building Ventilation – ventilation systems	University of Ghent, Architecture and Urban Development, Building Physics and Installation techniques
Building insulation – Sustainability of	VITO, Unit Transition Energy and Environment,

buildings

1.2. WP 2 INTERIM REPORT STRUCTURE

This second work package aimed at the application of the detailed measurement strategy in the field, that resulted from the first work package (reported in Chapter 5 in 'WP1 Sampling Strategy').

It includes the assessment of

- physical and chemical parameters in the indoor environment of sustainable and ventilated buildings;
- biological agents (fungi and bacteria) in ventilated sustainable buildings
- the functioning of ventilation systems (ventilation rate, use, efficiency, …)
- the air tightness of buildings
- noise nuisance related to ventilation

These measurements in the field have been preceded by a recruitment phase to select representative houses and schools, and by the formulation of a measurement programme for the measurements on site.

This report on 'WP2 Fieldwork and Measurements' includes a description of the recruitment strategy that was followed, and also reports a brief description of the buildings, selected for fieldwork (CHAPTER 2). All applied measurement methods and techniques, and their application in the field for *Clean Air, Low Energy* are reported in CHAPTER 3. Questionnaires that have been sent to the participating schools and houses, in order to obtain the necessary additional information to allow a correct data interpretation, are described in (CHAPTER 4). The last chapter (CHAPTER 5) then gives a descriptive overview of the outcomes of the sample analysis *Clean Air, Low Energy*. All detailed results are inventoried in Annex 1 of this report.

CHAPTER 2 RECRUITMENT OF A REPRESENTATIVE SET OF BUILDINGS

2.1. TARGET PROFILE OF THE SAMPLE SET

In 'Chapter 3 Building Characteristics; aspects to be studied', reported in the document 'Work Package 1', the target profile of the buildings to be recruited in *Clean Air, Low Energy* was described. Taking into account the different use destinations of houses and school buildings, and their implication on the building construction and the ventilation system, the target profiles of houses and schools were described separately.

Table 2 and Table 3 show the target profiles for residences and schools, and the different features of the ventilation system that have been prioritised to be considered in the recruitment of relevant buildings.

Table 2 Overview of school characterisation

School category	Very airtight	Airtight	Moderately airtight
Selection criterion	$n_{50} \leq 0.6$	$0.6 < n_{50} \leq 2.5$	$n_{50} \geq 2.5$
Expected ventilation system	(D without heat recovery) D with heat recovery	(C) C demand controlled D without heat recovery D with heat recovery	C C demand controlled D without heat recovery
Optional features	Earth-to-air heat exchanger		-

Table 3 Overview of dwelling characterisation

Dwelling category	Very airtight	Airtight	Moderately airtight
Selection criterion	$n_{50} \leq 0.6$	$0.6 < n_{50} \leq 2.5$	$n_{50} \geq 2.5$
Expected ventilation system	D with heat recovery	(C) C demand controlled D with heat recovery	C C demand controlled (D with heat recovery)
Optional features	Earth-to-air heat exchanger Ground coupled heat exchanger with a heat transfer fluid Thermal recovery wheel Integrated heating Small plastic ducts		-

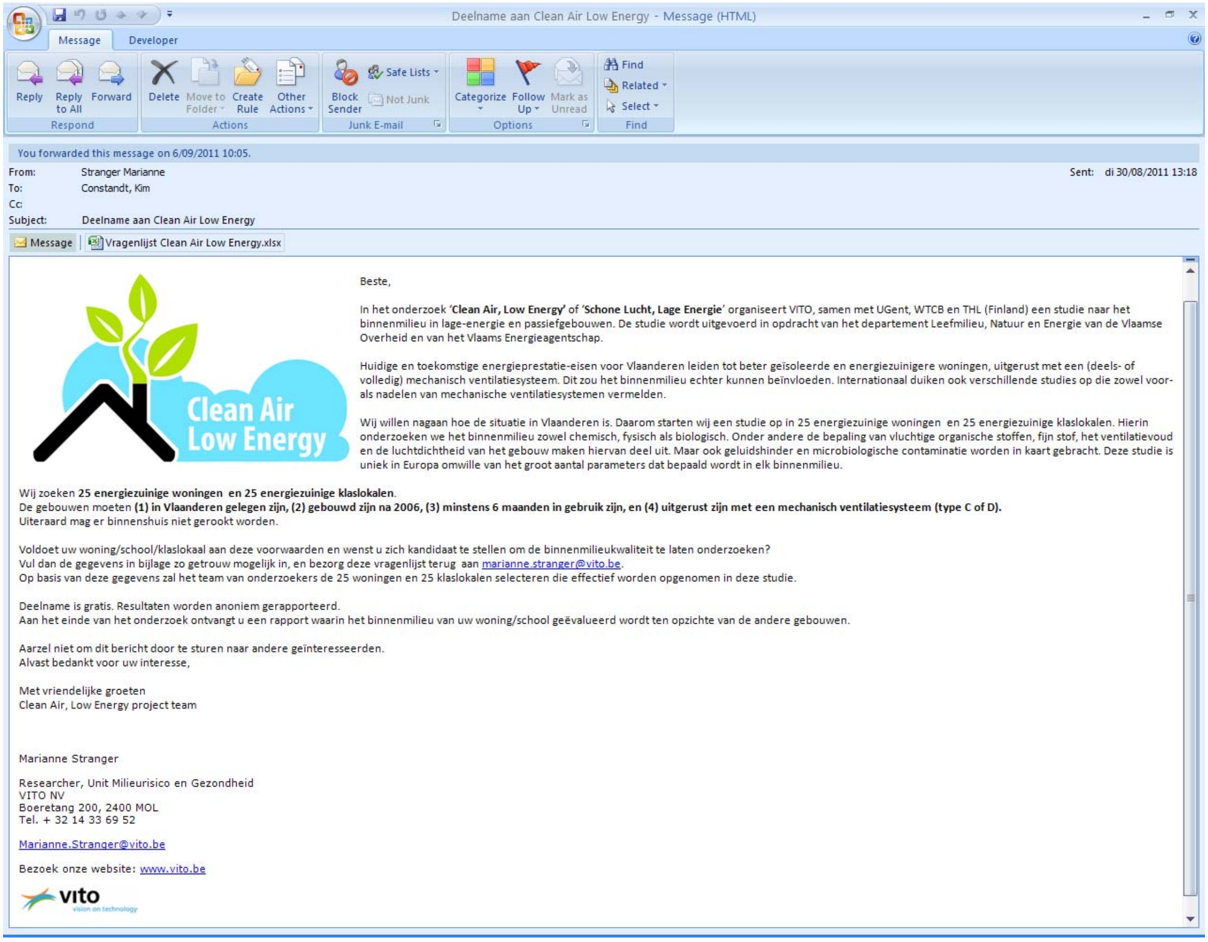
2.2. RECRUITING POTENTIALLY RELEVANT BUILDINGS

The strategy to obtain a set of potentially representative residences and school buildings for *Clean Air, Low Energy* consisted of two phases.

The first phase (1) was initiated in August 2011 by formulating a recruitment message, shown in Figure 2. Attached to the message, a brief questionnaire on building characteristics was sent (see

Annex A). Candidates could express their interest in participating in the field study, by sending the completed questionnaire to VITO. The recruitment message has been sent to the steering committee of *Clean Air Low Energy* (members were invited to forward the message to their relevant contacts) and to contacts from VITO. Furthermore it has been uploaded on the website www.ecobouwers.be which is typically visited by professionals as well as private persons, interested in sustainable building.

Figure 2 Recruitment message, distributed to obtain a set of potentially representative residences and schools for Clean Air Low Energy



You forwarded this message on 6/09/2011 10:05.

From: Stranger Marianne
To: Constandt, Kim
Cc:
Subject: Deelname aan Clean Air Low Energy
Sent: di 30/08/2011 13:18

Message | Vragenlijst Clean Air Low Energy.xlsx

Beste,

In het onderzoek '**Clean Air, Low Energy**' of '**Schone Lucht, Lage Energie**' organiseert VITO, samen met UGent, WTCB en THL (Finland) een studie naar het binnenmilieu in lage-energie en passiefgebouwen. De studie wordt uitgevoerd in opdracht van het departement Leefmilieu, Natuur en Energie van de Vlaamse Overheid en van het Vlaams Energieagentschap.

Huidige en toekomstige energieprestatie-eisen voor Vlaanderen leiden tot beter geïsoleerde en energiezuinigere woningen, uitgerust met een (deels- of volledig) mechanisch ventilatiesysteem. Dit zou het binnenmilieu echter kunnen beïnvloeden. Internationaal duiken ook verschillende studies op die zowel voor- als nadelen van mechanische ventilatiesystemen vermelden.

Wij willen nagaan hoe de situatie in Vlaanderen is. Daarom starten wij een studie op in 25 energiezuinige woningen en 25 energiezuinige klaslokalen. Hierin onderzoeken we het binnenmilieu zowel chemisch, fysisch als biologisch. Onder andere de bepaling van vluchtige organische stoffen, fijn stof, het ventilatievoud en de luchtdichtheid van het gebouw maken hiervan deel uit. Maar ook geluidshinder en microbiologische contaminatie worden in kaart gebracht. Deze studie is uniek in Europa omwille van het groot aantal parameters dat bepaald wordt in elk binnenmilieu.

Wij zoeken **25 energiezuinige woningen en 25 energiezuinige klaslokalen**.
De gebouwen moeten **(1) in Vlaanderen gelegen zijn, (2) gebouwd zijn na 2006, (3) minstens 6 maanden in gebruik zijn, en (4) uitgerust zijn met een mechanisch ventilatiesysteem (type C of D).**
Uiteraard mag er binnenshuis niet gerookt worden.

Voldoet uw woning/school/klaslokaal aan deze voorwaarden en wenst u zich kandidaat te stellen om de binnenmilieukwaliteit te laten onderzoeken?
Vul dan de gegevens in bijlage zo getrouw mogelijk in, en bezorg deze vragenlijst terug aan marianne.stranger@vito.be.
Op basis van deze gegevens zal het team van onderzoekers de 25 woningen en 25 klaslokalen selecteren die effectief worden opgenomen in deze studie.

Deelname is gratis. Resultaten worden anoniem gerapporteerd.
Aan het einde van het onderzoek ontvangt u een rapport waarin het binnenmilieu van uw woning/school geëvalueerd wordt ten opzichte van de andere gebouwen.

Aarzel niet om dit bericht door te sturen naar andere geïnteresseerden.
Alvast bedankt voor uw interesse,

Met vriendelijke groeten
Clean Air, Low Energy project team

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In total 50 potentially relevant residence owners volunteered to participate in the field campaign of *Clean Air Low Energy*. The building characteristics of their houses were inventoried.

Although this recruitment message was addressed to schools as well, no school volunteered using the above described communication way. A list of approximately 90 potentially relevant schools (including kindergartens, primary schools, high schools, university colleges, closed rehabilitation institutions, and gymnasiums), supplemented with information on the school building and the ventilation system, was supplied by Agion and GO!. For the majority of the buildings, including all except one passive school building, the construction activities were still on-going, delayed or finished less than 6 months before scheduling the fieldwork, which made these schools unsuitable for Clean Air Low Energy.

2.3. SELECTING RELEVANT BUILDINGS FOR CLEAN AIR, LOW ENERGY

The second phase (2) of the recruitment was initiated by inventorying building characteristics from the houses that volunteered by completing the first questionnaire. These characteristics included details on the ventilation system, the insulation level, the air tightness (if available), the heat transfer system (if applicable) of the building. 25 residences were then selected from the 50 volunteers, aiming at a representative set of buildings, that reflects the current and future stock of sustainable buildings in Flanders. The residence owners of the selected houses were informed on their acceptance by e-mail. They received more details on the field work and their involvement/participation in this work and were asked to confirm their participation once more.

Addresses were exchanged with all involved project partners and each party contacted the respective houses and schools individually to make appointments for fieldwork activities.

Schools potentially representative for Clean Air Low Energy were contacted by phone. If needed school characteristics were verified or extended. Based on this information the school was either accepted or rejected from the relevant school list. The different steps of the study were explained to the school principal and during this first contact the appointment for the first school visit was made.

2.4. DESCRIPTION OF THE BUILDINGS SELECTED IN CLEAN AIR LOW ENERGY

The overview of the selected school buildings is shown in Table 4. During the recruitment of the schools it became clear that the V50/K-level/E-level value was not easily accessible. As a result it could not be used as a selection criterion. Therefore, the selection of the school buildings was made based on the installed ventilation system and its features (heat recovery, demand controlled, …), and the construction year of the building. Building typology was also taken into account, with the aim of creating a realistic reflection of current and future school buildings in Flanders, and thus including new buildings as well as modular units. School type, municipality, province, environment or educational network were not considered as selection criteria.

In Table 4 it can be noticed that the most common occurring heat recovery system in this selection of schools is the thermal recovery wheel. Schools with other heat recovery systems, such as earth-to-heat exchanger or ground coupled heat exchanger with a heat transfer fluid, have not been found in the set of schools that has been contacted (±40). V50 values of schools have not been obtained at this stage.

The Clean Air, Low Energy selection of schools contains one kindergarten and one closed rehabilitation institute, the other schools are primary schools. In three schools sampling was done in modular units; the other schools had newly constructed classrooms. Five schools were situated in urban area, the other 4 schools were localized in rural environment. In every Flemish province, at least one school was selected.

Table 5 shows an overview of the selected residences for Clean Air Low Energy, some of their building characteristics and their locations. As detailed in section 2.1, V50 and ventilation system details (more specifically the optional features of the system) have been taken into account in the selection of the 25 residences; other information added to the table such as K-level, E-level, municipality, province and environment were not used as a selection criteria. Note that in section 2.1, n50 was proposed as a measure; the conversion of V50 to n50 will be added in report WP3.

Based on this selection of residences, 6 of the 25 houses were passive buildings, the other houses were low energy buildings, equipped with a ventilation system type C or D, each with relevant system features. The sample set includes one flat, of which 3 apartments. This selection of indoor sites, led to 15 residences in rural area, and 12 in urban environment.

Table 4 Overview of the school building characteristics

NR	School type	V50 (m^3/h)	Ventilation system	Vent. feature	System	Typology	Province	Environment
S1	primary school		D	thermal wheel	recovery	modular units	Antwerpen	urban
S2	primary school		C			new building	Limburg	rural
S3	primary school		C			new building	Limburg	rural
S4	kindergarten		D demand controlled	thermal wheel	recovery	modular units	Antwerpen	urban
S5	primary school		D	thermal wheel	recovery	modular units	Antwerpen	urban
S6	primary school		D demand controlled	thermal wheel	recovery	new building	Oost Vlaanderen	urban
S7	closed rehabilitation institute		D demand controlled			new building	West-Vlaanderen	rural
S8	primary school		D			new building	Antwerpen	urban
S9	primary school		C			new building	Vlaams Brabant	rural

Table 5 Overview of residence characteristics

Code	Year construction	V50 (m^3/h)	Ventilation system	Typology	K-level	E-level	Municipality	Province	Environment
R1	2008	1994	D	detached	39	70	Rijkevorsel	Antwerp	rural
R2	2009	2075	C	detached	35	60	Wortel	Antwerp	rural
R3	2009	-	D	detached	25	20	Retie	Antwerp	rural
R4	2010	1592	D	semi-detached	25	37	Arendonk	Antwerp	rural
R5	2010	280	D + aww	detached	15	33	Mol	Antwerp	rural
R6	2011	573	D	detached	30	46	Geel	Antwerp	urban
R7	2009	118	D + aww	detached	13	16	Balen	Antwerp	rural
R8	2007	5238	D	detached	36	83	Mol	Antwerp	rural
R9	2009	-	D	detached	26	26	Beverlo	Limburg	rural
R10	2010	1422	D	detached	32	52	Kaggevinne	Vlaams-Brabant	rural
R11-1	2009	687	D	flat	45	76	Gent	Oost-Vlaanderen	urban
R11-2	2009	687	D	flat	45	76	Gent	Oost-Vlaanderen	urban
R11-3	2009	687	D	flat	45	76	Gent	Oost-Vlaanderen	urban
R12	2008	2479	D + bww	detached	24	46	Kessel	Antwerp	urban
R13	2006	874	D + aww	detached	25	39	Duffel	Antwerp	rural
R14	2007	386	D	detached	20	45	Merelbeke	Oost-Vlaanderen	urban
R15	2009	192	D + aww	semi-detached	14	25	St.Amandsberg	Oost-Vlaanderen	urban
R16	2007	1383	D	detached	34	51	Heverlee	Vlaams-Brabant	rural
R17	2009	-	D	semi-detached	36	74	Kessel-Lo	Vlaams-Brabant	rural
R18	2008	1933	C	semi-detached	37	69	Holsbeek	Vlaams-Brabant	rural
R19	2009	101	D+aww	terraced	14	27	Deurne	Antwerpen	urban
R20	2010	298	D + bww	detached	14	40	St.Pauwels	Oost-Vlaanderen	rural
R21	2008	-	C	semi-detached	36	83	Zwijndrecht	Antwerpen	urban
R22	2010	129	D	terraced	18	27	Mortsel	Antwerpen	urban
R23	2010	559	D + aww	detached	30	40	Rotselaar	Vlaams-Brabant	rural

K-level = measure for thermo insulation, the lower the value, the more insulated
aww= earth-to-heat exchanger
bww = ground coupled heat exchanger with a heat transfer fluid
V50: measure for air tightness of the residence, the higher the more cracks and chinks
Residence code in bold: residence is passive house

CHAPTER 3 MEASUREMENT METHODS, APPLIED IN THE FIELD

3.1. INTRODUCTION

In order to collect the data as scheduled in the detailed sampling strategy (see Interim Report WP1), four different teams contacted the house owners and school principles, to organise their fieldwork activities. Each team scheduled their own appointments. The timing of the fieldwork activities from the different teams is shown in Table 6.

Table 6 Time span and timing of the fieldwork activities from the different involved teams

	Timing
IAQ assessment	September 2011 – April 2012
Ventilation assessment	*To be completed*
Acoustics	March 2012 -April 2012
Biological assessment	December 2011 – February 2012

Indoor air quality and the building ventilation were studied in all selected residences and schools. Acoustics as well as biological assessments however, were organized in a subset of the 25 residences and the 26 classrooms: the indoor acoustics were evaluated in 8 residences and 3 schools, whilst the biological study was performed in 15 residences and 5 schools. Table 7 and Table 8 give an overview of the locations that have been selected for the assessment of the different parameters in the residences and schools. The selections of the subsets of schools and houses were made taking into account the different ventilation systems and their features, in relation to the potential influence on acoustic comfort and biological parameters respectively.

Table 7 Overview of the different parameters determined in the Clean Air Low Energy schools

	Amount of indoor sampling sites	IAQ assessment	Ventilation assessment	Acoustics	Biological assessment
S1	2	X	X*		
S2	3	X	X*		X
S3	3	X	X*		X
S4	3	X	X*		X
S5	3	X	X*	X	X
S6	3	X	X*		
S7	3	X	X*	X	X
S8	3	X	X*		
S9	3	X	X*	X	
Total	26				

* Not finalized yet

Table 8 Overview of the different parameters determined in the Clean Air Low Energy residences

	Amount of indoor sampling sites	IAQ assessment	ventilation assessment	Acoustics	Biological assessment
R1	1	X	X	X	X
R2	1	X	X	X	X
R3	1	X	X		X
R4	1	X	X		X
R5	1	X	X		
R6	1	X	X		
R7	1	X	X		
R8	1	X	X		X
R9	1	X	X		
R10	1	X	X		
R11-1/2/3	3	X	X		
R12	1	X	X		
R13	1	X	X		
R14	1	X	X		X
R15	1	X	X		X
R16	1	X	X	X	X
R17	1	X	X		X
R18	1	X	X		X
R19	1	X	X	X	X
R20	1	X	X		X
R21	1	X	X	X	X
R22	1	X	X	X	X
R23	1	X	X	X	X
Total:	25				

3.2. MEASUREMENT METHODS IN THE FIELD

3.2.1. METHODS TO ASSESS CHEMICAL PARAMETERS STUDIED IN CLEAN AIR LOW ENERGY

Table 9 gives an overview of the methods, applied in the field in order to determine the scheduled chemical parameters on the houses and the schools.

Table 9 overview of the applied methods to assess chemical parameters in houses and schools

Compound	Measurement technique	Sampling time	Sampling site
TVOC	Radiello passive sampler	Houses: 7 days Schools: 5 days	Houses: living room Schools: classroom Parallel outdoor
VOC (MTBE, benzene, trichloroethene, toluene, tetrachloroethene, ethylbenzene, m-+p-xylene, styrene, o-xylene, 1,2,4-trimethylbenzene, 1,4-dichlorobenzene, hexane, heptane, cyclohexane, n-butylacetate, α-pinene, 3-carene, d-limonene, and TVOC)	Radiello passive sampler	Houses: 7 days Schools: 5 days	Houses: living room Schools: classroom Parallel outdoor
Aldehydes (total aldehydes, formaldehyde and acetaldehyde)	Umex passive sampler	Houses: 7 days Schools: 5 days	Houses: living room Schools: classroom Parallel outdoor
$PM_{2.5}$ (mass concentration)	MS&T Harvard type impactor	Houses: 7 days– 24h Schools: 5 days – teaching hours	Houses: living room Schools: classroom Parallel outdoor
PMx (time evolution)	Grimm optical PM monitoring	Houses: 7 days Schools: 5 days	
CO_2	Catec Klimabox (schools and living rooms) + CO_2meter K33-ELG (bedrooms)	Houses: 7 days Schools: 5 days	Houses: living room + bedroom(s) Schools: classroom

Examples of installations in the field are shown in Figure 3. For each location, indoor and outdoor samples have been collected simultaneously. In residences, indoor air was sampled in the living room; at school, indoor air was monitored in 3 classrooms per school. The settings of the mechanical ventilation system were kept under normal operating conditions during the measurements. Passive samplers were attached to a stand, that contains a small ventilator. This small ventilator provided the minimal air movement, necessary for indoor passive sampling. In outdoor air, the sampling equipment is placed in an open metal shelter (see Figure 3), in order to protect it from rain and to install it in a child-proof way. In agreement with the detailed sampling strategy established in WP1, fieldwork at school was performed during 5 days; fieldwork in houses during 7 days. Table 10 gives a description of the school building and the sampling sites at school.

The following paragraphs describe in detail how the sampling and sample analysis were performed for each measured compound.

→ Volatile Organic Compounds

Volatile organic compounds have been sampled using radiello passive samplers (Radiello Code 130). The samplers have been exposed respectively during 7 and 5 days, in residences and schools, both in indoor and outdoor air (based on WP1, chapter 5 ‘Detailed sampling strategy) . After exposure, the passive samplers were chemically desorbed using carbon disulfide (CS_2). An internal standard (2-fluorotoluene) is added to the extract. Subsequent analysis of the extract is performed by GC-MS.

In order to allow the set of collected VOCs be comparable to existing datasets in the Surveillance of the health situation in Flemish residences (2007-2008-2009-2010-2011 Flemish Agency for Care and Health/Vito; 2011), the identified and quantified set of VOCs has been extended to the following compounds: MTBE, benzene, trichloroethene, toluene, tetrachloroethene, ethylbenzene, m-+p-xylene, styrene, o-xylene, 1,2,4-trimethylbenzene, 1,4-dichlorobenzene, hexane, heptane, cyclohexane, n-butylacetate, α-pinene, 3-carene, d-limonene, and TVOC.

TVOC are measured in full-scan mode, its quantified compounds are measured in selected ion monitoring (SIM) modus. External standards are used for calibration; air concentrations are calculated taking into account the exposure time of the passive sampler and average temperature during exposure.

At school, one passive sampler is exposed in each classroom and on the playground, both during 5 schooldays. In the residences, passive samplers were exposed during 7 days in the living room and on the backyard of the house. In one school duplicate samples are collected on every sampling site.

Table 10 Description of the sampling sites in classrooms

Classroom code	**Description of the sampling site**
S1-C1	Modular unit, kindergarten, installation in the sitting area, wall below inlet and outlet ventilation system
S1-C2	Modular unit, kindergarten, installation in the creative area, wall of entrance door
S2-C1	New building, primary school, installation in the sitting area, corner, ground floor
S2-C2	New building, primary school, installation in the back of the classroom, corner, ground floor
S2-C3	New building, primary school, installation in the back of the classroom, first floor,
S3-C1	New building, primary school, installation in the front of the room, first floor
S3-C2	New building, primary school, installation in the front of the room, ground floor
S3-C3	New building, primary school, installation in the front of the room, ground floor
S4-C1	Modular unit, primary school, installation in the back of the room, first floor
S4-C2	Modular unit, kindergarten, installation in the back of the room, ground floor, facing the street side
S4-C3	Modular unit, kindergarten, installation in the back of the room ,ground floor
S5-C1	Modular unit, kindergarten, installation in the back of the room, ground floor
S5-C2	Modular unit, kindergarten, installation in the back of the room ,ground floor
S5-C3	Modular unit, kindergarten, installation in the back of the room, ground floor
S6-C1	New building, primary school, installation in the front of the room, first floor
S6-C2	New building, primary school, installation in the front of the room, first floor
S6-C3	New building, primary school, installation in the back of the room, ground floor
S7-C1	Passive building, closed rehabilitation institute, kitchen
S7-C2	Passive building, closed rehabilitation institute, shop
S7-C3	Passive building, closed rehabilitation institute
S8-C1	New building, primary school; installation in the front of the room.
S8-C2	New building, primary school, installation next to side window.
S8-C3	New building, primary school, installation in the front of the room.
S9-C1	New building, primary school, installation next to side wall
S9-C2	New building, primary school, installation next to side wall with couch
S9-C3	New building, primary school, installation next to side wall

Figure 3 Examples from installations in the field (schools and residences)

Indoor installations:

In a classroom

In a residence

Outdoor installations:

On a playground

In a residential urban backyard

→ Adehydes

Aldehydes have been monitored using SKC diffusive samplers (UMEx100). The operational principle of these passive samplers is based on chemisorption, in which aldehydes react with dinitrophenylhydrazine (DNPH).

After exposure the aldehydes were extracted using acetonitrile; they were analysed using LC-UV. The air concentrations were calculated taking into account the exposure time and the average temperature during exposure.

The identified and quantified aldehydes are formaldehyde, acetaldehyde, total aldehydes and total other aldehydes (other than formaldehyde and acetaldehyde).

At school, one passive sampler is exposed in each classroom and on the playground, during 5 schooldays. In the residences, passive samplers were exposed during 7 days in the living room and on the backyard of the house. In one school duplicate samples are collected on every site.

→ Particulate matter ($PM_{2.5}$ gravimetrical)

$PM_{2.5}$ was monitored using the MS&T Area Sampler. These samplers consist of a Harvard-type impactor (MS&T Area Samplers, Air Diagnostics and Engineering, Inc., Harisson, ME, USA) and a quasi-noiseless pump (Air Diagnostics and Engineering, Inc., air sampling pump, model SP-280E) that operates at 10 LPM. $PM_{2.5}$ is collected on Teflon membrane filters (37 mm with supporting ring, 2 µm pore size, Pall Corporation, USA), supported by a drain disk.

The Harvard-type impactors allow the assessment of the mass concentration of $PM_{2.5}$ during a continuous measuring period or in selected time intervals. In order to avoid overloading of the filter medium, $PM_{2.5}$ collection in residences (as well as the simultaneous outdoor sampling), was performed during 3 successive days of 24h. This determined mass concentration can then be compared and evaluated to existing (e.g. Flemish) guidelines and limit values. In the selected indoor sites at school (and the respective outdoor sites) on the other hand, $PM_{2.5}$ has been collected discontinuous, during teaching hours (i.e. 08:00 a.m. to 16:00 p.m.), in 5 successive school days (from Monday until Friday). The mass of each filter has been determined after 48h conditioning in a temperature and relative humidity controlled room (50±5% RH and 20±1°C), before and after sampling. The mass concentration was calculated taking into account the sampling time.

→ Particulate matter (time evolution)

Using a Grimm 1.108 Dust Monitor Monitor, PM_1/$PM_{2.5}$/PM_{10} fractions have been monitored simultaneously in indoor and outdoor air. The equipment operates at a flow rate of 1.2 LPM, and optically detects particles with a diameter in the range of 0.3 to 20 µm. The equipment reports the particles in different classes, depending on their sizes. Using this output, the different fractions of fine dust (PM_1, $PM_{2.5}$, PM_{10}) are calculated. The output of this measurement also allows to study the different PM fractions over time in each house and school. Because these output data are based on optical measurements, the output data of Grimm 1.108 cannot be compared with the results of gravimetrical filter analysis as absolute values.

The Grimm 1.108 stores the collected data in a time resolution of 15 minutes. For Clean Air Low Energy the optical monitoring pf PM was performed during 5 successive school days at school and during 7 successive days in residences.

→ **Carbon dioxide**

The CO_2 levels in Clean Air, Low Energy were monitored as a measure of room ventilation. Therefore, the CaTeC Climabox3 has operated indoors and outdoors at every sampling location. Indoor sampling in residences was performed in the living room; indoor sampling at school was performed in every participating classroom. The Climabox3 was adapted to monitor CO_2 in the range of 0-10.000 ppm.

Prior to the installation in the field the monitor was programmed to register CO_2 at a time resolution of 1 minute.

3.2.2. PHYSICAL PARAMETERS STUDIED IN CLEAN AIR LOW ENERGY

Table 11 gives an overview of the methods, applied in the field in order to assess the scheduled physical parameters on the houses and the schools.

Table 11 overview of the applied methods to assess physical parameters in houses and schools

Compound	Measurement technique	Sampling time	Sampling site
Temperature	Catec Klimabox	Houses: 7 days Schools: 5 days	Houses: living room Schools: classroom Parallel outdoor
Relative humidity	Catec Klimabox	Houses: 7 days Schools: 5 days	Houses: living room Schools: classroom Parallel outdoor
Draught	e.g. OMNIPORT 20	Houses: 1h Schools: 1h	Houses: living room Schools: classroom
Noise nuisance due to ventilation system	Measurement installation noise, reverberation time and background noise levels Measurement of installation noise for different ventilation positions (normal rate, rate '2', and maximal rate), measurement of outdoor noise for rooms with natural air supply	Rooms with natural air supply: 1 hour (sampling time per measurement = min. 30s, max. 15') Rooms with mechanical air supply : 30 minutes (sampling time per measurement = min. 30 s)	Houses (8): living room, bedroom Schools (7): classrooms
Ventilation rate	Flowbox measurements	- (instantaneous measurement)	Houses: all vents Schools: all vents
Air leakage (air tightness)	Pressurization tests	- (instantaneous measurement, total time +- 1h)	Houses: front door (intervention in rest of dwelling) Schools: classroom door

→ Temperature and relative humidity

Temperature and relative humidity are monitored (simultaneously with CO_2) using the CaTeC Climabox3, in a time resolution of one minute.

→ Draught – air speed

Indoor air speed is monitored as a measure for draught, using the Omniport 20 anemometer (E+E Electronik, Engerwitzdorf, Germany). In every classroom and living room the air speed is registered during the installation of the sampling equipment. The average value of a 2 minute measurement was reported. It should be mentioned that the outcome of this measurement is indicative for the situation during the installation of the equipment and did not take into account different settings of the mechanical ventilation system.

→ Noise nuisance due to the ventilation system

The following reference standards are used for acoustic measurements, calculations and evaluations:

NBN EN ISO 140-5:1998 Geluidsleer - Meting van geluidwering in gebouwen en bouwdelen - Deel 5: Veldmeting van luchtgeluidwering van geveldelen en gevels (ISO 140-5:1998)

NBN EN ISO/TR 140-13:1997 Geluidleer – Meting van geluidwering in gebouwen en gebouwdelen – Deel 13: Richtlijnen

NBN EN 12354-3:2000 Geluidsleer - Schatting van de geluidgedraging van gebouwen uit de bouwdeelgedraging – Deel 3 : Luchtgeluidwering tegen buitenlawaai

NBN EN ISO 3382:2000 Geluidsleer - Meten van nagalmtijd van zalen met verwijzing naar andere geluidsparameters (ISO 3382:1997)

NBN EN ISO 10 052:2005 Geluidwering – Praktijkmetingen van lucht- en contactgeluidisolatie en van installatiegeluid – Globale methode (EN ISO 10 052:2004)

NBN S 01-400-1:2008 Akoestische criteria voor woongebouwen

prNBN S 01-400-2:2012 Akoestische criteria voor schoolgebouwen

In order to evaluate the noise nuisance due to the ventilation system in residences and schools, acoustical measurements have been carried out in typically “noise sensitive” rooms such as bedrooms, living rooms and classrooms. Basically two different measurement strategies have been adopted, depending on the type of ventilation system.

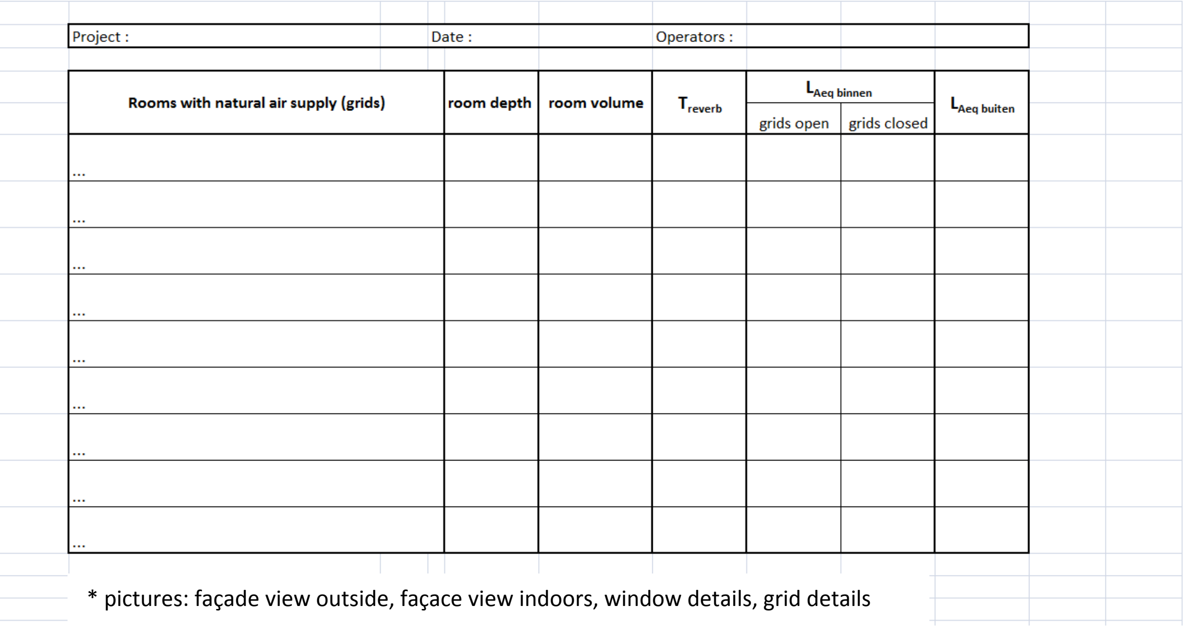
(1) Test sites with ventilation system C

For school and houses with natural air supply (system C), trickle ventilator are present in the façade panes of the examined classrooms, living rooms and bedrooms. These devices represent acoustical flaws in the building envelope, enabling the outdoor noise to penetrate more or less easily into the indoor spaces. In order to evaluate the potential acoustic discomfort due to the (opening of) these trickle ventilator, relevant data have been recorded and gathered systematically for each examined room. A list of the type of collected data per room is given in Table 12.

Table 12 The different types of collected data per room

type	quantity	unit
acoustic	Reverberation time T [1]	s
acoustic	A-weighted equivalent sound pressure level LAeq inside with grids open	dB
acoustic	A-weighted equivalent sound pressure level LAeq inside with grids closed	dB
acoustic	A-weighted equivalent sound pressure level LAeq outside at 2 m in front of each façade	dB
geometric	Room volume	m^3
geometric	Number of façade planes	-
geometric	Surface of façade planes	m^2
geometric	Total surface of all ‘weak’ elements (windows, built-in roll-down shutters, trickle ventilator)	m^2
geometric	Lengths of grid (per façade plane)	m
technical	Type of grid	-
technical	Type of glazing	-

Sheet for data collection (for 1 test site) :



Project : Date : Operators :

Rooms with natural air supply (grids)	room depth	room volume	T_{reverb}	$L_{Aeq\ binnen}$		$L_{Aeq\ buiten}$
				grids open	grids closed	
...						
...						
...						
...						
...						
...						
...						
...						
...						

* pictures: façade view outside, façace view indoors, window details, grid details

---

[1] duration required for the space-averaged sound energy density in an enclosure to decrease by 60 dB after the source emission has stopped (ISO 3382-2:2008)

Sheet for data collection (for 1 test room)

Project :
Room :
Location in building :

Orientation façade pan 1 :
Orientation façade pan 2 :

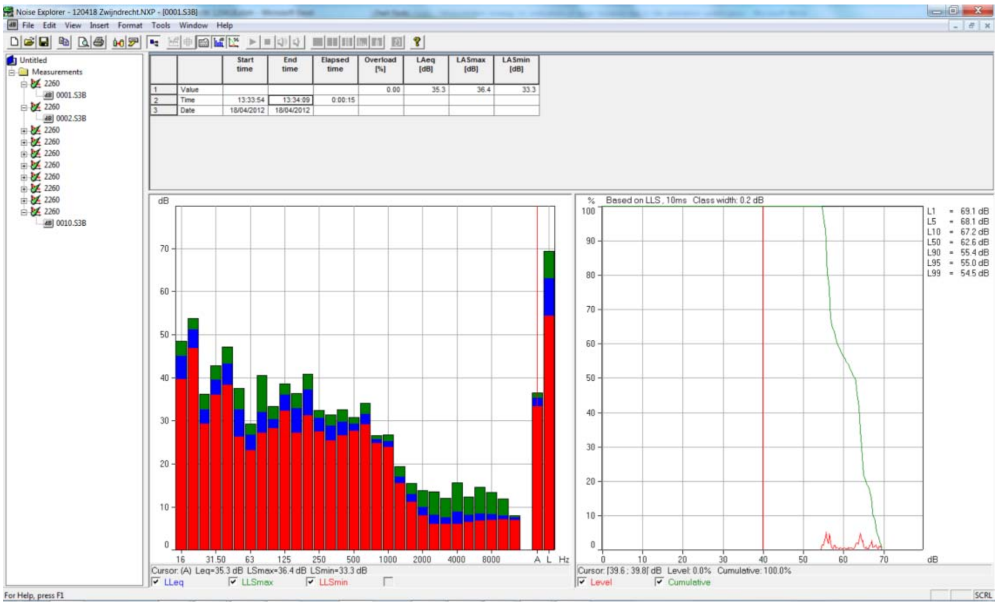
Sketch façade pane 1 (inside view) :
Sketch façade pane 2 (inside view) :

Indication of

- Length and width of the façade
- Length and width of the façade openings
- Length ventilation grids
- Type of glazing
- Type of window profiles
- Type of ventilation grids

As for the acoustic data, the measurement procedures described in the above-mentioned standards have been followed. A handheld integrating sound level meter type *B&K 2260 investigator* with application software *Basic sound analysis* has been used to record the sound pressure levels (SPL).

The linear sound pressure levels L_{Leq} (time averaged value), L_{LSmax} (maximum values), L_{LSmin} (minimum values), in 1/3-octave bands from 16 Hz to 12500 Hz as well as the overall linear (L) and A-weighted (A) SPL are stated for each SPL-measurement into processable data files as shown in Figure 1 and Figure 5.

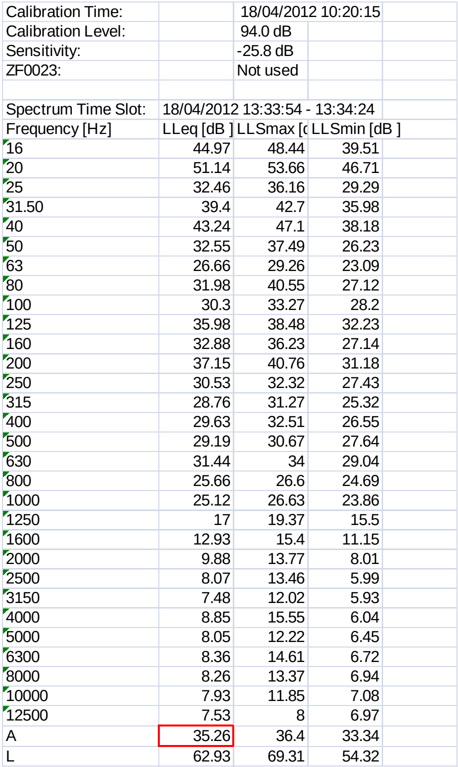


		Start time	End time	Elapsed time	Overload [%]	LAeq [dB]	LASmax [dB]	LASmin [dB]
1	Value				0.00	35.3	36.4	33.3
2	Time	13:33:54	13:34:09	0:00:15				
3	Date	18/04/2012	18/04/2012					

Cursor: (A) Leq=35.3 dB LSmax=36.4 dB LSmin=33.3 dB
☑ LLeq ☑ LLSmax ☑ LLSmin ☐

Cursor: [39.6 ; 39.8[dB Level: 0.0% Cumulative: 100.0%
☑ Level ☑ Cumulative

Figure 4 B&K Utility software Noise Explorer for data transfer (.nxp file with data exportable to Excel)



Calibration Time:		18/04/2012 10:20:15	
Calibration Level:		94.0 dB	
Sensitivity:		-25.8 dB	
ZF0023:		Not used	
Spectrum Time Slot:	18/04/2012 13:33:54 - 13:34:24		
Frequency [Hz]	LLeq [dB]	LLSmax [	LLSmin [dB]
16	44.97	48.44	39.51
20	51.14	53.66	46.71
25	32.46	36.16	29.29
31.50	39.4	42.7	35.98
40	43.24	47.1	38.18
50	32.55	37.49	26.23
63	26.66	29.26	23.09
80	31.98	40.55	27.12
100	30.3	33.27	28.2
125	35.98	38.48	32.23
160	32.88	36.23	27.14
200	37.15	40.76	31.18
250	30.53	32.32	27.43
315	28.76	31.27	25.32
400	29.63	32.51	26.55
500	29.19	30.67	27.64
630	31.44	34	29.04
800	25.66	26.6	24.69
1000	25.12	26.63	23.86
1250	17	19.37	15.5
1600	12.93	15.4	11.15
2000	9.88	13.77	8.01
2500	8.07	13.46	5.99
3150	7.48	12.02	5.93
4000	8.85	15.55	6.04
5000	8.05	12.22	6.45
6300	8.36	14.61	6.72
8000	8.26	13.37	6.94
10000	7.93	11.85	7.08
12500	7.53	8	6.97
A	35.26	36.4	33.34
L	62.93	69.31	54.32

Figure 5 Example of exported global and spectral measurement data in .xls file for one measurement (30 s)

This spectral data info (average, min, max) is not strictly evaluated against the acoustic comfort criteria in residences and schools, but informs us about the nature and reliability of the A-weighted equivalent SPL to be evaluated (35.26 dB for example). Widely deviating curves for minimum and maximum SPL indicate a strongly fluctuating sound. For predominant outdoor noise transmitted through the façade, this is to be expected. Conversely, when investigating mechanical ventilation noise, large deviations indicate a rather strong influence from the transmitted outdoor noise on the background noise level. Rather short measurement periods (30 s) have been employed when the examined noise disturbance was judged as rather continuously present. Sometimes two or three measurements were performed for one condition. For example, with the trickle ventilator closed there is a larger influence from disturbing non-ventilation related indoor noise to be expected, especially when occupants (namely children) are present. In that case several short measurement periods have been adopted[2]. A non-stop monitoring of the SPL during 24 hours would have been more accurate (unfortunately too time consuming) given the rather fluctuating nature of the traffic noise. An example of a measured SPL spectrum outdoor and indoor (grids open/grids closed) is given in Figure 6.

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[2] Note: to average different sound pressure levels, a conversion of the logarithmic quantities to obtain the actual physical quantities is necessary. A logarithmic conversion has to be applied again after the averaging of the physical quantities.

$$L_{average} = 10\lg\left(average\left(10^{\frac{L_1}{10}}, 10^{\frac{L_2}{10}}\right)\right)$$

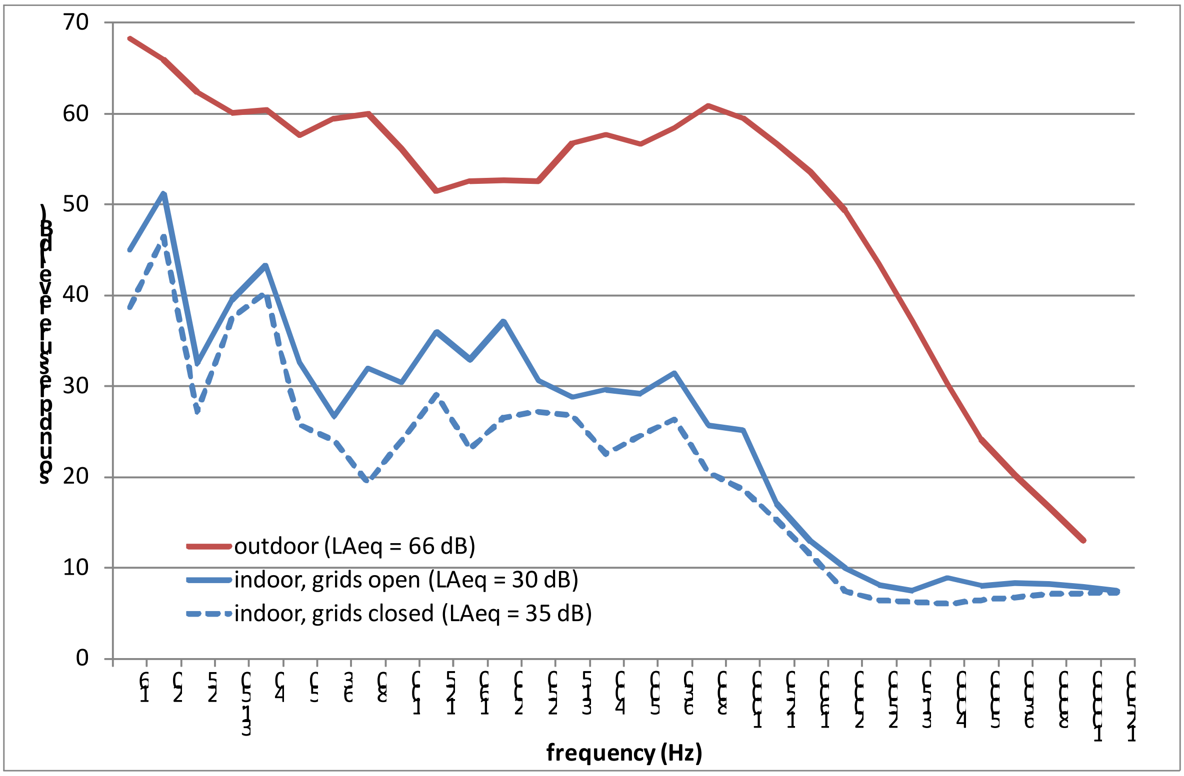

Figure 6 An example of a measured SPL spectrum outdoor and indoor (grids open/grids closed)

In each room the A-weighted equivalent sound pressure levels have been corrected for their room acoustic properties (volume and furnishing, influencing the resulting sound pressure levels) by taken into account the reverberation time at the octave bands of 500 Hz, 1000 Hz and 2000 Hz. The correction term k described in the standards ISO 10 052:2005 and NBN S 01-400-1:2008 has been calculated for each room enabling for a standardisation of the measured sound pressure levels.

$$L_{Aeq,indoor} - k$$

$$k = 10lg\frac{T_{500} + T_{1000} + T_{2000}}{3T_0}$$

with T_{500}, T_{1000} and T_{2000} the reverberation time at the respective octave bands of 500 Hz, 1000 Hz and 2000 Hz measured according to ISO 10 052:2005 with the integrated impulse response method[3].

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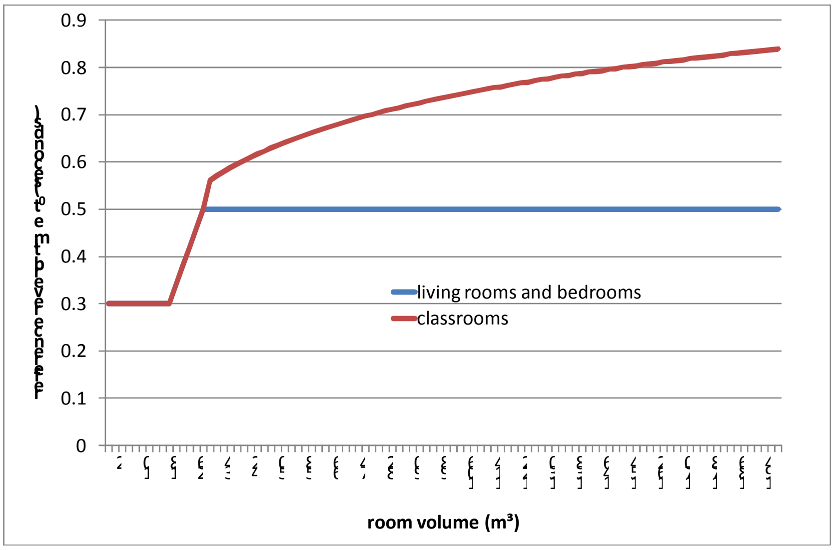
[3] The reverberation time is calculated from the impulse response measured directly using a simple hand clap as impulse source as defined in ISO 3382-2:2008. The survey method can be applied according to EN ISO 10 052:2004.

T_0 is the reference reverberation time (s) determined by the volume of the considered room as indicated below according to NBN S 01-400-1 (residences) and prNBN S 01-400-2 (schools) :

T_0 (s)	living rooms and bedrooms	classrooms
$V \leq 20\ m^3$	0.3	
$20\ m^3 < V \leq 30\ m^3$	$0.02xV - 0.1$	
$30\ m^3 < V$	0.5	$0.35xlg(1.25xV)$

(V = volume of the examined room, m³)



For further analysis, several parameters can be calculated from the reported data, both acoustic and geometric (see WP3), such as:

- Gain from closing the trickle ventilator : $L_{Aeq,in,open} - L_{Aeq,in,closed}$ (dB)
- Outdoor sound reduction : $L_{Aeq,out} - L_{Aeq,in,open}$ (dB)
- Equivalent room depth : room volume / ∑ façade pane surfaces (m)
- Relative weak element surface share (per pane) : surface weak elements / total façade surface x 100 (%)

The measurement data as well as the relevant level differences are tabulated in the annex and discussed in section 5.2.4.

(2) Test sites with ventilation system D

For residences and schools with mechanical air supply in living rooms, bedrooms and classroom, the resulting noise due to the mechanical ventilation system in these ‘noise sensitive rooms’ is to be measured. Therefore one has to examine first the existing background noise, i.e. the sound pressure level when the ventilation system is switched off. A standard measurement of the A-weighted equivalent sound pressure level L_{Aeq} has been made in all the examined rooms (except for one test site, see discussion of results, section 5.2.4) as described above for (system C) in order to determine the background noise. Next the ventilation system is put into action and SPL measurements are performed to determine the standardised installation noise $L_{Ainstal,nT}$ in the room corresponding to one well defined working condition, according to NBN EN ISO 10 052:2005. The standardised installation noise $L_{Ainstal,nT}$ is calculated from the results of three distinguished measurements :

$$L_{Ainstal,nT} = 10\lg\left(\frac{10^{\frac{LAeq1}{10}} + 10^{\frac{LAeq2}{10}} + 10^{\frac{LAeq3}{10}}}{3}\right) - k \quad (dB)$$

With

- $L_{Aeq,1}$ (dB): the equivalent SPL in the most acoustic reflecting corner of the room (at least 50 cm from walls)
- $L_{Aeq,2}$ and $L_{Aeq,3}$ (dB): the equivalent SPL from two measurements in the reverberant field of the room (at least 1.5m from the air valve)
- k [dB]: see above;
- T_0 [s]: see above.

Most systems could be put into three different working conditions: “1” (slow), “2” (medium), “3” (fast). Where possible the installation noise has been determined for each condition. An example of the type of spectral data obtained in a certain living room of the examined projects for the background noise and the installation noise for the three working points is Figure 7.

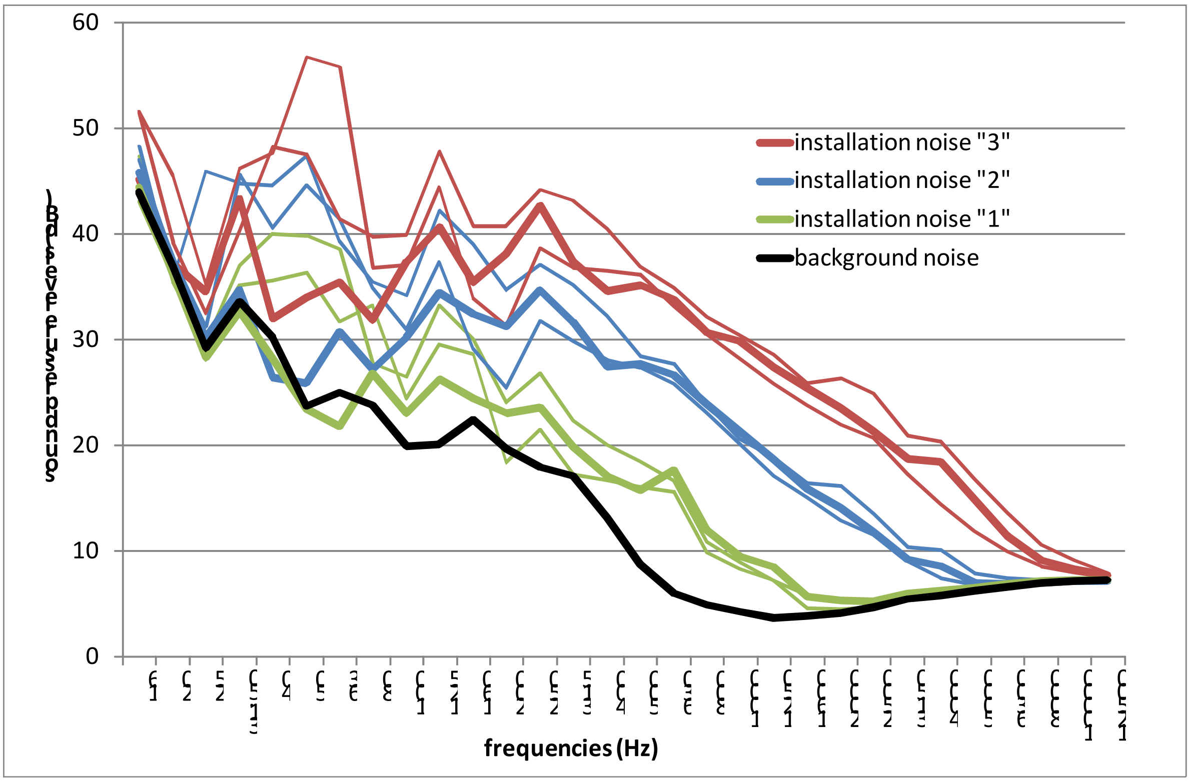


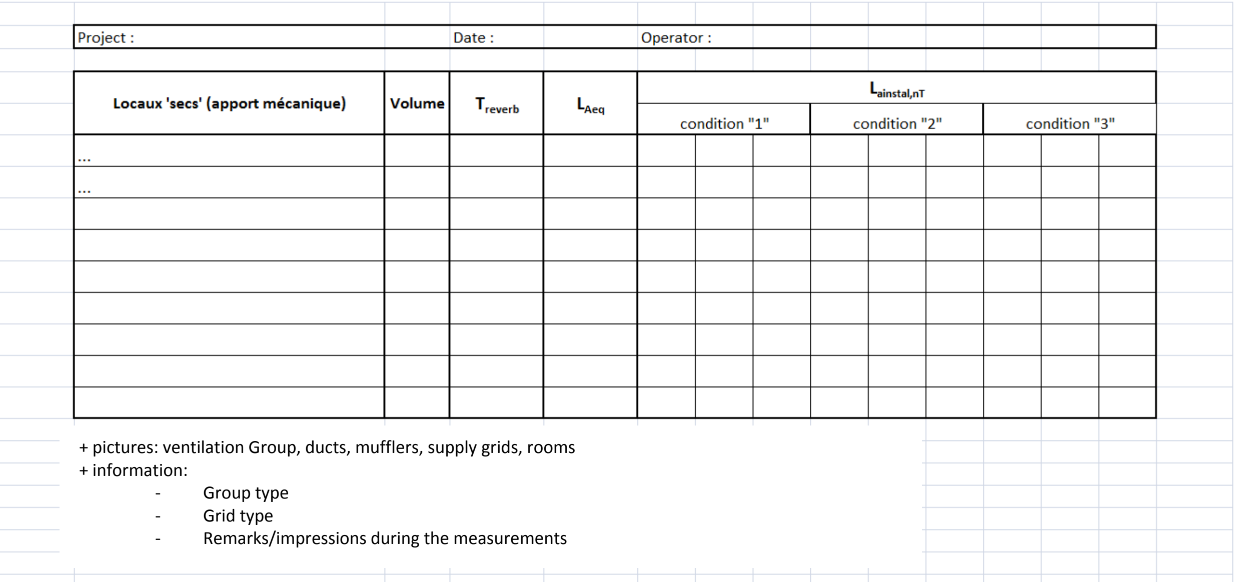
Figure 7 An example of background noise and the installation noise for the three working points

An overview of the collected data for each room during our visit is given in Table 13.

Table 13 Overview of the collected data in each room, in relation to acoustical measurements

type	quantity	unit
acoustic	Reverberation time	s
acoustic	A-weighted equivalent sound pressure level L_{Aeq} (system OFF)	dB
acoustic	A-weighted equivalent sound pressure levels L_{Aeq} (working condition “1”) – corner (positions) and reverberant field (two positions)	dB
acoustic	A-weighted equivalent sound pressure levels L_{Aeq} (working condition “2”) – corner (positions) and reverberant field (two positions)	dB
acoustic	A-weighted equivalent sound pressure levels L_{Aeq} (working condition “3”) – corner (positions) and reverberant field (two positions)	dB
geometric	Room volume	m³
geometric	Position of air inlet	-
geometric	Position of ventilation unit	-
technical	Type of air inlet	-
technical	Type and mounting of ventilation unit	-
technical	Type of ducts	-
technical	Type/presence of mufflers	-

Sheet for data collection (for 1 test site)



Project : Date : Operator :

Locaux 'secs' (apport mécanique)	Volume	T_{reverb}	L_{Aeq}	$L_{ainstal,nT}$								
				condition "1"			condition "2"			condition "3"		
…												
…												

+ pictures: ventilation Group, ducts, mufflers, supply grids, rooms
+ information:
  - Group type
  - Grid type
  - Remarks/impressions during the measurements

Besides the acoustical data, most of the collected information needed for further analysis of the installation noise (see WP3) is rather qualitative. Codes are used to indicate the positioning of the air inlet in the room, since the presence of reflective walls (M) and ceiling (P) are acoustically relevant. To indicate that an air inlet is situated in a three-plane corner, the code MMP is used (shown in Figure 8). By analogy, an inlet in the middle of the ceiling is indicated as P.

Figure 8 Examples of different (acoustically relevant) positioning of air inlets (MMP, MP and P)

To indicate the localisation of the room in relation to the position of ventilation unit, the vertical and horizontal distance are roughly indicated as “V+0, V+1, V+2” and “H+0, H+1, H+2” saying “0, 1 or 2 rooms away from the unit in vertical (V) or horizontal (H) direction. This indication will help us to interpret remarkable spectral or global level differences between different rooms.

Besides these geometrical relevant data, the measured installation noise compared to the background noise level as well as the gain/loss in SPL for the different working points (1, 2,3) in relation to the measured air flows, will be taken into account to analyse and evaluate the mechanical ventilation noise correctly (see WP3).

The measurement data as well as the relevant level differences are tabulated in annex 12-15 and discussed in section 5.2.4.

→ Ventilation rate

In both dwellings and schools, the fresh air ventilation rate was measured with a fan assisted zero pressure flow finder at the normal working point of the ventilation system. When no ‘normal’ position was indicated by the occupants, several working points were tested. For trickle ventilators in dwellings with simple exhaust ventilation, the size was measured and if possible, the design flow rate retrieved from product information.
During testing, several extraction or supply vents could not be tested due to their positioning in/behind furniture and wall flashings. For these vents, the flow rate will be estimated based on the design flow rate and the other measured flow rates in the dwelling.

→ Air leakage / air tightness

The air leakage in the dwellings and schools was tested using a building pressurization test, following the methodology proposed in the EN 13829 Standard:

NBN EN 13829: Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method (ISO 9972:1996, modified)

For the dwellings, the whole heated volume was tested. In the school buildings, the test was performed on a relevant section of the building. Whenever possible, the test was performed on an entire building block. Specific layout, maximum fan flow rate and internal separations, on the other hand, required to test only single class rooms in about half the schools. For all schools, infiltration rates will also be assessed based on the decay observed in measured CO_2 concentrations during periods of absence.

3.2.3. BIOLOGICAL AGENTS, STUDIED IN CLEAN AIR, LOW ENERGY

Table 14 gives an overview of the methods, applied in the field in order to assess the scheduled chemical parameters on the houses and the schools. The settings of the mechanical ventilation system were kept under normal operating conditions during the measurements.

Table 14 Overview of the applied methods to assess biological parameters in houses and schools

Compound	Measurement technique	Sampling time	Sampling site
Bioaerosol samples – fungi and yeast	Andersen 6-stage impactor	5 minutes total volume ~150L 28.3 L/min flow rate	15 Houses: living room, bedroom 15 classrooms Parallel outdoor
Bioaerosol samples – total bacteria	Andersen 6-stage impactor	5 minutes total volume ~150L 28.3 L/min flow rate	15 Houses: living room 15 classrooms Parallel outdoor
Settled dust sampling – fungi and yeast	Swap sampling	Not applicable - height of 1.5 to 2 m	Houses: living room, bedroom 15 classrooms
Settled dust sampling – total bacteria	Swap sampling	Not applicable - height of 1.5 to 2 m	Houses: living room, bedroom 15 classrooms

→ Bioaerosol samples

Bioaerosol samples were collected on DG18 agar medium using an Andersen 6-stage impactor, followed by enumeration of total fungi + yeasts in agreement with ISO 21527-1. Total bacteria in bioaerosol were collected on plate count agar medium, using the same impactor; the analysis was performed in agreement with ISO 4833. Both fungi and yeast, and total bacteria were collected by sampling a total volume of 141.5 L, at a flow of 28.3 $l.min^{-1}$ during 5 minutes.

For residences, sampling was performed in the living room, the bedroom as well as in the garden; at school, sampling was performed in each selected classroom, as well as on the playground. All samples were collected during the same house or school visit. Samples were collected in the middle of the room, at a height of 1-1.5m.

→ Settled dust sampling

Swab sampling was performed to complement the bioaerosol sampling. Prior to the sample collection step, all participating schools and houses received a post package, containing (1) two Petri dishes with a surface of 15cm for houses; three Petri dishes for schools; (2) a letter with instructions and explanations (see Annex); (3) a questionnaire for biological measurements.

The participants were contacted by the involved laboratory one week before the actual fieldwork took place. They were instructed to open the Petri dishes and to install:

- two halves in the living room and two halves in the bedroom for residences; or
- two halves in every participating classroom for schools.

The instructions were specified in the following way: the Petri dish should be installed at a height of 1.5m, be out of reach of children and pets (the inside of the dish should not be touched), and should not be closer than 1 meter to a window- or door opening. When the dishes were installed, a printed document saying ‘Please don’t touch or move’, was installed next to it. Any incident should be reported on the questionnaire for biological measurements.

On the same day as the bioaerosol sampling, the swap samples were collected from the Petri dish surface, that has been exposed for one week (7 days). The sample collection procedure was performed according to the PM229 (swap collection) method, sampling analysis of the yeast and fungi and the total bacteria was performed in agreement with ISO 21527-1 and ISO 4833 respectively.

CHAPTER 4 QUESTIONNAIRES

Several questionnaires have been distributed to complement the different fieldwork activities performed in Clean Air Low Energy.

4.1. QUESTIONNAIRE FOR DESCRIPTION OF THE BUILDING

See annex 3

4.2. QUESTIONNAIRE FOR INFORMATION DURING THE FIELD WORK (CHEMICAL, PHYSICAL PARAMETERS)

See annex 3

4.3. QUESTIONNAIRE FOR INFORMATION DURING THE FIELD WORK (BIOLOGICAL AGENTS)

See annex 3

CHAPTER 5 RESULTS AND OUTCOMES

5.1. CHEMICAL CHARACTERISATION

5.1.1. VOC CONCENTRATION LEVELS

Table 15 and Table 16 show the summary of the 18 VOCs as well as the TVOC concentrations, registered in Clean Air, Low Energy schools and residences. The full dataset can be found in the annex 4 of this document. Levels reported as a value below the detection limit, indicate a concentration level that is smaller than the lowest measuring point in the calibration line.

5.1.2. ALDEHYDE CONCENTRATION LEVELS

Table 17 and Table 18 give an overview of the formaldehyde, acetaldehyde and total aldehyde levels, measured in the Clean Air, Low Energy schools and residences. The full datasets can be found in the annex 5 of this document.

Table 15 Descriptive tables of the VOC levels, collected in Clean Air, Low Energy schools

Schools indoor (in µg.m^{-3})

	MTBE	Benzene	Trichloro-ethene	Toluene	Tetrachloro-ethene	Ethyl-benzene	m- + p-Xylene	Styrene	o-Xylene	1,2,4-Trimethyl-benzene	1,4-Dichloro-benzene	tVOC	Hexane	Heptane	Cyclo-hexane	n-Butyl-acetate	alfa-Pinene	3-Carene	d10-Limonene
Average	0,14	0,98	0,10	3,1	0,10	0,43	1,12	0,11	0,41	1,65	0,15	318	0,84	0,93	5,6	2,15	4,3	1,79	6,06
SD	0,1	0,57	0,0	2,68	0,0	0,34	1,11	0,04	0,44	4,4	0,06	193	0,63	1,33	14,0	2,03	7,1	1,98	6,5
RSD	70%	58%	0%	86%	0%	79%	99%	33%	107%	267%	38%	61%	75%	143%	248%	94%	165%	110%	107%
Minimum	0,10	0,10	0,10	0,94	0,10	0,10	0,29	0,10	0,10	0,21	0,100	184	0,28	0,10	0,238	0,20	0,10	0,23	0,50
Maximum	0,41	2,02	0,10	10,9	0,10	1,67	5,70	0,29	2,10	23,0	0,231	1175	2,38	5,5	72	8,5	34	6,5	20,3

Schools outdoor (in µg.m^{-3})

	MTBE	Benzene	Trichloro-ethene	Toluene	Tetrachloro-ethene	Ethyl-benzene	m- + p-Xylene	Styrene	o-Xylene	1,2,4-Trimethyl-benzene	1,4-Dichloro-benzene	tVOC	Hexane	Heptane	Cyclo-hexane	n-Butyl-acetate	alfa-Pinene	3-Carene	d10-Limonene
Average	0,144	1,06	0,10	2,07	0,11	0,22	0,53	0,11	0,16	0,32	0,153	336	0,88	0,273	0,42	0,24	0,14	0,22	0,25
SD	0,099	0,67	0,00	1,90	0,04	0,15	0,33	0,04	0,11	0,37	0,06	89	0,94	0,20	0,32	0,17	0,08	0,06	0,04
RSD	69%	63%	0%	92%	38%	70%	62%	36%	71%	116%	43%	26%	106%	73%	75%	70%	58%	29%	15%
Minimum	0,100	0,247	0,10	0,64	0,10	0,100	0,237	0,10	0,10	0,100	0,10	204	0,23	0,10	0,10	0,10	0,10	0,10	0,21
Maximum	0,39	2,27	0,10	6,6	0,23	0,57	1,32	0,22	0,44	1,30	0,27	494	3,2	0,63	0,88	0,59	0,31	0,34	0,32

Table 16 Descriptive tables of the VOC levels, collected in Clean Air, Low Energy residences

Residences indoor (in µg.m^{-3})

	MTBE	Benzene	Trichloro-ethene	Toluene	Tetrachloro-ethene	Ethyl-benzene	m- + p-Xylene	Styrene	o-Xylene	1,2,4-Trimethyl-benzene	1,4-Dichloro-benzene	tVOC	Hexane	Heptane	Cyclo-hexane	n-Butyl-acetate	alfa-Pinene	3-Carene	d10-Limonene
Average	0,48	1,64	0,17	10,9	0,14	1,14	1,78	0,42	0,66	2,78	0,1	455	1,58	7,3	1,18	3,1	11,8	4,3	15,3
SD	0,76	1,14	0,31	17,8	0,118	1,15	1,25	0,78	0,50	4,0	0,33	229	1,76	30	1,42	3,8	16,9	5,2	20,0
RSD	157%	70%	179%	164%	84%	101%	70%	183%	76%	142%	194%	50%	112%	415%	120%	123%	144%	123%	131%
Minimum	0,10	0,66	0,10	1,21	0,10	0,10	0,30	0,100	0,100	0,10	0,10	146	0,25	0,10	0,10	0,30	1,08	0,27	1,22
Maximum	2,78	5,80	1,63	89	0,65	4,60	5,0	2,86	2,14	17,2	1,76	1036	7,40	152	6,6	18,9	71	21,2	96

Residences outdoor (in µg.m^{-3})

	MTBE	Benzene	Trichloro-ethene	Toluene	Tetrachloro-ethene	Ethyl-benzene	m- + p-Xylene	Styrene	o-Xylene	1,2,4-Trimethyl-benzene	1,4-Dichloro-benzene	tVOC	Hexane	Heptane	Cyclo-hexane	n-Butyl-acetate	alfa-Pinene	3-Carene	d10-Limonene
Average	0,18	1,34	0,10	4,1	0,12	0,33	0,86	0,10	0,26	0,34	0,10	203	0,82	0,25	0,44	0,25	0,51	0,27	0,18
SD	0,12	0,78	0,00	9,4	0,06	0,29	0,75	0,00	0,23	0,26	0,02	70	0,70	0,18	0,40	0,142	0,84	0,40	0,16
RSD	86%	58%	0%	229%	51%	88%	87%	0%	91%	77%	23%	34%	85%	73%	93%	58%	167%	151%	87%
Minimum	0,10	0,65	0,10	0,76	0,10	0,10	0,26	0,10	0,10	0,10	0,10	74	0,23	0,10	0,10	0,10	0,10	0,10	0,10
Maximum	0,64	3,40	0,10	47	0,32	1,33	3,6	0,10	1,03	0,98	0,21	389	3,1	0,77	1,87	0,62	3,7	2,02	0,74

Table 17 Descriptive tables of the aldehyde levels, collected in Clean Air, Low Energy schools

Schools indoor (in $\mu g.m^{-3}$)

	Formaldehyde	Acetaldehyde	Other aldehydes (Total)	Total aldehydes
Average	16,9	8,5	37,8	14,0
SD	6,8	1,74	11,8	6,0
RSD	40%	20%	31%	43%
Minimum	5,0	6,3	14,1	3,9
Maximum	28,8	12,5	56	24,0

School outdoor (in $\mu g.m^{-3}$)

	Formaldehyde	Acetaldehyde	Other aldehydes (Total)	Total aldehydes
Average	3,9	6,1	20,2	11,4
SD	0,94	1,7	7,0	6,0
RSD	24%	28%	35%	53%
Minimum	2,8	3,4	10,1	3,3
Maximum	5,4	8,7	30	19,3

Table 18 Descriptive tables of the aldehyde levels, collected in Clean Air, Low Energy residences

Residences indoor (in $\mu g.m^{-3}$)

	Formaldehyde	Acetaldehyde	Other aldehydes (Total)	Total aldehydes
Average	25,9	8,7	50	17,0
SD	11,0	5,2	21,9	11,1
RSD	42%	60%	44%	65%
Minimum	12,1	4,1	22,8	3,9
Maximum	62	24	121	54

Residences outdoor (in $\mu g.m^{-3}$)

	Formaldehyde	Acetaldehyde	Other aldehydes (Total)	Total aldehydes
Average	2,92	2,65	12,1	7,1
SD	1,06	0,74	5,0	4,8
RSD	36%	28%	41%	69%
Minimum	1,43	0,94	3,9	0,32
Maximum	4,9	3,9	20,7	15,4

5.1.3. PM CONCENTRATION LEVELS

→ $PM_{2.5}$ concentrations (gravimetrical)

Table 19 and Table 20 show the overview of the $PM_{2.5}$ levels, measured in schools and houses. The average indoor level is higher in schools compared to residences, however, this should be evaluated case-wise in WP3, since the average outdoor $PM_{2.5}$ levels are higher for the schools as well. The high outdoor maximum value during the school campaign was measured during an high air pollution episode.

The full dataset can be found in Annex 6.

Table 19 Descriptive table of the $PM_{2.5}$ levels, collected in Clean Air Low Energy schools

(in µg.m^{-3})

	Indoor $PM_{2.5}$	Outdoor $PM_{2.5}$
Average	30.4	34.4
SD	16,6	25,3
RSD	55%	74%
Minimum	5,2	8,5
Maximum	66	74

Table 20 Descriptive table of the $PM_{2.5}$ levels, collected in Clean Air Low Energy residences

(in µg.m^{-3})

	Indoor $PM_{2.5}$	Outdoor $PM_{2.5}$
Average	13,5	20,5
SD	8,2	8,0
RSD	60%	39%
Minimum	7,3	8,1
Maximum	41	34

→ PMx concentrations (optical)

Table 21 and Table 22 show the overview of the monitoring of PMx for Clean Air Low Energy. It can be noticed that the PM_{10} to $PM_{2.5}$ ratio is higher in schools compared to residences, which is fairly expectable based in previous research results. These ratio might even increase when in WP3 only the teaching hours will be considered for school IAQ.

The full dataset can be found in Annex 7.

Table 21 Descriptive table of the PM_x levels, collected in Clean Air Low Energy schools

Schools indoor (in µg.m^{-3})

	PM_1	$PM_{2.5}$	PM_{10}	TSP	ratio $PM_{10}/PM_{2.5}$
Average	5,7	8,1	27,8	46	3,8
SD	3,2	3,9	14,2	23,6	2,08
RSD	56%	47%	51%	51%	55%
Minimum	1,51	2,78	4,3	4,9	1,07
Maximum	12,3	13,9	67	108	9,5

Schools outdoor (in µg.m^{-3})

	PM_1	$PM_{2.5}$	PM_{10}	TSP	ratio $PM_{10}/PM_{2.5}$
Average	48	50	60	74	1,88
SD	79	78	80	89	0,79
RSD	164%	157%	133%	121%	42%
Minimum	1,38	1,39	4,9	11,2	1,03
Maximum	201	202	220	269	3,5

Table 22 Descriptive table of the PM_x levels, collected in Clean Air Low Energy schools

Residences indoor (in µg.m^{-3})

	PM_1	$PM_{2.5}$	PM_{10}	TSP	ratio $PM_{10}/PM_{2.5}$
Average	10,5	12,6	20,7	29,4	1,76
SD	7,3	8,1	9,6	13,5	0,48
RSD	69%	64%	46%	46%	27%
Minimum	4,1	4,1	6,1	9,1	1,12
Maximum	38	44	54	66	3,4

Residences outdoor (in µg.m^{-3})

	PM_1	$PM_{2.5}$	PM_{10}	TSP	ratio $PM_{10}/PM_{2.5}$
Average	35	37	63	129	1,87
SD	59	59	82	265	1,11
RSD	170%	160%	129%	205%	59%
Minimum	1,15	1,16	2,8	4,5	1,01
Maximum	291	292	296	1124	4,7

5.1.4. CO_2 CONCENTRATIONS

Table 23and Table 24 give the overview of the CO_2 levels in houses and schools. Although the highest CO_2 level, reached in a classroom was 2455 ppm, the average CO_2 level did not exceed the values that were measured in residences. A case-wise analysis, related to the classroom occupancy, will clarify these values in WP3.

The full dataset can be found in Annex 8.

Table 23 Descriptive table of the CO_2 levels, collected in Clean Air Low Energy schools

Schools indoor (in ppm)

	Av. CO_2 (24h)	Min CO_2 (24h)	Max CO_2 (24h)
Average	480	312	1352
SD	96	66	484
RSD	20%	21%	36%
Minimum	308	132	610
Maximum	716	465	2455

Schools outdoor (in ppm)

	Av. CO_2 (24h)	Min CO_2 (24h)	Max CO_2 (24h)
Average	450	349	575
SD	38	76	66
RSD	8%	22%	11%
Minimum	404	176	472
Maximum	506	416	689

Table 24 Descriptive table of the CO_2 levels, collected in Clean Air Low Energy residences

Residences indoor (in ppm)

	Av. CO_2 (24h)	Min CO_2 (24h)	Max CO_2 (24h)
Average	606	395	1137
SD	105	64	381
RSD	17%	16%	34%
Minimum	385	285	464
Maximum	761	526	2352

Residences outdoor (in ppm)

	Av. CO_2 (24h)	Min CO_2 (24h)	Max CO_2 (24h)
Average	467	345	603
SD	72	65	111
RSD	15%	19%	18%
Minimum	361	248	426
Maximum	670	480	840

5.2. PHYSICAL PARAMETERS

5.2.1. TEMPERATURE MEASUREMENTS

The outcomes of the temperature measurements are reported in Table 25 and Table 26. The values have been used to calculate the uptake rate of gaseous compounds during the passive sampling. They will be discussed more in detail in WP3.

The full dataset can be found in Annex 9.

Table 25 Descriptive table of the temperatures, in Clean Air Low Energy schools

Schools indoor (in °C)

	Av. temp	Min temp	Max temp
Average	20,5	17,7	24,4
SD	1,5	1,8	3,2
RSD	7%	10%	13%
Minimum	18,1	14,3	20,6
Maximum	23,2	20,8	31,7

Schools outdoor (in °C)

	Av. temp	Min temp	Max temp
Average	8,3	3,0	21,0
SD	8,1	6,9	11,7
RSD	98%	232%	56%
Minimum	-4,2	-9,2	10,4
Maximum	18,3	12,3	-

Table 26 Descriptive table of the temperatures, in Clean Air Low Energy residences

Residences indoor (in °C)

	Av. temp	Min temp	Max temp
Average	19,9	17,6	22,9
SD	1,8	2,4	3,4
RSD	9%	14%	15%
Minimum	15,8	11,0	16,2
Maximum	22,8	21,2	33,7

Residences outdoor (in °C)

	Av. temp	Min temp	Max temp
Average	8,2	2,3	19,4
SD	2,7	3,4	5,4
RSD	32%	149%	28%
Minimum	4,0	-3,1	9,9
Maximum	13,9	9,5	27,5

5.2.2. RELATIVE HUMIDITY MEASUREMENTS

Table 27 and Table 28 describe the relative humidity in the schools and residences in Clean Air, Low Energy. The full dataset can be found in Annex 10.

Table 27 Descriptive table of the relative humidity, in Clean Air Low Energy schools

Schools indoor (in %)

	Av. RH (%)	Min RH (%)	Max RH (%)
Average	39	27,5	52
SD	13,9	11,3	12,7
RSD	35%	41%	24%
Minimum	15,5	8,2	20,6
Maximum	59	43	70

Schools outdoor (in %)

	Av. RH (%)	Min RH (%)	Max RH (%)
Average	74	32	91
SD	15,3	19,0	11,4
RSD	21%	59%	13%
Minimum	43	12,2	65
Maximum	94	62	100

Table 28 Descriptive table of the relative humidity, in Clean Air Low Energy residences

Residences indoor (in %)

	Av. RH (%)	Min RH (%)	Max RH (%)
Average	45	36	55
SD	6,4	8,3	7,8
RSD	14%	23%	14%
Minimum	33	17,5	41
Maximum	56	55	70

Residences outdoor (in %)

	Av. RH (%)	Min RH (%)	Max RH (%)
Average	80	41	96
SD	8,4	17,1	4,4
RSD	11%	41%	5%
Minimum	65	16,5	86
Maximum	91	75	100

5.2.3. DRAUGHT – INDOOR AIR SPEED REGISTRATION

Table 29 and Table 30 show the overview of the air speed, measured in the Clean Air, Low Energy schools and residences. The full dataset can be found in Annex 11.

Table 29 Descriptive table of the indoor air speed, in Clean Air Low Energy schools

	Av. Air speed (m/s)
Average	0,036
SD	0,02
RSD	51%
Minimum	0,003
Maximum	0,070

Table 30 Descriptive table of the indoor air speed, in Clean Air Low Energy residences

	Av. Air speed (m/s)
Average	0,030
SD	0,01
RSD	34%
Minimum	0,009
Maximum	0,045

5.2.4. NOISE NUISANCE

→ Results and outcomes for acoustical field measurements

Only a limited number of schools and residences have been acoustically examined. The test results for this limited selection (3 schools and 8 residences) are given in annex 12. The results for schools and residences are tabulated separately. Furthermore test sites with ventilation system C were treated separately from those with ventilation system D. Since the nature of possible acoustic disturbance is essentially different, another strategy for measurement and data collection has been adopted. Where for schools and residences with natural air supply (system C) we mainly focussed on the outdoor-indoor noise transmission, the noise provoked by (parts of) the mechanical ventilation system was closely examined in rooms with mechanical air supply (system D). Other measurement quantities and evaluation criteria apply in both cases.

(1) ROOMS WITH NATURAL AIR SUPPLY (ventilation system C)

See Annex 12:
TABLE AC-1 (Residences)
TABLE AC-5 (Schools)

For rooms with natural air supply, this is trickle ventilator in the façade plane(s), the following measurement data are listed in the above mentioned tables:

OUT : $L_{A,2m}$ (dB)
The A-weighted equivalent sound pressure level, measured outside at 2m in front of the façade. Often the examined rooms have two façade planes. Both values are then given (see column 1 and 2, “plane 1”, “plane 2”). For schools the second plane is not a façade plane but an indoor wall separating the classroom from the (sometimes noisy) corridor.

IN: L_{Aeq}-k (dB)
The A-weighted equivalent sound pressure level corrected for the reverberation time (by term k), measured in the considered room for two regimes : with trickle ventilator “open” (column 3) and with “closed” grids (column 4). Since these values have been normalised to a standard reverberation time, depending on the room volume, the values from different test sites can be compared with each other.

These values can be evaluated according to the comfort criteria in the Belgian standards NBN S 01-400-1 (residences) and prNBN S 01-400-2(schools).

Outdoor noise levels (OUT)

For a start, the outdoor noise levels can be situated in the described categories of the standard, as shown below.

Table 31 Environmental noise categories (extract from NBN S 01-400-1)

Class	Type description	L_{aref}
1	Mostly quiet, rural roads, quiet allotment with local traffic or in urban streets with local, limited traffic	60 dB
2	Urban streets with normal traffic on asphalt, one lane per direction of traffic flow	65 dB
3	Busy, slow-driving traffic	70 dB
4	Mostly urban streets with dense traffic (e.g. Beliard street in Brussels, Belgium), road with concrete road surface and busy traffic, along national roads, at approach roads to larger cities and at connection roads with mostly heavy traffic to industrial sites	≥ 77 dB

For the 3 residences with ventilation system C that have been acoustically examined (table AC-1), outdoor noise levels from 39 dB (case R2: Wortel - Poeleinde) to 66 dB (case R21: Zwijndrecht - Waterbos) were registered. We can conclude that the examined residences with natural air supply are situated in rather quiet environments. For residence R2 the environment was even so quiet (<< type 1) that extremely large fluctuations, independent from the orientation of the façade pane, are registered for occasional traffic passing by, going from 39 dB tot 55 dB. For case study R18 (Holsbeek - Dutselstraat) the registered outdoor noise levels (type 1) where quite stable depending on the examined façade pane: 60 dB in the front, 54 dB at the side, 43 dB in the back. The same findings go for site R21 with a well-pronounced level difference at the front (66 dB) and the back (54 dB) of the three-façade residence.

Only one of the three acoustically examined schools (table AC-5) is ventilated according to system C (S9). Since in this school all classrooms look out on the Ursulinenstraat (a dead end, small quiet street with hardly no traffic) or the interior playground (no simultaneous use, only some construction work going on in the back yard) , extremely low noise levels where registered in front of the considered façades: 50.4 dB in the Ursulinenstraat, 52.6 dB on the playground[4]. So no actual noise annoyance due to the outdoor environment and the presence of trickle ventilator is to be expected.

Indoor noise levels (IN)

The measured indoor noise levels, standardised to 'normal' reverberation conditions, can be compared to the aimed indoor noise levels when formulating acoustic façade insulation criteria in the NBN S 01-400-1 for living rooms and bedrooms and the prNBN S 01-400-2 for classrooms.

For residences, these indoor levels are 30 dB for improved acoustic comfort (VC) in living rooms and bedrooms, 34 dB for normal acoustic comfort (NC).

Table 32 Criteria for sound insulation of façade panes in residences according to NBN S 01-400-1

	Normal acoustic comfort	Increased acoustic comfort
Living room, kitch, study, and bedroom	$D_{Atr} \geq - 34 + m$ dB (1) And $D_{Atr} \geq 26$ dB	$D_{Atr} \geq - L_A - 30 + m$ dB (1) And $D_{Atr} \geq 30$ dB
Bedroom	$D_{Atr} \geq - 34 + m$ dB (1)(2)	

For regular classrooms the desired maximum noise level for normal comfort is 35 dB. By analogy, a value of maximum 31 dB can be assumed for improved comfort.

Table 33 Criteria for sound insulation of façade panes in schools according to prNBN S 01-400-2

Normal requirements	Raised requirements
$D_{Atr} \geq L_A - L_{Aeq,nT,\max} + m$ (1) and $D_{Atr} \geq 26\ dB$ (2)	$D_{Atr} \geq L_A - L_{Aeq,nT,\max} + 4 + m$ (1) and $D_{Atr} \geq 30\ dB$ (2)

Table 34 Criteria for stationary service equipment and reference reverberation according to prNBN S 01-400-2

	$L_{Aeq,nT,\max}$ [dB]	T_0 (1) [s]
CLASSROOMS		
Nursery school		
playrooms	35	0.6
quiet rooms	35	0.6
Primary school, secondary school, higher education		
regular classrooms, small group rooms, seminar rooms, tutorial rooms, language laboratories	35	$0{,}35 \times \lg(1{,}25 \times V)$

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[4] Note: the 'outdoor' levels given for "plane 2" are in fact indoor levels measured outside the classroom in the neighbouring corridor (with mechanical air extraction)

The indoor noise levels corresponding to the highest comfort level (VC) are indicated in green. The ones corresponding to the normal comfort criteria NC are orange coloured. When the NC is not met, the value is shown red.

Though the outdoor noise levels are rather low, as discussed earlier, still some indoor measurements do not meet the NC criteria in residences (red values, table AC-1, Annex L). This is the case for room R18-B1 (39.3 dB) and R18-BU (36.5 dB) both rooms situated at the front side with outdoor level 60.4 dB. Also room R21-B1 with an indoor level of 36.4 dB exceeds the normal comfort level of 34 dB. For these rooms, all exposed to outdoor noise levels greater than 60 dB, the sound insulation of façade panes in question is too weak to meet the NC indoor noise levels of the standards NBN S 01-400-1 and -2. When the trickle ventilator are closed, the indoor noise levels fall down below 34 dB. This could be a reason for the occupants to close their trickle ventilator in spite of the lack of ventilation and in favour of the acoustic comfort.

An important conclusion is that the indoor levels strongly depend on the outdoor noise exposure of the examined room. This indicates that no actual measures are taken to provide a better sound insulation for the façades panes enclosing rooms with higher noise exposure. As long as the NC-levels (or better, the VC-levels) are met, this is probably not an issue. But once the indoor levels exceed 34 dB in living rooms and bedrooms, acoustically improved façade elements are strongly recommended and justified. Since the indoor noise levels fall down considerably by closing the trickle ventilator when dealing with substantial outdoor noise (> 60 dB), the first element to be treat are actually the grids. They are generally known to be the weakest elements in the façade, determining almost completely the sound insulation against outdoor noise. In WP3 one will try to determine the necessary acoustic improvement of the sound insulation and the appropriate choice of ventilation grid to meet the NC criteria for indoor levels.

The indoor levels for the examined school with natural air supply (S9, table AC-5, Annex L) are indeed below the normal comfort level of 35 dB (average value: 33 dB). Nevertheless, taken into account the extremely quiet outdoor conditions (“plane 1”), we can conclude that more efforts are to be made, even in quiet surroundings, with respect to the façade insulation to be able to meet the VC-comfort levels (31 dB or lower). These levels can be found necessary in schools for children/pupils/students with auditory or communicative limitations.

To allow for a quick overview of the respective level differences, a second table is given for residences and schools with natural air supply (see annex 13, table AC-2 and AC-6). Here the corresponding columns give the level differences referring to the indoor noise levels under “normal” conditions, listed in column 3 (trickle ventilator “open”).

Outdoor-indoor sound reduction

So the first two columns (OUT) give an idea of the façade sound insulation since here the outdoor-indoor level differences (normalised to standard reverberation time) are calculated. A higher value indicates a better resistance to the passage of the outdoor noise to the indoor spaces. These insulation values are calculated for both façade planes (if any). They are useful indications, because a high indoor noise level can result from high outdoor noise levels and/or weak façade insulation. When measuring the same high indoor noise levels for two different sites or rooms, one can be caused by a weak façade insulation (so relative normal outdoor levels are not excluded) while the other can be caused by an extremely loud environment (so relative good façade insulation is not excluded).

Outdoor-indoor sound reductions are calculated for the examined residences (table AC-2, annex 13) going from only 10 dB to 36 dB with an average of 26 dB. The average value corresponds to the absolute minimum lower limit imposed by the NBN S 01-400-1 (see Table 32). This means that for all the calculated sound reductions below 26 dB, the NBN standard regarding sound insulation of façade panes is probably not met. These values are indicated in red. This is mainly the case for test site R18. The low value for R21-B2 has rather to do with disturbance from a vacuum cleaner (leading to higher indoor levels). The sound reductions beneath 26 dB for the project R2 are due to not simultaneously measured and strongly time fluctuating outdoor noise levels.

For the one examined school with natural air supply, all the values (only column “plane 1” has to be considered, “plane 2” regards interior wall) are below the absolute lower limit of 26 dB for sound insulation of façades panes, as given in Table 33. This has partly to do with the very low outdoor noise levels limiting the measurable outdoor-indoor noise reduction with existing outdoor noise (more appropriate method = loudspeaker method), partly with the ventilation noise transmitted through the interior wall (“plane 2”) raising somewhat the indoor noise levels.

Gains by closing trickle ventilator

The last column in table AC-2 (Annex 13, residences) and AC-6 (Annex 13, schools) indicates the gain (or loss in SPL) by closing the ventilation grid. A higher value indicates a higher probability of occupants closing the trickle ventilator to improve the indoor acoustic comfort. High gains result from noisy environments and mostly indicates a weak acoustic performance for the installed grids. Both outdoor noise levels and façade insulation have to be compared against these gains in the further analysis (WP 3) to investigate the influence of the grids on indoor sound levels.

When looking at the gains for the examined residences with natural air supply (table AC-2, Annex M), gains from -1 to 7 dB has been found. Of course the negative value measured in R2-LI has to do with the measurement uncertainty and the very small influence of the ventilation grid on the indoor levels due to very low (but fluctuating) outdoor levels. The hardly existing gain for R21-B2 can be explained partly by the low outdoor noise level, partly by the rather high back ground level due to vacuum cleaner noise.

For the examined school S9 we were unable to close the trickle ventilator for two of the three classrooms. In C2 a rather expected small gain of 2.5 dB was found mainly due to the low outdoor noise levels. Closing of these grids allows for reaching the VC comfort level of 31 dB.

For further analysis (WP3) these values will be compared with the collected data for the façade composition, in particular the % ‘weak’ elements, length of the trickle ventilator, glazing composition and the equivalent ‘depth’ of the room. These data have already been listed and roughly looked through for each examined room.

(2) ROOMS WITH MECHANICAL AIR SUPPLY (ventilation system D)

For examined rooms with mechanical air supply, focus has been laid on the noise caused by the functioning of the ventilation system. Therefore background noise levels as well as installation noise in different functioning regimes have been measured in each room. The following measurement data are listed in annex 14 (table AC-3 and AC-7):

L_{Aeq} – k (dB) “OFF” (column 1)
This is the background noise level measured as the A-weighted equivalent sound pressure level when the installation is put out of action. This value has been standardised (term k) throug a reference reverberation time, depending on the room volume, so they can be compared for the different rooms in the different projects.

$L_{Ainstal,nT}$ “ON” (columns 2 to 4)
These are the noise levels calculated from three (one in corner, two in reverberant field) measured A-weighted equivalent sound pressure levels for one functioning regime of the installation, “1” indicating the lowest regime, “3” the highest regime and “2” an intermediate one. These values are also corrected for the reverberation time, likewise the background noise level in the first column.

The values $L_{Ainstal,nT}$ “2” are considered as the “normal” installation noise values since occupants mostly use their installation in regime “2”. That’s why column 3 is highlighted in blue. One has to check of course if this regime assures the necessary air flows. Only an evaluation of the regime delivering enough (not too much) air flow can in fact be reasonably evaluated for the produced noise. In other words, the acoustic measurement data have to be evaluated in close relation to the measured air flow data (see WP3).

As a first approach we can evaluate the measured data according to the criteria of the NBN S 01-400-1 (Residences) and prNBN S 01-400-2 (Schools), without taking into account the corresponding air flow data. The Belgian acoustic criteria regarding installation noise for living rooms, bedrooms and classrooms are given below.

Table 35 Criteria for installation noise in residences according to NBN S 01-400-1:2008

		Normal acoustic comfort $L_{Ainstal, nT}$	Increased acoustic comfort $L_{Ainstal, nT}$
Bathroom / toilet	Mechanical ventilation	≤ 35 dB	≤ 30 dB
	Sanitary appliances	≤ 65 dB	≤ 60 dB
Kitchen	Mechanical ventilation	≤ 35 dB	≤ 30 dB
	Cooker hood	≤ 60 dB	≤ 40 dB
Living room, study	Mechanical ventilation	≤ 30 dB	≤ 27 dB
Bedroom	Mechanical ventilation	≤ 27 dB	≤ 27 dB
Technical rooms with installations for less than 10 houses		≤ 75 dB	≤ 75 dB
Technical rooms with installations for more than 10 houses		≤ 85 dB	≤ 85 dB

We refer to Table 34 for the criteria for stationary service equipment, such as ventilation noise in schools according to prNBN S 01-400-2:2012.

For the examined residential projects (table AC-3, Annex 14), the values for $L_{Ainstal,nT}$ that meet the VC-criteria, i.e. smaller or equal to 27 dB for living rooms and 25 dB for bedrooms, are indicated in green. The values exceeding the normal acoustic comfort level (30 dB for living rooms, 27 dB for bedrooms) are coloured red. Values that meet the NC-criteria (but not the VC-criteria) are shown in orange. When only taken into consideration the values in column 3 (“2”), we see that especially project R1 and R22 are dealing with high installation noise levels. The measurements made in the bedrooms for project R22 are though strongly influenced by the lack of doors, leading to direct noise transmission from the ventilation unit in the hall wall on the second floor. Project R1 is special in a way that this is a timber frame structure. Further analysis (WP3) has to show if this could be the main cause of the relatively high noise levels due to the ventilation system, in spite of the very low background noise levels. In working regime “3” almost all values exceed the normal comfort level imposed by the NBN standard. Project R19 excels remarkably by the low registered noise levels, in spite of the relatively high background levels due to traffic noise. It has to be checked if the criteria for nominal air flows are met in the examined rooms (WP 3).

The results for the two examined schools with mechanical air supply (table AC-7, Annex N), can be evaluated against the normal comfort level 35 dB and the improve comfort level of 31 dB in classrooms (see Table 34). In working regime “2”, we observe no compliance with the NC-criteria for project S5 and for room S7-C1. This last one happens to be a kitchen, so can be considered as practice room where higher noise levels can be allowed. For project S5 relatively high back ground levels were recorded.

The influence of the background noise on the measured installation noise levels has to be considered. Influences are to be expected for very small level differences between the background noise and the installation noise. This is often the case for lowest working regime (“1”).Table AC-4, Annex 15 (residences) and table AC-8, Annex 15 (schools) give the increase of the background noise level due to the ventilation system in regime “2” (column 1). Column 2 and 4 give the increase and decrease of the SPL by rising (2>3) and lowering (2>1) the working regime. These data are to be analysed in WP3 and discussed in the next report.

5.2.5. AIR TIGHTNESS – AIR LEAKAGE

Of the 23 dwellings (the flat considered as 1 building), 20 have been tested for building envelope leakage. In the 3 remaining dwellings (cases 3, 17 and 22), the test could not be executed, either due to the unfinished state of the building envelope, or due to the lack of a suitable window/door opening in which the test could be performed. For the tested dwellings, the bulk leakage flow rate at 50 Pa pressure difference (V_{50}) is reported in the annex. In several cases, the test had been executed very recently. Upon request of the occupants, the test was not repeated in these cases and the results from the first test are reported.

Table 36 Classroom leakage and residence leakage in classrooms and residences

Classrooms leakage (in m^3/h @ 50 Pa)

Average	**941**
SD	1201
RSD	128%
Minimum	94.4
Maximum	4635

Residences leakage (in m^3/h @ 50 Pa)

Average	**1505**
SD	1703
RSD	113%
Minimum	101
Maximum	7234

Mechanical ventilation flow rates were measured in all but 2 dwellings. One occupant refused to cooperate with the measurements (case 9), while in the second case (case 6), all supply and exhaust vents were inaccessible. In the cases that were measured, 9 had at least 1 inaccessible vent, but the majority of vents could be measured. The total measured supply and exhaust flow rates (sum of all supply / exhaust vents respectively) for the measured dwellings are reported in the annex. When possible, the flow rates were measured at the different operation modes of the fan. In these cases, the range of measured values (min – max) is reported. If this was not possible, the system was kept in its usual mode of operation and only 1 value is reported.

Table 37 Classroom and residence mechanical ventilation

Classrooms mechanical ventilation (in m^3/h)

Average	**131**
SD	157
RSD	119%
Minimum	28
Maximum	528

Residences mechanical ventilation (in m^3/h)

Average	**161**
SD	69
RSD	42%
Minimum	43
Maximum	309

5.3. BIOLOGICAL AGENTS

5.3.1. MEASUREMENT OF FUNGI, YEAST AND TOTAL BACTERIA IN BIOAEROSOLS

*Table 38*and *Table 39* show the overview of the fungi, yeast and total bacteria counts in bioaerosols, measured in the schools and houses of Clean Air, Low Energy. The full dataset can be found in annex 17.

Table 38 Descriptive table of fungi, yeast and total bacteria in Clean Air Low Energy schools

Schools indoor (in Total CFU/m^3)

	Fungi + yeast	Total bacteria
Average	1,7E+03	1,1E+04
SD	3,6E+03	1,7E+04
RSD	215%	146%
Minimum	2,1E+01	8,5E+01
Maximum	1,4E+04	5,9E+04

Schools outdoor (in Total CFU/m^3)

	Fungi + yeast	Total bacteria
Average	1,0E+03	1,3E+03
SD	1,2E+03	2,1E+03
RSD	122%	166%
Minimum	1,8E+02	1,8E+02
Maximum	3,2E+03	5,0E+03

Table 39 Descriptive table of fungi, yeast and total bacteria in Clean Air Low Energy residences

Residences indoor average Living room and bedroom (in Total CFU/m^3)

	Fungi + yeast	Total bacteria
Average	1,5E+02	1,4E+03
SD	1,6E+02	2,5E+03
RSD	105%	183%
Minimum	0,0E+00	5,7E+01
Maximum	7,2E+02	1,1E+04

Residences Living room (in Total CFU/m^3)

	Fungi + yeast	Total bacteria
Average	2,0E+02	1,7E+03
SD	2,0E+02	3,2E+03
RSD	101%	194%
Minimum	0,0E+00	6,4E+01
Maximum	7,2E+02	1,1E+04

Residences Bedroom (in Total CFU/m^3)

	Fungi + yeast	Total bacteria
Average	1,0E+02	1,0E+03
SD	8,0E+01	1,4E+03
RSD	80%	136%
Minimum	1,4E+01	5,7E+01
Maximum	3,1E+02	5,2E+03

Residences outdoor (in Total CFU/m^3)

	Fungi + yeast	Total bacteria
Average	4,2E+02	6,4E+02
SD	4,2E+02	1,0E+03
RSD	102%	163%
Minimum	9,9E+01	5,7E+01
Maximum	1,6E+03	3,8E+03

5.3.2. MEASUREMENT OF FUNGI, YEAST AND TOTAL BACTERIA IN SWAP SAMPLES

Table 40 and Table 41 show an overview of the fungi, yeast and bacteria in swap samples, collected in Clean Air, Low Energy schools and houses. The full dataset can be found in annex 18.

Table 40 Descriptive table of fungi, yeast and total bacteria in Clean Air Low Energy schools

(in Total CFU/m^2)

	Fungi	yeast	Total bacteria
Average	1,3E+00	1,1E+01	2,3E+02
SD	2,0E+00	2,1E+01	3,8E+02
RSD	153%	199%	162%
Minimum	5,0E-01	5,0E-01	5,0E-01
Maximum	8,0E+00	7,5E+01	1,2E+03

Table 41 Descriptive table of fungi, yeast and total bacteria in Clean Air Low Energy residences

(in Total CFU/m^2)

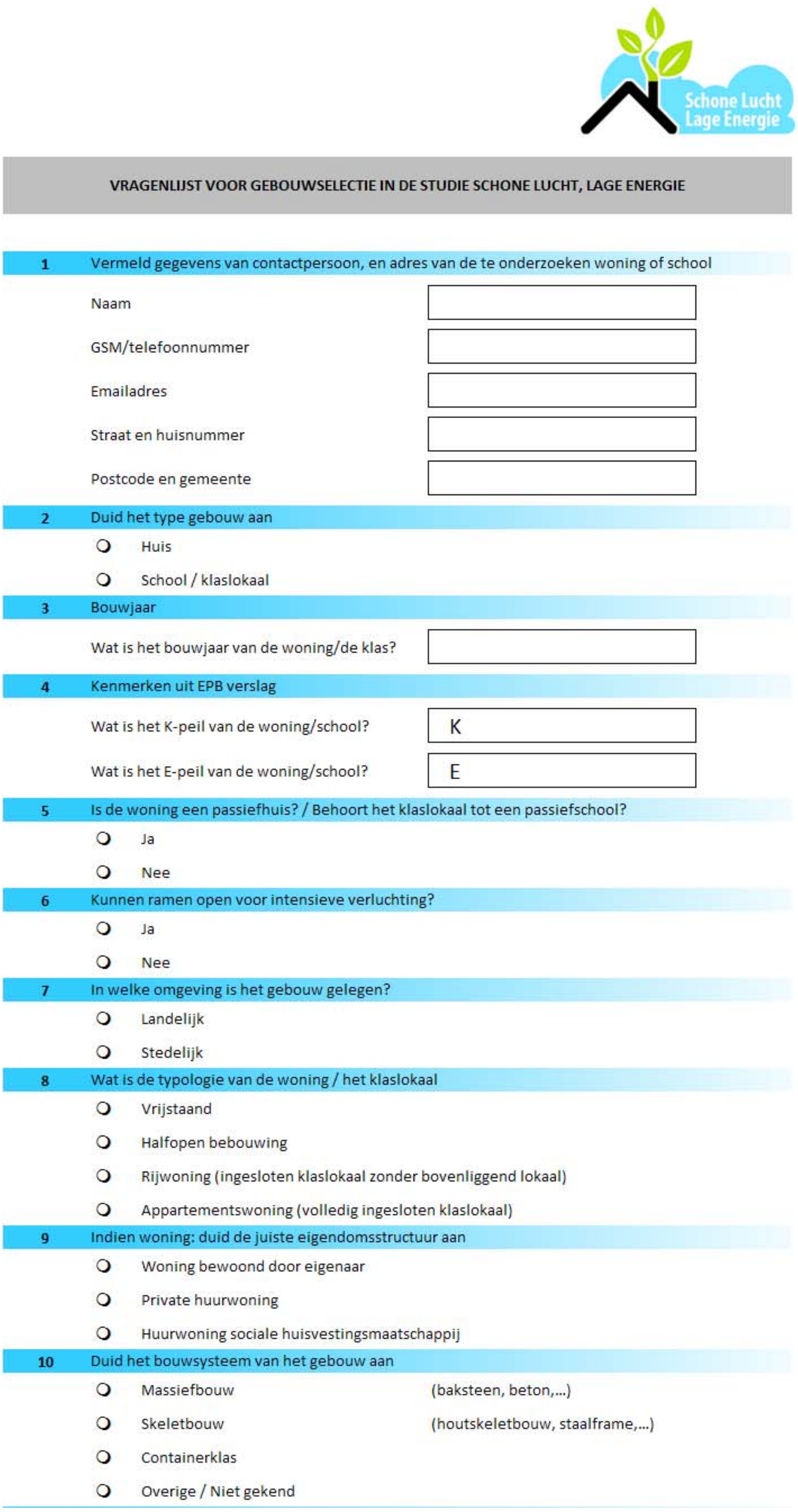
	Fungi	yeast	Total bacteria
Average	5,7E-01	3,7E+00	8,6E+01
SD	2,9E-01	9,0E+00	1,5E+02
RSD	50%	242%	177%
Minimum	5,0E-01	5,0E-01	5,0E-01
Maximum	2,0E+00	4,8E+01	7,8E+02

5.4. CONCLUSION OF RESULTS AND OUTCOMES

This chapter reports all the data, collected in the Clean Air, Low Energy schools and residences. Further analysis of the data will include an evaluation of the concentration levels and data collected in this study, with reference values that originate from previous studies. Furthermore the data will be evaluated to existing guidelines and limit values in indoor air. The relation between the indoor environment and the building envelop and ventilation system will also be explored in WP3.

ANNEX 1: QUESTIONNAIRE FOR RECRUITING

Part 1: Questionnaire for recruiting houses (and schools)



Schone Lucht Lage Energie

VRAGENLIJST VOOR GEBOUWSELECTIE IN DE STUDIE SCHONE LUCHT, LAGE ENERGIE

1 Vermeld gegevens van contactpersoon, en adres van de te onderzoeken woning of school

Naam ☐
GSM/telefoonnummer ☐
Emailadres ☐
Straat en huisnummer ☐
Postcode en gemeente ☐

2 Duid het type gebouw aan

- ○ Huis
- ○ School / klaslokaal

3 Bouwjaar

Wat is het bouwjaar van de woning/de klas? ☐

4 Kenmerken uit EPB verslag

Wat is het K-peil van de woning/school? K
Wat is het E-peil van de woning/school? E

5 Is de woning een passiefhuis? / Behoort het klaslokaal tot een passiefschool?

- ○ Ja
- ○ Nee

6 Kunnen ramen open voor intensieve verluchting?

- ○ Ja
- ○ Nee

7 In welke omgeving is het gebouw gelegen?

- ○ Landelijk
- ○ Stedelijk

8 Wat is de typologie van de woning / het klaslokaal

- ○ Vrijstaand
- ○ Halfopen bebouwing
- ○ Rijwoning (ingesloten klaslokaal zonder bovenliggend lokaal)
- ○ Appartementswoning (volledig ingesloten klaslokaal)

9 Indien woning: duid de juiste eigendomsstructuur aan

- ○ Woning bewoond door eigenaar
- ○ Private huurwoning
- ○ Huurwoning sociale huisvestingsmaatschappij

10 Duid het bouwsysteem van het gebouw aan

- ○ Massiefbouw (baksteen, beton,...)
- ○ Skeletbouw (houtskeletbouw, staalframe,...)
- ○ Containerklas
- ○ Overige / Niet gekend

11 Specifieer het type ventilatiesysteem

- ○ Ventilatiesysteem A: natuurlijke ventilatie
- ○ Ventilatiesysteem B: luchttoevoer via ventilator, luchtafvoer via roosters
- ○ Ventilatiesysteem C: luchttoevoer via rooster, luchtafvoer door ventilator - manueel bediend
- ○ Ventilatiesysteem C: luchttoevoer via rooster, luchtafvoer door ventilator - met vraagsturing
  (aanwezigheidsdetectie, CO2-meting, luchtvochtigheidsmeting,... bvb Renson C+, C+evo, Ducotronic,...)
- ○ Ventilatiesystem D: mechanische toevoer en mechanische afvoer - zonder warmteterugwinning
- ○ Ventilatiesystem D: mechanische toevoer en mechanische afvoer - met warmteterugwinning

12 Indien ventilatiesysteem D: duid aanwezige opties aan

- ○ Aardwarmtewisselaar (grondbuis, 'Canadese put', als voorverwarming of voorkoeling van de ventilatielucht)
- ○ Bodemwarmtewisselaar
  (ondergrondse water- of glycolleiding als voorverwarming voor de ventilatielucht, niet te verwarren met captatienet voor warmtepomp
- ○ Warmtewiel
- ○ Er vindt recirculatie van ventilatielucht plaats
- ○ De ventilatielucht wordt naverwarmd met een verwarmingselement (direct elektrisch, warmtepomp, gas,...)

13 Indien ventilatiesysteem D: welk type kanalen is toegepast?

- ○ Gegalvaniseerde ronde kanalen
- ○ Platte gegalvaniseerde instortkanalen
- ○ Flexibele kunststof kanalen (bvb. Ventichape, Hybalans,...)
- ○ Overige / Niet gekend

14 Werd er een luchtdichtheidsproef (blowerdoortest) uitgevoerd op de woning/het klaslokaal?

- ○ Nee
- ○ Ja (vul hieronder de testresultaten in)

n_{50} waarde (in- / exfiltratievoud)	[h-1 or m^3/h.m^3]
V_{50} waarde (oppervlakteluchtdichtheid)	[m^3/h.m^2]

Part 2: Questionnaire for recruiting schools

VRAGENLIJST VOOR GEBOUWSELECTIE IN DE STUDIE SCHONE LUCHT, LAGE ENERGIE

1 Vermeld gegevens van contactpersoon, en adres van de te onderzoeken school

Naam van de school

Straat en huisnummer

Postcode en gemeente

Naam van de contactpersoon (schooldirectie)

GSM/telefoonnummer

Emailadres

2 Welk deel van het gebouw aan dat voldoet aan de Clean Air Low Energy voorwaarden?

☐ De ganse school

☐ Enkele klaslokalen Aantal lokalen :

3 Welke onze onderwijsgraden volgen lessen in de energiezuinige klassen?

☐ Kleuteronderwijs

☐ Basisonderwijs

☐ Secundair onderwijs

4 Bouwjaar

Wat is het bouwjaar van de E-zuinige klassen?

5 Kenmerken uit EPB verslag

Wat is het K-peil van de energiezuinige klassen? K

Wat is het E-peil van de energiezuinige klassen? E

6 Behoort het klaslokaal (of klaslokalen) tot een passiefschool?

☐ Ja

☐ Nee

7 Kunnen ramen open voor intensieve verluchting?

☐ Ja

☐ Nee

8 In welke omgeving is het gebouw gelegen?

☐ Landelijk

☐ Stedelijk

9 Wat is de typologie van de nieuwbouw / de klaslokalen

☐ Gelijkvloers

☐ Hoogbouw

10 Duid het bouwsysteem van het gebouw aan

☐ Massiefbouw (baksteen, beton,…)

☐ Skeletbouw (houtskeletbouw, staalframe,…)

☐ Modulair systeem

☐ Overige / Niet gekend

11 Specifieer het type ventilatiesysteem

☐ Ventilatiesysteem C: luchttoevoer via rooster, luchtafvoer door ventilator - manueel bediend

☐ Ventilatiesysteem C: luchttoevoer via rooster, luchtafvoer door ventilator - met vraagsturing

(aanwezigheidsdetectie, CO2-meting, luchtvochtigheidsmeting,… bvb Renson C+, C+evo, Ducotronic,…)

☐ Ventilatiesystem D: mechanische toevoer en mechanische afvoer - zonder warmteterugwinning

☐ Ventilatiesystem D: mechanische toevoer en mechanische afvoer - met warmteterugwinning

12 Indien ventilatiesysteem D: duid aanwezige opties aan

☐ Aardwarmtewisselaar (grondbuis, 'Canadese put', als voorverwarming of voorkoeling van de ventilatielucht)

☐ Bodemwarmtewisselaar

(ondergrondse water- of glycolleiding als voorverwarming voor de ventilatielucht, niet te verwarren met captatienet voor warmtepomp

☐ Warmtewiel

☐ Er vindt recirculatie van ventilatielucht plaats

☐ De ventilatielucht wordt naverwarmd met een verwarmingselement (direct elektrisch, warmtepomp, gas,…)

13 Op welke wijze wordt de luchttoevoer naar de geventileerde klassen geregeld?

☐ Eén ventilator, voor verschillende klaslokalen

☐ Eén ventilator per klaslokaal

14 Werd er een luchtdichtheidsproef (blowerdoortest) uitgevoerd op het klaslokaal?

☐ Nee

☐ Ja, op klaslokaalniveau (vul hieronder de testresultaten in)

n_{50} waarde (in- / exfiltratievoud) [h-1 or $m^3/h.m^3$]

V_{50} waarde (oppervlakteluchtdichtheid) [$m^3/h.m^2$]

☐ Ja, op schoolniveau (vul hieronder de testresultaten in)

n_{50} waarde (in- / exfiltratievoud) [h-1 or $m^3/h.m^3$]

V_{50} waarde (oppervlakteluchtdichtheid) [$m^3/h.m^2$]

ANNEX 2: PREPARATION OF THE BIOLOGICAL FIELDWORK

Mol, 7 November 2011

Schone Lucht
Lage Energie

Beste deelnemer aan Clean Air, Low Energy,

Uw woning werd geselecteerd voor deelname aan het onderzoek 'Clean air, Low Energy'. Wij wensen u hierbij alvast te bedanken voor uw deelname.

Zoals u via e-mail werd toegelicht, bestaat dit onderzoek uit drie delen:

(1) luchtkwaliteitsonderzoek (VITO),

(2) biologisch onderzoek (Labo Servaco),

(3) onderzoek van het ventilatiesysteem (Universiteit Gent en WTCB).

Elk deel wordt door een ander onderzoeksteam uitgevoerd. Elk team neemt daarom in de nabije toekomst contact op om met u een afspraak in te plannen (mogelijks werd u reeds gecontacteerd).

Dit postpak is een noodzakelijk onderdeel van **biologisch onderzoek**. Uw hulp bij dit onderzoek is dan ook erg belangrijk. Dit pakket bevat 2 plastiek schalen. Voorlopig dient u nog geen actie te ondernemen en moeten de schaaltjes gesloten blijven. Binnenkort zal labo Servaco u contacteren. We vragen u dan om dit pakket te openen en **zowel in uw woonkamer als in uw slaapkamer, gedurende één week een geopende schaal (d.i. twee helften naast elkaar) te plaatsen.**

U gaat hierbij als volgt tewerk:

Stap 1: Eén week voor hun bezoek aan uw woning wordt u telefonisch gecontacteerd voor het team voor biologisch onderzoek, dit is Labo Servaco

Stap 2: Diezelfde dag legt u een plastiekschaaltje geopend (twee helften naast elkaar) zowel in uw woonkamer als in uw slaapkamer.

Stap 3: U selecteert hiervoor een plek, bijvoorbeeld op een kast, die:

- Op een hoogte van ongeveer 1.5m is
- Buiten bereik van kinderen/huisdieren is (de binnenkant van het schaaltje mag niet aangeraakt worden)
- Niet dichter dat 1m bij een raamopening of deuropening ligt

Stap 4: U opent beide schaaltjes zonder de binnenkant ervan aan te raken

Stap 5: U plaatst het bijgevoegd papier 'Gelieve niet aan te raken of te verplaatsen' naast de doosjes en informeert de andere bewoners van uw woning en eventueel poetspersoneel.

Binnen de week komt Labo Servaco een zogenaamd 'veegstaal' van de binnenkant van de schaaltjes nemen. Zij vegen dan met een doekje het oppervlak schoon en onderzoeken nadien het doekje op aanwezige schimmels en bacteriën in uw woonkamer en slaapkamer. Vingerafdrukken in het schaaltje zouden bijgevolg een vertekend beeld van uw woning geven. Gelieve op bijgevoegde vragenlijst in te vullen, en eventuele 'incidenten' (bvb schaaltje werd toch aangeraakt, huisdier liep erover, …) te melden.

Stap 6: Na het bezoek van labo Servaco vult u bijgevoegde vragenlijst in. U kan de ingevulde enquête versturen naar VITO, Luchtkwaliteitsmetingen, tav Françoise Geyskens; Boeretang 200; 2400 Mol of terugmailen naar Francoise.Geyskens@vito.be

Alvast bedankt voor uw hulp,

Indien u hierover nog vragen heeft, kunt u contact opnemen met Françoise Geyskens (014 33 69 57) of met Marianne Stranger (014 33 69 52)

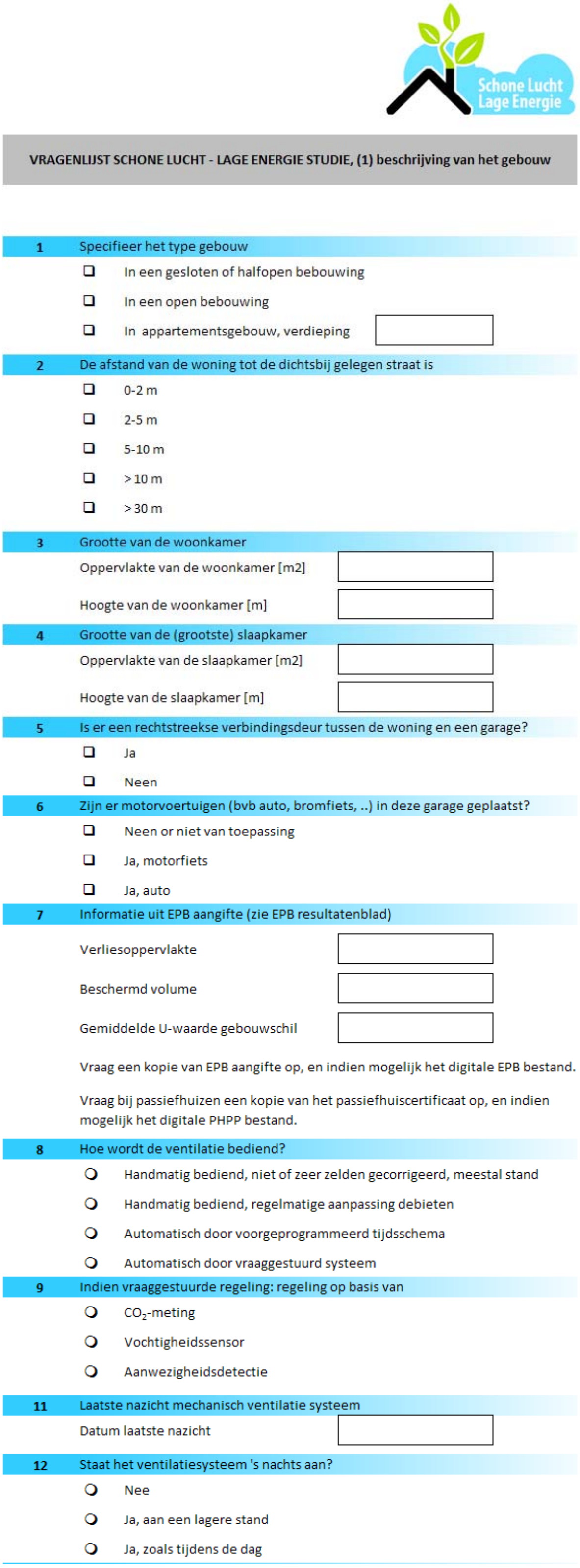
Met vriendelijke groeten
het 'Schone Lucht, Lage Energie' Onderzoeksteam

DIT IS ONDERZOEKSMATERIAL

GELIEVE NIET AAN TE RAKEN
EN NIET TE VERPLAATSEN

ANNEX 3 QUESTIONNAIRE FOR FIELDWORK

In the houses (part 1, part 2 and part 3)



Schone Lucht Lage Energie

VRAGENLIJST SCHONE LUCHT - LAGE ENERGIE STUDIE, (1) beschrijving van het gebouw

1 Specifieer het type gebouw

☐ In een gesloten of halfopen bebouwing

☐ In een open bebouwing

☐ In appartementsgebouw, verdieping ☐

2 De afstand van de woning tot de dichtsbij gelegen straat is

☐ 0-2 m

☐ 2-5 m

☐ 5-10 m

☐ > 10 m

☐ > 30 m

3 Grootte van de woonkamer

Oppervlakte van de woonkamer [m2] ☐

Hoogte van de woonkamer [m] ☐

4 Grootte van de (grootste) slaapkamer

Oppervlakte van de slaapkamer [m2] ☐

Hoogte van de slaapkamer [m] ☐

5 Is er een rechtstreekse verbindingsdeur tussen de woning en een garage?

☐ Ja

☐ Neen

6 Zijn er motorvoertuigen (bvb auto, bromfiets, ..) in deze garage geplaatst?

☐ Neen or niet van toepassing

☐ Ja, motorfiets

☐ Ja, auto

7 Informatie uit EPB aangifte (zie EPB resultatenblad)

Verliesoppervlakte ☐

Beschermd volume ☐

Gemiddelde U-waarde gebouwschil ☐

Vraag een kopie van EPB aangifte op, en indien mogelijk het digitale EPB bestand.

Vraag bij passiefhuizen een kopie van het passiefhuiscertificaat op, en indien mogelijk het digitale PHPP bestand.

8 Hoe wordt de ventilatie bediend?

○ Handmatig bediend, niet of zeer zelden gecorrigeerd, meestal stand

○ Handmatig bediend, regelmatige aanpassing debieten

○ Automatisch door voorgeprogrammeerd tijdsschema

○ Automatisch door vraaggestuurd systeem

9 Indien vraaggestuurde regeling: regeling op basis van

○ CO_2-meting

○ Vochtigheidssensor

○ Aanwezigheidsdetectie

11 Laatste nazicht mechanisch ventilatie systeem

Datum laatste nazicht ☐

12 Staat het ventilatiesysteem 's nachts aan?

○ Nee

○ Ja, aan een lagere stand

○ Ja, zoals tijdens de dag

13 Ramen

☐ Ramen met dubbele beglazing

☐ Ramen met drievoudige beglazing

14 Is er een dampkap boven het fornuis?

○ Nee

○ Ja, met afvoer

○ Ja, met een eigen opvangsysteem (koolstoffilter)

15 Is er luchtkoeling ('airco') aanwezig?

○ Ja

○ Nee

16 Indien ventilatiesysteem C: Zijn de verluchtingsroosters zichtbaar bevuild?

Ventilatiesysteem C = verluchtingsroosters en mechanische afvoer van lucht

○ Ja

○ Neen

17 Indien ventilatiesysteem D: Is de luchttoevoermond zichtbaar bevuild?

Ventilatiesysteem D = mechanische aan- en afvoer van lucht in het klaslokaal

○ Ja

○ Neen

18 Indien ventilatiesysteem D: Specifieer het type filter in het systeem

Filtertype

19 Indien ventilatiesysteem D: Hoe vaak worden de filters vervangen?

○ Nooit (of nog nooit tot op heden)

○ Jaarlijks

○ 2x per jaar

○ Vaker dan 2x per jaar

20 Indien ventilatiesysteem D: Hoe vaak worden de kanalen gereinigd?

○ Nooit (of nog nooit tot op heden)

○ 2-jaarlijks

○ Jaarlijks

○ Vaker dan 1x per jaar

21 Indien ventilatiesysteem D: Is er een zomerbypass aanwezig in

○ Nee / onbekend

○ Ja, gedeeltelijke bypass

○ Ja, volledige bypass mogelijk

22 Welke van onderstaande materialen/producten komen voor in de woonkamer

Type vloerbekleding

○ vloertegels

○ tapijt

○ linoleum

○ andere:

Behandeling muren

○ geschilderd

○ behangpapier

○ vinylbehangpapier

○ andere:

Type plafond

○ welfsels bezet en geverfd

○ gyprocpanelen en geverfd

○ kunststofpanelen

○ houten panelen

○ andere:

Type gordijnen

○ stof (textiel)

○ kunststof (zonneblinden)

○ andere:

Wekelijks gebruikte producten in de woonkamer

○ reinigingsproducten

○ luchtverfrisser (spray, elektrisch, ..)

○ boenwasproducten

○ hobby: lijmen, verven, vernissen

○ andere:

Meubilair

○ vezelplaat

○ massief

○ kunststof (sommige kunststoffen hebben houtpatroon)

○ andere materialen

23 Vraag een kopie van onderstaande documentatie op

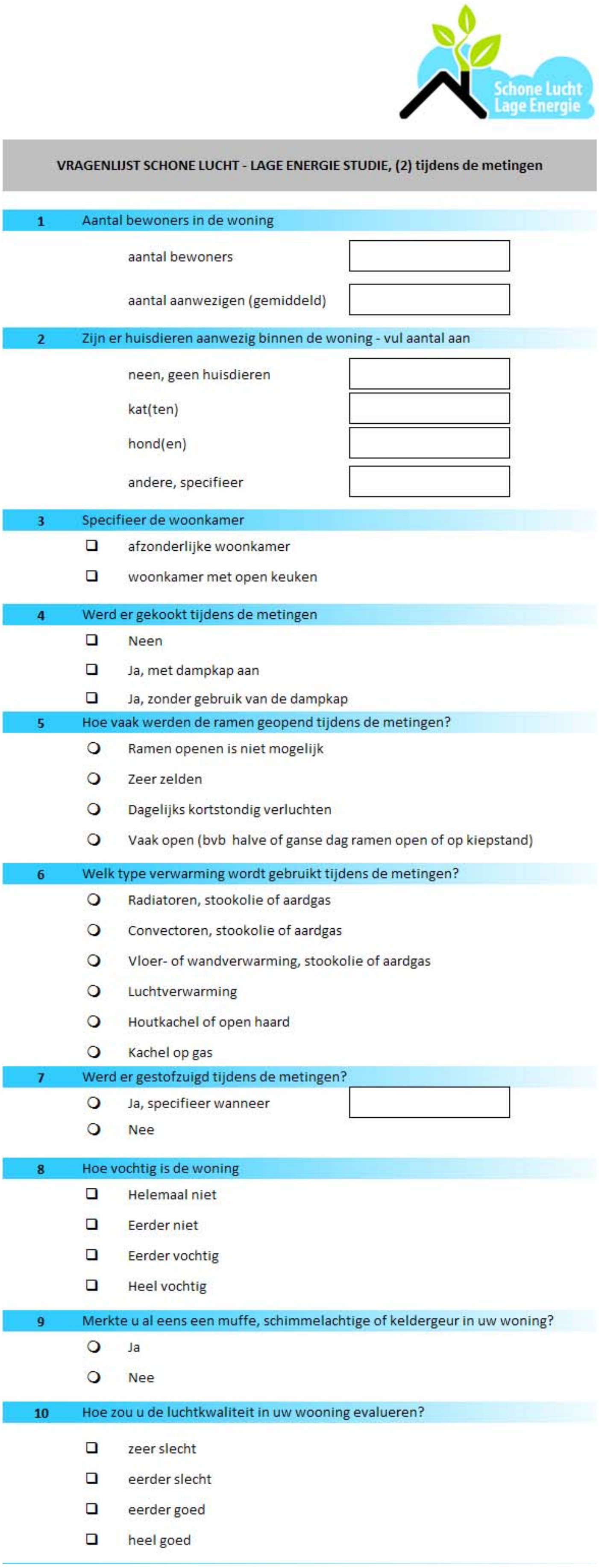
☐ Verslag EPB aangifte

☐ Digitale kopie van EPB bestand (indien mogelijk)

☐ Bij passiefhuis: Passiefhuiscertificaat

☐ Bij passiefhuis: digitala kopie van PHPP-berekening (indien mogelijk)

☐ Inregelrapport ventilatie (indien beschikbaar)



VRAGENLIJST SCHONE LUCHT - LAGE ENERGIE STUDIE, (2) tijdens de metingen

1 Aantal bewoners in de woning

aantal bewoners	
aantal aanwezigen (gemiddeld)	

2 Zijn er huisdieren aanwezig binnen de woning - vul aantal aan

neen, geen huisdieren	
kat(ten)	
hond(en)	
andere, specifieer	

3 Specifieer de woonkamer

- ☐ afzonderlijke woonkamer
- ☐ woonkamer met open keuken

4 Werd er gekookt tijdens de metingen

- ☐ Neen
- ☐ Ja, met dampkap aan
- ☐ Ja, zonder gebruik van de dampkap

5 Hoe vaak werden de ramen geopend tijdens de metingen?

- ○ Ramen openen is niet mogelijk
- ○ Zeer zelden
- ○ Dagelijks kortstondig verluchten
- ○ Vaak open (bvb halve of ganse dag ramen open of op kiepstand)

6 Welk type verwarming wordt gebruikt tijdens de metingen?

- ○ Radiatoren, stookolie of aardgas
- ○ Convectoren, stookolie of aardgas
- ○ Vloer- of wandverwarming, stookolie of aardgas
- ○ Luchtverwarming
- ○ Houtkachel of open haard
- ○ Kachel op gas

7 Werd er gestofzuigd tijdens de metingen?

- ○ Ja, specifieer wanneer
- ○ Nee

8 Hoe vochtig is de woning

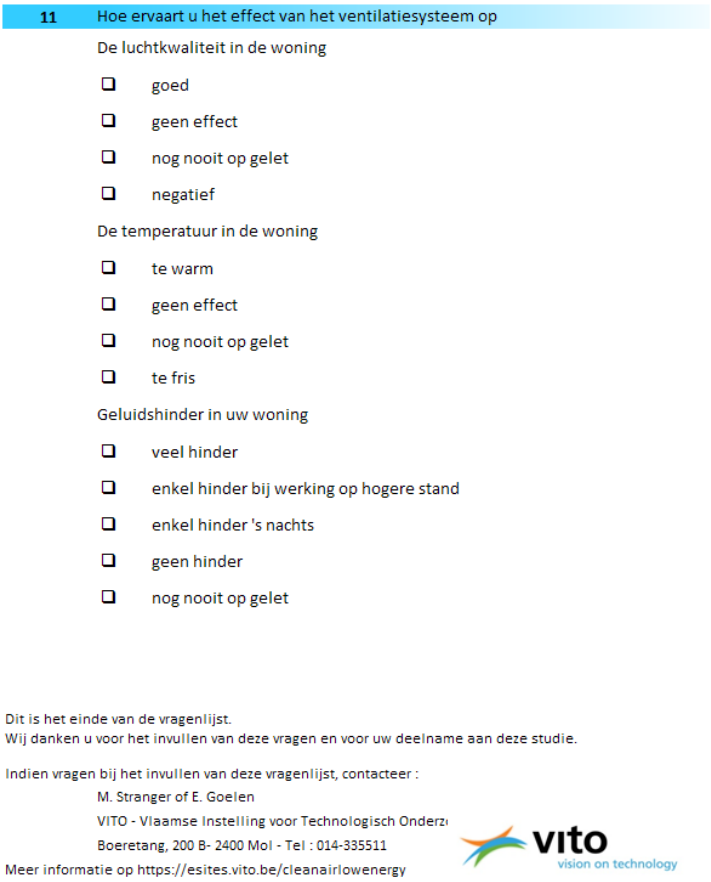
- ☐ Helemaal niet
- ☐ Eerder niet
- ☐ Eerder vochtig
- ☐ Heel vochtig

9 Merkte u al eens een muffe, schimmelachtige of keldergeur in uw woning?

- ○ Ja
- ○ Nee

10 Hoe zou u de luchtkwaliteit in uw wooning evalueren?

- ☐ zeer slecht
- ☐ eerder slecht
- ☐ eerder goed
- ☐ heel goed



11 Hoe ervaart u het effect van het ventilatiesysteem op

De luchtkwaliteit in de woning

- ☐ goed
- ☐ geen effect
- ☐ nog nooit op gelet
- ☐ negatief

De temperatuur in de woning

- ☐ te warm
- ☐ geen effect
- ☐ nog nooit op gelet
- ☐ te fris

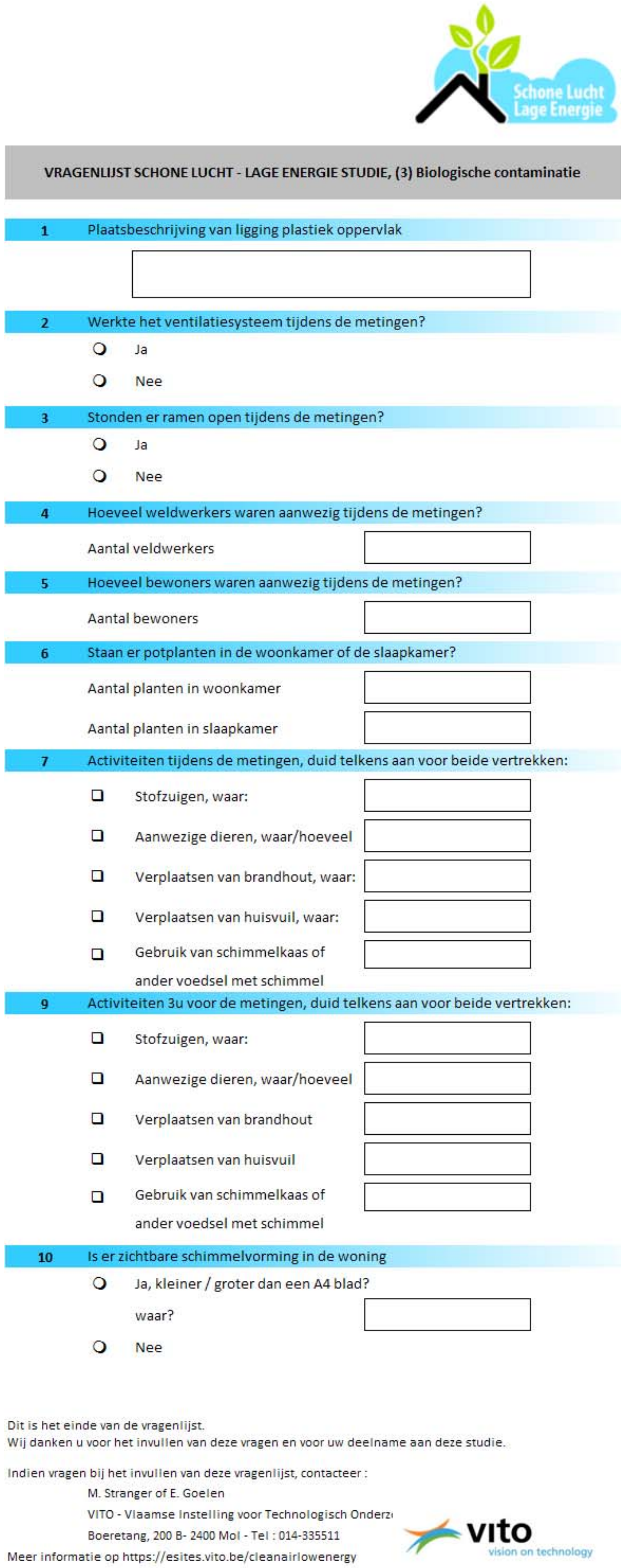
Geluidshinder in uw woning

- ☐ veel hinder
- ☐ enkel hinder bij werking op hogere stand
- ☐ enkel hinder 's nachts
- ☐ geen hinder
- ☐ nog nooit op gelet

Dit is het einde van de vragenlijst.
Wij danken u voor het invullen van deze vragen en voor uw deelname aan deze studie.

Indien vragen bij het invullen van deze vragenlijst, contacteer :
M. Stranger of E. Goelen
VITO - Vlaamse Instelling voor Technologisch Onderz
Boeretang, 200 B- 2400 Mol - Tel : 014-335511
Meer informatie op https://esites.vito.be/cleanairlowenergy

Annex 3 Questionnaire for Fieldwork



VRAGENLIJST SCHONE LUCHT - LAGE ENERGIE STUDIE, (3) Biologische contaminatie

1 Plaatsbeschrijving van ligging plastiek oppervlak

2 Werkte het ventilatiesysteem tijdens de metingen?

○ Ja

○ Nee

3 Stonden er ramen open tijdens de metingen?

○ Ja

○ Nee

4 Hoeveel weldwerkers waren aanwezig tijdens de metingen?

Aantal veldwerkers

5 Hoeveel bewoners waren aanwezig tijdens de metingen?

Aantal bewoners

6 Staan er potplanten in de woonkamer of de slaapkamer?

Aantal planten in woonkamer

Aantal planten in slaapkamer

7 Activiteiten tijdens de metingen, duid telkens aan voor beide vertrekken:

- ☐ Stofzuigen, waar:
- ☐ Aanwezige dieren, waar/hoeveel
- ☐ Verplaatsen van brandhout, waar:
- ☐ Verplaatsen van huisvuil, waar:
- ☐ Gebruik van schimmelkaas of ander voedsel met schimmel

9 Activiteiten 3u voor de metingen, duid telkens aan voor beide vertrekken:

- ☐ Stofzuigen, waar:
- ☐ Aanwezige dieren, waar/hoeveel
- ☐ Verplaatsen van brandhout
- ☐ Verplaatsen van huisvuil
- ☐ Gebruik van schimmelkaas of ander voedsel met schimmel

10 Is er zichtbare schimmelvorming in de woning

○ Ja, kleiner / groter dan een A4 blad?

waar?

○ Nee

Dit is het einde van de vragenlijst.
Wij danken u voor het invullen van deze vragen en voor uw deelname aan deze studie.

Indien vragen bij het invullen van deze vragenlijst, contacteer :
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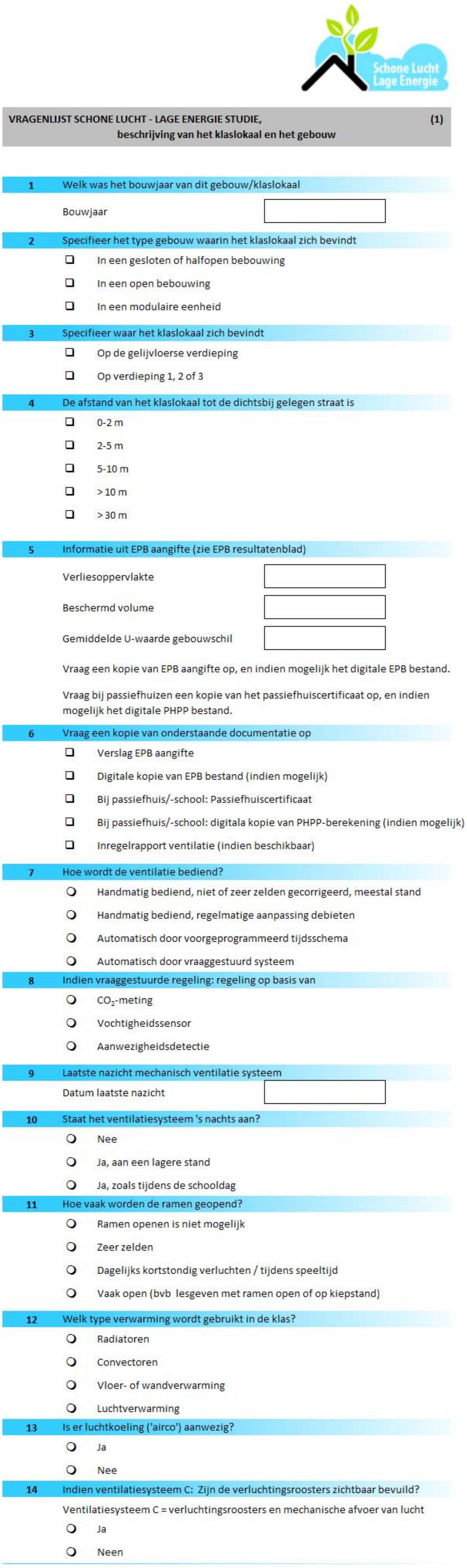


Schone Lucht
Lage Energie

VRAGENLIJST SCHONE LUCHT - LAGE ENERGIE STUDIE, (1)
beschrijving van het klaslokaal en het gebouw

1 Welk was het bouwjaar van dit gebouw/klaslokaal

Bouwjaar

2 Specifieer het type gebouw waarin het klaslokaal zich bevindt

- ☐ In een gesloten of halfopen bebouwing
- ☐ In een open bebouwing
- ☐ In een modulaire eenheid

3 Specifieer waar het klaslokaal zich bevindt

- ☐ Op de gelijkvloerse verdieping
- ☐ Op verdieping 1, 2 of 3

4 De afstand van het klaslokaal tot de dichtsbij gelegen straat is

- ☐ 0-2 m
- ☐ 2-5 m
- ☐ 5-10 m
- ☐ > 10 m
- ☐ > 30 m

5 Informatie uit EPB aangifte (zie EPB resultatenblad)

Verliesoppervlakte

Beschermd volume

Gemiddelde U-waarde gebouwschil

Vraag een kopie van EPB aangifte op, en indien mogelijk het digitale EPB bestand.

Vraag bij passiefhuizen een kopie van het passiefhuiscertificaat op, en indien mogelijk het digitale PHPP bestand.

6 Vraag een kopie van onderstaande documentatie op

- ☐ Verslag EPB aangifte
- ☐ Digitale kopie van EPB bestand (indien mogelijk)
- ☐ Bij passiefhuis/-school: Passiefhuiscertificaat
- ☐ Bij passiefhuis/-school: digitala kopie van PHPP-berekening (indien mogelijk)
- ☐ Inregelrapport ventilatie (indien beschikbaar)

7 Hoe wordt de ventilatie bediend?

- ○ Handmatig bediend, niet of zeer zelden gecorrigeerd, meestal stand
- ○ Handmatig bediend, regelmatige aanpassing debieten
- ○ Automatisch door voorgeprogrammeerd tijdsschema
- ○ Automatisch door vraaggestuurd systeem

8 Indien vraaggestuurde regeling: regeling op basis van

- ○ CO_2-meting
- ○ Vochtigheidssensor
- ○ Aanwezigheidsdetectie

9 Laatste nazicht mechanisch ventilatie systeem

Datum laatste nazicht

10 Staat het ventilatiesysteem 's nachts aan?

- ○ Nee
- ○ Ja, aan een lagere stand
- ○ Ja, zoals tijdens de schooldag

11 Hoe vaak worden de ramen geopend?

- ○ Ramen openen is niet mogelijk
- ○ Zeer zelden
- ○ Dagelijks kortstondig verluchten / tijdens speeltijd
- ○ Vaak open (bvb lesgeven met ramen open of op kiepstand)

12 Welk type verwarming wordt gebruikt in de klas?

- ○ Radiatoren
- ○ Convectoren
- ○ Vloer- of wandverwarming
- ○ Luchtverwarming

13 Is er luchtkoeling ('airco') aanwezig?

- ○ Ja
- ○ Nee

14 Indien ventilatiesysteem C: Zijn de verluchtingsroosters zichtbaar bevuild?

Ventilatiesysteem C = verluchtingsroosters en mechanische afvoer van lucht

- ○ Ja
- ○ Neen

15 Indien ventilatiesysteem D: Is de luchttoevoermond zichtbaar bevuild?

Ventilatiesysteem D = mechanische aan- en afvoer van lucht in het klaslokaal

○ Ja

○ Neen

16 Indien ventilatiesysteem D: Hoe vaak worden de filters vervangen?

○ Nooit (of nog nooit tot op heden)

○ Jaarlijks

○ 2x per jaar

○ Vaker dan 2x per jaar

17 Indien ventilatiesysteem D: Hoe vaak worden de kanalen gereinigd?

○ Nooit (of nog nooit tot op heden)

○ 2-jaarlijks

○ Jaarlijks

○ Vaker dan 1x per jaar

18 Indien ventilatiesysteem D: Is er een zomerbypass aanwezig in

○ Nee / onbekend

○ Ja, gedeeltelijke bypass

○ Ja, volledige bypass mogelijk

19 Welke van onderstaande materialen of producten komen voor in het klaslokaal

Type vloerbekleding

○ vloertegels

○ tapijt

○ linoleum

○ andere:

Behandeling muren

○ geschilderd

○ behangpapier

○ vinylbehangpapier

○ andere:

Type plafond

○ welfsels bezet en geverfd

○ gyprocpanelen en geverfd

○ kunststofpanelen

○ houten panelen

○ andere:

Type gordijnen

○ stof (textiel)

○ kunststof (zonneblinden)

○ andere:

Regelmatig gebruikte producten

○ vernis

○ verf

○ kleefmiddelen

○ bordstiften

○ schoolbordkrijt

○ andere:

Meubilair

○ vezelplaat

○ massief

○ kunststof

(sommige kunststoffen hebben houtpatroon)

○ andere materialen

Schone Lucht
Lage Energie

VRAGENLIJST SCHONE LUCHT - LAGE ENERGIE STUDIE (2), tijdens de staalname

1 Klasactiviteiten tijdens de staalname. Vul aan

Aantal leerlingen aanwezig in de klas

maandag	
dinsdag	
woensdag	
donderdag	
vrijdag	

Reinigen van de vloer, meubels of ramen met een product

type product	

☐ zelden gebruikt
☐ dikwijls gebruikt

Gebruik van luchtverfrissers in het klaslokaal

type product	

☐ zelden gebruikt
☐ dikwijls gebruikt

2 Wordt het klaslokaal na de schooluren nog voor andere doeleinden gebruikt

○ Ja, specifieer doel en tijdstip
○ Nee

3 Hoe vochtig is het klaslokaal gewoonlijk?

☐ helemaal niet
☐ eerder niet
☐ eerder vochtig
☐ heel vochtig

4 Merkte u al eens een muffe, schimmelachtige of keldergeur in uw klas?

○ Ja
○ Nee

5 Is er zichtbare vochtschade in de klas?

○ Ja
○ Nee

6 Is er zichtbare schimmelvorming in de klas?

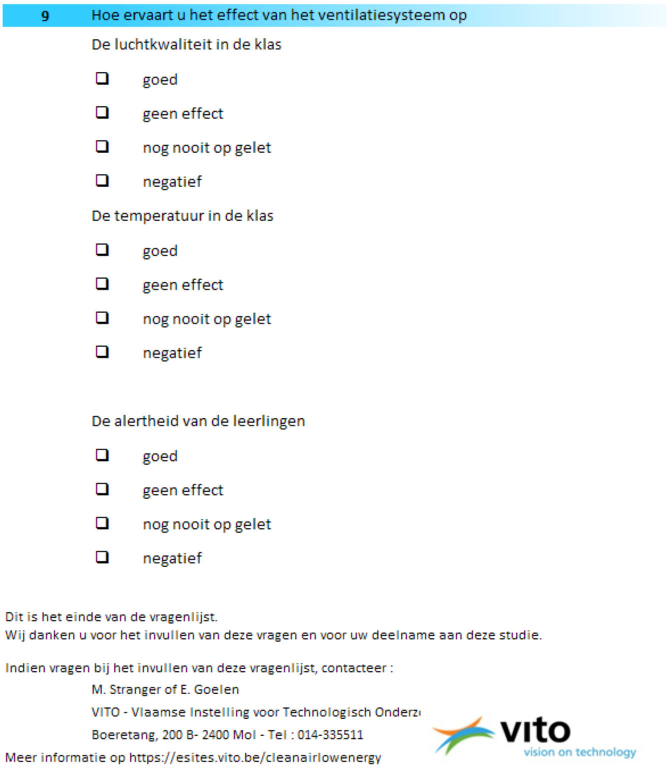
○ Ja, kleiner / groter dan een A4 blad?
○ Nee

7 Hoe stoffig is het klaslokaal gewoonlijk?

☐ helemaal niet
☐ eerder niet
☐ eerder stoffig
☐ heel stoffig

8 Hoe zou u de luchtkwaliteit in uw klas evalueren?

☐ zeer slecht
☐ eerder slecht
☐ eerder goed
☐ heel goed



9 Hoe ervaart u het effect van het ventilatiesysteem op

De luchtkwaliteit in de klas

☐ goed
☐ geen effect
☐ nog nooit op gelet
☐ negatief

De temperatuur in de klas

☐ goed
☐ geen effect
☐ nog nooit op gelet
☐ negatief

De alertheid van de leerlingen

☐ goed
☐ geen effect
☐ nog nooit op gelet
☐ negatief

Dit is het einde van de vragenlijst.
Wij danken u voor het invullen van deze vragen en voor uw deelname aan deze studie.

Indien vragen bij het invullen van deze vragenlijst, contacteer :
M. Stranger of E. Goelen
VITO - Vlaamse Instelling voor Technologisch Onderz
Boeretang, 200 B- 2400 Mol - Tel : 014-335511
Meer informatie op https://esites.vito.be/cleanairlowenergy

BELANGRIJK – VRAAG GERICHT AAN DE DIRECTIE

Met het oog op sensibilisering en vergroten van de bekendheid van dit onderzoeksproject, plaatsen wij graag de coördinaten van uw school en foto's van de meetapparatuur in de deelnemende klassen op onze projectwebsite http://wwwb.vito.be/flies.

Het is belangrijk te weten dat geen enkel bekomen resultaat gekoppeld zal worden aan de namen van deelnemende scholen.

Gelieve uw akkoord hiervoor op deze pagina te bevestigen.

Naam School: ________________________________

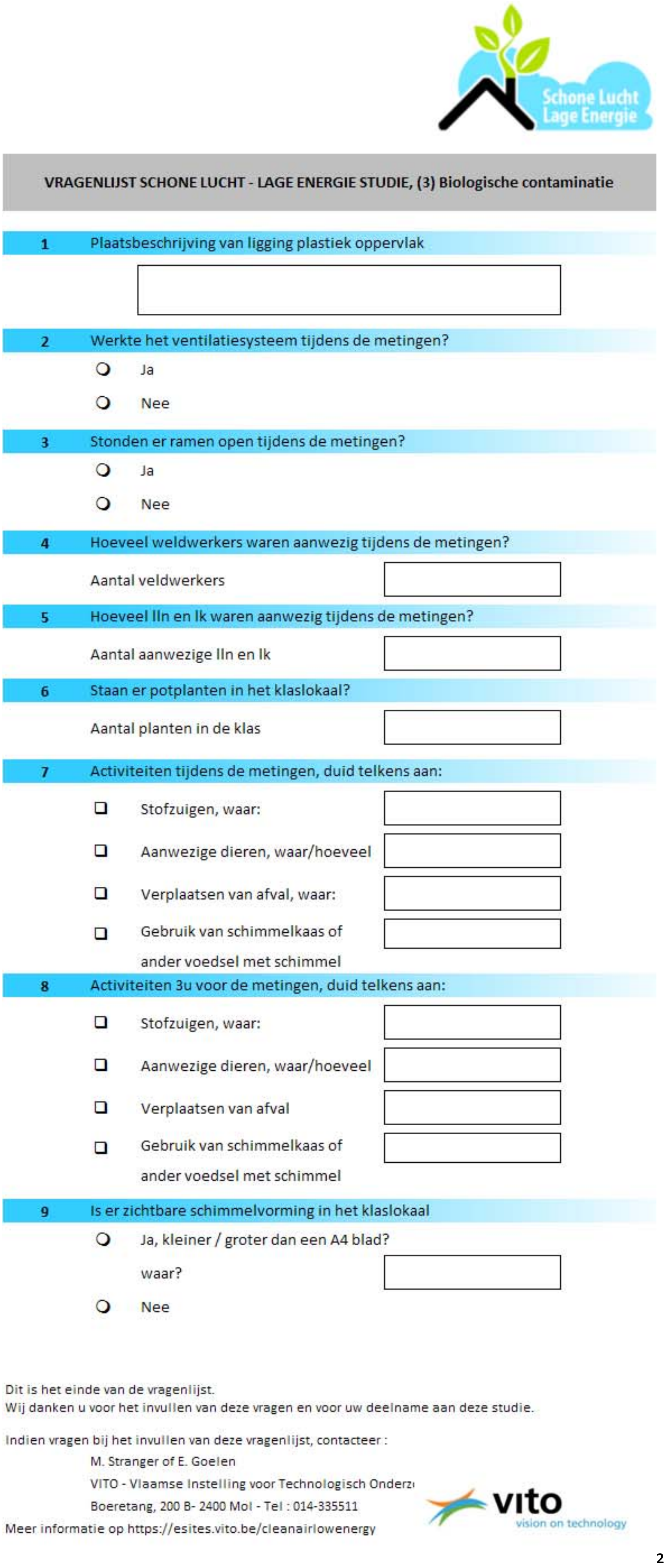
Adres School: ________________________________

____

De directie gaat **akkoord** / **niet akkoord** met de vermelding van naam, adres en foto's genomen op school en in de klassen op de website http://wwwb.vito.be/flies
(gelieve te schappen wat niet past)

naam + handtekening directie

Datum: ________________________________



Schone Lucht
Lage Energie

VRAGENLIJST SCHONE LUCHT - LAGE ENERGIE STUDIE, (3) Biologische contaminatie

1 Plaatsbeschrijving van ligging plastiek oppervlak

☐

2 Werkte het ventilatiesysteem tijdens de metingen?

○ Ja

○ Nee

3 Stonden er ramen open tijdens de metingen?

○ Ja

○ Nee

4 Hoeveel weldwerkers waren aanwezig tijdens de metingen?

Aantal veldwerkers ☐

5 Hoeveel lln en lk waren aanwezig tijdens de metingen?

Aantal aanwezige lln en lk ☐

6 Staan er potplanten in het klaslokaal?

Aantal planten in de klas ☐

7 Activiteiten tijdens de metingen, duid telkens aan:

☐ Stofzuigen, waar: ☐

☐ Aanwezige dieren, waar/hoeveel ☐

☐ Verplaatsen van afval, waar: ☐

☐ Gebruik van schimmelkaas of ander voedsel met schimmel ☐

8 Activiteiten 3u voor de metingen, duid telkens aan:

☐ Stofzuigen, waar: ☐

☐ Aanwezige dieren, waar/hoeveel ☐

☐ Verplaatsen van afval ☐

☐ Gebruik van schimmelkaas of ander voedsel met schimmel ☐

9 Is er zichtbare schimmelvorming in het klaslokaal

○ Ja, kleiner / groter dan een A4 blad?

waar? ☐

○ Nee

Dit is het einde van de vragenlijst.
Wij danken u voor het invullen van deze vragen en voor uw deelname aan deze studie.

Indien vragen bij het invullen van deze vragenlijst, contacteer :
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ANNEX 4 VOC LEVELS IN CLEAN AIR LOW ENERGY SCHOOLS AND RESIDENCES

Indoor VOC concentrations at school

Average concentrations (µg/m³) per location, per component

Location	Vito-nr	MTBE	Benzene	Trichloroethene	Toluene	Tetrachloroethene	Ethylbenzene	m- + p-Xylene	Styrene	o-Xylene	1,2,4-Trimethyl-benzene	1,4-Dichloro-benzene	tVOC	Hexane	Heptane	Cyclohexane	n-Butylacetate	α-Pinene	3-Carene	d10-Limonene
S1-C1	**20110949**	0,36	1,22	**0,100**	4,1	**0,100**	0,72	1,85	**0,100**	0,69	2,05	**0,100**	244	1,27	0,70	0,89	1,90	6,2	3,4	1,10
S1-C2	**20110950**	0,41	1,24	**0,100**	4,3	**0,100**	0,74	1,85	**0,100**	0,72	1,59	**0,100**	278	1,57	0,61	0,91	2,04	5,2	3,2	1,00
S2-C1	**20110960**	**0,100**	0,264	**0,100**	10,9	**0,100**	1,67	5,7	**0,100**	2,10	0,49	**0,100**	226	0,42	3,8	11,2	8,5	0,37	0,49	0,82
S2-C2	**20110961**	**0,100**	0,293	**0,100**	9,4	**0,100**	0,58	1,64	**0,100**	0,71	0,214	**0,100**	239	0,51	3,7	12,8	3,3	0,71	0,84	1,51
S2-C3	**20110962**	**0,100**	**0,100**	**0,100**	8,6	**0,100**	1,15	2,85	**0,100**	0,63	0,247	**0,100**	296	0,58	1,66	72	1,42	1,73	1,26	2,19
S3-C1	**20111012**	**0,100**	0,45	**0,100**	3,7	**0,100**	0,211	0,55	**0,100**	**0,100**	0,35	**0,100**	220	0,54	0,35	1,14	1,56	0,99	1,45	0,50
S3-C2	**20111013**	0,275	0,56	**0,100**	4,7	**0,100**	0,30	0,79	**0,100**	0,278	0,60	**0,100**	338	0,92	0,60	9,6	0,98	3,7	4,9	1,60
S3-C3	**20111014**	**0,100**	0,38	**0,100**	4,2	**0,100**	0,251	0,61	**0,100**	0,225	0,35	**0,100**	247	0,45	0,260	0,42	1,21	1,84	0,88	0,99
S4-C1	**20111339**	**0,100**	0,67	**0,100**	0,97	**0,100**	**0,100**	0,296	**0,100**	**0,100**	0,273	0,207	184	0,282	**0,100**	0,266	0,201	1,23	0,53	11,3
S4-C1-d	**20111343**	**0,100**	0,69	**0,100**	0,94	**0,100**	**0,100**	0,287	**0,100**	**0,100**	0,269	0,213	239	0,31	**0,100**	0,287	0,215	1,19	0,48	10,9
S4-C2	**20111340**	**0,100**	0,67	**0,100**	1,34	**0,100**	**0,100**	0,32	**0,100**	**0,100**	0,31	**0,100**	220	0,299	**0,100**	0,238	1,11	2,20	1,18	3,0
S4-C3	**20111341**	**0,100**	0,69	**0,100**	1,33	**0,100**	0,225	0,46	**0,100**	**0,100**	0,36	0,204	271	0,33	**0,100**	1,44	1,46	3,3	0,95	15,1
S5-C1	**20111365**	**0,100**	0,63	**0,100**	1,41	**0,100**	0,30	0,49	**0,100**	0,208	0,97	**0,100**	261	0,284	**0,100**	0,269	0,59	15,4	5,7	13,7
S5-C2	**20111366**	**0,100**	0,55	**0,100**	1,31	**0,100**	0,231	0,45	**0,100**	**0,100**	0,78	**0,100**	210	0,36	0,39	6,0	2,39	14,7	6,5	20,3
S5-C3	**20111367**	**0,100**	0,65	**0,100**	1,69	**0,100**	0,203	0,39	**0,100**	**0,100**	0,50	**0,100**	273	0,35	**0,100**	0,47	0,61	34	5,3	19,1
S6-C1	**20120266**	**0,100**	2,01	**0,100**	3,2	**0,100**	0,41	1,08	**0,100**	0,54	6,0	0,230	657	2,27	5,5	3,4	1,41	1,73	0,39	11,1
S6-C2	**20120267**	**0,100**	2,02	**0,100**	5,1	**0,100**	0,71	2,03	0,286	1,15	23,0	0,231	1175	2,37	1,11	6,4	6,6	2,44	0,68	11,9
S6-C3	**20120268**	**0,100**	1,98	**0,100**	3,3	**0,100**	0,33	0,70	**0,100**	0,225	0,86	0,214	380	2,38	0,66	0,75	1,55	1,85	0,47	11,0
S7-C1	**20120323**	**0,100**	1,69	**0,100**	1,53	**0,100**	0,38	0,83	**0,100**	0,228	0,285	**0,100**	271	0,76	0,285	0,46	3,0	2,13	0,54	2,28
S7-C2	**20120324**	**0,100**	1,63	**0,100**	1,46	**0,100**	0,47	1,26	**0,100**	0,296	0,36	**0,100**	264	0,72	0,246	0,83	2,03	1,51	0,36	1,70
S7-C3	**20120325**	**0,100**	1,75	**0,100**	1,55	**0,100**	0,37	0,69	**0,100**	0,234	0,247	**0,100**	256	0,79	0,253	0,47	2,12	1,45	0,34	0,62
S8-C1	**20120348**	**0,100**	1,23	**0,100**	2,01	**0,100**	0,257	0,72	**0,100**	0,221	0,77	0,206	240	0,93	0,54	1,09	1,44	**0,100**	0,219	1,74
S8-C2	**20120349**	**0,100**	1,28	**0,100**	1,57	**0,100**	0,50	0,86	**0,100**	0,262	0,87	0,207	359	0,96	0,66	0,98	6,4	0,30	0,220	14,5
S8-C3	**20120350**	0,40	1,28	**0,100**	1,76	**0,100**	0,285	0,78	**0,100**	0,257	0,80	0,201	274	1,05	0,55	0,91	3,6	**0,100**	0,213	1,89
S9-C1	**20120695**	**0,100**	0,77	**0,100**	1,21	**0,100**	0,36	1,29	**0,100**	0,96	1,28	0,218	279	0,62	0,41	0,45	0,36	5,9	4,9	0,98
S9-C2	**20120696**	**0,100**	0,84	**0,100**	1,33	**0,100**	0,40	0,70	**0,100**	0,260	0,45	0,216	361	0,77	1,76	17,7	1,25	1,19	0,67	1,14
S9-C3	**20120697**	**0,100**	0,82	**0,100**	1,50	**0,100**	0,33	0,76	**0,100**	0,243	0,38	0,214	332	0,52	0,41	1,13	0,78	3,7	2,25	1,69
0,100 = 0,5DL	**Average**	0,139	0,98	0,100	3,1	0,100	0,43	1,12	0,107	0,41	1,65	0,150	318	0,84	0,93	5,6	2,15	4,3	1,79	6,06
	SD	0,097	0,57	0,000	2,68	0,000	0,34	1,11	0,036	0,44	4,4	0,058	193	0,63	1,33	14,0	2,03	7,1	1,98	6,5
	RSD	70%	58%	0%	86%	0%	79%	99%	33%	107%	267%	38%	61%	75%	143%	248%	94%	165%	110%	107%
	Minimum	0,100	0,100	0,100	0,94	0,100	0,100	0,287	0,100	0,100	0,214	0,100	184	0,282	0,100	0,238	0,201	0,100	0,213	0,50
	Maximum	0,41	2,02	0,100	10,9	0,100	1,67	5,70	0,286	2,10	23,0	0,231	1175	2,38	5,5	72	8,5	34	6,5	20,3

Outdoor VOC concentrations at school

Average concentrations (µg/m³) per location, per component																				
Location	**Vito-nr**	**MTBE**	**Benzene**	**Trichloroethene**	**Toluene**	**Tetrachloroethene**	**Ethylbenzene**	**m- + p-Xylene**	**Styrene**	**o-Xylene**	**1,2,4-Trimethyl-benzene**	**1,4-Dichloro-benzene**	**tVOC**	**Hexane**	**Heptane**	**Cyclohexane**	**n-Butylacetate**	**α-Pinene**	**3-Carene**	**d10-Limonene**
S1-OUT	**20110951**	0,39	1,26	**0,100**	3,5	**0,100**	0,57	1,32	**0,100**	0,44	1,30	**0,100**	287	1,29	0,63	0,88	0,59	0,31	0,34	0,215
S2-OUT	**20110963**	**0,100**	0,247	**0,100**	6,6	**0,100**	**0,100**	0,237	**0,100**	**0,100**	**0,100**	**0,100**	204	0,30	0,47	**0,100**	**0,100**	**0,100**	**0,100**	0,220
S3-OUT	**20111015**	**0,100**	0,42	**0,100**	1,90	**0,100**	**0,100**	0,42	**0,100**	**0,100**	0,202	**0,100**	335	0,48	**0,100**	0,223	**0,100**	**0,100**	0,208	0,222
S4-OUT	**20111342**	**0,100**	0,75	**0,100**	0,77	**0,100**	**0,100**	0,30	**0,100**	**0,100**	0,206	**0,100**	339	0,31	**0,100**	0,236	0,232	**0,100**	0,207	0,231
S5-OUT	**20111368**	**0,100**	0,64	**0,100**	0,64	**0,100**	**0,100**	0,255	**0,100**	**0,100**	**0,100**	**0,100**	414	0,228	**0,100**	**0,100**	**0,100**	**0,100**	0,206	0,294
S6-OUT	**20120269**	0,209	2,27	**0,100**	1,48	0,230	0,264	0,53	0,222	0,209	0,271	0,266	369	3,2	0,44	0,77	0,289	0,256	0,282	0,32
S7-OUT	**20120326**	**0,100**	1,84	**0,100**	1,49	**0,100**	0,32	0,58	**0,100**	0,201	0,205	0,201	494	0,80	0,243	0,45	0,42	**0,100**	0,214	0,239
S8-OUT	**20120351**	**0,100**	1,33	**0,100**	1,20	**0,100**	0,223	0,62	**0,100**	**0,100**	0,299	0,202	348	0,91	0,277	0,83	**0,100**	**0,100**	0,215	0,239
S9-OUT	**20120698**	**0,100**	0,80	**0,100**	1,07	**0,100**	0,210	0,53	**0,100**	**0,100**	0,213	0,204	231	0,44	**0,100**	0,229	0,268	**0,100**	0,217	0,242
0,100 = 0,5DL	**Average**	0,144	1,06	0,100	2,07	0,114	0,221	0,53	0,114	0,161	0,32	0,153	336	0,88	0,273	0,42	0,244	0,141	0,221	0,247
	SD	0,099	0,67	0,000	1,90	0,043	0,155	0,33	0,041	0,114	0,37	0,065	89	0,94	0,198	0,32	0,172	0,082	0,064	0,036
	RSD	69%	63%	0%	92%	38%	70%	62%	36%	71%	116%	43%	26%	106%	73%	75%	70%	58%	29%	15%
	Minimum	0,100	0,247	0,100	0,64	0,100	0,100	0,237	0,100	0,100	0,100	0,100	204	0,228	0,100	0,100	0,100	0,100	0,100	0,215
	Maximum	0,39	2,27	0,100	6,6	0,230	0,57	1,32	0,222	0,44	1,30	0,266	494	3,2	0,63	0,88	0,59	0,31	0,34	0,32

Indoor VOC concentrations in residences

		Average concentrations (µg/m³) per location, per component																		
Location	**Vito-nr**	**MTBE**	**Benzene**	**Trichloroethene**	**Toluene**	**Tetrachloroethene**	**Ethylbenzene**	**m- + p-Xylene**	**Styrene**	**o-Xylene**	**1,2,4-Trimethyl-benzene**	**1,4-Dichloro-benzene**	**tVOC**	**Hexane**	**Heptane**	**Cyclohexane**	**n-Butylacetate**	**α-Pinene**	**3-Carene**	**d10-Limonene**
R1-IN	**20111089**	0,237	1,14	**0,100**	2,75	**0,100**	0,32	0,66	**0,100**	0,219	0,270	**0,100**	146	0,55	0,273	0,36	0,90	3,6	0,93	1,22
R2-IN	**20111093**	0,239	1,52	**0,100**	4,2	**0,100**	1,55	1,44	**0,100**	0,53	0,79	**0,100**	163	0,91	0,41	0,41	1,78	7,1	1,17	2,97
R3-IN	**20111106**	**0,100**	1,04	**0,100**	4,6	**0,100**	1,57	1,20	**0,100**	0,41	0,74	**0,100**	274	0,76	0,58	0,72	1,65	4,2	0,55	4,9
R4-IN	**20111110**	**0,100**	1,41	**0,100**	9,8	**0,100**	4,5	1,32	1,28	0,44	10,1	**0,100**	647	1,14	1,05	1,72	2,54	11,1	5,1	27,3
R5-IN	**20111163**	0,38	2,07	**0,100**	6,0	**0,100**	0,87	2,15	**0,100**	0,74	0,58	**0,100**	358	1,35	1,71	1,22	0,66	22,2	8,6	14,4
R6-IN	**20111167**	0,37	2,51	**0,100**	5,2	**0,100**	1,56	5,0	0,52	2,14	5,2	**0,100**	671	1,76	1,24	6,6	5,1	9,6	4,3	6,9
R7-IN	**20111171**	0,67	3,0	**0,100**	6,8	0,271	4,6	4,5	2,86	1,58	2,28	1,76	450	3,7	3,6	2,07	2,44	10,4	4,2	33
R8-IN	**20111175**	0,46	5,8	0,37	5,9	0,274	1,04	2,65	0,231	0,93	1,94	**0,100**	1036	7,4	152	**0,100**	18,9	4,8	1,3	12,0
R9-IN	**20111295**	**0,100**	0,87	**0,100**	2,61	**0,100**	0,38	0,51	**0,100**	**0,100**	0,228	**0,100**	269	0,50	0,241	0,68	3,0	1,68	0,272	96
R10-IN	**20111299**	**0,100**	0,66	**0,100**	1,21	**0,100**	**0,100**	0,30	**0,100**	**0,100**	**0,100**	**0,100**	169	0,247	**0,100**	**0,100**	0,48	1,08	0,48	5,1
R11-IN-1	**20120066**	2,78	2,09	**0,100**	12,6	**0,100**	1,41	3,7	0,47	1,37	3,9	**0,100**	892	1,85	1,19	1,04	3,8	1,90	0,66	4,6
R11-IN-2	**20120067**	1,75	1,86	**0,100**	7,7	**0,100**	0,85	2,23	**0,100**	0,78	2,38	**0,100**	520	1,34	0,89	0,80	1,60	2,01	1,24	2,37
R11-IN-3	**20120068**	0,34	2,06	**0,100**	6,8	0,224	0,66	1,67	**0,100**	0,59	1,74	**0,100**	643	1,18	0,62	0,84	1,09	1,62	0,68	34
R12-IN	**20120205**	**0,100**	0,95	**0,100**	89	**0,100**	0,60	0,76	2,85	0,284	0,78	**0,100**	480	0,58	0,39	0,43	5,9	11,2	4,5	26,2
R13-IN	**20120207**	2,67	0,69	**0,100**	3,8	0,65	0,38	0,64	**0,100**	0,267	1,25	**0,100**	441	0,51	0,73	**0,100**	0,298	20,6	7,9	6,2
R14-IN	**20120409**	**0,100**	0,86	**0,100**	31	**0,100**	0,35	1,05	**0,100**	0,39	6,8	**0,100**	701	0,65	3,4	**0,100**	4,5	58	21,2	17,9
R15-IN	**20120411**	**0,100**	0,92	**0,100**	2,10	**0,100**	0,220	0,52	0,212	0,246	0,261	**0,100**	401	0,75	0,37	0,50	1,36	71	18,1	36
R16-IN	**20120450**	**0,100**	0,92	**0,100**	11,1	**0,100**	0,36	0,78	**0,100**	0,297	0,44	**0,100**	271	0,48	0,43	0,32	1,26	9,1	4,5	6,0
R17-IN	**20120452**	**0,100**	0,92	**0,100**	3,1	**0,100**	2,32	1,27	0,49	0,48	0,46	**0,100**	364	0,94	5,8	3,4	2,62	5,4	2,39	6,0
R18-IN	**20120490**	0,57	2,53	**0,100**	21,3	**0,100**	0,96	2,41	**0,100**	0,71	2,72	**0,100**	217	5,5	2,14	1,19	0,42	2,11	2,56	3,3
R19-IN	**20120492**	0,204	3,2	**0,100**	21,8	**0,100**	1,15	3,1	**0,100**	1,32	7,1	**0,100**	439	4,2	2,02	2,18	1,52	6,3	1,74	12,1
R20-IN	**20120570**	0,214	1,12	1,63	2,81	**0,100**	1,00	2,53	**0,100**	0,99	0,61	**0,100**	242	1,37	1,23	2,73	5,9	5,7	2,12	5,3
R21-IN	**20120572**	**0,100**	1,06	**0,100**	3,3	**0,100**	0,66	1,34	**0,100**	0,52	0,86	**0,100**	380	0,75	0,63	0,42	1,21	1,22	0,53	2,89
R22-IN	**20120709**	**0,100**	1,10	**0,100**	5,2	**0,100**	0,46	0,99	**0,100**	0,32	0,65	0,214	685	0,77	0,75	0,97	6,7	14,0	5,6	12,4
R23-IN	**20120794**	**0,100**	0,72	**0,100**	1,39	**0,100**	0,68	1,74	**0,100**	0,66	17,2	**0,100**	504	0,32	**0,100**	0,47	1,51	8,3	5,9	2,49
0,100 = 0,5DL	**Average**	0,48	1,64	0,172	10,9	0,141	1,14	1,78	0,42	0,66	2,78	0,171	455	1,58	7,3	1,18	3,1	11,8	4,3	15,3
	SD	0,76	1,14	0,31	17,8	0,118	1,15	1,25	0,78	0,50	4,0	0,33	229	1,76	30	1,42	3,8	16,9	5,2	20,0
	RSD	157%	70%	179%	164%	84%	101%	70%	183%	76%	142%	194%	50%	112%	415%	120%	123%	144%	123%	131%
	Minimum	0,100	0,66	0,100	1,21	0,100	0,100	0,30	0,100	0,100	0,100	0,100	146	0,247	0,100	0,100	0,30	1,08	0,272	1,22
	Maximum	2,78	5,80	1,63	89	0,65	4,60	5,0	2,86	2,14	17,2	1,76	1036	7,40	152	6,6	18,9	71	21,2	96

Outdoor VOC concentrations in residences

Average concentrations (µg/m³) per location, per component																				
Location	**Vito-nr**	**MTBE**	**Benzene**	**Trichloroethene**	**Toluene**	**Tetrachloroethene**	**Ethylbenzene**	**m- + p-Xylene**	**Styrene**	**o-Xylene**	**1,2,4-Trimethylbenzene**	**1,4-Dichlorobenzene**	**tVOC**	**Hexane**	**Heptane**	**Cyclohexane**	**n-Butylacetate**	**α-Pinene**	**3-Carene**	**d10-Limonene**
R1-OUT	**20111090**	0,225	1,27	**0,100**	2,17	**0,100**	0,30	0,75	**0,100**	0,234	0,293	**0,100**	164	0,62	**0,100**	0,294	0,31	0,34	0,216	**0,100**
R2-OUT	**20111094**	**0,100**	1,24	**0,100**	2,24	**0,100**	0,270	0,64	**0,100**	0,213	0,254	**0,100**	188	0,64	0,228	0,298	0,273	0,33	**0,100**	**0,100**
R3-OUT	**20111107**	**0,100**	0,97	**0,100**	2,69	**0,100**	0,264	0,78	**0,100**	0,223	0,241	**0,100**	94	0,69	0,235	0,222	**0,100**	1,90	0,273	**0,100**
R4-OUT	**20111111**	**0,100**	1,16	**0,100**	2,20	**0,100**	0,283	0,74	**0,100**	0,231	0,286	**0,100**	103	0,72	0,241	0,254	0,35	0,69	0,241	**0,100**
R5-OUT	**20111164**	0,36	2,26	**0,100**	2,81	**0,100**	0,54	1,18	**0,100**	0,41	0,47	**0,100**	209	1,01	0,36	0,41	0,35	0,56	0,34	**0,100**
R6-OUT	**20111168**	0,35	2,55	**0,100**	2,97	**0,100**	0,55	1,22	**0,100**	0,42	0,77	**0,100**	203	1,04	0,41	0,63	0,39	0,47	0,261	0,240
R7-OUT	**20111172**	0,64	3,4	**0,100**	6,0	0,32	1,33	3,6	**0,100**	1,03	0,98	**0,100**	74	3,1	0,70	0,85	0,40	1,56	0,53	0,74
R8-OUT	**20111176**	0,52	3,3	**0,100**	5,9	0,297	0,91	2,39	**0,100**	0,80	0,98	**0,100**	221	2,48	0,77	0,89	0,35	3,7	2,02	0,53
R9-OUT	**20111296**	**0,100**	0,98	**0,100**	1,69	**0,100**	0,245	0,60	**0,100**	**0,100**	0,218	**0,100**	189	0,56	0,234	0,74	**0,100**	**0,100**	**0,100**	**0,100**
R10-OUT	**20111300**	**0,100**	0,74	**0,100**	0,76	**0,100**	**0,100**	0,260	**0,100**	**0,100**	**0,100**	**0,100**	197	0,232	**0,100**	**0,100**	**0,100**	**0,100**	**0,100**	**0,100**
R11-OUT	**20120069**	**0,100**	1,62	**0,100**	2,72	**0,100**	0,37	0,93	**0,100**	0,298	0,47	**0,100**	205	0,71	0,33	0,52	0,40	**0,100**	**0,100**	0,262
R12-OUT	**20120206**	**0,100**	0,71	**0,100**	0,92	**0,100**	**0,100**	0,34	**0,100**	**0,100**	**0,100**	**0,100**	207	0,35	0,201	**0,100**	**0,100**	**0,100**	**0,100**	**0,100**
R13-OUT	**20120208**	0,276	0,65	**0,100**	0,92	0,200	**0,100**	0,34	**0,100**	**0,100**	0,235	**0,100**	249	0,290	**0,100**	**0,100**	**0,100**	**0,100**	**0,100**	**0,100**
R14-OUT	**20120410**	**0,100**	0,93	**0,100**	47	**0,100**	**0,100**	0,38	**0,100**	**0,100**	**0,100**	**0,100**	296	0,53	0,200	0,238	**0,100**	**0,100**	**0,100**	**0,100**
R15-OUT	**20120412**	**0,100**	0,85	**0,100**	1,18	**0,100**	**0,100**	0,37	**0,100**	**0,100**	**0,100**	**0,100**	213	0,66	**0,100**	0,247	**0,100**	**0,100**	**0,100**	**0,100**
R16-OUT	**20120451**	**0,100**	0,89	**0,100**	1,38	**0,100**	0,256	0,61	**0,100**	**0,100**	0,226	**0,100**	249	0,37	**0,100**	0,201	0,229	**0,100**	**0,100**	**0,100**
R17-OUT	**20120453**	**0,100**	0,95	**0,100**	1,70	**0,100**	0,254	0,64	**0,100**	0,209	0,262	**0,100**	155	0,43	**0,100**	0,218	0,230	**0,100**	**0,100**	0,202
R18-OUT	**20120491**	**0,100**	0,86	**0,100**	1,09	**0,100**	**0,100**	0,42	**0,100**	**0,100**	**0,100**	**0,100**	165	0,43	**0,100**	0,247	**0,100**	**0,100**	**0,100**	**0,100**
R19-OUT	**20120493**	**0,100**	1,10	**0,100**	1,84	**0,100**	0,32	0,87	**0,100**	0,262	0,39	**0,100**	131	0,92	0,31	0,89	0,33	**0,100**	0,233	**0,100**
R20-OUT	**20120571**	**0,100**	1,35	**0,100**	2,45	**0,100**	0,32	0,80	**0,100**	0,260	0,39	**0,100**	243	1,65	0,32	1,87	0,276	0,57	0,50	0,216
R21-OUT	**20120573**	**0,100**	1,14	**0,100**	2,22	**0,100**	0,40	1,06	**0,100**	0,34	0,48	**0,100**	287	0,69	0,286	0,33	0,62	**0,100**	**0,100**	0,218
R22-OUT	**20120710**	**0,100**	1,04	**0,100**	1,17	**0,100**	0,233	0,60	**0,100**	**0,100**	0,241	0,215	389	0,51	**0,100**	0,293	0,260	0,207	0,229	0,256
R23-OUT	**20120795**	**0,100**	0,84	**0,100**	0,99	**0,100**	**0,100**	0,272	**0,100**	**0,100**	**0,100**	**0,100**	248	0,283	**0,100**	**0,100**	**0,100**	**0,100**	**0,100**	**0,100**
0,100 = 0,5DL	**Average**	0,177	1,34	0,100	4,1	0,122	0,33	0,86	0,100	0,258	0,34	0,105	203	0,82	0,249	0,44	0,246	0,51	0,267	0,181
	SD	0,152	0,78	0,000	9,4	0,062	0,290	0,75	0,000	0,234	0,260	0,0240	70	0,70	0,183	0,40	0,142	0,84	0,40	0,158
	RSD	86%	58%	0%	229%	51%	88%	87%	0%	91%	77%	23%	34%	85%	73%	93%	58%	167%	151%	87%
	Minimum	0,100	0,65	0,100	0,76	0,100	0,100	0,260	0,100	0,100	0,100	0,100	74	0,232	0,100	0,100	0,100	0,100	0,100	0,100
	Maximum	0,64	3,40	0,100	47	0,32	1,33	3,6	0,100	1,03	0,98	0,215	389	3,1	0,77	1,87	0,62	3,7	2,02	0,74

ANNEX 5 ALDEHYDE LEVELS IN CLEAN AIR LOW ENERGY SCHOOLS AND RESIDENCES

Indoor aldehyde concentrations at school

Average concentrations ($\mu g/m^3$) per location, per compound					
Location	**Vito-nr**	**Formaldehyde**	**Acetaldehyde**	**other aldehydes (total)**	**Total aldehyde**
S1-C1	**20110952**	24,7	7,3	55	24,0
S1-C2	**20110953**	23,3	7,1	50	20,5
S2-C1	**20110964**	18,1	7,6	42	17,4
S2-C2	**20110965**	13,6	7,5	37	17,7
S2-C3	**20110966**	23,6	9,0	53	22,5
S3-C1	**20111016**	14,9	6,5	36	15,9
S3-C2	**20111017**	26,9	7,6	56	22,9
S3-C3	**20111018**	26,6	7,6	52	19,7
S4-C1	**20111350**	5,0	6,3	14,1	3,9
S4-C2	**20111352**	8,0	7,0	18,4	4,7
S4-C3	**20111353**	12,5	7,8	24,8	6,0
S5-C1	**20111375**	28,8	9,1	48	11,7
S5-C2	**20111376**	21,1	7,3	36	9,1
S5-C3	**20111377**	14,1	7,5	27,8	7,6
S6-C1	**20120276**	14,4	11,9	42	17,6
S6-C2	**20120277**	17,6	12,5	51	22,9
S6-C3	**20120278**	18,0	11,8	46	18,3
S7-C1	**20120327**	9,0	9,8	29,4	12,5
S7-C2	**20120328**	9,7	9,1	29,9	12,9
S7-C3	**20120329**	9,2	8,9	27,7	11,3
S8-C1	**20120352**	9,4	8,9	24,8	8,2
S8-C2	**20120353**	13,0	10,4	31	10,0
S8-C3	**20120354**	10,8	9,7	27,4	8,7
S9-C1	**20120699**	23,4	6,6	38	9,7
S9-C2	**20120700**	23,5	9,8	48	16,6
S9-C3	**20120701**	20,1	6,7	38	12,2
	Average	16,9	8,5	37,8	14,0
	SD	6,8	1,74	11,8	6,0
	RSD	40%	20%	31%	43%
	Minimum	5,0	6,3	14,1	3,9
	Maximum	28,8	12,5	56	24,0

Outdoor aldehyde concentrations at school

Average concentrations (µg/m^{3}) per location, per compound					
Location	**Vito-nr**	**Formaldehyde**	**Acetaldehyde**	**other aldehydes (total)**	**Total aldehyde**
S1-OUT	**20110954**	4,9	6,1	25,8	15,9
S2-OUT	**20110967**	4,2	5,7	26,6	17,9
S3-OUT	**20111019**	3,1	5,5	23,3	15,7
S4-OUT	**20111354**	2,97	5,7	13,5	5,9
S5-OUT	**20111378**	2,80	5,0	10,1	3,3
S6-OUT	**20120279**	3,8	8,7	30	19,3
S7-OUT	**20120330**	4,7	8,7	23,0	11,3
S8-OUT	**20120355**	3,3	5,8	13,1	5,1
S9-OUT	**20120702**	5,4	3,4	16,5	8,4
	Average	3,9	6,1	20,2	11,4
	SD	0,94	1,69	7,0	6,0
	RSD	24%	28%	35%	53%
	Minimum	2,80	3,4	10,1	3,3
	Maximum	5,4	8,7	30	19,3

Indoor aldehyde concentrations in residences

		Average concentrations (µg/m³) per location, per compound			
Location	**Vito-nr**	**Formaldehyde**	**Acetaldehyde**	**other aldehydes (total)**	**Total aldehyde**
R1-IN	**20111091**	23,9	5,7	49	20,2
R2-IN	**20111095**	16,0	4,9	34	14,5
R3-IN	**20111108**	18,6	5,6	42	18,8
R4-IN	**20111112**	62	5,8	121	54
R5-IN	**20111165**	36	16,4	83	35
R6-IN	**20111169**	38	9,2	79	34
R7-IN	**20111173**	37	12,9	56	8,6
R8-IN	**20111177**	21,5	6,5	33	6,7
R9-IN	**20111297**	19,2	5,5	27,5	3,9
R10-IN	**20111301**	13,1	5,1	22,8	5,6
R11-IN-1	**20120070**	20,6	7,7	43	16,2
R11-IN-2	**20120071**	22,9	6,2	43	14,6
R11-IN-3	**20120072**	19,8	6,7	39	13,3
R12-IN	**20120209**	19,4	6,4	43	18,1
R13-IN	**20120211**	40	8,5	70	22,8
R14-IN	**20120413**	25,5	17,7	63	23,3
R15-IN	**20120415**	12,1	23,7	46	14,7
R16-IN	**20120454**	25,8	6,8	43	11,3
R17-IN	**20120456**	23,0	6,6	36	7,2
R18-IN	**20120494**	15,8	4,8	27,7	8,0
R19-IN	**20120496**	27,2	6,0	41	8,6
R20-IN	**20120574**	22,0	5,9	38	11,6
R21-IN	**20120576**	36	8,4	60	17,7
R22-IN	**20120711**	33	19,4	73	24,4
R23-IN	**20120796**	18,7	4,1	35	13,0
	Average	25,9	8,7	50	17,0
	SD	11,0	5,2	21,9	11,1
	RSD	42%	60%	44%	65%
	Minimum	12,1	4,1	22,8	3,9
	Maximum	62	24	121	54

Outdoor aldehyde concentrations in residences

Average concentrations (µg/m³) per location, per compound					
Location	**Vito-nr**	**Formaldehyde**	**Acetaldehyde**	**other aldehydes (total)**	**Total aldehyde**
R1-OUT	**20111092**	1,86	2,85	19,6	15,4
R2-OUT	**20111096**	2,86	2,80	20,2	15,1
R3-OUT	**20111109**	2,06	2,49	17,7	13,6
R4-OUT	**20111113**	3,1	2,86	20,7	15,3
R5-OUT	**20111166**	1,89	2,86	13,3	9,1
R6-OUT	**20111170**	1,86	3,0	15,3	11,0
R7-OUT	**20111174**	1,86	2,68	4,4	0,33
R8-OUT	**20111178**	1,43	2,63	3,9	0,32
R9-OUT	**20111298**	2,00	2,83	5,7	1,38
R10-OUT	**20111302**	2,79	2,80	7,2	2,10
R11-OUT	**20120073**	3,2	3,9	15,4	9,0
R12-OUT	**20120210**	3,3	3,6	19,3	13,1
R13-OUT	**20120212**	2,24	2,72	12,1	7,7
R14-OUT	**20120414**	3,0	2,82	9,0	3,7
R15-OUT	**20120416**	2,48	2,82	7,7	2,95
R16-OUT	**20120455**	2,4	3,2	9,1	4,1
R17-OUT	**20120457**	2,74	3,1	9,3	4,1
R18-OUT	**20120495**	3,3	1,22	9,3	5,1
R19-OUT	**20120497**	3,6	1,15	9,3	4,8
R20-OUT	**20120575**	4,7	3,5	12,4	4,8
R21-OUT	**20120577**	4,8	2,39	11,8	5,1
R22-OUT	**20120712**	4,9	1,83	13,2	6,8
R23-OUT	**20120797**	4,9	0,94	13,2	7,6
	Average	2,92	2,65	12,1	7,1
	SD	1,06	0,74	5,0	4,8
	RSD	36%	28%	41%	69%
	Minimum	1,43	0,94	3,9	0,32
	Maximum	4,9	3,9	20,7	15,4

ANNEX 6 PM2.5 PARTICULATE MATTER LEVELS IN CLEAN AIR LOW ENERGY SCHOOLS AND RESIDENCES

Indoor PM$_{2.5}$ concentrations at school

Concentration PM 2,5 (µg/m^3) per location	
Location	**Concentration (µg/m^3)**
S1-C1	56
S1-C2	35
S2-C1	29,5
S2-C2	34
S2-C3	23,2
S3-C1	16,9
S3-C2	18,6
S3-C3	19,6
S4-C1	17,1
S4-C2	21,5
S4-C3	8,0
S5-C1	23,1
S5-C2	27,5
S5-C3	25,8
S6-C1	25,7
S6-C2	36
S6-C3	31
S7-C1	
S7-C2	6,0
S7-C3	5,2
S8-C1	37
S8-C2	32
S8-C3	54
S9-C1	47
S9-C2	66
S9-C3	65
Average	30,4
SD	16,6
RSD	55%
Minimum	5,2
Maximum	66

Outdoor PM$_{2.5}$ concentrations at school

Concentration PM 2,5 (µg/m³) per location	
Location	**Concentration (µg/m³)**
S1-OUT	30
S2-OUT	14,2
S3-OUT	10,8
S4-OUT	8,5
S5-OUT	51
S6-OUT	70
S7-OUT	36
S8-OUT	15,3
S9-OUT	74
Average	34,4
SD	25,3
RSD	74%
Minimum	8,5
Maximum	74

Indoor $PM_{2.5}$ concentrations in residences

Concentration PM 2,5 (µg/m³) per location	
Location	**Concentration (µg/m³)**
R1-IN	7,3
R2-IN	10,9
R3-IN	9,6
R4-IN	9,1
R5-IN	9,3
R6-IN	14,7
R7-IN	41
R8-IN	20,0
R9-IN	8,6
R10-IN	9,3
R11-IN-1	9,3
R11-IN-2	10,1
R11-IN-3	8,6
R12-IN	7,7
R13-IN	8,3
R14-IN	10,2
R15-IN	19,8
R16-IN	8,9
R17-IN	15,7
R18-IN	15,4
R19-IN	9,1
R20-IN	11,3
R21-IN	11,6
R22-IN	18,0
R23-IN	34
Average	13,5
SD	8,2
RSD	60%
Minimum	7,3
Maximum	41

Outdoor $PM_{2.5}$ concentrations in residences

Concentration PM 2,5 (µg/m³) per location	
Location	**Concentration (µg/m³)**
R1-OUT	16,3
R2-OUT	15,9
R3-OUT	14,7
R4-OUT	17,2
R5-OUT	24,4
R6-OUT	31
R7-OUT	28,4
R8-OUT	27,1
R9-OUT	11,0
R10-OUT	11,6
R11-OUT	13,1
R12-OUT	8,1
R13-OUT	9,2
R14-OUT	24,3
R15-OUT	20,6
R16-OUT	24,8
R17-OUT	23,7
R18-OUT	17,5
R19-OUT	20,5
R20-OUT	34
R21-OUT	33
R22-OUT	32
R23-OUT	12,2
Average	20,5
SD	8,0
RSD	39%
Minimum	8,1
Maximum	34

ANNEX 7 PMX LEVELS IN CLEAN AIR LOW ENERGY SCHOOLS AND RESIDENCES

Indoor PM$_x$ concentrations in schools

PMx concentrations, per location, per size fraction					
Location	**PM1**	**PM2.5**	**PM10**	**TSP**	**ratio PM10/PM2.5**
S1-C1	10,2	12,2	32	49	2,65
S1-C2	12,3	13,7	34	62	2,46
S2-C1	6,1	8,2	35	53	4,3
S2-C2	5,9	8,6	27,9	46	3,2
S2-C3	7,8	10,2	22,8	39	2,24
S3-C1	7,0	11,4	28,2	45	2,47
S3-C2	5,5	8,1	29,1	41	3,6
S3-C3	6,5	9,8	31	52	3,1
S4-C1	2,38	3,6	21,2	55	5,8
S4-C2	2,63	4,3	18,4	32	4,3
S4-C3	1,79	2,78	12,0	23,1	4,3
S5-C1	1,93	4,7	31	71	6,7
S5-C2	1,51	2,83	26,8	54	9,5
S5-C3	1,73	4,1	29,4	58	7,2
S6-C1	10,1	12,0	27,0	40	2,26
S6-C2	-	-	-	-	-
S6-C3	-	-	-	-	-
S7-C1	4,4	5,0	7,1	8,4	1,41
S7-C2	2,74	2,95	4,3	4,9	1,44
S7-C3	4,9	5,2	5,5	5,7	1,07
S8-C1	5,9	11,9	67	108	5,7
S8-C2	4,7	7,4	26,9	38	3,6
S8-C3	5,6	11,3	56	81	5,0
S9-C1	10,0	13,9	29,5	33	2,11
S9-C2	9,9	13,1	38	55	2,92
S9-C3	-	-	-	-	-
Average	5,7	8,1	27,8	46	3,8
SD	3,2	3,9	14,2	23,6	2,08
RSD	56%	47%	51%	51%	55%
Minimum	1,51	2,78	4,3	4,9	1,07
Maximum	12,3	13,9	67	108	9,5

Outdoor PM$_x$ concentrations in schools

PMx concentrations, per location, per size fraction					
Location	**PM1**	**PM2.5**	**PM10**	**TSP**	**ratio PM10/PM2.5**
S1-OUT	23,5	27,4	46	61	1,69
S2-OUT	8,6	11,0	23,1	39	2,10
S3-OUT	9,8	13,9	22,9	27,1	1,65
S4-OUT	6,9	11,0	29,6	37	2,70
S5-OUT	4,4	6,5	11,0	13,6	1,70
S6-OUT	201	202	220	269	1,09
S7-OUT	170	171	175	179	1,03
S8-OUT	5,1	5,2	7,7	11,2	1,48
S9-OUT	1,38	1,39	4,9	28,1	3,5
Average	48	50	60	74	1,88
SD	79	78	80	89	0,79
RSD	164%	157%	133%	121%	42%
Minimum	1,38	1,39	4,9	11,2	1,03
Maximum	201	202	220	269	3,5

Indoor PM$_x$ concentrations in residences

PMx concentrations, per location, per size fraction					
Location	**PM1**	**PM2.5**	**PM10**	**TSP**	**ratio PM10/PM2.5**
R1-IN	17,9	19,9	26,1	29,8	1,31
R2-IN	10,6	13,7	22,3	28,8	1,62
R3-IN	7,2	9,0	17,5	32	1,94
R4-IN	7,7	8,9	14,0	20,0	1,56
R5-IN	7,0	8,8	19,5	29,7	2,23
R6-IN	16,7	18,8	31	40	1,65
R7-IN	38	44	54	66	1,23
R8-IN	20,6	22,5	32	47	1,44
R9-IN	7,5	10,2	21,5	36	2,11
R10-IN	7,1	8,6	14,3	21,1	1,67
R11-IN-1	5,8	7,5	13,9	21,9	1,85
R11-IN-2	4,1	4,1	6,1	9,1	1,48
R11-IN-3	8,6	10,8	17,2	21,5	1,59
R12-IN	4,7	6,6	14,8	24,5	2,25
R13-IN	5,0	7,8	18,5	27,4	2,38
R14-IN	7,7	9,5	15,2	21,4	1,61
R15-IN	5,9	8,8	30	62	3,4
R16-IN	8,4	8,8	9,9	11,6	1,12
R17-IN	13,8	16,2	27,4	40	1,69
R18-IN	17,9	20,7	26,7	29,9	1,29
R19-IN	7,1	9,0	19,1	31	2,14
R20-IN	8,3	11,2	17,2	19,1	1,54
R21-IN	10,7	12,0	16,0	19,7	1,34
R22-IN	6,5	8,1	13,2	20,0	1,62
R23-IN	7,4	10,7	20,8	24,4	1,95
Average	10,5	12,6	20,7	29,4	1,76
SD	7,3	8,1	9,6	13,5	0,48
RSD	69%	64%	46%	46%	27%
Minimum	4,1	4,1	6,1	9,1	1,12
Maximum	38	44	54	66	3,4

Outdoor PM$_x$ concentrations in residences

PMx concentrations, per location, per size fraction

Location	PM1	PM2.5	PM10	TSP	ratio PM10/PM2.5
R1-OUT	21,0	22,9	29,8	33	1,31
R2-OUT	17,9	19,9	26,1	29,8	1,31
R3-OUT	19,4	22,3	106	126	4,7
R4-OUT	21,4	24,1	33	37	1,37
R5-OUT	44	47	202	722	4,3
R6-OUT	57	61	78	91	1,28
R7-OUT	58	62	268	1124	4,3
R8-OUT	65	69	85	92	1,23
R9-OUT	17,1	21,5	47	61	2,20
R10-OUT	15,1	17,7	22,3	23,8	1,26
R11-OUT	20,6	23,6	30	32	1,27
R12-OUT	291	292	296	297	1,01
R13-OUT	10,7	12,9	15,7	16,3	1,22
R14-OUT	22,1	25,7	35	42	1,35
R15-OUT	3,0	3,1	3,8	4,5	1,25
R16-OUT	26,9	28,5	32	34	1,11
R17-OUT	3,4	3,5	5,3	14,4	1,52
R18-OUT	20,9	22,9	29,2	36	1,28
R19-OUT	2,25	2,27	3,6	9,4	1,60
R20-OUT	8,0	9,3	15,4	20,5	1,66
R21-OUT	1,15	1,16	2,83	4,9	2,44
R22-OUT	36	39	50	59	1,26
R23-OUT	13,2	15,3	44	60	2,88
Average	35	37	63	129	1,87
SD	59	59	82	265	1,11
RSD	170%	160%	129%	205%	59%
Minimum	1,15	1,16	2,8	4,5	1,01
Maximum	291	292	296	1124	4,7

ANNEX 8 CO_2 LEVELS IN CLEAN AIR LOW ENERGY SCHOOLS AND RESIDENCES

Indoor CO_2 concentrations in schools

	Concentration CO_2 (ppm) per location		
Location	**Av. CO_2 (24h)**	**Min CO_2 (24h)**	**Max CO_2 (24h)**
S1-C1	652	286	1049
S1-C2	377	132	610
S2-C1	482	302	1582
S2-C2	494	325	1852
S2-C3	494	352	1703
S3-C1	429	373	760
S3-C2	414	325	1321
S3-C3	431	322	1205
S4-C1	464	345	989
S4-C2	389	253	1048
S4-C3	508	355	1467
S5-C1	617	327	2080
S5-C2	412	258	1491
S5-C3	528	380	1422
S6-C1	548	320	1091
S6-C2	444	225	1538
S6-C3	552	362	1125
S7-C1	379	337	709
S7-C2	308	245	717
S7-C3	441	274	758
S8-C1	445	307	1324
S8-C2	346	217	1151
S8-C3	616	357	2455
S9-C1	521	372	1686
S9-C2	461	284	1852
S9-C3	716	465	2171
Average	480	312	1352
SD	96	66	484
RSD	20%	21%	36%
Minimum	308	132	610
Maximum	716	465	2455

Outdoor CO_2 concentrations in schools

	Concentration CO_2 (ppm) per location		
Location	**Av. CO_2 (24h)**	**Min CO_2 (24h)**	**Max CO_2 (24h)**
S1-OUT	407	176	472
S2-OUT	404	347	623
S3-OUT	417	358	564
S4-OUT	466	411	540
S5-OUT	443	368	522
S6-OUT	462	376	540
S7-OUT	506	403	599
S8-OUT	504	416	628
S9-OUT	445	291	689
Average	450	349	575
SD	38	76	66
RSD	8%	22%	11%
Minimum	404	176	472
Maximum	506	416	689

Indoor CO_2 concentrations in residences

	Concentration CO_2 (ppm) per location		
Location	**Av. CO_2 (24h)**	**Min CO_2 (24h)**	**Max CO_2 (24h)**
R1-IN	385	305	464
R2-IN	469	322	887
R3-IN	574	345	1163
R4-IN	603	405	978
R5-IN	718	431	925
R6-IN	531	285	1076
R7-IN	722	471	1190
R8-IN	761	487	2352
R9-IN	725	426	1257
R10-IN	539	383	727
R11-IN-1	678	417	1245
R11-IN-2	523	346	733
R11-IN-3	698	421	1477
R12-IN	567	384	838
R13-IN	679	431	1642
R14-IN	758	441	1423
R15-IN	761	504	1201
R16-IN	536	387	1644
R17-IN	587	411	1199
R18-IN	520	318	1062
R19-IN	547	297	952
R20-IN	542	360	976
R21-IN	694	526	1262
R22-IN	541	394	736
R23-IN	490	369	1016
Average	606	395	1137
SD	105	64	381
RSD	17%	16%	34%
Minimum	385	285	464
Maximum	761	526	2352

Outdoor CO_2 concentrations in residences

	Concentration CO_2 (ppm) per location		
Location	**Av. CO_2 (24h)**	**Min CO_2 (24h)**	**Max CO_2 (24h)**
R1-OUT	393	304	446
R2-OUT	436	336	477
R3-OUT	410	286	694
R4-OUT	426	307	535
R5-OUT	555	427	744
R6-OUT	450	364	542
R7-OUT	565	382	702
R8-OUT	670	480	840
R9-OUT	415	335	483
R10-OUT	482	432	543
R11-OUT	513	374	710
R12-OUT	361	253	426
R13-OUT	470	389	559
R14-OUT	395	248	501
R15-OUT	477	318	623
R16-OUT	400	294	472
R17-OUT	517	405	633
R18-OUT	486	355	659
R19-OUT	496	397	642
R20-OUT	490	321	723
R21-OUT	405	268	686
R22-OUT	396	248	547
R23-OUT	536	424	690
Average	467	345	603
SD	72	65	111
RSD	15%	19%	18%
Minimum	361	248	426
Maximum	670	480	840

ANNEX 9 TEMPERATURE LEVELS IN CLEAN AIR LOW ENERGY SCHOOLS AND RESIDENCES

Indoor temperatures in schools

Temperature (°C) per location			
Location	**Av. temp**	**Min temp**	**Max temp**
S1-C1	22,7	18,7	27,3
S1-C2	22,7	18,7	29,6
S2-C1	22,3	20,2	27,9
S2-C2	22,2	20,2	26,2
S2-C3	23,2	20,8	26,9
S3-C1	19,6	18,3	21,1
S3-C2	19,7	18,1	22,5
S3-C3	20,2	18,5	22,6
S4-C1	18,5	14,3	24,8
S4-C2	18,6	15,8	22,7
S4-C3	21,5	20,2	30,4
S5-C1	19,4	17,5	21,5
S5-C2	18,1	15,2	20,7
S5-C3	18,4	16,2	21,6
S6-C1	20,8	14,4	23,9
S6-C2	21,8	19,3	31,7
S6-C3	20,7	17,8	28,4
S7-C1	19,8	17,1	21,1
S7-C2	20,8	20,1	22,0
S7-C3	19,0	17,4	20,6
S8-C1	20,4	15,8	22,4
S8-C2	20,8	16,5	24,8
S8-C3	21,8	16,5	24,3
S9-C1	19,0	16,7	21,6
S9-C2	19,8	17,6	23,3
S9-C3	21,9	18,9	25,4
Average	20,5	17,7	24,4
SD	1,5	1,8	3,2
RSD	7%	10%	13%
Minimum	18,1	14,3	20,6
Maximum	23,2	20,8	31,7

Outdoor temperatures in schools

Temperatuur (°C) per locatie			
Location	**Av. temp**	**Min temp**	**Max temp**
S1-OUT	18,3	12,3	35,2
S2-OUT	17,3	8,6	40,6
S3-OUT	14,0	5,8	23,0
S4-OUT	6,2	2,2	10,7
S5-OUT	7,1	5,5	15,0
S6-OUT	-2,7	-6,8	10,8
S7-OUT	-4,2	-9,2	13,0
S8-OUT	5,5	2,6	10,4
S9-OUT	13,1	5,9	30,4
Average	8,3	3,0	21,0
SD	8,1	6,9	11,7
RSD	98%	232%	56%
Minimum	-4,2	-9,2	10,4
Maximum	18,3	12,3	40,6

Indoor temperatures in residences

Temperatuur (°C) per locatie			
Location	**Av. temp**	**Min temp**	**Max temp**
R1-IN	19,5	18,8	22,0
R2-IN	21,1	18,5	33,7
R3-IN	21,7	15,9	22,6
R4-IN	20,8	20,4	21,2
R5-IN	21,3	20,3	23,1
R6-IN	21,0	19,8	23,3
R7-IN	22,6	21,2	25,5
R8-IN	21,2	19,6	23,8
R9-IN	19,0	17,8	23,5
R10-IN	20,3	19,1	26,8
R11-IN-1	20,0	18,2	28,0
R11-IN-2	16,9	13,6	18,5
R11-IN-3	19,3	15,5	21,0
R12-IN	19,0	17,6	20,5
R13-IN	22,8	17,1	26,4
R14-IN	20,2	18,2	22,6
R15-IN	21,1	19,8	23,1
R16-IN	18,3	16,7	20,1
R17-IN	18,9	16,2	23,2
R18-IN	18,5	16,6	20,0
R19-IN	20,8	20,4	21,2
R20-IN	21,7	17,8	23,3
R21-IN	16,7	11,0	21,8
R22-IN	19,9	15,5	20,7
R23-IN	15,8	15,1	16,2
Average	19,9	17,6	22,9
SD	1,8	2,4	3,4
RSD	9%	14%	15%
Minimum	15,8	11,0	16,2
Maximum	22,8	21,2	33,7

Outdoor temperatures in residences

Temperature (°C) per location			
Location	**Av. temp**	**Min temp**	**Max temp**
R1-OUT	10,4	8,9	15,8
R2-OUT	10,7	9,2	24,5
R3-OUT	13,9	8,1	21,2
R4-OUT	13,8	9,5	26,7
R5-OUT	5,3	-3,1	16,2
R6-OUT	6,0	-0,1	13,5
R7-OUT	5,9	1,0	23,8
R8-OUT	5,0	0,3	9,9
R9-OUT	7,7	1,1	15,3
R10-OUT	8,3	4,4	12,1
R11-OUT	4,0	-0,3	23,3
R12-OUT	6,1	1,6	22,4
R13-OUT	6,6	1,8	11,8
R14-OUT	7,6	0,8	25,8
R15-OUT	8,1	2,4	24,7
R16-OUT	6,6	0,1	14,3
R17-OUT	7,1	0,7	13,9
R18-OUT	9,6	0,2	20,9
R19-OUT	8,7	0,3	21,5
R20-OUT	9,7	2,7	22,4
R21-OUT	11,2	1,0	27,5
R22-OUT	10,5	2,3	23,9
R23-OUT	6,6	-0,1	15,0
Average	8,2	2,3	19,4
SD	2,7	3,4	5,4
RSD	32%	149%	28%
Minimum	4,0	-3,1	9,9
Maximum	13,9	9,5	27,5

ANNEX 10 RELATIVE HUMIDITY IN CLEAN AIR LOW ENERGY SCHOOLS AND RESIDENCES

Indoor relative humidity in schools

	RH (%) per location		
Location	**Av. RH (%)**	**Min RH (%)**	**Max RH (%)**
S1-C1	59	43	69
S1-C2	59	35	70
S2-C1	53	38	65
S2-C2	53	37	64
S2-C3	51	39	61
S3-C1	57	39	69
S3-C2	59	42	68
S3-C3	57	41	66
S4-C1	37	25,0	55
S4-C2	38	25,5	53
S4-C3	32	20,7	44
S5-C1	42	36	56
S5-C2	46	39	57
S5-C3	42	34	53
S6-C1	24,3	11,9	42
S6-C2	23,7	8,2	41
S6-C3	22,6	10,4	42
S7-C1	16,8	8,7	32
S7-C2	15,5	11,8	34
S7-C3	17,0	12,8	20,6
S8-C1	35	28,0	51
S8-C2	34	24,7	58
S8-C3	34	26,1	55
S9-C1	38	29,3	45
S9-C2	39	23,8	46
S9-C3	35	25,1	48
Average	39	27,5	52
SD	13,9	11,3	12,7
RSD	35%	41%	24%
Minimum	15,5	8,2	20,6
Maximum	59	43	70

Outdoor relative humidity in schools

RH (%) per location			
Location	**Av. RH (%)**	**Min RH (%)**	**Max RH (%)**
S1-OUT	79	27,9	98
S2-OUT	69	19,8	91
S3-OUT	80	44	95
S4-OUT	81	56	99
S5-OUT	86	39	100
S6-OUT	43	12,2	65
S7-OUT	71	12,5	85
S8-OUT	94	62	100
S9-OUT	59	15,5	85
Average	74	32	91
SD	15,3	19,0	11,4
RSD	21%	59%	13%
Minimum	43	12,2	65
Maximum	94	62	100

Indoor relative humidity in residences

RH (%) per location			
Location	**Av. RH (%)**	**Min RH (%)**	**Max RH (%)**
R1-IN	48	42	49
R2-IN	39	17,5	57
R3-IN	56	51	69
R4-IN	56	55	58
R5-IN	41	34	51
R6-IN	50	39	56
R7-IN	41	35	57
R8-IN	44	33	68
R9-IN	53	39	70
R10-IN	43	26,7	52
R11-IN-1	35	23,5	43
R11-IN-2	35	29,5	41
R11-IN-3	33	26,5	50
R12-IN	49	43	58
R13-IN	35	28,6	47
R14-IN	45	39	54
R15-IN	44	36	55
R16-IN	46	41	51
R17-IN	45	34	58
R18-IN	44	33	54
R19-IN	44	37	55
R20-IN	42	34	50
R21-IN	53	38	69
R22-IN	42	38	45
R23-IN	51	46	59
Average	45	36	55
SD	6,4	8,3	7,8
RSD	14%	23%	14%
Minimum	33	17,5	41
Maximum	56	55	70

Outdoor relative humidity in residences

RH (%) per location			
Location	**Av. RH (%)**	**Min RH (%)**	**Max RH (%)**
R1-OUT	85	56	93
R2-OUT	84	34	95
R3-OUT	82	44	100
R4-OUT	82	40	100
R5-OUT	85	40	100
R6-OUT	81	59	93
R7-OUT	87	32	100
R8-OUT	90	75	99
R9-OUT	91	56	100
R10-OUT	88	72	100
R11-OUT	65	16,5	86
R12-OUT	84	28,6	98
R13-OUT	83	60	95
R14-OUT	82	21,5	99
R15-OUT	81	23,2	97
R16-OUT	91	60	100
R17-OUT	85	58	97
R18-OUT	69	30	89
R19-OUT	75	37	96
R20-OUT	69	31	98
R21-OUT	65	24,4	100
R22-OUT	65	21,1	86
R23-OUT	74	35	97
Average	80	41	96
SD	8,4	17,1	4,4
RSD	11%	41%	5%
Minimum	65	16,5	86
Maximum	91	75	100

ANNEX 11 INDOOR AIR SPEED IN CLEAN AIR LOW ENERGY SCHOOLS AND RESIDENCES

Indoor air speed in schools

Average wind spreed (m/s) per location	
Locatie	**Wind speed (m/s)**
S1-C1	0,058
S1-C2	0,053
S2-C1	0,070
S2-C2	0,060
S2-C3	0,063
S3-C1	0,035
S3-C2	0,035
S3-C3	0,043
S4-C1	0,033
S4-C1-d	0,033
S4-C2	0,035
S4-C3	0,045
S5-C1	0,023
S5-C2	0,025
S5-C3	0,018
S6-C1	?
S6-C2	0,044
S6-C3	0,049
S7-C1	0,007
S7-C2	0,005
S7-C3	0,003
S8-C1	0,004
S8-C2	0,035
S8-C3	0,038
S9-C1	0,040
S9-C2	0,057
S9-C3	0,043
Average	0,036
SD	0,02
RSD	51%
Minimum	0,003
Maximum	0,070

Indoor air speed in residences

Average wind spreed (m/s) per location	
Locatie	**Wind speed (m/s)**
R1-IN	0,040
R2-IN	0,035
R3-IN	0,038
R4-IN	0,040
R5-IN	0,043
R6-IN	0,045
R7-IN	0,013
R8-IN	0,043
R9-IN	0,031
R10-IN	0,018
R11-IN-1	0,033
R11-IN-2	0,030
R11-IN-3	0,033
R12-IN	0,015
R13-IN	0,035
R14-IN	0,009
R15-IN	0,016
R16-IN	0,029
R17-IN	0,029
R18-IN	0,025
R19-IN	0,038
R20-IN	0,035
R21-IN	0,040
R22-IN	0,023
R23-IN	0,023
Average	0,030
SD	0,01
RSD	34%
Minimum	0,009
Maximum	0,045

ANNEX 12 RESULTS AND OUTCOMES FOR ACOUSTICAL FIELD MEASUREMENTS

Table AC-1

SYSTEM C (grids)	OUT		IN	
Location	$L_{A,2m}$ (dB) "plane 1"	$L_{A,2m}$ (dB) "plane 2"	L_{Aeq} - k (dB) "open"	L_{Aeq} - k (dB) "closed"
R1-LI	-	-	-	-
R1-B1	-	-	-	-
R1-B2	-	-	-	-
R1-B3	-	-	-	-
R1-B4	-	-	-	-
R2-LI	54,8	43,1	**18,3**	**19,0**
R2-B1	43,1	57,7	**22,7**	**16,4**
R2-B2	54,8	43,1	**21,1**	**18,0**
R2-B3	54,8	-	**19,7**	**16,5**
R2-B4	38,9	54,8	**18,9**	**17,4**
R16-LI	-	-	-	-
R16-B1	-	-	-	-
R16-B2	-	-	-	-
R16-B3	-	-	-	-
R16-B4	-	-	-	-
R18-LI	54,2	43,4	**33,4**	**27,8**
R18-B1	60,4	-	**39,3**	**32,3**
R18-B2	54,2	43,4	**29,3**	**23,8**
R18-B3	-	-	-	-
R18-B4	-	-	-	-
R18-BU	60,4	-	**36,5**	**32,3**
R19-LI	-	-	-	-
R19-B1	-	-	-	-
R19-B2	-	-	-	-
R19-B3	-	-	-	-
R19-B4	-	-	-	-
R21-LI	-	-	-	-
R21-B1	66,0	-	**36,4**	**31,1**
R21-B2	53,6	-	**32,0**	**31,6**
R21-B3	53,6	-	**26,2**	**24,6**
R21-B4	-	-	-	-
R22-LI	-	-	-	-
R22-B1	-	-	-	-
R22-B2	-	-	-	-
R22-B3	-	-	-	-
R22-B4	-	-	-	-
R23-LI	-	-	-	-
R23-B1	-	-	-	-
R23-B2	-	-	-	-
R23-B3	-	-	-	-
R23-B4	-	-	-	-
Average	54	48	**28**	**24**
SD	7,2	6,8	7,6	6,6
RSD	13%	14%	27%	27%
Minimum	39	43	**18**	**16**
Maximum	66	58	**39**	**32**

Table AC-5

SYSTEM C (grids)	OUT		IN	
Location	$L_{A,2m}$ (dB) "plane 1"	$L_{A,2m}$ (dB) "plane 2"	L_{Aeq} - k (dB) "open"	L_{Aeq} - k (dB) "closed"
S5-C1	-	-	-	-
S5-C2	-	-	-	-
S5-C3	-	-	-	-
S7-C1	-	-	-	-
S7-C2	-	-	-	-
S7-C3	-	-	-	-
S9-C1	50,4	47,2	33,1	-
S9-C2	50,4	43,0	32,9	30,4
S9-C3	52,6	43,9	32,9	-
Average	51	45	33	30
SD	1,3	2,2	0,1	-
RSD	2%	5%	0%	-
Minimum	50	43	33	30
Maximum	53	47	33	30

ANNEX 13 RESULTS AND OUTCOMES FOR ACOUSTICAL FIELD MEASUREMENTS (AC-2 AND AC-6)

Table AC-2

SYSTEM C (grids)	OUT		IN	
Location	DELTA (dB) "plane 1"	DELTA (dB) "plane 2"	L_{Aeq} - k (dB) "open"	DELTA (dB) "closed"
R1-LI	-	-	-	-
R1-B1	-	-	-	-
R1-B2	-	-	-	-
R1-B3	-	-	-	-
R1-B4	-	-	-	-
R2-LI	36,5	**24,8**	18,3	-0,7
R2-B1	**20,4**	34,9	22,7	6,3
R2-B2	33,7	**22,1**	21,1	3,1
R2-B3	35,1	-	19,7	3,2
R2-B4	**20,0**	35,9	18,9	1,5
R16-LI	-	-	-	-
R16-B1	-	-	-	-
R16-B2	-	-	-	-
R16-B3	-	-	-	-
R16-B4	-	-	-	-
R18-LI	**20,7**	**10,0**	33,4	5,6
R18-B1	**21,1**	-	39,3	6,9
R18-B2	**24,9**	**14,1**	29,3	5,4
R18-B3	-	-	-	-
R18-B4	-	-	-	-
R18-BU	**23,9**	-	36,5	4,3
R19-LI	-	-	-	-
R19-B1	-	-	-	-
R19-B2	-	-	-	-
R19-B3	-	-	-	-
R19-B4	-	-	-	-
R21-LI	-	-	-	-
R21-B1	29,7	-	36,4	5,3
R21-B2	**21,6**	-	32,0	0,3
R21-B3	27,3	-	26,2	1,6
R21-B4	-	-	-	-
R22-LI	-	-	-	-
R22-B1	-	-	-	-
R22-B2	-	-	-	-
R22-B3	-	-	-	-
R22-B4	-	-	-	-
R23-LI	-	-	-	-
R23-B1	-	-	-	-
R23-B2	-	-	-	-
R23-B3	-	-	-	-
R23-B4	-	-	-	-
Average	26	**24**	28	4
SD	6,1	10,6	7,6	2,5
RSD	23%	45%	27%	69%
Minimum	**20**	**10**	18	-1
Maximum	36	36	39	7

Table AC-6

SYSTEM C (grids)	OUT		IN	
Location	**DELTA (dB) "plane 1"**	**DELTA (dB) "plane 2"**	**L_{Aeq} - k (dB) "open"**	**DELTA (dB) "closed"**
S5-C1	-	-	-	-
S5-C2	-	-	-	-
S5-C3	-	-	-	-
S7-C1	-	-	-	-
S7-C2	-	-	-	-
S7-C3	-	-	-	-
S9-C1	**17,4**	14,2	33,1	-
S9-C2	**17,5**	10,1	32,9	2,5
S9-C3	**19,7**	11,0	32,9	-
Average	**18**	12	33	2
SD	1,3	2,1	0,1	-
RSD	7%	18%	0%	-
Minimum	**17**	10	33	2
Maximum	**20**	14	33	2

ANNEX 14 RESULTS AND OUTCOMES FOR ACOUSTICAL MEASUREMENTS (AC-3 AND AC-7)

Table AC-3

SYSTEM D (inlets)	IN - "OFF"	IN - "ON"		
Location	**L_{Aeq} - k (dB)**	**$L_{Ainstal,nT}$ "1" (dB)**	**$L_{Ainstal,nT}$ "2" (dB)**	**$L_{Ainstal,nT}$ "3" (dB)**
R1-LI	18,2	**20,1**	**25,6**	**32,0**
R1-B1	18,7	**24,3**	**36,7**	**41,7**
R1-B2	18,3	**19,2**	**27,8**	**30,9**
R1-B3	20,0	**24,1**	**37,7**	**41,2**
R1-B4	-	-	-	-
R2-LI	18,3	**24,5**	**32,7**	**42,1**
R2-B1	-	-	-	-
R2-B2	-	-	-	-
R2-B3	-	-	-	-
R2-B4	-	-	-	-
R16-LI	26,4	-	**26,9**	**39,2**
R16-B1	23,2	-	**26,0**	**35,8**
R16-B2	20,8	-	**24,7**	**35,7**
R16-B3	25,6	-	**24,6**	**36,2**
R16-B4	25,6	-	**24,5**	**33,6**
R18-LI	-	-	-	-
R18-B1	-	-	-	-
R18-B2	-	-	-	-
R18-B3	-	-	-	-
R18-B4	-	-	-	-
R18-BU	-	-	-	-
R19-LI	17,3	-	**23,6**	**27,7**
R19-B1	18,9	-	**27,0**	**27,2**
R19-B2	20,6	-	**20,5**	**22,5**
R19-B3	17,5	-	**19,1**	**20,2**
R19-B4	-	-	-	-
R21-LI	-	-	-	-
R21-B1	-	-	-	-
R21-B2	-	-	-	-
R21-B3	-	-	-	-
R21-B4	-	-	-	-
R22-LI	18,5	**21,3**	**30,1**	**38,6**
R22-B1	21,9	**26,5**	**36,5**	**43,8**
R22-B2	20,2	**34,7**	**44,1**	**51,4**
R22-B3	21,5	**34,1**	**43,2**	**50,7**
R22-B4	-	-	-	-
R23-LI	18,4	-	**22,0**	**27,3**
R23-B1	18,0	-	**26,5**	**34,2**
R23-B2	20,1	-	**21,5**	**26,0**
R23-B3	18,6	-	**22,4**	**29,1**
R23-B4	22,4	-	**23,1**	**29,3**
Average	20	25	28	35
SD	2,7	5,6	7,1	8,2
RSD	13%	22%	25%	24%
Minimum	17	19	19	20
Maximum	26	35	44	51

Table AC-7

SYSTEM D (inlets)	IN - "OFF"	IN - "ON"		
Location	**L_{Aeq} - k (dB)**	**$L_{Ainstal,nT}$ "1" (dB)**	**$L_{Ainstal,nT}$ "2" (dB)**	**$L_{Ainstal,nT}$ "3" (dB)**
S5-C1	28,6	**32,1**	**39,2**	**45,2**
S5-C2	27,2	**32,7**	**40,5**	**44,8**
S5-C3	27,0	**33,8**	**41,4**	**45,8**
S7-C1	-	-	**39,5**	-
S7-C2	-	-	**34,1**	-
S7-C3	-	-	**32,7**	-
S9-C1	-	-	-	-
S9-C2	-	-	-	-
S9-C3	-	-	-	-
Average	28	33	38	45
SD	1	1	4	0
RSD	3%	3%	10%	1%
Minimum	27	32	33	45
Maximum	29	34	41	46

ANNEX 15 RESULTS AND OUTCOMES FOR ACOUSTICAL MEASUREMENTS (AC-4 AND AC-8)

Table AC-4

SYSTEM D (inlets)	IN - "OFF"	IN - "ON"		
Location	**DELTA (dB)**	**DELTA "1" (dB)**	**$L_{Ainstal,nT}$ "2" (dB)**	**DELTA "3" (dB)**
R1-LI	7,3	5,5	25,6	6,5
R1-B1	18,0	12,4	36,7	5,0
R1-B2	9,5	8,6	27,8	3,1
R1-B3	17,7	13,6	37,7	3,4
R1-B4	-	-	-	-
R2-LI	14,4	8,2	32,7	9,4
R2-B1	-	-	-	-
R2-B2	-	-	-	-
R2-B3	-	-	-	-
R2-B4	-	-	-	-
R16-LI	0,6	-	26,9	12,3
R16-B1	2,7	-	26,0	9,8
R16-B2	3,9	-	24,7	11,0
R16-B3	-1,0	-	24,6	11,5
R16-B4	-1,1	-	24,5	9,1
R18-LI	-	-	-	-
R18-B1	-	-	-	-
R18-B2	-	-	-	-
R18-B3	-	-	-	-
R18-B4	-	-	-	-
R18-BU	-	-	-	-
R19-LI	6,3	-	23,6	4,1
R19-B1	8,1	-	27,0	0,2
R19-B2	0,0	-	20,5	2,0
R19-B3	1,6	-	19,1	1,1
R19-B4	-	-	-	-
R21-LI	-	-	-	-
R21-B1	-	-	-	-
R21-B2	-	-	-	-
R21-B3	-	-	-	-
R21-B4	-	-	-	-
R22-LI	11,6	8,8	30,1	8,5
R22-B1	14,6	10,0	36,5	7,4
R22-B2	23,9	9,4	44,1	7,2
R22-B3	21,6	9,1	43,2	7,5
R22-B4	-	-	-	-
R23-LI	3,6	-	22,0	5,3
R23-B1	8,5	-	26,5	7,7
R23-B2	1,3	-	21,5	4,5
R23-B3	3,8	-	22,4	6,7
R23-B4	0,7	-	23,1	6,2
Average	8	10	28	6
SD	7,5	2,4	7,1	3,3
RSD	97%	25%	25%	51%
Minimum	-1	5	19	0
Maximum	24	14	44	12

Table AC-8

SYSTEM D (inlets)	IN - "OFF"	IN - "ON"		
Location	**DELTA (dB)**	**DELTA "1" (dB)**	**$L_{Ainstal,nT}$ "2" (dB)**	**DELTA "3" (dB)**
S5-C1	10,6	7,1	39,2	6,0
S5-C2	13,4	7,8	40,5	4,3
S5-C3	14,4	7,5	41,4	4,4
S7-C1	-	-	39,5	-
S7-C2	-	-	34,1	-
S7-C3	-	-	32,7	-
S9-C1	-	-	-	-
S9-C2	-	-	-	-
S9-C3	-	-	-	-
Average	13	8	38	5
SD	2	0	4	1
RSD	15%	5%	10%	19%
Minimum	11	7	33	4
Maximum	14	8	41	6

ANNEX 16 AIR TIGHTNESS OF CLEAN AIR LOW ENERGY RESIDENCES

Clean air low energy Residences

Location	Total Supply (m³/h)	Total exhaust (m³/h)	V50 (m³/h)
R1-IN	176	112	1994
R2-IN	nvt	238 - 331	2075
R3-IN	122 - 176	234 - 287	-
			measurement impossible
R4-IN	256	229	1592
R5-IN	115	72	280
	1 vent inaccessible	1 vent inaccessible	
R6-IN	-	-	573
	all vents inaccessible		
R7-IN	43 - 99	53 - 114	118
R8-IN	38 - 126	18 - 68	5238
R9-IN	-	-	-
	refused cooperation		n50 = 2.35
R10-IN	309	244	1422
		1 vent inaccessible	
R11-IN	68	64	687
		1 vent inaccessible	
R12-IN	145 - 267	72 - 109	2479
		1 vent inaccessible	
R13-IN	87 - 163	116 - 204	874
R14-IN	88 - 328	63 - 226	386
R15-IN	175	214	192
	3 vents inaccessible		
R16-IN	86 - 271	60 - 125	1859
	1 vent inaccessible	3 vents inaccessible	
R17-IN	94 - 294	82 - 226	-
			measurement impossible
R18-IN	nvt	94 - 164	1933
R19-IN	81 - 182	19 - 45	101
		4 vents inaccessible	
R20-IN	126	102	298
		1 vent inaccessible	
R21-IN	nvt	30 - 79	-
			measurement impossible
R22-IN	94	187	129
	1 vent inaccessible		
R23-IN	138 - 455	26 - 110	559

ANNEX 17 FUNGI, YEAST AND TOTAL BACTERIA COUNTS IN BIOAEROSOLS OF CLEAN AIR, LOW ENERGY SCHOOLS AND RESIDENCES

Bioaerosols in schools

Average (CFUs/cm2) per location and per parameter		
Location	**Total CFU/m3**	**Total CFU/m3**
	Fungi + yeast	**Total bacteria**
S2-in-C1	2,1E+01	8,5E+01
S2-in-C2	6,4E+01	9,0E+02
S2-in-C3	1,6E+02	4,5E+02
S3-in-C1	1,8E+02	1,3E+03
S3-in-C2	1,1E+02	3,7E+02
S3-in-C3	1,4E+02	1,5E+03
S4-in-C1	1,1E+02	9,5E+03
S4-in-C2	2,8E+01	8,0E+03
S4-in-C3	4,9E+01	2,1E+03
S5-in-C1	6,4E+01	4,0E+03
S5-in-C2	3,3E+02	1,5E+04
S5-in-C3	1,8E+03	1,1E+04
S7-in-C1	1,4E+04	***5,9E+04***
S7-in-C2	3,9E+03	***2,0E+04***
S7-in-C3	4,5E+03	***3,8E+04***
Average	1,7E+03	1,1E+04
SD	3,6E+03	1,7E+04
RSD	215%	146%
Minimum	2,1E+01	8,5E+01
Maximum	1,4E+04	5,9E+04

Average (CFUs/cm2) per location and per parameter		
Location	**Total CFU/m3**	**Total CFU/m3**
	Fungi + yeast	**Total bacteria**
S2-in-out	5,6E+02	5,7E+02
S3-in-out	5,4E+02	2,3E+02
S4-in-out	6,0E+02	1,8E+02
S5-in-out	1,8E+02	3,3E+02
S7-in-out	3,2E+03	5,0E+03
Average	1,0E+03	1,3E+03
SD	1,2E+03	2,1E+03
RSD	122%	166%
Minimum	1,8E+02	1,8E+02
Maximum	3,2E+03	5,0E+03

Annex 17 Fungi, yeast and Total bacteria counts in bioaerosols of Clean Air, Low Energy schools and residences

Bioaerosols in residences

Average (CFUs/cm2) per location and per parameter		
Location	**Total CFU/m3**	**Total CFU/m3**
	Fungi + yeast	**Total bacteria**
R1-in-liv	3,5E+01	1,2E+02
R1-in-bed	4,2E+01	5,7E+01
R2-in-liv	9,9E+01	3,3E+02
R2-in-bed	1,6E+02	5,4E+02
R3-in-liv	2,1E+01	2,3E+02
R3-in-bed	1,4E+01	3,3E+02
R4-in-liv	3,9E+02	4,0E+02
R4-in-bed	4,9E+01	2,2E+02
R8-in-liv	0,0E+00	9,7E+02
R8-in-bed	7,8E+01	9,4E+02
R14-in-liv	3,6E+02	3,5E+02
R14-in-bed	4,2E+01	1,7E+02
R15-in-liv	1,1E+02	7,4E+03
R15-in-bed	5,7E+01	5,2E+03
R16-in-liv	1,5E+02	1,3E+03
R16-in-bed	1,5E+02	1,6E+03
R17-in-liv	7,2E+02	6,2E+02
R17-in-bed	1,1E+02	4,8E+02
R18-in-liv	2,7E+02	1,2E+03
R18-in-bed	1,3E+02	4,1E+02
R19-in-liv	1,1E+02	6,4E+01
R19-in-bed	7,8E+01	3,3E+02
R20-in-liv	4,9E+01	1,5E+02
R20-in-bed	4,2E+01	1,6E+02
R21-in-liv	6,4E+01	1,3E+02
R21-in-bed	3,5E+01	1,5E+03
R22-in-liv	1,7E+02	5,0E+02
R22-in-bed	2,0E+02	4,4E+02
R23-in-liv	4,1E+02	1,1E+04
R23-in-bed	3,1E+02	3,1E+03
Average	1,5E+02	1,4E+03
SD	1,6E+02	2,5E+03
RSD	105%	183%
Minimum	0,0E+00	5,7E+01
Maximum	7,2E+02	1,1E+04
Average	2,0E+02	1,7E+03
SD	2,0E+02	3,2E+03
RSD	101%	194%
Minimum	0,0E+00	6,4E+01
Maximum	7,2E+02	1,1E+04
Average	1,0E+02	1,0E+03
SD	8,0E+01	1,4E+03
RSD	80%	136%
Minimum	1,4E+01	5,7E+01
Maximum	3,1E+02	5,2E+03

Average (CFUs/cm2) per location and per parameter		
Location	**Total CFU/m3**	**Total CFU/m3**
	Fungi + yeast	**Total bacteria**
R1-in-out	2,8E+02	4,5E+02
R2-in-out	9,1E+02	3,1E+02
R3-in-out	1,1E+02	1,1E+02
R4-in-out	9,9E+01	6,4E+01
R8-in-out	1,6E+02	1,1E+02
R14-in-out	2,3E+02	4,7E+02
R15-in-out	2,0E+02	3,0E+02
R16-in-out	5,9E+02	2,3E+03
R17-in-out	3,1E+02	2,6E+02
R18-in-out	9,0E+02	3,8E+03
R19-in-out	1,3E+02	5,7E+01
R20-in-out	2,6E+02	1,4E+02
R21-in-out	1,4E+02	4,9E+02
R22-in-out	2,9E+02	4,5E+02
R23-in-out	1,6E+03	2,4E+02
Average	4,2E+02	6,4E+02
SD	4,2E+02	1,0E+03
RSD	102%	163%
Minimum	9,9E+01	5,7E+01
Maximum	1,6E+03	3,8E+03

ANNEX 18 FUNGI, YEAST AND TOTAL BACTERIA COUNTS IN SETTLED DUST OF CLEAN AIR, LOW ENERGY SCHOOLS AND RESIDENCES

Gemiddelde (CFUs/cm2) per locatie en per component			
Location	**gisten CFUs/cm2**	**schimmels CFU/cm2**	**kiemgetal CFU/cm2**
S2-in-C1	3,0E+00	7,0E+00	4,9E+01
S2-in-C2	**5,0E-01**	**5,0E-01**	3,0E+01
S2-in-C3	**5,0E-01**	**5,0E-01**	4,9E+02
S3-in-C1	**5,0E-01**	1,0E+00	7,0E+00
S3-in-C2	**5,0E-01**	2,0E+00	1,2E+03
S3-in-C3	**5,0E-01**	**5,0E-01**	1,5E+01
S4-in-C1	**5,0E-01**	1,0E+00	3,1E+01
S4-in-C2	**5,0E-01**	2,0E+00	9,8E+01
S4-in-C3	2,0E+00	7,5E+01	1,8E+02
S5-in-C1	**5,0E-01**	**5,0E-01**	2,3E+01
S5-in-C2	8,0E+00	2,5E+01	4,2E+02
S5-in-C3	**5,0E-01**	4,1E+01	9,6E+02
S7-in-C1	1,0E+00	3,0E+00	1,0E+00
S7-in-C2	**5,0E-01**	**5,0E-01**	1,0E+00
S7-in-C3	**5,0E-01**	**5,0E-01**	**5,0E-01**
Average	1,3E+00	1,1E+01	2,3E+02
SD	2,0E+00	2,1E+01	3,8E+02
RSD	153%	199%	162%
Minimum	**5,0E-01**	**5,0E-01**	**5,0E-01**
Maximum	8,0E+00	7,5E+01	1,2E+03

Gemiddelde (CFUs/cm2) per locatie en per component				
Location		**gisten CFUs/cm2**	**schimmels CFU/cm2**	**kiemgetal CFU/cm2**
R1-in-liv		**5,0E-01**	**5,0E-01**	1,0E+00
R1-in-bed		**5,0E-01**	**5,0E-01**	**5,0E-01**
R2-in-liv		**5,0E-01**	**5,0E-01**	4,0E+00
R2-in-bed		**5,0E-01**	**5,0E-01**	2,9E+01
R3-in-liv		**5,0E-01**	**5,0E-01**	2,9E+01
R3-in-bed		**5,0E-01**	**5,0E-01**	2,5E+01
R4-in-liv		**5,0E-01**	**5,0E-01**	3,3E+01
R4-in-bed		**5,0E-01**	**5,0E-01**	3,4E+01
R8-in-liv		**5,0E-01**	1,0E+00	3,9E+01
R8-in-bed		**5,0E-01**	**5,0E-01**	1,8E+01
R14-in-liv		**5,0E-01**	3,0E+00	1,6E+01
R14-in-bed		**5,0E-01**	**5,0E-01**	6,0E+00
R15-in-liv		**5,0E-01**	7,0E+00	3,5E+02
R15-in-bed		**5,0E-01**	**5,0E-01**	2,7E+02
R16-in-liv		1,0E+00	7,5E+00	1,6E+02
R16-in-bed		**5,0E-01**	2,0E+00	9,1E+01
R17-in-liv		**5,0E-01**	**5,0E-01**	1,5E+01
R17-in-bed		**5,0E-01**	**5,0E-01**	1,1E+02
R18-in-liv		**5,0E-01**	3,0E+00	6,5E+01
R18-in-bed		**5,0E-01**	1,0E+00	2,0E+01
R19-in-liv		**5,0E-01**	8,0E+00	1,1E+02
R19-in-bed		**5,0E-01**	2,0E+00	1,7E+01
R20-in-liv		**5,0E-01**	3,0E+00	3,2E+01
R20-in-bed		**5,0E-01**	**5,0E-01**	7,5E+00
R21-in-liv		**5,0E-01**	**5,0E-01**	4,6E+01
R21-in-bed		**5,0E-01**	**5,0E-01**	1,1E+02
R22-in-liv		**5,0E-01**	4,8E+01	8,5E+01
R22-in-bed		**5,0E-01**	1,5E+01	3,2E+01
R23-in-liv		2,0E+00	2,0E+00	7,8E+02
R23-in-bed		**5,0E-01**	**5,0E-01**	5,3E+01
Average		5,7E-01	3,7E+00	8,6E+01
SD		2,9E-01	9,0E+00	1,5E+02
RSD		50%	242%	177%
Minimum		**5,0E-01**	**5,0E-01**	**5,0E-01**
Maximum		2,0E+00	4,8E+01	7,8E+02
Average	**Living**	6,3E-01	5,7E+00	1,2E+02
SD		4,0E-01	1,2E+01	2,0E+02
RSD		63%	211%	173%
Minimum		**5,0E-01**	**5,0E-01**	1,0E+00
Maximum		2,0E+00	4,8E+01	7,8E+02
Average	**Bedroom**	5,0E-01	1,7E+00	5,5E+01
SD		0,0E+00	3,7E+00	7,0E+01
RSD		0%	219%	127%
Minimum		**5,0E-01**	**5,0E-01**	**5,0E-01**
Maximum		**5,0E-01**	1,5E+01	2,7E+02

5,0E-01	Halve detectielimiet

Clean Air, Low Energy

Work Package 3: Interpretation, valorisation possibilities and policy recommendations

"Exploratory research on the quality of the indoor environment in energy-efficient buildings: the influence of outdoor environment and ventilation"

LNE/OL200900012/10034/M&G

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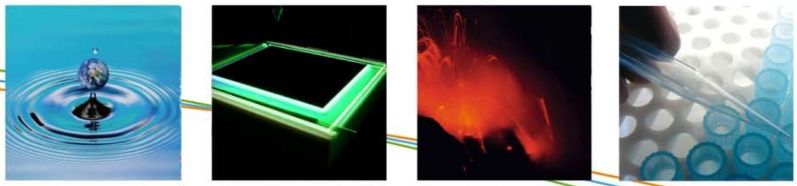

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ACH	Air change rate per hour
ACR	Air Change Rate
AER	Air Exchange Rate
CAV	Constant Air Volume
CFU/m^3	colony forming units per m^3
CO	Carbon monoxide
CO_2	Carbon dioxide
DCV	Demand-Controlled Ventilation
I/O ratio	Indoor/outdoor ratio
IAP	Indoor Air Pollution
IAQ	Indoor Air Quality
MVHR	Mechanical ventilation with Heat Recovery
NO_2	Nitrogen dioxide
n50	Amount of air changes of a building volume in one hour, under a pressure of 50 Pa, due to in- and exfiltration
O_3	Ozone
PEF	Peak Expiratory Flow
PFT	Perfluor carbon tracer
PMV	Predicted mean vote
PPD	Predicted percentage of dissatisfaction
RH	Relative Humidity
SAV	Seasonally Adapted Ventilation
EEBs	Energy-efficient buildings
SF6	Sulphur hexafluoride
SHS	Sick House Syndrome
SPL	Sound Pressure Level
STI	Speech Transmission Index
Temp	Temperature
TH	Teaching hours
TSP	Total Suspended Particles
v50	Leakage flow at 50 Pa, per m2 building envelope, as defined according to EPB
VOC	Volatile organic compounds

CHAPTER 1 INTRODUCTION

In this exploratory study, *Clean Air Low Energy*, the indoor air quality of 51 indoor sites in low energy buildings, equipped with a mechanical ventilation system (controlled supply and exhaust air as well as trickle ventilators with controlled exhaust air) in Flanders has been determined, in total in 25 houses and 26 classrooms. Each indoor environment is characterized chemically, physically and biologically; the energy performance and the building envelope of each indoor location are assessed as well.

1.1. STRATEGY OF WP3

1.1.1. PROJECT PLAN OF WORK

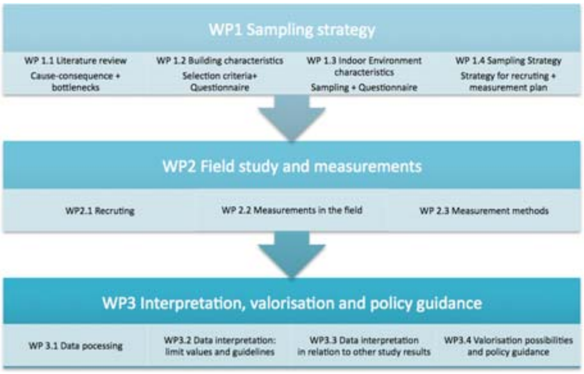
The sampling campaign in Clean Air Low Energy focussed on the chemical, physical, and biological characterisation of the indoor environment in energy-efficient buildings. This implies a physico-chemical analysis of the indoor environment as well as the corresponding outdoor air; the quantification of fungi and bacteria indoors and the corresponding outdoor air, the measurements of noise nuisance related to building ventilation (both ventilation system-related and outdoor environment related) and the measurement of the effectiveness of the ventilation system in relation to the theoretical ventilation and air infiltration.

This large dataset allows an exploratory comparison which is reported in this third work package (Work Package 3). In this step the indoor environments of passive, low-energy and traditional houses and schools in Flanders will be evaluated and compared, and different ventilation system types will be contrasted.

The indicative results of this study lead to the formulation of policy options and guidance for environmental policy and other entities. Needs for further research, and practical guidelines for citizens will also result from this research. For this reason, in the building selection phase significant attention was put on the possibility to extrapolate the data obtained from this relatively limited set of buildings, to the whole region of Flanders.

A schematic overview of the different work phases in Clean Air, Low Energy is shown in Figure 1.

Figure 1: Clean Air, Low Energy flowchart



1.2. WP 3 FINAL REPORT STRUCTURE

This third work package reports on the interpretation of the Clean Air Low Energy dataset, and on the valorisation possibilities and policy guidance, that result hereof.

After a descriptive analysis of the identified and quantified parameters, the respective influences of the ventilation system, of the building envelope and of the ventilation rate on the indoor air quality in relation to the ambient air quality was assessed. The indirect influence of noise nuisance on the building ventilation (use of the ventilation system) and on the resulting indoor air quality was assessed as well. Furthermore other potentially influencing parameters (like duct characteristics, the type of heat recovery system, etc) are explored as well.

The quantified building and indoor environmental parameters are then evaluated in relation to existing guidelines and limit values and to other Flemish, Belgian and EU – study results.

CHAPTER 2 DATA ANALYSIS

This chapter reports the analysis of the Clean Air Low Energy dataset. In a first phase, a descriptive analysis of each identified and quantified parameter in the houses and schools and their respective outdoor concentration levels is reported. In a second phase, the indoor air quality (chemical, physical as well as biological parameters) and its relation to the outdoor air quality, is described in function of

1. the ventilation system (controlled exhaust and supply air versus controlled exhaust air);
2. the building envelope (building air tightness);
3. the total air change rate;
4. noise nuisance (as a result from the outdoor environment as well as ventilation system).

2.1. DESCRIPTIVE ANALYSIS OF THE CLEAN AIR LOW ENERGY DATASET

2.1.1. CHEMICAL AND BIOLOGICAL PARAMETERS

Overall, it should be noted that some compounds have occurred at concentration levels below the detection limit of the sampling method in all schools and residences that were monitored in Clean Air Low Energy. These include indoor and outdoor trichloroethylene, tetrachloroethylene, styrene, 1,4-dichlorobenzene and MTBE. The latter occurred at levels approximating the detection limit in all except 2 outdoor school sites as well as in 13 of the 25 houses. Furthermore, both o-xylene and heptane occurred at levels below the detection limit of 0,1 µm/m^{3}in a considerable amount of schools and houses. α-pinene was not detected in outdoor air.

Of all identified organic compounds in Clean Air Low Energy, formaldehyde, d-limonene, α-pinene, and toluene were most abundant in indoor air. Even though they occurred at higher concentration levels in residences compared to schools, their highest abundance in the identified and quantified set of compounds was confirmed both in schools as well as in residences.
As a consequence of the larger variety and quantity of indoor sources, residential TVOC also occurs at higher concentrations compared to classroom levels (residential average: 455 ± 229 µg/m^3 in residences, classroom average 318 ± 193 µg/m^3).

Average classroom $PM_{2.5}$ as well as average indoor residential $PM_{2.5}$ are lower than their corresponding average outdoor levels. The higher average $PM_{10}/PM_{2.5}$ ratio of 3.8 ± 2.1 in classrooms compared to residences (1.8 ± 0.5), indicates a more pronounced contribution of coarser resuspended particulate matter in the classrooms, compared to residences.
Because of this resuspension, caused by the movement of the pupils in the classroom, indoor school $PM_{2.5}$ levels are expected to be higher than the residential levels. Although this can be noticed in the dataset, more detailed analysis (reported in 2.2) will further explore the interaction between building ventilation, indoor and outdoor PM levels.

Because of the mechanical ventilation (trickle ventilators combined with controlled exhaust as well as controlled supply and exhaust air), indoor CO_2 levels were fairly low in the Clean Air Low Energy schools and houses; the residential 24h-average value (606 ± 104 ppm) approximated the teaching hour average, i.e. the mean classroom concentrations during the occupied period (658 ± 166 ppm).

Levels of total viable bacteria and fungi were determined from active air samples as well as from swab samples of settled dust from standard surfaces.

In residences, the average levels of total viable fungi indoors were comparable or slightly lower compared to the outdoor average concentrations (1.5 x 10^2 and 4.2 x 10^2 CFU/m^3, respectively). In five schools monitored for biological contamination, the average indoor value exceeded the outdoor value slightly (1.7 x 10^3 and 1.0 x 10^3 CFU/m^3, respectively). A clear difference was found between the average indoor and outdoor total bacteria count: both in residences (1.4 x 10^3 and 6.4 x 10^2 CFU/m^3, respectively) and schools (1.1 x 10^4 and 1.3 x 10^3 CFU/m^3, respectively) the indoor levels exceed the outdoor ones. This is a normal phenomenon, as bacterial levels indoors are largely driven by the occupants themselves and many times exceed outdoor levels. This can also be seen in the fact that school indoor environments with higher occupancy had higher levels compared to residences, and also the difference between indoor and outdoor was more pronounced in classrooms compared to residential living rooms or bedrooms. Also fungal levels were most likely affected by higher occupancy/activity levels in classrooms causing resuspension of particles from floors and other surfaces.

Swab samples were collected only indoors; total viable yeast, fungi and bacteria were enumerated separately. Generally, levels of yeast, fungi and bacteria were higher in schools compared to homes. As with active air samples, bacterial levels were found about one order of magnitude higher compared to fungal levels on indoor surfaces A more detailed analysis is reported in paragraph 2.2.

2.1.2. BUILDING ENVELOPE: BUILDING AIR TIGHTNESS – VENTILATION RATE

→ Schools

The initially proposed classification of selected school buildings for the Clean Air Low Energy study was solely based on one of the building properties: the airtightness of the building envelope, as shown in *Table 1*. The indoor environment of the classrooms is expected to depend largely on the total air exchange rate, which is the sum of the natural air infiltration rate and the rate of deliberate ventilation of the room. The ventilation rates depend on the characteristics of the ventilation system and the actual set point chosen by the inhabitants, and were measured in the classrooms. The infiltration rate is estimated to be a fixed fraction of the airtightness of the building envelope which was measured in situ and defined at a reference pressure difference of 50 Pascal.

Taking into account the quantified air tightness of the school buildings and the ventilation rate, as well as the number of people present, a new classroom classification is created

Table 1 Initial strategy for school building classification

School category	Very airtight	Airtight	Moderately airtight
Selection criterion	$n_{50} \leq 0.6$	$0.6 < n_{50} \leq 2.5$	$n_{50} \geq 2.5$
Expected ventilation system	(D without heat recovery) D with heat recovery	(C) C demand controlled D without heat recovery D with heat recovery	C C demand controlled D without heat recovery
Optional features	Earth-to-air heat exchanger		-

Air tightness in classrooms

Since the leakage characteristics of the internal partitions are unknown, a whole wing was tested whenever possible (3 schools, 8 classrooms). The other classrooms were tested individually. In a 5 classrooms, the leakage rate was estimated by engineering judgement due to obviously leaky partitions or due to impossible correct execution of the blowerdoor (pressurization)-test. 2 schools consisted of individual classrooms connected to an open hallway.

The classrooms proved to be leakier than the dwellings, therefore, a 4th airtightness group (classrooms and residences were categorized in groups of airtightness) was introduced that allows to separate the very leaky cases from the rest. By application of these categories, 3 very airtight, 4 airtight, 7 moderately airtight and 12 leaky classrooms were found with n50 values lower than 0.6, between 0.6 and 2.5, between 2.5 and 10 and higher than 10 respectively. The median value is 7.7 and the average 8.2.

With an average n50 value of 14.75, the modular class units are far more leaky than the traditionally constructed classrooms, which have an average n50 value of 5.36.

Air change rate in classrooms

In contrast to the measurements in the dwellings, the measurements in the classrooms could not be executed during occupancy. Therefore, the air flow rate preferably selected by the occupants was not known. Very few systems, however, allowed selection of the air flow rate in the classroom. Therefore, all systems were measured in the normal operating mode. Several teachers indicated disabling the system due to noise and draft. Opening of windows was not taken into account to calculate the total air change rates. Actual air change rates during classes may be considerably higher than the total air change rates achieved with the ventilation system due to the opening of windows, although most teachers (if present) indicated that the frequency of opening varies a lot. Another cause of differing actual air change rates is, when available, the selection of lower air flow rates during operation.

The total air change rate, taking into account mechanical ventilation, adventitious ventilation (ventilation by airflows through components of the ventilation system that are not induced by the fans) and infiltration, was calculated and divided by the average of the actual number of students reported by the teacher over the course of 1 week. In accordance with EN 13779 [5], which defines 4 classes of indoor air quality based on the pollution level or flow rate per person (IDA-classes), the flow rate per pupil was classified according to the IDA classes, with flow rates per pupil lower than 6 l/s corresponding to IDA 4, between 6 and 10 l/s to IDA 3, between 10 and 15 l/s to IDA 2 and flow rates over 15 l/s to IDA 1. Due to the large number of very low flow rates, a 5th class was defined as flow rates per pupil lower than 3 l/s. IDA 1 was only achieved in 1 classroom. IDA 2 was found in 4 classrooms, IDA 3 in 9, IDA 4 in 7 and the additional class ‘IDA 5’ in 5 classrooms. These results are shown in figure 2. The horizontal lines in the figure mark the lower limit of the specified IDA classes.

The minimal design flow rate specified in the EPB (Flemisch Energy Performance of Buildings decree) annex 6 is 1.5 l/s/m². 9 classroom achieve a flow rate higher than that design flow rate, 20 classrooms a flow rate of at least 75% of that.

The CEN report CR 1752 [6] specifies 3 design flow rates for classrooms at 6, 4.2 and 2.4 l/s/m² and is thus more strict. Only 6 classroom achieve a flow rate higher than the design flow rate of lowest of the 3 classes proposed in the CEN report, 8 attain half of that and the remaining 12 have even lower flow rates. The CEN report stipulates a design occupancy of 0.5 pupils/m², the EPB annex half of that. In comparison, the actual occupancy reported in the classrooms is rather low with a median of 0.31 and a mean of 0.24 pupils/m². All these results are summarized in Figure 3 by means of box and whiskers plots.

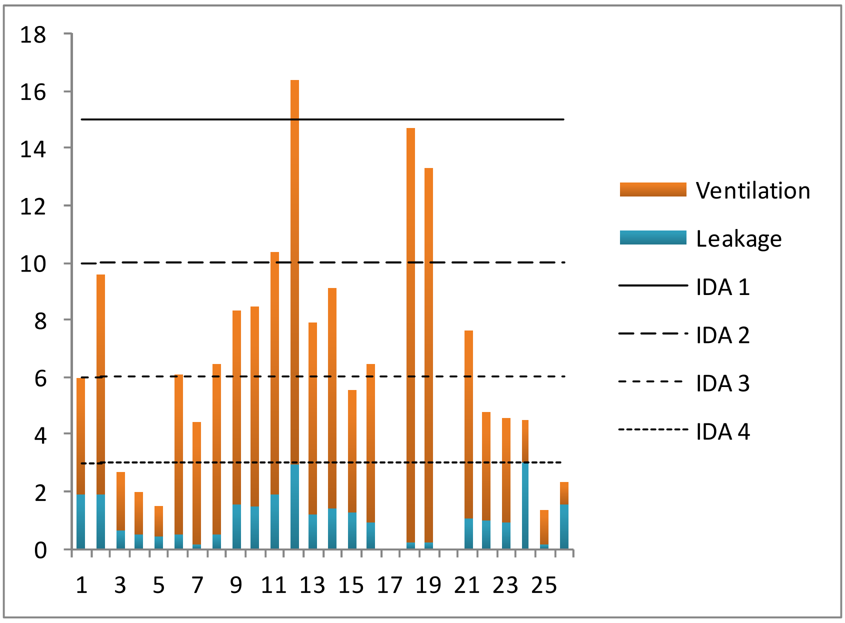


Figure 2 Total air flow rate per pupil (no occupancy data available for classroom 17 and 20)

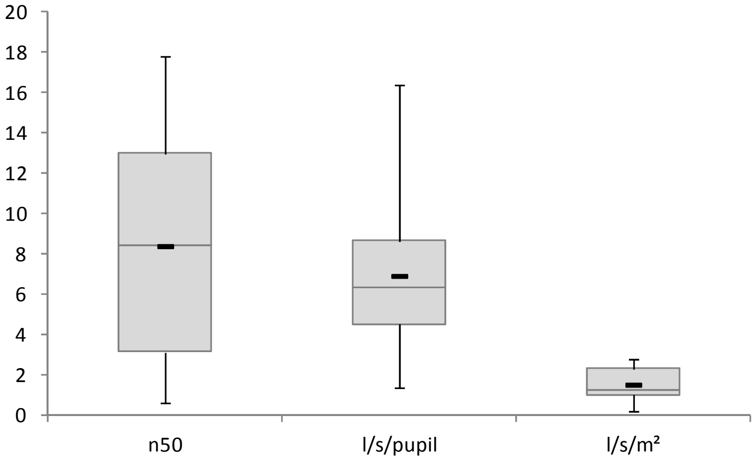


Figure 3 Box and Whiskers plot of leakage air change rate at 50 Pa (n50), total ventilation per pupil and design flow rate in the classrooms

→ **Residences**

The initial classification of the houses, according to air tightness is shown in Table 2. We rearranged the houses into categories based on measured data of total air exchange rate. The actual classification of the residential buildings, based on the Clean Air Low Energy data, is described below.

Table 2 Initial strategy for dwelling characterisation

Dwelling category	Very airtight	Airtight	Moderately airtight
Selection criterion	$n_{50} \leq 0.6$	$0.6 < n_{50} \leq 2.5$	$n_{50} \geq 2.5$
Expected ventilation system	D with heat recovery	(C) C demand controlled D with heat recovery	C C demand controlled (D with heat recovery)
Optional features	Earth-to-air heat exchanger Ground coupled heat exchanger with a heat transfer fluid Thermal recovery wheel Integrated heating Small plastic ducts		-

Air tightness in residences

As was described in the WP-2 report, the goal of the case selection was to achieve a spread of dwellings within 3 categories: very airtight, airtight and moderately airtight with n50 values under 0.6, between 0.6 and 2.5 and over 2.5 respectively. The results of the airtightness tests demonstrate that this ambition has been achieved. Of the 25 dwellings, 6 were in the very airtight class, 8 were airtight and 11 were moderately airtight, with a median value of 2.3 and average of 2.1 (including 3 estimated values (cases 3, 17 and 21) for the cases where a correct measurement was not possible due to insufficient completion of the wind barrier and the lack of a suitable opening for the installation of the equipment), the general level of airtightness in the sample is considerably better than that for recently built standard construction [1] (median = 4.9, average = 6). With a n50 value of 0.15, the most airtight case is a passive house, which is 4 times less leaky than the passive house standard (0.6), which is generally accepted as very ambitious.

Air change rate in residences

The occupants operated their ventilation system at a much lower rate (median=0.24 ACH, average=0.24 ACH) than the design flow rate specified in the Belgian residential ventilation standard [2] (about 1 ACH). Reasons for this behaviour were not systematically dealt with in the questionnaire, but anecdotal evidence was gathered through conversations with the occupants. Amongst others, noise and draft were the chief reasons given by occupants for selecting lower flow rates. Additionally, most occupants did not perceive ventilation as necessary. The selected flow rates are also in the lower tier of the flow rates required by European standards [3]. This, however, does not take into account the effect of infiltration and adventitious ventilation. If this is taken into account, the total air change rate is higher, though still substantially lower than the design flow rate (median=0.38, average=0.37). For the calculation of the latter, since not enough detailed information on wind conditions during the test period were available, a ratio of 15 and 25 between the infiltration rate at 50 Pa and that at operating conditions was assumed for rural and urban locations respectively. For simple exhaust systems, the adventitious ventilation was estimated at 0.5-1 times the mechanical flow rate, in accordance with observations from previous studies [4]. Opening of windows was not taken into account. Again, the total air change rates are among the lowest found in a broad literature review [3], possibly due to a lack of 'sence of need' by the occupants.

The ventilation standard [2] requires that the design flow rate can be achieved. Therefore, in a subsection of the cases (16 of the 25 cases), the highest selectable flow rate was also tested along with the preferred selection of the occupants. In none of the dwellings with heat recovery ventilation (13 of 16), the design flow rate was achieved in all spaces. 4 dwellings with heat recovery ventilation achieved a total supply flow rate equal or greater than the total design flow rate. The median of the ratio between these two flow rates was 0.78, the average 0.75. If only the bedrooms are considered, this is 0.80 and 0.81 respectively. For the exhaust flow rates, this ratio was on average 0.86, 0.96, 1.02 and 0.88 for kitchens, toilets, bathrooms and service rooms respectively. This can be explained by the fact that the total design flow rate for supply and exhaust are not balanced in the Belgian standard. The design flow rate for exhaust is usually smaller than that for supply. Since heat recovery ventilation achieves optimal performance when both flow rates are nearly balanced, exhaust flow rates tend to be relatively higher in practice.

One case with simple exhaust ventilation was intentionally oversized by the occupant. It's total exhaust rate was 2.2 times higher than the design flow rate for exhaust. The remaining 2 cases with simple exhaust ventilation had a tendency to have too little ventilation capacity, comparable to that observed in heat recovery ventilation systems. The ratio of total exhaust flow rate and design flow rate was on average 0.52, while, considering each one of the exhaust spaces individually, this ratio was 0.45, 0.83, 0.38 and 0.94 for kitchens, toilets, bathrooms and service rooms respectively. The tendency to have relatively higher exhaust flow rates observed in heat recovery systems is not found in simple exhaust systems. The trickle ventilators in the cases with exhaust ventilation were overall in accordance with the standard's requirements or larger.

The results for leakage and total air change rate for the dwellings are summarized by box and whiskers plots in Figures 4 and 5. Figure 6 lists the measured total air change rate and its distribution between leakage and ventilation for all dwellings. The horizontal lines correspond to the lower limits of the classes that were proposed above. Figure 7 shows the correspondence between required design flow and measured maximum flow rate for all bedrooms and living rooms in the dwellings.

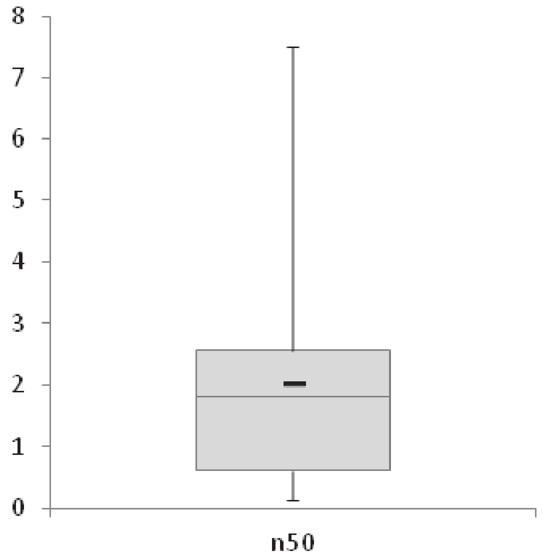


Figure 4 Box and Whiskers plot of leakage air change rates at 50 Pa (n50) for the residences

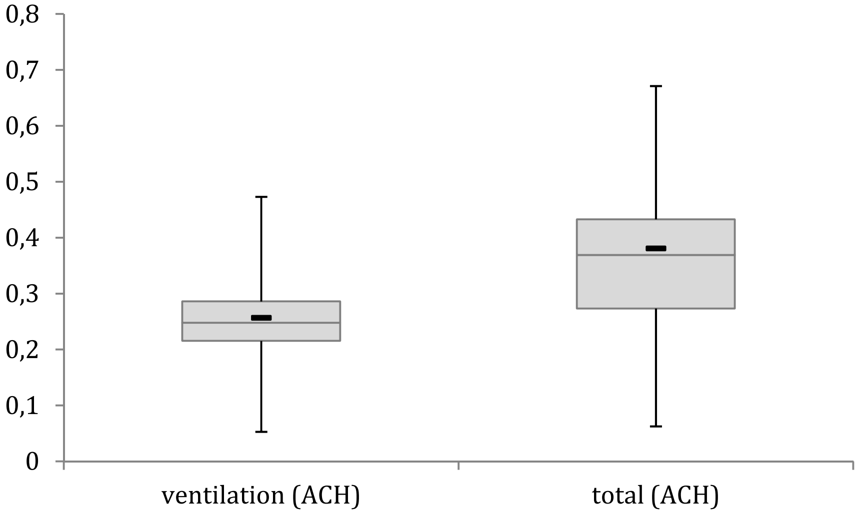


Figure 5 Box and Whiskers plot of total and ventilation air change rates for the residences

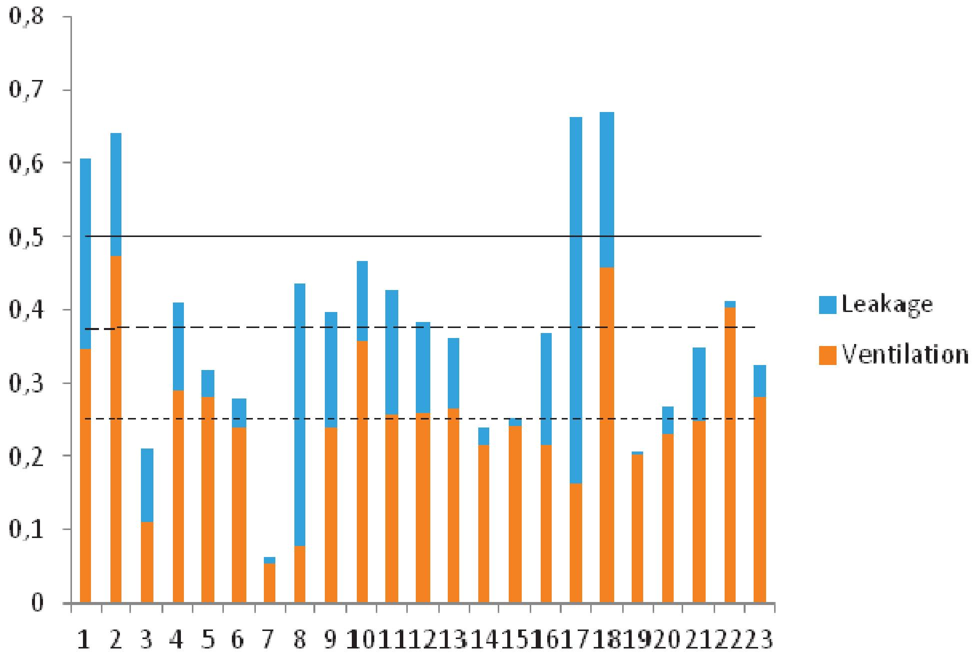


Figure 6 total air change rate (ACH) in the residences, subdivided by leakage and ventilation

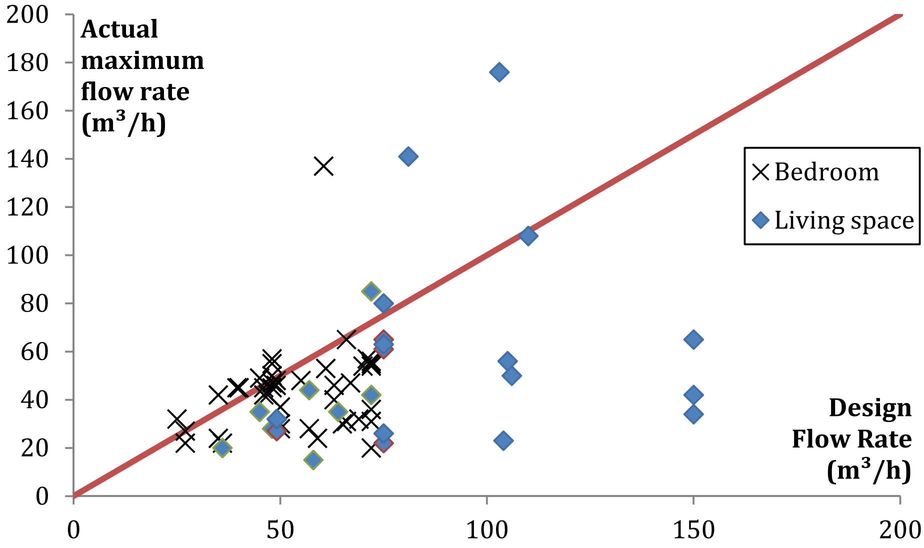


Figure 7 Actual maximum mechanical flow rate and design flow rate for all living spaces and bedrooms in the residences with heat recovery ventilation

2.1.3. ACOUSTICS

→ Schools

Only 3 schools were examined acoustically: S5 (system D), S7 (system D – passive building) and S9 (system C). In Figure 8 the overall sound pressure levels (A-weighted) are compared for the 9 examined classrooms. For modular unit school S5, the values are given for the ventilation system in regime 2. For school S7 there was only one working regime. The values for school S9 correspond to the situation where the trickle ventilators were ‘open’. The lowest SPL are registered for the system C school, which was indeed situated in a very calm area. An average SPL of 33 dB is recorded. The acoustic comfort value of 35 dB in classrooms[1] was respected for this school. As for the passive building S7 an average value of 35.4 dB was noted, where 2 of the examined 3 classrooms exceed the 35 dB comfort value. For the modular unit school S5 shows not one of the tested classrooms comply with the prNBN criterion.

These results of course do not reflect the average values to be expected for ‘typical’ system C and system D schools. The results for system C schools depend of course strongly of outdoor environment. The examined system D schools are very specific: a modular unit school (S5) and a ‘passive’ school (S7). For the modular unit school one can expect similar values for similar modular unit – mechanical ventilation system combinations.

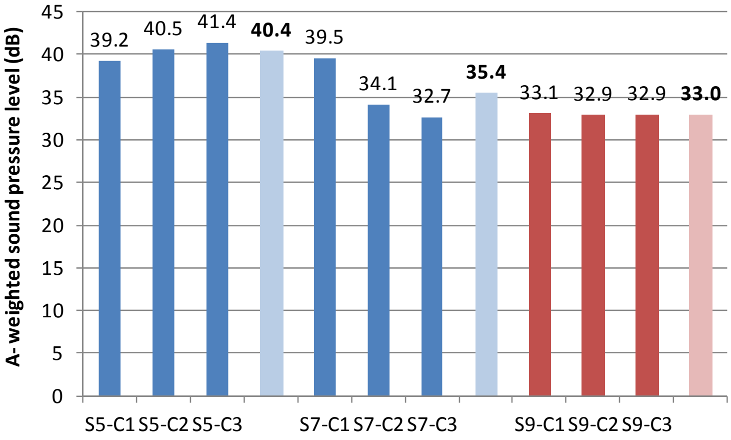


Figure 8 Overall sound pressure levels in the classroom of the examined Clean Air Low Energy schools (blue: system D schools – regime 2, red: system C schools)

Acoustic comfort in system D schools

When calculating the specific mechanical ventilation noise for the system D schools (by subtracting from the overall all SPL the background levels one a energetically base), the figures in Figure 9 can be found. These values have to meet the 35 dB comfort value from the NBN draft standard.

For the ‘passive’ school S7 a relatively high level of 39.5 dB is registered for classroom C1. This room is in fact equipped as an industrial kitchen. A higher limit for the comfort level is defendable. We can assume the limit value of 40 dB for ‘ateliers’ (workshops) in the prNBN S 01-400-1. In this case, the acoustic comfort in the teaching room can be considered acceptable. The other two classrooms respect the comfort value of 35 dB for common class rooms.

The modular unit schools show similar results for the three tested classrooms, all 4 to 6 dB above the limit value of 35 dB in working regime 2. Figure 10 gives the results for the three different working regimes separately. Regime 1, with an average A-SPL of 31 dB seems to respect the

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[1] Comfort value according to draft standard for acoustic comfort in school building prNBN S 01-400-2

acoustic comfort criterion. The noise levels increase with almost 10 dB when switching from regime 1 to regime 2. This subjectively corresponds with a doubling of the loudness.

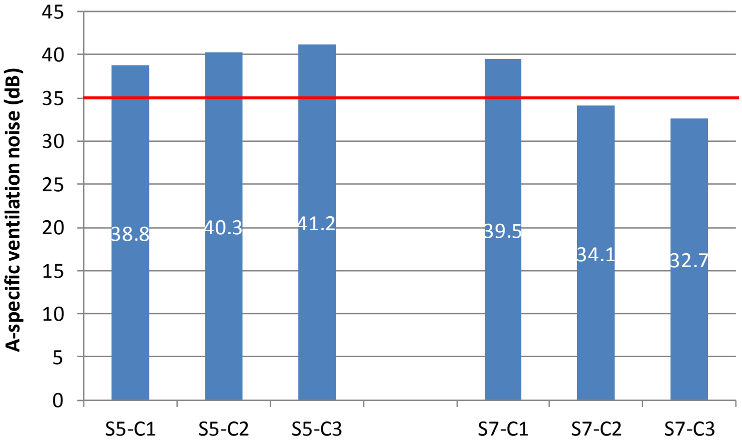

Figure 9 Overview of specific mechanical ventilation noise for examined Clean Air Low Energy system D schools, related to the acoustic comfort value from prNBN S 01-400-2

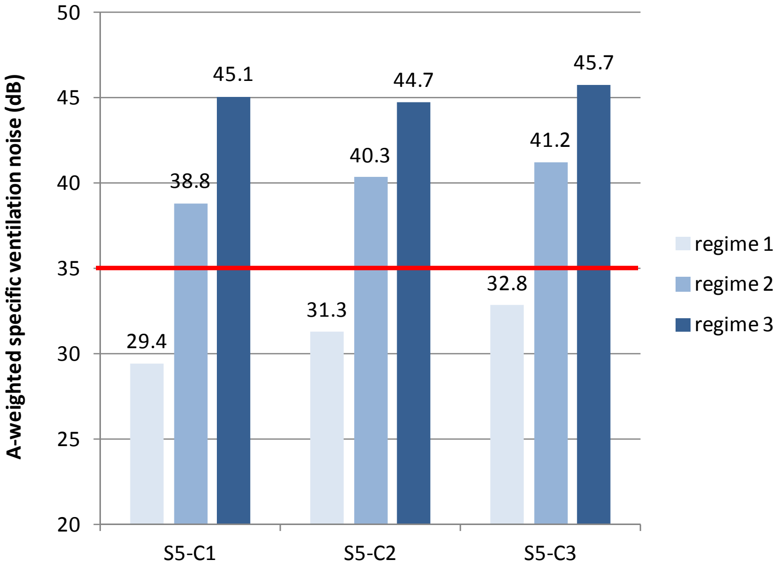

Figure 10 Mechanical ventilation noise for three different working regimes in Clean Air Low Energy school S5

Noise levels versus air flow rates

Noise levels increase with the air flow rates. This can be seen in Figure 10 where higher working regimes (air flow rates) correspond with higher noise levels. Only air flow rates for regime 3 are available. These are plotted against the corresponding noise levels, together with the data for project S7 in Figure 11. For modular unit school 5 the influence from air flow rate to the noise level is very obvious. This of course has to do with the identical ventilation systems and classrooms. The only influencing parameter is the realised air flow rates, so the correlation with the resulting noise level is clear. Small differences in air flow rates were to be expected.

For school S7, we indeed find a higher air flow rate for the ‘kitchen’ classroom, resulting in a higher SPL. On the other hand, the lowest SPL, this is 32.7 dB is registered for room S3. For a correct interpretation, the complete system should be analysed (group, ducts, mufflers) per classroom.

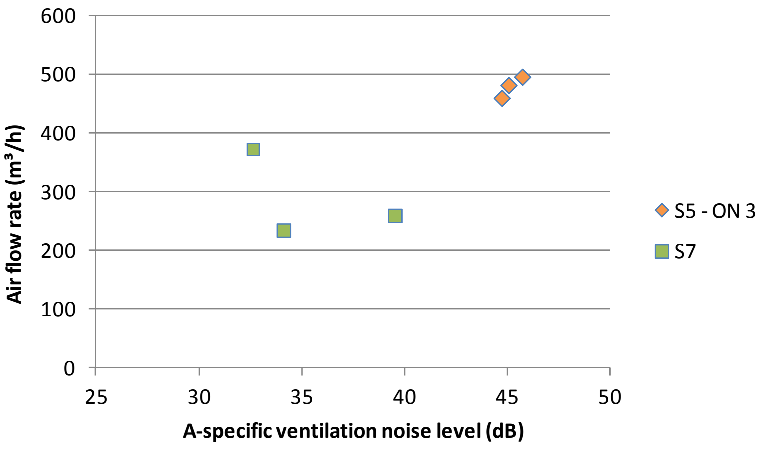

Figure 11 Noise levels against air flow data for acoustically examined system D schools

Since the classrooms don’t differ a lot in surface area, a nominal air flow rate of about 300 m³/h is required in all the rooms, resulting in a more or less same spread noise levels against the ratio of the air flow rate to the design flow rate (Figure 12).

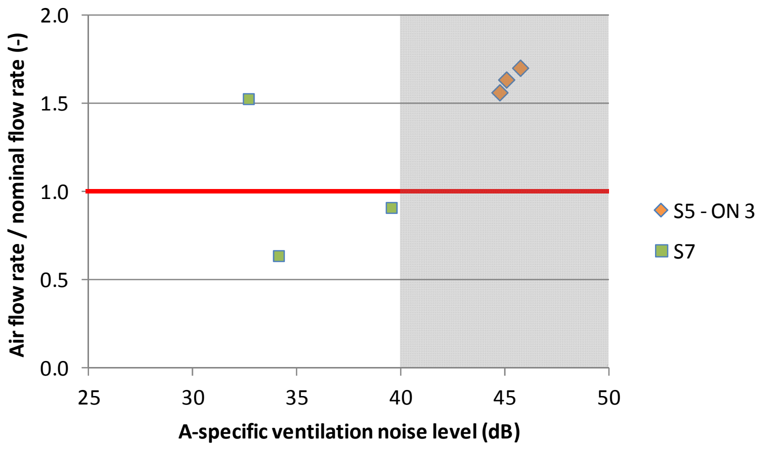

Figure 12 Noise levels versus air flow rate ratio for system D school S5 and S7

From this figure we can conclude that only one classroom (S7-C3) of the 6 examined system D rooms meets the acoustic and ventilation criteria according to Belgian standards at the same time. The ‘kitchen’ classroom almost reaches the ratio 1 for ventilation.

No air flow rate data were available for regime 1 and 2 in the modular unit classroom (S5). For regime 1 the acoustic comfort value is not exceeded (Figure 10). However, it is very unlikely that this regime meets the ventilation requirement in terms of air flow rate.

Acoustic comfort in system C schools

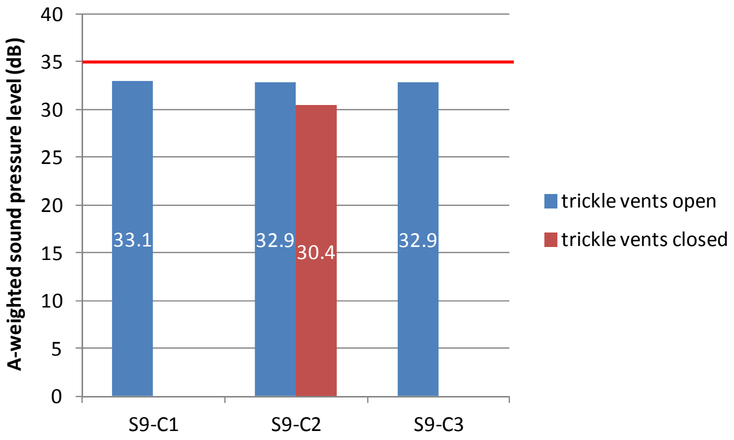

Figure 13 Indoor noise levels for system C classrooms

Comparable noise levels are registered for all the system C classrooms of project S9. With an average A-weighted sound pressure level of 33 dB when the trickle ventilators are open, the acoustic comfort level of 35 dB according to the Belgian draft standard prNBN S 01-400-2 for school buildings is met for all rooms. In classroom C1 and C3 the trickle ventilator couldn't be closed easily so no data are available for closed vents. Closing the trickle vent in room C2 reduces the noise level with 2.5 dB (Figure 13). The higher comfort level of 31 dB is then respected.

Because of the quiet environment, no real danger of closing the vents due to noise can be suspected. The noise levels are low and closing the vents doesn't lower the noise levels a lot (difference of 3 dB become 'remarkable').

However, teachers indicate that they open the windows often. If this happens during the teaching periods, pupils are exposed to higher noise levels, approaching the outdoor noise levels. The outdoor levels measured at 2 m in front of the façade, as well as the noise levels in the adjacent hall way is illustrated in Figure 14. The outdoor noise levels are very low, indicating a very calm environment. However, when opening the windows, the indoor levels will certainly exceed the 35 dB comfort level. The classrooms are also exposed to relatively high noise levels in the hall way due to mechanical air extraction, especially C1 where the noise levels are almost as high as outdoor. Given the high percentage of weak sound insulation of the interior wall between the classrooms and the hall way, the noise from the mechanical air extraction probably affects the indoor noise level to some degree. That's one of the reasons why the Belgian draft standard limits also the noise in hall ways, to a value of 45 dB. In the hall way next to room C1 this level is exceeded.

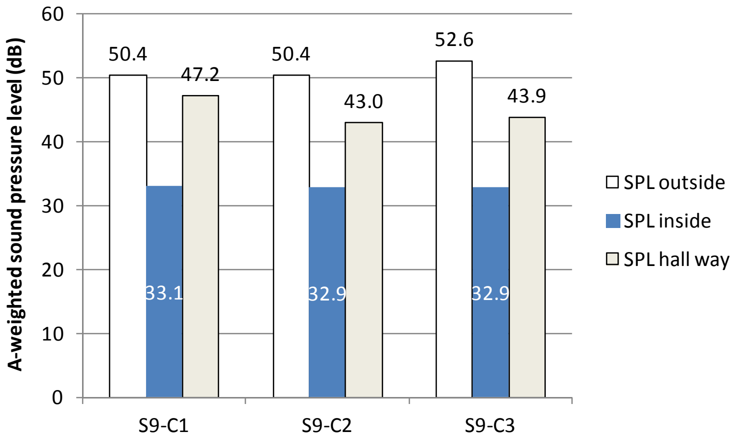

Figure 14 Outdoor and indoor noise levels for Clean Air Low Energy school S9

Given the extreme quiet outdoor conditions, no acoustically improved trickle vents are really necessary to respect the maximum comfort value of 35 dB. However, to reach the high comfort level of 31 dB according to the Belgian draft standard or when outdoor conditions are noisier, sound insulation improving measures are necessary. A complete analysis should be made whether not only the trickle vents but also the window glazing and possibly the interior wall have to be improved acoustically.

→ Residences

Sound pressure levels were registered in living rooms and bedrooms belonging to 8 different residences: R1, R2, R16, R18, R19, R21, R22 and R23. Noise nuisance from the mechanical air inlets for system D and from the outdoor environment through ventilation openings in the façade for system C are to be examined.

The indicated noise levels (A-weighted equivalent sound pressure levels, A-SPL) in what follows are all converted to a standard reverberation time according to the NBN S 01-400-1, in order to make fair comparisons between the A-SPL measured in different rooms.

Acoustic comfort in system C and D

- *Bedrooms*

An overview of the A-weighted sound pressure levels (A-SPL) measured in the 27 different bedrooms is given in Figure 15.

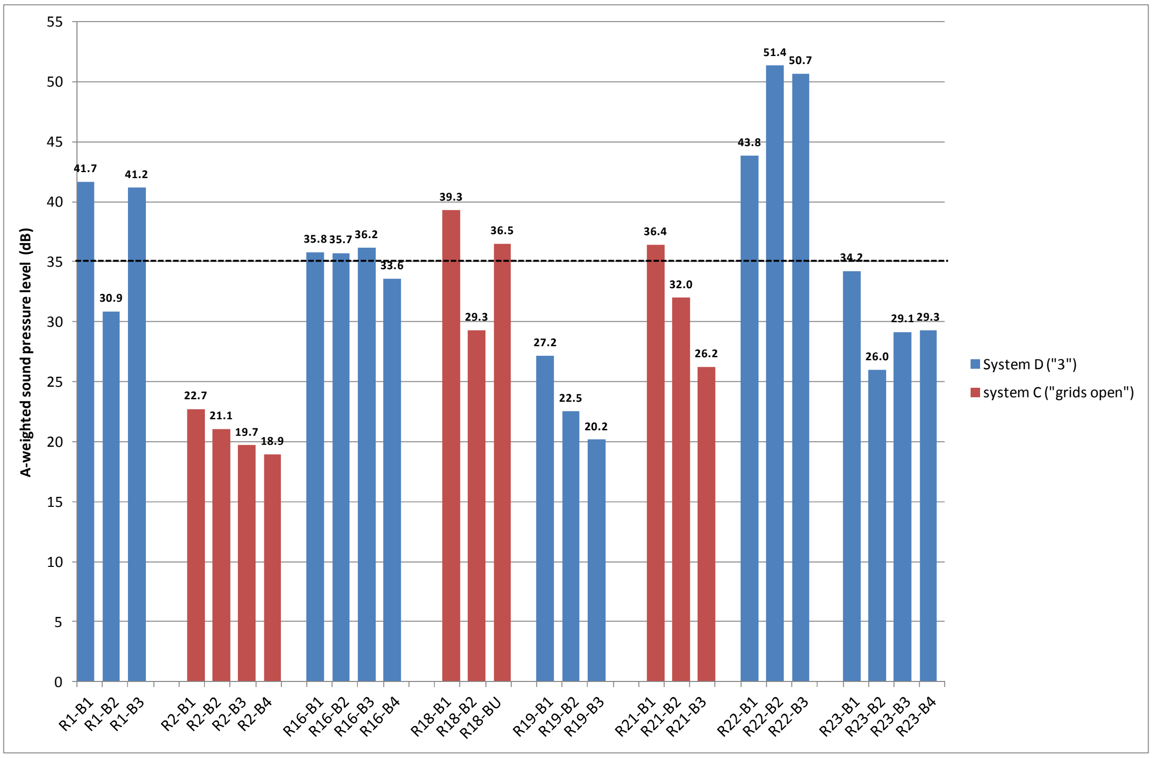

Figure 15 A-weighted sound pressure levels registered in the bedrooms for the examined dataset (8 residences) with ventilation systems D in highest working regime ("3") and ventilation systems C with trickle ventilators in open position

The red bars indicate measured A-SPL for the 10 examined bedrooms within 3 different residences with natural air supply, i.e. with adjustable openings in the façade. The blue bars (17 cases belonging to 5 different residences) give the results for the A-SPL in the bedrooms with mechanical air supply[2] (system D).

The A-SPL for system C bedrooms with open ventilation devices are compared to the A-SPLs for system D bedrooms with the mechanical ventilation system in working regime “3”, this is the highest selectable flow rate. This flow rate does not necessary correspond to the design flow rate, as discussed further. However for almost all the acoustically examined residences, maximum flow rates (regime “3”) seems to be necessary to comply with the design flow rates as required by the Belgian residential ventilation standard. Results for noise nuisance related to air flow rates are discussed in section 2.1. As for the system C bedrooms, all trickle ventilators are open during the SPL measurements. For this dataset, the highest registered A-SPL (51.4 dB) is found for a bedroom with mechanical air supply (R22-B2). We have to specify that for test cases R22-B2 and R22-B3 both situated on the second floor of a terraced house, the remarkable high sound levels are due to a lack of interior doors and the vicinity of the ventilation group (not yet shielded) installed on hall way on the second floor as well.

So excluding the results for R22, the values registered for system D bedrooms are situated between 20.2 dB (R19-B3) and 41.7 dB (R1-B1) for the highest selectable air flow rate (“3”), as illustrated in Figure 16.

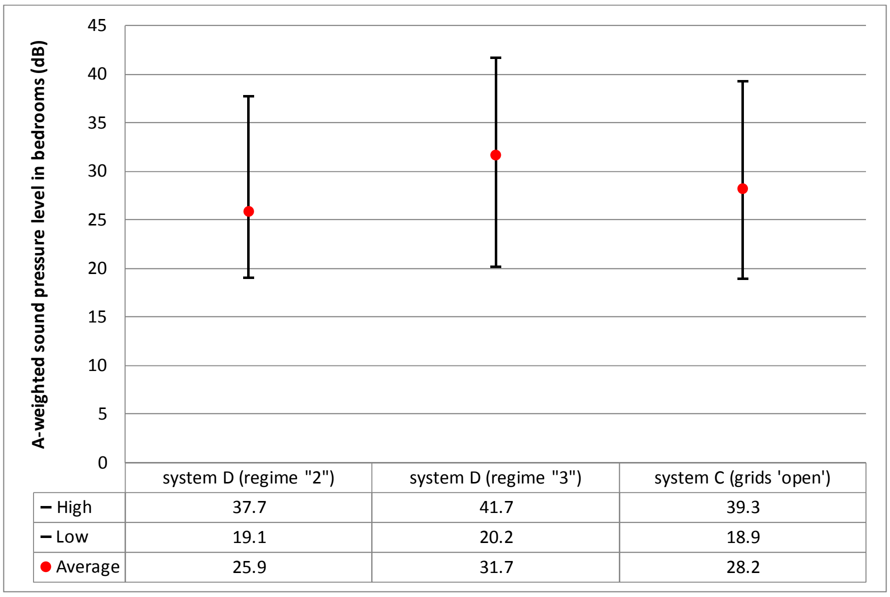

Figure 16 Maximum, minimum and average values for A-SPL for system D (14) and system C (10) bedrooms

The minimum value of 18.9 dB (R2-B4) and the maximum value of 39.3 dB (R18-B1) for system C bedrooms can be considered of the same order. The dispersion of the results for system C bedrooms are mainly due to differences in the outdoor noise levels, while the dispersion in the results for system D bedrooms rather comes from different installation characteristics. The average A-SPL for system D bedrooms (regime “3”) seems to be 3.5 dB higher than for system C bedrooms (trickle ventilators ‘open’). Considering the data for system D bedrooms under regime “2”, we find a somewhat smaller dispersion and a substantially[3] lower average A-SPL value. A

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[2] We prefer to look at the results for living rooms separately since their typical room characteristics have a considerable influence on the resulting A-SPL.

[3] . A difference between of 3 dB or higher can be considered significant and clearly perceptible for human hearing, so affecting the acoustic comfort appreciation

tendency of users switching their ventilation system to a medium regime cannot be excluded. Unfortunately this regime mostly doesn't allow respecting the design flow rates.

Beside the actual noise levels, an important comfort parameter is also the time fluctuation of the perceived noise: where for system C bedrooms the A-SPL is likely to fluctuate considerably, the A-SPL are assumed to be quite stable during day and night time for system D bedrooms. This could make the same A-SPL in system D more tolerable than in system C, for rather low noise values.

Referring now to the Belgian standard NBN S 01-400-1:2008 for dwellings, a maximum SPL of 35 dB can be assumed. This value is derived from the energetic sum of the maximum (specific) installation noise level 27 dB and the minimum façade sound insulation aiming a maximum indoor level of 34 dB. The limit value of 35 dB is indicated on the graph in Figure 15.

For the system D bedrooms only 9 of the 17 examined cases respects this rather tolerant standard criteria of 35 dB. Only 2 of the 5 residences entirely meet the standard comfort value.

On the other hand 7 out of 10 system C bedrooms meet the NBN standard. This could indicate a rather higher probability of satisfactory acoustic comfort in bedrooms for residences with ventilation system C (natural supply, mechanical extraction)[4], but large differences are to be expected according to the outdoor noise exposure of the considered rooms.

Living rooms: system D and C

- *Living rooms*

A similar comparison can be made for the measured A-SPL in the living rooms of the examined residences. The results of the measured A-SPL in 7 living rooms of the 8 examined residences are shown in Figure 17 (system D living rooms with highest air flow rate "3") and Figure 18 (system D living rooms with medium air flow rate "2").

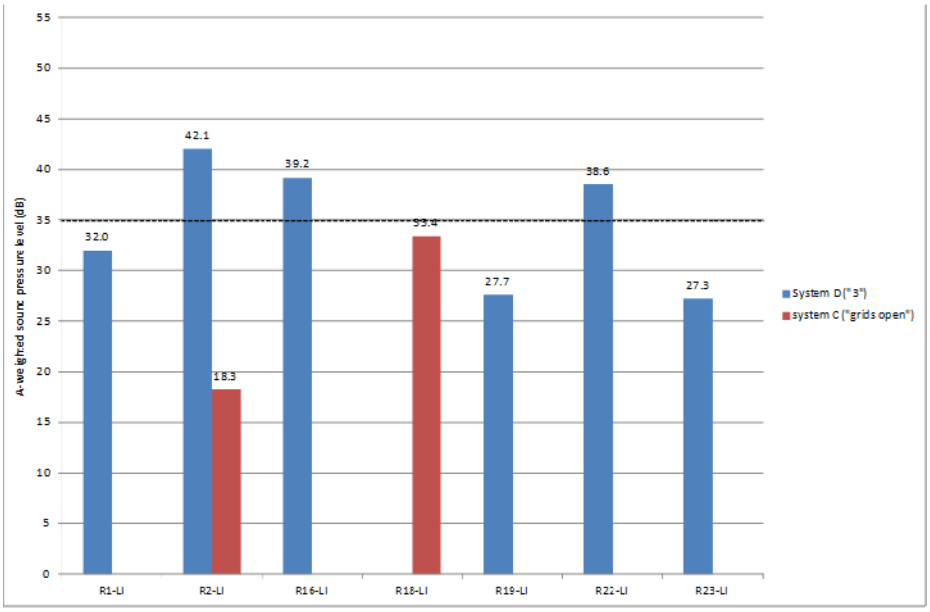

Figure 17 Results for the A-weighted sound pressure levels in the studied living rooms, system D (highest flow rate "3") and system C (trickle ventilators 'open')

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[4] Assuming a considerable decrease of the outdoor noise levels (minimum 5 dB) by night time.

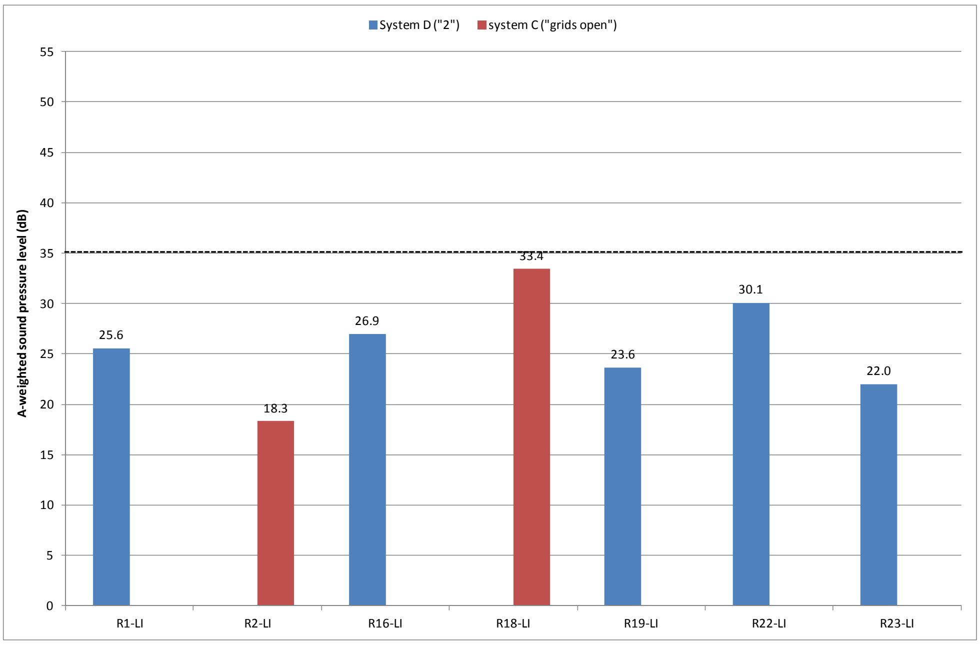

Figure 18 Results for the A-weighted sound pressure levels in the studied living rooms, system D (medium flow rate "2") and system C (trickle ventilators 'open')

We consider both working regimes "2" and "3" because for acoustically examined system D living rooms, as discussed further, the highest selectable air flow rate seems not always to be necessary to reach the design flow rates according to the Belgian residential ventilation standard.

The red bars, indicating the A-SPL for the system C living rooms, only show two results because of the limited number of examined system C residences.

Figure 19 indicates an average A-SPL for the system C living rooms (with trickle ventilators 'open') of 26 dB, the same value as for system D living rooms under regime "2". Under this regime, all registered A-SPL meet the NBN requirement of 35 dB[5] for living rooms (Figure 18). For the highest selectable working regime ("3") an average A-SPL of 33 dB (+7 dB) is calculated. Figure 17 shows that under these conditions 2 of the 5 examined system D living rooms no longer meet the NBN requirements.

Compared to the results for bedrooms, we find remarkable smaller dispersions for the A-SPL in living rooms (especially for system D) while the mean values stay in the same order (Figure 19). In section 2.1 we will put these figures against the available measured air flow rates for system D rooms.

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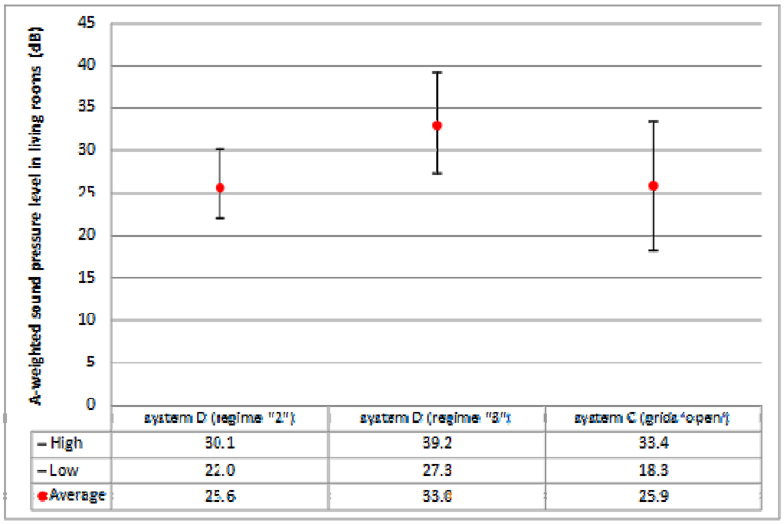
[5] This value is calculated from the energetic sum of the maximum allowable indoor noise levels from installations (30 dB) and from outdoor noise transmission (34 dB) according to the acoustic comfort criteria for dwellings in the NBN S 01-400-1 (2008), presuming both contributions might occur at the same time.



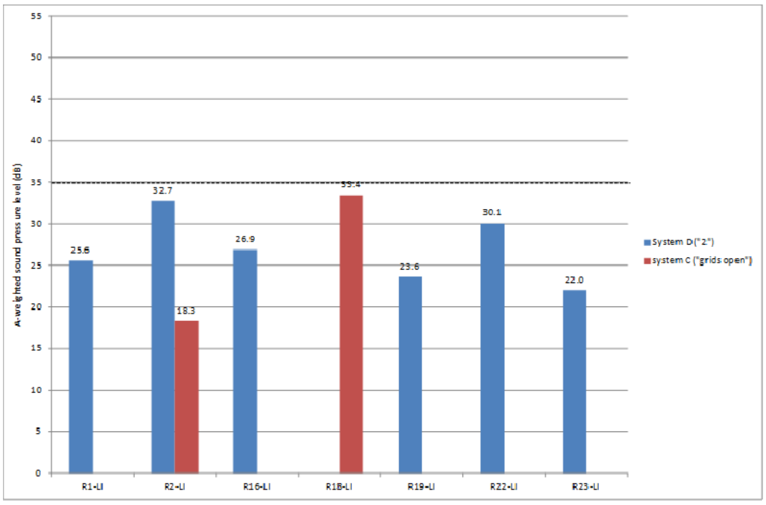
	system D (regime "2")	system D (regime "3")	system C (grids 'open')
– High	30.1	39.2	33.4
– Low	22.0	27.3	18.3
● Average	25.6	33.8	25.9

Figure 19 Maximum, minimum and average A-SPL values for system D (5) and system C (2) living rooms

When roughly comparing system C and D results for living rooms and bedrooms and relating them to the NBN acoustic comfort criteria, we adopted a maximum noise level of 35 dB for both types of rooms. Hereby we presumed both installation noise contribution and outdoor noise transmission occurring at the same time and contributing substantially to the overall measured A-SPL.

In reality for the examined system C rooms the outdoor noise transmission is predominant and so the installation noise becomes negligible. In this case the A-weighted sound pressure levels can be considered as the 'outdoor noise transmission specific' A-SPL and so can be directly related to the 34 dB indoor noise criteria derived from the façade insulation requirement.

For system D rooms the outdoor noise transmission together with all other back ground noise contributions, can have an important influence on the overall measured A-SPL, especially for quiet systems and/or low working regimes (low installation noise levels) and/or high background noise levels. The NBN criteria for (specific) mechanical ventilation noise, namely 30 dB in living rooms and 27 dB in bedrooms have to be checked for the A-SPL measured corrected for the background noise. Therefore we energetically subtract the background noise level (ventilation system off) from the overall A-SPL to determine the A-weighted 'specific' ventilation noise level. In what follows, we look more into details at the results for system C and system D residences, related to the 'specific' noise level requirements derived from the NBN S 01-400-1.



Acoustic comfort in residences with ventilation system C

Acoustic measurements were performed in three different residences with ventilation system C : R2, R18 and R21. The graph below (Figure 20) compares the registered outside noise levels, inside noise levels when trickle ventilators are opened and inside noise levels when the trickle ventilators are closed. The top level of each bar indicates the A-SPL for the defined conditions (outside, inside ‘open’, inside ‘closed’). As expected the indoor noise levels decrease when closing the trickle ventilator. The figures on the bars indicate the level differences between the different bar height, representing the ‘outside-inside noise level difference’ and the ‘gain from closing the trickle vents’.

We can observe a strong dependency of the measured inside noise levels according on the outdoor noise levels, while rather high noise levels up to 66 dB are not excluded. This indicates a general weak façade sound insulation, going from 22 dB to 35 dB. The highest “inside-outside” noise reductions are found for project R2, where extremely low background noise levels (± 20 dB) were recorded due to the extreme quiet environment. The two other projects were situated in noisier environments, with a clear difference in noise exposure according to the orientation in relation to the road traffic.

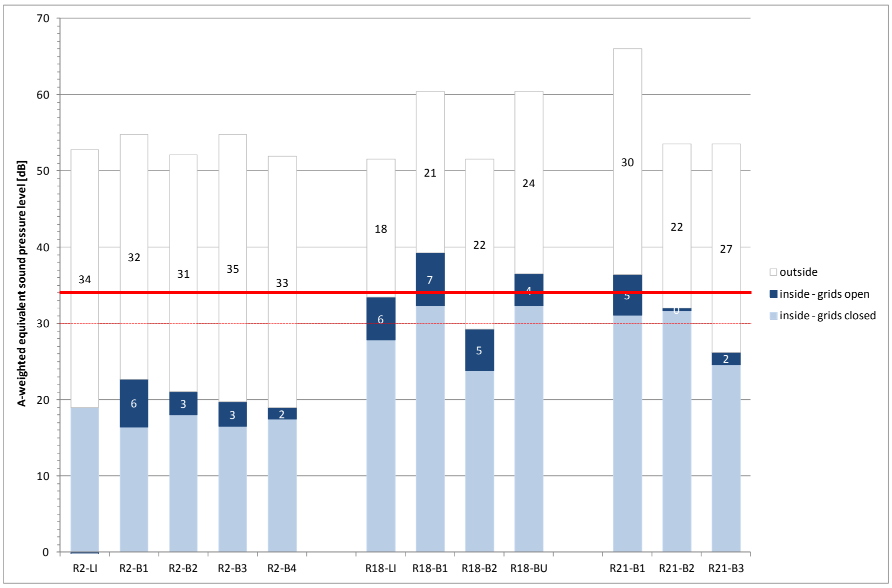


Figure 20 A-weighted equivalent sound pressure levels measured in system C residences' living rooms (LI) and bedrooms (B): outside, inside with open trickle vents and inside with closed trickle vents

In order to analyse correctly the differences in measured indoor sound levels between the projects and the different rooms, all the project characteristics have to be taken into account. Beside the outdoor noise conditions, the façade composition and room characteristics[6] could play an important role. Relevant façade and room characteristics of the studied rooms with ventilation system C, together with the measured data for the indoor and outdoor noise levels are indicated in *Table 3*.

Table 3 Overview of noise levels, façade and room characteristics for studied rooms in residences with ventilation system C

	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Room	L_{Aeq} (dB)		V/S_{netto}	D_{Atr} façade (dB)		type	R_{Atr} glazing (dB)		Trickle ventilator	
	out	in	(m)	estimated	NBN	glazing	estimated	NBN*	Length (m)	D_{neAtr} (dB) NBN*
R2-LI	55.1	18.3	5.4	37	26	4/15/6	R2-LI	55.1	18.3	5.4
R2-B1	57.8	22.7	11.3	35	26	4/14/4	R2-B1	57.8	22.7	11.3
R2-B2	55.1	21.1	16.3	34	26	4/15/4	R2-B2	55.1	21.1	16.3
R2-B3	54.8	19.7	18.2	35	26	4/15/4	R2-B3	54.8	19.7	18.2
R2-B4	54.9	18.9	13.2	36	26	4/15/4	R2-B4	54.9	18.9	13.2
R18-LI	54.5	33.4	13.3	21	26	4/15/4	R18-LI	54.5	33.4	13.3
R18-B1	60.4	39.3	18.1	21	26	4/15/4	R18-B1	60.4	39.3	18.1
R18-B2	54.5	29.3	3.9	25	26	4/15/4	R18-B2	54.5	29.3	3.9
R18-BU	60.4	36.5	10.3	24	26	4/14/4	R18-BU	60.4	36.5	10.3
R21-B1	66	36.4	10.0	30	32	4/15/4	R21-B1	66	36.4	10.0

** with 3 dB safety margin*

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[6] The indoor noise levels have already been corrected for the influence from the sound absorption in the room by conversion to a reference reverberation time

Column 2 and 3 give the data for measured outdoor and indoor noise levels (open trickle ventilators). The overall outside noise levels, measured at 2 m in front of the considered façade, are rather low, varying from 54 dB to 66 dB[7]. In red, the data exceeding the 34 dB limit of the NBN standard [7] for the indoor noise levels (corrected for reverberation time).

Column 4 is the ratio of the room volume to the surface of all acoustically 'weak façade elements' (S_{netto}), such as windows, built-in shutter boxes, and traditional roof parts limiting the room space. A high value indicates rather favourable 'geometrical' conditions as the sound is transmitted through a small 'weak' surface and/or into a large volume. However the value is not an indication for the sound insulation of these weak elements. Remarkably favourable geometric conditions (low values) are noted for living room R2-LI with large window openings on two sides and for bedroom R18-B2 situated partly under the roof. Nevertheless, not being exposed to high noise levels and disposing of not so 'weak elements' (heavier glazing for R2-L1 because of large dimensions and higher average sound insulation from roof parts compared to windows or trickle vents for R18-B2), the indoor levels remain low for R2-LI and acceptable for R18-B2. In theory the V/S factor has to be doubled to gain 3 dB in terms of acoustic comfort. The rather small influence from the geometrical conditions is seen in case R18-B1 where the highest indoor noise level is found against a very high V/S_{netto} value (relatively small window surface compared to the room volume). The outside noise level (column 2) remains the most influencing parameter to the indoor noise level (column 3)[8].

Columns 5 gives the façade insulation D_{Atr} (= $D_{2m,nT,w}$ + C_{tr}), calculated from the outdoor-indoor noise reduction, also indicated on the white bars in Figure 20. However, because of the relatively low outdoor levels, the full insulation capacity could probably not be measured for most cases with the existing traffic noise. So the actual sound insulation of the façade is probably higher for most of the cases. That's why an evaluation of the acoustic comfort according to the NBN standard is more reliable based on the indoor noise levels (column 3) in this study.

According to the Belgian standard, the minimum façade sound insulation (column 6) in order to realise an indoor noise level of maximum 34 dB, mainly depends on the outdoor noise level as shown in Figure 21 Minimum façade sound insulation as a function of the outdoor noise level, according to the NBN S 01-400-1. As said above, these criteria could not be verified properly based on sound insulation measurements with the actual traffic noise.

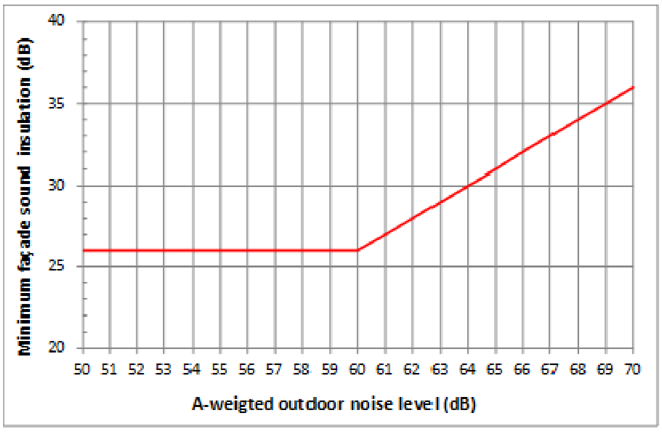

Figure 21 Minimum façade sound insulation as a function of the outdoor noise level, according to the NBN S 01-400-1

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[7] If the rooms were exposed from different sides (more than one façade pane) to outdoor noise, the indicated value is calculated as the energetic sum of the measured values in front of each façade pane.

[8] However, this relationship could not be investigated properly in this study since traffic noise was mostly strongly fluctuating and indoor-outdoor measurements were not performed simultaneously

According to the NBN S 01-400-1 a minimum sound insulation of 26 dB has to be adopted when the outdoor noise levels are below 60 dB. Only one case (R21-B1) seems to be exposed to substantially higher outdoor noise levels (R21-B1). For all cases exceeding 60 dB (R21-B1 and to a lesser degree R18-B1 and R18-BU), the comfort criteria of 34 dB for the indoor noise level is not met.

In column 7 the composition of the glazing is indicated, mostly 4/15/4 (checked on site). Column 8 gives the corresponding sound insulation R_w+C_{tr} (=R_{Atr}) against traffic noise, generally 25 dB, as to be expected from the glazing composition. Column 9 indicates the minimum performance for the glazing (or other 'weak façade element, except for trickle ventilators) as suggested by the NBN standard. This value is calculated from the outdoor noise level (column 2), the geometrical conditions (column 4) and the length of the trickle vent (column 10). A safety margin of 3 dB is taken into account (so 3 dB lower values could still lead to compliance). A high R_{Atr}-value for the glazing, could come from high outdoor noise levels and/or unfavourable geometrical conditions and/or large trickle vents.

Columns 10 and 11 give some information about the trickle ventilator for each room: length of the device (if more than one, the sum) and minimum sound insulation[9] suggested by the NBN standard in order to guarantee the maximum indoor noise level of 34 dB. The Belgian standard suggests a 3 dB higher value for the trickle ventilators compared to the sound insulation of the glazing. Other combinations are of course possible.

So the minimum suggested sound insulation D_{neAtr} (=$D_{ne,w}$ + C_{tr}) for the trickle ventilators depends on the length of the device, the outdoor noise level and the geometrical conditions.

The highest value of 37 dB is suggested for room R21-B1 mainly due to the higher outdoor levels. This bedroom is located at the street side facing the highway (separated by a large open field), being exposed to 66 dB outdoor. The actual trickle ventilator is integrated in the roller shutter box (Figure 22). No technical information about this device is given. When closing the device, the indoor noise level falls down from 36 dB to 31 dB. Given this important gain on the overall indoor noise level and the maximum 'comfort value' of 34 dB, the probability of users closing the trickle vent due to noise disturbance is considerable. An overall outdoor-indoor noise reduction of 30 dB has already been realised for this room in spite of the basic thermal glazing 4/15/4 with an expected R_{Atr} value of 25 dB. Based on prediction calculations according to EN 12354-3 an overall outdoor noise reduction of 30 dB could not have been realised without an acoustically improved trickle ventilator. We can assume that sound absorptive material was added in the shutter box in order to realise an important acoustic attenuation approaching the prescribed 37 dB (- 3 dB) by the Belgian standard. Anyhow, a further gain in façade insulation, to lower the indoor level beneath 34 dB, would probably only be possible by replacing the glazing, suspected to be the weakest element in the façade. To approach the prescribed value of 34 dB (-3 dB) for the window, a glazing of type 8/15/5 (or acoustical equivalent) would be recommended here.

This case clearly shows that although the ventilation device is not expected to be the cause of the noise disturbance, closing the device could considerably reduce the indoor noise level and 'solve' the noise problem at the expense of the indoor air quality. The real solution to avoid the tendency of closing the trickle vents because of noise nuisance, lays in an integrated approach were all 'weak' elements (trickle vents as well as roller shutters and windows) have a sufficient, well-balanced sound insulation capacity.

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[9] The prescribed minimum values refer to the open condition of the trickle vent. A 3 dB safety margin is again taken into account.

Figure 22 Pictures of outdoor environment, indoor space and trickle ventilator for room R21-B1

Within the same project, rooms B2 and B3 are situated at the backside of the building. Considerably lower outdoor noise levels are measured here (*Figure 20*). The indoor level is to be expected in the range of 26 dB, as measured in B3. The indoor level for B2 was influenced by the background noise from a vacuum cleaner at the ground level. In spite of the less severe outdoor conditions at the back, apparently the same trickle vents has been installed in these rooms. This seems to be a common approach for the three examined projects: all the rooms are equipped with the same type of trickle ventilator in spite of the altering outdoor noise conditions according to the room orientation.

As for the project R18, both the rooms R18-B1 and R18-BU, where indoor noise levels higher than 34 dB were found, are located at the front side and so being exposed to higher outdoor noise levels (strong fluctuating, regularly traffic flows passing by, see Figure 23). In both rooms the same type of trickle ventilators is installed. Based on the appearance it seems to be a basic trickle vent. A value of about 26 dB ($D_{ne,Atr}$) for the sound insulation of these types of 'common' devices can be presumed.

Figure 23 Picture of outdoor environment, indoor space and trickle ventilator for room R18-B1

Together with a common thermal glazing (4/15/4, expected R_{Atr}-value of 25 dB) prediction calculations indicate that an outdoor-indoor reduction of 24 dB for R18-BU is achievable. The same reduction is confirmed by the outdoor-indoor measurements. However, for room R18-B1 prediction calculations indicate a feasible noise reduction of 26 dB while a reduction of merely 21 dB can be calculated based on the measurements. This could be explained by the non-simultaneously measured indoor-outdoor noise levels (since traffic noise was strongly fluctuating), the error margin on the input data (D_{neAtr} and R_{Atr} too positive for trickle vent and window, eg. because of leaks) and/or an additional transmission path via the roof part for room R18-B1 (not taken into account in prediction, nor in S_{netto} to define the minimum R_{Atr}).

According to prediction calculations a sufficient sound insulation could be realised for room R18-BU with a R_{Atr} for the window of minimum 26 dB (preferably 29 dB) and a D_{neAtr} for the trickle ventilator of 29 dB (preferably 32 dB), or an acoustical equivalent combination. According to prediction calculations, by replacing the existing trickle ventilators by acoustical improved model (or by adding an attenuating module) with R_{Atr} of minimum 31 dB, an indoor level below 34 dB becomes achievable without changing the glazing. At least the same measures have to be taken for R18-B1.

Again tendency to close the trickle vents because of noise disturbance is not excluded here. Measurements show that the indoor noise levels drop down to a value of 32 dB for both rooms by closing the ventilation devices (Figure 20).

For project R2, situated in a very quiet environment, with only occasionally traffic passing by, another type of trickle ventilators was seen, mounted between the glass pane and the window frame, with an expected D_{neAtr}-value between 24 dB and 28 dB(Figure 24).

Figure 24 Picture of outdoor environment, indoor space and trickle ventilator for room R2-B2

Very high noise reductions are calculated from the indoor and outdoor measurements. They possibly give a too favourable impression since the occasional traffic noise in a very quite environment and the lack of simultaneous indoor-outdoor measurements. Nevertheless, the absolute indoor noise levels being so low, no user tendency to close the trickle vents from noise disturbance is to be expected here.

Mechanical ventilation noise in system D residences

Measurements have been carried in 22 rooms belonging to 5 different residences equipped with ventilation system D. Since the nature of the rooms, living rooms and bedrooms, air is supplied by a mechanical ventilation system. The degree of possible noise disturbance from this mechanical air supply is examined by common A-SPL measurements for different working regimes. Acoustical measurements were performed for at least two ‘working’ conditions: regime 3 (highest selectable) and regime 2 (medium, mostly used). Additional, the background noise level has been measured; this is the remaining noise when the ventilation system was turned off. For each examined room, these three data (overall A-weighted sound pressure levels, A-SPL) are indicated by the bars on Figure 25.

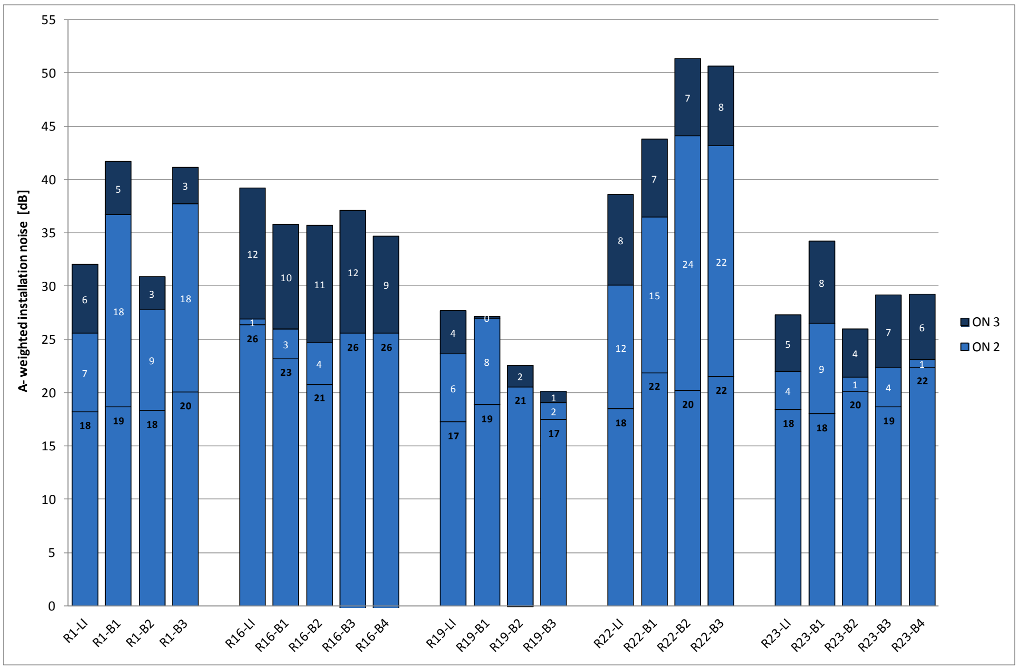

Figure 25 A-weighted sound pressure levels for rooms with mechanical air supply (system D) for different operating conditions: regime 3 (highest), regime 2 (medium) and system off (background noise)

The dark blue bars indicate the A-SPL for working regime 3, the blue ones the A-SPL for working regime 2. The background noise level is indicated by the black scores and figures in the blue bars. The white figures in the dark blue bars indicate the SPL-difference between regime 3 and 2. The white figures in the blue bars give the SPL-difference between regime 2 and the background level.

As for the background levels, generally low levels were registered, typical for very airtight buildings. Only for project R16 the background levels are somewhat higher. The nearby high way traffic is the cause of these higher levels.

Remarkable high ventilation noise levels are found for project R22, especially rooms B2 and B3. This has (partly) to do with the lack of doors for all the rooms (still had to be installed at the moment of measurements). Also for project R1 remarkable high A-SPL are found for rooms B1 and B3. While the other studied projects were traditionally heavy masonry building, this project happens to be a timber frame construction. Since this is a light construction type, sound and vibrations are easily induced and conducted by the structure. However, acceptable noise levels were found in the other rooms of the project. A defect in the ventilator reported by the owner, resulting indeed in clearly noticeable shifting resonance peaks at 50 Hz in regime 3, 40 Hz in regime 2 and 25 Hz in regime 1.

On the other hand, we registered remarkable low noise levels for project 19, even on working regime 3, especially for bedroom B2 and B3 on the 2nd floor (farthest away for the unit). A check with the corresponding air flow rates has to be made, to make sure that the design flow rates are actually respected.

The influence of the background noise (BGN) on the measured ventilation noise levels (especially regime 1 and 2) is noticeable for projects R19, R16 and R23. Very small difference between the BGN and the noise levels (regime 2) were found here. For project R19 (especially B2 and B3) this is due to very low ventilation noise levels, being of the same order as the (low) background levels. The same goes for project R23 (except for room B1 were relatively high ventilation noise levels were found). For R16 the influence is due to the high levels of BGN (because of the nearby highway), approaching the actual ventilation noise levels. When the difference between the BGN and the ventilation noise level becomes small (whether this is due to high BGN levels and/or low ventilation noise levels) this always results in an overrating of the actual 'specific' ventilation noise; this is the noise only due to the ventilation system. In order to correct for this influence, we can 'energetically' subtract the BGN for the ventilation noise levels (comprising the BGN)[10]. We then obtain the so called 'specific' ventilation noise.

In order to evaluate if the noise coming from the ventilation system lies within acceptable limits, 'specific' ventilation noise levels have to be considered. That's why we applied the BGN correction[11] to the noise levels indicated in *Figure 25*. The corrected values, indicated in Table 4, can now be evaluated against the acoustic comfort levels (normal or high) in the Belgian standard. Values in red indicate specific ventilation noise exceeding the maximum standard value, being 30 dB for living rooms and 27 dB for bedrooms. Green values indicate compliance to the high comfort requirements; this is 27 dB for living rooms and 25 dB for bedrooms. Both limit values together with the level differences between regime 2 and 3 are illustrated in *Figure 26* for bedrooms and *Figure 28****Error! Reference source not found.*** for living rooms.

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[10] This correction is only 100% accurate if the BGN is stable and the BGN is not too high compared to the ventilation noise.

[11] The correction was made for level differences down to 1 dB. For smaller differences, a default reduction of 7 dB was applied.

Table 4 Measurement data for A-SPL levels in residences with ventilation system D (corrected for background noise) – red values : exceeding the normal comfort NBN values, green values : respecting the high comfort NBN values

SYSTEM D (inlets)	**OFF**	**ON**	
Location	**background noise * [dB]**	**regime "2" ** (dB)**	**regime "3" ** (dB)**
R1-LI	18.2	24.7	31.8
R1-B1	18.7	36.6	41.6
R1-B2	18.3	27.3	30.6
R1-B3	20.0	37.7	41.1
R16-LI	26.4	19.9	39.0
R16-B1	23.2	22.7	35.5
R16-B2	20.8	22.5	35.6
R16-B3	25.6	17.6	35.8
R16-B4	25.6	17.5	32.8
R19-LI	17.3	22.5	27.3
R19-B1	18.9	26.3	26.5
R19-B2	20.6	13.5	18.1
R19-B3	17.5	13.9	16.8
R22-LI	18.5	29.8	38.5
R22-B1	21.9	36.3	43.8
R22-B2	20.2	44.1	51.3
R22-B3	21.5	43.1	50.6
R23-LI	18.4	19.5	26.7
R23-B1	18.0	25.9	34.1
R23-B2	20.1	15.7	24.7
R23-B3	18.6	20.1	28.7
R23-B4	22.4	16.1	28.3

** corrected for reverberation time*

*** corrected for reverberation time and background noise*

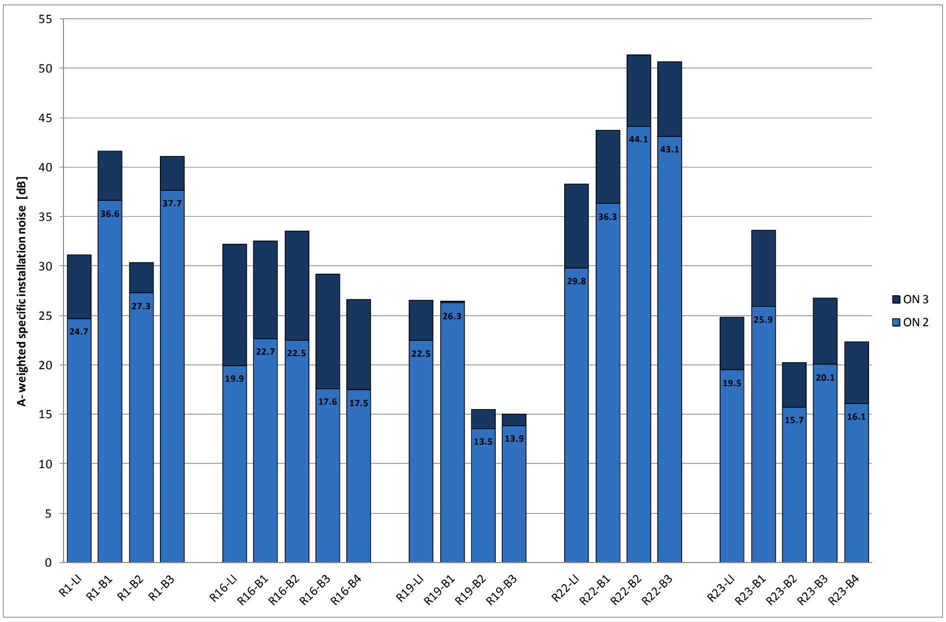

Figure 26 Specific ventilation noise levels for system D bedrooms related to the NBN requirements for high and standard acoustic comfort in dwellings [7]

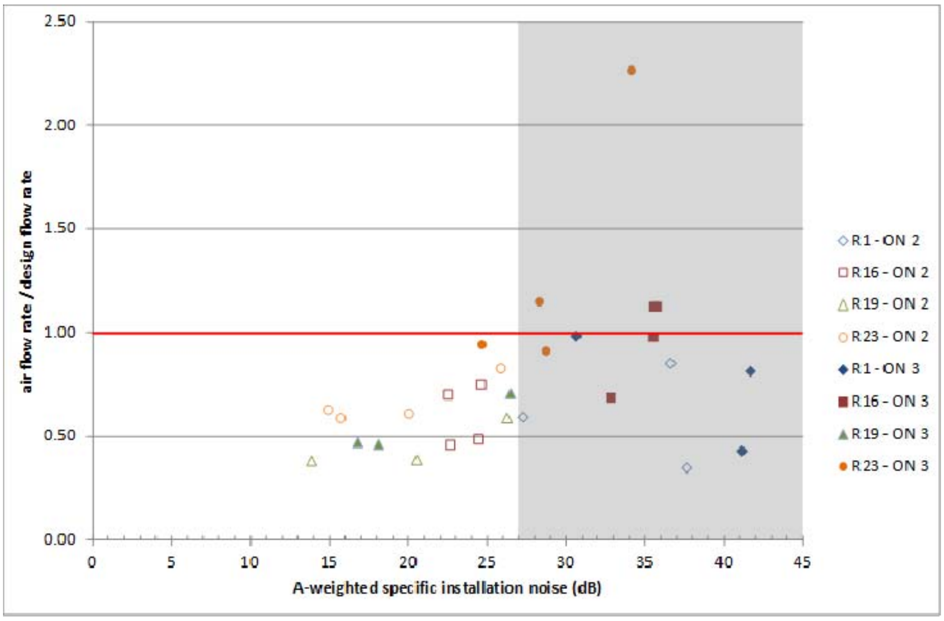

Figure 27 Ratio of air flow rate and design flow rate against the A-weighted specific ventilation noise levels for Clean Air Low Energy bedrooms (selection of available data)

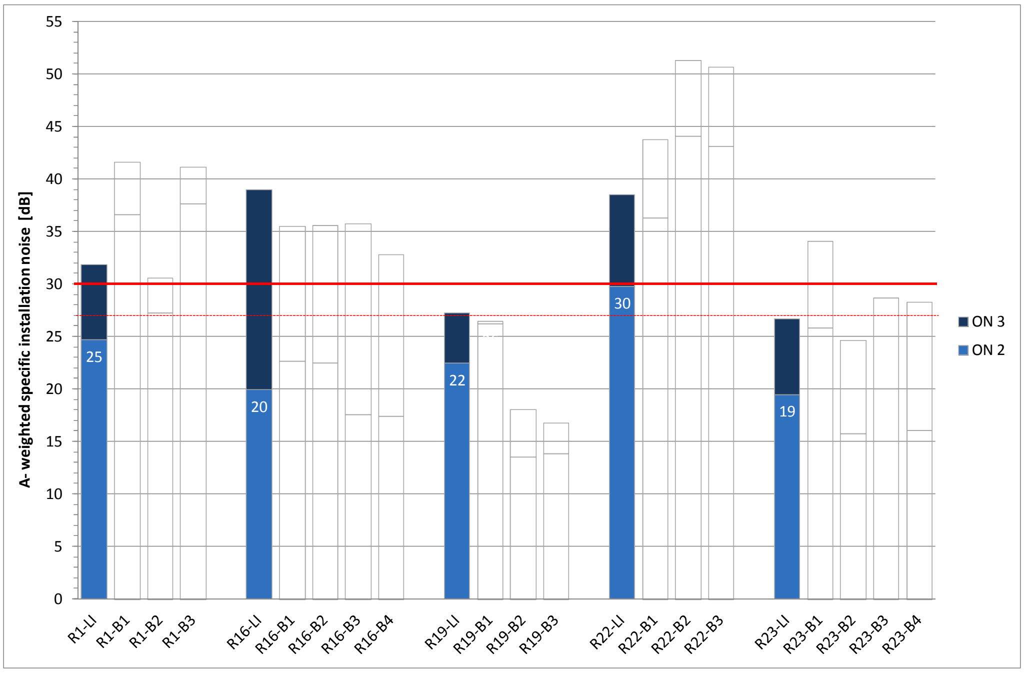

Figure 28 Specific ventilation noise levels for system D living rooms related to the NBN requirements for high and standard acoustic comfort in dwellings [7]

So based on this small scale sample of system D bedrooms, to reach the nominal airflow rate according to the Belgian ventilation standard, the highest working regime seems to be necessary in most cases (and in some cases still insufficient). However this working regime, when delivering the necessary airflow rate, seems to be too noisy according to the Belgian acoustic standard.

As for the living rooms, an even smaller sample is only available. All 5 living rooms meet the acoustic NBN requirement of 30 dB (normal comfort) in regime 2. In the highest regime two of them still meet the normal comfort requirement. Based on this limited number of measurements, we could conclude that the acoustic requirement for living rooms (3 dB less severe) seems to be less difficult to fulfil. Even the high comfort criterion (27 dB) is met for 4 out of 5 living rooms in regime 2.

In Figure 29 these results are compared to the corresponding ratio of the airflow rate to the design airflow rate (no data available for R22). Points approaching a ratio ≈ 1 more or less deliver the required air flow rate. The hollow markers represent ‘regime 2’ data, filled markers ‘regime 3’ data. As observed before, all living rooms respect the acoustic comfort criterion in regime 2. Only one living room meets the required air flow rate at the same time. Again this happens to be a room in project R23. Living room R1 almost reaches the required air flow rate, while R16 et R19 remain below a ratio of 0.5. When switching to regime 3, R19 stays below a ratio of 0.5, while approaching the acoustic comfort value of 30 dB. As for R16 the design flow rate is reached in regime 3, unfortunately resulting in a much too high noise level.

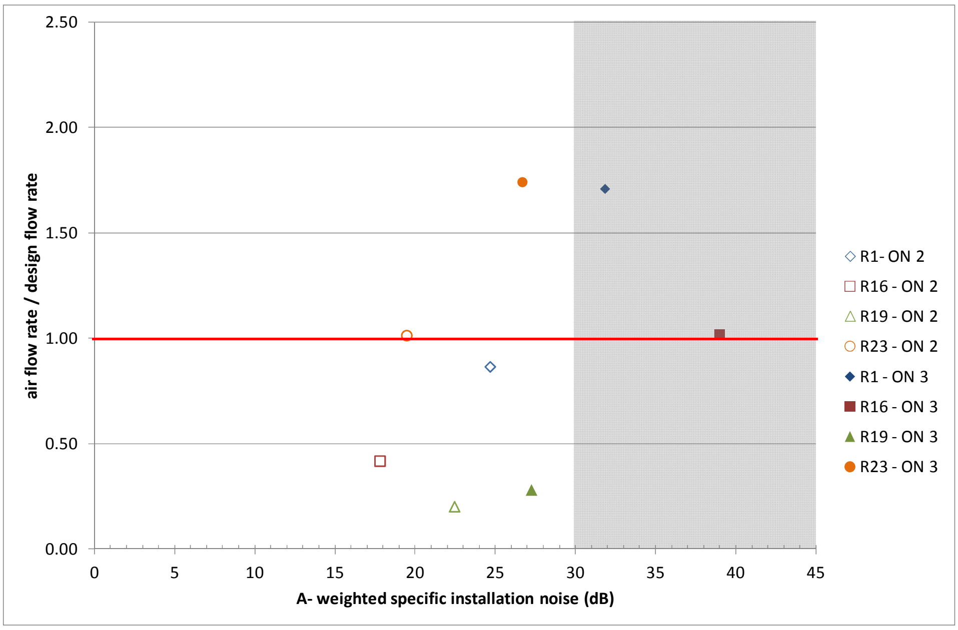

Figure 29 Ratio of air flow rate and design flow rate against the A-weighted specific ventilation noise levels for Clean Air Low Energy living rooms (selection of available data)

Users’ appreciation of noise nuisance from ventilation system

The questionnaire asked the users about the noise nuisance due to the ventilation system in the house, indicating whether they had:

- much nuisance
- only nuisance when operating at a higher position
- no nuisance
- never paid attention

The two extremes “much nuisance” and “never paid attention” didn’t occur in the users’ appreciation. For 12 of the 22 examined system D residences “no nuisance” was reported. For 8 system D residences “only nuisance when operating at a higher position” was reported. Only a small variability in users’ appreciation can be revealed from the results of the questionnaire. No real urgent noise issue has been reported.

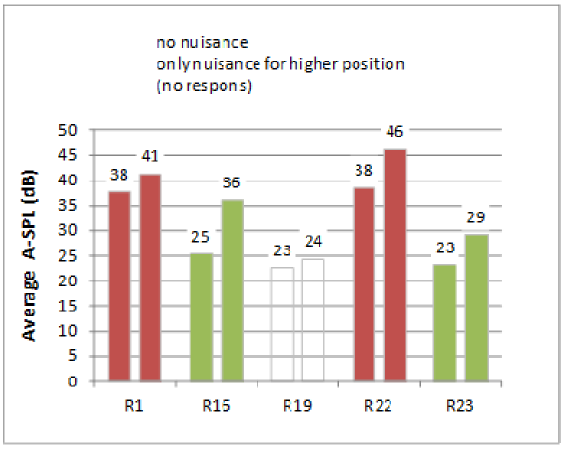

Figure 30 Average noise levels for system D residences (first bar: regime 2, second bar: regime 3,) against users' appreciation, red : only nuisance for higher position, green : no nuisance (no colour = no answer)

Comparing the measured sound pressure levels (average for all rooms within each project) to the user's appreciation for the system D residences within the acoustical study (Figure 30), the highest SPL-values indeed correspond with the less positive appreciation. Considering the acoustic comfort limit of 35 dB, these seem in fact to be the two residences exceeding already in 'regime 2' the comfort limit. The residence were the occupants did not respond to the noise nuisance question, happens to be the most 'quiet' one. So in spite of the rather small scale measurement campaign, a fair correlation between our measurement results and the users' appreciation has been found (indicating also a certain reliability of the employed overall noise level limit of 35 dB).

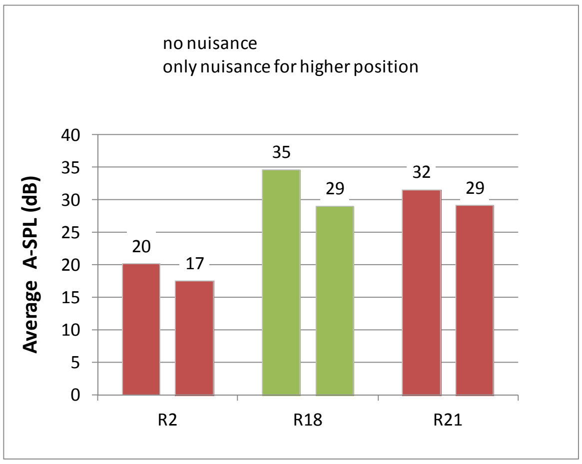

Figure 31 Average noise levels for system C residences (first bar: open trickle vents, second bar: closed trickle vents) against users' appreciation, red : only nuisance for higher position, green : no nuisance

As for the residences with ventilation system C (Figure 31), this tendency is less clear, most likely because of the small number of only 3 examined residences. Precisely the occupants of project R18 reported "no nuisance", in spite of the relatively high measured noise levels. On the other hand, occupants of project R2 where the lowest noise levels were reported, indicate "only nuisance for higher position". In contrast with system D residences, where generally the noise levels staid within the same order for the different rooms within the same project, traffic noise nuisance is largely dependent on the orientation of the room. Average values might not be the most adequate figures to compare to the users' appreciation. For project R18 for instance, the perceived traffic noise is not constantly present and not at to same degree for all the rooms. The noisiest rooms turned out to be a study room and a children room occupied by a child where a higher user tolerance can be expected.

Another explanation could lay in the formulation of the predefined answers of the questionnaire, suggesting may be for residences with ventilation system C only noise nuisance in the rooms with mechanical extraction (no focus on outdoor noise), such as bathrooms and kitchens. No measurements have been carried out in these kinds of rooms. However noise disturbance can be expected in living rooms with open kitchens from the mechanical air exhaust in this room. Again this tendency could not be confirmed based on our data set, since both project R2 (nuisance at higher position) and R10 (no nuisance) dispose of open kitchens (Table 5).

Table 5 Users' appreciation for system C residences related to the presence of an open kitchen

System C	Noise nuisance	Open kitchen
R2	Yes, at higher position	yes
R18	no	yes
R21	Yes, at higher position	no

Since the occupants of project R2 clearly pointed out this kind of nuisance during our visit, more additional measurements have been carried out in the living room for different working regimes of the extraction in the kitchen (Figure 32). According to the air flow rate measurements, working regime 2 doesn't provide enough air extraction (61 m³/h against a design rate of 75 m³/h). For regime 3 (82 m³/h) the corresponding noise level of 42 dB is largely exceeding the 35 dB comfort. These results clearly point out an acoustic discomfort in the living room from the mechanical air extraction in the open kitchen, corresponding to the users' appreciation.

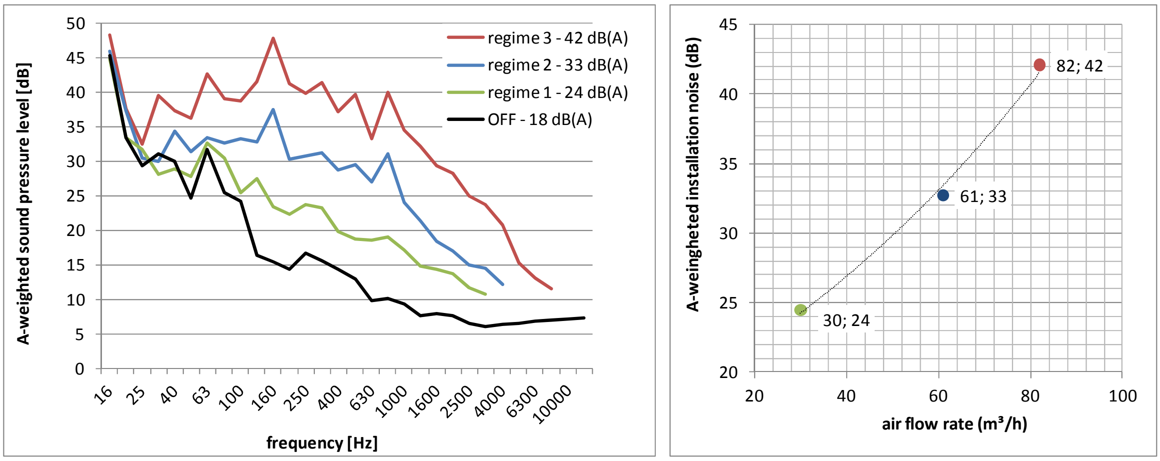

Figure 32 Sound pressure levels in living room of project R2 due to mechanical air exhaust in the open kitchen

2.1.4. BUILDING CHARACTERISTICS AND VENTILATION SYSTEM USES

Questionnaires concerning building characteristics and properties of the ventilation systems were collected in order to assist in the selection of appropriate residences and classrooms for this study. During the measurement phase, additional questionnaires were filled in by the home owners and researchers. Home owners could comment on their appreciation of indoor air quality, the operation mode of the ventilation system, indicated if they used the vacuum cleaner during measurement campaign, etc. The researchers collected technical data on the ventilation system and the building, e.g. surface and height of the investigated rooms.

→ Schools

Seven of the schools are primary schools, one is a kindergarten, and one is a closed rehabilitation institute for children. All of the schools are constructed or renovated in the years 2006-2011, an overview of the school characteristics is shown in Table 6. Information on U-values or energy classification of the school (E-level) could not be obtained for all of the participants, partially because some of the classes are renovations or extension to existing schools, which require less administration in Flemish energy performance regulations. One of the schools is a certified passive building. Three schools are equipped with a simple exhaust ventilation system, which adds up to 9 classes. The remaining 17 classes have mechanical air intake and exhaust. All of these have a heat recovery ventilation system, although this was not always indicated by the building owners in the questionnaire we used to select the schools. Both rotary and plate heat exchangers are present in the schools.

Table 6 Overview of Clean Air Low Energy schools characteristics

	Passive building	Env.	Building system	Ventilation system				heat exchange system
S1	no	urban	modular unit	D	mechanical supply	mechanical exhaust		thermal recovery wheel
S2	no	rural	newly built	C	trickle vents	mechanical exhaust	demand controlled	n.a.
S3	no	rural	newly built	C	trickle vents	mechanical exhaust		n.a.
S4	no	urban	modular unit	D	mechanical supply	mechanical exhaust		thermal recovery wheel
S5	no	urban	modular unit	D	mechanical supply	mechanical exhaust		thermal recovery wheel
S6	no	urban	newly built	D	mechanical supply	mechanical exhaust	demand controlled	thermal recovery wheel
S7	yes	rural	newly built	D	mechanical supply	mechanical exhaust	demand controlled	unknown
S8	no	urban	newly built	D	mechanical supply	mechanical exhaust		unknown
S9	no	rural	newly built	C	trickle vents	mechanical exhaust		n.a.

In the questionnaires and during visits to the school, most users indicate that the operation of the ventilation system can be set manually, but is nevertheless kept constant most of the time. In three schools, the ventilation rate is set automatically with a scheduled programme, in which the ventilation rate is lower during absence. Although three schools mention the presence of demand controlled operation based on CO_2 detections, we suspect based on our inspections of the installation that this automatic operation is not functional or not present.

→ **Residences**

The 25 Clean Air Low Energy residences are build in Flanders between 2008 and 2011. 15 residences are detached houses, 5 semi-detached, 2 are terraced houses, and one of the buildings consists of three apartments, an overview is shown in Table 7. Six residences are build with a lightweight wood frame structure, the others have a more common brick or concrete structure.

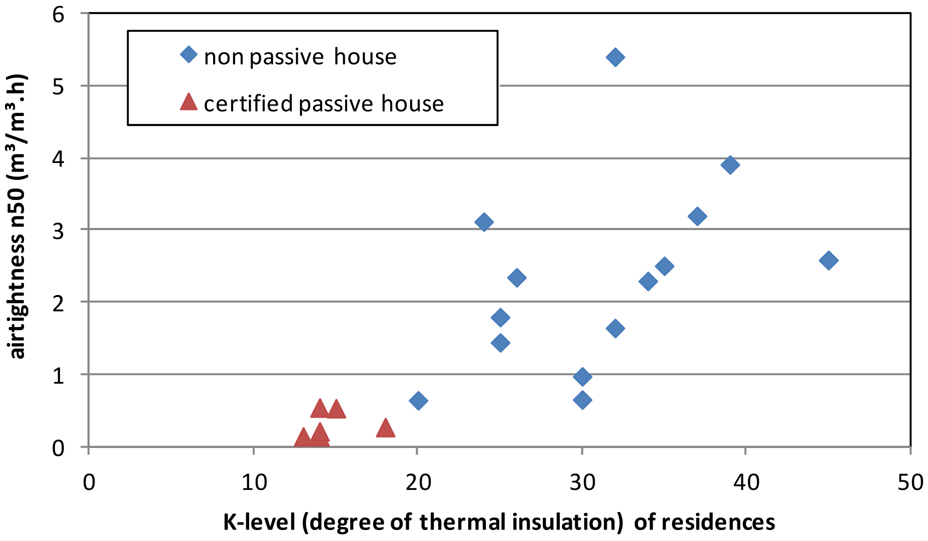

Figure 33 Scatter diagram showing K-level and airtightness of Clean Air Low Energy dwellings
(3 dwellings, in which the air tightness could not be measured are not included)

Figure 33 shows the K-level of the dwellings in relation to the airtightness of the building envelope. The K-level is a concept in Belgian energy regulations which correlates the average U-value of the building enclosure with the ratio of volume and exposed surface of the building. A highly insulated building with a high internal volume compared to its exposed surface will have a low K-level. Figure 33 suggests a correlation between airtightness and K-level. It appears that the best insulated houses have paid more attention to minimise air leakages through the envelope. The six passive houses participating in the study all have an n50 value lower than 0.6, as is required for the certification by PHP. They also attain the lowest K-levels of the Clean Air Low Energy residences. From 2006 till the end of 2011, the Flemish energy performance regulation imposed a maximum K-level of 45. All of the dwellings under investigation fulfil this requirement. The median K level of all new built Flemish single family houses decreased from 41 in 2006 to 34 in 2010 [12]. The average K-level of the Clean Air Low Energy residences is 27 and the median 26, which means our sample is better insulated compared to the Flemish building practice.

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[12] Cijferrapport
Energieprestatieregelgeving, EPB in cijfers 2006-2011, Vlaams energieagentschap, De Baets K. Roelens W, Jonckheere T, april 2012]

Table 7 Overview of Clean Air, Low Energy residences characteristics

	built	K	E	Passive	Env.	Construction		Ventilation system			Optional features	Ducts
R1	2008	39	70	no	rural	frame construction	(wood frame, steel frame, ..)	D	mechanical supply	mechanical exhaust	recirculation of ventilation air	galvanized round ducts
R2	2009	35	60	no	rural	massive building	(bricks, concrete,...)	C	trickle vents	mechanical exhaust man.	n.a.	n.a.
R3	2009	25	20	no	rural	massive building	(bricks, concrete,...)	D	mechanical supply	mechanical exhaust		flexible plastics
R4	2010	25	37	no	rural	massive building	(bricks, concrete,...)	D	mechanical supply	mechanical exhaust	post-heating of ventilation air	galvanized round ducts
R5	2010		33	yes	rural	frame construction	(wood frame, steel frame, ..)	D	mechanical supply	mechanical exhaust	earth-to-air heat exchanger	galvanized round ducts
R6	2011	30	46	no	urban	massive building	(bricks, concrete,...)	D	mechanical supply	mechanical exhaust		galvanized round ducts
R7	2009	13	16	yes	rural	n.a.		D	mechanical supply	mechanical exhaust	earth-to-air heat exchanger	other - unknown
R8	2007	32	74	no	rural	massive building	(bricks, concrete,...)	D	mechanical supply	mechanical exhaust	post-heating of ventilation air	flexible plastics
R9	2009	26	26	no	rural	massive building	(bricks, concrete,...)	D	mechanical supply	mechanical exhaust	none	flexible plastics
R10	2010	32	52	no	rural	massive building	(bricks, concrete,...)	D	mechanical supply	mechanical exhaust	none	other - unknown
R11	2009	45	76	no	urban	massive building	(bricks, concrete,...)	D	Partly mechanical supply	mechanical exhaust man.	post-heating of ventilation air	flexible plastics
R12	2008	24	46	no	urban	massive building	Ytong	D	mechanical supply	mechanical exhaust	ground coupled heat exchanger, heat transfer fluid	galvanized round ducts
R13	2006	25	39	no	rural	frame construction	(wood frame, steel frame, ..)	D	mechanical supply	mechanical exhaust	earth-to-air heat exchanger	galvanized round ducts
R14	2007	20	45	no	urban	frame construction	(wood frame, steel frame, ..)	D	mechanical supply	mechanical exhaust	recirculation of ventilation air	galvanized round ducts
R15	2009	14	25	yes	urban	frame construction	(wood frame, steel frame, ..)	D	mechanical supply	mechanical exhaust	earth-to-air heat exchanger	galvanized round ducts
R16	2007	34	51	no	rural	massive building	(bricks, concrete,...)	D	mechanical supply	mechanical exhaust		galvanized round ducts
R17	2009	36	74	no	rural	massive building	(bricks, concrete,...)	D	mechanical supply	mechanical exhaust	none	galvanized round ducts
R18	2008	37	69	no	rural	massive building	(bricks, concrete,...)	C	trickle vents	mechanical exhaust demand controlled	n.a.	n.a.
R19	2009	14	27	yes	urban	massive building	(bricks, concrete,...)	D	mechanical supply	mechanical exhaust	earth-to-air heat exchanger	galvanized round ducts
R20	2010	14	40	yes	rural	massive building	(bricks, concrete,...)	D	mechanical supply	mechanical exhaust	ground coupled heat exchanger, heat transfer fluid	galvanized round ducts
R21	2008	36	83	no	urban	massive building	(bricks, concrete,...)	C	trickle vents	mechanical exhaust man.	n.a.	n.a.
R22	2010	18	27	yes	urban	frame construction	(wood frame)	D	mechanical supply	mechanical exhaust		galvanized round ducts
R23	2010	30	40	no	rural	massive building	(bricks, concrete, ...)	D	mechanical supply	mechanical exhaust	earth-to-air heat exchanger	galvanized round ducts

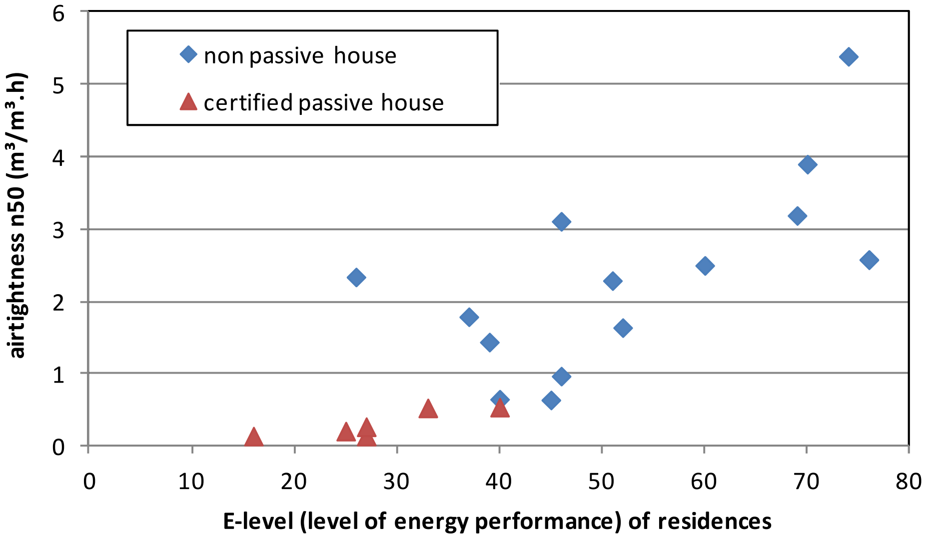

Figure 34 Scatter diagram showing E-level and air tightness of the Clean Air Low Energy Dwellings (3 dwellings, in which the air tightness could not be measured, are not included)

The E-level is an indicator for the energy performance of a building in Belgian energy regulations. Since 2006, the maximum E-level for houses was set to 100. If the building permit was requested after 1 January 2010, the E-level is legally restricted to 80. All houses participating in the study except one have an E-level which is lower than 80. The average E-level is 49, the median 46. This is considerably better compared to the Flemish median[13] for single family houses which decreased from 87 in 2006 to 76 in 2009, and decreased even further to 69 in 2010 due to the tightened legal requirements Figure 35 displays that there is indeed a strong correlation between airtightness and the level of energy performance, as was expected in workpackage 1.

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[13] Cijferrapport
Energieprestatieregelgeving, EPB in cijfers 2006-2011, Vlaams energieagentschap, De Baets K. Roelens W, Jonckheere T, april 2012]

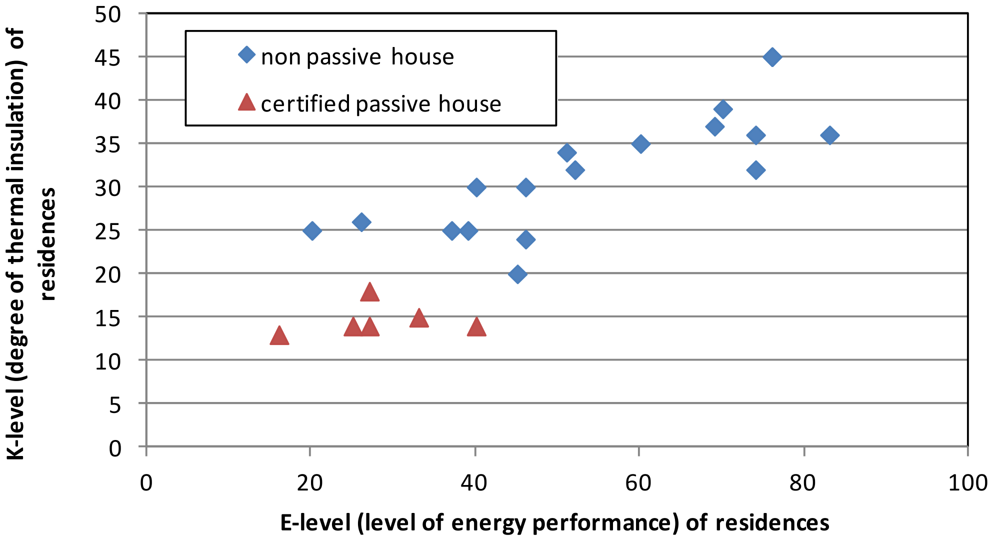

Figure 35 Scatter diagram showing K-levels and E-levels of the participating houses, including all dwellings

Figure 35 plots the K-levels and E-levels of the participating houses, including the 3 dwellings which were not displayed in previous graphs because of a lack of trustworthy measurement of the airtightness. The passive houses all have low E-levels, but it should be noted that some non-passive houses also perform very well on the E-level, and even better than some of the passive houses, despite higher K-levels. The rules to certificate passive houses stipulate a maximum yearly demand for space heating. The E-level doesn’t only look at the energy demand for space heating, but also incorporates the efficiency of HVAC installations who fulfil this demand, the energy consumed for hot water production, the potential beneficial impact of photovoltaic energy production on the roof of the house, etc.

The airtightness of the building enclosure has an impact on the E-level. For some of the buildings, the n50-value was measured, and the E-level was calculated by the architect or engineer considering the actual permeability of the envelope. If the building owner does not perform this measurement, a rather restrained default value is used in the calculation, which was the case in 12 buildings under investigation. It was not possible to update the E-level using the airtightness which was measured in this study. The effect of doing so would in any case be limited to a few E-level points.

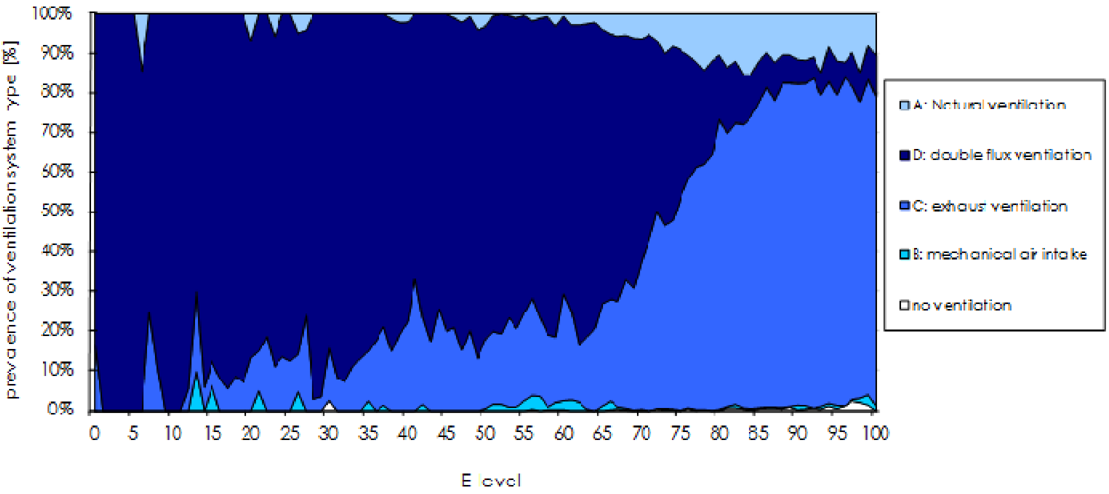

Figure 36 Graph showing the prevalence of ventilations systems in relation to E-level in all single family dwellings built between 2006 and 2011 in Flanders[14]

In this study, the average E-level of dwellings with a ventilation system C is 71, compared to 46 for buildings with ventilation type D. This corresponds to the trend which is apparent from Figure 36: for houses with low E-values, system D is the most prevalent system according to the statistics of the Flemish Energy Agency. For less energy efficient houses, ventilation type C has the greatest market share.

It should be noted that there is much more variation in user behaviour, activities and number of occupants in the dwellings compared to the schools, where only teaching activities take place (except for the passive school in this research). Furthermore, the n50 value and air changes per hour are derived for the whole building, whereas the measurements of the indoor pollutants are executed in one particular room (living room and bedroom for some pollutants). The interior finishes of the living room and the actual layout of the building plan (e.g. open vs closed kitchen, garage integrated in the house,...) also show a great variety amongst the Clean Air Low Energy dwellings. Because of this greater variation, it is expected that the relation between IAQ and properties of the ventilation system will be less pronounced in dwellings compared to schools.

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[14] Cijferrapport
Energieprestatieregelgeving, EPB in cijfers 2006-2011, Vlaams energieagentschap, De Baets K. Roelens W, Jonckheere T, april 2012]

2.2. VENTILATION SYSTEM, BUILDING ENVELOPE, VENTILATION RATE AND THEIR INFLUENCE ON INDOOR AIR QUALITY

Because of the considerable amount of variables in this large dataset and the relatively low number of observations (i.e. data points for each variable), a statistical analysis of the data is not possible. This is in particular true for biological parameters assessed, which were measured only in a subset of schools/residences. Exploring the probability of a significant difference between the means of two groups (student t-test) won't lead to reliable results either, because it is not possible to recruit buildings that lead to comparable groups sizes for each variable that is considered in Clean Air Low Energy.

However, this exploratory study does allow a classification of the data, taking into account several relevant parameters that were put forward in Clean Air, Low Energy WP1 and WP2. Although the significance of the differences between groups cannot be quantified, visualizing the results clearly indicates which parameters are more relevant in studying the indoor environment in new-build houses and schools, equipped with mechanical ventilation systems. Therefore, in the following paragraphs, the data are compared by visualizations in Box and Whiskers plots, showing the 25th and the 75th percentile, as well as median, minimum and maximum concentration levels.

In order to study the potential relation of the indoor environmental quality with parameters that are related to the school or residential buildings, the answer to the following questions was explored for:

Does the ventilation system have an influence on the indoor air quality?

Buildings are grouped based on the characteristics of their ventilation system: mechanical exhaust ventilation versus mechanical supply and exhaust ventilation.

Does the building airtightness influence the indoor air quality?

Buildings are grouped based on their airtightness, potential differences between the air quality of the different groups are studied.

Does the total air change rate influence the indoor air quality?

Buildings are grouped based on their total air change rate, potential differences between the indoor air quality of the different groups are studied.

Does noise nuisance affect building ventilation?

And is there any indication of an indirect relation with indoor air quality?

The following paragraphs (numbers 2.2.1, 2.2.2, 2.2.3, and 2.1) report on the study of these potential influencing parameters.

2.2.1. VENTILATION SYSTEM VERSUS INDOOR AIR QUALITY AND INDOOR ENVIRONMENT

As concluded in Clean Air Low Energy WP1, the type of ventilation system may impact on the indoor environment. On the one hand, adapted and well-maintained air filters in a mechanical supply and exhaust ventilation (type D) may purify the incoming air by removing certain compounds such as fine dust from the air stream. On the other hand, a contaminated air inlet may also negatively impact on the building indoor environment. Therefore, this paragraph classifies the Clean Air Low Energy buildings in two classes:

1. Buildings equipped with a mechanical exhaust ventilation (type C)
2. Buildings equipped with a mechanical supply and exhaust ventilation (type D)

As a consequence of the Clean Air Low Energy sample size and sample set characteristics, the selection of Clean Air Low Energy schools and residences is composed in the following way:

Schools:
- 6 classrooms equipped with mechanical ventilation system C (of which 3 rooms subjected to biological characterisation);
- 20 classrooms equipped with mechanical ventilation system D (of which 12 rooms subjected to biological characterisation)

Houses
- 3 residences equipped with mechanical ventilation system C (of which 3 subjected to biological characterisation);
- 22 residences equipped with mechanical ventilation system D (of which 12 subjected to biological characterisation).

The following paragraphs discuss the houses and classroom ventilation effectiveness and indoor air quality in terms of ventilation systems C and D.

→ Schools

Figure 37 shows both the classroom air tightness and the total air change rate of the classrooms, equipped with ventilation systems C and D respectively.

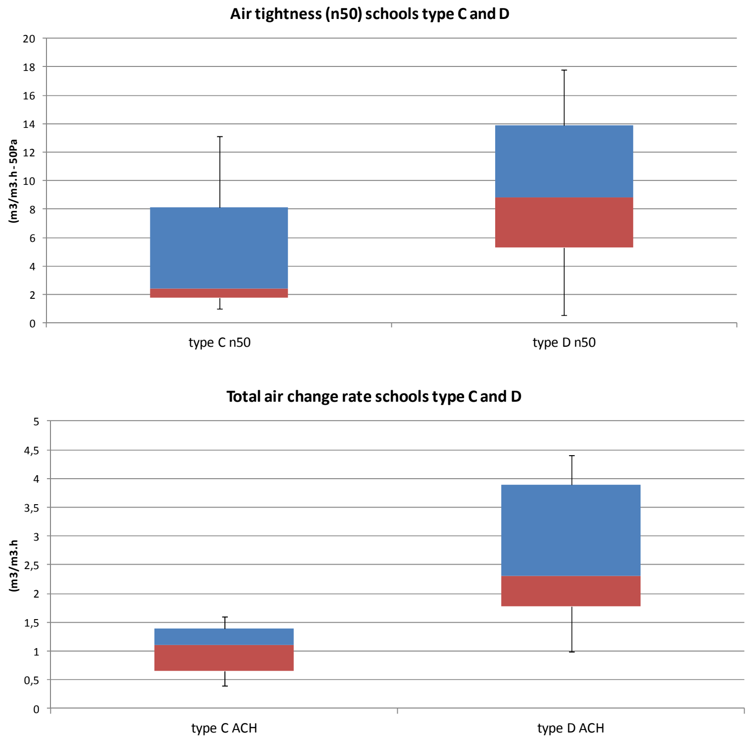


Figure 37 Box and Whiskers plot showing air tightness and ACH of classrooms, with ventilation system type C and type D

The efficiency of a ventilation heat recovery unit is higher if the building enclosure is more airtight. It is therefore surprising that the average and mean n_{50} value of the buildings with system D is higher compared to the classrooms equipped with system C. This can be explained by the fact that all of the modular class rooms tested in this set of schools have a poor airtightness, despite being equipped with ventilation system D.

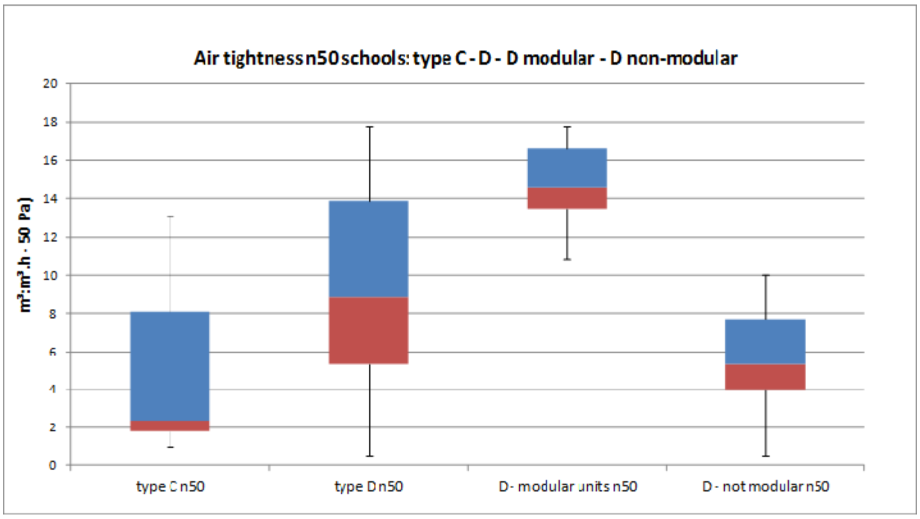


Figure 38 shows that the airtightness of the traditional built classrooms (no modular units) with mechanical ventilation is comparable to the class rooms with ventilation system C which all have a traditional construction.

It should be noted that in some of the schools, the ventilation rate can be influenced by the teacher or by a centralised control unit. The total air change rate refers to the rate which is mostly set when people are present in the building. A possible reduction of the ventilation rates, for example during night time and weekends, is thus not included in the calculated 'total air change rates'. For some of the pollutants (e.g. $PM_{2.5}$ or CO_2), this has little influence on the analysis, since the reported values are teaching hour average values. It might however have some effect on the indoor concentrations of substances emitted by building materials but still, it describes the indoor environment as it is.

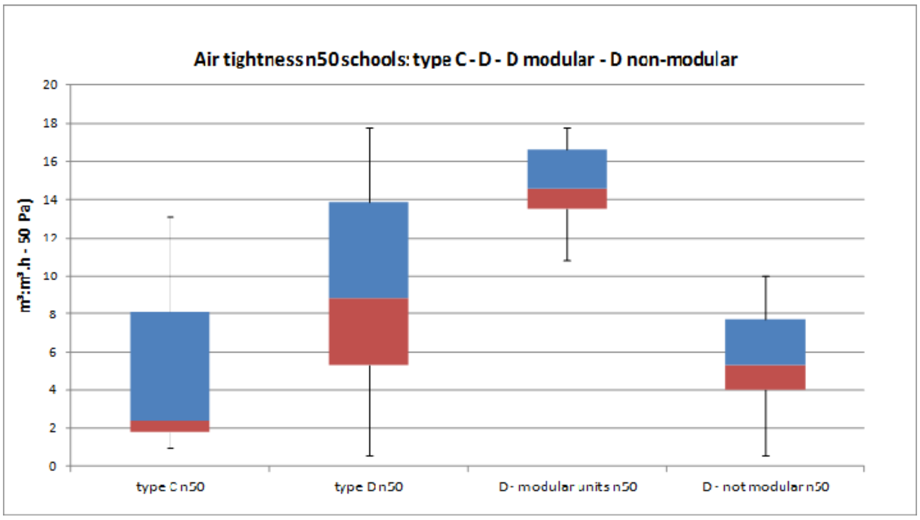


Figure 38 Box and Whiskers plot showing air tightness and ACH of classrooms, with ventilation type C and type D – and extra division between modular units and non-modular units.

The indoor air quality in classrooms equipped with mechanical supply and exhaust ventilation (type D), is potentially influenced by the following factors related to ventilation:

1. Possible purification of the incoming air through the air intake filter system
2. Possible contamination of the incoming air through the air intake filter system, ducts or heat recovery system
3. And specifically in the case of the Clean Air Low Energy schools dataset, the higher air change rate compared to classrooms with a mechanical exhaust ventilation (see Figure 37).

Although according to Figure 37 the total air change rate is highest in classrooms with a ventilation system type D, the average indoor CO_2 levels in classrooms with system C and system D don’t differ considerably. This can be noticed in Table 8 and Figure 39, where the indoor CO_2 concentrations are only moderately improved in classrooms with a mechanical ventilation system type D compared to rooms with ventilation system type C. The impact of the higher total air change rate is mostly reflected in the maximal registered CO_2 level; which is 60 ppm lower in the system D classrooms.

Table 8 Overview of the teaching hour CO_2 levels in classrooms with ventilation system C and D

	Average	Median	Maximum
Teaching hour average – system C	659 ± 190 ppm	576 ppm	992 ppm
Teaching hour average – system D	657 ± 163 ppm	684 ppm	929 ppm

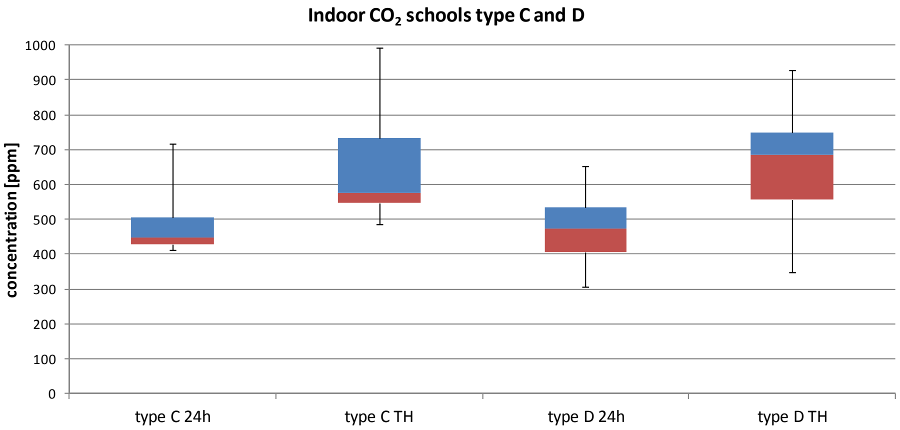


Figure 39 24-h and teaching hour (TH) average indoor CO_2 levels in classrooms with ventilation system C and D

The fact that the lowest indoor TVOC levels were monitored in classrooms with ventilation system D (shown in Figure 40), is most probable the consequence of the higher air change rate in these rooms. However, an outlier value was registered in one ventilation system D classroom, which results most probably from one event in the room during the measurements (could not be related to the classroom questionnaire).

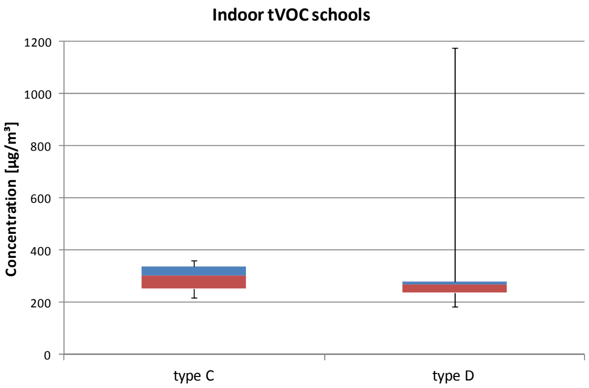


Figure 40 Indoor TVOC levels in classrooms with ventilation system C and D

The more detailed occurrence of the volatile organic compounds can be seen in Figure 41. The plots indicate concentration levels in ventilation system D rooms for TVOC, for most VOC compounds, for indoor total aldehyde (Figure 42) as well as for formaldehyde to be moderately lower compared to system C classrooms in this dataset; e.g. formaldehyde concentration levels in system D rooms were characterized by P75: 18,0 $\mu g.m^{-3}$ whilst system C classrooms were characterised by P75: 23 µg.m^{-3}. It should however be stressed that this dataset does not allow a conclusion on consistently and significantly reduced concentration levels in system D ventilated classrooms. Exceptions are acetaldehyde and terpenes, such as limonene, pinene and carene which were found in higher concentrations in 3 schools equipped with ventilation system D. Consulting the questionnaire information from those classrooms, revealed that for these schools teachers have reported to use 'sufficient quantities' of detergents during cleaning activities as well as the occasional use of air fresheners. However no quantitative association could be found.

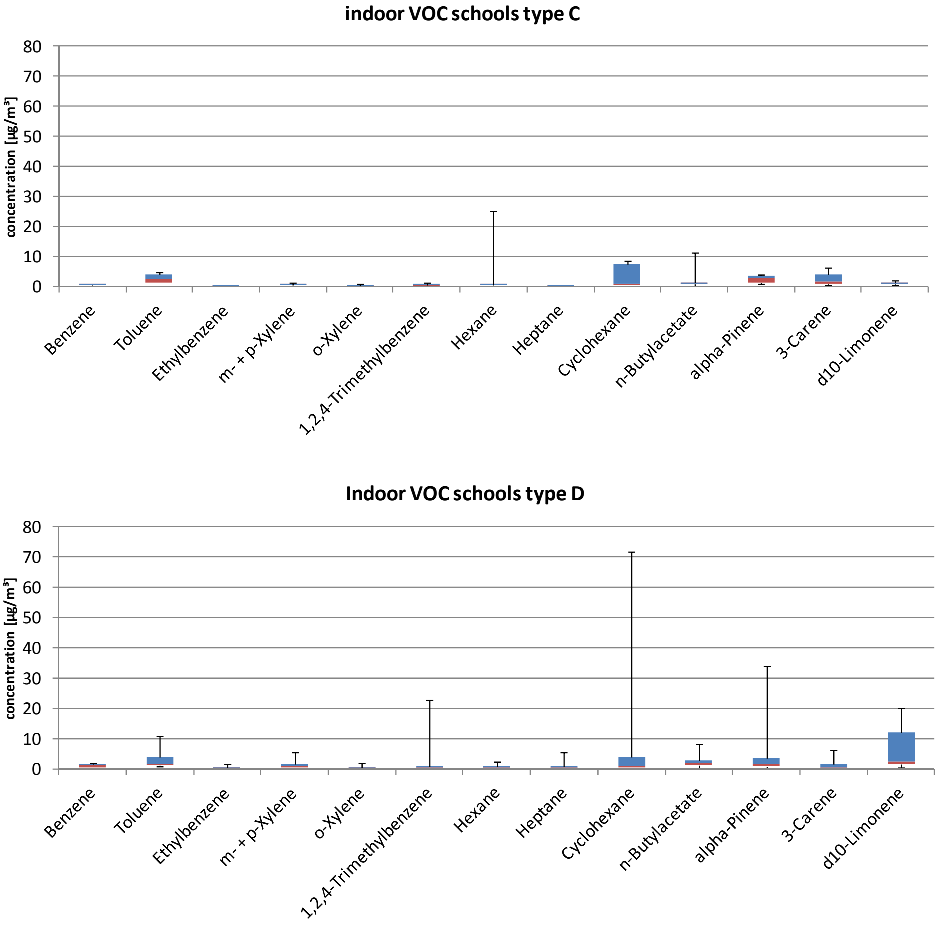


Figure 41 Indoor VOC levels in classrooms with ventilation system C and D

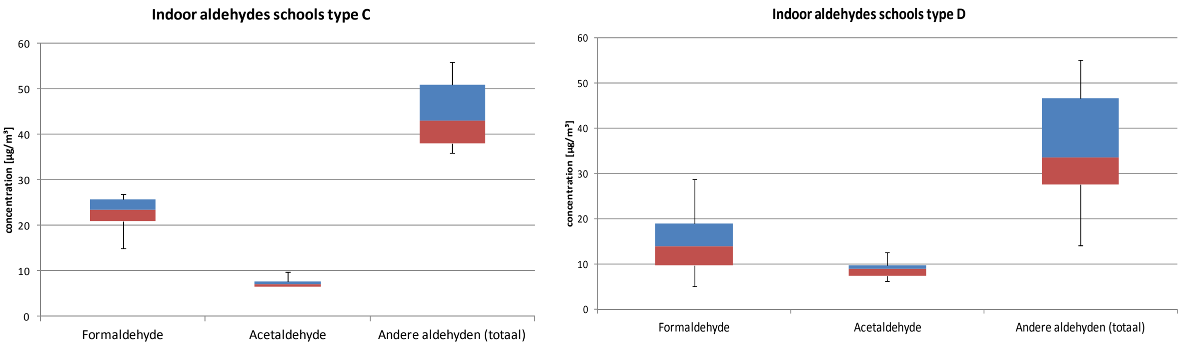


Figure 42 Indoor aldehyde levels in classrooms with ventilation system C and D

Indoor $PM_{2.5}$ occurs at a lower and smaller concentration range in classrooms with a mechanical ventilation system D, as shown in Figure 43. According to Table 9 both the average and 75th percentile are also considerably lower in classrooms with a system type D. This is most probably the result of the effectiveness of the air filtration system in the mechanical air supply system.

This hypothesis is confirmed in Figure 43, where the ratio of indoor PM_{10} to $PM_{2.5}$ is higher in rooms with air supply filtration. Since literature has proven the considerable contribution of resuspended PM in classrooms, mostly consisting of coarser material, this higher ratio refers to the lower levels of indoor $PM_{2.5}$, which partly originates from outdoor air in classrooms.

Although the 75th percentiles of the indoor/outdoor ratios for $PM_{2.5}$ (gravimetrical) are fairly equal for both ventilation systems, the lower median level (equalizing unity for ventilation system D) as well as lower 25th percentile also indicate the effectiveness of the air intake filters to remove fine dust from the incoming air.

Table 9 Overview of the indoor PM levels in classrooms with ventilation system C and D

	Average	Median	75% percentile
Indoor PM (grav) system C	38.8 ± 23.4	33.3	60.5
Indoor PM (grav) system D	27.7 ± 13.6	27.5	34.5

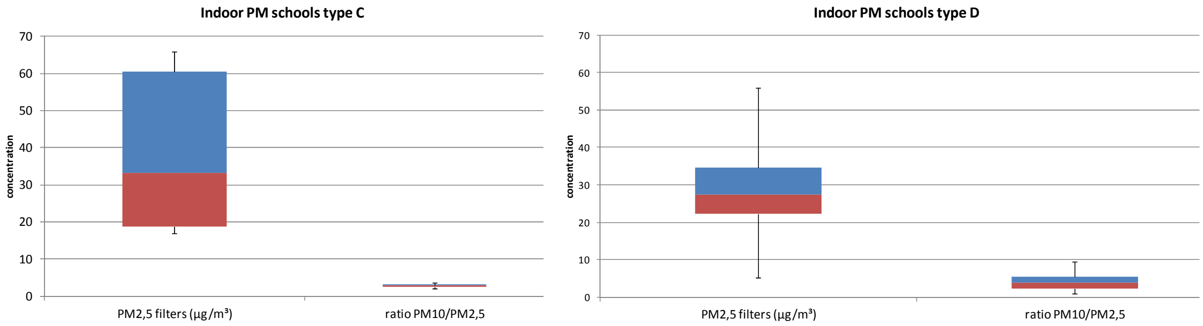


Figure 43 Indoor PM levels in classrooms with ventilation system C and D

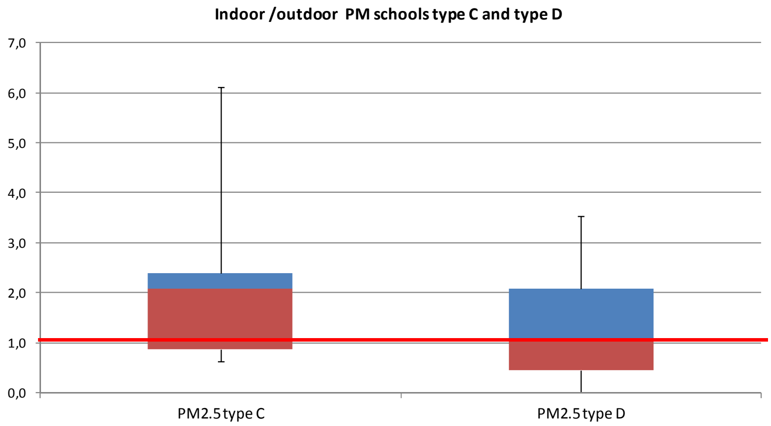


Figure 44 Indoor – outdoor ratio of PM levels in classrooms with ventilation system C and D

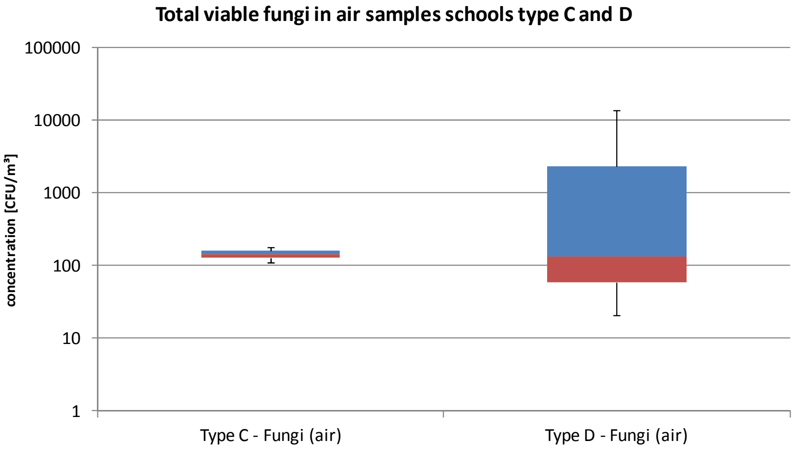


Figure 45 Total viable fungi in air samples from classrooms type C and type D

Figure 45 and *Figure 46* compare the levels of total viable fungi and bacteria for classrooms in schools of type C and D, whereas *Figure 47* shows the indoor/outdoor ratio of fungi and bacteria for schools type C and D. Fungal levels were found somewhat higher in schools of type D compared to type C. However, the differences are largely driven by higher fungal levels in one school, in which the 'classrooms' were mostly not used as regular classrooms, but included for example a kitchen, which typically contains several so called natural sources for microbes, such as food stuff and garbage. For bacteria, clearly higher levels were observed in type D schools compared to type C schools, only partly explainable by above mentioned exceptional school. Indoor/outdoor ratio of fungi and bacteria were higher in type D schools compared to type C schools, but again, only for bacteria the difference was really considerable.

Generally it is believed that mechanical ventilation with filtration of incoming air as compared to natural ventilation reduces the amount of outdoor air microbes indoors, but little data is available on the effect of different mechanical ventilation systems on indoor microbes (e.g. here type C and D). This effect is typically particularly visible for fungi or fungal markers, for which the main source in 'normal' (i.e. without a strong indoor source of microbes, such as for example moisture damage.) indoor environments is the outdoor air. The effect of mechanical ventilation is less pronounced for bacteria, for which a major source are the occupants of the buildings themselves. Nevertheless, this does not explain the clear difference in bacterial levels for type C and D classrooms and the indoor/outdoor ratios in the present exploratory study. It was mentioned earlier that indoor air quality in classrooms with ventilation system D could also be influenced by contamination of the incoming air through the air intake filter system, tubing or heat exchange system – such scenario cannot be excluded in the case of bacteria and type D schools. However, the comparison between category C and D schools in his study needs to be made with great caution, as only 1 and 4 schools of type C and D, respectively, were compared for biological agents. Short-term air samples are known to be highly susceptible towards fluctuations of microbial levels during the measurements, an issue that can be overcome only by a larger number of samples taken. Sample numbers had, however, to be restricted in this exploratory study. Higher levels of bacteria in classrooms type D compared to type C were not confirmed in the analyses of swab samples (data not shown), which indicates that indeed, the issue of variation of microbial levels in short-term air samples may have contributed to the observed differences in bacterial levels between type C and D schools. These swab samples represent settled dust from a standard surface that was exposed for one week; settled dust accumulated over a longer period of time is expected to be less prone to short-term fluctuation of microbial levels in air, a reason for why this additional sample material was collected and analyzed in Clean Air Low Energy. Taken all factors into consideration, the findings presented here need to be considered indicative rather than conclusive and prompt further research to investigate the issue of the type of ventilation system being a possible determinant of microbial levels in indoor air of classrooms.

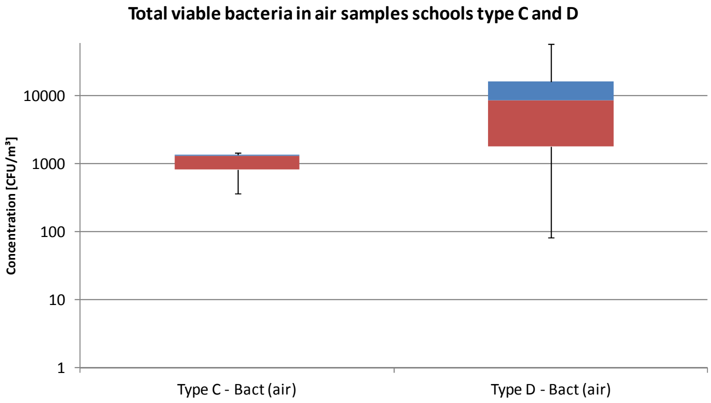


Figure 46 Total viable bacteria in air samples from classrooms type C and type D

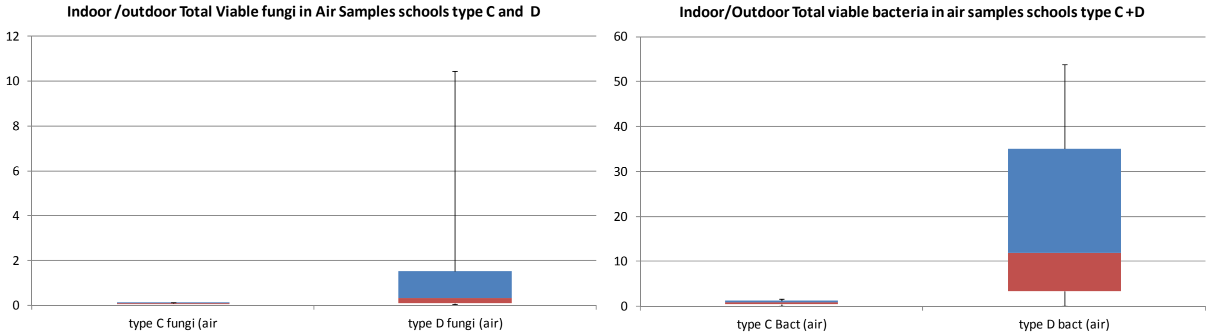


Figure 47 Indoor – outdoor ratio of total viable fungi and total bacteria in air samples

Concerning the indoor environmental conditions, the classroom temperatures did not vary between the two ventilation systems. The indoor relative humidity however, was found to be clearly lower in classrooms equipped with a ventilation system D, as a result of the increased air supply per pupil in rooms with system D. This dryer indoor air is also reflected in the 25th and the 75th percentile (respectively 24% and 42% in type D classrooms), see Table 10 and Figure 48 which are different from the values measured in the classrooms with ventilation system C (respectively 39% and 57%). The indoor air velocity in classrooms equipped with ventilation system C was slightly higher (0.05 ± 0.01 m/s) than that in ventilation system D classrooms (0.03 ± 0.02 m/s).

Table 10 Overview of the indoor temperature, relative humidity and air velocity

	Average	Median	25th percentile	75th percentile
Temperature (°C) system C	20.8 ± 1.5	20.2	19.7	22.2
Temperature (°C) system D	20.3 ± 13.3	20.7	19.0	21.5
Relative humidity (%) System C	49.1 ± 9.2	53.0	39.0	57.0
Relative humidity (%) System D	33.9 ± 13.3	34.0	23.7	42.0
Air velocity (m/s) System C	0.05 ± 0.01	0.04	0.04	0.06
Air velocity (m/s) System D	0.03 ± 0.02	0.03	0.01	0.04

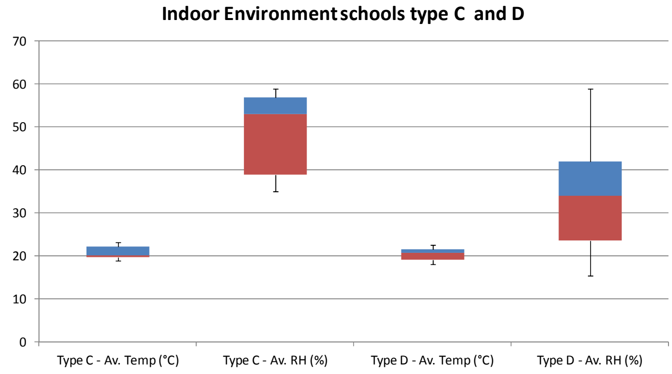
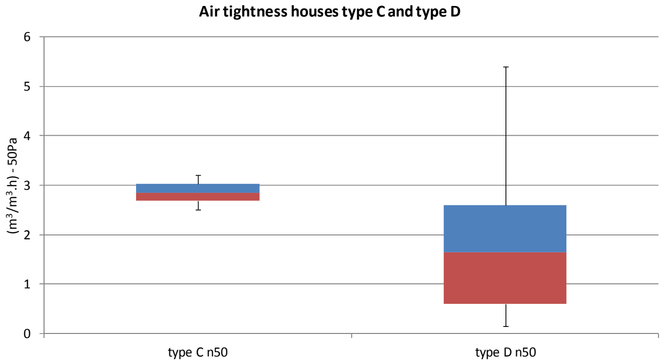


Figure 48 Temperature and relative humidity in classrooms with ventilation system C and D

→ Residences

It should be emphasized that the data that are compared and reported in this paragraph don't result from an equal group size distribution. In fact the group 'ventilation type C' is only represented by 3 residences, whilst the group 'type D' is represented by 22 residences. This results from the recruitment phase, in which considerably more volunteers owned a residence with mechanical ventilation system D than system C. Differences between the groups should thus be considered with caution and can only be reported as indicative, based on this particular sample set.

Furthermore, in one of the houses with simple exhaust ventilation, we were unable to perform a test in order to assess the airtightness. The actual airtightness had to be estimated based on visual inspection of the building.



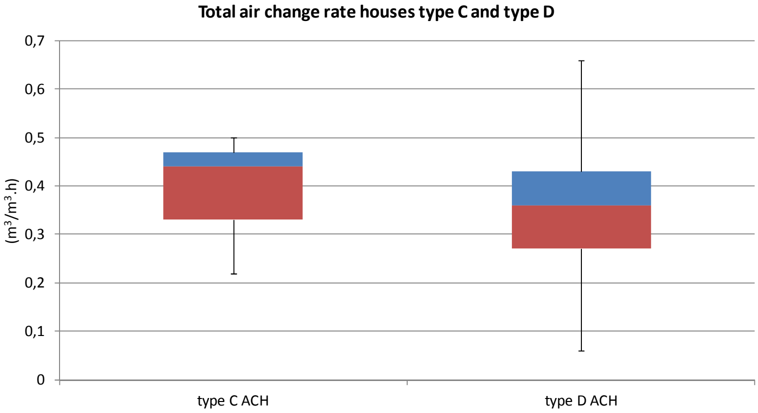


Figure 49 Box and Whiskers plot showing air tightness and ACH of the residences, with ventilation type C and D

On average, the residences with ventilation system D have a better airtigtness compared to the houses with system C. A very airtight building shell is favourable for the efficiency of the heat recovery unit. The average and median total air change rate of the houses with system C is slightly higher compared to the dwellings with system D, despite the very low ratio of total exhaust flow rate and design flow rate of 0.52, as shown in Table 11 (see 2.1.2).

Table 11 ratio's of infiltration versus total air change rate for ventilation system C and D

	Average	Median	Minimum	Maximum
Ratio infiltration / total air change rate system C	0.29 ± 0.03	0.29	0.26	0.32
Ratio infiltration / total air change rate system D	0.28 ± 0.03	0.28	0.03	0.82

Similar to the classroom indoor environment, the indoor air quality in residences equipped with mechanical supply and exhaust ventilation (type D), is potentially influenced by the following factors related to the ventilation system:

1. Possible purification of the incoming air through the air intake filter system
2. Possible contamination of the incoming air through the air intake filter system, ducts or heat exchange system
3. And specifically in the case of the Clean Air Low Energy residences dataset, on average a better air tightness and on average a slightly higher air change rate compared to residences with a mechanical exhaust ventilation (see Figure 49).

The more increased total air change rate in the houses with ventilation system type C is reflected in moderately lower indoor CO_2 levels. The average indoor concentration, the median as well as the maximum concentration level are somewhat higher in the residences equipped with mechanical supply and exhaust ventilation (type D), see Table 12 and Figure 50.

Table 12 overview of the 24h average CO_2 levels in residences with ventilation system C and D

[ppm]	Average	Median	Maximum
Indoor CO_2 (24h) system C	560 ± 118	519	694
Indoor CO_2 (24h) system D	615 ± 105	587	761

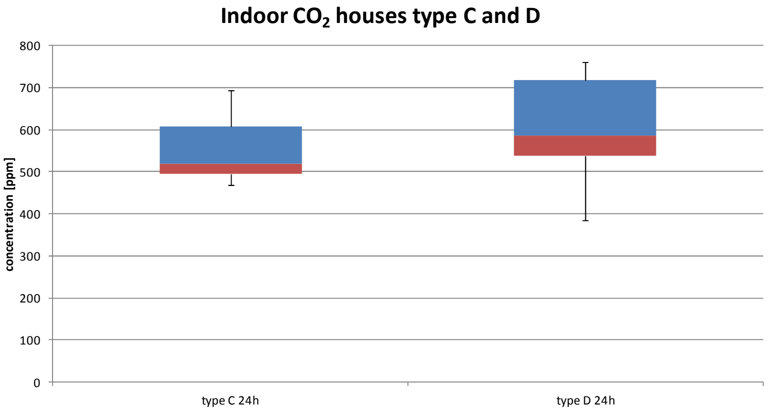


Figure 50 24-h average indoor CO_2 levels in residences with ventilation system C and D (3 houses vs 22 houses)

Figure 51 plots the indoor TVOC levels in de residences, respectively with ventilation system C and system D. Although according to the plot, the indoor levels in residences with ventilation system C are lower than those in residences with a system D, this cannot be considered as a representative conclusion for the comparison between the ventilation systems in general. However, because of its larger sample size, the reported concentration ranges for residences with a system D is more likely a representative indication of the indoor TVOC levels in residences equipped with a mechanical supply and exhaust ventilation. A similar conclusion is valid for the comparison of the individual VOC compounds Figure 52. The maximum values, reported for toluene, 1,2,4-trimethylbenzene, α-pinene, 3-carene and d-limonene, have been measured in different houses and are not related to each other. In the residence with a concentration level of 96 µg/m^{-3} of limonene, no use of air fresheners was reported.

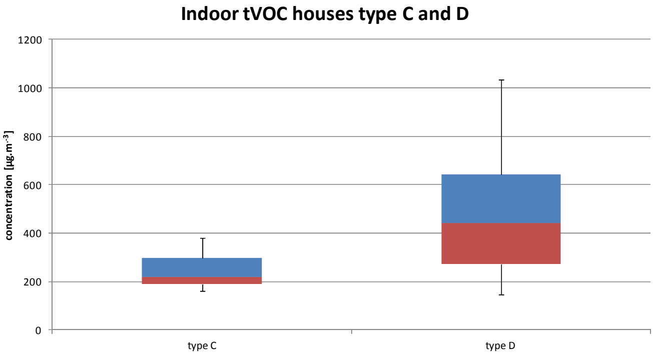
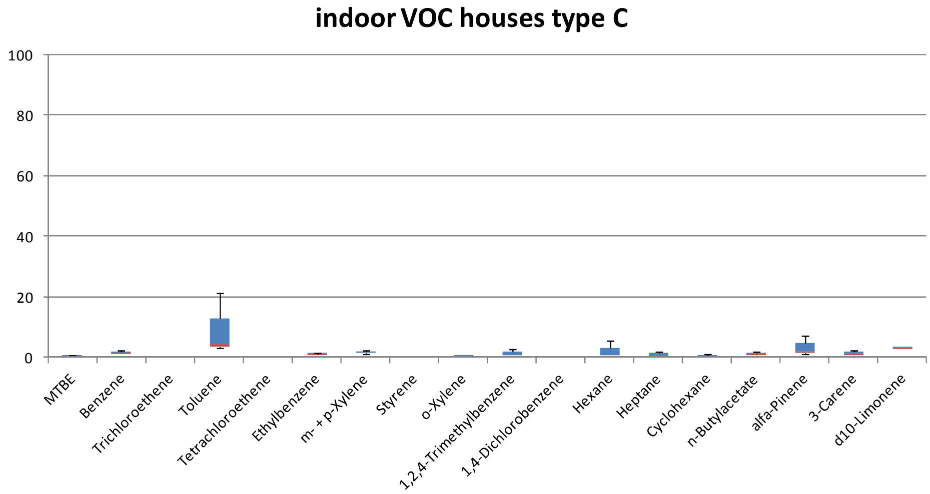


Figure 51 Indoor TVOC levels in residences with ventilation system C and D (3 houses vs 22 houses)



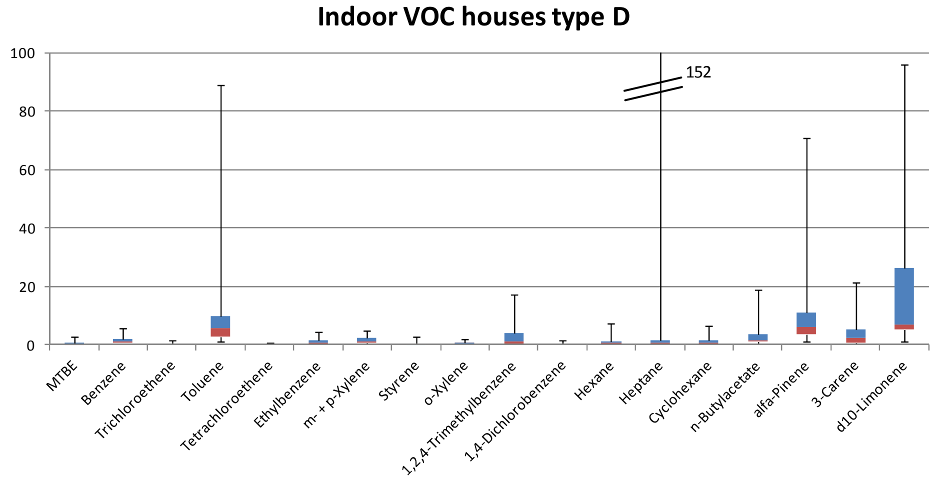


Figure 52 Indoor VOC levels in residences with ventilation system C and D

Although the median formaldehyde concentration is found to be slightly higher in residences with ventilation system D, no clear difference can be identified in this dataset (see Figure 53). The larger variation in the graphical view of the ventilation system D part of the plot is more likely the result of the larger dimensions of the dataset than the type of ventilation.

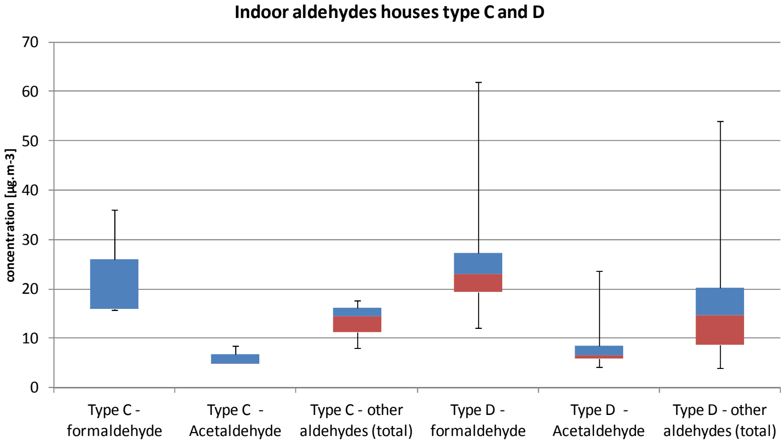


Figure 53 Indoor aldehyde levels in residences with ventilation system C and D

Median, average and 75th percentile $PM_{2.5}$ concentrations in residences with both ventilation systems are of comparable magnitude (Figure 54). The wider range of concentrations in the residences with a ventilation system type D, is the result of the larger dataset. Indoor – outdoor ratio’s in both system C and D residences are all below unity. This is not an unusual finding for residences, where resuspension of settled dust is far less predominant than in classrooms, as a consequence of the clearly lower amount of occupants in residences.

Table 13 Overview of the indoor PM levels in residences with ventilation system C and D

	Average	Median	75th percentile
Indoor PM (grav) system C	12.6 ± 2.4	11.6	13.5

Indoor PM (grav) system D	13.6 ± 8.7	9.4	15.4

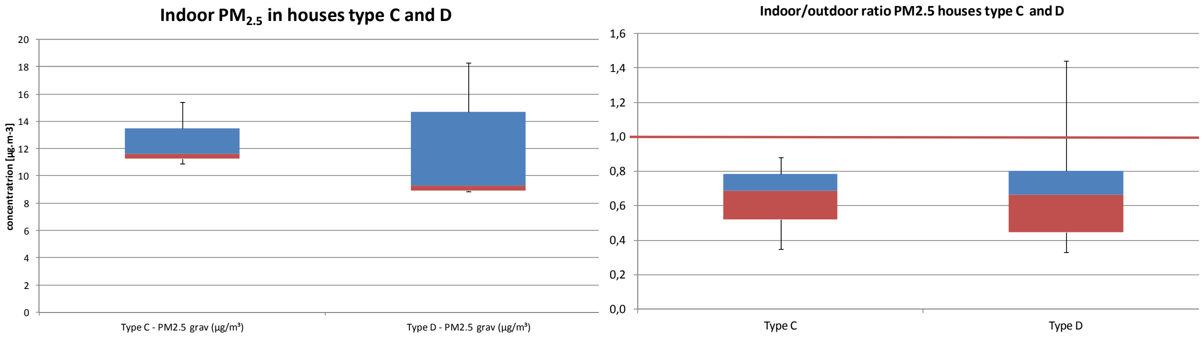


Figure 54 Indoor $PM_{2.5}$ levels in residences with ventilation system C and D

Contrary to the finding in classrooms, the indoor environmental parameters temperature, relative humidity and air velocity are all of comparable magnitude in residences with ventilation system C and D (Table 14 and Figure 55). This results from the different sources of humidity during normal household activities, which is an absent source in classroom.

Table 14 Overview of the indoor temperature, relative humidity and air velocity

	Average	Median	25th percentile	75th percentile
Temperature (°C) system C	18.7 ± 2.2	18.5	19.7	22.2
Temperature (°C) system D	20.1 ± 1.7	20.2	19.1	21.2
Relative humidity (%) System C	45.3 ± 7.1	44.0	41.5	48.5
Relative humidity (%) System D	44.4 ± 6.5	44.0	41.3	48.8
Air velocity (m/s) System C	0.03 ± 0.01	0.04	0.03	0.04
Air velocity (m/s) System D	0.03 ± 0.01	0.03	0.02	0.04

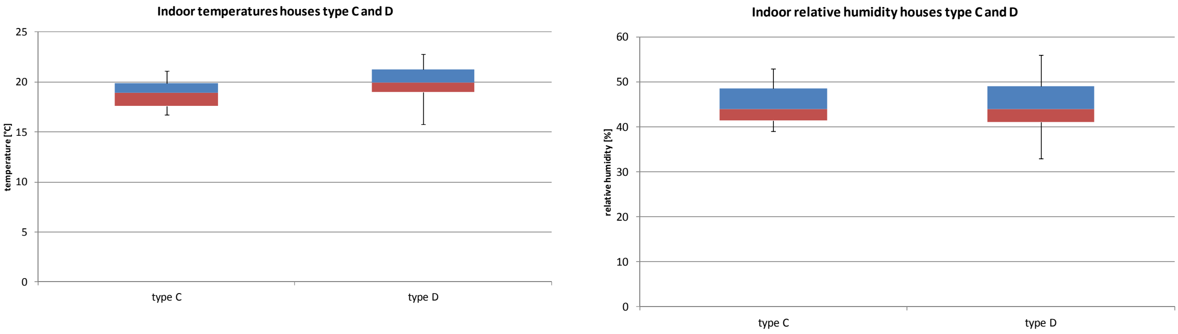


Figure 55 Temperature and relative humidity in residences with ventilation system C and D

Unlike the situation in schools there were no clear differences in fungal and bacterial levels in indoor air visible for residences of type C and D (*Figure 56* and *Figure 57*). Air samples were typically taken in two rooms of the house, the living room as well as the bedroom. Total viable fungal and bacterial levels seem largely comparable in living- and bedrooms of type C and D houses. A bigger variation in values (between minimum and maximum values) is visible always for type D buildings, which is due to the larger dataset obtained for type D houses (3 versus 12 houses of type C and D, respectively, were monitored for biologicals). Results for swab samples of these homes looked comparable, i.e. did not show any clear differences between the two ventilation types.

Indoor/outdoor ratios of viable fungi and bacteria seem to be somewhat higher in type D houses (Figure 58), however, it is unclear whether this difference is not rather a consequence of the barely comparable datasets (3 versus 12 houses) of the two ventilation types.

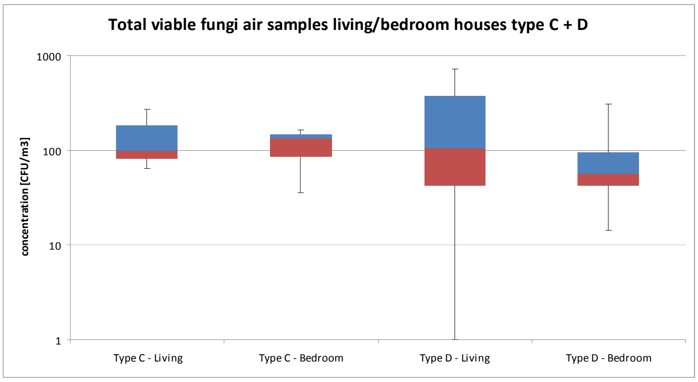


Figure 56 Total viable fungi in air samples in residences of type C and D (living and bedrooms).

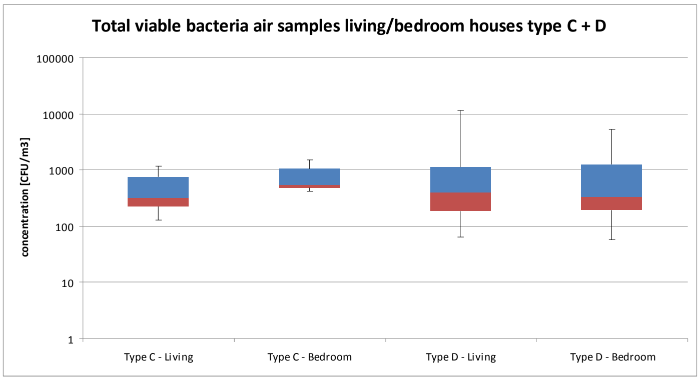


Figure 57 Total viable bacteria in air samples in residences of type C and D (living and bedrooms).

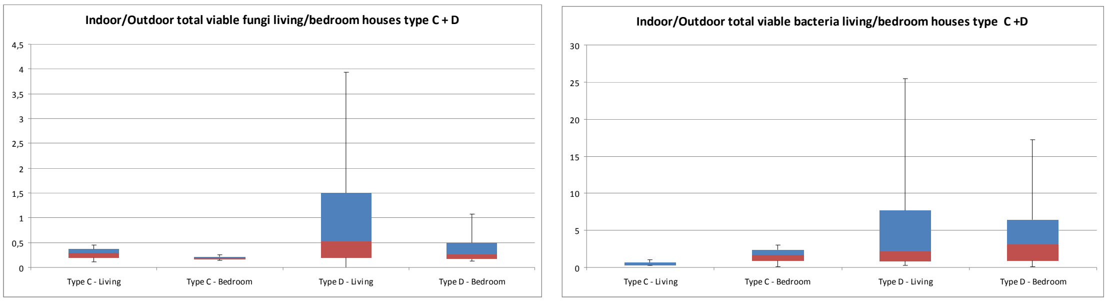


Figure 58 Indoor-Outdoor ratio of viable fungi and bacteria in air samples.

2.2.2. BUILDING AIRTIGHTNESS VERSUS INDOOR AIR QUALITY

In order to explore the influence of airtightness of the building envelope on the indoor environment, 4 different groups of airtightness have been defined:

Airtightness group 1: n50 ≤ 0.6

Airtightness group 2: 0.6< n50 ≤ 2.5

Airtightness group 3: 2.5 < n50 ≤ 10 (for houses n50 > 2.5, since n50 did not exceed 3)

Airtightness group 4 n50 > 10

Applied on the set of Clean Air Low Energy classrooms, the following distribution between the different groups was achieved:

- Group 1: 3 classrooms (of which 3 rooms subjected to biological characterisation)
- Group 2: 4 classrooms (of which 3 rooms subjected to biological characterisation)
- Group 3: 7 classrooms (of which 3 rooms subjected to biological characterisation)
- Group 4: 12 classrooms (of which 6 rooms subjected to biological characterisation)

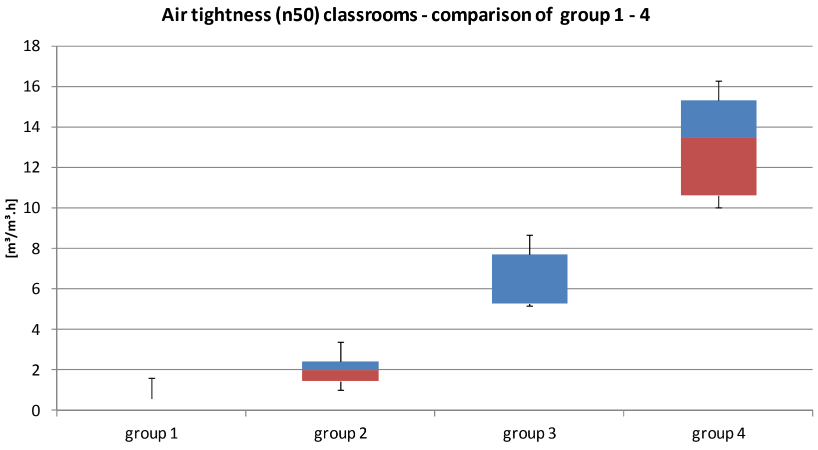
It should however be emphasized that group 1 consists of the one passive school currently in use in Flanders. Since this is a rehabilitation institute, the classroom settings may somehow differ from those of a traditional classroom. E.g. the first classroom of group 1 is a kitchen, the second room was a shop.

For the Clean Air Low Energy residences, the results presented in this paragraph are based on the following distribution:

- Group 1: 6 residences (of which 4 subjected to biological characterisation)
- Group 2: 8 residences (of which 4 subjected to biological characterisation)
- Group 3: 11 residences (of which 7 subjected to biological characterisation)
- Group 4: no residences in group 4

→ Schools

According to Figure 59 it can be noticed that the most airtight classrooms are characterized by the most controlled total air change rate, typically with least variation. Group 1 is represented by the passive school building. The total air change rate increases and shows a wider distribution when airtightness groups 3 and 4 are considered. According to this figure, group 4 classrooms are characterized by the higher air leakage, and thus have more openings and cracks. This leads to the higher total air change rate in this group, compared to the other airtightness groups.



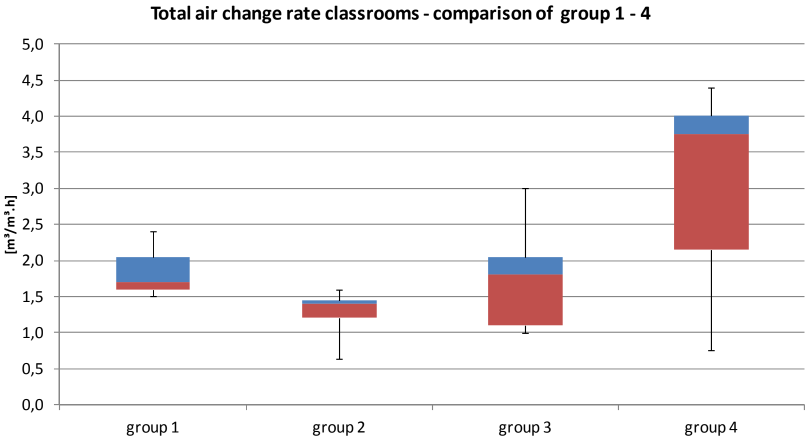


Figure 59 Box and Whiskers plot showing the airtightness and total air change rate of classrooms, categorized in airtightness groups

In spite of their highest total air change rate (see Figure 59), group 4 classrooms are characterized by the highest indoor CO_2 concentrations for 24-h as well as teaching hour averages (see Figure 60). This finding could indicate that the openings and cracks in the envelop of these buildings do contribute to the higher air change rate that was measured in these classrooms, but don't contribute to a decrease of the indoor CO_2 levels. Therefore it may be concluded that the incoming air through openings and cracks in these buildings is rather originating from other indoor environments (like a hallway, or another classroom) than from outdoor air.

As a consequence, the lowest average CO_2 levels are registered in the most airtight buildings; the highest in the least airtight buildings. Since in the most airtight classrooms the air change rate is strongly dependant on the ventilation system, a comparison of Figure 59 and Figure 60 may indicate that in this dataset the most effective aeration is obtained in most airtight buildings.

The differences between CO_2 levels in the airtightness groups are most pronounced for the teaching hour average CO_2 levels. According to Table 15, this is also confirmed by the 75th percentile concentration of each airtightness group.

Table 15 Overview of the teaching hour (TH) average CO_2 levels in classrooms, categorized by airtightness

	Average	Median	75th percentile
Indoor CO_2 (TH) group 1	404 ± 57	398	431
Indoor CO_2 (TH) group 2	546 ± 45	550	565
Indoor CO_2 (TH) group 3	688 ± 136	687	758
Indoor CO_2 (TH) group 4	741 ± 145	732	796

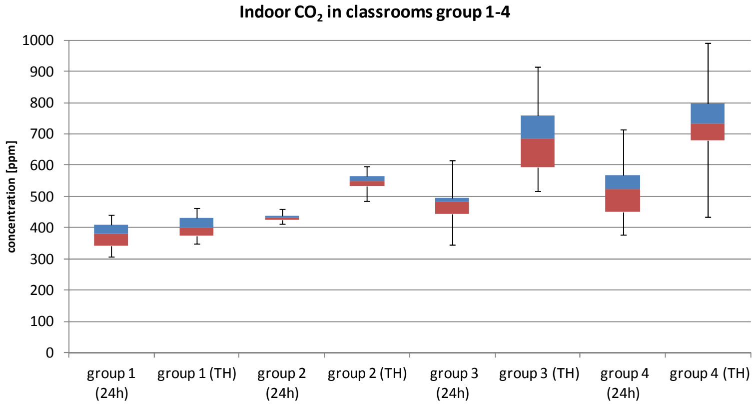


Figure 60 24-hour and teaching hour average CO_2 levels in classrooms, categorized by airtightness

As shown in Figure 61 no distinct difference between the indoor TVOC concentration of the airtightness groups can be identified. Considering the individually identified and quantified VOC compounds however (Figure 62), the different behaviour of VOCs in classrooms of airtightness group 1 and the other groups can be noticed. For certain VOC components, like benzene, ethylbenzene, or xylene isomers, typically originating from outdoor air, comparable concentration levels were monitored indoors. But for other compounds however, like toluene, cyclohexane or limonene, typically originating from indoor sources, lower levels were registered in airtightness group 1, which was previously identified having most effective aeration. The most elevated levels on the other hand were monitored in groups 3 and 4.

Again it should however be emphasized that group 1 consists of the one passive school currently in use in Flanders. Since this is a closed rehabilitation institute, the classroom settings may somehow differ from those of a traditional classroom. E.g. the first classroom of group 1 is a kitchen, the second room was a shop.

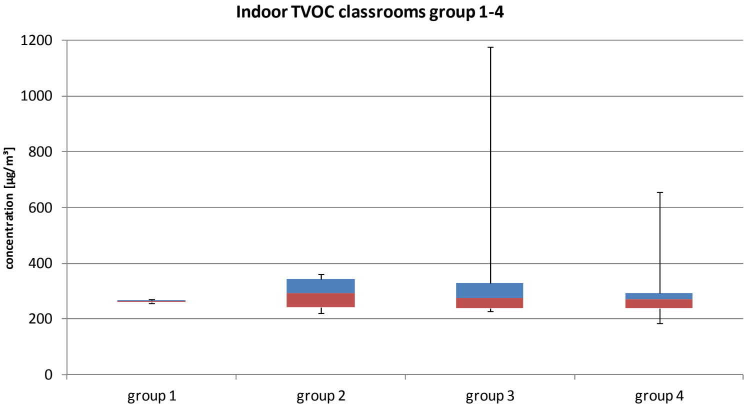


Figure 61 Indoor TVOC levels in classrooms, categorized by airtightness

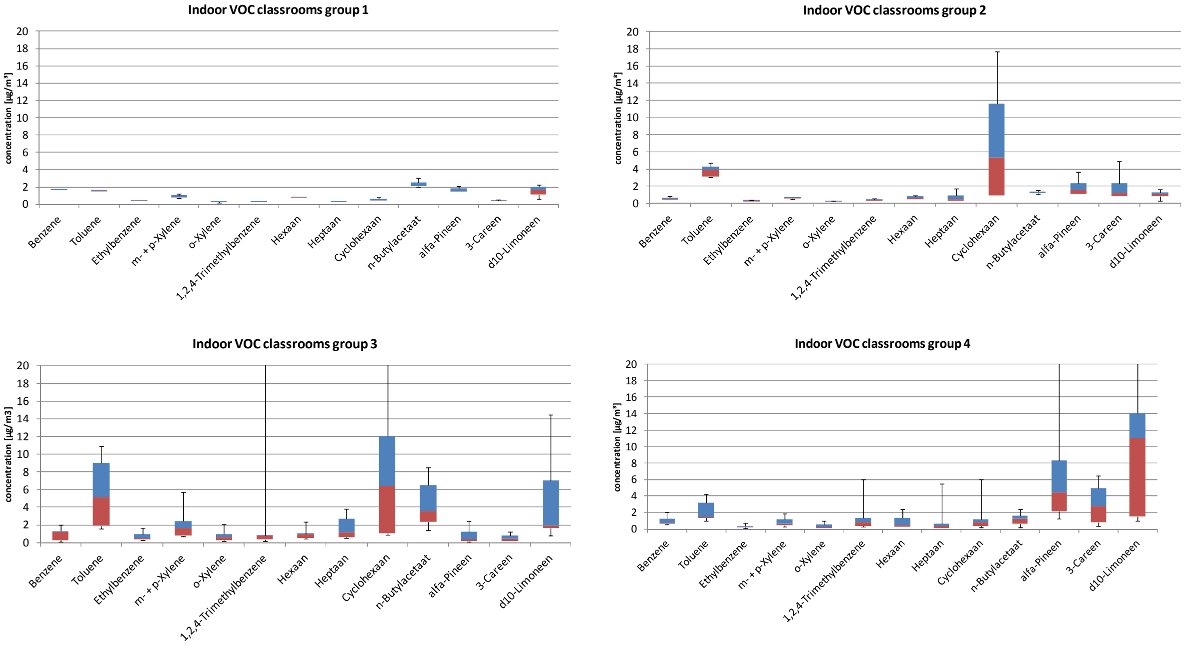


Figure 62 Indoor VOC levels in classrooms, categorized by airtightness

For acetaldehyde, no difference can be identified between the different airtightness groups. However, similarly to VOC compounds that are related to mainly indoor sources, formaldehyde as well as total other aldehyde levels are found to be at lower concentration levels in airtightness group 1 (Figure 63), which was previously identified as having most effective aeration of all airtightness groups. $PM_{2.5}$ also occurred at the lowest concentration and at a clearly decreased indoor-outdoor ratio in airtightness group 1. No distinct difference could be identified between the other airtightness groups. Indoor-outdoor ratios of the other airtightness groups exceeded unity in some cases (Figure 64).

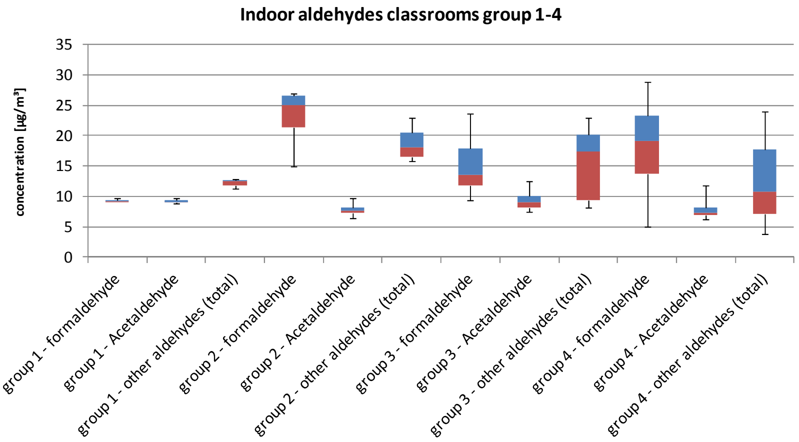


Figure 63 Indoor aldehyde concentration levels in the classrooms, categorized by airtightness

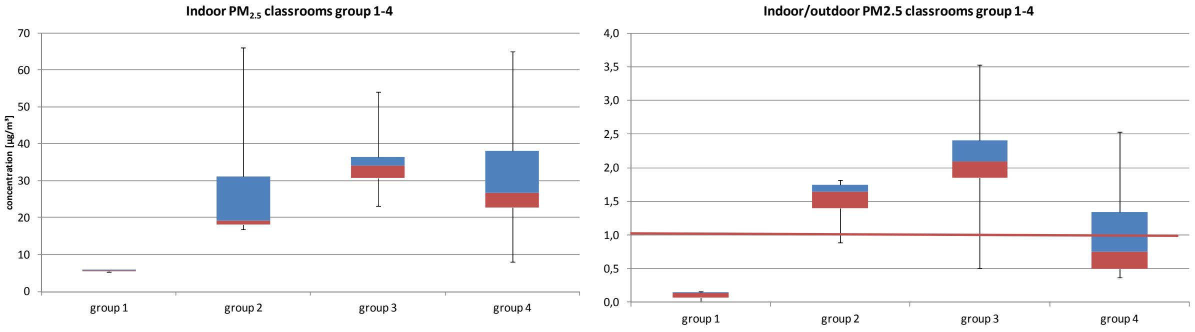


Figure 64 Indoor PM$_{2.5}$ and its I/O ratio in the classrooms, categorized by airtightness

In this dataset, the indoor temperatures can be considered as independent of the level of airtightness of the classrooms (Figure 65). However, a clearly lower relative humidity was monitored in the 3 classrooms of airtightness group 1. This group 1 is characterized by the most airtight building envelope. On condition that the Clean Air Low Energy school building envelope behaves similar to the Clean Air Low Energy residences, buildings with lowest air leakage are found to be the best insulated buildings (paragraph 2.1.4). The lower indoor relative humidity reported in Figure 65 is then in agreement with Howden and Chapman (2007) and Paul et al. (2010) have also reported to find lower indoor relative humidity in buildings with an increased insulation level (see literature review, WP1). The low relative humidity in these airtightness group 1 classrooms certainly don't originate from outdoor conditions, since during the monitoring period, the outdoor relative humidity was 71%.

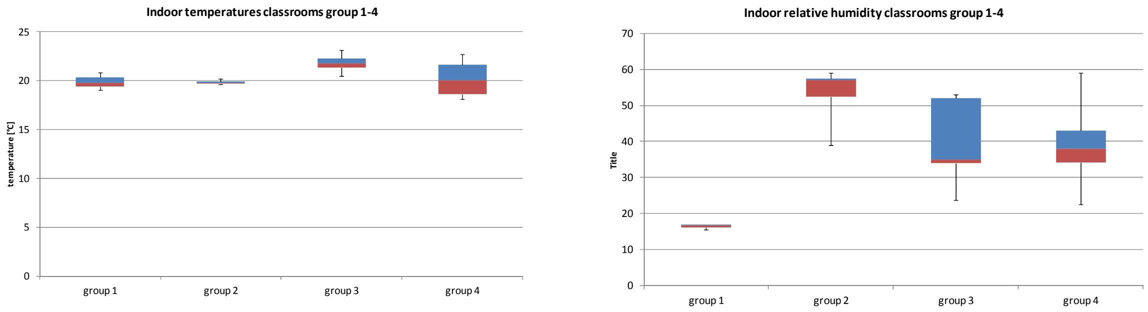


Figure 65 Indoor temperatures and relative humidity in the classrooms, categorized by airtightness

The most striking result with respect to biological contaminants in classrooms when grouping the schools by airtightness is the clearly higher level of viable fungi and bacteria in the air of the school from group1, i.e. the most airtight building (*Figure 66*). However, as mentioned at the beginning of this chapter under 2.2.2, the school in question is in fact a rehabilitation institute, in which the classrooms differ from traditional classrooms, in that for example classroom 1 represents a kitchen, classroom 2 a shop. Related to this we can expect a very different situation in terms of indoor sources of microbes, especially when considering a kitchen or shop with food items and similar. Therefore, the elevated levels of viable fungi and bacteria under group 1 are much more likely related to the difference in building use, rather than due to airtightness of the building envelope. For classrooms from schools group 2, 3 and 4 there are no clear differences visible for viable fungi, whereas viable bacteria seem elevated in the least airtight building, compared to groups 2 and 3 (also confirmed in swab samples; data not shown).

With respect to the indoor/outdoor ratios of viable fungi the elevated ration for the class 1 school confirms the presence of indoor sources for viable fungi as discussed above (Figure 67). For bacteria, the least airtight classrooms seem to have higher indoor/outdoor ratios of viable bacteria, confirming also Figure 67. It was speculated earlier in connection with the highest CO_2 levels found for group 4 classrooms, that the cracks and openings reducing airtightness in these classrooms may not connect to outdoors, but rather to other indoor spaces, which may also partly explain the elevated bacterial levels in these classrooms. Since bacterial levels indoors are associated with occupancy, it would be interesting to explore whether occupancy in group 4 classrooms was higher than in classrooms from other groups, which could explain both, higher CO_2 and bacterial levels.

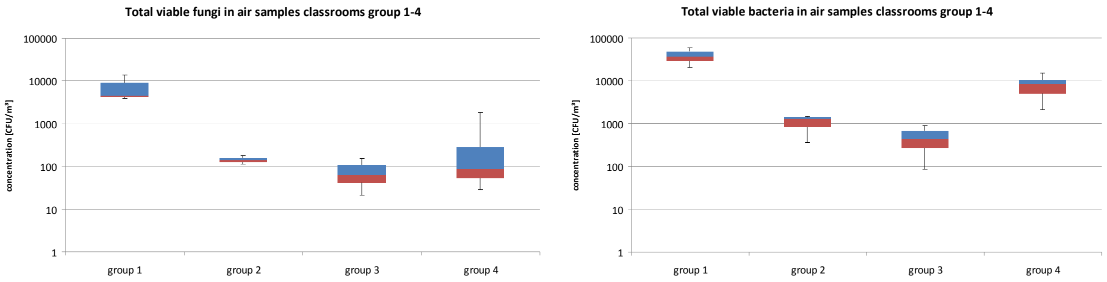


Figure 66 Total viable fungi and bacteria in air of classrooms, categorized by airtightness

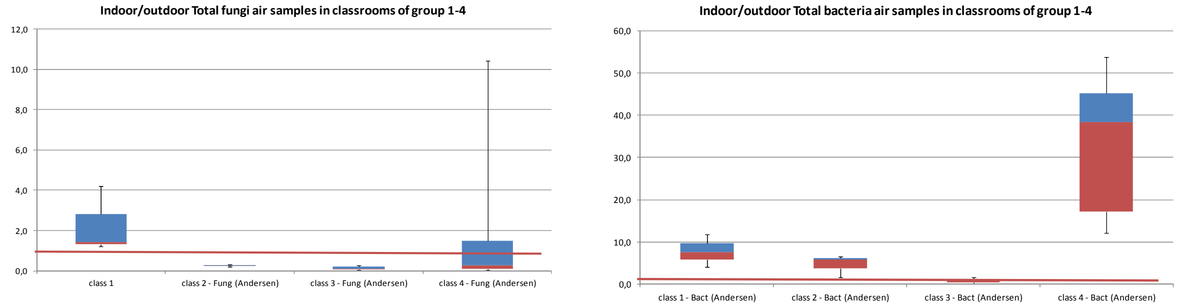


Figure 67 Indoor-outdoor ratios of total viable fungi and bacteria in air samples, categorized by airtightness

→ Residences

Since none of the residences with an airtightness exceeding 3 m³/m³.h was part of the Clean Air Low Energy dataset, for residences only 3 airtightness groups have been established, group one including the most airtight houses; group 3 representing the least airtight houses from Clean Air Low Energy.

According to Figure 68 the most airtight residences from group 1 are characterized by a moderately lower total air change rate. The most elevated total air change rate was found in residences of airtightness group 3. This results from the contribution of openings and cracks in the building envelope of less airtight buildings to the total air change rate.

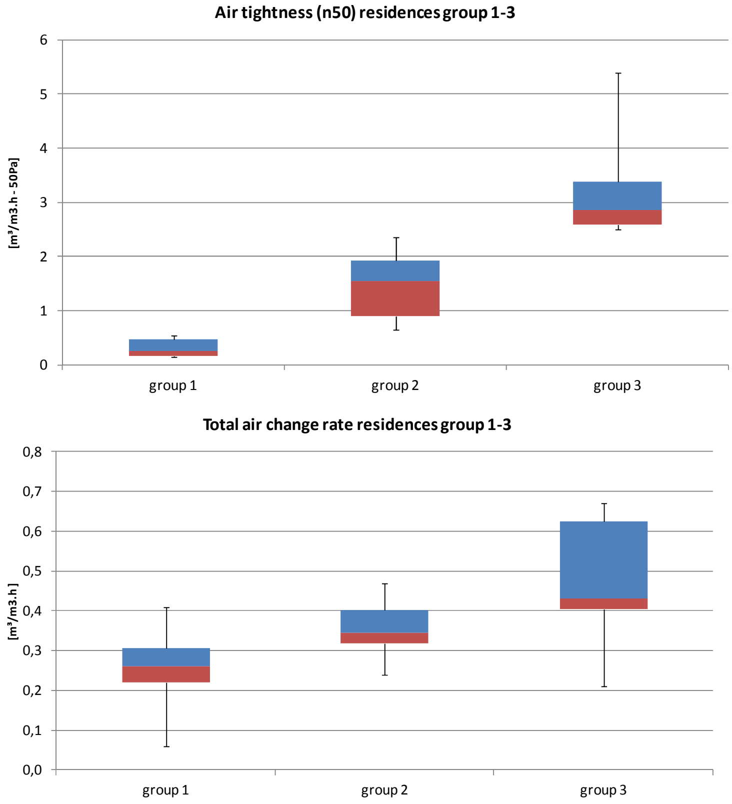


Figure 68 plots showing the airtightness and the total air change rate of the residences, categorized by airtightness

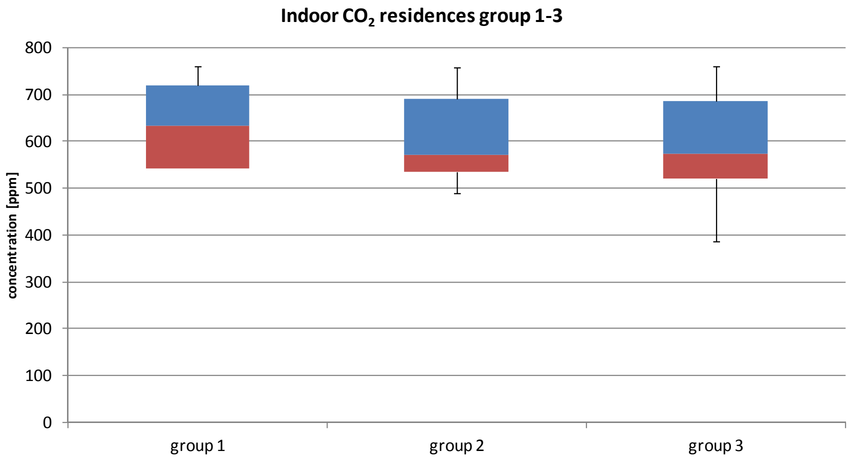


Figure 69 Indoor 24-h average CO_2 level in residences, classified by airtightness

Contrary to the findings in the study of classroom CO_2 levels in relation to airtightness, the residential indoor CO_2 level appeared to be independent of the airtightness. Both 25th and 75th percentile of the airtightness groups are similar, as shown in Figure 69. This finding indicates that a high building airtightness does not necessarily prevent an effective building aeration.

This comparable CO_2 level, which is an indication of a comparable aeration, is reflected in all the other chemical compounds monitored in the residences. According to this set of residences, there is no indication of a difference between the TVOC levels (Figure 70), the individual VOCs (Figure 71), aldehydes (Figure 72) and $PM_{2.5}$ concentrations (Figure 73) of the different airtightness groups.

Temperature and relative humidity appeared to be also independent of the residence airtightness (Figure 74).

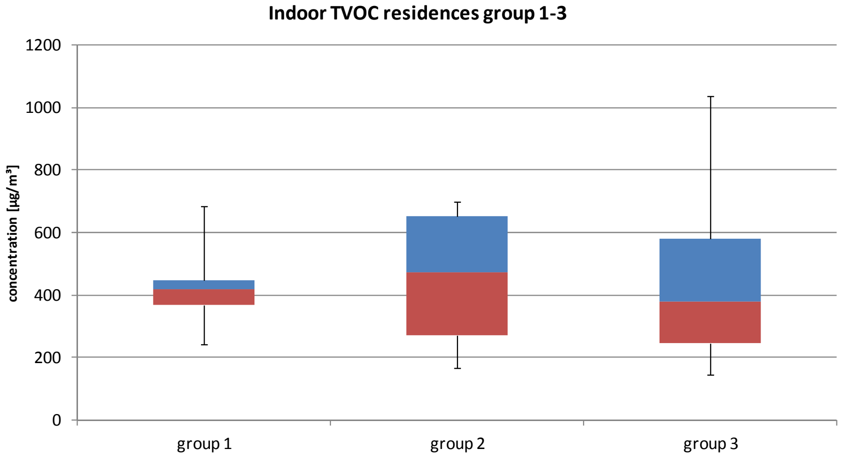


Figure 70 Indoor TVOC in residences, classified by airtightness

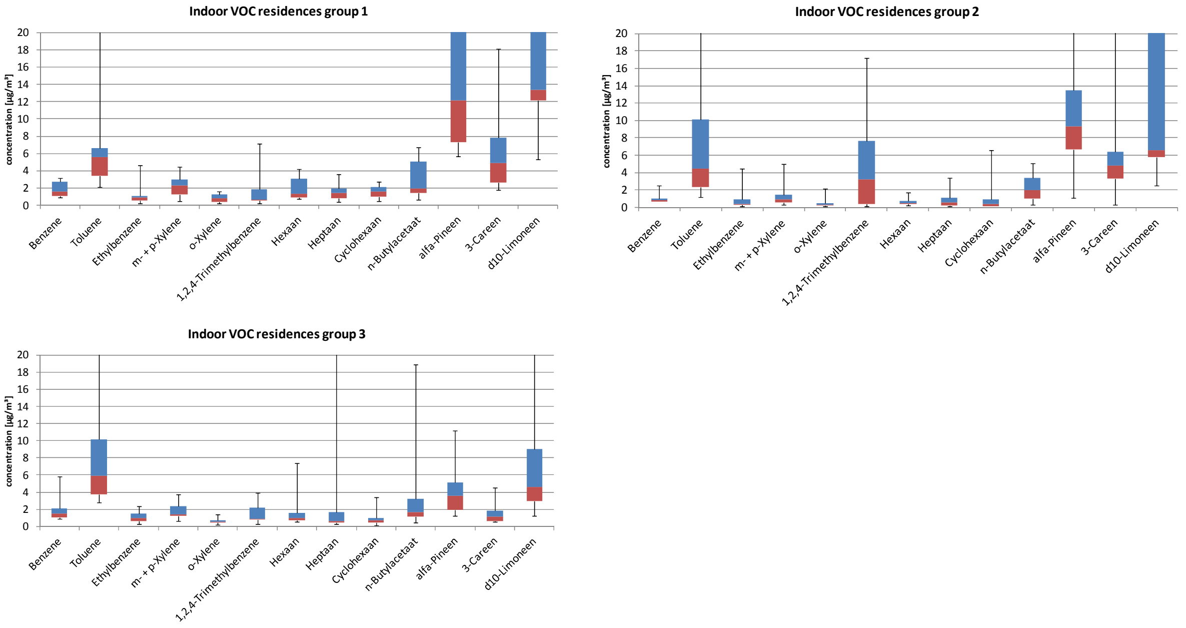


Figure 71 Indoor VOC levels in residences, categorized by airtightness

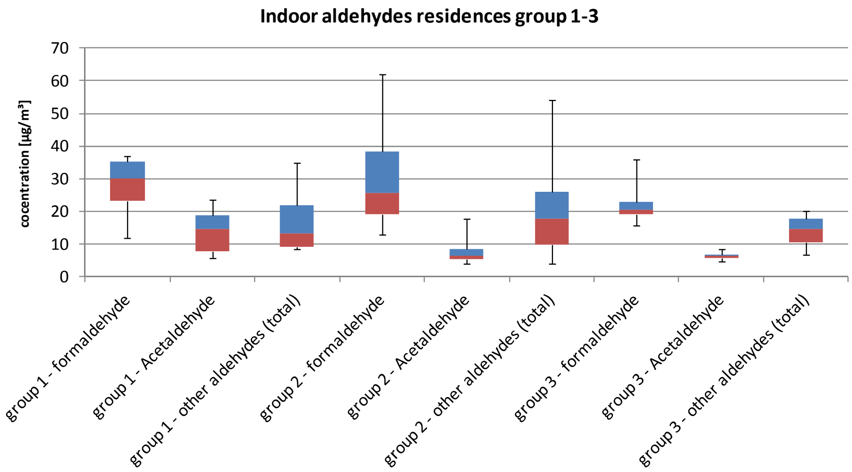


Figure 72 Indoor aldehydes in residences, categorized by airtightness

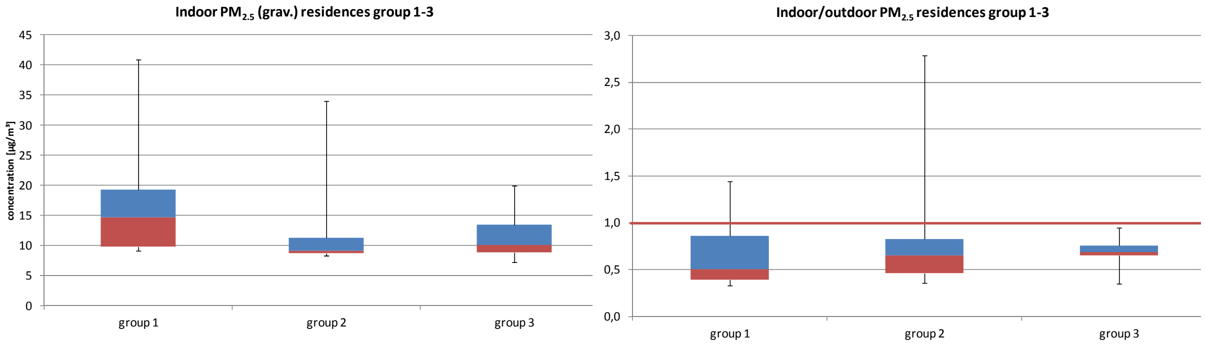


Figure 73 Indoor $PM_{2.5}$ and its indoor-outdoor ratio in residences, categorized by airtightness

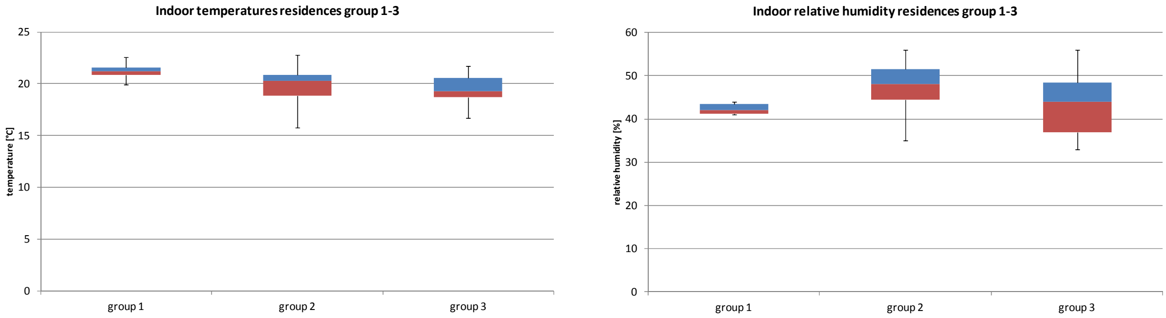


Figure 74 Indoor temperatures and relative humidity in residences, categorized by airtightness

No clear trends or differences were observed for viable fungi in the air of living- and bedrooms of residences categorized by airtightness (Figure 75). For bacteria, somewhat lower levels were observed in group 3 residences, best visible when comparing the means (also confirmed by swab samples; data not shown). In addition, indoor/outdoor ratios of both fungi and bacteria were found to be lowest in group 3 residences (Figure 76). Generally, somewhat higher microbial levels were detected in the air of the living rooms, compared to the bedrooms (within each airtightness group). It could be speculated whether this might indicate the dependency on activity and occupancy, presence of pets, plants and other sources of microbes in the living areas of these houses.

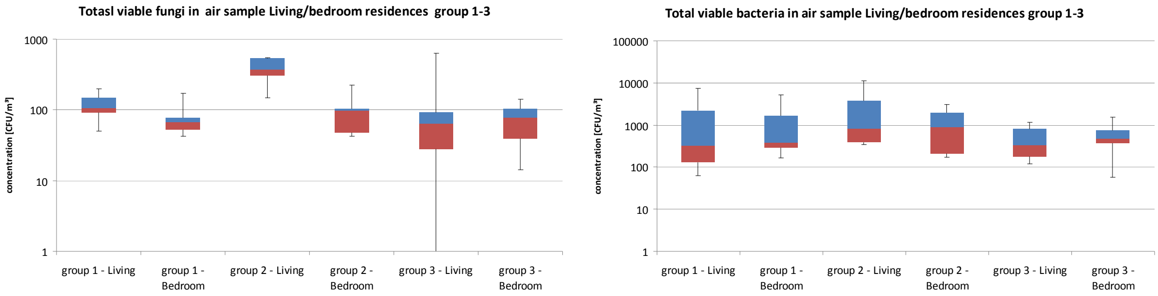


Figure 75 Total viable fungi and bacteria in air samples from houses categorized by airthightness.

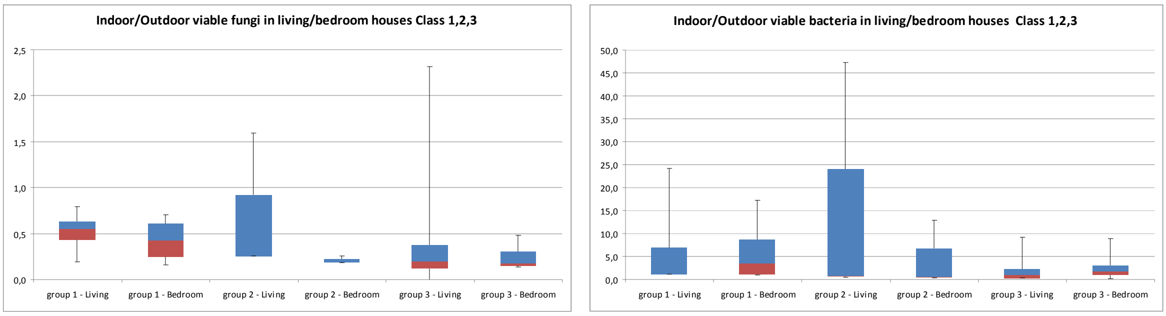


Figure 76 Indoor/outdoor ratios of total viable fungi and bacteria in air samples from houses categorized by airthightness.

→ Conclusion building airtightness versus IAQ

In general for Clean Air Low Energy schools, it can be concluded that more airtight classrooms were characterized by a lower total air change rate. In spite of their lower air change rate, the indoor CO_2 levels indicated a more effective aeration in the most airtight classrooms. There was an indication that in these most airtight classrooms (group 1), the lowest IAQ levels, especially for compounds with common indoor sources, have been identified. These more airtight classrooms were however characterized by the lowest relative humidity (note that this conclusion is based on 3 classrooms of one very airtight school building). No difference could be noticed between the other airtightness groups.

Viable fungi and bacteria in the air appeared on the other hand to be increased in the most airtight classrooms. Based on this dataset, this finding can however not be attributed to the level of airtightness, as the activities in these classrooms were atypical.

For residences, more airtight buildings were characterized by a lower air change as well. However the indoor CO_2 levels indicated a similar level of aeration in buildings with a different level of airtightness. All chemical compounds, as well as temperature and relative humidity appeared to be independent of the level of airtightness of residences. No clear trends could be identified for viable fungi and bacteria in residential indoor air in buildings of different levels of airtightness.

2.2.3. TOTAL AIR CHANGE RATE VERSUS INDOOR AIR QUALITY

The total air change rate of a building is a more precise way of considering both the building airtightness as well as the building ventilation that results from the mechanical ventilation system. By characterising the Clean Air Low Energy buildings in clusters or classes based on their total air change rate, the direct influence of the building envelope and its ventilation system on the indoor environment can be quantified.

In the following the schools and residences are clustered based on total air change rate. The considered parameter however is different for Clean Air Low Energy houses and schools.

- For classrooms, the total air change rate is recalculated to IDA classes, corrected for the amount of pupils present in that classroom. The results presented in this paragraph are based on the following amount of classrooms per total air change rate class:
    - IDA class 1: 1 classroom (of which 1 room subjected to biological characterisation)
    - IDA class 2: 4 classrooms (of which 4 rooms subjected to biological characterisation)
    - IDA class 3: 9 classrooms (of which 6 rooms subjected to biological characterisation)
    - IDA class 4: 7 classrooms (of which 1 room subjected to biological characterisation)
    - IDA class 5: 5 classrooms of which 3 rooms subjected to biological characterisation)
- For residences, the classes are defined based on the whole building air change rate
    - Class 1 > 0.5 ACH: 4 residences (of which 4 rooms subjected to biological characterisation)
    - Class 2 > 0.375 ACH: 9 residences (of which 3 rooms subjected to biological characterisation)
    - Class 3 > 0.25 ACH: 8 residences (of which 5 rooms subjected to biological characterisation)
    - Class 4 < 0.25 ACH: 4 residences (of which 3 rooms subjected to biological characterisation)

For classrooms, the IDA classification from the EN 13779 standard is the applicable requirement. An additional 5th class at half the flow rate of IDA 4 was added to distinguish between classrooms with moderate and considerable low flow rates.

For dwellings, IDA based classification is less relevant due to the high variability of the occupancy as well as the internal partitioning. A minimal total air change rate of 0.5 ACH, however, is generally recommended. Therefore, a classification of the dwellings in relation to this recommendation is used.

→ Schools

As illustrated in the plots shown in Figure 77, no distinct difference can be identified between the airtightness of the Clean Air Low Energy classrooms, grouped in IDA classes 1 to 5. This results from the wide variations of the airtightness within one IDA class.

However, when considering the total air change rates of the different IDA classes, a decrease of the total air change rate can be noticed when shifting from IDA class 3 to IDA class 5.

It should be noticed that IDA class 1 is represented by only one classroom. The room, being characterized by a considerable high air leakage (n50 = 14.1 $m^3/m^3.h$) and a rather high air change rate (3.9 ACH), was populated by only 10 pupils. This resulted in its classification in IDA class 1.

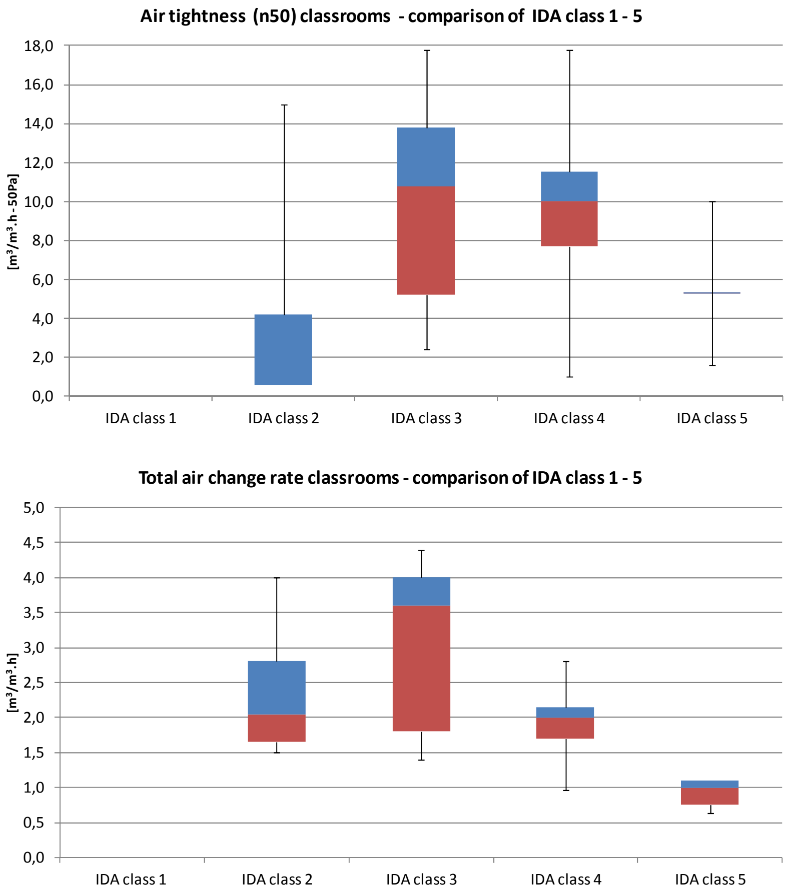


Figure 77 Plots showing the air tightness and the total air change rate of classrooms in the 5 difference IDA classes

The positive influence of the classroom total air change rate on the indoor CO_2 levels can be noticed in the 24-h as well as the teaching hour (TH) average CO_2 concentrations (see Figure 78). This tendency of indoor CO_2 concentrations to increase when shifting to a higher IDA class is however most pronounced in the teaching hour average CO_2 levels, as shown in Table 16. This indicates the efficiency of the ventilation system to remove indoor generated CO_2 from the classroom air.

Additionally, this plot emphasizes the different behaviour of the one classroom that was classified in IDA class 1. Although the settings of the ventilation installation, combined with the classroom air tightness and its occupancy indicate a classification in IDA class 1, the CO_2 levels in this classroom are considerably increased compared to the other rooms. This may be the result of an incorrect use, or a shutdown of the ventilation system in this room during the air quality assessment, which will bias the rest of the reported results for this IDA class 1 room. Also, this classroom is part of 'air tightness group 4' as reported in 2.2.2, and was previously indicated as being the least airtight group of classrooms, with possibly cracks and openings to the inside (hallway, other rooms) of the school building. However, since the indoor teaching hour CO_2 level in this particular classroom was the highest concentration, registered in Clean Air Low Energy, it is most likely that the ventilation system operated incorrectly during the air quality assessment. Therefore, the data for IDA class 1 will be reported in the following, but won't be included in the discussion.

Table 16 Overview of the teaching hour average CO_2 levels in classrooms, categorized in IDA classes

	Average [ppm]	Median [ppm]	75% percentile [ppm]
Teaching hour CO_2 IDA class 1	928.8	n.a.	n.a.
Teaching hour CO_2 IDA class 2	497.8 ± 193.4	431.2	543.0
Teaching hour CO_2 IDA class 3	602.0 ± 95.6	616.3	671.7
Teaching hour CO_2 IDA class 4	717.3 ± 145.6	727.3	811.6
Teaching hour CO_2 IDA class 5	748.3 ± 162.4	732.4	782.8

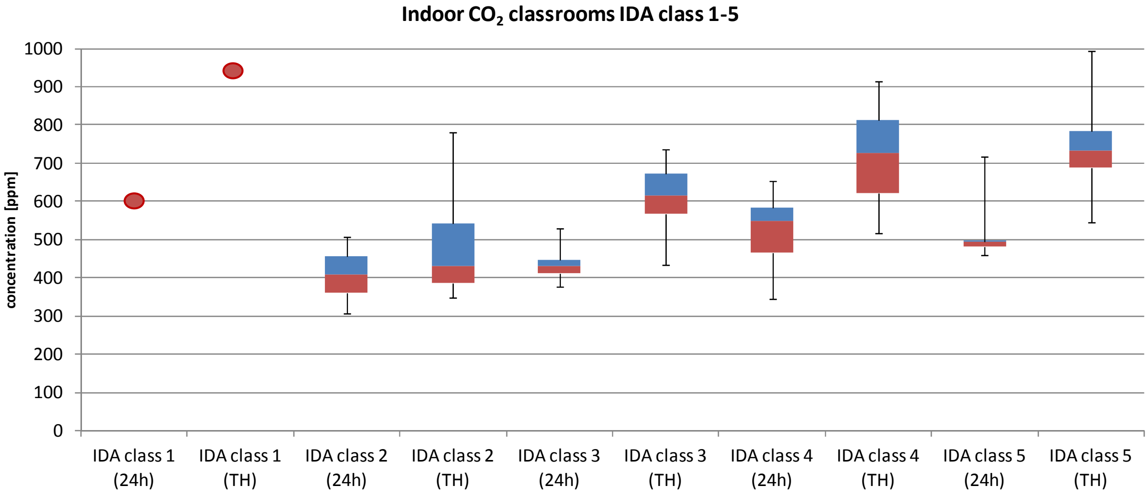


Figure 78 24-h and teaching hour (TH) average CO_2 concentrations in the classrooms, categorized in IDA classes

According to the set of Clean Air, Low Energy classrooms, the IDA class of the room does not impact considerably on the indoor TVOC levels. The median value of IDA class 4 is moderately higher than IDA 2 and 3, but the 75th percentiles as well as the error bars overlap between the different classes. One outlier was identified in IDA class 3, however no specific source could be identified based on the questionnaire or on the fieldwork report.

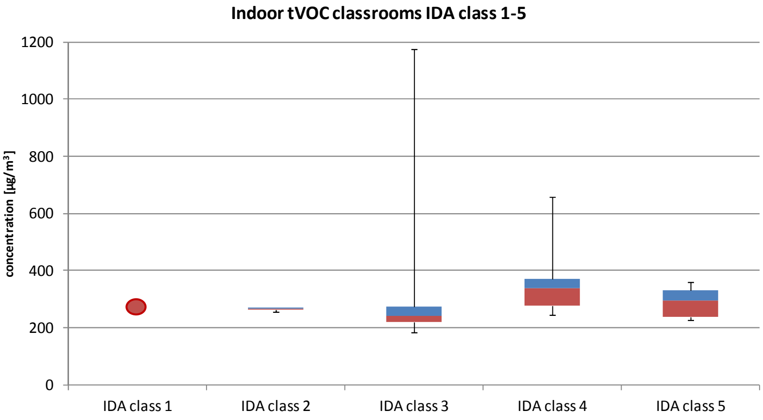


Figure 79 Indoor TVOC levels in classrooms, categorized in IDA classes

A clear trend in the indoor occurrence of the individual quantified VOC components could not be identified in this set of classrooms, except for toluene (see Figure 80). Toluene occurs in IDA class 2 classrooms at an average concentration of 1.4 ± 0.1 µg/m³ (75th percentile 1.5 µg/m³); 2.7 ± 1.6 µg/m³ (75th percentile 1.3 µg/m³) in IDA class 3; 2.8 ± 1.4 µg/m³ (75th percentile 3.7 µg/m³) in IDA class 4 and 6.3 ± 4.6 (75th percentile 9.4 µg/m³) in IDA 5 classrooms. For the other compounds there is an indication of lower concentration levels in IDA class 2 classrooms compared to rooms with a higher IDA class ranking. However, no clear distinction can be made between the indoor VOC level of schools in IDA class 3, 4 and 5.

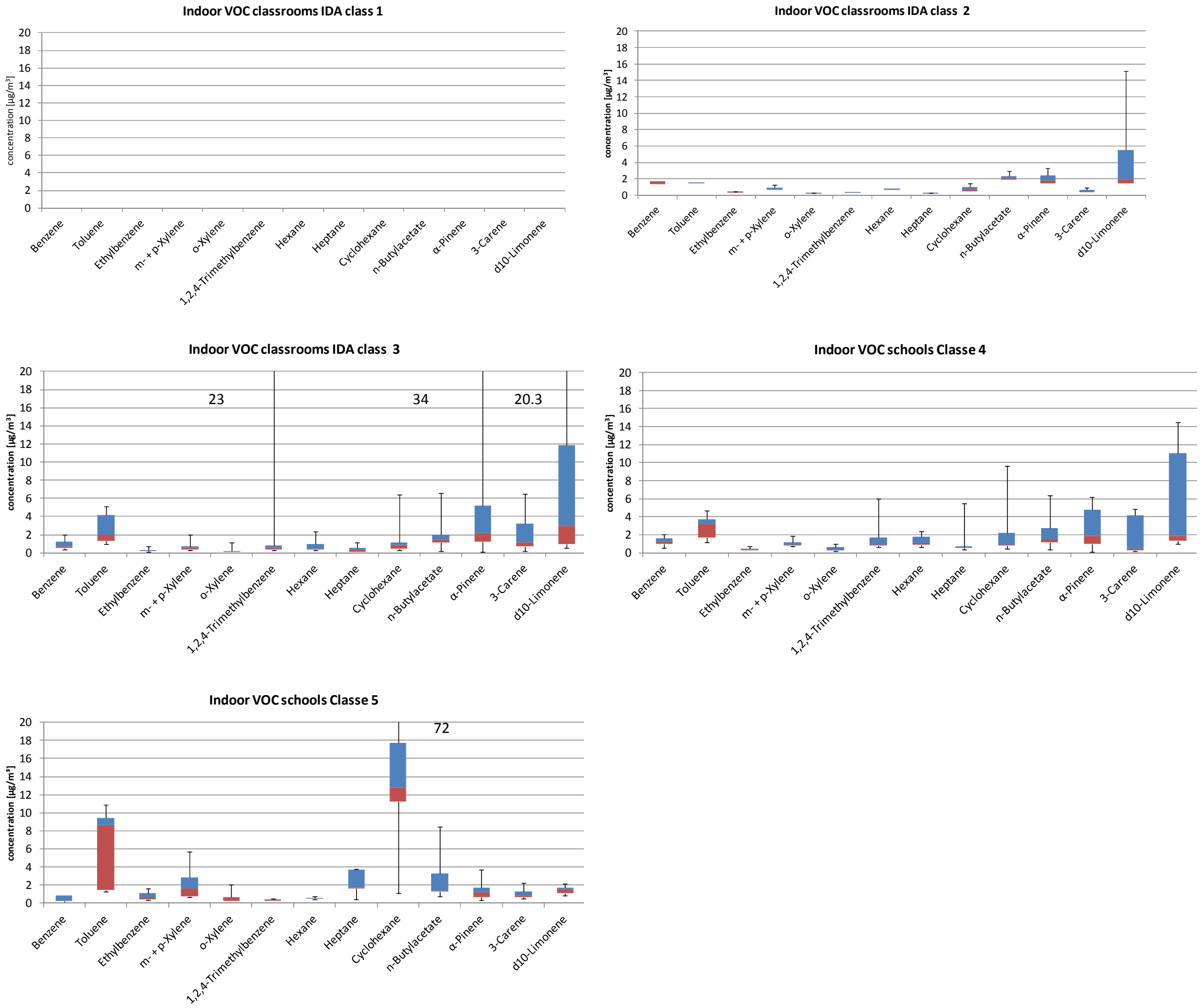


Figure 80 Indoor VOC levels in classrooms, categorized in IDA classes

According to this Clean Air Low Energy set of schools, indoor formaldehyde levels also tends moderately increase when moving to a higher IDA class (see Table 17). On the other hand, acetaldehyde levels and the concentration of total other aldehydes did not show the same tendency to increase in the same way the formaldehyde levels do (see Figure 81).

The most clear and distinct differences between the different IDA classes was identified for indoor $PM_{2.5}$ mass concentrations. Median, average and 75th percentile concentration levels increased considerably when increasing the IDA class of the classroom. The highest indoor $PM_{2.5}$ levels were identified for IDA class 5 classrooms. This set of rooms consists of classrooms equipped with a ventilation system C. The indoor-outdoor ratios of $PM_{2.5}$, shown in Figure 83, are clearly different in IDA class 2 compared to IDA class 3-5. Whilst all indoor-outdoor ratios are well below 0.5 for IDA class 2, the ratios exceed unity for the higher IDA classes. This confirms the efficiency of good ventilation rate settings in combination with a ventilation system D, in which the incoming air is purified through a filter system for the reduction of incoming $PM_{2.5}$.

Table 17 Overview of indoor formaldehyde levels in classrooms, categorized in IDA classes

	Average [µg/m³]	Median [µg/m³]	75% percentile [µg/m³]
IDA class 1	28.8	n.a.	n.a.
IDA class 2	10.1 ± 1.6	9.4	10.4
IDA class 3	15.6 ± 7.3	14.9	21.1
IDA class 4	18.7 ± 6.3	18.0	24.1
IDA class 5	19.8 ± 4.2	20.1	23.5

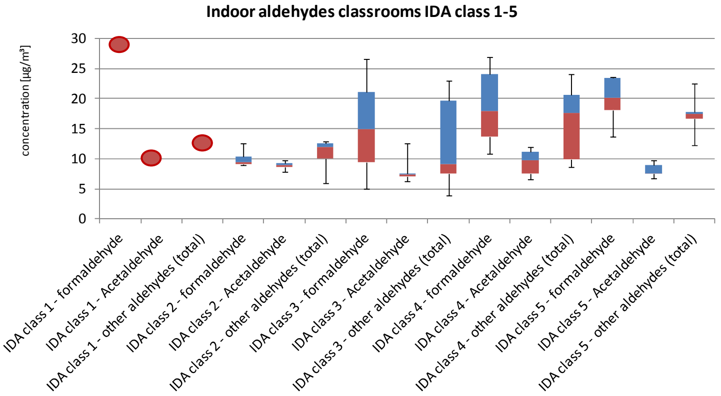


Figure 81 Indoor aldehyde levels in classrooms, categorized in IDA classes

Table 18 Overview of indoor $PM_{2.5}$ levels in classrooms, categorized in IDA classes

	Average [µg/m³]	Median [µg/m³]	75% percentile [µg/m³]
IDA class 1	23.1	n.a.	n.a.
IDA class 2	6.4 ± 1.4	6.0	7.0
IDA class 3	26.3 ± 8.1	25.8	35.0
IDA class 4	37.8 ± 14.6	32.0	50.0
IDA class 5	43.5 ± 20.4	34.0	65.0

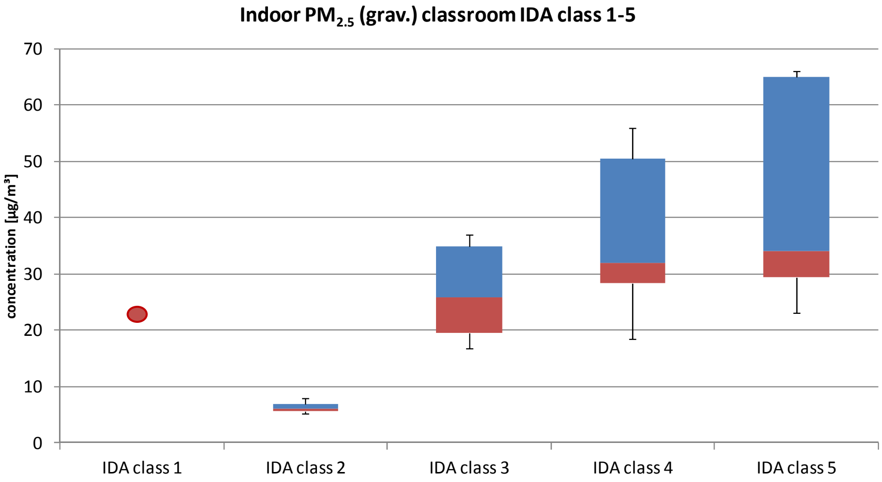


Figure 82 Indoor $PM_{2.5}$ levels in classrooms, categorized in IDA classes

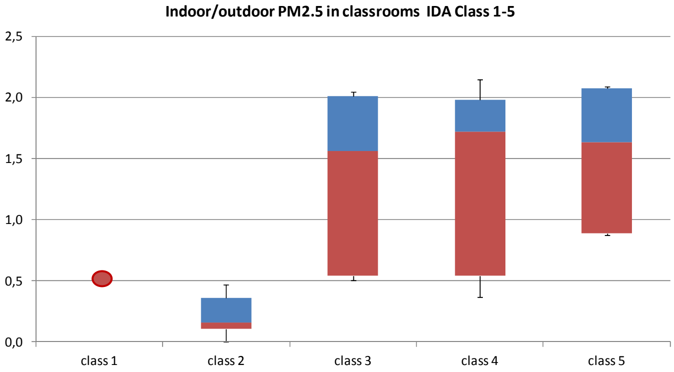


Figure 83 Indoor-outdoor $PM_{2.5}$ ratio's in classrooms, categorized in IDA classes

In general, the Clean Air, Low Energy pollutants that tend to increase when moving from a lower IDA class to a higher IDA class were toluene, formaldehyde, $PM_{2.5}$ and CO_2. In order to compare the increment of these concentrations between the classrooms that were categorized in the different IDA classes, Figure 84 plots the average concentration levels that were calculated for each of these 4 compounds for each IDA class. The plot confirms the most distinct increment for $PM_{2.5}$, and the least distinct increment for toluene.

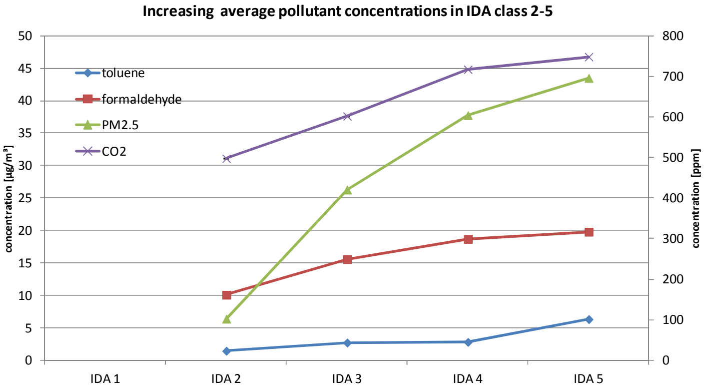


Figure 84 Increment of the average pollutant concentrations considering IDA 2 to IDA 5

In all IDA classes a similar indoor temperature, approximating 20°C was identified. Indoor relative humidity levels were found to be very low in IDA class 2 classrooms, with a minimal value of 15.5% and a 75th percentile of 20.7%. The relative humidity of the higher IDA classes cannot be considered different based on this dataset. Note that information on IDA1 is missing in this dataset.

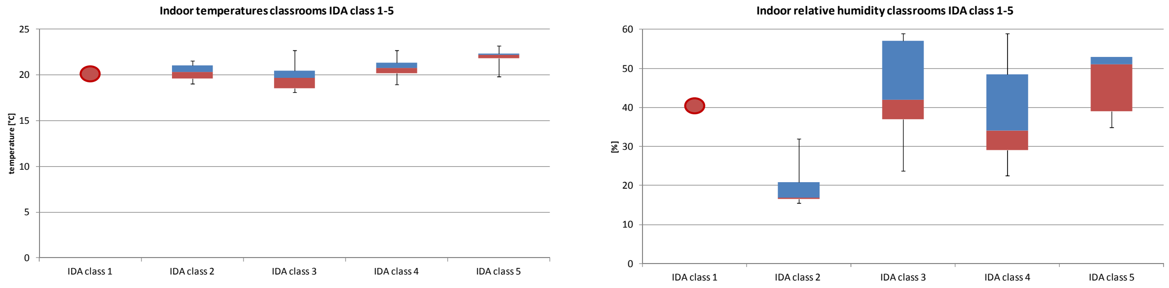


Figure 85 Indoor classroom temperature and relative humidity, categorized in IDA classes

Figure 86 illustrates the levels of total viable fungi and bacteria in classrooms grouped by IDA classes 1 to 5. A major issue in this comparison is the small number of data points in each IDA class, which is a particular issue for the biological measurements that were conducted in only 1, 4, 6, 1 and 3 classrooms in IDA classes 1-5, respectively. As mentioned earlier, single determinations of microbe from short-term air samples are highly susceptible towards fluctuations in airborne microbes and multiple samples are necessary to characterise the microbial characteristics of a building with confidence. In addition, the classroom of IDA class 1 will be excluded from the considerations here, as it was mentioned earlier in this chapter that inappropriate use or function of the ventilation system might have occurred in this classroom. Also Figure 47 indicated that the data point of IDA class 1 is in contradiction to the overall trend visible. The general trend – excluding IDA class 1 – is a reduction in levels of both total viable bacteria and fungi with increasing IDA class , i.e. lower air change rate. Since lower IDA class is among others linked to higher occupancy in the classrooms, this result is somewhat counterintuitive, in particular for bacteria. However, these results are in fact in line with the earlier findings of elevated levels of bacteria in fully mechanically ventilated classrooms (type D schools), indicating that higher air exchange may not necessarily mean a reduction of airborne microbes. It could be possible that a constant airflow keeps resuspended microbes in the air rather than supporting settling and deposition of bacteria and fungi. However, as mentioned at the beginning of this paragraph, in order to really investigate further into this issue, clearly higher number of samples and equal group sizes will be necessary. Indoor/outdoor ratios of airborne bacteria and fungi did not show any clear pattern, but seemed to somewhat decrease with increasing IDA class (data not shown).

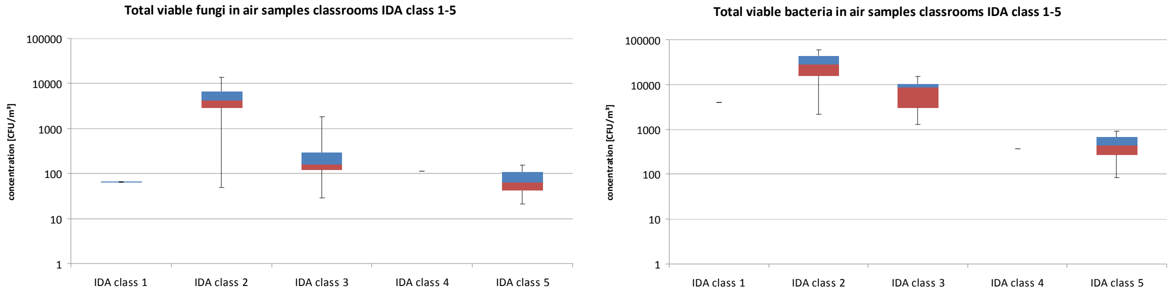


Figure 86 Total viable fungi and bacteria in indoor air of classrooms categorized by IDA classes 1-5.

→ Residences

As illustrated in the plots shown in Figure 87, the residences categorized in class 1, which implies the highest air change rates, are least airtight. When moving to the higher total air change rate classes, characterized by a successive lower total air change rate, the residential buildings become more airtight.

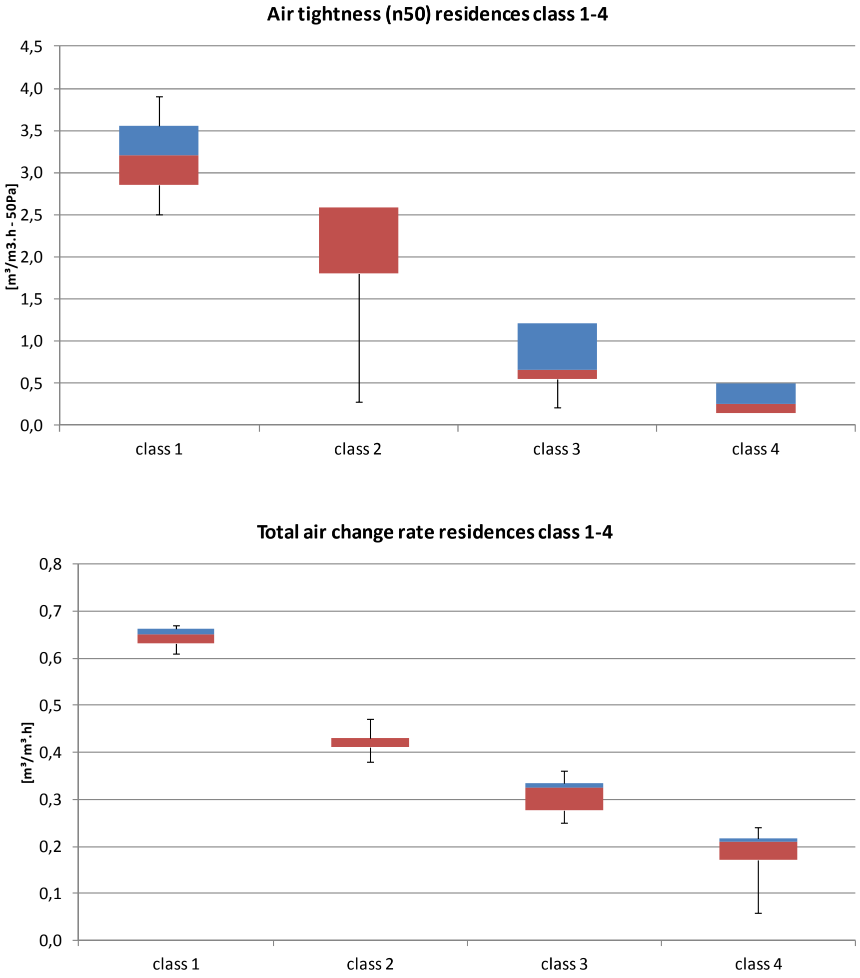


Figure 87 Plots showing the air tightness and the total air change rate of residences in the 4 classes of air change rate

The positive effect of an elevated total air change rate on the indoor CO_2 levels is only noticeable in total air change rate class 1 of the Clean Air Low Energy residences (see Figure 88). Class 1 is pictured in the Box and Whiskers plot by a lower median as well as 75th percentile concentration level than the other air tightness classes. No difference can be identified between the 24-hour average CO_2 levels in the other total air change classes.

A similar pattern is seen in the measured TVOC levels in the residences, pictured in Figure 89. The TVOC levels are indicated to be lowest in total air change class 1, with the highest air change rate. No clear difference can be identified between the TVOC levels in the other 3 total air change rate classes.

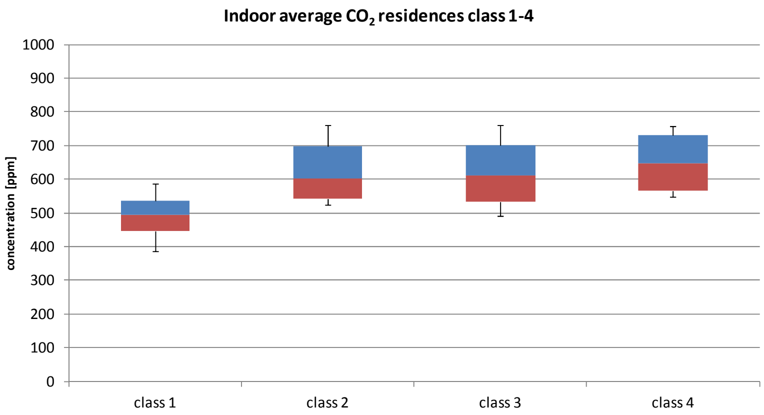


Figure 88 Indoor 24-hour average CO_2 levels in residences, categorized in air change rate classes

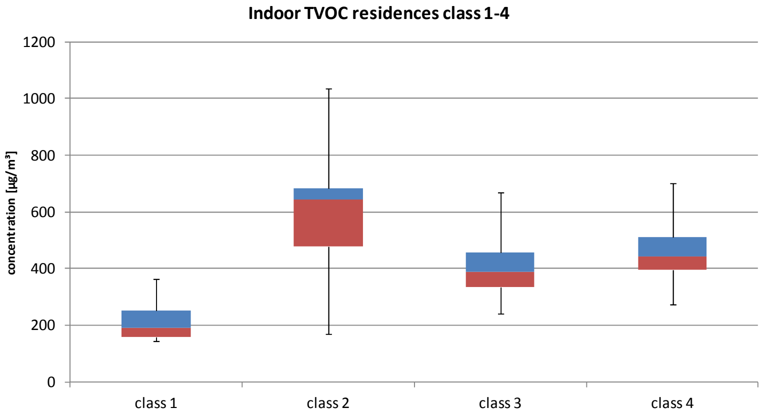


Figure 89 Indoor TVOC levels in residences, categorized in air change rate classes

The identified individual VOC compounds in residential indoor air behave similar to the TVOC levels. The lowest median, average and 75th percentile concentration levels were found in residences of class 1. The levels in the other total air change rate classes are slightly augmented compared to this class 1, but this dataset does not reveal any clear distinction between the VOC concentrations in classes 2 to 4. This indicates that only a very good total air change rate, exceeding 0.5 ACH may positively influence the indoor VOC levels and may lead to an improvement with the other total air change rates. A specifically focussed sampling campaign is however needed to conform this statement.

Although for aldehydes no clear trend between the total air change rate classes and the indoor levels could be identified, there is an indication that the two classes with the lowest air change rate have a moderately increased indoor formaldehyde concentration (Figure 91). According to this dataset, the indoor occurrence of $PM_{2.5}$ is also not susceptible to the total air change rate of a residence (Figure 92).

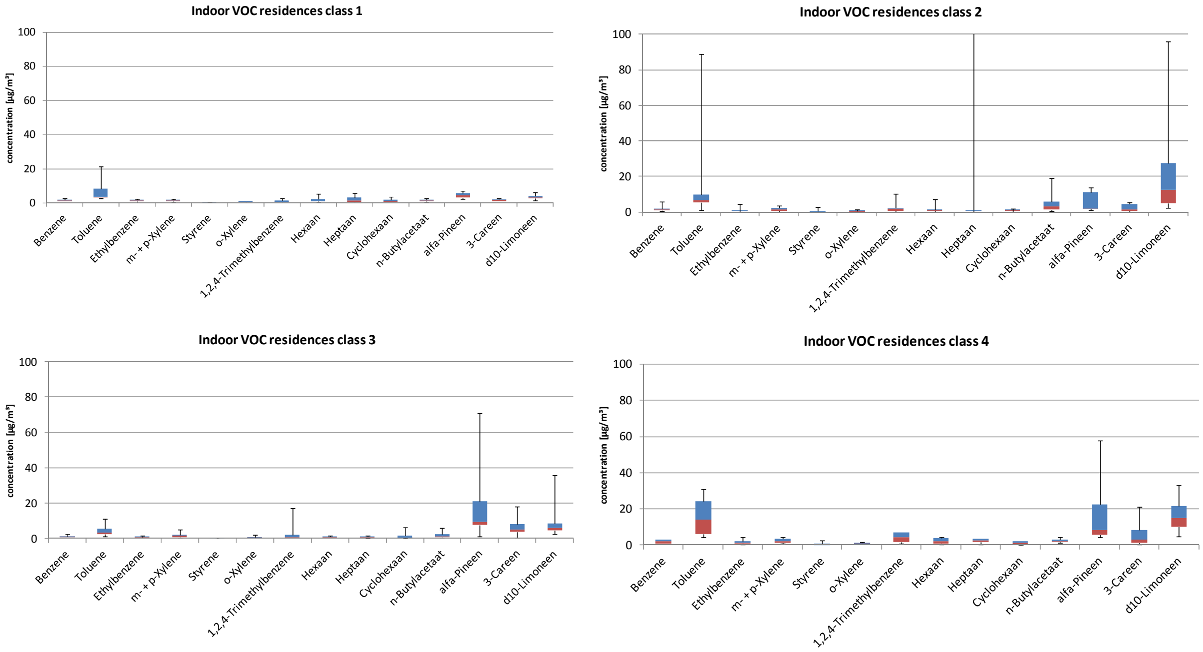


Figure 90 Indoor VOC levels in residences, categorized in air change rate classes

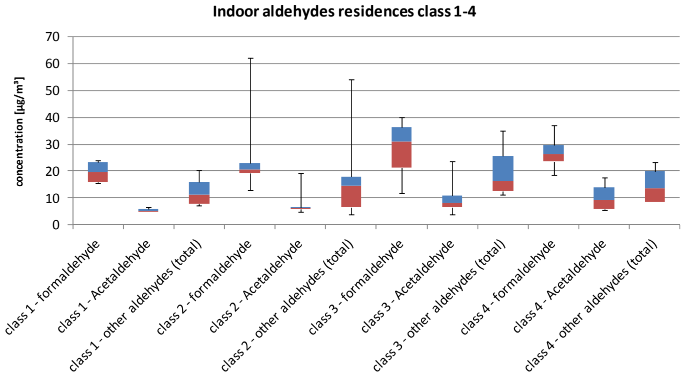


Figure 91 Indoor aldehyde levels in residences, categorized in air change rate classes

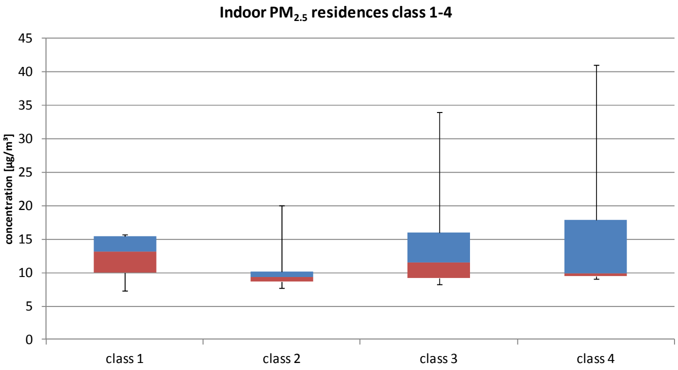


Figure 92 Indoor $PM_{2.5}$ levels in residences, categorized in air change rate classes

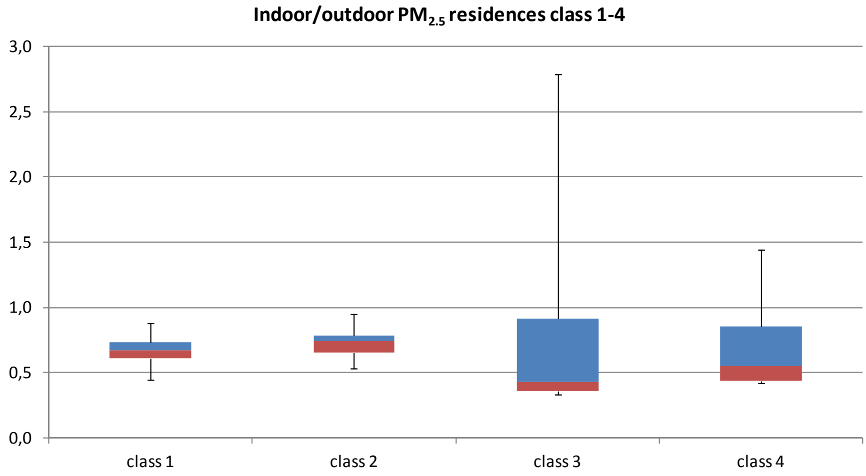


Figure 93 Indoor-outdoor ratio of $PM_{2.5}$ *in residences, categorized in air change classes*

According to this dataset, the total air change rates does not seem to influence the indoor temperatures or the relative humidity (see Figure 94).

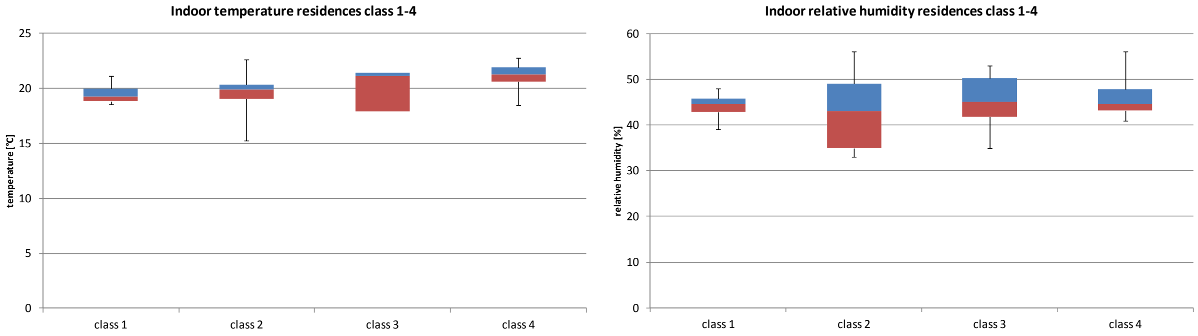
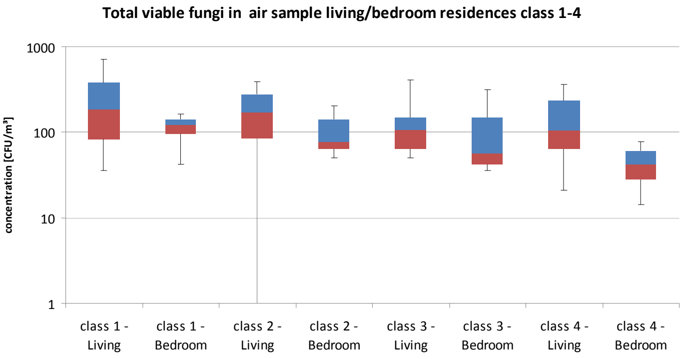


Figure 94 Indoor temperatures and relative humidity in residences, categorized in air change classes

For total viable fungi a slight, but more or less linear decrease of the concentrations in air of residences of classes 1 to 4 was visible, indicating lower levels at lower air exchange rates (Figure 95), somewhat in line with what has been seen for classrooms earlier. For fungi, slightly higher levels were always measureable in the living room compared to the bedroom within each class, most likely due to higher levels of activity/resuspension in the living quarters or the presence of indoor sources of fungi (potted plants, foodstuffs, etc). For total viable bacteria, no clear trend was visible, but lowest levels were also observed in class 4 living and bedrooms. An interpretation for this finding needs to be made carefully due to the very low sample numbers. As mentioned earlier, higher air exchange rates could mean a more constant airflow, keeping resuspended bacteria in the air and detectable through active air sampling. No clear trends were visible from the indoor/outdoor ratios of airborne bacteria and fungi (data not shown).



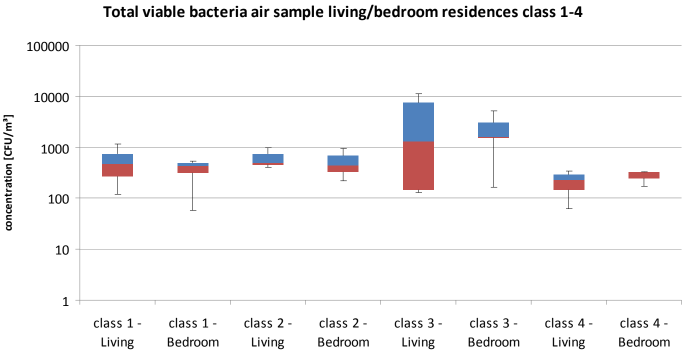


Figure 95 Total viable fungi and bacteria in air samples of houses categorized by Total air change rate classes 1 (highest) to 4 (lowest).

→ Conclusion total air change rate versus IAQ

In general, it can be concluded for the Clean Air Low Energy buildings, that the indoor occurrence of chemicals in relation to total air change rates, was different in classrooms and living rooms of residences.

On the one hand a lower IDA class (higher total air change rate per pupil) in classrooms implies lower $PM_{2.5}$, formaldehyde, CO_2 and to a lesser extent toluene concentrations – pollutants related to indoor sources. Viable fungi and bacteria however seemed to be more increased in the lower IDA classes.

On the other hand, a lower ACH class (higher total air change rate) in residences does not imply distinct differences between the occurrence of chemical components in the living rooms. There is only an indication of a minor improvement for TVOC, formaldehyde and CO_2 in the lowest ACH class, compared to the other classes. Viable fungi and bacteria however, seemed again increment in lower ACH classes.

3 aspects can be identified, that may cause the different behaviour of chemicals in schools and residences:

1. The group of Clean Air Low Energy classrooms is clearly more homogeneous than the group of residences.

   The variation between the different classroom indoor environments is lower than the variation between the various residential indoor environments. Residences are characterised by a much wider variety of different indoor sources (such as cooking, household products, furniture, etc...), whilst most schools have common indoor sources. A comparison of the 25th -75th percentile ranges for some relevant pollutants confirms this:

   - TVOC classrooms 239-314 µg/m³ versus houses 271-643 µg/m³
   - Formaldehyde classrooms 11-23 µg/m³ versus houses 20-36 µg/m³

   This more homogeneous profile of the Clean Air Low Energy classrooms may lead to more clear relations between the IDA class of a classroom and its corresponding IAQ.

2. The IDA class categorization, calculated as the total air change rate per student may reveal a more representative classification of the actual ventilation performance in a classroom than the self-defined classes (of total air change rates) for residences. In this latter system, the residences are categorized in 4 classes, not taking into account the amount of occupants (since this is variable from day-to-day and within one day).

3. For schools, the mechanical ventilation rate is monitored on a classroom level. IAQ assessment is performed in that same classroom. Whereas, for houses the strategy is different, in the sense that the total air change rate and the airtightness are monitored and calculated on building level. The IAQ of residences is determined in the living room.

2.1. NOISE NUISANCE FROM OUTDOOR ENVIRONMENT AND VENTILATION SYSTEM

→ Schools

See discussion under **Error! Reference source not found.** (schools)

→ Residences

Plotting the average A-weighted sound pressure levels (A-SPL) measured in a selection of the Clean Air Low Energy residences, against the data for the corresponding airtightness, a rather unexpected correlation between both appears (Figure 96). One very airtight system D residence (R22) shows a remarkably higher average A-SPL, due to a lack of doors (noise ventilation unit in hall way). For the other system D residences (red squares) we could, based on this very small scale data set, suspect an inversely proportional relationship between airtightness of the building and the noisiness of the ventilation system: the most airtight residences turn out to be also the most 'quiet' ones. For the system C residences, we only dispose of two test cases. The rooms in system C residences dispose of ventilation openings in their façade, compromising both airtightness and acoustic comfort. The expected correlation airtightness – noise levels is anyhow confirmed by this small dataset.

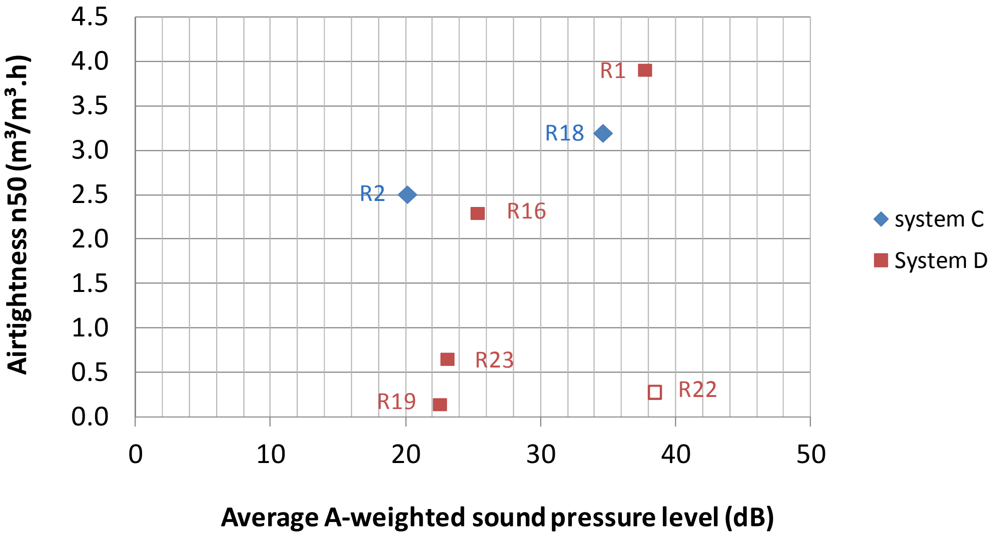


Figure 96 Noise levels against airtightness for a random selection of system C and system D clean Air Low Energy residences.

Still, in order to interpret correctly the noise level data, and possibly find an explanation for this supposed correlation, we have to take into account all the possible influence parameters.

System C residences

For the system C residences, a complete analyse has been discussed earlier in 2.1.3. Here the most influencing parameter to the indoor sound levels seemed to be the outdoor noise exposure (Figure 97). Project R2 is indeed situated in a very quiet environment, compared to project R18. The outdoor noise levels are in no way related with the airtightness of the building. However, a correlation between the indoor-outdoor noise reduction and the airtightness can be expected. Only two datasets are available to confirm this expected correlation (Figure 98). Indeed, the most airtight system C residence (R2) happens to be to acoustically most isolated one. Though, a larger data set would be necessary to confirm this as on overall tendency.

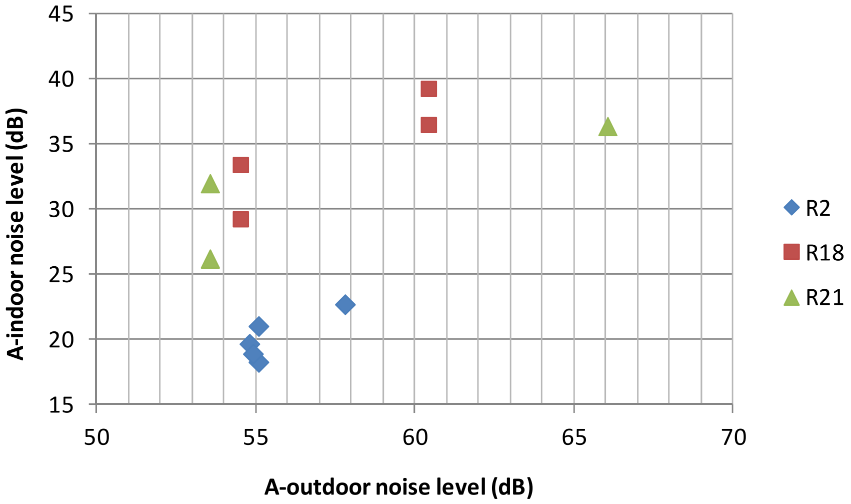


Figure 97 Outdoor noise levels against indoor noise levels for the examined living rooms and bedrooms in system C Clean Air Low Energy houses

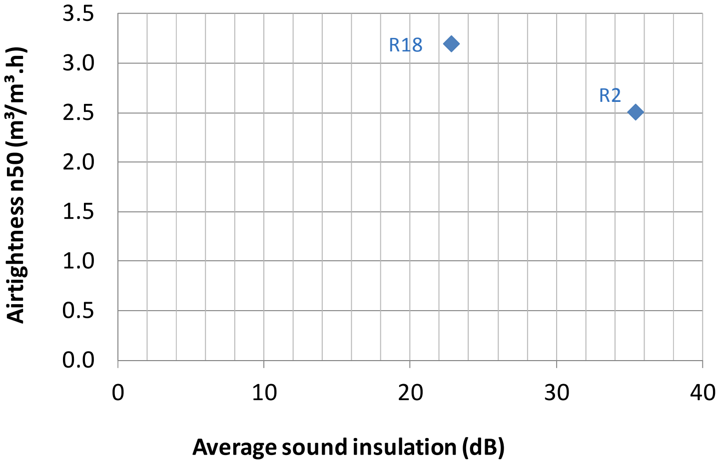


Figure 98 Average sound insulation against airtightness for two system C residences

System D residences

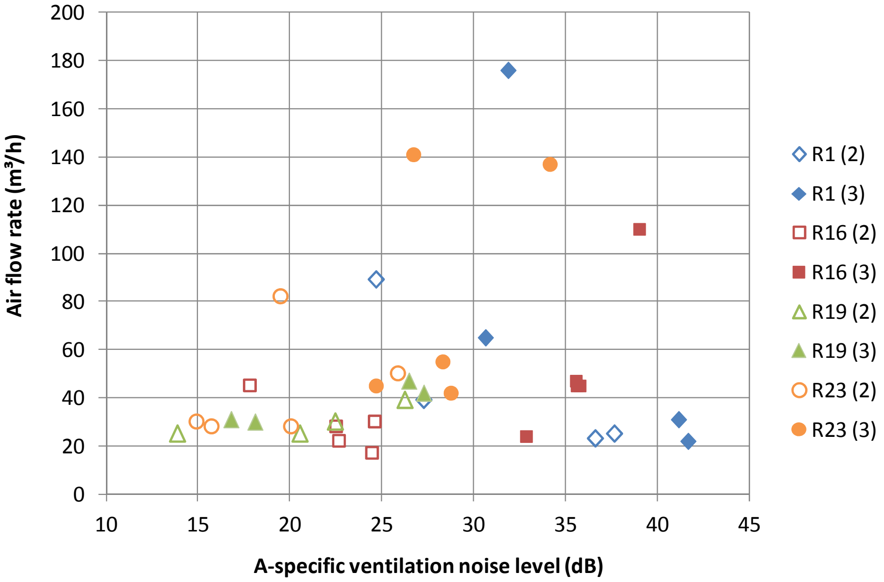


Figure 99 Air flow rate versus specific mechanical ventilation noise in system D Clean Air Low Energy residences (living rooms and bedrooms)

Figure 55 shows the A-weighted noise levels from the mechanical ventilation system in bedrooms and living rooms (working regimes 2 and 3) against the corresponding measured air flow rates. We expect the noise levels to increase with higher air flow rates, since higher air flow velocities are likely to produce more aerodynamic noise in the ducts. The air flow rate can be considered as a good indication of the air velocity when assuming more or less the same duct sections for the examined projects. Only exception is project R1 were rectangular PVC tubes were integrated in the timber frame walls. Here slightly higher air flow velocities are to be expected for equal air flow rates. However, the highest noise levels in this project were registered for rooms directly served from the attic by the ceiling (so no tubes in walls).

When considering the results for bedrooms separately from these for living rooms, a certain trend line could be imagined increasing with air flow rates and noise levels, for most of the projects and working regimes (Figure 100 and Figure 101). Some group of points seem to have a steeper trend line than others. Those who are situated at the left hand of the graph are the most interesting cases in terms of acoustic comfort guidelines, combining high air flow rates with faire noise levels, as long as they meet the design flow rates from the Belgian ventilation standard. As discussed earlier based on Figure 14 and Figure 16, in most cases working regime 3 seems to be necessary at the expense of the acoustic comfort. Only for project R19, where the lowest noise levels were registered, the air flow rates stay far below the design rates in regime 3 (bedrooms and living room). The most satisfying project in terms of both acoustic comfort and air flow rates seems to be R23.

However for some residences no real trend can be detected or some data points deviate largely from the presumed trend line formed by the other data (only for bedrooms). This observation points out that the measured noise levels are not only determined by air flow rates and sometimes other influence parameters become predominant. Isolated points (mostly to do with anomalies) or group of points (mostly to do with room or system parameters) that are situated in the lower right part of the graph, combining small air flow rates with high noise levels, have to be checked against for their cause of their extreme "noisiness". These cases could also be interesting in terms of guidelines.

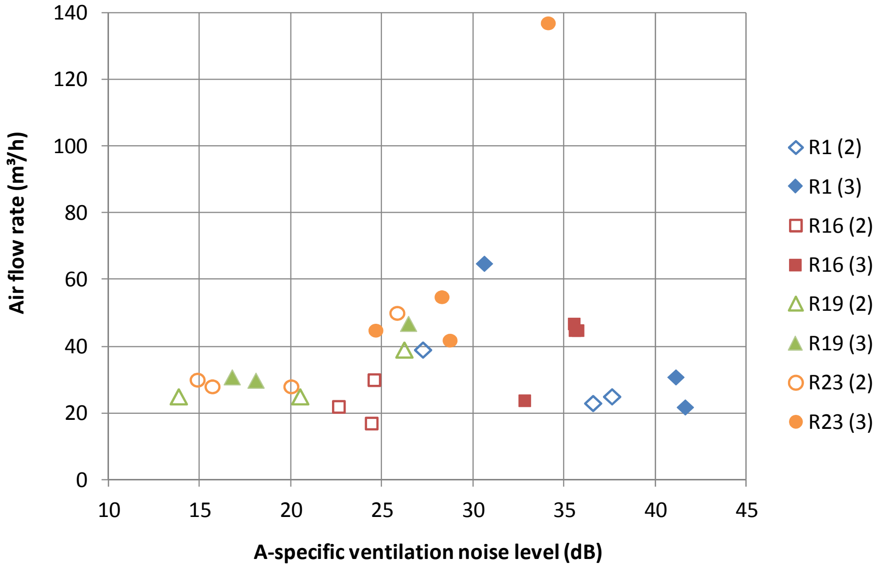


Figure 100 Air flow rate versus specific mechanical ventilation noise in system D Clean Air Low Energy residences (bedrooms)

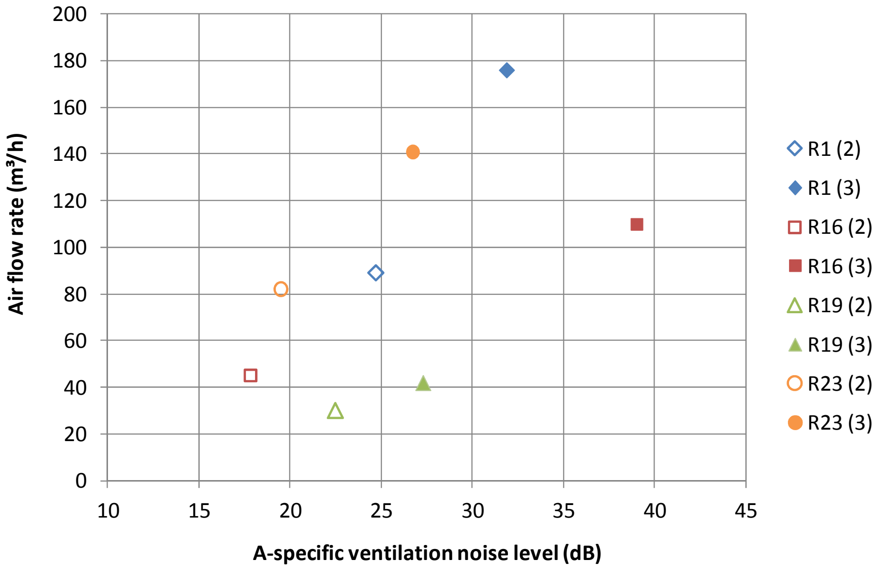


Figure 101 Air flow rate versus specific mechanical ventilation noise in system D Clean Air Low Energy residences (living rooms)

Following (system and room) influence parameters have to be taken into consideration:

- Ventilation group : noise production, mounting, location
- Mufflers : type, section, length, position

- Duct work : type, section, mounting, length, curves or other irregularities
- Air inlets : type, position
- Room volume

*For each examined room, relevant available installation characteristics are summarized in * see Figure 102*

Based on these data, a short discussion of the results for each project is given in order to map out the most important influence parameters with respect to the ventilation noise levels. We refer to the measured specific noise levels listed in *Table 4* (Figure 13 for bedrooms, Figure 15 for living rooms).

Table 19 Relevant installation characteristics for Clean Air Low Energy residences (system D)

1	2	3	4a	4b	5	6	7	8
room	group	mounting	position		mufflers	ducts	Inlets*	angle
			H	V				
R1-LI	*Vent-Axia* *Air Minder Plus* 40 dB(A) @ 3m	On timber frame floor, PE foam inserted (attic, +2)	0	2	Exhaust + supply ± 1 m Flexibles	Flexibles Sheet steel (O) PVC (rectangular)	Type 1	2
R1-B1			1	1				2
R1-B2			1	1				2
R1-B3			0	1				2
R16-LI	*Euroair* *325.5 BYR* 48 dB(A) @ 1 m	On interior wall (attic, +2)	3	2	Exhaust + supply	Sheet steel (O)	Type 1	2
R16-B1			0	1				2
R16-B2			1	1				2
R16-B3			2	1				3
R16-B4			3	1				3
R19-LI	*Drexel und Weiss* *Aerosilent* 35 dB(A) @ ?	On heavy floor, silent blocks on concrete support (storeroom, 0)	1	0	Exhaust + supply ± 1.20 m Semi-rigid	Sheet steel (O)	Type 1	1
R19-B1			0	1			Type 2	3
R19-B2			0	2				3
R19-B3			1	2				3
R22-LI	*Paul* *Thermos200/300 DC* 46 dB(A) @ 3 m	On party wall (hall way ,+2)	2	2	Exhaust + supply ± 1.20 m Semi-rigid	Sheet steel (O)	Type 1	4
R22-B1			1	1				3
R22-B2			1	0				3
R22-B3			1	0				3
R23-LI	*J.E. Stork Air* 46 dB(A) @ 1 m	On interior wall (storeroom, +1)	2	1	Exhaust + supply ± 2.50 m Flexibles	Sheet steel (O)	Type 1	2
R23-B1			1	0				3
R23-B2			2	0				3
R23-B3			3	0				2
R23-B4			4	0				3

** see Figure 102*

Columns 4a and 4b indicate the distance from the considered room to the ventilation unit, in term of “rooms to cross” in horizontal (4a) and vertical (4b) direction. This is at the one hand an indication of the probable attenuation of the ventilator noise by the distance, and at the other hand an indication of the probability of curve or other irregularities, raising the aerodynamic noise in the duct. Both probabilities need to be taken in to consideration by imagining the trace of the ductwork from the ventilator to the considered room.

Column 7 indicates the type of air inlet devices based on external appearance. Only two different types were found for the examined residences. They are illustrated in Figure 102.

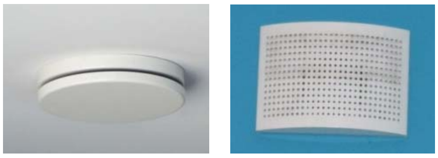


Figure 102 Two types of air inlets: type 1 (left) and type 2 (right)

As for column 8, in indication is given of the number of planes forming the angle in which the air inlet is located. The number of reflecting wall and/or ceiling planes (1, 2, 3 or 4) are in indication of the reflection and thus amplification one can expect for the sound radiated by the inlet. The influence of this parameter is probably small and hard to check within this study where too much parameters change at the same time.

No exactly comparable data are available for the sound production of the ventilation groups (column 2). At first sight the unit in R19 seems to be the quietest one. Low noise levels are registered here, but these are probably (also) due to the low air flow rates.

A brief analysis of the results per project is given in order to point out the most important influence parameters on the mechanical noise levels.

Residence R1

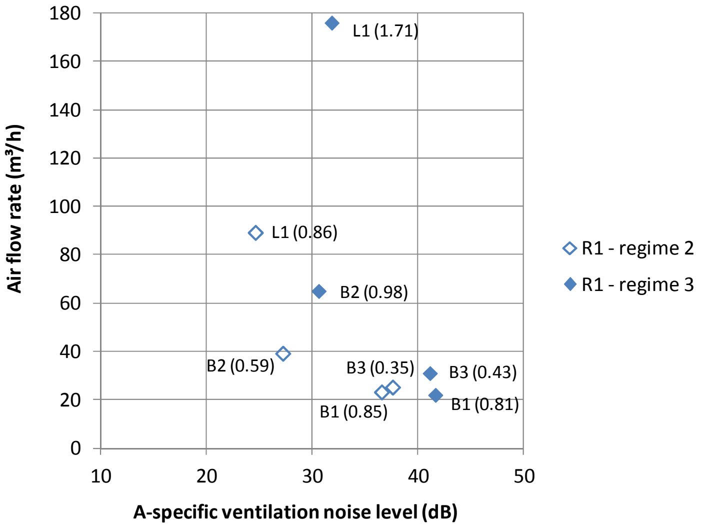


Figure 103 A-weighted specific ventilation noise levels against air flow rates for residence R1 for medium and high ventilation regime (between brackets : the ratio of the air flow rate to the design flow rate)

Where for L1 (regime 2) and B2 (regime 3) fair results were found in terms of air flow and noise levels, there is clearly something wrong for B3 and B1. Both rooms situated on the first floor together with room B2, combine low flow rates with high noise levels, with no substantial difference for regime 2 and 3. This could indicate a defect in the system. The low air flow rate for B1 is given his small volume within acceptable limits. The high noise level could (partly) be explained by the small volume of the room. Room B3 is the nearest room to the ventilation unit in the attic. This could also partly explain the high noise levels. When leaving out these two data points, the slope for L1 and B2 for switching from regime 2 to 3 is more or less the same. Here the air flow rate is clearly in influencing factor for the reached noise level. Room B2 seems to be noisier than L1 (more or less same noise levels for lower air flow rates). This can be explained by the localisation of the room, one storey beneath the attic where the ventilation unit is mounted on the timber frame floor. Given the short distance between the ventilator noise and room B2, the amount of ventilator noise is expected to be higher. An acoustically more performing muffler behind the unit, just before leaving the attic, could be helpful to reduce the noise level in B2 so that in regime 3 the acoustic comfort level of 27 dB could be respected. Another compromising parameter is the lightweight timber frame construction. Vibration and noise are induced and transported easily by the structure of the building. This could also contribute to the relatively high noise levels in the bedrooms, situated on the first floor below the ventilation unit.

So the distance to the ventilator unit and air flow rate seemed to be the most determining parameters for the registered noise levels in this project. When rooms nearby the ventilation unit are unavoidable, a well performing muffler directly after the unit, is strongly recommended.
The lightweight structure is also presumed to be a compromising factor in terms of installation noise nuisance. Decoupling of the unit (partly done here) to attenuate the structure borne noise and vibration transmission, together with shielding of the unit for the airborne noise transmission are recommended is lightweight structures. The influence of the altering duct sections and materials on the aerodynamic noise production is difficult to verify.

Residence R16

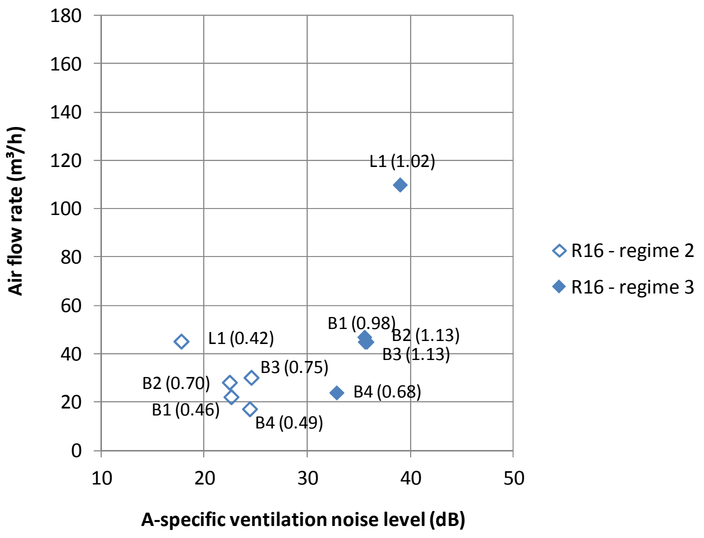


Figure 104 A-weighted specific ventilation noise levels against air flow rates for residence R16 for medium and high ventilation regime (between brackets : the ratio of the air flow rate to the design flow rate)

For this project all the rooms deliver the necessary air flow rates in regime 3, unfortunately in expense of high noise levels. A clear influence from the air flow rate on the noise levels can be pointed out based on the figures for regime 2 and 3. However, a remarkable increase in noise level is found for LI when switching form regime 2 to 3. This could indicate a turbulence increasing with the air flow. The living room is indeed the farthest located room from the ventilation unit in the attic. The amount of ventilator noise could be assumed less because of the long distance. When switching to a higher regime and so producing higher air velocities, more turbulence can be generated at the curves bending to the air inlet or and the inlet itself. A problem of communication by the ductwork between LI and B4 also appears here. The exact trace of the ducts should be known to analyse this problem. A muffler at the in the first part behind the inlets could solve the problem. The surprisingly lower noise level for B4 in regime 3 compared to B1, 2 and 3 apparently has to do with the lower air flow rate gain. The higher noise levels for B3 and B4 compared to B1 and B2 has to do with the influence of the background noise, as discussed before.

As the air velocity and thus the air flow rates rise, the amount of aerodynamic noise becomes predominant. So to realise the required air flow rates, one should limit the air velocities by choosing air ducts with sufficiently large sections. To limit the risks of turbulence at high air flow rates, the duct trace should be simplified as far as possible. When complicated turns are unavoidable, avoid placing air inlets right behind.

Residence R19

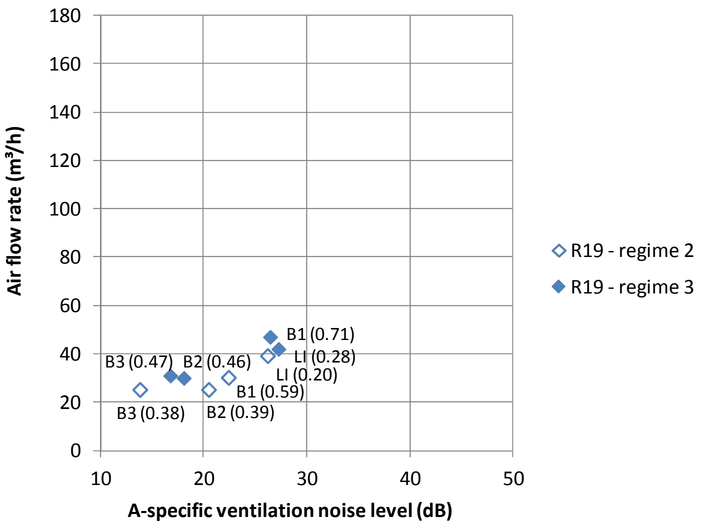


Figure 105 A-weighted specific ventilation noise levels against air flow rates for residence R19 for medium and high ventilation regime (between brackets : the ratio of the air flow rate to the design flow rate)

Remarkable low noise levels were registered for this project. Considering the corresponding remarkably low air flow rates, the low noise levels are less surprisingly. Since ventilation noise levels are very low for this project and the background noise strongly fluctuating, the influence of the background noise is unavoidable for regime 2, leading sometimes to illogical results. When switching from regime 2 to 3, no large increase is found for the air flow rate and the corresponding noise levels for bedrooms B2 and B3 on the second floor and the living room in the back of the ground floor. For some reason the air flow rates do not raise high enough here. For bedroom B1 situated on the first floor right above the store room with ventilation group, a larger air flow rate and corresponding noise level is reached in regime 3. In spite of the presence of the group, one can presume the amount of ventilator noise rather limited since a relatively low level was found compared to the nearest rooms in the other projects. The measurement made in the store room (39 dB at regime 2, 43 dB at regime 3) indeed could point out a very quiet ventilation unit. The decrease of the noise level for the bedrooms B2 and B3 at the second floor has to do with the lower air flow rates rather than the longer distance to the unit. Anyway, the noise levels are too low to perceive any effect of distance to ventilator unit. This is the only project where another type of air inlets was used. However, no substantial effect can be found on the noise levels based on these figures with low air flow rates.

When noise sensitive rooms are directly situated near the ventilation unit, a good sound insulation of the separating floor or wall and well performing mufflers may not be sufficient to realise adequate comfort levels. In that case a unit with especially low noise production may be recommended.

Residence R22

For this project no air flow data are available. However the highest nose levels were registered here (see Figure 13 and Figure 15). We note that interior doors were not yet installed during the acoustic measurements. The noise levels in B2 and B3 were greatly influenced by this lack of doors, since the ventilation unit was mounted on the hall way of the second floor. The lowest value was found in the living room on the ground floor, this is the room located the farthest from the unit. However this seemed to be to noisiest living room compared to the other project (Figure 15). It is hard to tell to what cause this could be due. The duct trace from the ventilation unit to the living room may be very complicated since the renovation character. The position of the air inlet in a corner consisting of 4 reflecting planes is also very unfavourable. The actual influence of the inlet position cannot be estimated based on these figures.

When ventilation unit are mounted in hall ways, an acoustically isolated chamber should be build around is. Care should also be taken to the sealing of the interior doors directly giving out onto the unit. Inlets should not be placed into complicated corners with a lot of reflecting panes. For mechanical ventilation systems installed in renovated houses, the necessary room should be provided for the ductwork in order to avoid complicated traces.

Residence 23

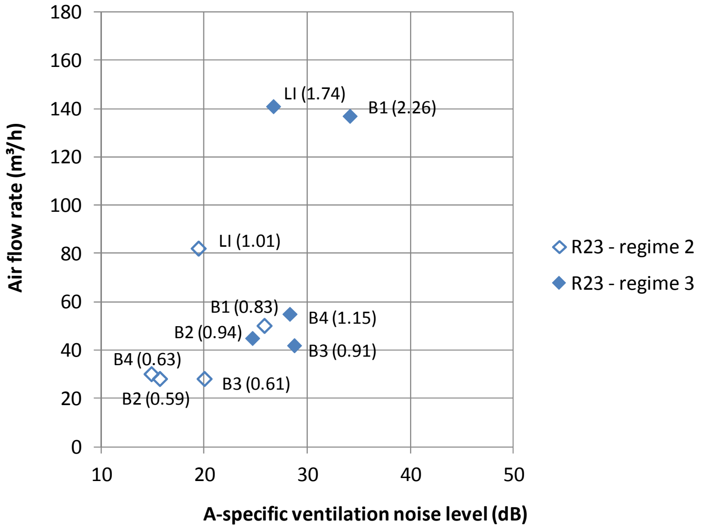


Figure 106 A-weighted specific ventilation noise levels against air flow rates for residence R23 for medium and high ventilation regime (between brackets : the ratio of the air flow rate to the design flow rate)

This seems to be most ‘exemplary’ project in terms of air flow rate and acoustic comfort. For B2, B3 and B4, all situated along the same hall way, comparable air flow rates are realised in regime 2. The differences in noise levels have to do with the influence form very low, fluctuating back ground noise. For higher noise levels, a clear correlation between air flow rates and noise levels can be seen. Taken into consideration the air flow rate for B3 in regime 3, a lower noise level could have been expected. Given the situation of the bedrooms, this could have to do with the presence of a curve in the ductwork just before the air inlet. For the living rooms a surprisingly low noise levels are registered given the corresponding air flow rates. This could have to do with the large volume and the favourable position of the air inlet, enabling the radiated ventilation noise to be diffused quickly in the room. As for bedroom B1, the noise level remains fair in regime 3 given the extremely high air flow rates and the proximity of the unit. One could say the muffler (very long flexible sound absorbing duct) is doing a good job.

The position of the air inlet has to be wisely chosen: not immediately after a split or curve, preferably in the middle of a wall or ceiling and as far away as possible from any corners. A longue, muffler is recommended in case of noise sensitive rooms near the unit.

2.2. OTHER POTENTIAL INFLUENCING PARAMETERS

2.2.1. HEAT RECOVERY SYSTEMS AND DUCT CHARACTERISTICS AND THEIR INFLUENCE ON INDOOR AIR QUALITY

Heat recovery systems which are part of ventilation system D are not expected to impact on the indoor concentration levels of chemical air pollutants, such as VOCs or PM. However, although not systematically proven, heat recovery systems are sporadically reported to be a potential source of biological indoor contamination.

Because of the small variation in heat recovery systems that is typically applied for school buildings, an evaluation of the impact of the different systems on the indoor air quality cannot be made based on this dataset.

However, since the broader variation in heat recovery systems that is typically applied in Flemish residential buildings is reflected in the Clean Air Low Energy residences dataset, this issue can be explored using the residential dataset. Apart from the mainstream counterflow or crossflow heat exchanger in the ventilation unit, some dwellings are equipped with an earth-to-air heat exchanger or a ground coupled heat exchanger with heat transfer fluid. Both systems are used to preheat the outdoor air during winter season, or precool the air in summer, thanks to the high thermal inertia of the soil. In the earth-to-air heat exchanger, air is circulated in large underground ducts, whereas the other type circulates a heat transfer fluid and uses a separate heat exchanger to influence the temperature of the intake air.

In the Clean Air Low Energy dwellings there is also a variation in the type of ventilation ducts. Most houses are equipped with galvanised steel ducts. Some have plastic ducts instead. These plastic ducts usually have a smaller diameter compared to their galvanised counterparts, so they can be integrated in the structure of the floor or ceiling. Because of the smaller diameter, different materials and potential presence of internal ridges in the plastic ducts, the type of ventilation ducts might have an impact on indoor air quality.

Another ‘option’ of ventilation system D is the presence of internal air recirculation. Flemish EPB regulations impose minimum air flows entering some rooms, and rules for air flows leaving the building in kitchens, bathrooms, etc. Both legally required flows are not necessary equal to each other. Often the air flow leaving the building has to be increased in order to balance both flows. Another option is to recirculate part of the airflow entering the sleeping rooms and passing this to the living room. The rationale behind this measure is that sleeping rooms and living rooms are hardly ever used at the same time. The impact of this measure on indoor air quality is explored based on the limited Clean Air Low Energy dataset.

Table 20 gives an overview of the different heat recovery systems, the presence of recirculation and the duct types occurring in the Clean Air Low Energy dataset, and the respective air concentrations of viable fungi and bacteria measured. It should be emphasized that these values only result from subgroups of the 21 residences that have a mechanical supply and exhaust ventilation system; the values and conclusions should be considered with caution.

There are no clear and consistent (in living and bedrooms of the same home) differences in fungal levels between the different possible variations of system D in the investigated dwellings. Average bacterial levels in living and bedrooms are elevated in the earth-to-air heat exchanger group compared to other heat recovery systems. From these very limited data it cannot be concluded whether these higher levels are due to fluctuations between measurements, presence of significant indoor sources of bacteria, contamination in ventilation ducts (due to low maintenance), or do in fact indicate a susceptibility of this type of heat exchange system towards bacterial contamination of indoor air.

Table 20 Indoor fungi, yeast and bacteria in indoor air versus heat recovery systems

		D with galvanised ducts without recirculation or earth coupled heat exchanger	D with galvanised ducts and recirculation of air	D with plastic ducts	D with galvanised ducts and earth-to-air heat exchanger	D with galvanised ducts and ground coupled heat exchanger, heat transfer fluid
living room	Total viable fungi [CFU/m³]	2,7E+02	2,0E+02	1,1E+01	2,1E+02	4,9E+01
	Viable bacteria [CFU/m³]	6,3E+02	2,3E+02	6,0E+02	6,3E+03	1,5E+02
bedroom	Total viable fungi [CFU/m³]	1,2E+02	4,2E+01	4,6E+01	1,5E+02	4,2E+01
	Viable bacteria [CFU/m³]	7,5E+02	1,1E+02	6,4E+02	2,9E+03	1,6E+02
total air change rate dwelling [ACH]		5,0E-01	4,3E-01	3,3E-01	2,6E-01	2,7E-01
		(7 residences)	(2 residences)	(2 residences)	(3 residences)	(1 residence)

2.2.2. PASSIVE RESIDENTIAL BUILDINGS VERSUS NON-PASSIVE RESIDENTIAL BUILDINGS

No difference could be identified when comparing the indoor air quality of passive building residences to the energy-efficient, non-passive buildings in the same dataset. Finding is in agreement with the exploration of the indoor air concentration in relation to the building airtightness of the residences, reported in section 2.2.2.

2.3. THE PERCEPTION OF THE INDOOR ENVIRONMENT

→ Schools

For every classroom it was reported that the indoor environment was not humid at all (in 11 cases) or rather not humid (in 13 cases). For 4 classrooms, a mouldy smell has been reported, but these rooms are different from the classroom for which a visible moisture damage was reported or the room for which visible fungi was reported.

For 5 rooms the teachers reported a 'rather dusty' indoor environment, however, no clear difference with the other classrooms could be identified. In one school, 2 rooms that were reported to be 'very dusty' and one room was reported to be 'rather dusty'; this school appeared to have the most elevated $PM_{2.5}$ levels of the Clean Air Low Energy schools dataset.

The indoor air quality was evaluated to be 'very good' in one classroom and 'rather good' in 15 rooms. However, it was evaluated to be also 'very bad' for one classroom, and 'rather bad' for 5 classrooms. This almost similar set of classrooms has reported that ventilation has a negative influence in the indoor air quality. No particular increase of indoor CO_2 was registered for these classrooms.

Ventilation was reported to have a negative impact on the indoor temperature in 8 classrooms. This could be related to the orientation of the airflows of supply air. During fieldwork it was registered that these airflows may be oriented towards the pupils in some cases, which might influence the answer to this question.

→ Houses

All respondents have reported to have no humidity problem in the residence, which is in agreement with the relative humidity measurements. Only one respondent has reported to live in a rather mouldy house, although no increment of any related parameter was registered.

The perception of the indoor environment was reported to be 'very good' in 10 residences, and 'rather good' in 13 cases. One respondent has reported to have a 'rather bad' indoor air quality, although none of the monitored chemical, physical or biological parameters has occurred in a concentration level that differs from the rest of the dataset. For the same residence, it was reported that ventilation makes the indoor environment too chilly (this residence was equipped with trickle vents). All other respondents reported that ventilation doesn't influence the indoor temperature or that they never paid attention.

Data interpretation: guidelines and limit values

2.4. OVERVIEW OF GUIDELINES FOR CHEMICAL AND BIOLOGICAL CONTAMINATION

Table 21 Overview of Flemish, European and worldwide guidelines and intervention values for indoor air quality

Compound	Flemish Indoor Environmental Decree Guidelines (reference)	Flemish Indoor Environmental Decree Intervention	WHO	EU Directive Ambient air	Anses	US EPA (toxicological limit value RfC)	Clean Air Low Energy schools - # Exceeding Flemish reference	Clean Air Low Energy residences - # Exceeding Flemish reference
	Flanders	Flanders			France			
MTBE						3000 µg/m^3		
Benzene	≤ 2 µg/m^3	10 µg/m^3	No threshold	5 µg/m^3	≤ 30 µg/m^3 (1-14 days) 10 µg/m^3 (long term)		3 / 27 (7%)	8/25 (32%)
Trichloroethene	≤ 200 µg/m^3		No threshold		≤ 20 µg/m^3 (long term)		0 / 27	0 / 26
Toluene	≤ 260 µg/m^3					400 µg/m^3	0 / 27	0 / 26
Tetrachloroethene	≤ 100 µg/m^3		0.25 mg/m^3 (annual av.)		≤ 1380 µg/m^3 (1-14 days) ≤ 250 µg/m^3 (long term)		0 / 27	0 / 26
Ethylbenzene						1000 µg/m^3		
Xylene isomers						100 µg/m^3		
Styrene								
1,2,4-Trimethylbenzene								
1,4-Dichlorobenzene								
tVOC	≤ 200 µg/m^3						26 / 27 (96%)	22 /25 (88%)
Hexaan								
Heptaan								
Cyclohexaan								
n-Butylacetaat								
alfa-Pineen								
3-Careen								
d10-Limoneen								
CO$_2$	≤ 900 mg/m^3 (492 ppm)						21 / 27 (78%)	22 / 25 (80%)
Formaldehyde	≤ 10 µg/m^3	100 µg/m^3 (30 min)	0.1 mg/m^3 also protect. long term		50 µg/m^3 (2h) 10 µg/m^3 (long term)		20 / 27 (74%)	25 / 25 (100%)
Acetaldehyde	≤ 4 600 µg/m^3					9 µg/m^3	0 / 27	0 / 25
Total other aldehydes	≤ 20 µg/m^3						24 / 27 (89%)	25 / 25 (100%)
PM$_{2.5}$	≤ 15 µg/m^3			10 µg/m^3 annual, 25 µg/m^3 24h	12	15 µg/m^3	22 / 27 (81%)	7 / 25 (28%)
PM$_{10}$	≤ 40 µg/m^3			20 µg/m^3 annual, 50 µg/m^3 24h				
Temperature	20°C ≤ T ≤ 24°C (winter)						11 / 27 (41%) <20°C	12 / 25 (48%) < 20°C
Relative humidity	30% ≤ RH ≤ 55% (winter)						6 / 27 (22%) <30% 5 / 27 (19%) >55%	2 / 25 (8%) > 55%
Draught	< 0.1 m/s						0 / 27	0 / 25
fungi								
yeast								
bacteria								
Micro-organisms	≤ 500 CFU/m^3							
Fungi	≤ 200 CFU/m^3						5/ 15 (33%)	6 / 15 (40%)

An overview of current indoor air quality guidelines and intervention values is listed in Table 21. Comparing the concentrations measured for each compound in every indoor location with the Flemish Indoor Environmental Decree, all schools and residences seem to behave differently, as a result of the different indoor sources present in both indoor micro-environments. The amount of schools/residences exceeding a guideline in the Flemish Environmental Decree, are listed in the two last columns of Table 21.

The following conclusion can be made:

- Formaldehyde and total other aldehyde concentrations in all residences exceeded the guideline value of 10 µg/m³ in the Flemish Environmental Decree; less exceedings were registered in schools,
- Even more schools exceeded the TVOC guideline value (96%) than residences did (88%). However, it should be emphasized that the increment is larger in residential indoor air, as a result of the wider variety of indoor VOC sources.
- In about 80% of both schools and houses the CO_2 guideline value has been exceeded; in spite of the lower average concentration levels compared to other studies (see CHAPTER 4).
- The considerably higher $PM_{2.5}$ levels in classrooms is reflected in the larger number of classrooms with concentration levels beyond the indoor air quality guideline of 15 µg/m³, compared to residences. This parameter is clearly influenced by room occupancy in classrooms.
- The relative humidity deviation from the guideline values is most pronounced in classrooms. Classrooms have less diversity in potential indoor sources of humidity which leads to an indoor relative humidity strongly determined by the ventilation system and the incoming air. The lowest levels were registered in the most airtight classrooms, i.e. the passive school classrooms: with an average relative humidity of 16 % ± 0.8% and a 75th percentile of 17% the lower limit value of the Flemish Indoor Environmental Decree was not reached.
- Only in few cases the benzene guideline value was exceeded. All monitored values were noticeably below the benzene intervention value.
- For draught, trichloroethene, tetrachloroethene and toluene none of the registered concentration levels in classrooms or residences exceeded the guideline values.

With respect to biological contaminants there are no valid European wide or worldwide guidelines currently available. Considerable climatic/geographic variation in fungal and bacterial levels makes the definition of a common threshold not feasible. Even country specific guidelines are scarce and are typically based on baseline data, rather than on health effects data. For fungi, existing quantitative standards and guidelines range from <100 to >1000 CFU/m³. For bacteria, hardly any guidelines are existing.

The Flemish Indoor Environmental Decree proposed a level of < 200CFU/m³ for fungi as acceptable, but does not differentiate between homes and schools. 33% of classrooms and 23% of living and bedrooms from 6 residential homes (40% of homes affected) exceed this value in Clean Air Low Energy.

The Flemish guideline value for fungi seems relatively low. In Finland, as a comparison, fungal levels exceeding 500 CFU/m³, and fungal indoor/outdoor ration >2 are used as thresholds to indicate a potential indoor fungal source, prompting further investigation. For bacteria, levels exceeding 4500 CFU/m³, are considered to indicate inadequate ventilation. Applying these thresholds to Clean Air Low Energy, 27% of classrooms (from 2 schools) and 47% of classrooms (from 3 schools) would exceed the fungal and bacterial levels, respectively. For 15 investigated homes, only 1 and 2 homes would exceed the fungal and bacterial threshold, respectively. However, it has to be noted that these values were elaborated and validated for a subarctic climate and measurements during winter months, and are thus unlikely to be applicable to the Flemish indoor environments.

2.5. OVERVIEW OF GUIDELINES FOR VENTILATION AND BUILDING ENVELOPE

→ **Schools:**

ventilation:

For classroom ventilation, the European standard EN 13779 is applicable. This standard, however, only specifies a number of performance levels, without setting a minimum requirement. In Flanders, the EPB directive, however, specifies that at least IDA 3, or 5.5 $m^3/h/m^2$, is required as a design flow rate. This flow rate was only achieved in 9 of the 26 classrooms.

Airtightness:

No requirements on airtightness are enforced. The Belgian residential ventilation standard, however, advises to limit leakage to 3 ACH @ 50 Pa for mechanical ventilation and 1 ACH @ 50 Pa for heat recovery ventilation.

→ **Residences:**

ventilation:

The Belgian residential ventilation standard NBN D 50-001 specifies the design flow rates for all the components for residences in Flanders. Since this is a descriptive standard, the total design flow rate will depend on the specific geometry of each individual dwelling, although for mechanical ventilation it is generally about 1 ACH, while for exhaust ventilation it is usually about 0.5 ACH. As was mentioned above, none of the dwellings achieved the design flow rates in each room, only 5 in 16 measured cases had a maximum flow rate equal to or higher than the total design flow rate.

Airtightness:

No requirements on airtightness are enforced. The Belgian residential ventilation standard, however, advises to limit leakage to 3 ACH @ 50 Pa for mechanical ventilation and 1 ACH @ 50 Pa for heat recovery ventilation. Although the sample of residences in this project had low leakage rates compared to the current building practise, this recommendation was only respected in 9 of the 23 cases.

2.6. OVERVIEW OF GUIDELINES FOR NOISE NUISANCE

For rooms, especially bedrooms, in residences with natural air supply (system C) significantly exposed to outdoor noise (60 dB(A) can be considered so), the acoustical performance of ‘weak’ façade elements such as windows, roller shutter boxes and trickle ventilators, have to be studied. Generally acoustically improved glazing together with improved trickle vents is necessary. The type of glazing and trickle ventilator can differ for different rooms within one project according to their outdoor noise exposure (eg. front façade with improved glazing and trickle vents).

For system D residences, special attention has to be paid to the acoustic comfort in bedrooms. In order to avoid noise nuisance in these noise sensitive rooms, the air velocities have to be limited as much as possible, preserving the respect of the legal nominal air flow rate requirements. The ductwork has to be kept as simple as possible: avoid unnecessary curves and other 'irregularities' causing turbulence. It is recommended to respect a certain distance between air inlets and unavoidable branching or bends. To avoid excessive noise from the ventilation group, "quiet" groups are to be chosen, especially when bedrooms or other noise sensitive rooms are located nearby. Sufficiently performing (thickness of sound absorbing lining and length) mufflers are to be applied right after the ventilation group.

For schools, the same types of guidelines are to be expected (but due to the small dataset not entirely confirmed) to guarantee the acoustic comfort in classrooms in system C and system D buildings. The thread of the acoustic comfort in modular unit classrooms is clearly pointed out and possibly needs further study. Special attention has to be paid to possible noise disturbance from noisy air extraction systems in adjoining hall ways.

2.7. CLEAN AIR LOW ENERGY IN RELATION TO OTHER STUDIES ON INDOOR AIR QUALITY

The characterized indoor environment in Clean Air Low energy schools is compared to school indoor environments, assessed in BiBa (BiBa, on the indoor air quality in Flemish primary schools, Flemish Government, Department of Environment, nature and energy, January 2010) and by OQAI (Observatoire de la qualité de l'air intérieur, 10 ans de recherche, France 2012) in Table 22.

The best agreement can be identified between the datasets of BiBa and OQAI, which is most obviously the consequence of a similar classroom indoor environment, that is aerated via window opening. The different occurrence of certain compounds in the Clean Air Low Energy school's dataset supports this hypothesis.

- As expected the major difference is identified for the CO_2 levels in Clean Air Low Energy schools; the teaching hour average concentration in mechanically ventilated classrooms is only 50% of the value quantified in BiBa, the maximum average CO_2 concentration is reduced by 63% in Clean Air Low Energy schools.
- Certain individual VOC components are found in somewhat lower concentration levels in Clean Air Low Energy schools (such as xylenes, and toluene), while other compounds are found in comparable ranges in both studies. The TVOC concentrations in both studies are of comparable magnitude.
- In this dataset, formaldehyde as well as total other aldehyde concentration levels are found to occur in lower concentration levels in Clean Air Low Energy schools.
- Even though the average absolute $PM_{2.5}$ concentration is fairly higher in Clean Air Low energy classrooms, the positive influence of the mechanical intake ventilation systems can be noticed in the indoor-outdoor ratios of both Clean Air Low Energy and BiBa, having respective values of 0.88 ± 0.65 and 1.25 ± 1.08.
- With respect to biological contaminants, only few systematic and comparable studies have been carried out. The authors are not aware of any systematic surveys being conducted in Belgium that Clean Air Low Energy could be compared to. As characteristics of biological contaminants vary considerable depending on climate, and are also strongly depending on the type of sampling, no studies on biological contaminants are added to the overview tables 17 and 18. A review of the studies of viable indoor air microbes in schools (Meklin

2002[15]) found mean fungal levels in classrooms from below 100 CFU/m^3 (studies in Denmark, Norway, Finland and Canada) up to more than 1000 CFU/m^3 (studies from California, Kansas, Orlando and Taiwan), clearly showing the dependency of indoor fungal levels on country and climate. Mean bacterial levels in classrooms ranged from hundreds to over thousand CFU/m^3 in these studies. With reference to these earlier studies, particularly the mean viable bacteria levels found for classrooms in Clean Air Low Energy seem high. The higher levels mostly derive from two out of the five schools monitored for biological agents, for which most of the classrooms exceeded the threshold of bacteria defined in the Finnish Indoor Air Quality guidelines (4500 CFU/m^3).

The indoor environment of clean air low energy residences is compared to the outcomes of the Surveillance of the indoor environment in complaint-free Flemish houses, 2008-2011, based on an assessment of the indoor air quality of 356 houses (Flemish Government, Agency for Care and Health, January 2012) in Table 23. The set of houses in this surveillance study is a reflection of the current building stock in Flanders. As a consequence, it contains residences of any building typology, unknown building airtightness, and the major fraction of the houses is aerated through window opening. Therefore, the largest differences between the two datasets are identified for the indoor CO_2 levels.

- Both the average CO_2 concentration, as well as the P75 level are reduced by 16% in Clean Air Low Energy, compared to the Surveillance dataset. The highest measured average concentration in Clean Air Low Energy is only 46% of the same value in the Surveillance dataset.
- VOCs and aldehydes occur in equal or somewhat lower concentrations in Clean Air Low Energy. Also TVOCs and total other aldehydes occur in similar concentration levels in the houses of both datasets (a lower average value in the dataset is most often not confirmed by a lower P75 value of the same dataset). Limonene however, occurs in considerably lower quantities in Clean Air Low Energy houses. However, since this is related to the amount of indoor limonene sources used indoors, this is may also be a the consequence of consumer product choices and uses indoors than resulting from a more energy-efficient building envelope or mechanical ventilation systems.
- Both temperature and relative humidity ranges are larger in the Surveillance residences. This could on the one hand be a consequence of the more controlled environment in Clean Air Low Energy. On the other hand, it may also be a reflection of the fact that Clean Air Low Energy was performed in wintertime, whilst the Surveillance of complaint-free houses ran during summer and wintertime.
- Numerous studies have reported fungal levels in indoor air of residential homes, far less have looked at bacterial levels systematically. From those studies it can be concluded that in particular fungal levels vary greatly in time and space, over several orders of magnitude, as also reported above for indoor air in schools. This fact again makes it difficult to relate the levels obtained in Clean Air Low Energy to other studies, as we are not aware of systematic surveys being conducted in Belgium earlier. Generally speaking it can be mentioned, that the mean fungal and bacterial levels are well in line with many other studies and do not seem elevated for most of the residences, which also finds confirmation in the fact that only three of fifteen homes monitored for biological contaminants would have be considered for further investigation based on the Finnish Indoor Air Quality guidelines.

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[15] Teija Meklin, Doctoral Thesis; Microbial exposure and health in schools – effects of moistrue damage and renovation. National Public Health institute, Kuopio, Finland. 2002

Table 22 Comparison of Clean Air Low Energy schools to existing IAQ assessment studies

Compound	Clean air Low Energy schools				BiBa		OQAI (France)			
	Average ± stdev	Min-max	P25	P75	Average ± stdev	Min-max	Average ± stdev	Min-max	P25	P75
MTBE [µg/m^3]	0,14 ± 0,10	0,10 - 0,41	0,10	0,10	0.36 ± 0.46	0.02 – 3.22				
Benzene [µg/m^3]	0,98 ± 0,57	0,10 - 2,02	0,60	1,28	1.41 ± 0.88	0.44 – 4.0	2.1 ± 2.2	DL – 8.5	DL	7.7
Trichloroethene [µg/m^3]	0,10 ± 0,00	0,10 - 0,10	0,10	0,10			2.3 ± 6.4	DL – 28.2	DL	20.8
Toluene [µg/m^3]	3,13 ± 2,68	0,94 - 10,90	1,38	4,15	3.49 ± 4.82	0.91 – 40.4	5.2 ± 5.1	1.7 – 24.4	2.1	17.1
Tetrachloroethene [µg/m^3]	0,10 ± 0,00	0,10 - 0,10	0,10	0,10	0.37 ± 0.44	0.10 – 2.16	1.1 ± 2.3	DL – 11.5	DL	5.4
Ethylbenzene [µg/m^3]	0,43 ± 0,34	0,10 - 1,67	0,24	0,49	1.74 ± 4.36	0.17 – 36.2	2.2 ± 1.3	1.2 – 6.0	1.3	2.6
m- + p-Xylene [µg/m^3]	1,12 ± 1,11	0,29 - 5,70	0,52	1,28	4.88 ± 6.79	0.61 - 166	4.4 ± 3.5	1.6 – 14.9	1.9	7.1
Styrene [µg/m^3]	0,11 ± 0,04	0,10 - 0,29	0,10	0,10			1.5 ± 0.7	0.9 – 4.0	1.1	3.3
o-Xylene [µg/m^3]	0,41 ± 0,44	0,10 - 2,10	0,15	0,59	1.08 ± 1.16	0.20 – 26.6	1.6 ± 2.1	DL – 8.9	DL	5.7
1,2,4-Trimethylbenzene [µg/m^3]	1,65 ± 4,41	0,21 - 23,0	0,33	0,87	5.3 ± 19.9	0.34 - 178				
1,4-Dichlorobenzene [µg/m^3]	0,15 ± 0,06	0,10 - 0,23	0,10	0,21			1.8 ± 3.9	DL – 9.9	DL	9.4
tVOC [µg/m^3]	318 ± 193	184 – 1175	239	314	238 ± 164	18 – 1126				
Hexane [µg/m^3]	0,84 ± 0,63	0,28 - 2,38	0,39	0,95						
Heptane [µg/m^3]	0,93 ± 1,33	0,10 - 5,50	0,25	0,68						
Cyclohexane [µg/m^3]	5,65 ± 14,03	0,24 - 72	0,47	4,70						
n-Butylacetate [µg/m^3]	2,15 ± 2,03	0,20 - 8,50	1,05	2,26						
alfa-Pinene [µg/m^3]	4,27 ± 7,06	0,10 -34,00	1,19	3,70						
3-Carene [µg/m^3]	1,79 ± 1,98	0,21 - 6,50	0,48	2,73						
d10-Limonene [µg/m^3]	6,06 ± 6,46	0,50 - 20,30	1,12	11,20						
CO$_2$ (24h) [ppm]	480 ± 96	308 - 716			933 ± 394	408 - 2683				
CO$_2$ (TH) [ppm]	658 ± 166	350 - 993			1305 ± 504	703 - 2708				
Formaldehyde [µg/m^3]	16,9 ± 6,8	5,0 - 28,8	11,2	23,4	26.0 ± 13	6.3 - 71	25.1 ± 14.8	6.8 – 66.2	15.7	30.7
Acetaldehyde [µg/m^3]	8,5 ± 1,7	6,3 - 12,5	7,3	9,6	5.40 ± 1,84	2.2 - 12,0	6.3 ± 2.1	2.7 – 10.7	4.3	8.1
Total other aldehydes [µg/m^3]	14,02 ± 6,02	3,90 - 24,0	9,25	18,15	33.0 ± 15.0	8.7 – 78.0				
PM$_{2.5}$ [µg/m^3]	30 ± 17	5 - 66	20	36	23.2 ± 13.9	4.1 – 59.5				
I/O PM$_{2.5}$	0.88 ± 0.65				1.25 ± 1.08					
Temperature [°C]	20,5 ± 1,5	18,1 - 23,2	19,4	21,8	19 ± 2	14 - 24				
Relative humidity [%]	39,2 ± 13,9	15,5 -59,0	32,5	52,5	43 ± 11	29 -87				
Draught [m/s]	0,04 ± 0,02	0,00 - 0,07	0,03	0,05						
Total viable fungi [CFU/m^3]	1669,7 ± 3591,0	21,2 - 13533,6	63,6	1088,3						
Total viable bacteria [CFU/m^3]	11403,5 ± 16676,4	84,8 - 58996,5	1106,0	12749,1						

Table 23 Comparison of Clean Air Low Energy residences to existing IAQ assessment studies

Compound	**Clean air Low Energy residences**				**Surveillance of the indoor environment of complaint-free houses 2008-2011 (356 houses)**			
	Average ± stdev	**Min-max**	**P25**	**P75**	**Average ± stdev**	**Min-max**	**P25**	**P75**
MTBE [µg/m^3]	0,5 ± 0,8	0,1 - 2,8	0,1	0,4	1.84 ± 7.1	0.1 - 93	0.1	0.65
Benzene [µg/m^3]	1,6 ± 1,1	0,7 - 5,8	0,9	2,1	1.54 ±2.09	0.1 – 24.3	0.56	1.6
Trichloroethene [µg/m^3]	0,2 ± 0,3	0,1 - 1,6	0,1	0,1	0.34 ± 1.19	0.1 – 12.0	0.1	0.1
Toluene [µg/m^3]	10,9 ± 17,8	1,2 - 89,0	3,1	9,8	35 ± 409	0.92 – 7704	3.1	11.3
Tetrachloroethene [µg/m^3]	0,1 ± 0,1	0,1 - 0,7	0,1	0,1	1.43 ±11.2	0.1 – 195	0.1	0.232
Ethylbenzene [µg/m^3]	1,1 ± 1,2	0,1 - 4,6	0,4	1,4	1.34 ±2.38	1.34 – 30.0	0.4	1.23
m- + p-Xylene [µg/m^3]	1,8 ± 1,3	0,3 - 5,0	0,8	2,4	3.8 ±7.4	0.212 – 78.0	0.97	3.3
Styrene [µg/m^3]	0,4 ± 0,8	0,1 - 2,9	0,1	0,2	0.26 ±1.53	0.1 – 28.0	0.1	0.1
o-Xylene [µg/m^3]	0,7 ± 0,5	0,1 - 2,1	0,3	0,8	1.3 ±2.09	0.1 – 14.5	0.35	1.21
1,2,4-Trimethylbenzene [µg/m^3]	2,8 ± 4,0	0,1 - 17,2	0,6	2,7	3.7 ± 9.5	3.7 – 138	0.64	3.1
1,4-Dichlorobenzene [µg/m^3]	0,2 ± 0,3	0,1 - 1,8	0,1	0,1	0.19 ±0.53	0.1 – 6.9	0.1	0.1
tVOC [µg/m^3]	455 ± 229	146 - 1036	271	643	443 ± 604	39 - 7517	242	458
Hexane [µg/m^3]	1,6 ± 1,8	0,2 - 7,4	0,6	1,4	2,01 ± 3,2*	0,10 - 31	0,64	1,75
Heptane [µg/m^3]	7,3 ± 30,2	0,1 - 152,0	0,4	1,7	2,76 ± 6,7*	0,10 - 54	0,53	2,18
Cyclohexane [µg/m^3]	1,2 ± 1,4	0,1 - 6,6	0,4	1,2	2,41 ± 5,7*	0,10 - 58	0,45	1,92
n-Butylacetate [µg/m^3]	3,1 ± 3,8	0,3 - 18,9	1,2	3,8	2,82 ± 3,9*	0,22 - 28,7	0,80	2,76
alfa-Pinene [µg/m^3]	11,8 ± 16,9	1,1 - 71,0	2,1	11,1	10,8 ± 23,9*	0,34 - 164	2,11	9,0
3-Carene [µg/m^3]	4,3 ± 5,2	0,3 - 21,2	0,9	5,1	3,3 ± 7,0*	0,10 - 60	0,71	3,1
d10-Limonene [µg/m^3]	15,3 ± 20,0	1,2 - 96,0	4,6	17,9	31 ± 61*	1,37 - 500	7,1	26,8
CO_2 (24h) [ppm]	606 ± 105	385 - 761	536	698	722 ± 185	416 – 1645	591	834
Formaldehyde [µg/m^3]	25,9 ± 11,0	12,1 - 62,0	19,2	33,0	26.6 ± 17.4	2.23- 180	16.3	31.0
Acetaldehyde [µg/m^3]	8,7 ± 5,2	4,1 - 23,7	5,7	8,5	8.7 ±17.7	0.74 – 264	4.1	8.7
Total other aldehydes [µg/m^3]	25,9 ± 11,0	3,9 - 54,0	8,6	20,2	14.2 ±9.7	3.6 – 252	8.5	17.6
$PM_{2.5}$ [µg/m^3]	13,5 ± 8,2	7,3 - 41,0	9,1	15,4				
Temperature [°C]	19,9 ± 1,8	5,8 - 22,8	19,0	21,1	21.1 ± 2.2	15.2 – 27.6	19.7	22.5
Relative humidity [%]	44,6 ± 6,4	33,0 - 56,0	41,0	49,0	51 ± 9.3	27.7 – 74	45	58

Compound	**Clean air Low Energy residences**				**Surveillance of the indoor environment of complaint-free houses 2008-2011 (356 houses)**			
Draught [m/s]	0,03 ± 0,01	0.01 – 0.05	0,02	0,04	0.08 ± 0.08	0.001 – 0.71	0.04	0.09
Total viable fungi [CFU/m³] – living room	1,96E+02 ± 1,99E+02	0,00E+00 - 7,21E+02	5,65E+01	3,14E+02				
Total viable bacteria [CFU/m³] – living room	1,96E+02 ± 1,99E+02	6,36E+01 - 1,13E+04	1,87E+02	1,06E+03				
Total viable fungi [CFU/m³] – bedroom	1,01E+02 ± 8,02E+01	1,41E+01 - 3,11E+02	4,24E+01	1,41E+02				
Total viable bacteria [CFU/m³] – bedroom	1,04E+03 ± 1,41E+03	5,65E+01 - 5,22E+03	2,76E+02	1,23E+03				

** Measured in 180 houses*

2.8. CLEAN AIR LOW ENERGY IN RELATION TO OTHER STUDIES ON VENTILATION AND AIR TIGHTNESS

→ **Schools:**

Ventilation:

Air flow rates per pupil in 11 randomly selected Danish schools in the ’80 ’s ranged from 1.8 to 15.4 l/s per pupil [7], with a mean of 6.4. In a US study, the average estimated air flow rate per pupil was 4.25 l/s (range 0.9 – 11.7, n = 104). With an average flow rate per pupil of 6.3 l/s (range 1.3 – 14.8), the flow rates found in the schools in this study are within the same range, although the flow rates measured in this study were measured at maximum selected fan power. As was mentioned in the results section, typical operating flow rates are lower.

Airtightness:

No good references for school leakage rates were found in literature.

→ **Residences:**

Ventilation:

A comprehensive literature review by Dimitroulopoulou [5] demonstrates that the required design flow rates in the Belgian standard are high compared to the average requirements in European standards for mechanical ventilation (1 vs 0.5 ACH). Nevertheless, in most of these standards, 0.5 ACH is also the minimal required air change rate, while in the Belgian standard, the design flow rate is usually not achieved in normal operating conditions. The average air flow rate measured in the dwellings in this project (0.24 ACH) is much lower than the range of measured air flow rates from other European countries reported in the same literature review (0.35-1 ACH).

A large survey in the Netherlands by BBA Binnenmilieu and preliminary results from the ongoing OPTIVENT project also found large discrepancies between the actual maximum flow rate and the required design flow rate.

Airtightness:

In a literature review [3] of European airtightness measurements in dwellings it is suggested that 4-6 ACH @ 50 Pa is a good estimate for the average achieved leakage level for dwellings across Europe. There are, however, large differences with tighter construction in the Nordic region and rather leaky constructions in southern Europe. The average leakage rate found for the dwellings in this study (2.4) is about 50% better than common practise.

2.9. CLEAN AIR LOW ENERGY IN RELATION TO OTHER STUDIES ON NOISE NUISANCE

→ Schools

The study Lichtveld Buis & Partners on the indoor environment in 60 primary schools ordered by VROM, OCW, SZW and VWS, reported by Versteeg H. (“Kwaliteit binnenmilieu in basisscholen”, 2008) already pointed out that nuisance from outdoor noise for schools with natural air supply leads to insufficient use of the ventilation devices. Disturbance of the acoustic comfort due to installation noise in schools with mechanical air supply was also found. Most nuisances were reported from mechanical air supply and exhaust. Since the very limited acoustical dataset for schools in the Clean Air Low Energy study, the noise nuisance of system C and D schools could not be compared reliably. However the few results indicate a possible problem of noise nuisance in system D schools.

→ Houses

The report “Gezondheid en ventilatie in woningen in Vathorst” where the relation between health complaints, indoor environment and building characteristics was studied in 99 dwellings (September 2007, GG Eemland), discussed in “Onderzoek Vathorst : maken ventilatiesystemen ziek?” (Harm G., 2008) indicates more noise nuisance due to mechanical ventilation in living rooms and bedrooms, though lower background noise levels compared to natural ventilation systems. The dataset in the Clean Air Low Energy study was too small to confirm this, but the results are not necessarily inconsistent with this conclusion. Anyhow, based on the acoustic comfort value in the Belgian standard, noise nuisance for both mechanical and natural ventilation systems were reported in the Clean Air Low Energy study.

The study “Woonkwaliteit Binnenmilieu in nieuwbouwwoningen” orderd by VROM-inspectie Regio Oost, also indicates noise nuisance due to mechanical ventilation since no direct requirements in the Bouwbesluit were provided.

CHAPTER 3 RESULTS AND CONCLUSIONS

The study Clean Air Low Energy has been organized to explore the indoor environment of energy-efficient, mechanically ventilated buildings in Flanders. It was focussed to residential buildings and classrooms.

As concluded from the literature review, reported in WP1, it is the first study in its kind to explore the interaction between chemical, physical and biological indoor/outdoor parameters and (1) building envelope characteristics, such as airtightness and total air change rate, (2) ventilation system characteristics, such as ventilation system type and heat recovery systems, and (3) noise nuisance, related to the ventilation system and the outdoor environment.

In order to study these inter-relations, the answer to the following questions has been explored in the Clean Air Low Energy dataset:

> *Does the ventilation system have an influence on the indoor air quality?*
> *Does building airtightness influence the indoor air quality?*
> *Does the total air change rate influence the indoor air quality?*
> *Does noise nuisance affect building ventilation and is there any indication of an indirect relation with indoor air quality?*

In general for **Clean Air Low Energy schools**, it can be concluded that the physico-chemical quality of the indoor air in energy-efficient, mechanically ventilated classrooms is improved or equal to the indoor air quality typically monitored in traditional classrooms (i.e. ventilated through window opening). Mainly for CO_2, $PM_{2.5}$ and the I/O ration of $PM_{2.5}$, considerably lower levels have been registered in the Clean Air Low Energy classrooms.

In this dataset, airtightness didn’t seem to influence the indoor air quality. Overall, no significant degradation of the indoor air quality with better building airtightness was observed. However, the type mechanical ventilation system, as well as the total air change rate, were indicated to be related to the physico-chemical as well as biological contaminants in the classrooms. Especially when the results for indoor air quality are compared to previous studies with lower air exchange rates, a clear improvement indoor air quality is observed.

According to this dataset, indoor CO_2 is not influenced by the mechanical ventilation system type. However, in the studied classrooms, mechanical ventilation systems with controlled supply and exhaust air, tend to reduce $PM_{2.5}$ in incoming air, which leads to reduced indoor levels, as well as to reduced $PM_{2.5}$ I/O ration compared to classrooms with trickle ventilators and mechanical exhaust. The higher total air change rate in ventilation system D classrooms of this dataset, is characterised by only moderately lower indoor TVOC, certain individual VOCs, formaldehyde, total other aldehyde levels as well as relative humidity inside these rooms.

A moderate increase of draught (air speed) in the studied classrooms with trickle ventilators and controlled air exhaust, compared to controlled supply and exhaust air. In the BiBa study (On the indoor air quality in traditionally built schools, 2010), 25 of the 90 studied classrooms were equipped with trickle ventilators (without controlled exhaust air); only 64% actually hereof actually used the trickle ventilation during the fieldwork. Although draught was not quantified in that study, it was mentioned by the teacher to be the main reason for closing the trickle ventilators.

The total air change rate of the classrooms, recalculated to IDA classes taking into account the total number of present pupils in the rooms, was fairly well associated with the indoor CO_2, $PM_{2.5}$, formaldehyde, and to a lesser extent toluene concentrations. In fact, a higher IDA class implied increased indoor levels of the latter listed compounds. It should be noted that compared to NBN EN 13779, for each IDA class considerably lower indoor CO_2 levels were measured than the recommended concentrations. This indicates that in this dataset a certain discrepancy was found between both methods to assign the IDA classes in schools, i.e. by calculating the 'total air change rate per pupil' and by 'the difference between indoor and outdoor CO_2 levels'.

The association between indoor air concentrations and IDA classes (thus air supply per person) is very much in line with the recently reported conclusions of the EU project HEALTHVENT (December 2012), which aim was to develop health-based ventilation guidelines for non-industrial buildings in Europe (offices, homes, schools, nursery, homes and day-care centres). Those guidelines aim at to clarify the role of ventilation on reconciling IAQ health based quality by protecting people staying indoors most of their life time against air pollution risk factors, and at the same time taking into account the need for having more efficient energy use for comfort in buildings. The outcomes of this study indicated that a provision of 7-8l/sec/pers is enough to avoid significant health problem when one doesn't know anything about building and pollutants. However, a minimal health based ventilation rate guideline of 4l/sec/pers would be advisable when all source control measures have been guaranteed: good outdoor air (WHO guidelines) and clean materials and no other sources indoors but the occupants themselves. See http://www.healthvent.byg.dtu.dk/. Since in non of the studied classrooms an action on source control has been taken up to now, the advisable ventilation rate according to HEALTHVENT would be 7-8l/sec/pers, which translated according to NBN EN 13779 equals IDA 3 or less.

In general for **Clean Air Low Energy residences**, it can be concluded that the physico-chemical quality of the indoor air in energy-efficient, mechanically ventilated houses was found to be moderately improved or equal to the indoor air quality monitored in traditional buildings (i.e. ventilated through window opening). The best improvement was found for indoor $CO_{2,}$ for other compounds less distinct improvements are found.

In residences, the majority of the measured physico-chemical compounds was found to be independent of the mechanical ventilation system or the building airtightness. Overall, no significant degradation of the indoor air quality with better building airtightness was observed. Only in houses that are characterised by the most elevated total air change rate (equal or larger than 0.5 ACH), remarkably lower indoor CO_2, VOCs, TVOC and to a lesser extend aldehydes were monitored in comparison to the other total air change rate levels. Overall, no significant differences in indoor air quality were observed between the 2 ventilation system types apart from differences in air change rate.

Clearly fewer and less apparent relationships between building total air change rate or ventilation system and the indoor environment were found in the Clean Air Low Energy houses, especially when compared to the classrooms. This finding was attributed to several reasons: (1) the group of Clean Air Low Energy classrooms is clearly more homogeneous than the group of residences as a result of the wider variety and higher abundance of indoor sources in residences; (2) the IDA class recalculation of the total air change rate per classroom to an air supply per child, present in that room, is indicated to be better associated to the indoor environment than the total air change rate of a whole house to the indoor air quality of its living room, not being recalculated to the amount of persons present throughout the sampling period. The bulk exposure to CO_2 for example will be located in the bedrooms. This relative independence of flow rate and pollutant concentrations that are mainly linked to indoor sources also suggests that these sources are in equilibrium conditions with the indoor environment.

Although good IAQ results are found while the installed maximum flow rates do not meet the design flow rate, these two results have no direct connection. The design flow rate is supposed to provide good IAQ in fully occupied design conditions and without air supply through leakage. This does not correspond to the occupancy and leakage levels in the measurement period.

Biological indoor air quality, the majority, but not all of the scientific literature points towards a positive, i.e. reducing impact of mechanical ventilation (with filtration of incoming air, compared to natural ventilation) and higher air exchanges on fungal and - to a lesser extent - bacterial levels in indoor air. The positive effect is generally believed to be due to removal of outdoor particles, including microbes, through filtration and due to removal of particles through exhaust air. However, no systematic comparisons have been made within energy efficient buildings, comparing as here for example mechanic exhaust to mechanic intake and exhaust systems. The findings in Clean Air Low Energy generally somewhat oppose these concepts, in particular with respect to bacteria in indoor air and in particular for schools. Higher bacterial levels were found in classrooms with ventilation type D compared to type C; a tendency towards lower bacterial and fungal levels in classrooms with lower air exchange rate was observed.

It is impossible to conclude from this study whether these findings actually indicate a real effect of certain building types under study on the microbial contaminants in the indoor air, or whether the results are not rather an effect of the very low sample size, susceptible towards the known variability in short-term active air samples, the presence of strong indoor sources of bacteria and fungi or maybe some cases of inadequate maintenance of the ventilation systems in the study schools. Also, since there is a lack of baseline level information on microbial contaminants in complaint-free houses and schools in Belgium, the data cannot be measured to levels in traditional, non-mechanically ventilated buildings. The health relevance of elevated bacterial levels in indoor air is unclear. However, the results of this study are certainly interesting and call for further research to clarify the indications obtained in Clean Air Low Energy.

CHAPTER 4 VALORISATION POSSIBILITIES AND POLICY RECOMMENDATIONS

4.1. CHEMICAL – PHYSICAL – BIOLOGICAL CHARACTERISATION

- In energy-efficient, mechanically ventilated (trickle ventilators with controlled exhaust as well as controlled supply and exhaust air) buildings, most chemical compounds occur at similar or somewhat lower concentration levels compared to traditional buildings. Mechanically ventilated buildings are clearly more effectively ventilated than traditional buildings. This finding indicates that sufficiently ventilated buildings, may be characterised by even more reduced indoor concentration levels if an efficient source reduction strategy would be implied. More guidance on the usage of low-emitting building materials and consumer products; labelling of products, or regulations on material emissions would be of considerable value to achieve this goal.

- There is a lack of baseline information of viable fungi and bacteria in Belgium, Flanders, in complaint-free, traditional houses and schools. Also the interrelation between chemical/physical/biological characteristics and their behaviour in traditional, in newly built and in renovated buildings should be studied more in detail.

- It is unclear in how far a constant airflow in mechanically ventilated classrooms may affect on keeping resuspended microbial material suspended in the air rather than supporting settling and deposition of bacteria and fungi on surfaces. In order to investigate more in depth into this issue, clearly higher number of samples and equal group sizes of mechanically ventilated and non-mechanically ventilated classrooms are necessary.

- In classrooms, IDA classes are a very appropriate indicator for chemical/physical contaminants in indoor air ($PM_{2.5}$, CO_2, toluene, formaldehyde). Indoor levels of these compounds tend to increase when moving to a higher IDA class. Viable bacteria seem to behave anti-correlated in this particular dataset. As listed in this paragraph, more research on the (co-)occurrence of the compounds in indoor air is needed (as specified earlier, the reported results may be influenced by specific characteristics of the studied classrooms).

- The buildings studied in Clean Air Low Energy are new built constructions. Since renovations are even more common today and in the future in our regions, and because renovations often imply a much more complex interplay between the existing and the renewed elements of the building, it is important to study this same set of parameters in renovated buildings and compare the indoor environment with this dataset. An interesting aspect of repeating a similar study like Clean Air Low Energy in renovated buildings, is the impact of individual initiatives of house owners, compared to renovations guided by an architect.

- It is difficult to consider the one passive school studied in Clean Air Low Energy as an indoor environment representative for all passive schools that are currently being built or will be built in Flanders. Because of the fact that the studied school was a closed rehabilitation institute, not all classrooms had a typical classroom setup in this case. For instance, the first classroom was a kitchen, the second had a shop inside. Specific products in these rooms may have biased the indoor environment, mainly its biological characterisation. However, since this conclusion should be reported as hypothetical, more research on the indoor environments of operational passive schools is needed.

- In future studies, it might be interesting to increase the level of detail of the measurements even more. Monitoring the actual amount of people present and the actual instantaneous ventilation, infiltration rates and air quality, might provide additional insights, especially concerning the effects of demand controlled ventilation systems. Associated costs and the intrusion of the privacy of the inhabitants might however hamper this research methods.

4.2. VENTILATION SYSTEM

- Sensibilisation and information on use and maintenance of the ventilation system, in schools as well as in residences, is needed (generally the ventilation system is used at a low set point; even shut-down effect in one classroom), since most of the users do not seem to be aware of the impact or functionality of their ventilation system. More specifically for schools, guidance on a good maintenance strategy, focussed on the different actors in a school (school principal, prevention advisors, teachers, school building cleaning personnel and external cleaning services) can be beneficial. The development of a code of good practice for ventilation systems in schools could in this case be a suitable action (cfr. Code of good practice for ventilation systems in residential buildings, WTCB).

- Recommendations on a correct dimensioning of a ventilation system, with the aim to prevent a day-to-day operation in the highest position (which implies potentially more noise nuisance) to achieve a sufficient ventilation rate as a function of the typical amount of occupants. Informing or sensibilisation of relevant actors in the dimensioning of a ventilation system, such as manufacturers of ventilation systems, installers and architects, may contribute to the prevention us under-dimensioned ventilation systems.

- Quality assurance for ventilation systems would imply an added value to the quality of the indoor environment: commissioning is necessary since this study, in accordance with others, demonstrates that the design flow rates specified in the standards are not met in a majority of cases. This can be traced back to simultaneous occurrence of inadequate or absent design and a lack of quality control during installation, allowed to exist by the fact that commissioning is virtually non-existent and the performance of the system is therefore never checked. It is recommended that a commissioning report is required.

- The relatively good indoor air quality that was found in spite of all shortcomings of the ventilation systems clearly demonstrates the necessity of either good understanding of the control of the ventilation system or automated control. This, however, does not imply that the design flow rates are too high. Further research is needed to assess if a reduction of the legally required flow rates is really acceptable. IF these requirements would be lowered, a thorough inspection of the actual flow rates of the ventilation system is essential, because there will be less margin.

- Supply and exhaust flow rates in the standard are not balanced, leading to a number of interpretation problems for heat recovery ventilation and generally lower total air change rates for exhaust ventilation. This could be addressed by specifying e.g. in guidelines that the total design flow rates for supply and exhaust should be equal. The supply or exhaust design flow rates in each specific project (which ever of both is the lowest) should be increased to achieve equal total design flow rates for supply and exhaust.

- There is a need for more attention towards the noise produced by the ventilation system itself (or noise entering through the vents from outside the buildings. Results indicate an actual risk of ventilation flow rates being lowered because of noise nuisance, especially in bedrooms with mechanical air supply (system D), which may in turn result in poor IAQ. Architects and installers have to be well informed about the interest of sound reducing measures such as duct silencers and ventilation units with low noise production, to ensure both acoustic comfort and indoor air quality.

- The study indicates a possibly major problem of noise nuisance in modular unit schools due to mechanical ventilation system. More case studies have to be examined to point out a possible need to reconsider the concept of mechanical ventilation in this type of school building.

- Architects have to be made aware of the noise nuisance that is likely to occur in bedrooms or living rooms in 'open plan' projects (with natural air supply, system C) from mechanical air extraction in adjoining bathrooms or kitchens. Additional noise reducing measures such as mufflers in the end ducts have to be considered.

- There is an indication that system D with an earth-to-air heat exchanger risks to have more elevated indoor bacterial levels. Other options such as earth coupled heat exchangers with heat transfer fluid, recirculation of air and the presence of plastic ducts did not indicate differences to the 'regular' system D. It should be stressed that the magnitude of this dataset can only lead to an indication of an aspect that may need more attention in future research.

- Conclusions on the successfulness of maintenance initiatives of ventilation systems cannot be formulated based on this dataset. This would have implied additional detailed questionnaires on the last maintenance and how and when this has been performed. In spite of the fact that this kind of study was not part of Clean Air, Low Energy it would be a valuable additional research programme.

- Since all studied constructions were built after 2006 and the majority of the buildings is only in use since 3 to 4 years, the long-term influence of aging ventilation systems and the maintenance initiatives organised by house owners or school building responsibles, is not included in this study. It will however be valuable to organize a follow-up study in these buildings after 5 to 10 years usage of the ventilation system, including the effectiveness of the ventilation system, and its influence on indoor microbial and chemical contamination.

4.3. BUILDING ENVELOPE

- The IAQ in energy-efficient, mechanically ventilated houses and schools was found to be moderately improved or equal to the indoor air quality monitored in traditional buildings.

There is no indication that the trend towards energy efficient buildings will cause detrimental effects on IAQ and human health.

- A very airtight building does not necessarily imply a poor IAQ.
- Increasing the airtightness of building enclosures (reducing cracks and small openings, sealing windows,...) can be a very cost effective energy reduction measure and should be stimulated, e.g. by transferring knowledge to designers and craftsmen. The data in this study indicate that e.g. in the studied modular units improvement is possible on the level of airtightness.
- A lower airtightness and a higher total air change rate of classrooms don't necessarily lead to a decrease in pollutants typically formed indoors, such as CO_2 and bacteria. Depending on location of openings and cracks, not all incoming air may be originating from outdoors (needs more study)
- In case of significant outdoor noise levels (L_A > 60 dB), the acoustic performance of trickle ventilators and other 'weak' façade elements such as windows and roller shutter boxes has to studied carefully in order to prevent users from closing the trickle vents because of noise nuisance. Especially for noise sensitive rooms (bedrooms, classrooms) acoustically improved trickle vents and acoustic glazing (e.g. asymmetric or laminated) seem to be necessary. Architects and their clients have to be sensitized about the need of a well-balanced sound insulation of acoustically weak façade elements according to the outdoor noise exposure to ensure the use of trickle vents to supply sufficient air flow rates.

4.4. HEAT EXCHANGE SYSTEMS

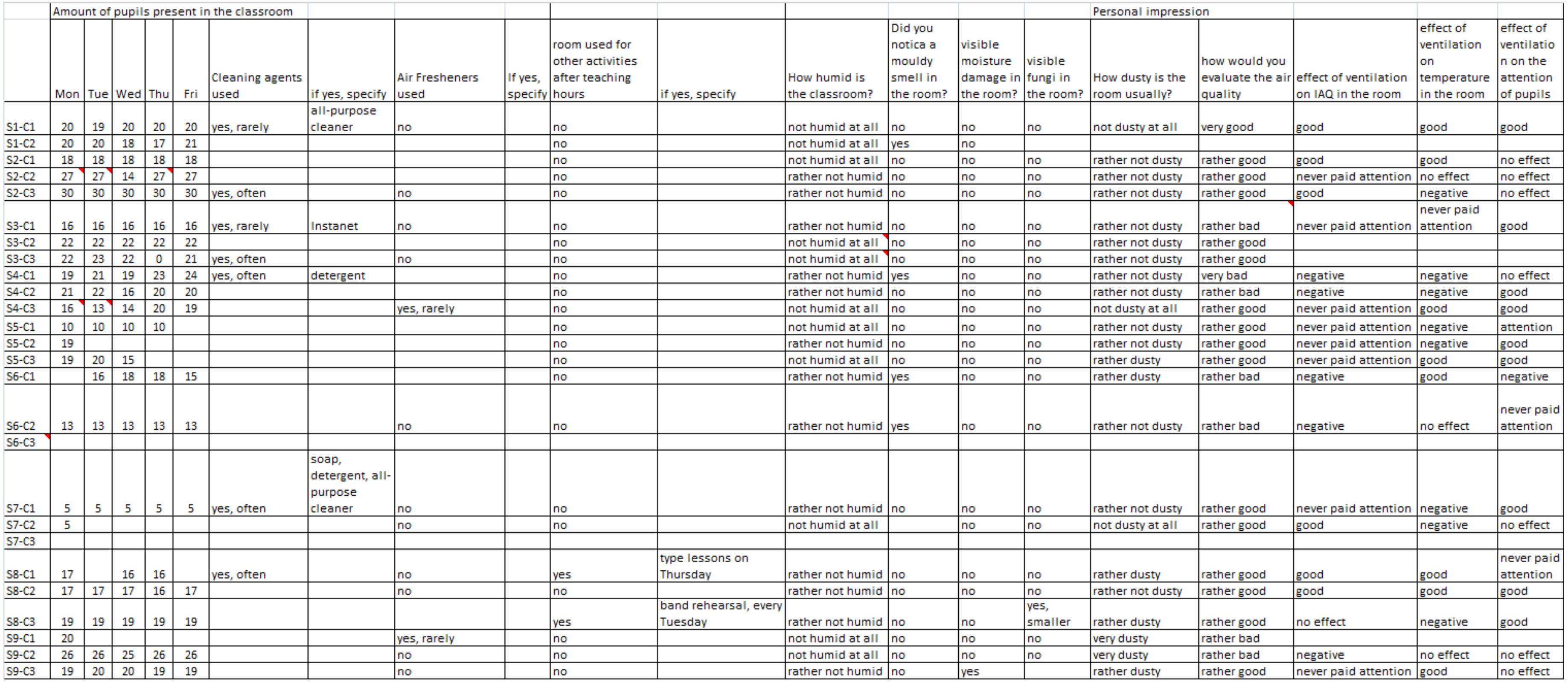
- The relation between the presence of an earth-to-air heat exchangers and indoor bacterial levels should be studied more in detail, in order to formulate a representative conclusion.
- According to Clean Air Low Energy there is no indication for negative influences of other heat exchange systems on the indoor environment

ANNEX 1: QUESTIONNAIRES SCHOOL BUILDINGS

1. The school building

						Ventilation							Dirt in intake Type C	Dirt in intake type D				type of materials occuring					
	construction year		building type	Specify the position of the classroom	distance to nearest street	Operation?	if demand controlled	date of last check-up	ventilation on during the night?	How often were windows opened?	type of heating used	air cooling system	are the ventilation grids visibly dirty	is the intake dirty	how often are the filters replaced	How often is the tubing system cleaned?	heat transfer system present	floor covering	Wall treatment	Type of ceiling	type of curtains	Often used products	furniture
S1-C1	2010	D	detached	ground floor	2,5m			sep/12		daily, briefly during play time	air heating	yes		yes				other	other	synthetic p	other	paint	synthetic
S1-C2		D		ground floor	2,5m	manually, but usually fixed position			yes, similar to day settings	very rare		yes	no	no				linoleum	other	synthetic plates		paint	massive
S2-C1	2011	C	detached	ground floor	>10m					often	radiators	no						tiles	painted	other	synthetic (s	paint	fibre plate
S2-C2	2011	C	detached	ground floor	>10m					often	radiators	no						tiles	painted	other	synthetic (s	paint	fibre plate
S2-C3	2011	C	detached	1st, 2nd, 3rd floor	>30m	automatically, with time programme			yes, similar to day settings	often	radiators	no		no	yearly			tiles	painted	synthetic p	synthetic (s	chalk	synthetic
S3-C1	2010	C		1st, 2nd, 3rd floor	2,5m					often	radiators	no						tiles	painted			paint	
S3-C2	2010	C		ground floor	>10m	automatically, demand controlled				daily, briefly during play time	radiators	no	no	no				tiles	painted	synthetic plates		paint	fibre plate
S3-C3	2010	C		ground floor	>10m	automatically, demand controlled				daily, briefly during play time	radiators	no	no	no				tiles	painted	calc plates painted		paint	fibre plate
S4-C1	2010	D	detached	ground floor	2,5m	automatically, with time programme	CO2 detection	nov/11	yes, lower position	very rare	convectors	yes		no	yearly	2-yearly	yes, full bypass possible	linoleum	other	calc plates painted		paint	fibre plate
S4-C2	2010	D	detached	ground floor	2,5m	automatically, with time programme	CO2 detection	nov/11	yes, lower position	not possible	convectors	yes		no	yearly	2-yearly	yes, full bypass possible	linoleum	other	calc plates painted		paint	fibre plate
S4-C3	2010	D	detached	ground floor	2,5m	automatically, with time programme	CO2 detection	nov/11	yes, lower position	not possible	convectors	yes		no	yearly	2-yearly	yes, full bypass possible	linoleum	other	calc plates painted		paint	fibre plate
S5-C1		D								very rare			no					linoleum					
S5-C2	2010	D		ground floor	>30m	automatically, demand controlled	CO2 detection		yes, similar to day settings	very rare	air heating	no	yes	yes	yearly	never (up to now)		linoleum	other	other		glues	others
S5-C3	2009	D	modular unit	ground floor	>30m	automatically, demand controlled				very rare		yes			yearly	never (up to now)		linoleum		synthetic p	other	chalk	
S6-C1		D		1st, 2nd, 3rd floor	5,-10m	automatically, demand controlled	CO2 detection			not possible	radiators							tiles	painted	calc plates	textile	glues	synthetic
S6-C2	2011	D	detached	ground floor	5,-10m	automatically, with time programme	CO2 detection		yes, lower position	not possible	radiators	no			never (up to now)	never (up to now)	no or missing	tiles	painted	synthetic p	textile	paint	synthetic
S6-C3		D																					
S7-C1		D		1st, 2nd, 3rd floor																			
S7-C2	2006	D	detached	1st, 2nd, 3rd floor	>30m	automatically, with time programme			yes, lower position	very rare	air heating	no		no	twice per year	never (up to now)		other	painted	other	synthetic (s	felt-tip pen	synthetic
S7-C3		D																					
S8-C1	2010	D	detached	ground floor	>30m	automatically, with time programme				very rare	floor or wall heating		yes					linoleum	painted	other		glues	synthetic
S8-C2	2010	D	modular unit	ground floor	>30m					very rare	floor or wall heating	no	no	yes				linoleum	other	other		glues	fibre plate
S8-C3	2010	D	detached	ground floor	>30m					very rare	floor or wall heating	no	yes	no									
S9-C1	2006	C	detached	ground floor	0-2m	manually, but usually fixed position				often	radiators	no	yes					linoleum	painted			glues	fibre plate
S9-C2	2006	C	detached	1st, 2nd, 3rd floor	0-2m	manually, but usually fixed position			yes, similar to day settings	often	radiators	no	yes					linoleum	painted			paint	fibre plate
S9-C3	2006	C	detached	1st, 2nd, 3rd floor		manually, but usually fixed position				daily, briefly during play time	radiators	no	yes					linoleum	painted		other	paint	fibre plate

2. During the measurements



	Amount of pupils present in the classroom															Personal impression					
	Mon	Tue	Wed	Thu	Fri	Cleaning agents used	if yes, specify	Air Fresheners used	If yes, specify	room used for other activities after teaching hours	if yes, specify	How humid is the classroom?	Did you notica a mouldy smell in the room?	visible moisture damage in the room?	visible fungi in the room?	How dusty is the room usually?	how would you evaluate the air quality	effect of ventilation on IAQ in the room	effect of ventilation on temperature in the room	effect of ventilation on the attention of pupils
S1-C1	20	19	20	20	20	yes, rarely	all-purpose cleaner	no		no		not humid at all	no	no	no	not dusty at all	very good	good	good	good
S1-C2	20	20	18	17	21					no		not humid at all	yes	no						
S2-C1	18	18	18	18	18					no		not humid at all	no	no	no	rather not dusty	rather good	good	good	no effect
S2-C2	27	27	14	27	27					no		rather not humid	no	no	no	rather not dusty	rather good	never paid attention	no effect	no effect
S2-C3	30	30	30	30	30	yes, often		no		no		rather not humid	no	no	no	rather not dusty	rather good	good	negative	no effect
S3-C1	16	16	16	16	16	yes, rarely	Instanet	no		no		rather not humid	no	no	no	rather not dusty	rather bad	never paid attention	never paid attention	good
S3-C2	22	22	22	22	22					no		not humid at all	no	no	no	rather not dusty	rather good			
S3-C3	22	23	22	0	21	yes, often		no		no		not humid at all	no	no	no	rather not dusty	rather good			
S4-C1	19	21	19	23	24	yes, often	detergent			no		rather not humid	yes	no	no	rather not dusty	very bad	negative	negative	no effect
S4-C2	21	22	16	20	20					no		rather not humid	no	no	no	rather not dusty	rather bad	negative	negative	good
S4-C3	16	13	14	20	19			yes, rarely		no		not humid at all	no	no	no	not dusty at all	rather good	never paid attention	good	good
S5-C1	10	10	10	10						no		not humid at all	no	no	no	rather not dusty	rather good	never paid attention	negative	attention
S5-C2	19									no		rather not humid	no	no	no	rather not dusty	rather good	never paid attention	negative	good
S5-C3	19	20	15							no		not humid at all	no	no	no	rather dusty	rather good	never paid attention	good	good
S6-C1		16	18	18	15					no		rather not humid	yes	no	no	rather dusty	rather bad	negative	good	negative
S6-C2	13	13	13	13	13			no		no		rather not humid	yes	no	no	rather not dusty	rather bad	negative	no effect	never paid attention
S6-C3																				
S7-C1	5	5	5	5	5	yes, often	soap, detergent, all-purpose cleaner	no		no		rather not humid	no	no	no	rather not dusty	rather good	never paid attention	negative	good
S7-C2	5							no		no		not humid at all		no	no	not dusty at all	rather good	good	negative	no effect
S7-C3																				
S8-C1	17		16	16		yes, often		no		yes	type lessons on Thursday	rather not humid	no	no	no	rather dusty	rather good	good	good	never paid attention
S8-C2	17	17	17	16	17			no		no		rather not humid	no	no	no	rather not dusty	rather good	good	good	good
S8-C3	19	19	19	19	19					yes	band rehearsal, every Tuesday	rather not humid	no	no	yes, smaller	rather dusty	rather good	no effect	negative	good
S9-C1	20							yes, rarely		no		not humid at all	no	no	no	very dusty	rather bad			
S9-C2	26	26	25	26	26			no		no		not humid at all	no	no	no	very dusty	rather bad	negative	no effect	no effect
S9-C3	19	20	20	19	19			no		no		rather not humid	no	yes		rather dusty	rather good	never paid attention	good	no effect

ANNEX 2: QUESTIONNAIRES RESIDENCES

1. The residential buildings

												EPB			Ventilation							Dirt in intake ! dirt in intake type D						type of materials occuring					
	building type		distance to nearest street	surface living room [m2]	hight living room [m2]	volume living room [m3]	surface bedroom [m2]	hight bedroom [m2]	volume bedroom [m3]	direct door house and garage?	engines in garage?	verliesoppervlakte (m²)	beschermd volume (m³)	gemiddelde U waarde (W/m²K)	Operation?	if demand controlled	date of last check-up	ventilation on during the night?	Windows	Cooker hood	air cooling system	are the ventilation grids visibly dirty	is the intake dirty	specify the filter type	how often are the filters replaced	How often is the tubing system cleaned?	heat transfer system present	floor covering	Wall treatment	Type of ceiling	type of curtains	weekly used products on the living room	furniture
R1	detached	D	5,-10m	57,42	2,5	143,55	21,76	2,4	52,224	no	no or not applicable	446,89	681,64	0,462	automatically, with time programme		aug/11	yes, lower position	double glazing	yes, with exhaust	no		no	stoffilter/dampkapfilter	more often than twice per year	never (up to now)	yes, full bypass possible	tiles	painted	chalc plate	textile	cleaning agents	fibre plate
R2	detached	C	5,-10m	29	2,6	75,4	29	2,6	75,4	yes	yes, a car	425,15	827,4	0,46	automatically, demand controlled	humidity sensor	sep/11	yes, similar to day settings	double glazing	yes, with exhaust	no	no						tiles	other	roof supports, plastere		cleaning agents	fibre plate
R3	detached	D	>10m	64	2,7	172,8	18	2,5	45	no	no or not applicable	729,73	1343,85	0,32	automatically, with time programme	motion controller	sep/11	yes, similar to day settings	double glazing	yes, with exhaust	no		yes		yearly	never (up to now)	yes, full bypass possible	other	painted	roof suppo	textile	cleaning agents	fibre plate
R4	semi-detached or terraced	D	5,-10m	26,7	2,75	73,425	17,12	2,6	44,512	yes	no or not applicable	540,4	970,33	0,32	automatically, with time programme			no	double glazing	yes, with carbon filter	no		no	G4	twice per year	never (up to now)	yes, full bypass possible	tiles	other	other		cleaning agents	fibre plate
R5	detached	D	5,-10m	52,5	2,43	127,575	17,4	2,39	41,586	no	no or not applicable	484,16	716,67	0,18	manually, but usually fixed position		okt/11	yes, similar to day settings	tripple glazing	yes, with carbon filter	no		yes	Ecopleat 6 van Camfil	twice per year	never (up to now)	yes, full bypass possible	tiles	painted	chalc plates painted		cleaning agents	fibre plate
R6	detached	D	5,-10m	42	2,58	108,36	14	2,54	35,56	no	no or not applicable				manually, frequent flow adjustments			yes, similar to day settings	double glazing	yes, with exhaust	no			ACS AP173X322X24-F7	never (up to now)	never (up to now)	yes, full bypass possible	tiles	painted	roof suppo	textile	cleaning agents	fibre plate
R7	detached	D	2,5m	150	2,65	397,5	12,95	2,65	34,3175	yes	yes, a car	303,13	450	0,117	manually, but usually fixed position		nov/11	yes, similar to day settings	tripple glazing	yes, with carbon filter	no		no	F7	yearly	never (up to now)	yes, full bypass possible	tiles	painted	wooden plates		cleaning agents	massive
R8	detached	D	5,-10m	48	2,5	120	35	2,5	87,5	yes	yes, a car	569,19	971,71	0,4	manually, but usually fixed position			yes, similar to day settings	double glazing	yes, with exhaust	no		no	G4	never (up to now)	never (up to now)	yes, full bypass possible	tiles	painted	roof suppo	other	cleaning agents	fibre plate
R9	detached	D		60	2,6	156	15	2,55	38,25	no	no or not applicable	538,34	858,6	0,32	manually, but usually fixed position			yes, similar to day settings	double glazing	yes, with exhaust	no		no		yearly	never (up to now)	yes, full bypass possible	other	other	roof supports, plastere		cleaning agents	others
R10	detached	D	5,-10m	43,5	2,5	108,75	18	2,4	43,2	no	no or not applicable	593,81	864,49	0,37	automatically, with time programme		aug/11	yes, lower position		yes, with exhaust	no			gaas van ca 1cm dikte	twice per year	yearly	yes, full bypass possible	tiles	painted	roof supports, plastere		cleaning agents	massive
R11-1	flat	D	0-2m	40	2,5	100	17	2,5	42,5	no	no or not applicable				manually, but usually fixed position			yes, lower position	double glazing	yes, with exhaust	no	yes	no		yearly	never (up to now)	no or missing	other	painted	roof supports, plastere		cleaning agents	fibre plate
R11-2	flat	D	>30m			0				no	yes, a car				automatically, with time programme			no	double glazing	yes, with exhaust	no	yes						other	painted	roof suppo	synthetic (s	other	massive
R11-3	flat	D	0-2m	86	2,8	240,8				no	no or not applicable							yes, similar to day settings	double glazing	yes, with exhaust	no	no						other	painted	roof suppo	textile	cleaning agents	massive
R12	detached	D	>10m	107,57	2,6	279,682	11,5		0	yes	yes, a car	627,66	802,09	0,268	automatically, demand controlled	motion controller	jan/09	yes, lower position	tripple glazing	yes, with carbon filter	yes		yes		twice per year	never (up to now)	yes, full bypass possible	tiles	painted	roof suppo	textile	cleaning agents	fibre plate
R13	detached	D	5,-10m	50	2,6	130	20	2,4	48	yes	no or not applicable	622	866	0,28	automatically, with time programme		sep/11		tripple glazing	yes, with carbon filter	no		no	F6	twice per year	never (up to now)	yes, full bypass possible	tiles	painted	chalc plate	synthetic (s	cleaning agents	fibre plate
R14	detached	D	5,-10m	14,4	2,75	39,6	17	2,43	41,31	no	no or not applicable	336	455	0,305	automatically, with time programme		jan/12		double glazing	yes, with carbon filter	no		no	cooker hood filter	more often than twice per year	never (up to now)	yes, full bypass possible	tiles	painted	other	textile	cleaning agents	fibre plate
R15	semi-detached or terraced	D	2,5m	32	2,7	86,4	18	2,5	45	no	no or not applicable				manually, but usually fixed position		feb/12	yes, similar to day settings	tripple glazing	yes, with carbon filter	no		no	EU7 G3 F7	twice per year	never (up to now)	no or missing	tiles	painted	chalc plates painted		cleaning agents	massive
R16	detached	D	2,5m	45	2,7	121,5	15		0	yes	no or not applicable				automatically, with time programme		aug/11	yes, lower position	double glazing	yes, with carbon filter	no		yes	G3	more often than twice per year	never (up to now)	yes, full bypass possible	other	painted	roof suppo	synthetic (s	cleaning agents	fibre plate
R17	semi-detached or terraced	D	2,5m	54	2,36	127,44	16,65	2,47	41,1255	no	yes, a car	470,91	964,55	0,49	automatically, with time programme			yes, lower position	double glazing	yes, with exhaust	no		no		twice per year	never (up to now)	yes, full bypass possible	tiles	painted	roof suppo	textile	cleaning agents	fibre plate
R18	semi-detached or terraced	C	2,5m	60	2,4	144	20	2,5	50	yes	yes, a car	390	513	0,406	manually, but usually fixed position	motion controller		yes, similar to day settings		yes, with exhaust	no	no						tiles	painted	roof suppo	synthetic (s	cleaning agents	fibre plate
R19	semi-detached or terraced	D	0-2m			0			0	no	no or not applicable								tripple glazing	yes, with carbon filter								other	painted	roof suppo	textile	cleaning agents	
R20	detached	D	5,-10m	40	2,6	104	17	2,5	42,5	yes	no or not applicable	526,07	485	0,15	manually, but usually fixed position			yes, similar to day settings	tripple glazing	yes, with carbon filter	no		no	cassettes	twice per year	never (up to now)	yes, full bypass possible	tiles	other	other	textile	other	massive
R21	semi-detached or terraced	C	2,5m	51	2,49	126,99	18	2,48	44,64	yes	no or not applicable				manually, but usually fixed position		dec/09	yes, similar to day settings	double glazing	yes, with exhaust	no	no						other	painted	roof suppo	textile	cleaning agents	fibre plate
R22	semi-detached or terraced	D	0-2m	28		0	14	2,9	40,6	no	no or not applicable	343,1	655,8	0,2	manually, but usually fixed position		nov/11	yes, similar to day settings	tripple glazing	yes, with carbon filter	no		yes	F7	more often than twice per year	never (up to now)	yes, full bypass possible	tiles	painted	other		cleaning agents	fibre plate
R23	detached	D	5,-10m	50	3	150			0	no	no or not applicable				automatically, with time programme		jan/11	yes, lower position	tripple glazing	yes, with exhaust	no		yes		twice per year	never (up to now)	no or missing	other	painted	roof supports, plastere		cleaning agents	massive

2. During the measurements

			Pets										Personal impression					
	house occupants	occupants present	pets in the house?	cat(s)	dog(s)	other (specify)	specify the living room	cooking activities during fieldwork?	How often were windows opened?	type of heating used	vacuum cleaning during the measurements?		is the house humid?	mouldy smell in your house?	how would you evaluate the air quality	effect of ventilation on IAQ in the house	effect of ventilation on temperature in the house	noise nuicance in the house
R1	1	1	no				living room with open kitche	yes, cooker hood on	very rare	floor or wall heating	no		not at all	no	rather good	good	never paid attention	only nuisance when operating at a higher positi
R2	3	3	no				living room with open kitche	yes, cooker hood on	not possible	wood-burning stove, or open fire pl	yes	Wednesday morning	not at all	no	rather good	good	no effect	only nuisance when operating at a higher positi
R3	5	5	no				living room with open kitche	yes, cooker hood on	not possible	floor or wall heating	yes	Thursday morning, 3/11/2011	not at all	no	very good	good	no effect	only nuisance when operating at a higher positi
R4	4	3	no				living room with open kitche	yes, cooker hood on	not possible	floor or wall heating	yes	daily	rather not h	no	rather good	good	no effect	only nuisance when operating at a higher positi
R5	5		no				living room with open kitche	yes, cooker hood on	very rare		yes	10+11+12/11/2011	not at all	no	rather good	good		only nuisance when operating at a higher positi
R6	2	1	yes			2 paroquet	living room with open kitche	yes, cooker hood on	very rare	floor or wall heating	yes	11/11/2011 - 10.30-11.00u	not at all	no	very good	good	never paid attention	only nuisance when operating at a higher positi
R7	2	2	yes		1		living room with open kitche	yes, cooker hood on	very rare		yes	storeroom daily, on Sunday th	not at all	no	very good	good		no nuisance
R8	4	4	no				living room with open kitche	no	very rare	floor or wall heating	yes	17+19+20+23/11/2011	not at all	no	rather good	never paid attention	no effect	no nuisance
R9	3	2	no				living room with open kitche	yes, cooker hood on	very rare	floor or wall heating	yes	Monday	rather not h	no	rather good	never paid attention	no effect	only nuisance when operating at a higher positi
R10	4	3	no				living room with open kitche	yes, cooker hood on	very rare	radiator, oil fuel or natural gas	yes	30/11/2011	not at all	no	rather good	good	no effect	no nuisance
R11-1	3	3	no				living room with open kitche	yes, cooker hood on	very rare	convectors, oil fuel or natural gas	yes	15/01/2012 - 14h10	rather not h	no	rather good	good	too chilly	
R11-2	2		no				living room with open kitche	yes, cooker hood on	daily, briefly	radiator, oil fuel or natural gas	yes		not at all	no	very good	good	never paid attention	no nuisance
R11-3	2	2	no				living room with open kitche	yes, cooker hood on	often	radiator, oil fuel or natural gas	yes	once	not at all	no	rather good	negative	no effect	no nuisance
R12	4	4	yes	4			living room with open kitche	yes, cooker hood on	very rare	floor or wall heating	yes	Friday morning, 20/12/2011	not at all	no	very good	never paid attention	never paid attention	no nuisance
R13	4	3	no				living room with open kitche	yes, cooker hood off	very rare	floor or wall heating	yes		not at all	no	very good	good	no effect	no nuisance
R14	4	4	yes	1			living room with open kitche	yes, cooker hood on	not possible	radiator, oil fuel or natural gas	yes		not at all	no	very good	good	no effect	no nuisance
R15	6	6	yes		1		living room with open kitche	no	very rare		yes	every 48h	not at all	no	very good	good	no effect	only nuisance when operating at a higher positi
R16	4	4	no				living room with open kitche	yes, cooker hood on	very rare	radiator, oil fuel or natural gas	yes	1+5/03/2012	not at all	no	very good	good	never paid attention	no nuisance
R17	5	5	no				living room with open kitche	yes, cooker hood on	very rare	floor or wall heating	yes	2/03/2012	not at all	no	very good	good	never paid attention	no nuisance
R18	4	4	no				living room with open kitche	yes, cooker hood on	very rare	radiator, oil fuel or natural gas	yes		rather not h	yes	rather good	good	no effect	no nuisance
R19	5		no				living room with open kitche	no	very rare		no			no				
R20	4	3	no				separate living room	yes, cooker hood on	very rare		no		not at all	no	rather good	good	no effect	no nuisance
R21	5	5	no				separate living room	yes, cooker hood on	daily, briefly	radiator, oil fuel or natural gas	yes	23/mrt	not at all	no	rather bad	never paid attention	too chilly	only nuisance when operating at a higher positi
R22	4	2	no				living room with open kitche	yes, cooker hood on	very rare	floor or wall heating	yes	5/apr	not at all	no	rather good	good		only nuisance when operating at a higher positi
R23	5	5	no				living room with open kitche	yes, cooker hood on	very rare	wood-burning stove, or open fire pl	yes	13/apr	not at all	no	rather good	good	no effect	no nuisance

3. Biological measurements

								other activities during the measurements						activities 3 hours before the measurements							
	petri dish position	mechanical ventilation system on?	windows open?	how many fieldworkers present?	how many occupants present	quantity of potplants in the living room	quantity of potplats in the bedroom	vacuum cleaning	present pets	quantity of present pets	moving of firewood	moving of garbage	presence of blue chees or other fungeous food	vacuum cleaning	present pets	quantity of present pets	moving of firewood	moving of garbage	presence of blue chees or other microbe-rich foodstuffs	visible fungi in the house	if yes, where
R1	living room/kitchen + bedroom	yes	no	1	1	1	0	living and bedroom												no	
R2	living room + bedroom	yes	no	1	3	2	0	living room			living room									no	
R3	kitchen + bedroom	yes	no	0	5	3	0	living and bedroom				living room								no	
R4	kitchen + bedroom	yes	no	0	4	3	0													no	
R5																					
R6																					
R7																					
R8	living room + bedroom	yes	no	1	4	1	0	living and bedroom			living room									no	
R9																					
R10																					
R11-1																					
R11-2																					
R11-3																					
R12																					
R13																					
R14																					
R15	living room/kitchen + bedroom	yes	no	2	6	4	0		living room	1				living room	living room	1		living room		no	
R16	living room + bedroom	yes	no	1	3	6	0													no	
R17	living room + bedroom	yes	no	1	5	1	1	living and bedroom												no	
R18	living room + bedroom	yes	no	1	3	2	0													no	
R19	living room + bedroom	yes	no	1	7	5	0							living room				living room		no	
R20	living room + bedroom	yes	no	2	3	11	0	living and bedroom												no	
R21																					
R22	living room + bedroom	yes	no	1	4	2	0	living and bedroom												no	
R23	living room	yes	no	1	3	6	0													yes, larger than A4 page	basement

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