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Afshari, Alireza; Bergsøe, Niels Christian; Iqbal, Ahsan

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STATENS BYGGEFORSKNINGSINSTITUT
AALBORG UNIVERSITET KØBENHAVN

REDUKTION AF OVERFØRSEL AF FORURENINGER MELLEM LEJLIGHEDER, FASE 2

UNDERSØGELSE AF METODER TIL TÆTNING OG REDUKTION AF OVERFØRSEL AF FORURENINGER FRA TOBAKSRØG MELLEM LEJLIGHEDER I ÆLDRE ETAGEBOLIGER

SBI 2017:05

Reduktion af overførsel af forureninger mellem lejligheder, Fase 2

Undersøgelse af metoder til tætning og reduktion af overførsel af forureninger fra tobaksrøg mellem lejligheder i ældre etageboliger

Alireza Afshari
Niels Christian Bergsøe
Ahsan Iqbal

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Indhold

Forord

I etageejendomme kan beboere blive udsat for luftforureninger, som stammer fra aktiviteter i de omkringliggende lejligheder. Aktiviteterne kan for eksempel være madlavning og tobaksrygning. I ældre etageboliger kan der være utætheder for eksempel ved rørgennemføringer og langs vægge, hvor gasser og partikler kan bliver overført fra en lejlighed til en anden.

Tobaksrøg er en særlig udfordring, da gasser, partikler og lugte fra tobaksrygning af mange anses som en særlig gene. I en rapport fra SBi (Gunner, et al. 2012) blev overførslen af ultrafine partikler og sporgas mellem to etageadskilte lejligheder målt før og efter tætning af etageadskillelsen. I den nederste af lejlighederne blev der anvendt tændte cigaretter til generering af partikler og sporgas til måling af luftoverførsel. Tætning af etageadskillelsen, som blev udført i den øverste lejlighed, omfattede en membran af polyethylen, tagklæber og fugemasse.

Før tætning af gulvet blev ca. 4 % af de ultrafine partikler og ca. 14 % af den anvendte sporgas overført. Efter tætningen blev overførslen af ultrafine partikler og gasser reduceret med en faktor 3 til henholdsvis ca. 1,6 % og ca. 5 %. Forsøget blev udført i en etageejendom fra slutningen af 1800-tallet.

I Sverige er der udviklet en membran, som kan adsorbere gasser og partikler, og i Danmark er der udviklet en membran, som er omtrent uigennemtrængelig for gasser og partikler. Der er behov for at undersøge de to membraner og udførelsesmetoder under både laboratorieforhold og i praksis i etageboliger.

Projektet blev gennemført i to faser. I fase 1 er to membraner, ”cTrap” fra Lunds Universitets InnovationsSystem (LUIS), Sverige og ”Ico-Vario” fra Icopal, Danmark, afprøvet og analyseret under kontrollerede forhold i laboratoriet med henblik på bestemmelse af membranernes evne til at reducere indeluftens indhold af gasser og ultrafine partikler.

På grundlag af undersøgelsen i fase 1 konkluderes at:

- membraner er i stand til at reducere overførslen af ultrafine partikler fra cigaretrøg og stearinlys
- membraner er i stand til at reducere overførslen af kemiske stoffer (VOC)
- cTrap har en lav vanddamp-diffusionsmodstand fra to sider, mens IcoVario har en lav vanddampdiffusionsmodstand fra én side. Der er behov for at afprøve, måle og evaluere membranerne i eksisterende etageboliger
- der er også behov for at analysere langtidsydeevnen af membranerne i eksisterende etageboliger

Denne afrapportering vedrører fase 2, som har til formål i praksis at afprøve, måle og evaluere metoder til tætning og reduktion af overførsel af forureninger fra tobaksrøg mellem lejligheder i ældre etageboliger. Metoderne omfattede anvendelse af de to membraner - eventuelt i kombination med tætning ved hjælp af fugemasse og tape.

Projektets formål i fase 2 var at afprøve, måle og evaluere i praksis metoder til tætning og reduktion af overførsel af forureninger fra tobaksrøg mellem lejligheder i ældre etageboliger. Metoderne omfattede anvendelse af de to membraner - eventuelt i kombination med tætning ved hjælp af fugemasse og tape.

Statens Byggeforskningsinstitut, Aalborg Universitet
Forskningsafdelingen for Energieffektivitet, Indeklima og bæredygtighed
April 2017

Søren Aggerholm
Forskningschef

Materiale

Den ene af to membraner er cTrap, som er udviklet ved Lunds universitets innovationssystem (LUIS, Lund, Sverige), se figur 1. cTrap består af fire lag: Et indre og et ydre beskyttende lag, et adsorberende lag og en semipermeabel barriere. cTrap har en indvendig side (ru side) og en udvendig side (glat side), og adsorberer kun de gasser og partikler, der kommer indefra. Membranen kan blandt andet adsorbere flygtige organiske forbindelser (VOC), mens vanddamp kan trænge igennem. cTrap er oprindelig udviklet til at fungere som spærre for VOC i forbindelse med fugtskader i konstruktioner, se bilag 2.

Den anden membran er IcoVario fra Icopal, se figur 2. Membranen er fugtadaptiv, og den tillader, at fugt i tag-, loft- og vægkonstruktioner kan afgives indad til rummet i forbindelse med udtørring af konstruktionen. Fugttransporten foregår ved vanddampdiffusion gennem en aktiv film, hvorimod VOC tilbageholdes, se bilag 3.

På grundlag af undersøgelsen i fase 1 konkluderes, at cTrap har en lav vanddamp-diffusionsmodstand *fra to sider*, mens IcoVario har en lav vanddampdiffusionsmodstand *fra én side*. Det blev besluttet at afprøve, måle og evaluere cTrap i eksisterende etageboliger.

Figur 1. cTrap (cTrap 2015).

Figur 2. IcoVario fra Icopal (Icopal, 2015).

Fremgangsmåde

Formålet med undersøgelsen var at kvantificere overførslen af ultrafine partikler (UFP) fra tobaksrøg og sporgas (N_2O) gennem membranen cTrap. I samarbejde med et firma, som er specialist i fugning og tætning, blev der udvalgt to lejligheder til at undersøge membranen.

Undersøgelsen blev gennemført i to lejligheder i to ældre etageboligbyggerier fra 1900 og 1908. Eksponeringslejligheden lå umiddelbart over kildelejligheden. Undersøgelsen blev gennemført i forskellige måneder i 2015. Under målingerne fandt ingen indendørsaktiviteter sted, som kunne indebære generering partikler, fx madlavning og rengøring.

Lejlighederne består af en entré, en stue, der vender mod en trafikeret vej, et værelse og et køkken, der begge vender mod gården, samt toilet og bad placeret centralt i lejligheden. Under hvert vindue i stue og værelse er der radiator med varmerør, der er ført gennem gulvet ved lysning. Der er naturligt aftræk fra toilet/badeværelse.

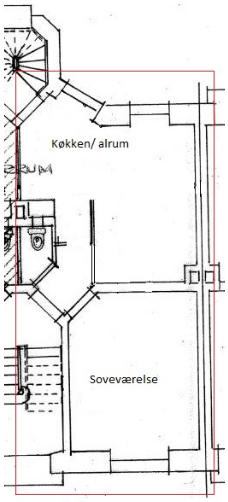
For at opnå et overtryk i kildelejligheden i forhold til eksponeringslejligheden blev der etableret en højere rumtemperatur i kildelejligheden. Dette blev sikret ved at holde temperaturen i kildelejligheden ca. 2-5 °C højere end i eksponeringslejligheden.

Kilde til generering af partikler bestod af fire tændte cigaretter i kildelejligheden, to i stuen og to i værelset. Koncentrationen af ultrafine partikler blev målt ved hjælp af partikeltællere af fabrikatet P-Trak ultrafine particle counter og to Condensation Particle Counter (CPC) model 3007 fra TSI Incorporated. Partikeltællerne målte simultant i hver af lejlighederne (CPC 3007) og udenfor (P-Trak).

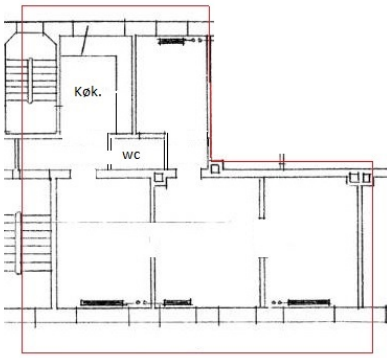
Desuden blev lejlighedernes luftskifte og luftoverførslen mellem de to lejligheder målt ved hjælp af Multi-Gas-monitorer, type 1302 fra Brüel & Kjær, der var placeret én i hver lejlighed. Endvidere blev der anvendt passiv sporgasteknik (PFT) til at måle den gennemsnitlige luftoverføring mellem lejlighederne. Temperatur og relativ luftfugtighed blev målt ved hjælp af dataloggere TinyTag type TGU-4500 fra Gemini. Under partikelgenereringen blev der opnået fuld opblanding ved brug af ventilatorer i rummet. Alle udeluftventiler var åbne, og aftrækskanalen på toilettet var lukket. I eksponeringslejligheden var alle vinduer, yderdøre og udeluftventiler lukkede, og aftrækskanalen på toilettet var åben.

Første del af undersøgelsen blev udført før tætning af gulvet i eksponeringslejligheden. Anden del af undersøgelsen blev udført efter tætning af gulvet.

Forud for anden del af undersøgelsen blev gulvet i eksponeringslejligheden tætnet. Fodlister og fejelister blev demonteret, og gulvet blev overalt dækket af membranen cTrap. Tætningen blev udført af et fagkyndigt firma. Membranen cTrap blev ført ca. 10 cm op ad væggene, hvor den blev tætnet med byggefugemasse og klemt med fodlister og fejelister, som blev genmonteret. Rørgennemføringer ved radiatorerne blev tætnet med tape og cTrap.



Lejlighed 1, Irmingersgade 9, 2100 København Ø



Lejlighed 2, Hørsholmgade 26, 2200 København N

Figur 3. Facadefotos og plantegninger af lejlighederne.

Figur 3 viser facadefotos og plantegninger af lejlighederne. Eksponeringslejlighed og kildelejlighed er opbygget ens. Lejlighed 1 har et areal 37,3 m^2 og en rumhøjde på 2,72 meter. Voluminet er således ca. 102 m^3. Lejlighed 2 har et areal på 60,1 m^2. Rumhøjden er 2,5 meter og voluminet er således ca. 150 m^3. I denne rapport præsenteres udvalgte resultater fra målinger i lejlighed 1.

Beregningsmetoder

Til at bestemme overførslen af ultrafine partikler og gasser er beregningsmetoden (1) anvendt, se bilag 1:

$$C_r\{t\} = \frac{\dot{V}C_o}{\dot{V}+V\gamma} + \frac{\dot{V}_{leak}C_s}{\dot{V}+V\gamma} + \frac{\dot{V}}{\dot{V}+V\gamma}\left(C_o - \frac{\dot{V}_{leak}C_s}{\dot{V}} + \frac{\dot{V}+V\gamma}{\dot{V}}C_{r_i}\right)e^{-\left(\dot{V}+V\gamma/V\right)t} \qquad (1)$$

Hvor

$C_r\{t\}$ er koncentration af forureninger på ethvert øjeblik i eksponeringslejligheden {forurening/m^3}.

C_{ri} baggrundskoncentration af forureninger i eksponeringslejligheden {forurening/m^3}.

C_s er koncentrationen af forureningen i kildelejligheden {forurening/m^3}.

C_0 er koncentrationen af udenfor forureninger {forurening/m^3}

γ er fjernelse af forureninger i eksponeringslejligheden (for gasser ignoreres) {1/h}

$\dot{V}$ er luftstrøm {m^3/h}

V er eksponeringslejlighedens volumen {m^3}

V_{leak} er lækage gennem gulvet i eksponeringslejligheden {m^3/h}

Luftskiftet i de to lejligheder er bestemt ved brug af sporgasteknik og henfaldsmetoden. Princippet er, at en kendt og målbar luftart (sporgas) doseres. Sporgassen fordeles, så fuldstændig opblanding sikres. Derefter afbrydes doseringen af sporgas, og sporgaskoncentrationen registreres over tid. Af henfaldskurven bestemmes luftskiftet således (2):

$$C\{t\} = C_o e^{-nt} \qquad (2)$$

Hvor

C_0 er startkoncentrationen i ppm

$C\{t\}$ er koncentrationen i ppm efter t

t er tiden i timer [h]

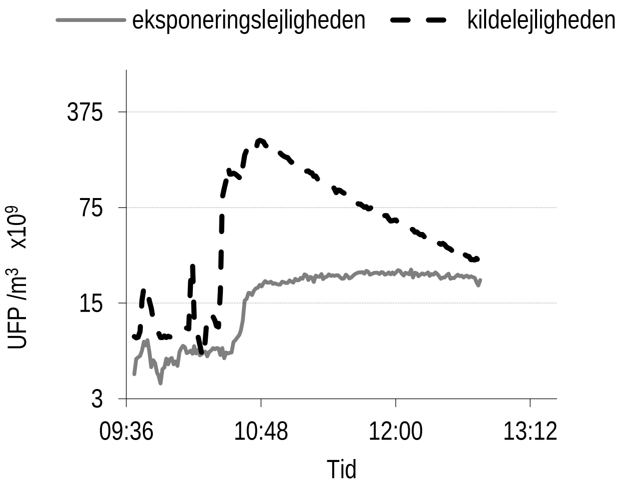
n er luftskiftet i gange pr. time [h^{-1}]

Resultater

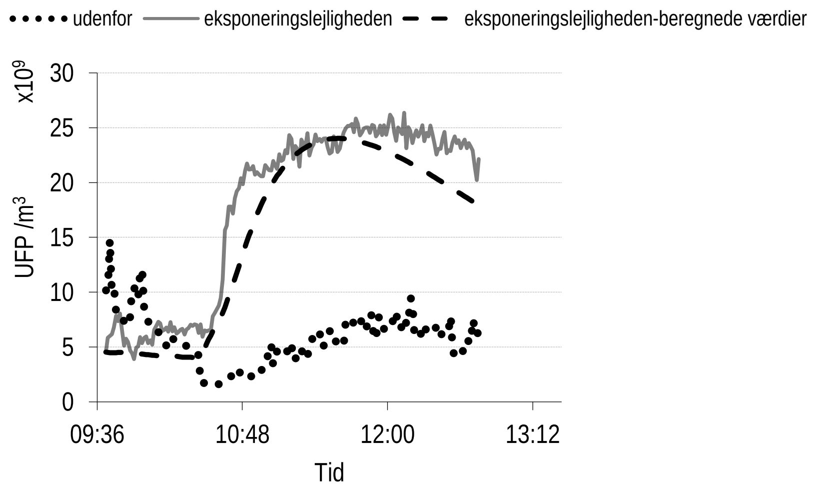
Før tætning

Undersøgelsen blev gennemført i to lejligheder i to ældre etageboligbyggerier. Her præsenteres udvalgte resultater fra lejlighed 1. Detaljerede resultater fremgår af bilagene.

Figur 4 viser de målte koncentrationsforløb for cigaretrøg i kildelejlighed og eksponeringslejlighed. Baggrundskoncentration i kildelejligheden var i gennemsnit ca.11,4 · 10^9 UFP/m^3, og i eksponeringslejligheden var den ca. 6,1 · 10^9 UFP/m^3, 40 minutter inden cigaretter blev tændt i kildelejligheden.



Figur 4. Baggrundskoncentration og målte værdier af ultrafine partikler under målingerne i lejlighederne før tætning af gulvet i eksponeringslejligheden.



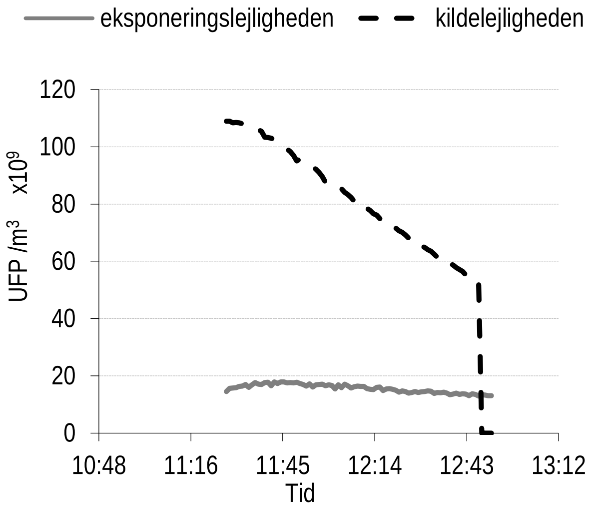
Figur 5. Resultat af måling og beregning af ultrafine partikler koncentrationen i eksponeringslejlighed før tætning af gulvet.

Figur 5 viser målt og beregnet koncentration af ultrafine partikler i eksponeringslejligheden. Beregningerne er udført jf. ligning (1). Det er forudsat, at der er fuldstændig opblanding af partikler og luft. Denne forudsætning indebærer, at koncentrationen i udsugningsluften af ultrafine partikler er lig med koncentrationen i luften i lejligheden. Ligningen bruges til beregning af koncentrationen af ultrafine partikler i den undersøgte lejlighed.

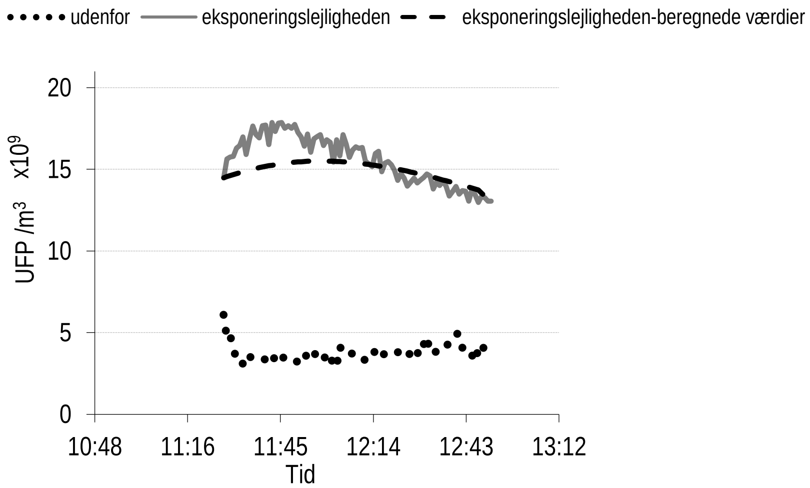
Resultaterne viser, at partikeloverførslen før tætning var 16 %.

Efter tætning

Efter tætningen blev luftskiftet i eksponeringslejligheden beregnet til 0,4 h^{-1}. Figur 6 viser de målte koncentrationsforløb for cigaretrøg i kildelejlighed og eksponeringslejlighed. Baggrundskoncentration i kildelejligheden var i gennemsnit ca. 12,5 · 109 UFP/m^3 og i eksponeringslejligheden ca. 16 · 109 UFP/m^3.



Figur 6. Målt koncentration af ultrafine partikler koncentrationen eksponeringslejligheden og kildelejligheden efter tætning af gulvet.



Figur 7. Resultat af måling og beregning af ultrafine partikler koncentrationen i eksponeringslejlighed efter tætning af gulvet.

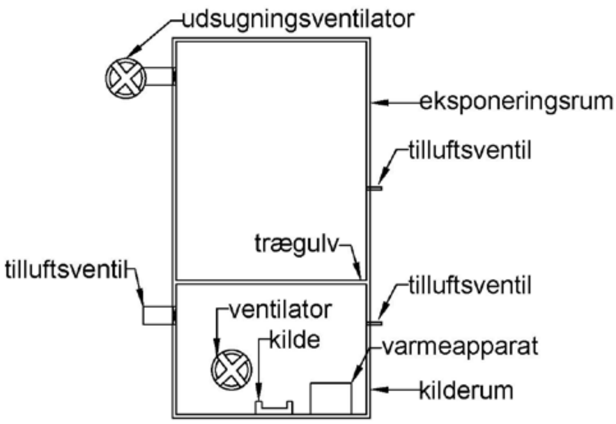
Figur 7 viser målt og beregnet koncentration af ultrafine partikler i eksponeringslejligheden. Til at beregne overførselsprocenten af ultrafine partikler fra kildelejligheden til eksponeringslejligheden anvendes ligning (1). Resultaterne viser, at efter tætningen blev partikeloverførslen reduceret fra 16 % til 7,6 %. Dette viser, at cTrap reducerer næsten 53 % af overførslen af ultrafine partikler.

Supplerende undersøgelser i laboratoriet

Der blev foretaget undersøgelser af overførslen af sporgas mellem kildelejligheden og eksponeringslejligheden. Desværre har måleresultaterne ikke kunnet analyseres på grund af tekniske problemer. Derfor blev der foretaget laboratorieundersøgelser i et prøvekammer med det formål at kvantificere overførslen af sporgas (N_2O) sammen med overførslen af ultrafine partikler.

Prøvekammeret blev opdelt vandret i to dele. Den øverste del (det eksponerede rum) var 1,26 m^3 og den nederste del (kilderummet) var 0,62 m^3. De to rum var adskilt af et trægulv. Målingerne blev udført med og uden cTrap under gulvet.

Resultaterne viser, at cTrap var i stand til at reducere overførslen af sporgas (N_2O) med 87,5 % og overførslen af ultrafine partikler med 97 %.

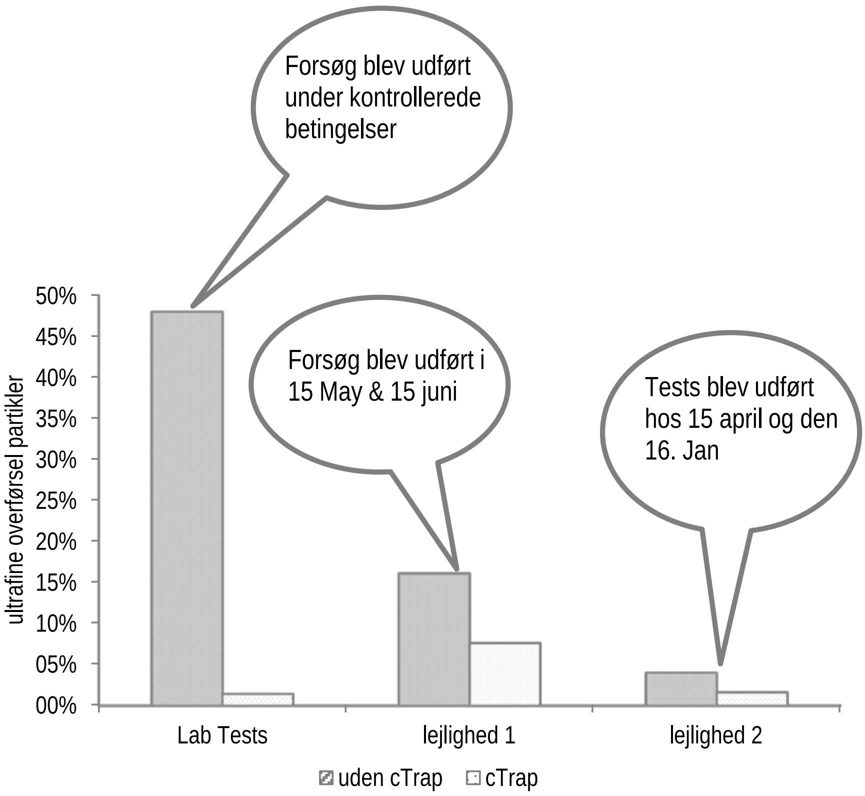


Figur 8. Prøvekammeret var opdelt i to dele med et trægulv som vandret adskillelse.

Diskussion

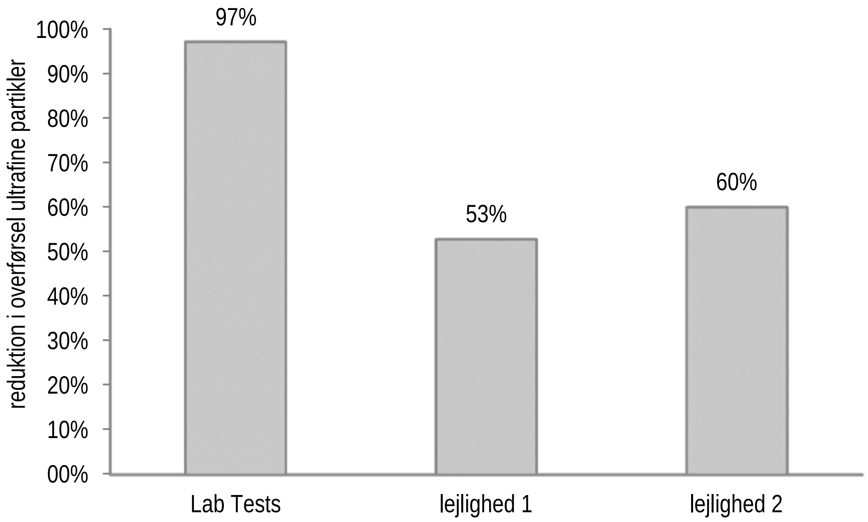
Denne rapport udgør en del af resultaterne af anden fase af et projekt i to faser om brug af tætningsmetode for reduktion af overførsel af forureninger fra tobaksrøg mellem lejligheder i ældre etageboliger.

Formålet med undersøgelsen var at kvantificere overførslen af ultrafine partikler (UFP) fra tobaksrøg og sporgas (N_2O) gennem to membraner. Den ene af to membraner er cTrap og den anden membran er IcoVario. cTrap kan blandt andet adsorbere flygtige organiske forbindelser (VOC) og ultrafine partikler, mens vanddamp kan trænge igennem. På grundlag af undersøgelsen i fase 1 konkluderes det, at cTrap har en lav vanddampdiffusionsmodstand fra to sider, mens IcoVario har en lav vanddampdiffusionsmodstand fra én side. Det blev besluttet at installere, måle og evaluere cTrap i eksisterende etageboliger.



Figur 9. Overførsel af ultrafine partikler fra tobaksrøg før og efter tætning med cTrap.

Resultaterne fra denne undersøgelse er opsummeret i figur 9. Resultaterne er et vigtigt skridt til bedre at kunne forstå membranens ydeevne som en tætningsmetode mod forureninger fra tobaksrøg. Derimod er kvantificering af overførslen af ultrafine partikler fra tobaksrøg gennem membraner mellem lejligheder i ældre etageboliger afhængig af flere faktorer; hvoraf nogle er ukontrollerbare, især målinger på stedet. Derfor er der i den foreliggende undersøgelse en forskel mellem resultaterne af laboratorieundersøgelserne og feltundersøgelserne.



Figur 10. Reduktion af overførslen af ultrafine partikler og N_2O mellem lejlighed 1 og 2 ved henholds laboratorieundersøgelser og feltundersøgelser.

Måleresultaterne fra laboratorieundersøgelsen viser, at membranen cTrap var i stand til at reducere overførslen af ultrafine partikler med ca. 97 % og N_2O med ca. 87 %, mens cTrap i lejlighed 1 og 2 var i stand at reducere overførslen af ultrafine partikler med ca. 53 % og ca. 60 %, se figur 10.

Dette indebærer, at der i ældre etageboliger kan være utætheder, hvor partiklerne kan komme igennem. Utæthederne er fx ved rørføringer, i gulvet og langs væggene.

Sammenfattende kan det konkluderes, at cTrap var i stand til at reducere overførslen af ultrafine partikler og sporgasser i de to undersøgte lejligheder med mellem 53 % og 60 %. Dette betyder, at anvendelse af cTrap ikke bare kan hjælpe med til at reducere koncentrationen af ultrafine partikler og gasser fra naborøg, men også til at undgå anvendelse af energikrævende, tekniske løsninger som fx luftrensere for at begrænse påvirkningen fra naboers rygning.

På grund af tekniske problemer var det ikke muligt at undersøge overførslen af sporgas i feltundersøgelserne, og derfor blev der gennemført en undersøgelse i laboratoriet.

Resultaterne viser, at cTrap var i stand til at reducere overførslen af sporgas (N_2O) med 87,5 % og overførslen af ultrafine partikler med 97 %. Det kan konkluderes, at laboratorieundersøgelsen viser, at cTrap er i stand til at reducere overførslen af gasser (N_2O) i samme størrelsesorden som ultrafine partikler.

Konklusion

På grundlag af undersøgelsen i fase 2 konkluderes at:

- Ifølge feltundersøgelsen er cTrap i stand til at reducere overførslen af ultrafine partikler fra cigaretrøg med ca. 60 %.

- Ifølge laboratorieundersøgelsen er cTrap i stand til at reducere overførslen af gasser (N_2O) i samme størrelsesorden som ultrafine partikler.
- Der er behov for at analysere langtidsydeevnen af membranerne i eksisterende etageboliger.

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Bilag 1

Detailed report in English

Reducing the transfer of contaminants among adjacent apartments

April 2016

Ahsan Iqbal, Alireza Afshari, Niels Christian Bergsøe

Danish Building Research Institute (SBi) Aalborg University Copenhagen

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Content

Overordnet konklusion

En unik type soft membran er blevet udviklet af et svensk firma. For at teste membranens ydeevne til at indfange luftbårne forureninger, har Statens Byggeforskningsinstitut (SBi) gennemført en undersøgelse. Undersøgelsen er baseret på laboratorieforsøg samt in-situ-målinger.

Laboratorieforsøgene er udført i SBi's laboratorie, hvor to tilstødende lejligheder blev simuleret i et testkammer. En lejlighed blev simuleret som en kildelejlighed, der genererede de forurenende stoffer, og den anden lejlighed blev simuleret som en lejlighed, der var eksponeret for de forurenende stoffer, som blev skabt i kildelejligheden. I kildelejligheden blev forureninger skabt ved anvendelse cigaretrøg. Den eksponerede lejlighed var placeret ovenover kildelejligheden. Begge lejligheder havde samme etageplan og rumhøjde. De simulerede lejligheder var adskilt af trægulve. Når ultrafine partikler (UFP) fra cigaretrøg blev genereret i kildelejligheden, trængte omkring 48 % af UFP igennem til den eksponerede lejlighed. På samme måde når N_2O i form af gaspartikler blev sprøjtet ind i kildelejligheden, her trængte 16,5 % af N_2O igennem til den eksponerede lejlighed. Derefter blev forseglingsmembranen opsat under trægulvet i den eksponerede lejlighed. Det kunne konstateres, at opsætning af forseglingsmembranen reducerede overførslen af UFP med 97 % og reducerede overførslen af N_2O med 87,5 % i forhold til overførslerne uden membranen.

En lignende procedure til at måling af overførslen af UFP blev gennemført med in-situ-målinger. In-situ-målingerne blev udført i to lejligheder i København. Målingerne blev udført uden (før renovering) og med membran (efter renovering). Tætningsmembranen kunne in situ reducere overførslen af UFP med 53-60 %. Der blev også gennemført en undersøgelse af beboernes oplevelse af effekten af forseglingsmembranen og det resulterende indeklima. Før renoveringen var beboerne konstant irriteret af cigaretlugt fra deres naboer. Men efter renoveringen oplever begge beboere et bedre indeklima, fordi der ikke længere lugter af cigaretter.

Executive summary

A unique type of fabric membrane has been developed by a Swedish company. To test the performance of the membrane for trapping airborne contaminants, a study was conducted by the Danish Building Research Institute (SBi). The study is based on the laboratory experiments as well as in situ measurements.

Laboratory tests were performed in the laboratory of SBi where two adjacent apartments were simulated in a test chamber. One apartment was simulated as a source apartment which generated the contaminants and the second apartment was simulated as an exposed apartment which was exposed to the contaminants generated by the source apartment.

In the source apartment contaminates were generated using cigarette smoke. Exposed apartment was situated above the source apartment. Both apartments had the same plan area and height. The simulated apartments were separated by wooden flooring. When the ultrafine particles (UFP) from cigarette smoke were generated in the source apartment, around 48% of UFP migrated to the exposed apartment.

Similarly when N_2O as gas particles was sprayed in the source apartment, 16.5% of the N_2O migrated to the exposed apartment. Then the sealing membrane was installed below the wooden flooring of the exposed apartment. It was noted that inclusion of the sealing membrane reduced the transfer of UFP down to 97% and reduced the transfer of N_2O down to 87.5% in comparison with the transfers without the membrane.

A similar procedure of measuring the transfer of UFP was adapted in situ measurements. In-situ measurements were performed in two apartments in Copenhagen. The measurements were carried out without (before renovations) and with membrane (after renovations). In situ the sealing membrane was able to reduce the transfer of UFP down to 53% to 60%.

A survey regarding occupant's perception of the performance of the sealing membrane and the resulting indoor air quality was also conducted. Before the renovation the occupants were continuously irritated by the cigarette smells from their neighbours. However, after the renovations both occupants perceive better indoor air quality as they don't smell cigarettes anymore.

Introduction

Air contaminants generally consist of particles and gases. Many contaminants may cause health problems. For instance scientific studies in the recent past have shown that the inhaling of volatile organic compounds (VOC) can cause health problems (US Department of Health and Human Services 2010, Goldman, Enewold et al. 2001, Hodgson, Wooley 1991). Likewise, exposure to fine and ultrafine airborne particles (UFP) has been identified as an important risk factor for human health (Pope III, Dockery 2006). In residential buildings, contaminants can transfer among adjacent apartments or from outside to inside for instance, tobacco smoke. Tobacco smoke, a great source of contaminants, contain more than several thousand chemical compounds including VOCs and UFP. Tobacco smoke may cause health problems not only for intended smokers but also for those who inhale these contaminants unintentionally i.e. passive smokers. Especially in multi-storey residential buildings, there is a risk of passive smoking due to active smoking of neighbours.

There are several different ways in which contaminates can be transferred from source apartments (that generates contaminants) to exposed apartments (that receives contaminants from the source apartment). Some of the common openings where contaminants can infiltrates from source apartments to exposed apartments includes electrical outlets, cable or phone jacks, HVAC system, plumbing pipes, cracks in walls, floors, building services shafts etc. However, due to ultrafine sizes, particle and gases may transfer from source apartments to exposed apartments through walls and ceiling where there is no visible cracks/opening.

Previous studies in Denmark have gathered information about technical solutions, such as sealing and air cleaner that prevent or reduce the transfer of contaminants in residential buildings. However, a very little attention has so far been paid to the technical solutions such as membrane for preventing or reducing the transfer of contaminants among neighbouring apartments. The transfer of contaminants from one apartment to another can be estimated by measuring the concentrations of traceable gases and ultrafine particle (UFP).

Danish Building Research Institute (SBi) has been analysing the performance of different solution to stop and/or reduce the transfer of unwanted contaminants. Afshari et al. (2010) concluded that when source apartment is located below the exposed apartment the contaminants transfer from source apartment is significantly high. Similar results have also been published by Ekberg & Shi (2009) and Afshari et. al. (2014). However, less attention so far has been paid on the methods that stop the migration of particles instead of diluting the concentration.

Markowicz & Larsson (2012) reported a novel concept for stopping and reducing unwanted emissions from building materials indoors by using a surface emissions trap membrane (also used in the present study). But the results did not show the performance of the membrane against UFP and gases. Gunner et al. (2014) showed that a plastic foil can reduce the significant amount of UFP transfer. Afshari et al. (2014) performed few lab experiments for evaluating the effectiveness of two types of commercially available membranes as a sealing against VOCs transfer. The experimental results of both membranes, showed the promising results in regards to stopping migration of VOCs.

In the present study the membrane used by Markowicz & Larsson (2012) is used as a sealing against the transfer of contaminants. The membrane captures the emissions at the source which immediately results in a fresh and healthier indoor air. The membrane does not release any emissions of its own. It does not use any energy and may allow a reduced ventilation rate while maintaining a satisfactory indoor air quality. The membrane is a long-term solution with a capacity of being used up to several decades after installation. The present study is based on lab tests as well as in-situ measurements. In-situ measurements were performed in 3 different apartments in Copenhagen however due to insufficient information from one of the apartments; results from only 2 apartments are included in the present study. In the last occupants' perception regarding the performance of the membrane as a sealing against contaminants were obtained.

From the findings of the present study a conference article is published. The article will be presented in INDOOR AIR 2016 – The 14th International Conference of Indoor Air Quality and Climate GHENT, BELGIUM July 3-8 2016.

AIM OF THE STUDY

Aim of the present study was to analyse the performance of the newly developed fabric membrane as sealing against contaminates in inhabited spaces. To analyse the contaminant transfer, UFP and N_2O were used. The performance was tested and analysed in a controlled laboratory environment, real life measurement as well as occupants' perception.

PHYSICS OF CONTAMINANTS TRANSFERS

Contaminant transfer rate in an apartment can be evaluated by applying mass balance equation among possible transfer roots of contaminants. The phenomenon can be expresses as mentioned in Figure 1. The apartment which is affected by the contaminants is termed as exposed apartment. The apartment which is generating the contaminants is termed as source apartment.

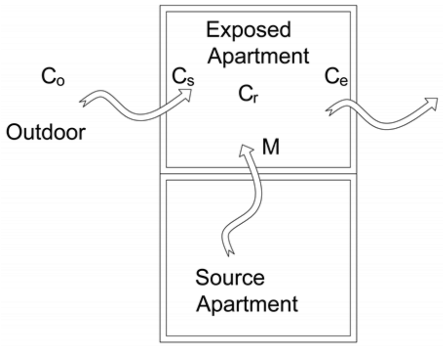

Figure 1 particle transfer schematic

The exposed apartment in Figure 1 is receiving contaminants from outdoor and from the source apartment. To estimate the amount of contaminants in the exposed apartment, the mass balance equation in the exposed apartment can be used. By considering the balanced ventilation, the mass balance equation can be expressed as:

$$\begin{aligned} &\textit{Pollutants removal rate} \\ &\quad = \textit{Input rate of pollutants} - \textit{output rate of pollutants} \\ &\quad + \textit{internal source of pollutants} \\ &\quad - \textit{internal sink of pollutants} \end{aligned}$$

$$V\frac{dC_r}{dt} = \dot{V}C_s - \dot{V}C_e + \dot{M} - \dot{R} \tag{1}$$

Where;

$\dot{V}$ air inflow/outflow rate in the exposed apartment in m^3/h

C_s Inflow particle concentration in particles/m^3

C_r Particle concentration in the exposed apartment in particles/m^3

C_e Outflow particle concentration in particles/m^3

$\dot{M}$ Particle source effect in particles/h

V Volume of the apartment in m^3

$\dot{R}$ Particle sink effect in particles/h

Sink Effect ($\dot{R}$) which cannot be ignored in some forms of contaminants e.g. UFP. Sink effect encompasses all the particle sinks other than air cleaning and ventilation for instance deposition of particles on the surfaces, agglomeration, chemical reaction etc. among these the particle deposition on horizontal surfaces due to the gravity can be approximated by:

$$\dot{R} = C_r V \frac{v}{H} = C_r V\gamma \tag{2}$$

Where v is the downward velocity of the (during the surface deposition process) and H is the characteristic length can be approximated as the average room height. γ is the ratio of the downward velocity and average room height. γ can be described as the total room particle sinking rate.

By assuming that the airflow rates were constant during the experimental time period, inflow contaminants concentration (C_s) is same as outdoor contaminants concentration ($C_o \equiv C_s$) and outflow particle concentration (C_e) is same as indoor particle concentration ($C_r \equiv C_e$) Eq. (1) can be written as,

$$V\frac{dC_r\{t\}}{dt} = \dot{V}C_o - \dot{V}C_r\{t\} + \dot{M} - C_r\{t\}V\gamma$$

$$\frac{dC_r\{t\}}{dt} + \left(\frac{\dot{V}+V\gamma}{V}\right)C_r\{t\} = \frac{\dot{V}}{V}C_o + \frac{1}{V}\dot{M}$$

Solving first order differential equation by considering integrating factor

$$e^{\int\frac{\dot{V}+V\gamma}{V}dt} = e^{\left(\frac{\dot{V}+V\gamma}{V}\right)t}$$

Multiply the integration factor on the both side of the differential equation

$$e^{\left(\frac{\dot{V}+V\gamma}{V}\right)t}\frac{dC_r\{t\}}{dt} + \left(\frac{\dot{V}+V\gamma}{V}\right)C_r\{t\}e^{\left(\frac{\dot{V}+V\gamma}{V}\right)t} = \left(\frac{\dot{V}}{V}C_o + \frac{1}{V}\dot{M}\right)e^{\left(\frac{\dot{V}+V\gamma}{V}\right)t}$$

$$\frac{d}{dt}\left(e^{\left(\frac{\dot{V}+V\gamma}{V}\right)t}C_r\{t\}\right) = \left(\frac{\dot{V}}{V}C_o + \frac{1}{V}\dot{M}\right)e^{\left(\frac{\dot{V}+V\gamma}{V}\right)t}$$

Integrating both sides

$$\int\frac{d}{dt}\left(e^{\left(\frac{\dot{V}+V\gamma}{V}\right)t}C_r\{t\}\right)dt = \int\left(\frac{\dot{V}}{V}C_o + \frac{1}{V}\dot{M}\right)e^{\left(\frac{\dot{V}+V\gamma}{V}\right)t}dt$$

$$e^{\left(\frac{\dot{V}+V\gamma}{V}\right)t}C_r\{t\} = \left(\frac{\dot{V}}{V}C_o + \frac{1}{V}\dot{M}\right)\frac{V}{\dot{V}+V\gamma}e^{\left(\frac{\dot{V}+V\gamma}{V}\right)t} + constant$$

$$C_r\{t\} = \frac{\dot{V}C_o}{\dot{V}+V\gamma} + \frac{\dot{M}}{\dot{V}+V\gamma} + constant \times e^{-\left(\frac{\dot{V}+V\gamma}{V}\right)t}$$

The above mentioned solution is a general solution for the equation. Particular solution at the initial value of $C_r\{0\} = C_{r_i}$ can be derived as follows:

$$constant = \frac{\dot{V}}{\dot{V}+V\gamma}\left(C_o - \frac{\dot{M}}{\dot{V}} + \frac{\dot{V}+V\gamma}{\dot{V}}C_{r_i}\right)$$

$$C_r\{t\} = \frac{\dot{V}C_o}{\dot{V}+V\gamma} + \frac{\dot{M}}{\dot{V}+V\gamma} + \frac{\dot{V}}{\dot{V}+V\gamma}\left(C_o - \frac{\dot{M}}{\dot{V}} + \frac{\dot{V}+V\gamma}{\dot{V}}C_{r_i}\right)e^{-\left(\frac{\dot{V}+V\gamma}{V}\right)t} \tag{3}$$

Or by simple re-arraigning

$$C_r\{t\} = \frac{\lambda C_o}{\lambda+\gamma} + \frac{\dot{M}}{V(1+\gamma)} + \frac{\lambda}{\lambda+\gamma}\left(C_o - \frac{\dot{M}}{V\lambda} + \frac{\lambda+\gamma}{\lambda}C_{r_i}\right)e^{-(\lambda+\gamma)t} \tag{4}$$

Where λ is the air change rates of the exposed apartment. λ is not the total air change rates. It is the air change rate caused by the outdoor air only. There have been studies e.g. Afshari et al. (2010) that suggest that the dominant source of contaminants is the apartment below the exposed apartment. Therefore, in such scenarios the Source effect ($\dot{M}$) can be approximated by:

$$\dot{M} = C_{exp}\dot{V}_{Leak}$$

Where C_{exp} is the contaminants concentration in the exposed apartment and $\dot{V}_{Leak}$ is the leakage from source apartment to the exposed apartment. By substituting the above equation in (4):

$$C_r\{t\} = \frac{\dot{V}C_o}{\dot{V}+V\gamma} + \frac{C_S\dot{V}_{Leak}}{\dot{V}+V\gamma} + \frac{\dot{V}}{\dot{V}+V\gamma}\left(C_o - \frac{C_S\dot{V}_{Leak}}{\dot{V}} + \frac{\dot{V}+V\gamma}{\dot{V}}C_{r_i}\right)e^{-\left(\frac{\dot{V}+V\gamma}{V}\right)t} \tag{5}$$

$$C_r\{t\} = \frac{\lambda C_o}{\lambda+\gamma} + \frac{C_S\dot{V}_{Leak}}{V(1+\gamma)} + \frac{\lambda}{\lambda+\gamma}\left(C_o - \frac{C_S\dot{V}_{Leak}}{V\lambda} + \frac{\lambda+\gamma}{\lambda}C_{r_i}\right)e^{-(\lambda+\gamma)t}$$

Eq. (5) is the governing equation that describes the increase in the concentration of contaminants in exposed apartment due to the contaminants concentration of source apartment and the outdoor atmosphere.

Reference to the whole section: PHYSICS OF CONTAMINANTS TRANSFERS: is Chapter 3 of (Nilsson 2003)

DEFINITION OF THE SELECTED MEMBRANE

The selected membrane (cTrap) in a commercially available membrane which is a multilayer and multifunctional cloth developed to trapping emissions from building materials.

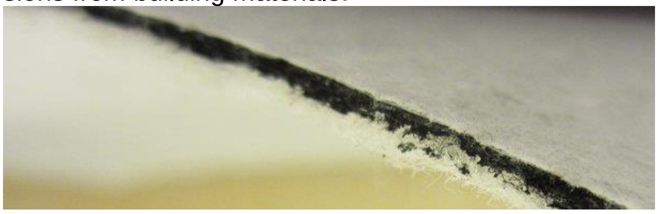

Figure 2 cTrap - a multilayer and multifunctional cloth

The cloth consists of two functional layers, a polymer layer which acts as a contaminants barrier and an adsorption layer which binds the contaminants. These layers interact in a unique way to ensure maximum effect. Moreover there are two inner and outer protective layers. Hence the membrane consists of four layers in total.

The membrane is applied with the adsorption layer facing the construction i.e. the surface from which the contaminants are spread. The cloth is flexible and can be installed on floors, walls, ceiling, over cavities etc. Moisture, i.e. water in the gaseous phase, passes easily through both of these layers while contaminates such as UFP, organic substances including odours are stopped and trapped irreversibly. Any flooring can then be laid above the membrane. When attached on a wall or ceiling the membrane cloth may be covered e.g. with a thin gypsum board.

Source (www.ctrap.se)

Laboratory experiments

Method

Laboratory test setup was built in SBi's laboratory in Hørsholm. The test Chamber was consisting of two compartments separated by a wooden floor as shown in Figure 3.

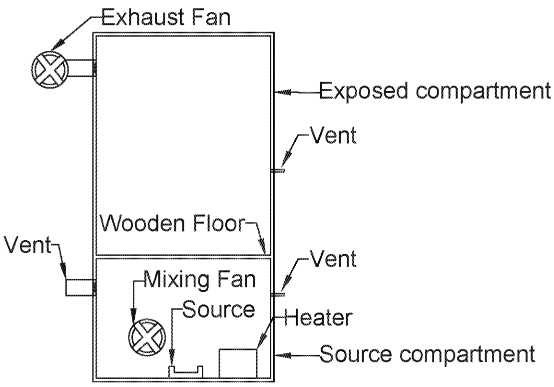

Figure 3 test chamber for the contaminant transfer lab tests

The overall dimension of the test chamber was 237 × 104 × 100 cm^3 (outer dimensions). The volume of the top chamber was 1.26 m^3 and the bottom chamber was 0.62 m^3.

Tests were conducted in two parts. Part 1 were the tests with the existing wooden floor as shown in Figure 3. Part 2 were the tests when the sealing membrane was placed below the wooden floor. In Part 1 of the tests, both top and bottom compartments were ventilated and care was taken that the exhaust air is not recirculating by any means. Bottom compartment was simulated as a source apartment and top compartment was simulated as an exposed apartment. The air change rate in the exposed apartment was 3.8 ACH. The test steps were as follows:

1) Measurements of leakage through the floor
    a. Using blower door technique
2) Measurements of air temperatures and relative humidity in both simulated apartments and outside of the apartments
3) Turning on the radiator in the source apartment to create a pressure difference due to the difference in temperatures
4) Measurements of UFP in both apartments and outside
5) Measurements of tracer gas (N_2O) in both apartments and outside
6) Measurements of air change rates (ACH) in both apartments
7) Lighting a cigarette in the source apartment
8) Spray of tracer gas N_2O in the source apartment
9) Monitoring and logging of the data in step 2 to 6 unless steady state concentrations achieve in both apartments.

UFP concentrations in both apartments were logged through two condensation based particle counters[1], outside concentrations was also measured by using condensation particle counter[2]. All particle counters were co-calibrated before the use in order to reduce the errors related to measurements using different instruments. The concertation of N_2O was measured

[1] TSI CPC 3007
[2] TSI P-Trak

and logged by using a multi-gas monitor[3]. Temperatures were logged using portable temperature loggers[4].

The measured contaminants transfer to the exposed apartment was then compared with the theoretical values in order to evaluate the approximate values of contaminants transfer. The theoretical values are achieved by using the equation derived in the chapter PHYSICS OF CONTAMINANTS TRANSFERS:

$$C_r\{t\} = \frac{\dot{V}C_o}{\dot{V}+V\gamma} + \frac{\dot{V}_{leak}C_s}{\dot{V}+V\gamma} + \frac{\dot{V}}{\dot{V}+V\gamma}\left(C_o - \frac{\dot{V}_{leak}C_s}{\dot{V}} + \frac{\dot{V}+V\gamma}{\dot{V}}C_{r_i}\right)e^{-\left(\dot{V}+V\gamma/V\right)t} \tag{6}$$

Where $C_r\{t\}$ is the theoretical contaminants concentration at any instant in the exposed apartment. C_{r_i} is the initial/background contaminants concentration in the exposed apartment. $\dot{V}\,\&V$ are the volume flow rate and volume of the exposed apartment, $\dot{V}$ was calculated from the measured value of air change rates (ACH). Tracer gas techniques were used to determine ACH. $\dot{V}_{leak}$ is the leakage through the floor of the exposed apartment. C_o is the outdoor contaminant concentration. C_s is the contaminant concentration in the source apartment. γ is the sink effect of the contaminants in the exposed apartment. For gases γ can be ignored.

During the tests, γ was unknown. The theoretical of contaminants concentration in the exposed apartment i.e. $C_r\{t\}$ are then compared with the measured values by adjusting the value of γ. Then a hypothetical value of contaminant concentration $\left(C_{(r,\dot{V}_{leak}=0)}\{t\}\right)$in the exposed apartment was obtained when there were no leakage through the floor i.e. $\dot{V}_{leak} = 0$.

$$C_{(r,V_{leak}=0)}\{t\} = \frac{\dot{V}C_o}{\dot{V}+V\gamma} + \frac{\dot{V}}{\dot{V}+V\gamma}\left(C_o + \frac{\dot{V}+V\gamma}{\dot{V}}C_{r_i}\right)e^{-\left(\dot{V}+V\gamma/V\right)t} \tag{7}$$

$C_r\{t\}$ is the concentration of contaminants which are migrated from the source apartment and from any other source e.g. outdoor. $C_{(r,\dot{V}_{leak}=0)}\{t\}$ in the concentration of contaminants which are from sources other than source apartment. Hence the difference in $C_r\{t\}$ and $C_{(r,\dot{V}_{leak}=0)}\{t\}$ is the actual concentration of the contaminants which are been transferred from the source apartment to the exposed apartment. The percentage of contaminants transferred is obtained by using the following formula:

$$\eta = \frac{\sum \Delta\left(C_r\{t\} - C_{(r,\dot{V}_{leak}=0)}\{t\}\right)\times \Delta t}{\sum C_s \times \Delta t} \times 100 \tag{8}$$

The η is the ratio of the actual transfer of particle to the maximum possible transfer of particle within the particular time span. Hence in Part 1 of the lab test η (η_o) was obtained with existing wooden floor.

Afterwards in Part 2, the sealing membrane was placed under the wooden floor to analyse the performance of the membrane as a sealing against the transfer of contaminants. In Part 2, all the 9 steps of Part 1 of the lab tests were repeated and the transfer of contaminants were analysed. Hence another value of η $(\eta_{sealing})$ was obtained.

The percentage decrease in contaminants transfer due to the addition of the sealing membrane was obtained as:

$$\chi = 100 \times \left(1 - \frac{\eta_{sealing}}{\eta_o}\right) \tag{9}$$

[3] Brüel & Kjær multigas monitor type 1302
[4] Tinytag data ultra TGU 1500

Findings

Part 1

Air change rates (ACH) in the exposed apartment was measured using tracer-gas-concentration decay method. The air change rate in the exposed apartment was 3.8 ACH. Leakage through the flooring was 2.8 m^3/h. To test the transfer of contaminants, the transfer of UFP and N_2O was examined. During Part 1 of the lab tests, after lightening the cigarettes, UFP concentrations in the source apartment, the exposed apartments and outdoor air were logged. The logged values of UFP concentration of both source apartment and the exposed apartment are mentioned in Figure 4.

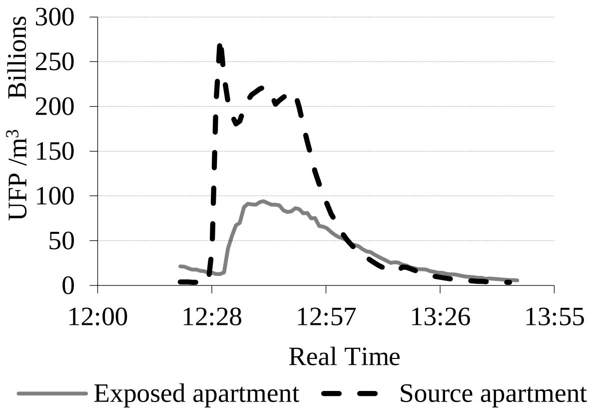

Figure 4 variation UFP in the source and the exposed apartments without the sealing membrane during the lab tests

The vertical axis is UFP concentration in billions and the horizontal axis is time. The average temperature difference between two apartments was 5K.

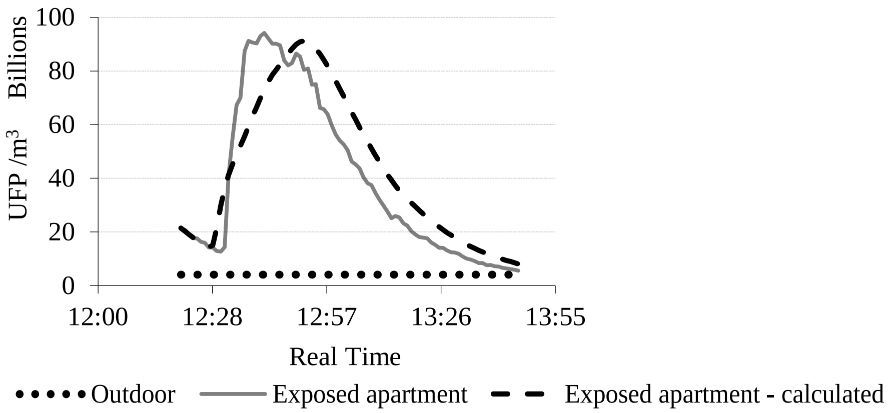

Figure 5 up to 48% of the UFP from source apartment were transferred to the exposed apartment without the membrane during the lab tests

Figure 5 illustrates three curves, Outdoor values which is a single average value of outdoor concentration during the experimental period. “Exposed apartment” which is the measured values of UFP in the exposed apartment, and “Exposed apartment - calculated” which is a curve obtained using Eq. (6). Since UFP sinking rate was not known, the value of γ was chosen in a way that the calculated values of UFP concentration give the best possible correlation with the measured values of UFP concentration in the exposed apartment. Figure 5 is obtained by using $\gamma = 0.4$ which is equivalent to the particle removal rate (from the exposed apartment) of 4.3 per hour. The total percentage of transferred UFP in the exposed apartment was obtained using

Eq. (8). Hence during Part 1 of the lab test 48% of UFP were transferred from source apartment to the exposed apartment.

Similar to UFP, N_2O gas was also measured and logged in the source and exposed apartments. The measured values are mentioned in Figure 6. The concentration of N_2O in the exposed apartment is mentioned on the primary vertical axis whereas concentration in the source apartment is mentioned in the secondary vertical axis.

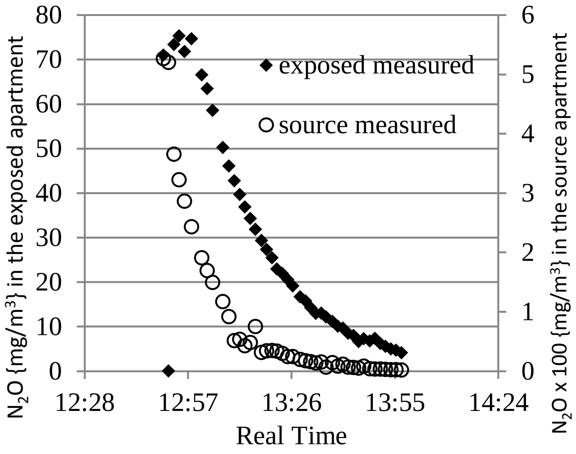

Figure 6 variations in the N_2O in the source and the exposed apartments during the lab tests without the sealing membrane

For N_2O sink rate is negligible i.e. $\gamma = 0$. Hence by using Eq. (6) the calculated values of N_2O concentration in the exposed apartment can be obtained. The calculated and measured values of N_2O concentrations in the exposed apartment are mentioned in Figure 7. Average outdoor concentration of N_2O is also mentioned in Figure 7. By using Eq. (8), it was found that 16.5% of N_2O were transferred into the exposed apartment from the source apartment.

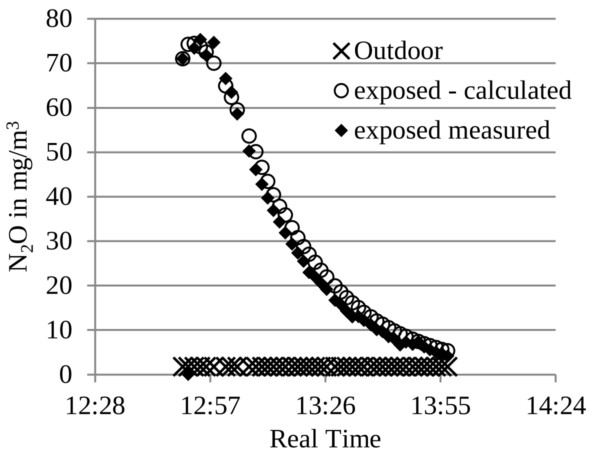

Figure 7 up to 16.5% of the N_2O from source apartment were transferred to the exposed apartment without the membrane during the lab tests

Part 2

In Part 2 of the lab test, the membrane was installed below the wooden flooring of the exposed compartment. In Part 2, a similar procedure was performed as of Part 1 i.e. experimental steps 1 to 9.

In Part 2 of the lab test, ACH remained almost unchanged i.e. 3.8 ACH. However, leakage through the flooring was decreased to 0.1 m^3/h. The measured concentrations of UFP in the source and the exposed apartments are illustrated in Figure 8. In Figure 8 vertical axis is UFP concentrations in billions and horizontal axis the time.

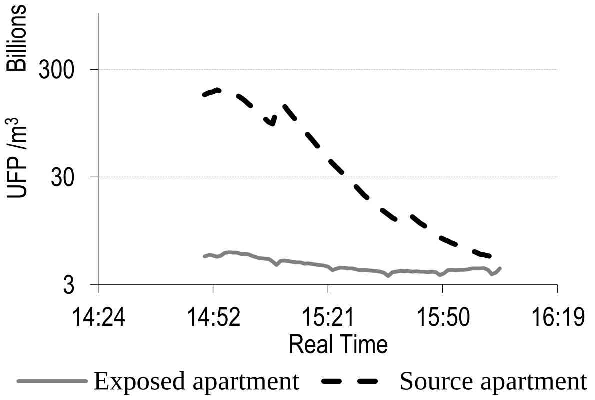

Figure 8 variation in UFP in the exposed and source apartments after installation of the sealing membrane during the lab tests

Using Eq. (6) and the same sinking rate as of Part 1 i.e. $\gamma = 0.4$, calculated values of UFP concentration in the exposed apartment were obtained. The calculated values and measured values of UFP concentrations are illustrated in Figure 9.

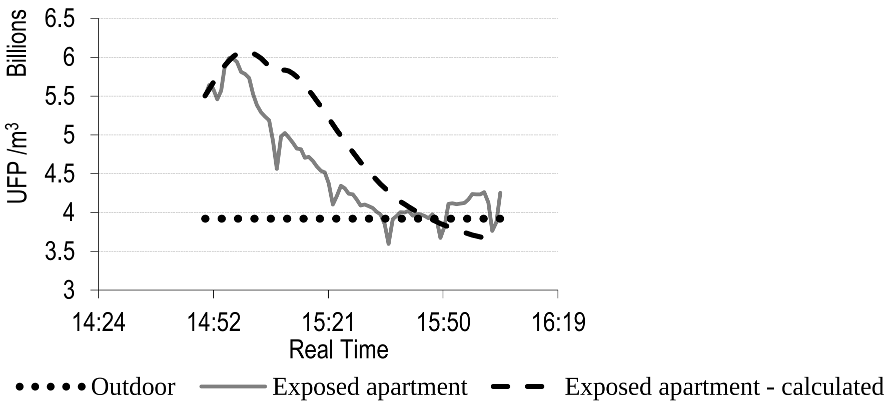

Figure 9 only 1.4 % of UFP from the source compartment were transferred to the exposed compartment after installation of the sealing membrane during the lab tests

From Eq. (8) it was calculated that only 1.4% of UFP were transferred into the exposed apartment from the source apartment. A similar procedure was also performed for N_2O. Measured values of N_2O in the source and exposed apartments are illustrated in Figure 10. The primary vertical axis is the concentration of N_2O in the exposed apartment whereas secondary vertical axis is the concentration of N_2O in the source apartment.

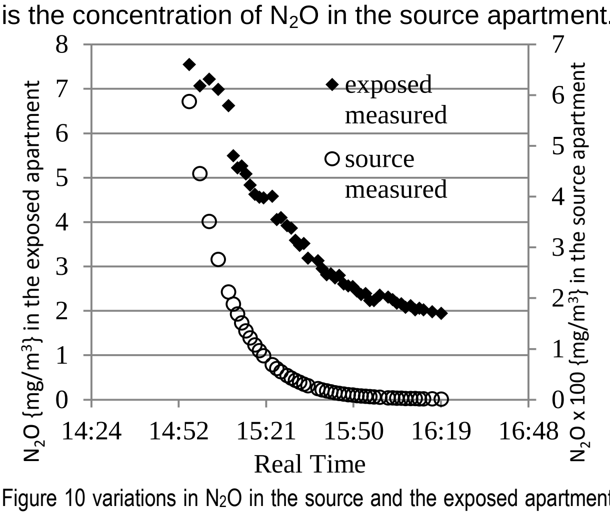

Figure 10 variations in N_2O in the source and the exposed apartments during the lab tests after the installation of the sealing membrane

The estimated concentrations of N_2O in the exposed apartment are obtained through Eq. (6) and using $\gamma = 0$, and the concentrations are illustrated in Figure 11. Measured concentration of N_2O in the exposed apartment and the outdoor concentrations are also mentioned in Figure 11. By using Eq. (8) it was calculated that only 2.1% of N_2O was transferred from source apartment to the exposed apartment.

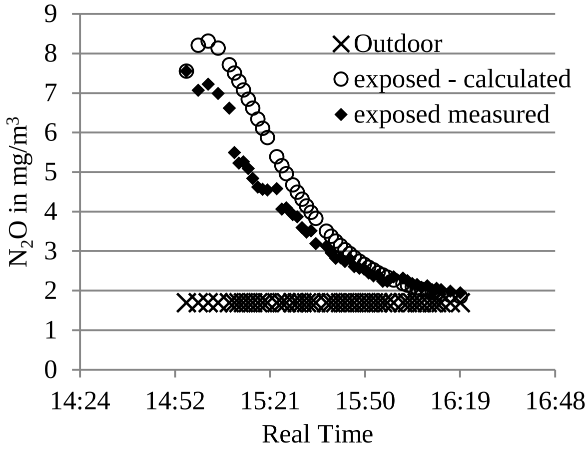

Figure 11 only 2.1% of N_2O from source compartment were transferred to the exposed compartment after installation of the sealing membrane during the lab tests

From Eq. (9) it was calculated that inclusion of the sealing membrane reduced transfer of UFP down to 97%. Likewise inclusion of sealing membrane reduced the transfer of N_2O down to 87%.

In-situ measurements

Method

In principle, contaminants in any apartment can migrated from any of the adjacent apartment as shown in Figure 12.

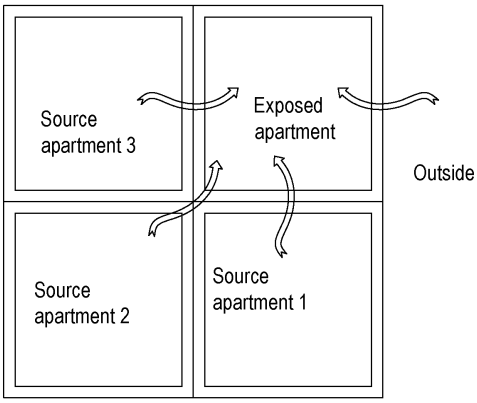

Figure 12 schematic of particle transfer into one apartment from adjacent apartments and outside

However, previous studies have shown that the dominant parts of contaminants transfer in any apartment is due to the apartment which is exactly below that apartment as shown in Figure 13 (Afshari et al. 2010).

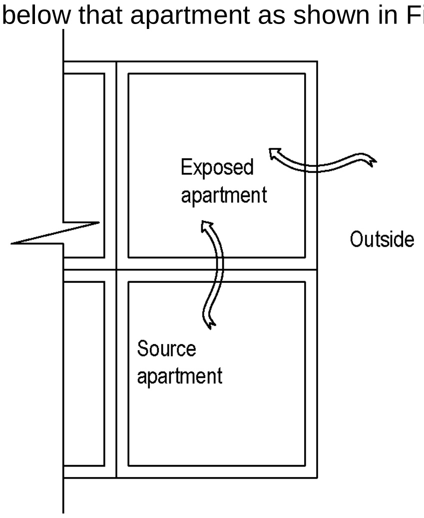

Figure 13 assumption that the main source of contaminants transfer are from the apartment below and outside

Therefore to reduce the complexities involved in the real life measurements, some assumptions were made – which are as follows:

1) The source apartment is situated exactly below the exposed apartment – as shown in Figure 13
2) The temperature outside all the boundaries of the exposed apartment (except the floor) is outdoor temperature – as shown in Figure 14
3) The contaminants concentration on one side of exposed apartment (where the measuring instrument was set-up) represents the average outdoor contaminants concentration
4) Contaminants concentration in the source apartment are uniformly distributed

5) Temperature in the source and exposed apartment is uniform
6) The ventilation rate obtained through passive tracer gas techniques represents the ventilation rate during the measurements.

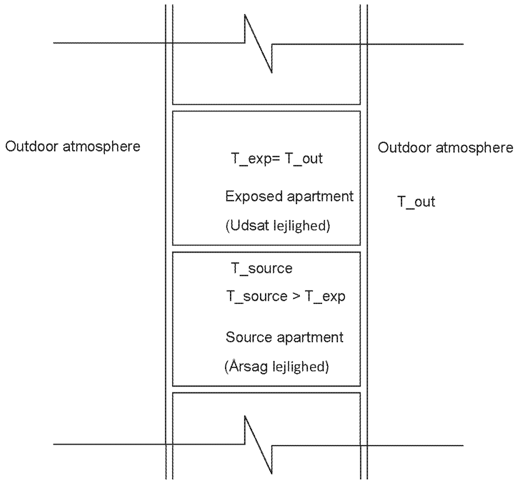

Figure 14 temperatures in the exposed apartment, source apartment and outdoor atmosphere

To analyse the performance of the sealing membrane in-situ, three apartments were selected in Copenhagen Denmark. The residents were already planning to renovate their apartment because of the following two reasons.

- The apartment was in need of refurbishment
- The residents were smelling cigarette smoke in their apartment.

However, due to insufficient results in one of the apartment, only two apartments are reported here in the present report. In-situ measurements were divided into two parts. Part 1 was the measurements of the transfer of contaminants in the existing floors of the apartments. Part 2 was the measurements of contaminant transfer after installation of the sealing membrane.

In Part1 of the measurements, all radiators of the exposed apartment were turned off and windows were opened to reduce the temperatures. After one hour all the windows were closed. Radiators in the source apartment were set to maximum to create a temperature difference. Moreover, portable heaters were also placed in the source apartment. It was also make sure that all the internal doors in both apartments are open i.e. creating a single zone. Three temperature loggers were placed in the exposed apartment. Three loggers were placed in the source apartment and one outdoor in order to measure the outdoor temperature and relative humidity. One particle counter was placed in the source apartment, one particle counter in the exposed apartment and one outside in order to measure background concentration. *The transfers of UFP were examined in the onsite measurements.* All counters were co-calibrated before the use. The instruments used in-situ measurements were same as used in the lab tests. The measurement steps were as follows:

1) Measurements of leakage through the floor
    a. Using passive tracer gas techniques[5]
    b. It was done before the measurements for a week
2) Measurements of the air change rates
    a. Using passive tracer gas techniques
    b. It was done before the measurements for a week
3) Creation of a pressure difference
    a) Turning off the radiators in the exposed apartment and opening of the windows until the room temperature reaches approximately outdoor temperature then closing of the window

[5] PFT Techniques

a. Turn on the radiator in the source compartment to create a pressure difference due to the difference in temperatures

4) Measurements of temperatures and humidity in both apartments and in outdoor
5) Measurements of UFP in both apartment and outdoor
6) Lighting a cigarette in the source apartment
7) Using a portable fan, mixing of the air in the source apartment
8) Monitoring and logging of the data in step 5 and 6.

Instruments used in-situ and in laboratory were same. During the measurements it was make sure that temperature in the source apartment is greater than the temperatures in the exposed apartment as shown in Figure 14. Afterwards, Part 2 of the onsite measurements was carried out. The measurement procedure in Part 2 was same as of Part 1.

Findings

Apartment 1 – Irmingersgade 9, 2100 Copenhagen

Part1

Part 1 of measurement (before the renovation) was conducted exactly in the same manner as mentioned in the Method section. During the measurements the temperature difference was approximately 3 K. The area of the apartment 1 was 37.3 m^2 with an average height of 2.72 m.

UFP concertation in the source and the exposed apartment are shown in Figure 15. The increase in UFP concentration in the exposed apartment was due to the increase in UFP concentration in the source apartment.

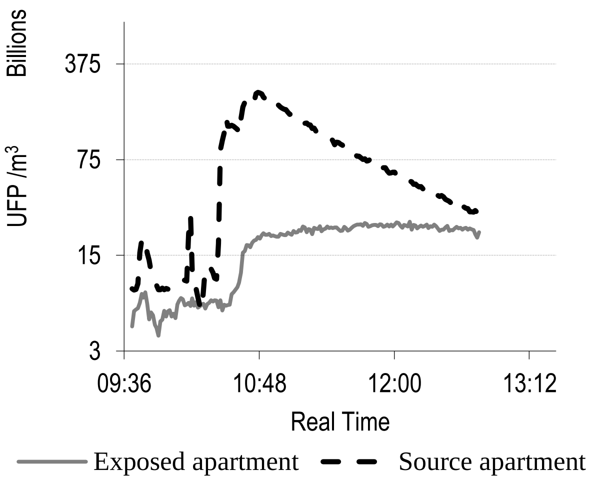

Figure 15 variations in UFP concentration in the source and the exposed apartment before the renovation of Apartment 1

Using Eq. (6) the calculated value of UFP concentration in the exposed apartment was obtained. The leakage rate was $\dot{V}_{leak} = 20m^3/h$. The sink rate that gave the best possible correlation with the measured values was $\gamma = 0.5$. The calculated and measured values of UFP concentrations in the exposed apartment are illustrated in Figure 16. Outdoor UFP concentrations are also mentioned in Figure 16. Using Eq. (8) it was calculated that the 16.2% of UFP from the source apartment was transferred into the exposed apartment.

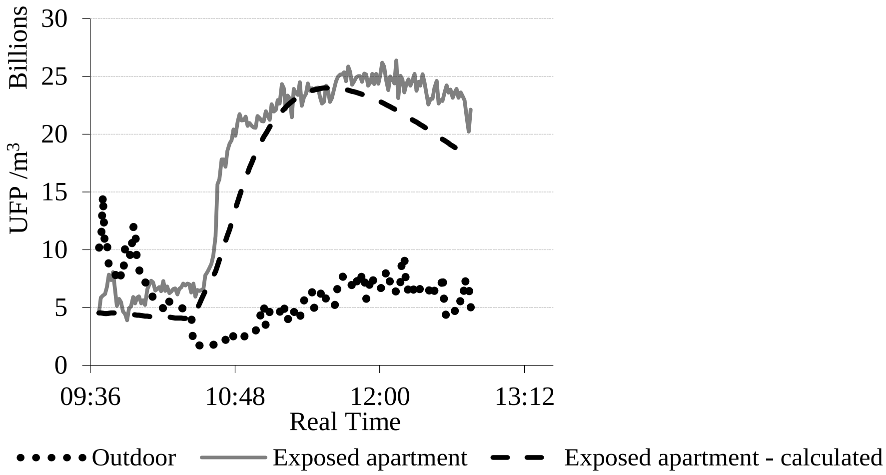

Figure 16 up to16.2% of UFP from the source apartment were transferred to the exposed apartment before the renovation of Apartment 1

Afterwards the apartment was renovated. The placement of the sealing membrane was carried out according to the guidelines provided by the manufacturer[6]. Few photos that were taken during the renovation work are shown in Figure 17.

Figure 17 condition of wooden flooring during the renovation

Figure 18 shows how the sealing membrane was placed before final wooden flooring. During the renovation, SBi provided the required quantity of the sealing membrane for the apartments.

[6] http://ctrap.se/en/installations/

Figure 18 installation of the sealing membrane (cTrap)

Part 2

After installation of the sealing membrane and the complete renovation of Apartment 1, Part 2 of the measurements was carried out. The measurements in Part 2 were carried out in the similar manner as of Part 1. UFP concentration in the source and the exposed apartments are shown in Figure 19.

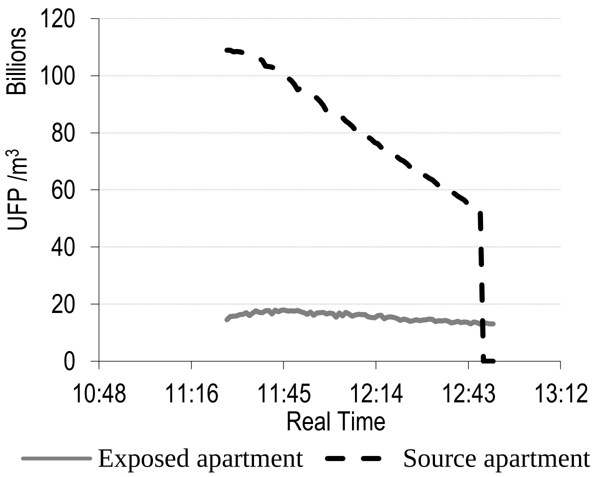

Figure 19 variation in UFP concentrations of the source and the exposed apartment after the renovation of Apartment 1

The increase in UFP concentration in the exposed apartment due to the increase in UFP concentration in the source apartment was not as high as it was before the renovation. However, for accurate analysis, the calculated values of UFP concentrations in the exposed apartment were obtained using Eq. (6) and are shown in Figure 20. The outdoor concentration and the measured UFP concentration in the exposed apartment are also shown in Figure 20. The calculated values are obtained by using $\dot{V}_{leak} = 15m^3/h$ and $\gamma = 0.5$ i.e. same value as used in Part 1. The difference in temperature during the measurement was 2K.

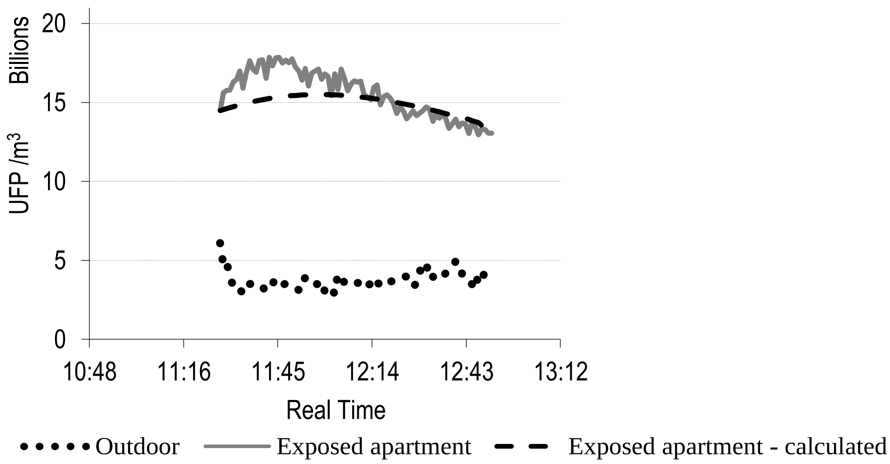

Figure 20 only 7.6% of UFP from the source apartment were transferred to the exposed apartment after the renovation of Apartment 1

Using Eq. (8) it was calculated that only 7.6% of UFP were migrated from the source apartment to the exposed apartment. Using Eq. (9) it was calculated that installation of the sealing membrane reduced the transfer of UFP down to 53%.

Apartment 2 – Hørsholmgade 26, 2200 Copenhagen

Part 1

A set of measurement before the renovation was conducted exactly in the same manner as of Apartment 1. The average difference in temperature between the source and the exposed apartments were 5K. The area of the apartment 1 was 60.1 m^2 with an average height of 2.5 m. Similar to the Apartment 1, passive tracer gas techniques were used to determine the air change rates and the leakage through the floor. Figure 21 shows UFP concentration of exposed and the source apartment during Part 1 of the measurements.

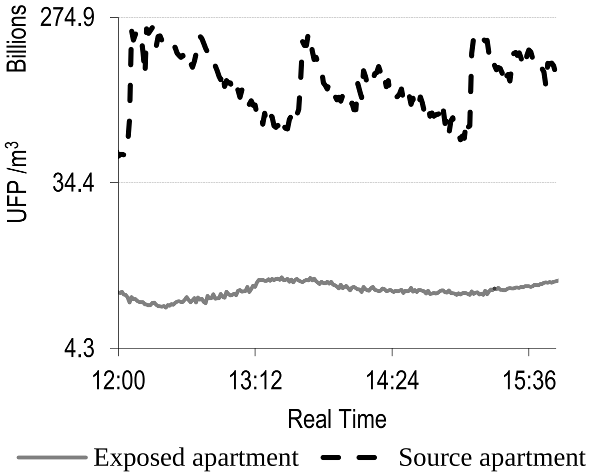

Figure 21 variations in UFP concentration in the source and the exposed apartments before the renovation of Apartment 2

Using Eq. (6) the calculated values of UFP concentration in the exposed apartment were obtained which are illustrated in Figure 22 along with the measured UFP concentration and outdoor UFP concentration.

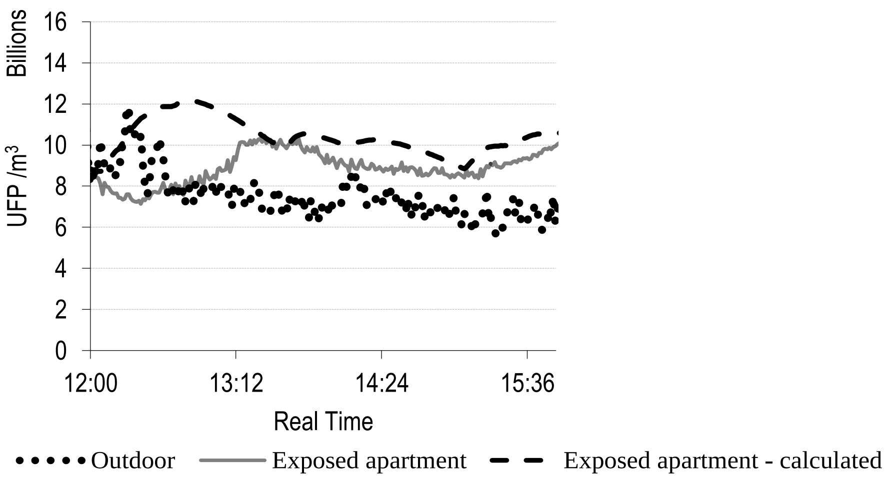

Figure 22 up to 4% of UFP from the source apartment were transferred to the exposed apartment before the renovation of Apartment 2

The calculated values in Figure 22 are obtained from the measured value of leakage through the floor i.e. $\dot{V}_{leak} = 10m^3/h$ and the particle sinking rate of $\gamma = 0.5$. From Eq. (8) it was calculated that 4% of UFP were transferred from the source apartment to the exposed apartment.

Part 2

The membrane sealing was placed in the similar manner as shown in Apartment 1. After the renovation, Part 2 of the measurements was carried out using the same measurement procedure as of Part 1 of the measurements.

UFP concentration in the source and the exposed apartments during Part 2 of the measurements are illustrated in Figure 23. The increase in UFP in the exposed apartments was due to the increase in UFP in the source apartment. The decrease in UFP with time is due to the ventilation rates. The difference in temperatures between the source and the exposed apartment was 4.8 K.

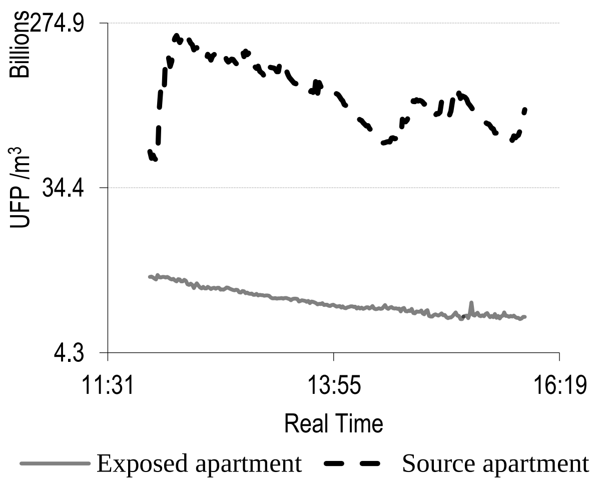

Figure 23 variations in UFP concentrations of the source and the exposed apartments after the renovation of Apartment 2

Using Eq. (6) calculated concentrations of UFP in the exposed apartment were obtained. Calculated concentrations and the measured concentrations in the exposed apartment are illustrated in Figure 24. Outdoor UFP concentration is also mentioned in Figure 24. The calculated values are obtained with the measured leakage rate of $\dot{V}_{leak} = 1m^3/h$ and the particle sinking value of $\gamma = 0.5$ i.e. same as Part 1.

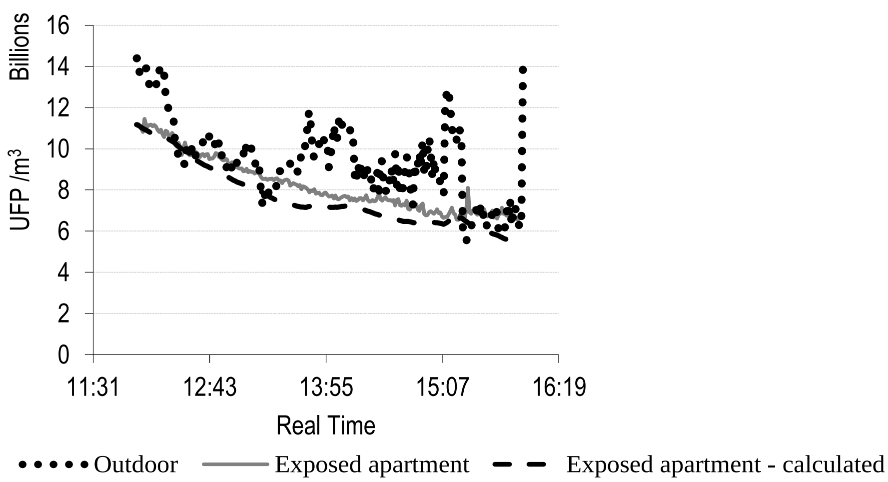

Figure 24 only 1.6% of UFP from the source apartment were transferred to the exposed apartment after the renovation of Apartment 2

Using Eq. (8) it was calculated that after renovation only 1.6% of UFP were transferred from the source apartment to the exposed apartment. Using Eq. (9) it was calculated that inclusion of the sealing membrane reduced the transfer of UFP down to 60%.

Problems, errors and sources of errors during the insitu measurements

Insitu measurements were performed before the laboratory measurements. The purpose of laboratory measurements were reduced the uncertainties in understanding the insitu performance. During insitu measurements, certain data was lost due to mishandling of the instruments. Foremost are the leakage rates through the ceiling of the exposed apartments. The data for the leakage rates through the ceilings were only available for after renovation measurements. Therefore the leakage rate before the renovation was calculated in an indirect manner. First using the measured leakage rate (using PFT) after the renovation was used to estimate the approximate sink rates of the particle in Eq. (7). Then the sink rate of after renovation measurements was assumed to be the same for the particles in before renovation measurements. Afterwards the leakage rates before the renovations were obtained by choosing the value that fits the curve shown in Figure 16 and Figure 22.

Similarly to measure the transfer of gases CO_2 was used in both apartments. However, due to some unknown errors in the measurements, results were discarded as it was impossible to make any conclusion out of them. Hence the laboratory experiments were performed for the analyses gas transfer as well as particle transfer in a controlled environment.

Occupants perception

After four months of the renovation the occupants' were asked to express their perception regarding the performance of the membrane in achieving the adequate indoor environment. An online questionnaire was distributed to the occupants. The questions and answers from the residents of each apartment are as follows:

Questions	**Answers**	
	Apartment 1	Apartment 2
Before the renovation		
To what extent were you bothered by the cigarette smoke before the renovation?	*High*	*High*
Did you experience any symptom of smoke on your or others in your apartment e.g. any disease or continuous illness?	*Low*	*No*
To what extent were you bothered by the other smells from other apartments e.g. cooking?	*Low*	*Medium*
Did you visualize the any dust particles coming from other apartment into your apartment?	*Low*	*No*
After the renovation		
Have the installation of sealing membrane reduced the smell(s) neighboring apartments?	*High*	*High*
Have the installation of sealing membrane changed the indoor air quality in any other ways, which are not associated with the smell of smoke?	*Yes*	*Yes*
How?	*Low ventilation is required*	*Better indoor air quality*
Would you like recommend others to use cTrap to stop odors from smoke or other types of odors?	*Yes*	*Yes*

The residents of both apartments were bothered by the smell from their neighbors. Even the residents of Apartment 1 were also occasionally able to visualize the particles in their apartment. However after installation of the sealing membrane both residents are highly satisfied. Moreover the residents of both apartments also perceive that indoor air quality is improved after renovation.

DISCUSSION

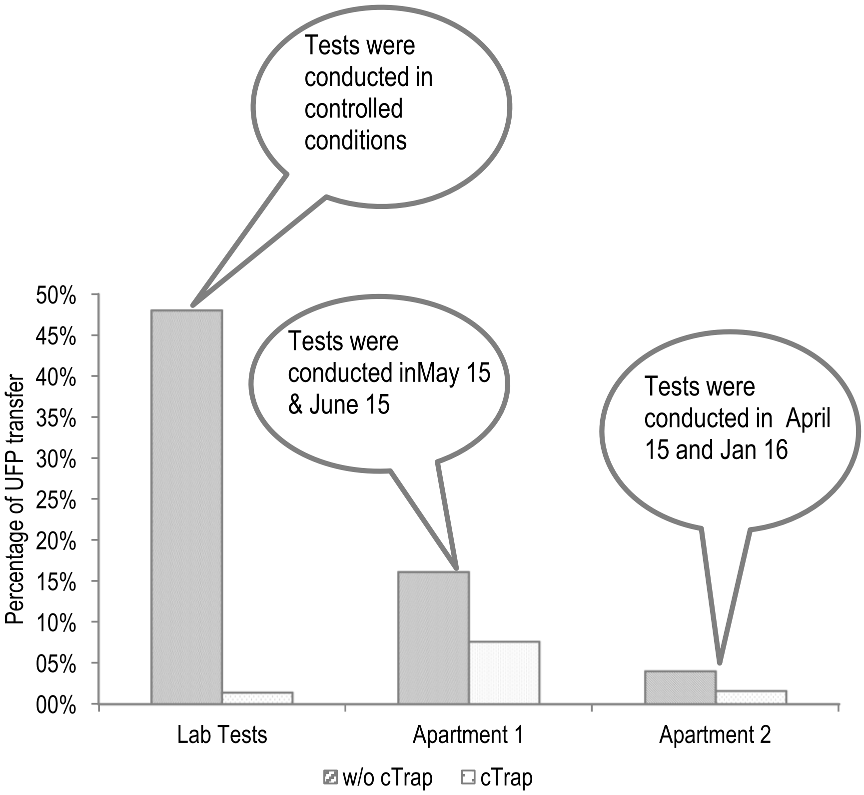

Figure 25 summary of the performance of the sealing membrane at different locations

The findings from the present study are summarised in Figure 25. The findings from the present study are an important step towards the understanding of performance of the membrane as a sealing against contaminants. However, contaminants transfer depends on several factors; some are uncontrollable especially in-situ measurements. Therefore in the present study there was a difference in the performance of membrane sealing in the laboratory and in-situ. In laboratory, where the floor was the only possibility of transferring of particles, the sealing reduced the transfer of UFP down to 97% and transfer of N_2O down to 87.5% from source to exposed apartment. Whereas; in-situ results showed that, in real life it is difficult to seal the floor as exactly as in the laboratory conditions. Therefore in real conditions the sealing membrane reduced the transfer of UFP down to 53% to 60% as shown in Figure 26.

Concentrations of outdoor UFP were measured on the one side of the apartments. However, due to the fact that outdoor particle concentration fluctuates among different outdoor locations for instance UFP concentration on the north side could be different from UFP concentration on the south side. Therefore there is a possibility of uncertainty in the accurate values of particles that are being transferred from outdoor. Likewise there is a possibility that the particles in the source apartment are not uniformly distributed.

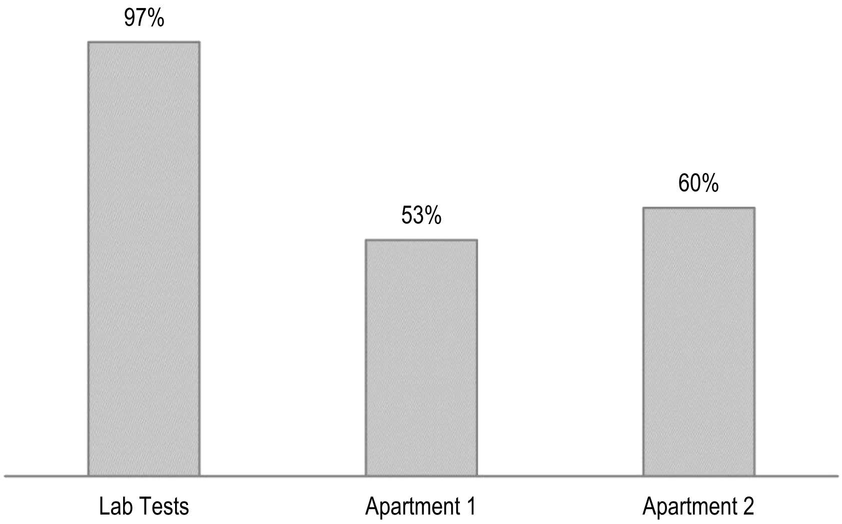

Figure 26 percentage of reduction in UFP transfer from source apartment to the exposed apartment during the study

Other possible reasons of underperformance of the membrane in-situ were the fact that the difference in temperature between source and exposed apartment was different during the measurements before and after renovation. These are the limitations that cannot be overcome in the real life experiments. Another possible reason of the underperformance of the membrane (in comparison with the lab tests) is the fact that in real apartments, there is always a chance of particle transfer through passages other than floor e.g. crakes in walls, electrical sockets, exhaust ducts etc.

The benefit of the studied sealing membrane over other solutions of contaminant reduction is that the sealing membrane stops and captures the contaminants before entering into the exposed zone instead of diluting the concentration of contaminants after they enter into the exposed zone. Therefore the occupants will be exposed to a reduced number of UFP whenever the cTrap will be used as sealing membrane against contaminants.

A small occupants survey was conducted after the renovation which showed that the occupants, before the refurbishment, were continuously irritated by cigarette smell from their neighbours. However, the occupants are fully satisfied with the performance of the membrane sealing as the occupants are not smelling cigarettes anymore. Moreover, after installation of the sealing membrane occupants are perceiving better indoor air quality.

Future work

To fully understand the performance of the sealing membrane, there is a need to analyse the performance at several temperature differences i.e. between source and exposed, exposed and outdoor. Likewise there is a need to analyse the performance of the sealing membrane after few years of installation in real life.

CONCLUSIONS

A novel sealing membrane was used to trap and stop the transfer of contaminants between two spaces. The study showed that the sealing membrane can trap the significant percentage of the UFP and N_2O. In ideal situation, i.e. laboratory conditions, the membrane reduced the transfer of UFP down to 97% and N_2O up to 87%. In real conditions i.e. in-situ, the membrane reduced the transfer of UFP down to 53% to 60%. A small occupant's survey was conducted after the renovation which shows that the users are fully satisfied with the performance of the membrane sealing and they perceive better indoor air quality. Hence it is concluded that the studied sealing membrane is an effective solution in trapping and stopping unwanted contaminants.

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Bilag 2

Produktblade cTrap

cTrap

www.ctrap.se
johan.mattsson@ctrap.se

The cTrap is a multilayer functional cloth developed to eliminate emissions in buildings with moisture related problems such as mold and odors. The cTrap captures the emissions at the source which immediately results in a fresher and healthier indoor air. The product is a result of more than 20 years of research on the indoor environment conducted at the Department of Laboratory Medicine, Lund University.



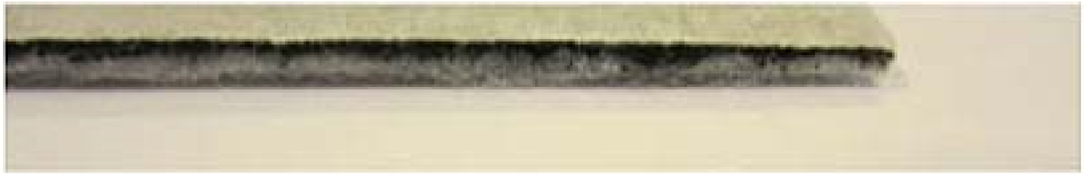

1 roll of 30 x 1.15 m. Thickness:1.9±0.1 mm.

Function

In a recently published study* the cTrap was found to reduce air concentrations of 20 different tested emission products commonly found in damp and moldy buildings, with an average of 98 percent. Mycotoxins were completely reduced, ie. with 100 percent, while water vapor substantially freely passed through the cTrap cloth. Radon is being captured efficiently. **

*Markowicz P, Larsson L, J Microbiol Meth 91:200-204, 2012
**SP report PX22726, 2012

Deliverability:
Over 100.000 sqm/year in a quality assured manufacturing process.



Four layers

1. An inner protective layer
2. An outer protective layer
3. An adsorption layer
4. A semipermeable barrier allowing more effective adsorption

The cTrap has an inside and an outside and adsorbs only emissions coming from the inside.

Installation

The cTrap is applied using a double sided adhesive tape directly on the surfaces (floor, wall, ceiling, over cavities and chinks etc.) from which the emissions are spread. Over the cTrap cloth is thereafter laid for example a laminate floor or (on ceilings and walls) a thin gypsum board. For best results the cTrap should be kept dry also after installation.

Contact

Johan Mattsson
+46 735-086533
johan.mattsson@ctrap.se

Bilag 3

Icopal dampspærre

ICOPAL IcoVario®

Anvendelse
IcoVario anvendes som dampspærre.

Egenskaber
IcoVario, der er en fugtadaptiv dampspærre, giver mulighed for, at fugt i tag-, loft- og vægkonstruktioner kan afgives indad til rummet i forbindelse med udtørring af konstruktionen. Fugttransporten foregår ved vanddampdiffusion gennem en aktiv film. IcoVario er patenteret.

Produktdata			**Blad nr. 154**
Opbygning Overside Underside	 Kunststoffilt pålagt i striber. Perforeret plastfolie.		
Farve	Blå.		
Montage	IcoVario udlægges med min. 5 cm i overlæg, som tapes sammen over fast underlag. Den plastbelagte side med tekst skal vende mod det opvarmede rum. Gennemføringer og samlinger samt tilslutninger til tilstødende bygningsdele skal tætnes med de af Icopal anbefalede produkter, herunder Icopal Rørmanchetter, Icopal Universaltape og Icopal Folieklæber.		
Tekniske data	Enhed	Værdi	Prøvningsmetode
Længde	m	40,0 +1/-0 %	EN 1848-2
Bredde	m	1,25 ±1 %	EN 1848-2
Tykkelse	mm	0,3 ±25 %	EN 1949-2
Vægt	kg/m^2	0,130 ±15 %	EN 1849-2
Trækstyrke, langs Trækstyrke, tværs	N/50 mm	> 150 > 100	EN 12311-2
Brudforlængelse, langs Brudforlængelse, tværs	%	> 40 > 20	EN 12311-2
Sømrivestyrke, langs Sømrivestyrke, tværs	N	> 100 > 100	EN 12310-1
Vandtæthed	kPa bestået	> 2	EN 1928
Diffusionsmodstand, Z	$GPasm^2/kg$	> 600	EN 1931
Dampspærre, type A EN 13984			

Icopal Danmark a/s,
Lyskær 5
DK-2730 Herlev, Danmark

11. november 2014

Denne rapport fremlægger resultaterne af en feltafprøvning af en metode til at nedbringe luftoverførslen mellem etageboliger. Feltafprøvningen viser, at ved at tætne etageadskillelsen med en særlig membran kan man halvere overførslen af ultrafine partikler fra en underliggende til en overliggende lejlighed. Den anvendte membran af fabrikatet cTrap er dermed et lovende bud på en metode til at reducere naborøg i etageboliger.

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