

Low-cost sensors for measuring particles and dust in the air



Presenter: Ana Sofia Fonseca (contact: agf@nfa.dk)

Co-authors: P. Kines, A. Brostrøm, J.B. Liisberg, S.H. Møller, T.N. Jensen, J.T. Rasmussen, F. Pleva, S.B. Jensen, J. Thalmann, T. Cole-Hunter, K.A. Jensen

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- 02 Objectives
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- 05 Safety culture assessment
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Introduction & motivation

WHY WE NEED LOW-COST DUST MONITORING?

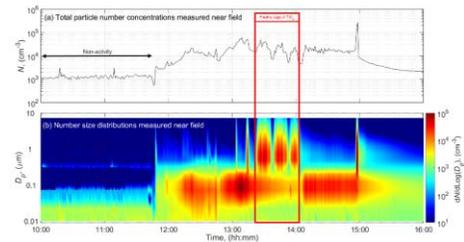
Invisible risks at work

- Millions of workers breathe millions of fine and ultrafine particles every day.
- These exposures silently drive asthma, COPD, silicosis, heart disease, and cancer.



Existing tools and their challenges

- Filter sampling is accurate, but slow.
- Time-resolved instruments: precise, but expensive and hard to use daily.
- Most workplaces simply can't see exposure as it happens.



Low-Cost Particle Sensors

- Compact. Affordable. Real-time.
- Detects emissions as they occur and empowers action.
- Turns invisible dust into visible data that workers and managers can understand instantly.



Promising, cost-effective solution for enhancing worker safety

Invisible dust → visible data → safer workplaces

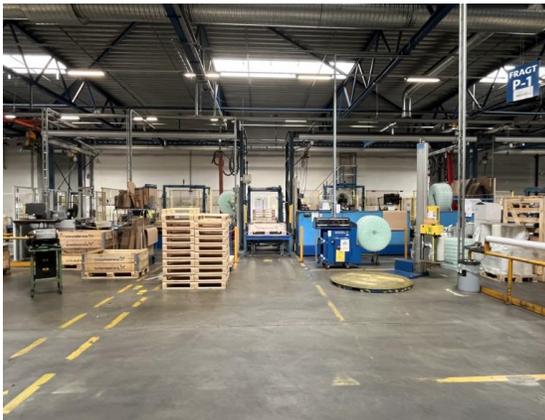
Objectives



OBJECTIVES

Can low-cost sensor-based monitoring improve the management of airborne particle exposure in workplaces?

1. Baseline measurements and identification of focus areas
2. Assessment of safety cultures
3. Establishment of sensors and dashboard
4. Integrate real-time feedback into risk management practices (dashboard with live and historical data)
5. Follow-up measurements to evaluate improvements and validate sensor performance and usability



Pump manufacturing
(distribution center)



Glass wool-based insulation
manufacturing (cutting and melting
process)



Plastics recycling
and manufacturing
(mixing station)



Building renovation or
demolition

Methodology

METHODOLOGY

1. Measurement strategy



2. Time-resolved measurements (LCS+Reference)

Low-cost sensor (LCS)



Alphasense OPC-N3

Benchmark instruments



OPS TSI 3330,
NanoScan TSI



4. Safety culture assessment



<https://nfa.dk/safetyobserver>



Interviews
and surveys
(VAI-2017 and
NOSACQ-50)

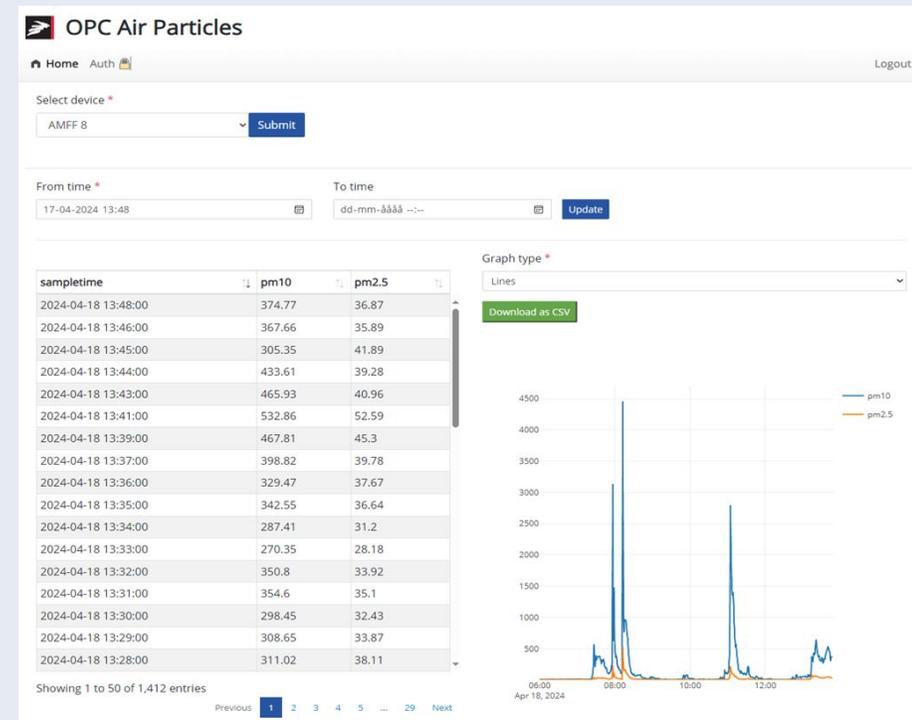
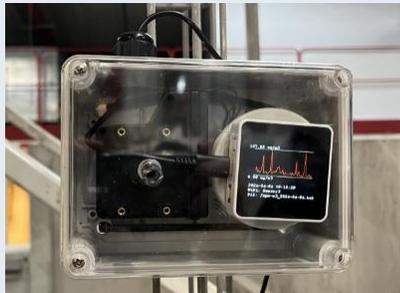
3. Complementary personal dust monitors and samplers



5. Data analysis

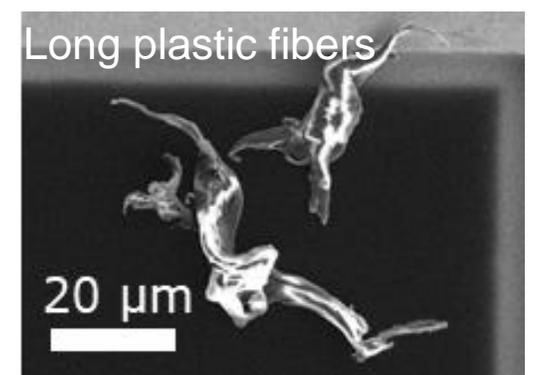
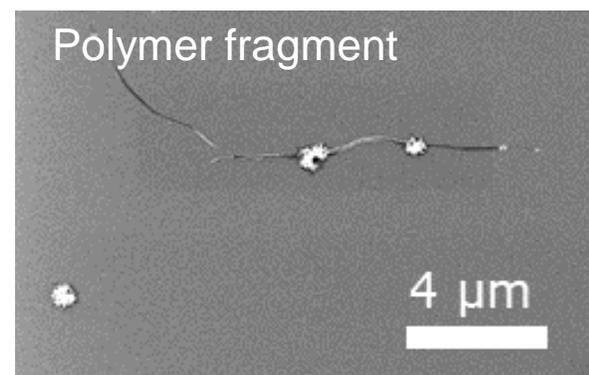
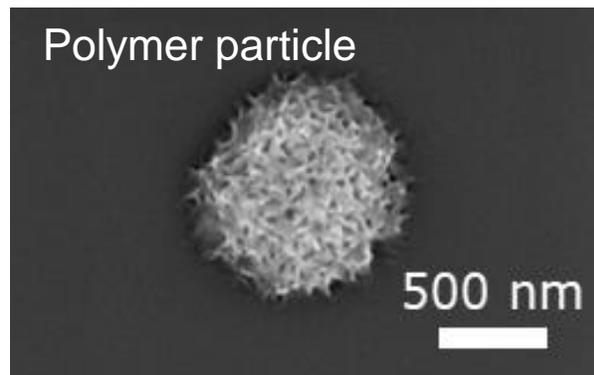
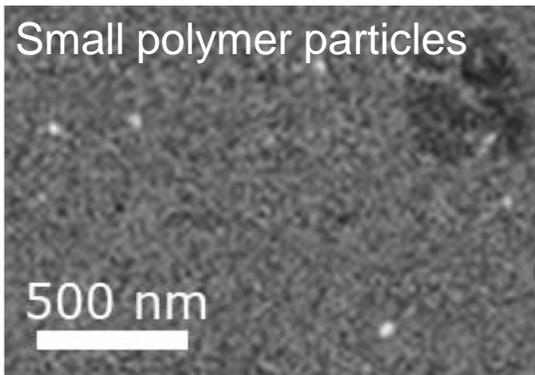
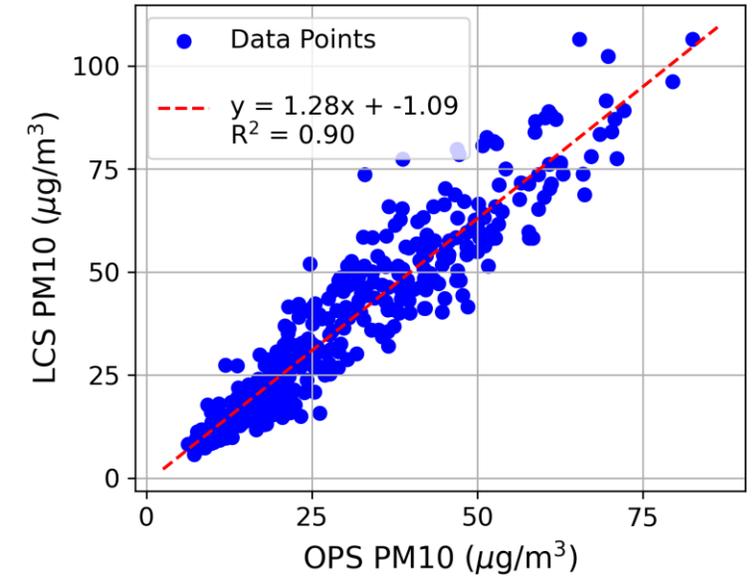
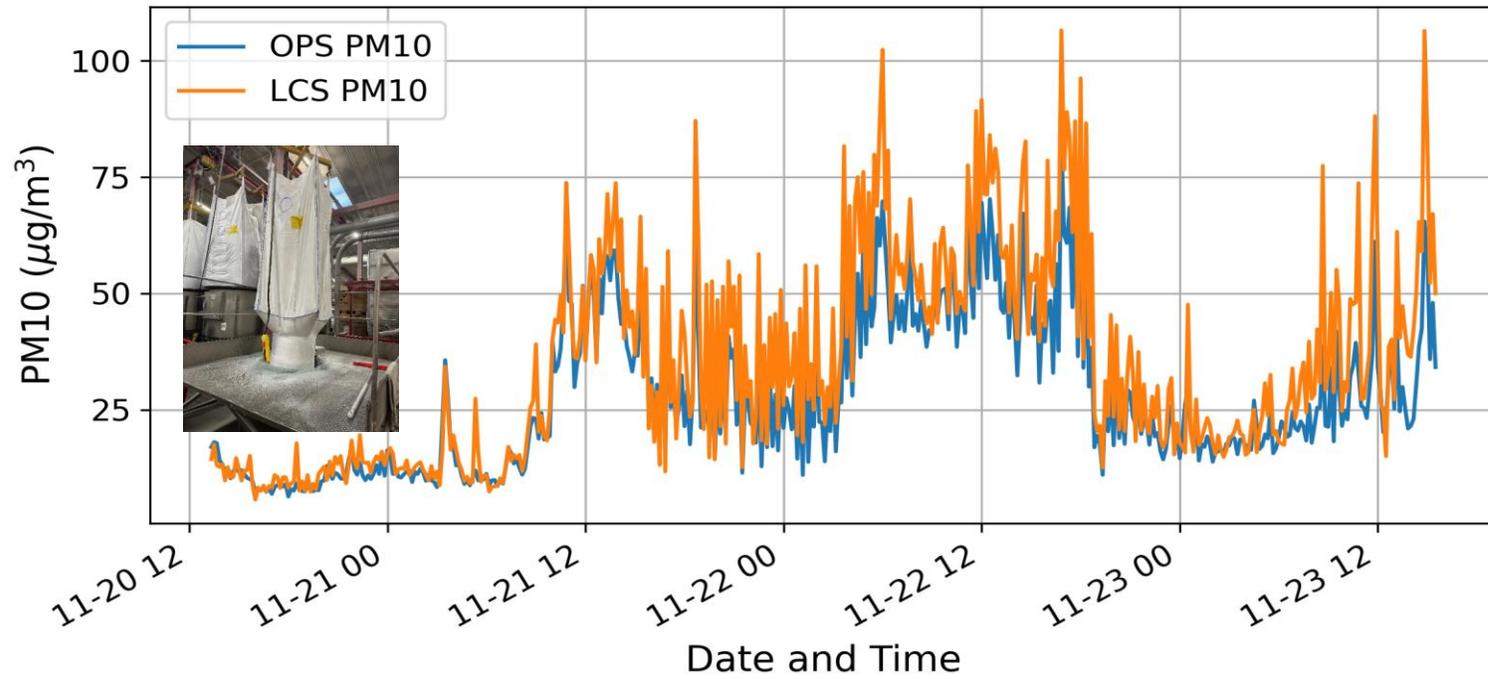
Pre- vs. post-intervention exposure levels to validate the effectiveness of the LCS and measure shifts in safety awareness and practices

Low-cost sensor performance



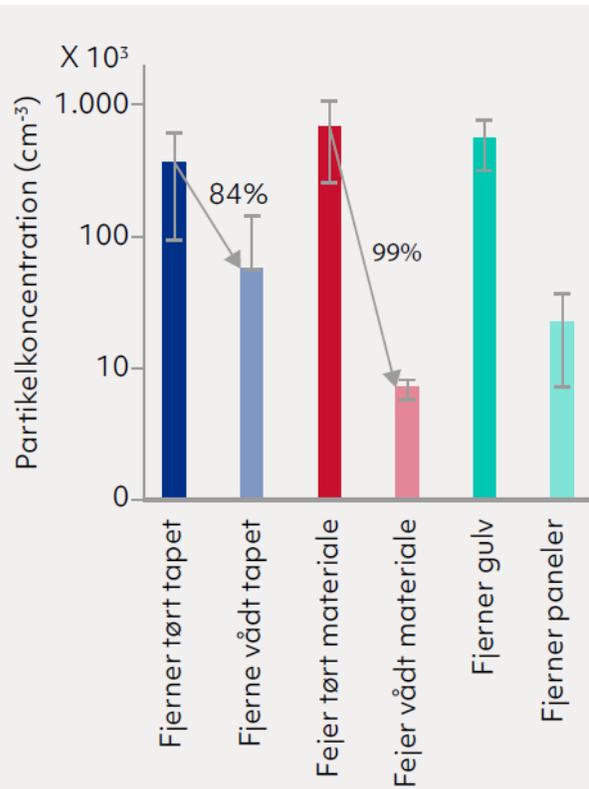
SENSOR PERFORMANCE

MIXING AT RECYCLED PLASTICS MANUFACTURING

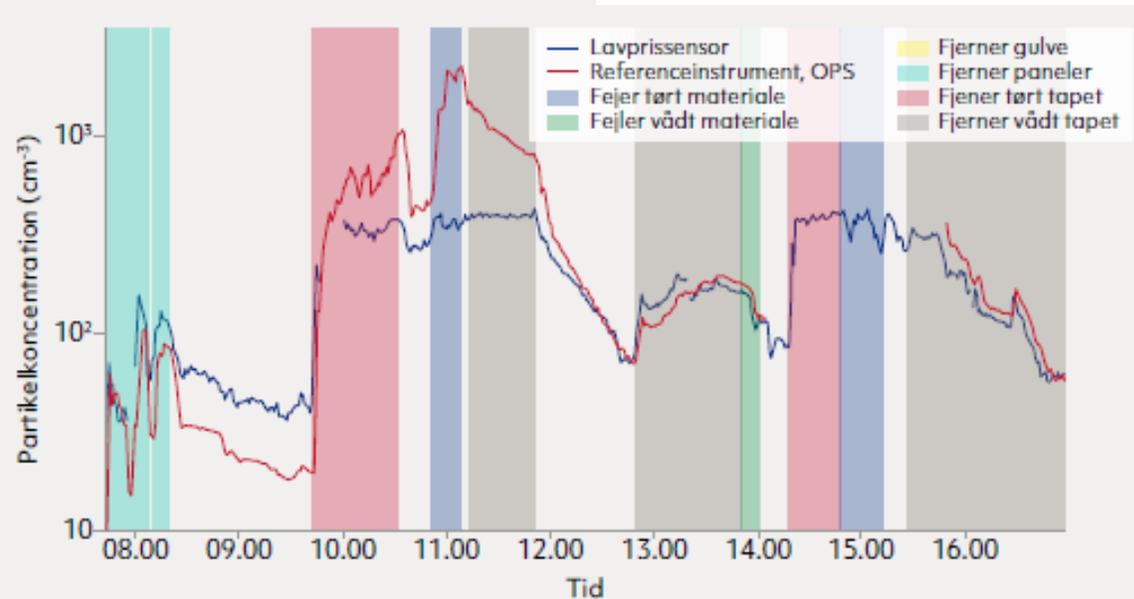


SENSOR PERFORMANCE

BUILDING RENOVATION TASKS



- Highest concentrations during floor removal, wallpaper removal, and dry sweeping.
- Dominated by small particles (63% ultrafine <0.1 μm; 96% <2.5 μm (respirable fraction)).
- LCS captured temporal variations and task-related exposure patterns.
- Wet methods reduced particles by 84-99%.
- Systematic underestimation of PN and PM fractions (especially PM₁).



ATMOSPHERIC ENVIRONMENT: X 26 (2025) 100336

Contents lists available at ScienceDirect

Atmospheric Environment: X

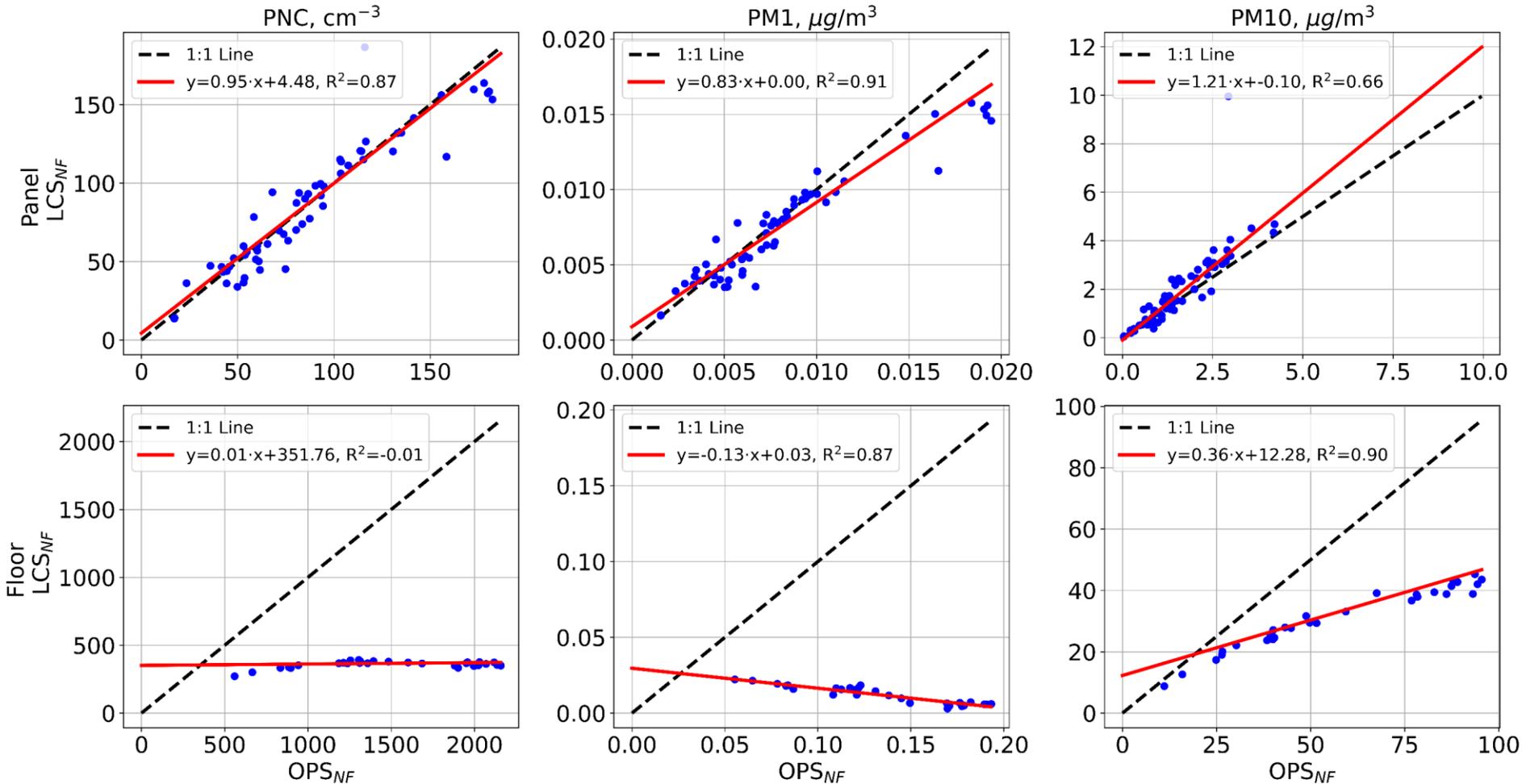
journal homepage: www.journals.elsevier.com/atmospheric-environment-x

Task specific assessment of particle exposure and low-cost sensor performance in indoor construction environments

Anders Brostrøm ^{a,1}, Josephine Thalmann ^{a,b,1}, Jesper Baldtzer Liisberg ^a, Frederika Husovská ^a, Søren Hanghøj Møller ^c, Julie Tølbøl Rasmussen ^c, Thomas Nørregaard Jensen ^c, Søren Bendt Jensen ^a, Keld A. Jensen ^a, Thomas Cole-Hunter ^{b,2}, Ana S. Fonseca ^{a,*,2}

SENSOR PERFORMANCE

BUILDING RENOVATION TASKS



Low PN and PM levels

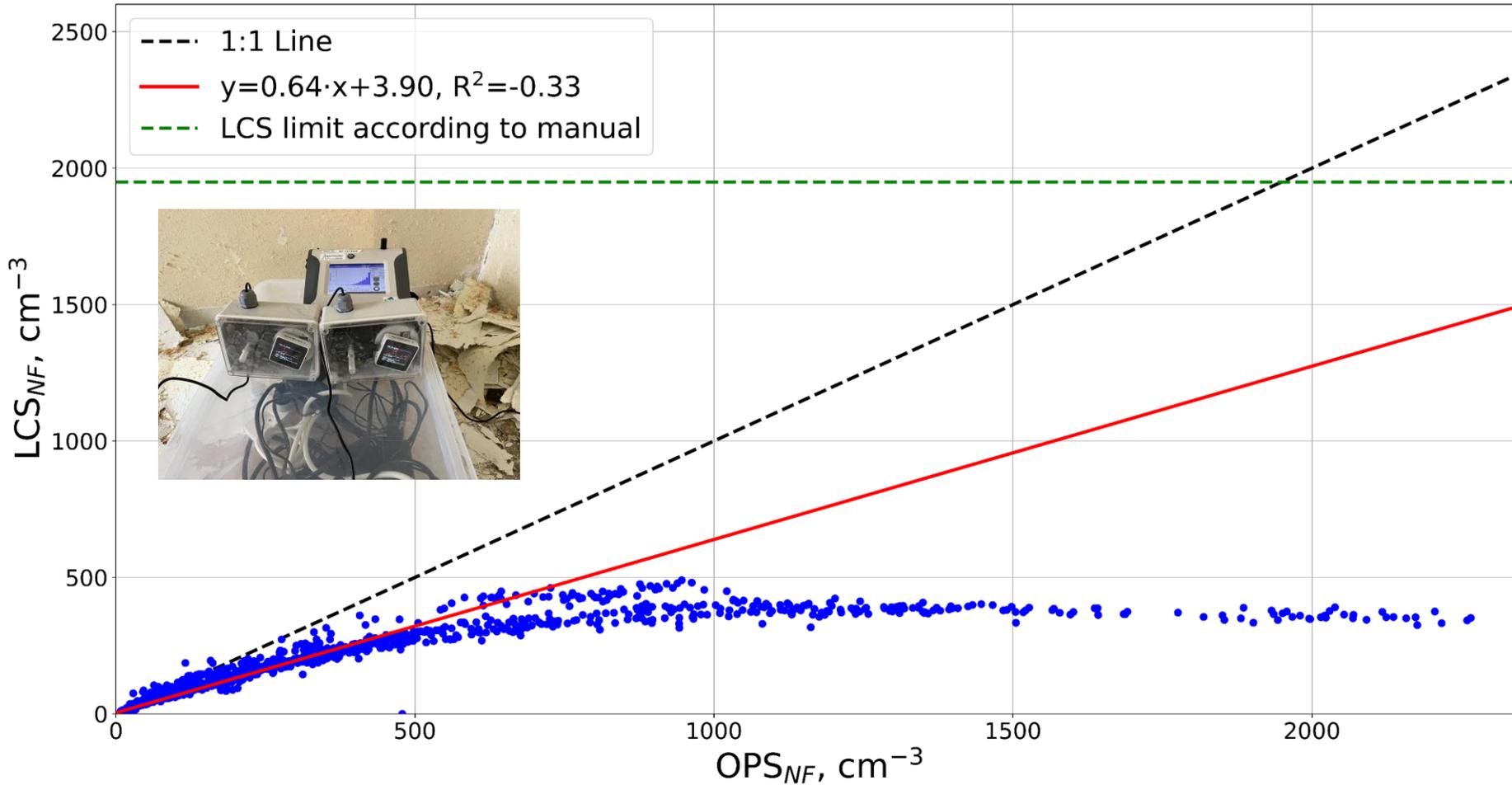


High PN and PM levels



SENSOR PERFORMANCE

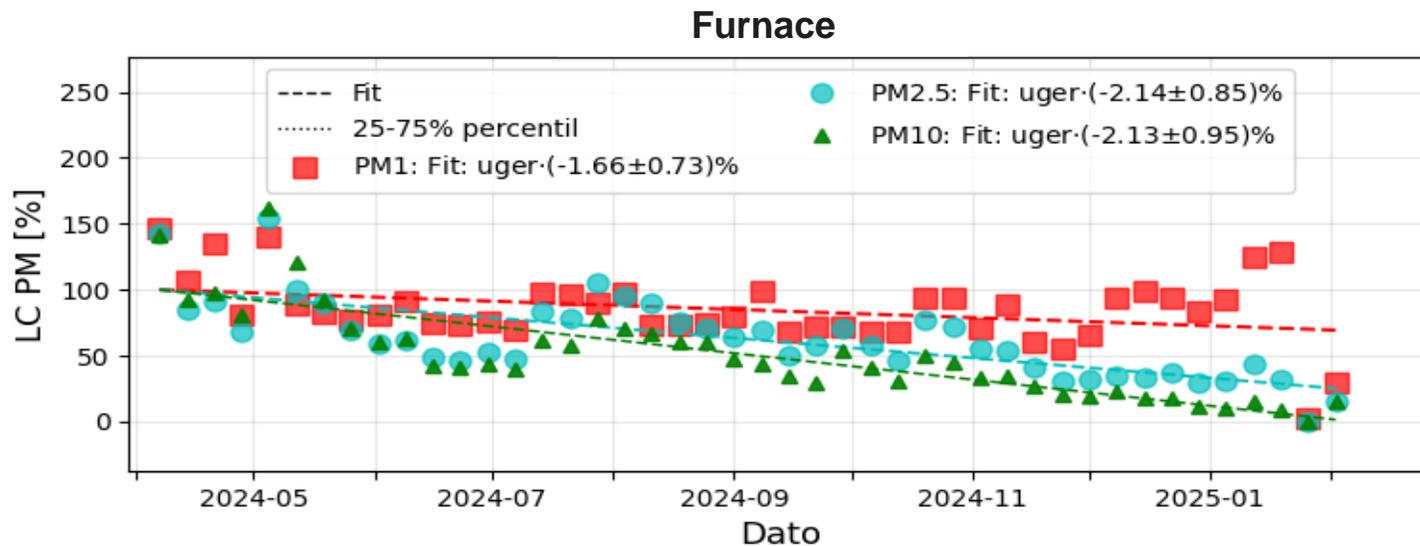
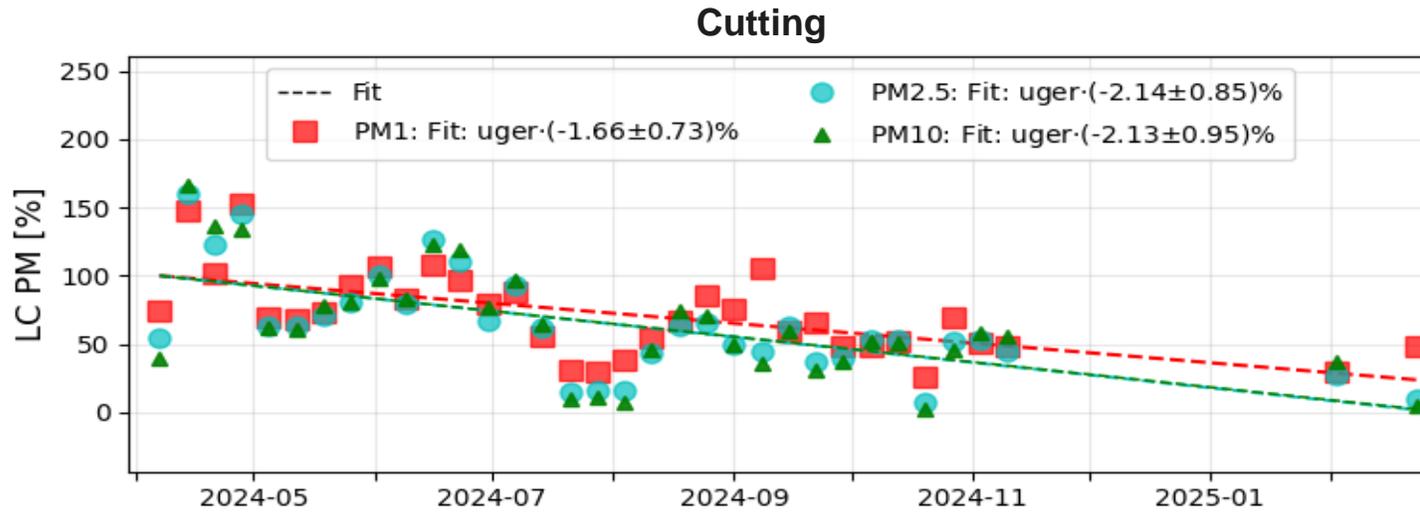
BUILDING RENOVATION TASKS



Low-cost sensor signal saturates above 400-500 particles/cm³

SENSOR STABILITY AND DRIFT

GLASS WOOL-BASED INSULATION MANUFACTURING (CUTTING AND MELTING PROCESS)

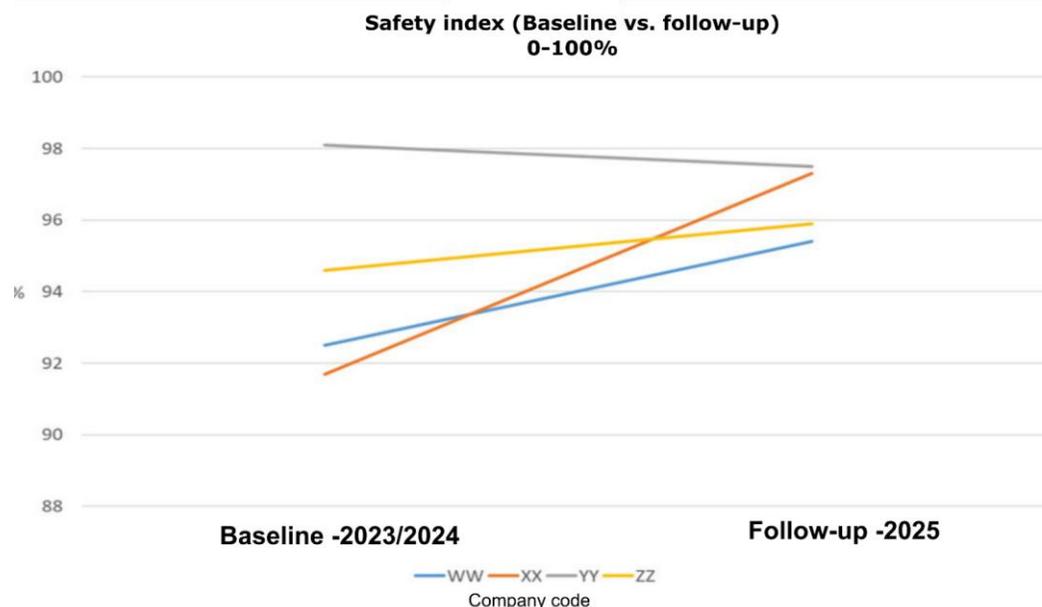
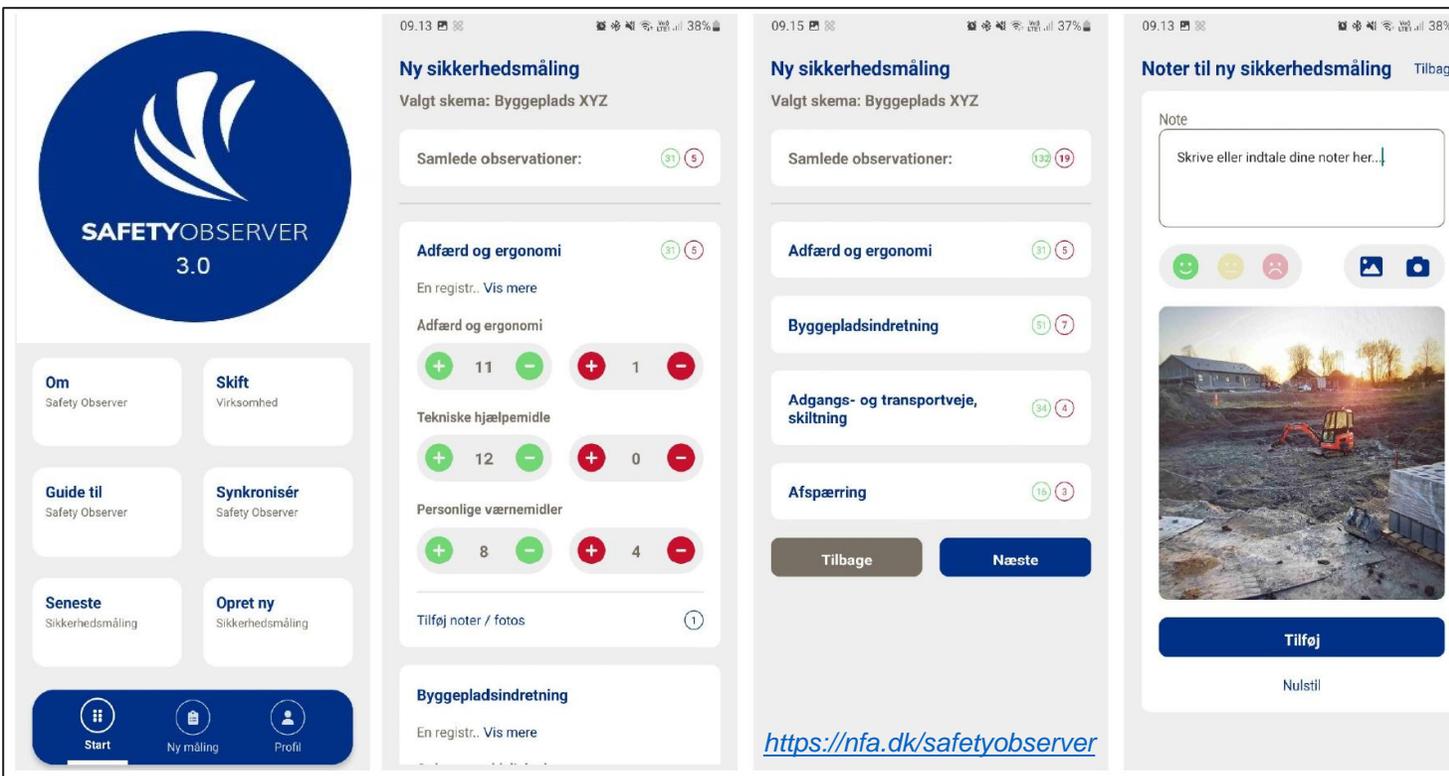


- Values normalized to the first fitted point.
- A gradual 1-2 % decrease per week was observed.
- Likely caused by optical fouling/sensitivity loss rather than changing emissions/exposures.
- Indicates the need for periodic cleaning or recalibration to maintain accuracy.

Safety culture assessment

SAFETY CULTURE ASSESSMENT

SAFETY OBSERVER 3.0 - SYSTEMATIC FIELD OBSERVATIONS OF CONDITIONS AND BEHAVIOURS



- High compliance (>90%) at both baseline and follow-up.
- +5 percentage point improvement overall.
- Largest gains observed in: order and cleanliness, ventilation, and use of PPE.
- Demonstrates a mature, proactive safety culture with consistent reinforcement of safe practices.

Conclusions

CONCLUSIONS

SIGNIFICANCE OF LOW-COST SENSORS FOR THE WORKING ENVIRONMENT

- At high concentrations (>500 particles/cm³), LCS tend to underestimate dust concentrations.
- Allows early detection during dust-intensive tasks.
- Supports exposure control decisions (wet methods, ventilation, respiratory protection)
- Increase exposure visibility and strengthen safety culture
- Future work: develop auto-calibration algorithms and integration for industrial use.



Thank you for listening!



Contact: Ana Sofia
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Use of silicone wristbands and skin wipes to measure personal exposure

Temamøde om nemme og billige måde at indsamle data om kemisk eksponering i arbejdsmiljøet

Stephanie C. Hammel

Senior researcher

10 March 2026

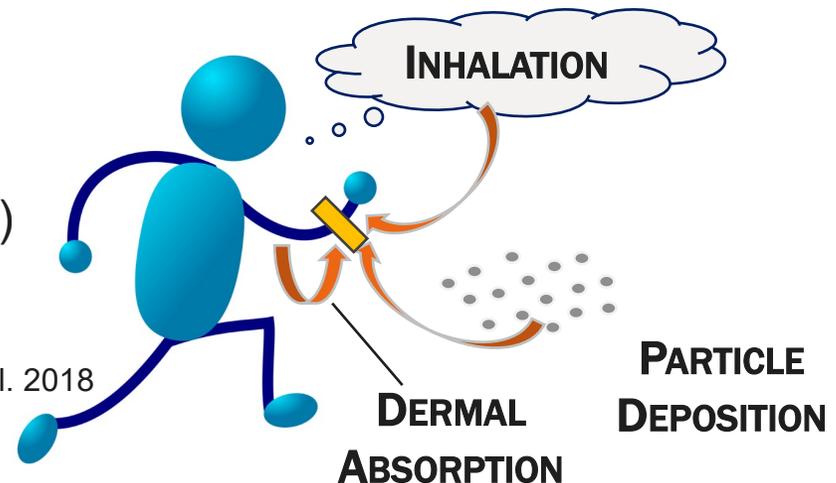


What are these tools?



Silicone wristbands

- First introduced by Dr. Kim Anderson's group at Oregon State University (US)
- Made of polydimethylsiloxane (PDMS) or "silicone"
- Personal passive samplers used to measure:
 - Adult ambient exposures
 - Occupational exposures
 - Children's exposures to consumer product chemicals
- Demonstrated to reflect internal dose (via urine and serum)



Silicone Wristbands as Personal Passive Samplers

Steven G. O'Connell, Laurel D. Kincl, and Kim A. Anderson*

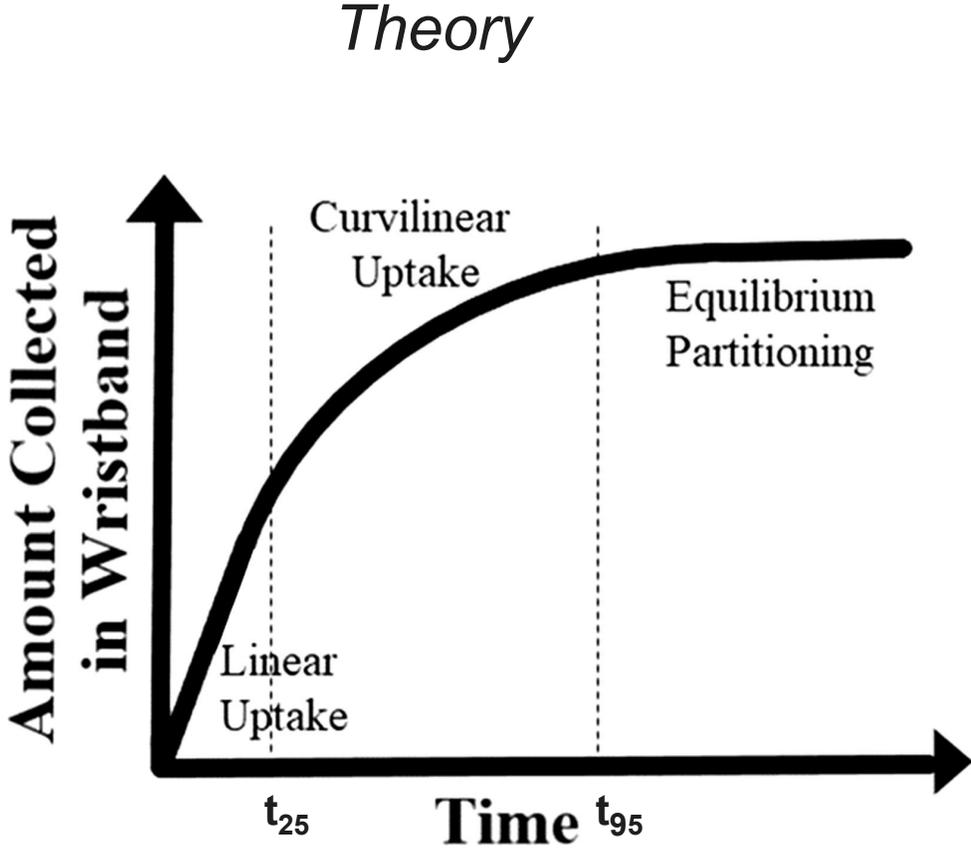
Department of Environmental and Molecular Toxicology and [†]College of Public Health and Human Sciences, Oregon State University, Corvallis, Oregon 97331, United States

Supporting Information

ABSTRACT: Active-sampling approaches are commonly used for personal monitoring, but are limited by energy usage and data that may not represent an individual's exposure or bioavailable concentrations. Current passive techniques often involve extensive preparation, or are developed for only a small number of targeted compounds. In this work, we present a novel application for measuring bioavailable exposure with silicone wristbands as personal passive samplers. Laboratory methodology affecting precleaning, infusion, and extraction were developed from commercially available silicone, and chromatographic background interference was reduced after solvent cleanup with good extraction efficiency (>96%). After finalizing laboratory methods, 49 compounds were sequestered during an ambient deployment which encompassed a diverse set of compounds including polycyclic aromatic hydrocarbons

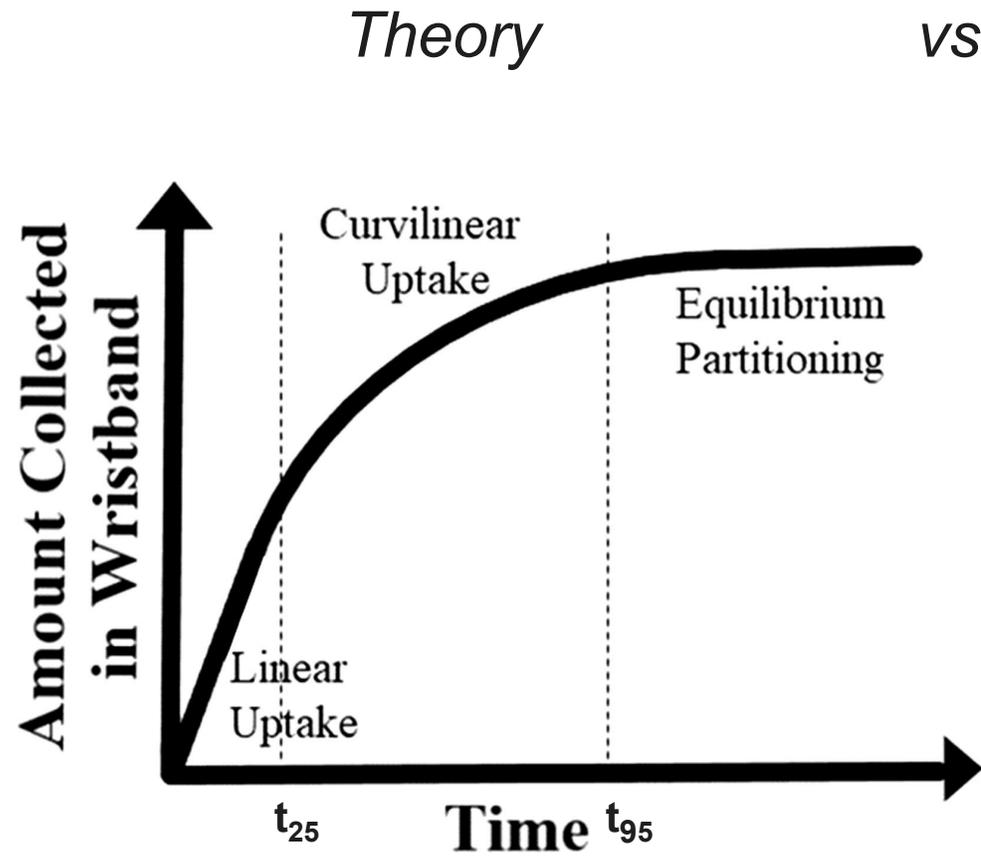


Wristbands as passive samplers



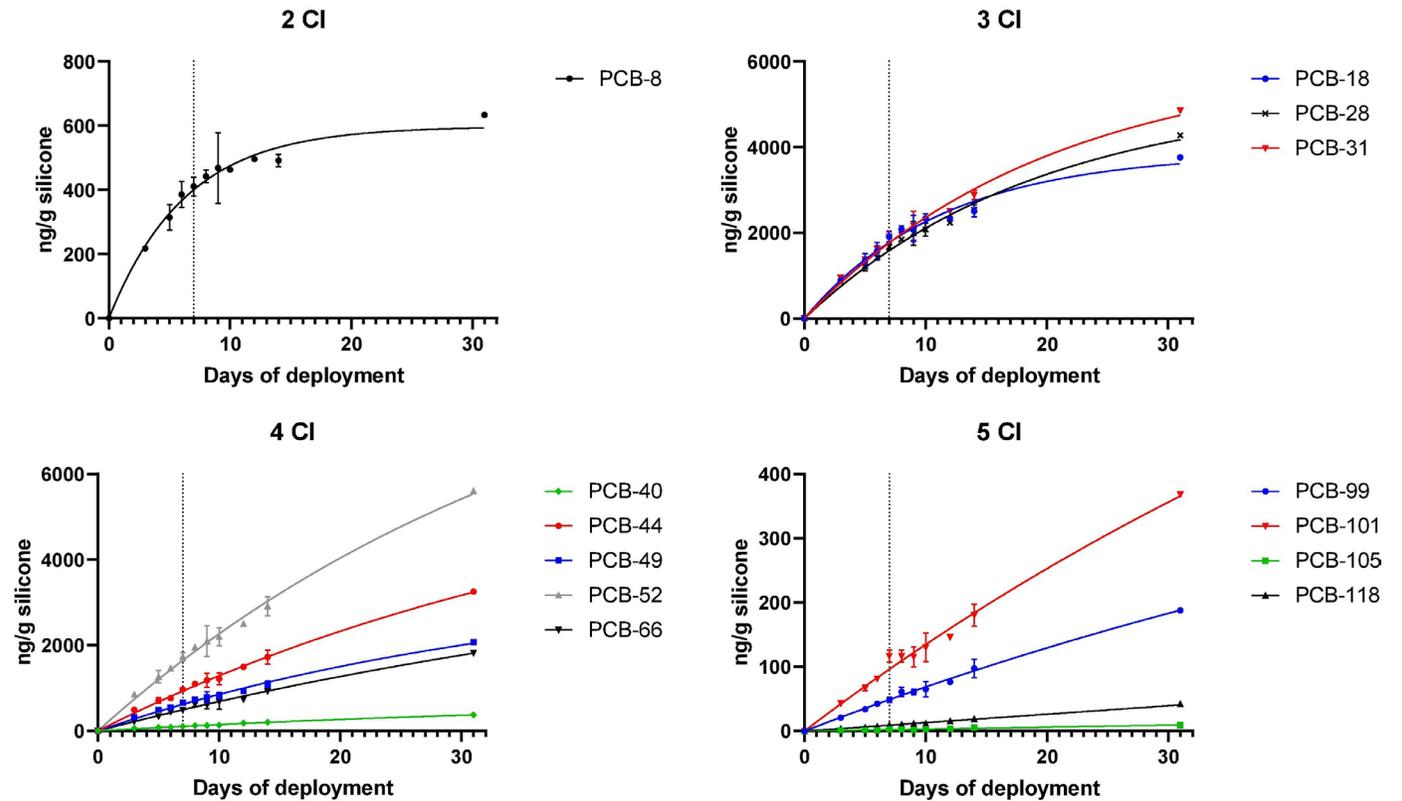
Adapted from Samon et al. 2022

Wristbands as passive samplers



vs.

Experimental



Adapted from Samon et al. 2022

Frederiksen et al. 2022

Skin wipes

- Alcohol wipes taken from the hands or another skin surface
- Samples from the skin lipid layer
- Shown to be effective for measuring a wide range of consumer product and industrial chemicals



Hammel et al. 2016

How do we use these tools to estimate dose?



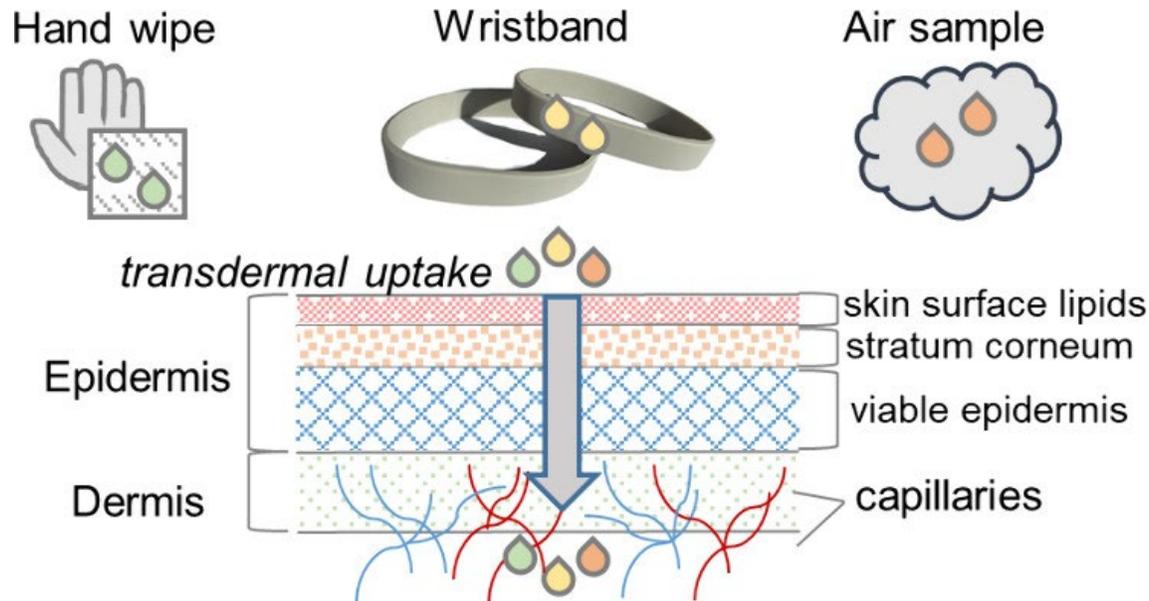
PCBs at Brøndby Strand Parkerne

- 5 of 12 fifteen-story apartment buildings were built in 1960s-70s with PCB sealants.
- Studies with former residents measured indoor air PCB concentrations of 300 – 5000 ng/m³, with lower chlorinated (tetra) PCBs dominant.

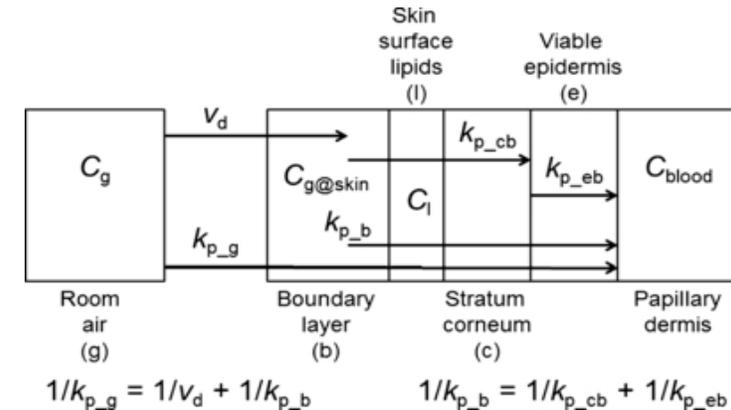
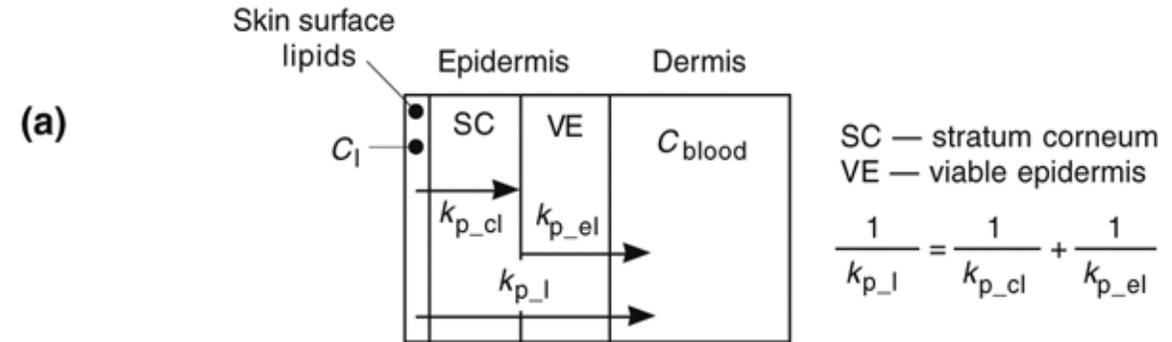


Translation to personal exposure

- Silicone as a proxy for skin surface lipids
- Hand wipes as the concentration in these skin lipids

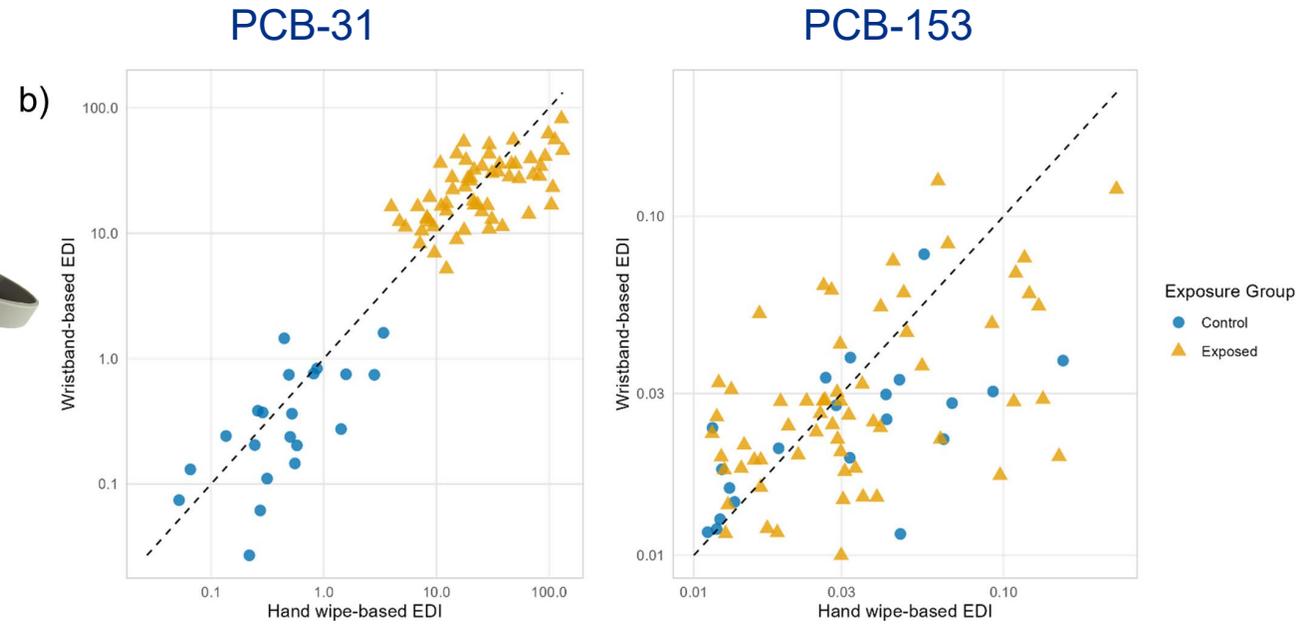


Hammel et al. 2025



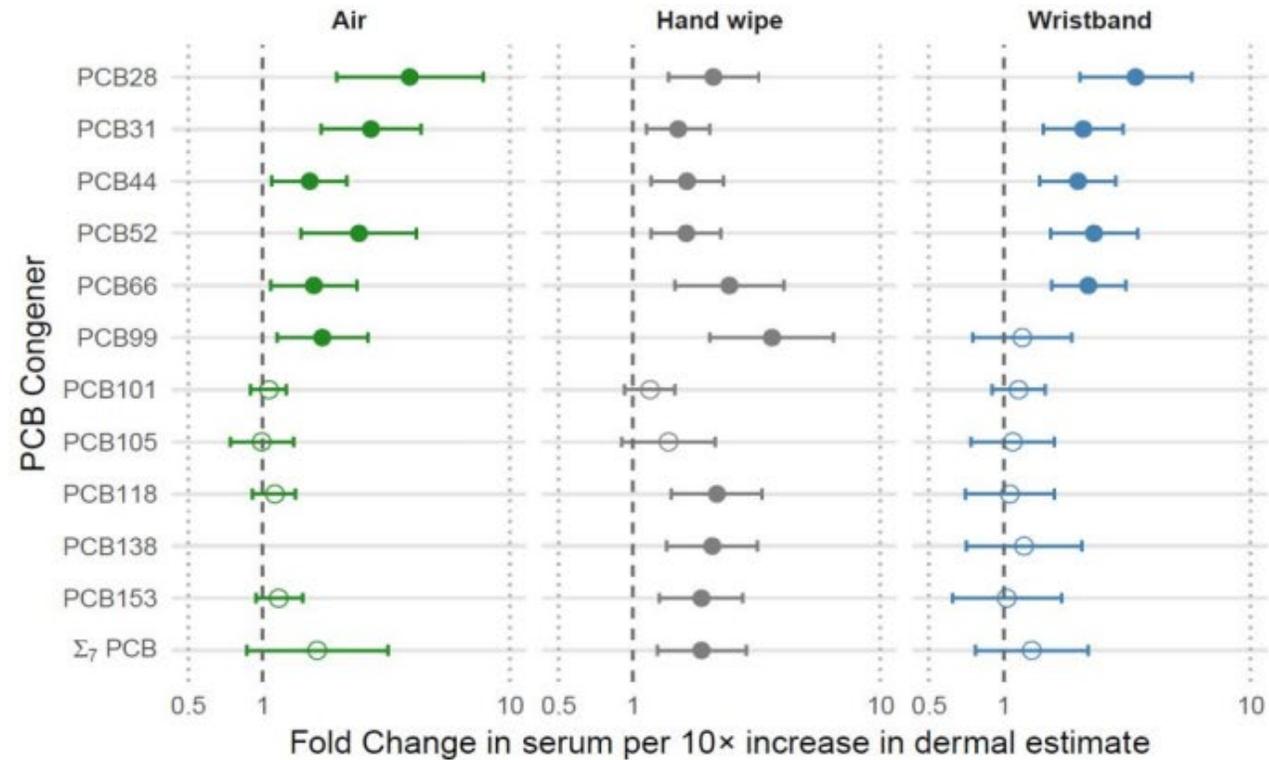
Comparing dermal estimates

Cohort of residents of a PCB-contaminated building compared to a reference population



Comparing dermal estimates to serum measures

*Total study population
(adjusted for exposure group)*



1.2 – 4.0 fold increase in serum per 10-fold increase in dermal estimate among lower chlorinated PCBs

Notable conclusions

- Wristband-based estimated daily intakes for dermal absorption showed strong agreement with hand wipes and air
- These estimates were also significantly correlated with serum measures.
- Residents were in a unique exposure scenario by being “at equilibrium” with their PCB-contaminated home environment
- But this showed promise for using wristbands alongside hand wipes as quantitative tools in exposure assessment and for other chemical classes



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Letter

Translating Silicone Wristbands to a Personal Exposure Estimate for Dermal Absorption: A Case Study with PCBs

Stephanie C. Hammel,^{*} Helle Vibeke Andersen, Lisbeth E. Knudsen, and Marie Frederiksen

Cite This: *Environ. Sci. Technol. Lett.* 2025, 12, 524–529

Read Online



ELSEVIER

Environmental Research
Available online 26 November 2025, 123432
In Press, Journal Pre-proof What's this?



Reflection of serum PCB concentrations in silicone wristbands, hand wipes, indoor air, and dust and the associations between exposure and thyroid hormone homeostasis

Stephanie C. Hammel [✉], Helle Vibeke Andersen [✉], Line Småstuen Haug [✉], Cathrine Thomsen [✉], Sofie Lillelund Ovesen [✉], Lisbeth E. Knudsen [✉], Marie Frederiksen [✉]

**How are we using these tools
in occupational settings?**



PCBs at Brøndby Strand Parkerne

- 5 of 12 fifteen-story apartment buildings were built in 1960s-70s with PCB sealants.
- Studies with former residents measured indoor air PCB concentrations of 300 – 5000 ng/m³, with lower chlorinated (tetra) PCBs dominant.
- Buildings could not be remediated and PCB concentrations exceeded guidance values so they were demolished.

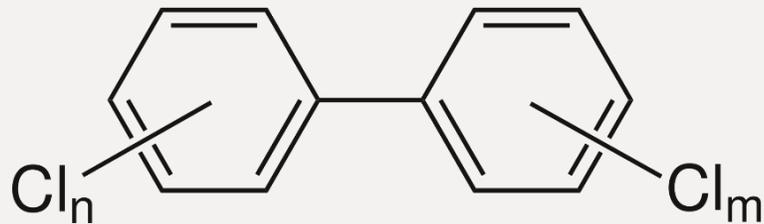


PCBs at Brøndby Strand Parkerne

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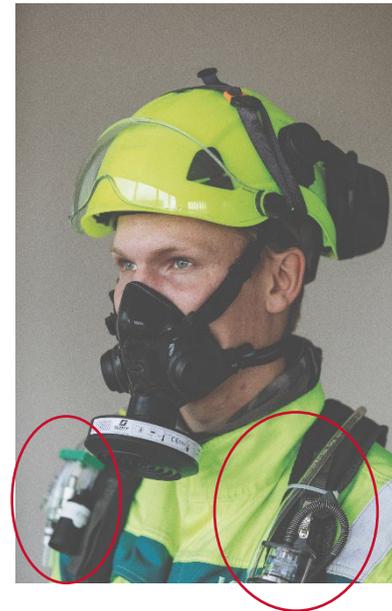


Case study Polychlorinated biphenyls (PCBs) & demolition workers



Evaluating work tasks during a single work day

- Each worker wore a wristband (n=46) and provided hand wipes before and after work (n=54 each)
 - Analyzed for all 209 PCB congeners
- Other samples taken-
 - Active air samples (background & personal)



Work tasks



Concrete work

Sealant cutting



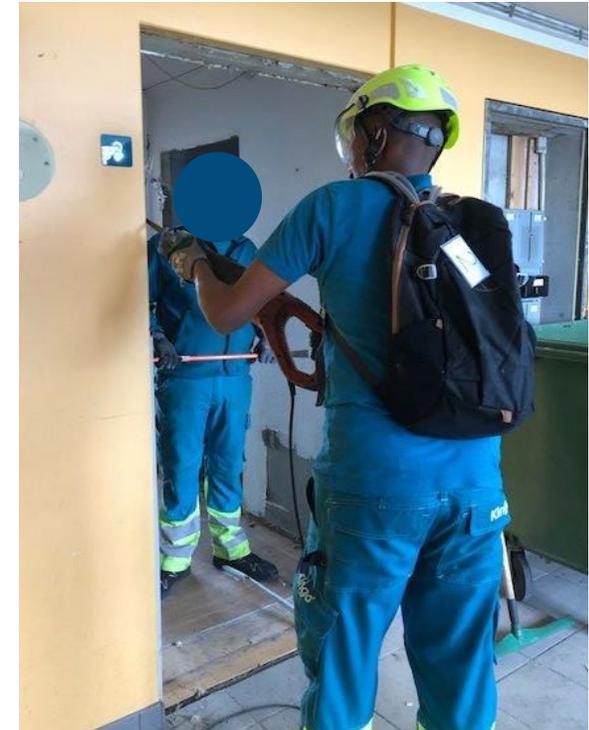
Shoring

Work tasks



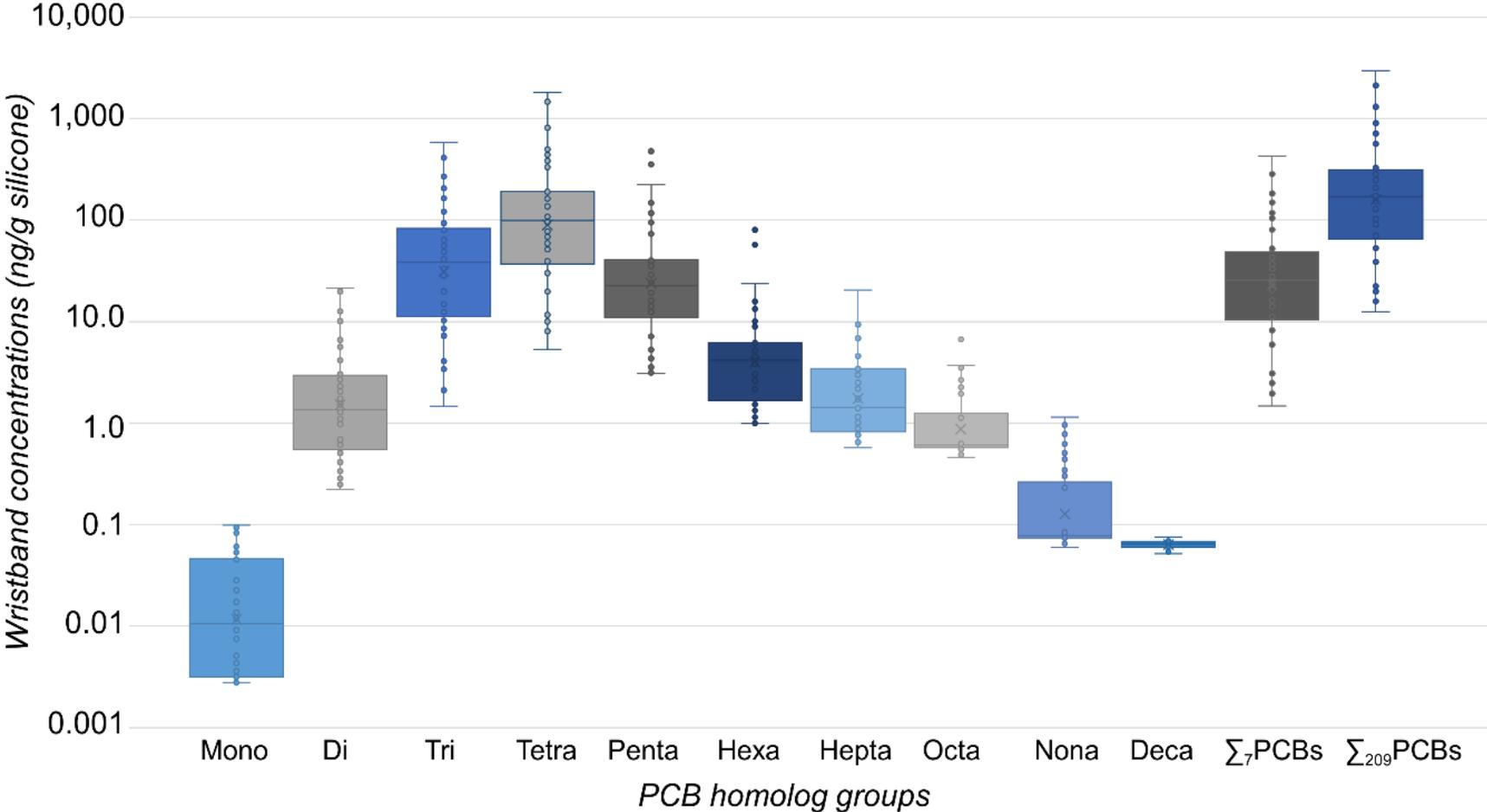
Scaffolding

Floor cutting

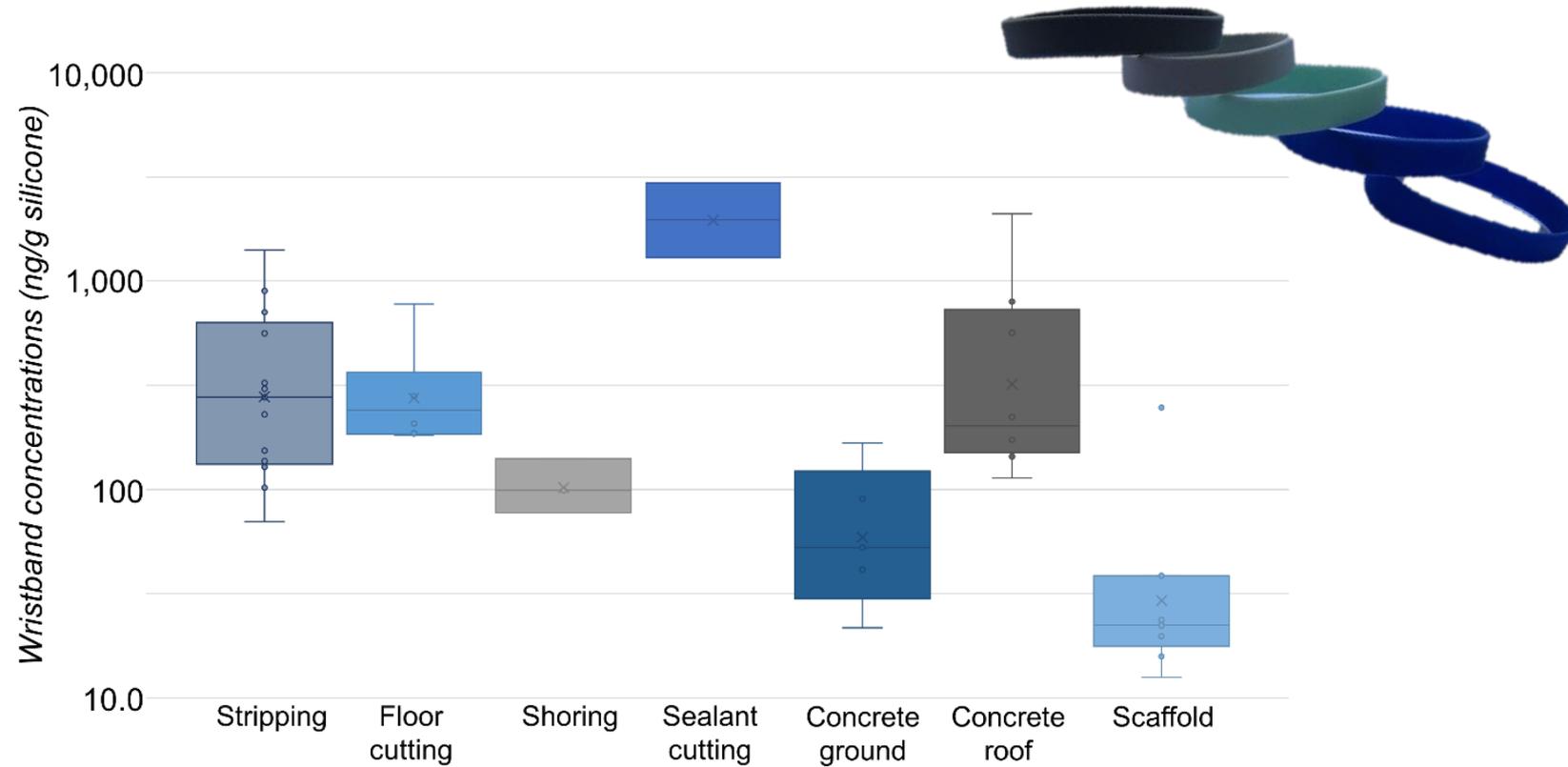


Interior stripping

Wristband concentrations by homolog group

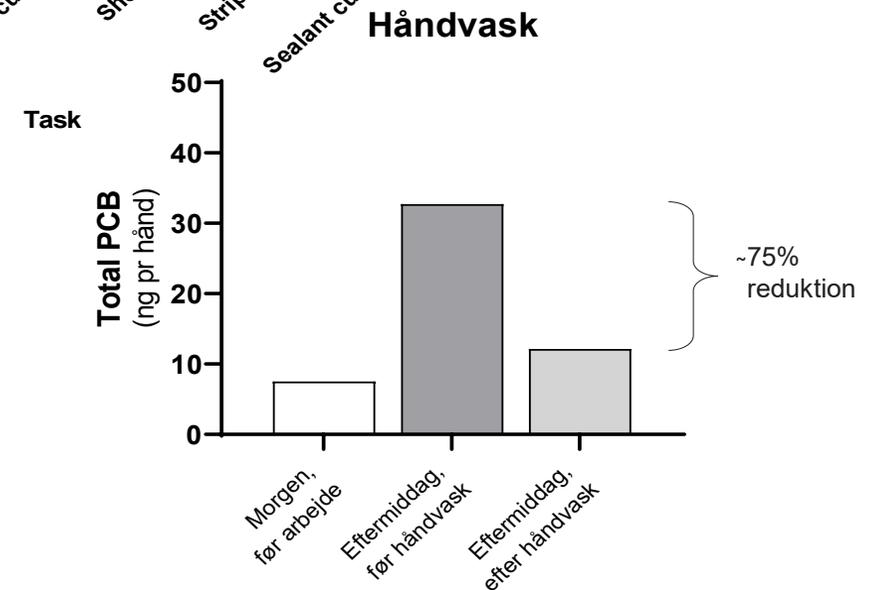
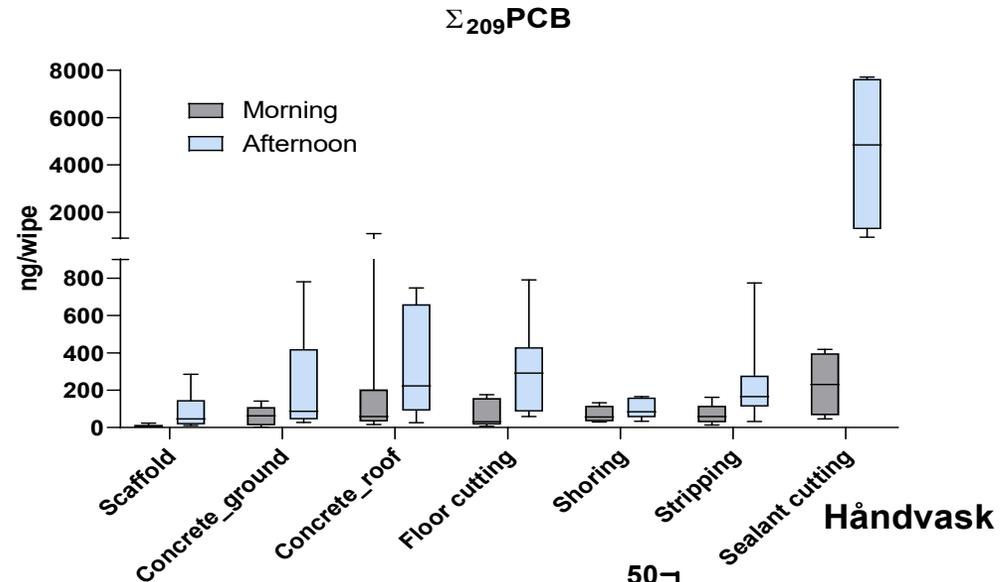


Wristband concentrations for Σ_{209} PCBs by worker tasks



What about hand wipes?

- Difference between pre- and post-work samples
- Post-work samples tended to be higher across the tasks.
- **One way to evaluate hand washing!**
- A median 75% reduction before and after handwashing, comparing one hand to the other.



Case study

Polychlorinated biphenyls (PCBs) & demolition workers

ENVIRONMENTAL
Science & Technology

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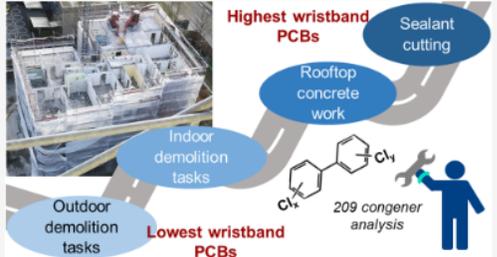
Quantifying 209 Polychlorinated Biphenyl Congeners in Silicone Wristbands to Evaluate Differences in Exposure among Demolition Workers

Stephanie C. Hammel* and Marie Frederiksen

 Cite This: *Environ. Sci. Technol.* 2024, 58, 6499–6508  Read Online

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ABSTRACT: A social housing estate in Denmark was designated for demolition due to exceedance of guidance values for polychlorinated biphenyls (PCBs) in indoor air. Here, we deployed precleaned silicone wristbands ($n = 46$) among demolition workers of these contaminated buildings during single workdays while conducting various work tasks. We established a method to analyze all 209 PCBs in wristbands to identify prominent congeners of exposure and evaluate differences between tasks. Wristbands were extracted using microwave-assisted extraction and then concentrated for gas chromatography-tandem mass spectrometry (GC-MS/MS) analysis. Twenty-nine chromatographic peaks representing 37 congeners were detected in every wristband, and tetra-CBs were the dominant homologue group. PCB-66, -44, and -70 were



DOI: [10.1021/acs.est.3c10304](https://doi.org/10.1021/acs.est.3c10304)

Concluding thoughts

- Wristbands and skin wipes → effective exposure assessment and screening tools
- Both non-invasive and inexpensive and can target specific microenvironments **like workplaces**
- Hand wipes often reflect the most recent exposure whereas wristbands can measure an aggregate exposure across a workweek.
- Could support evaluation of exposures to mixtures
 - Reduce the reliance on biomarkers
 - Provide opportunities to create individual exposure profiles

Some things to keep in mind

- Know your exposure pathway of interest!
- Both samples can be susceptible to contamination from dirty work clothes (which still may reflect relevant exposure).
 - Wristbands are typically worn under PPE.
- Chemicals of varying physicochemical properties may be sampled differently among skin wipes and wristbands.
 - This also applies for how these external measures relate to internal dose.
- Sampling time can matter, especially for skin wipes and for more ubiquitous chemicals.

Acknowledgements

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 - *Marie Frederiksen*
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 - *Pete Kines*
 - *Carla Ribalta*
 - *Vivi Kofoed*
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 - *Ana Sofia Fonseca*
 - *Vivi Schlünssen*
 - *Harald Meyer*
 - *Karin S. Hougaard*
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 - Arbejds miljø forskningsfonden (AMFF)
 - FFIKA



Big thank you to all of our participants as well as company contacts for their help and organization!

Thanks for listening!

Questions?

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Temamøde om nemme og billige målinger af kemiske eksponeringer i arbejdsmiljøet

Billig og hurtig
risikovurdering
af smitterisiko



CO₂ målinger i indeklimaet – hvornår er det tid at lufte ud?



Luftvejsinfektioner er også et arbejdsmiljøproblem

<https://www.sciencedirect.com/science/article/pii/S2950362026000111>

Linkedin: <https://www.linkedin.com/in/andrup-lars-b463225/>

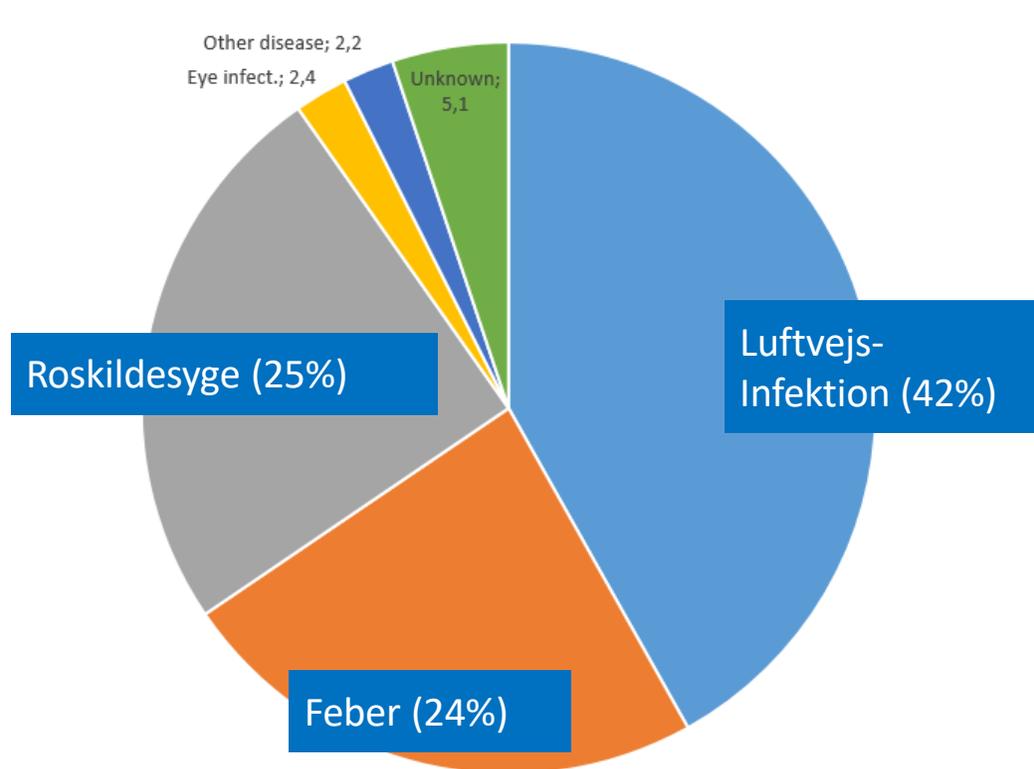


- ☀️ Luftvejsinfektioner er også et arbejdsmiljøproblem
- ☀️ Luftvejsinfektioner er langt den største årsag til sygefravær
- ☀️ Luftvejsinfektioner smitter via luften
- ☀️ Muligheder for at forebygge

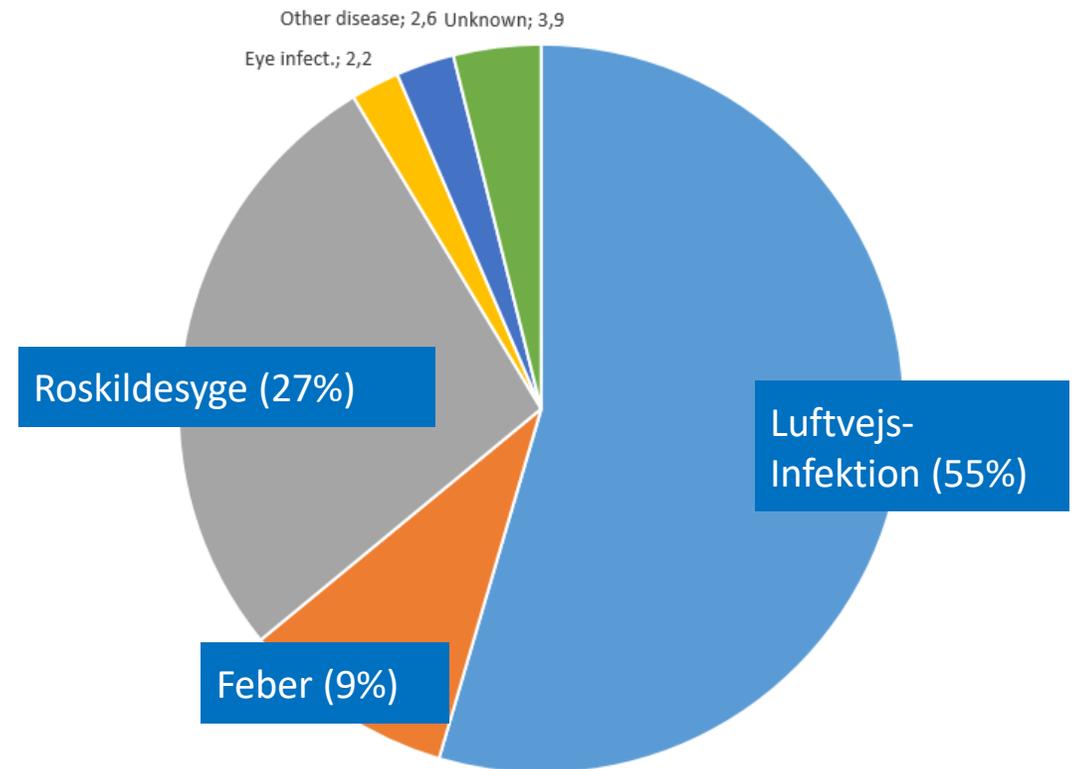


Sygefravær i 22 vuggestuer i Gentofte

Årsager til sygefravær - Børn



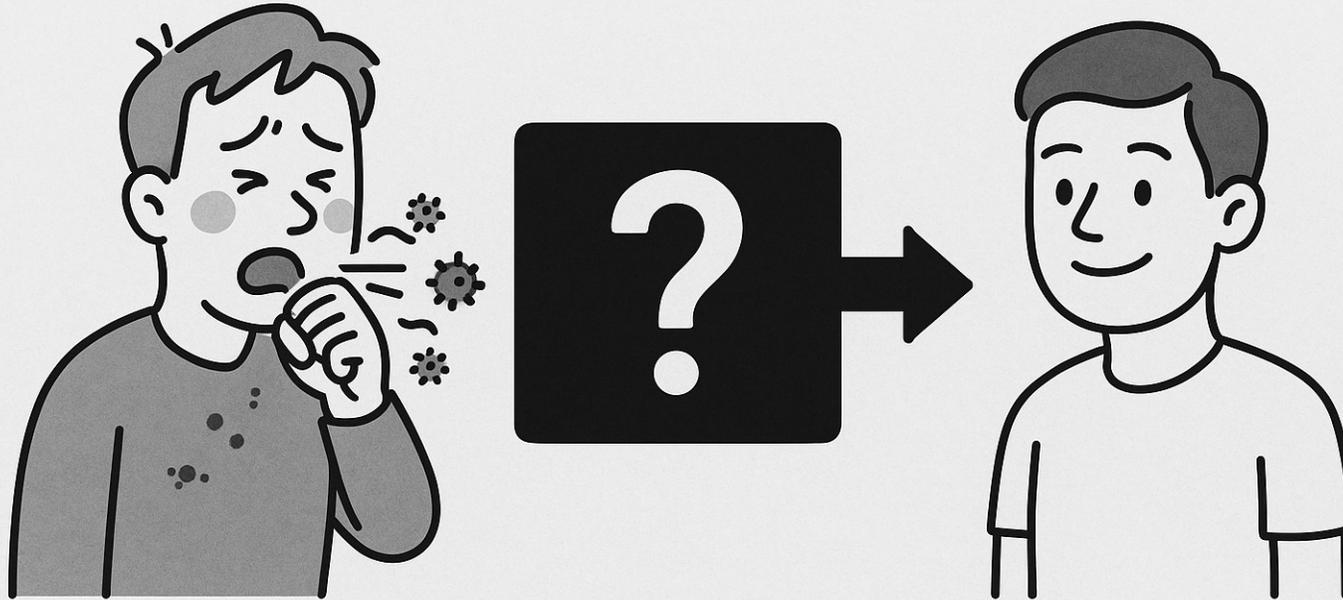
Årsager til sygefravær - Ansatte



936 absenteeism registrations with symptoms

231 absenteeism registrations with symptoms

Infektioner - Indeklima



Uden viden om smittevejen kan vi ikke bryde den

Kirkekor

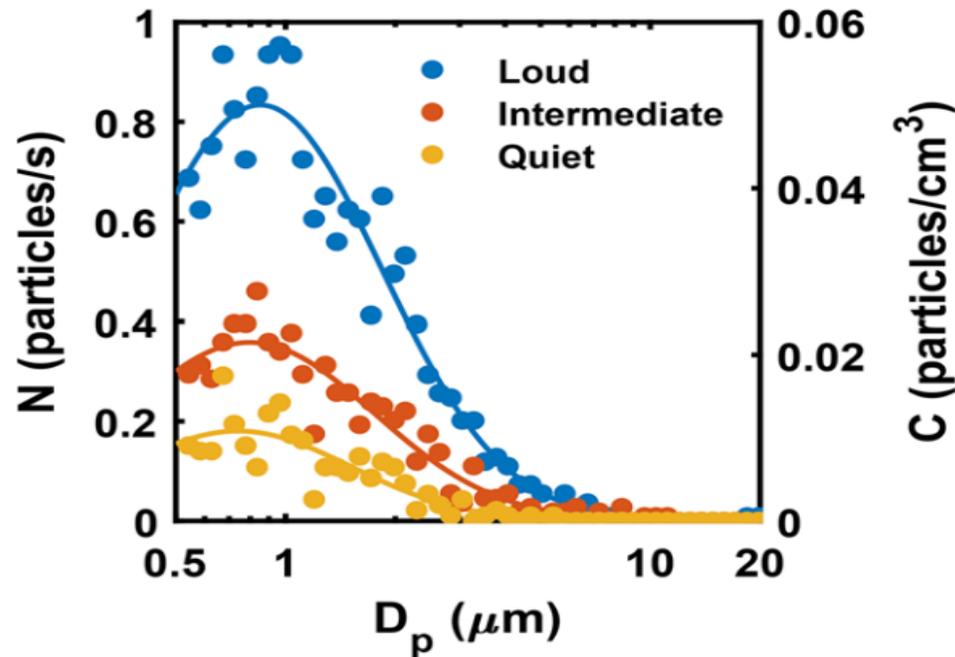
Superspreder-begivenhed March 10, 2020

Kor-øvning i “the Fellowship Hall” i en kirke i Mount Vernon, Skagit County i staten Washington.

Der var taget smitte-forebyggende forholdsregler (håndsprit, ingen kram og håndtryk og 2 meters afstand).

61 deltog – sang i ca 2½ time

53 blev syge og 2 døde



Asadi, S., et al. (2019)



 Debat

Forskere: COVID-19-spredning med aerosoler betyder et paradigmeskifte i forebyggelse

Der er brug for bl.a. interventioner, der øger luftskifte og renser luften, skriver 20 forskere i debatindlæg.

”Aerosolsmittes afgørende betydning for forståelse af spredning af SARS-CoV-2 var en erkendelse, der kom gradvist og med betydelig tøven fra bl.a. WHO. Erkendelsen er et paradigmeskifte, der åbner for et større fokus på strukturel forebyggelse af smitte, især gennem forbedret luftskifte.”

*”COVID-19 har lært os, at **det burde være muligt at forbedre forebyggelsen af en del af de plagsomme luftvejsinfektioner, der især spredes indendørs og derfor hyppigst om vinteren.**”*

Kåre Mølbak, Statens Serum Institut & Københavns Universitet, Svend Frederiksen, Lunds universitet, Sanne Grønvall Kjær Hansen, Odense Universitetshospital, Astrid K.N. Iversen, Oxford University, Elsebeth Tvenstrup Jensen, Statens Serum Institut, Brian Kristensen, Statens Serum Institut, Stig Koust, Teknologisk Institut, Steffen Loft, Københavns Universitet, Arsen Melikov, Danmarks Tekniske Universitet, Bjarke Frost Nielsen, Roskilde Universitet, Peter V. Nielsen, Aalborg Universitet, Michael Bang Petersen, Aarhus Universitet, Freja Rydahl Rasmussen, Teknologisk Institut, Daniel A. Sepulveda-Estay, Region Hovedstaden, Lone Simonsen, Roskilde Universitet, Thorkild I.A. Sørensen, Københavns Universitet, Christian M. Sørup, Region Hovedstaden, Henrik Ullum, Statens Serum Institut, Pawel Wargocki, Danmarks Tekniske Universitet, Peter Aaby, Syddansk Universitet

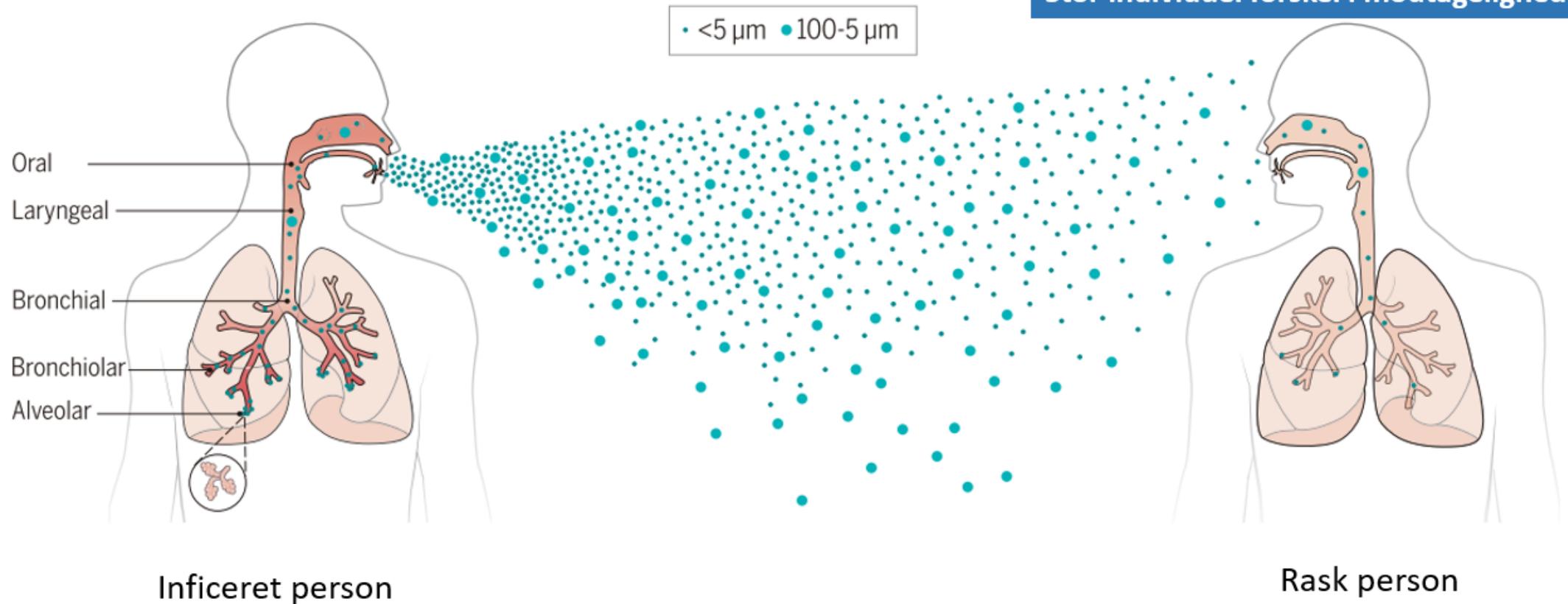
Smitte via små dråber (aerosoler)

Influenza, RS-virus, corona, rhinovirus etc.

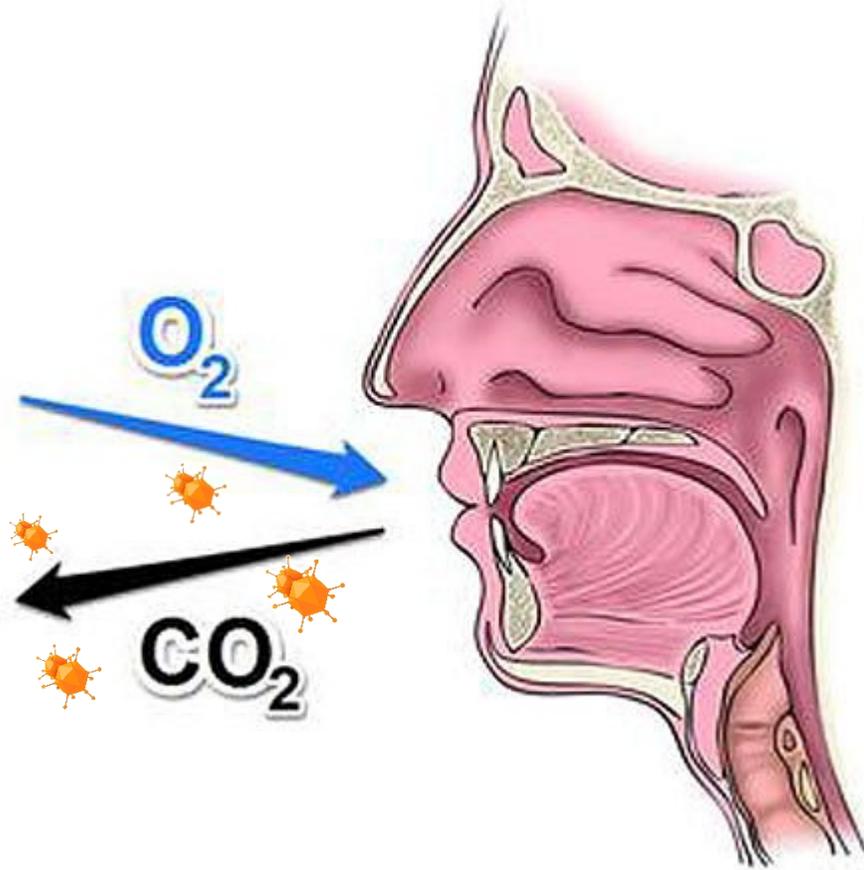
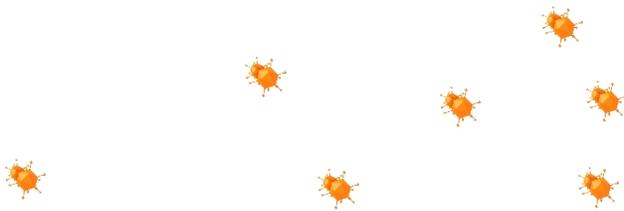
Aerosoler udskilles ved host, nys, tale, sang og ved simpel vejtrækning

Temperatur, RH m.m. har betydning for virus overlevelse og spredning

Stor individuel forskel i modtagelighed

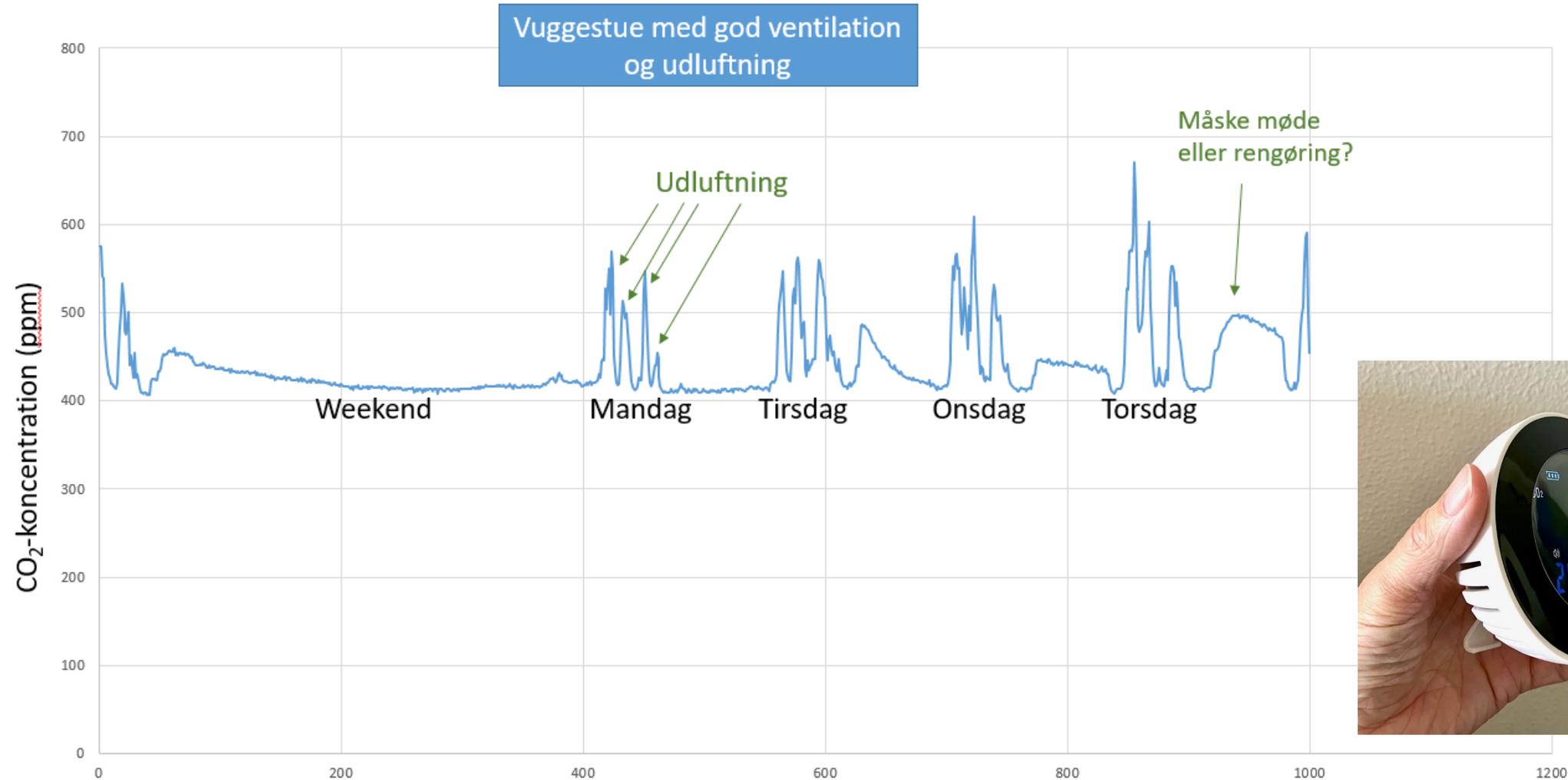


Forebyggelse af smitte

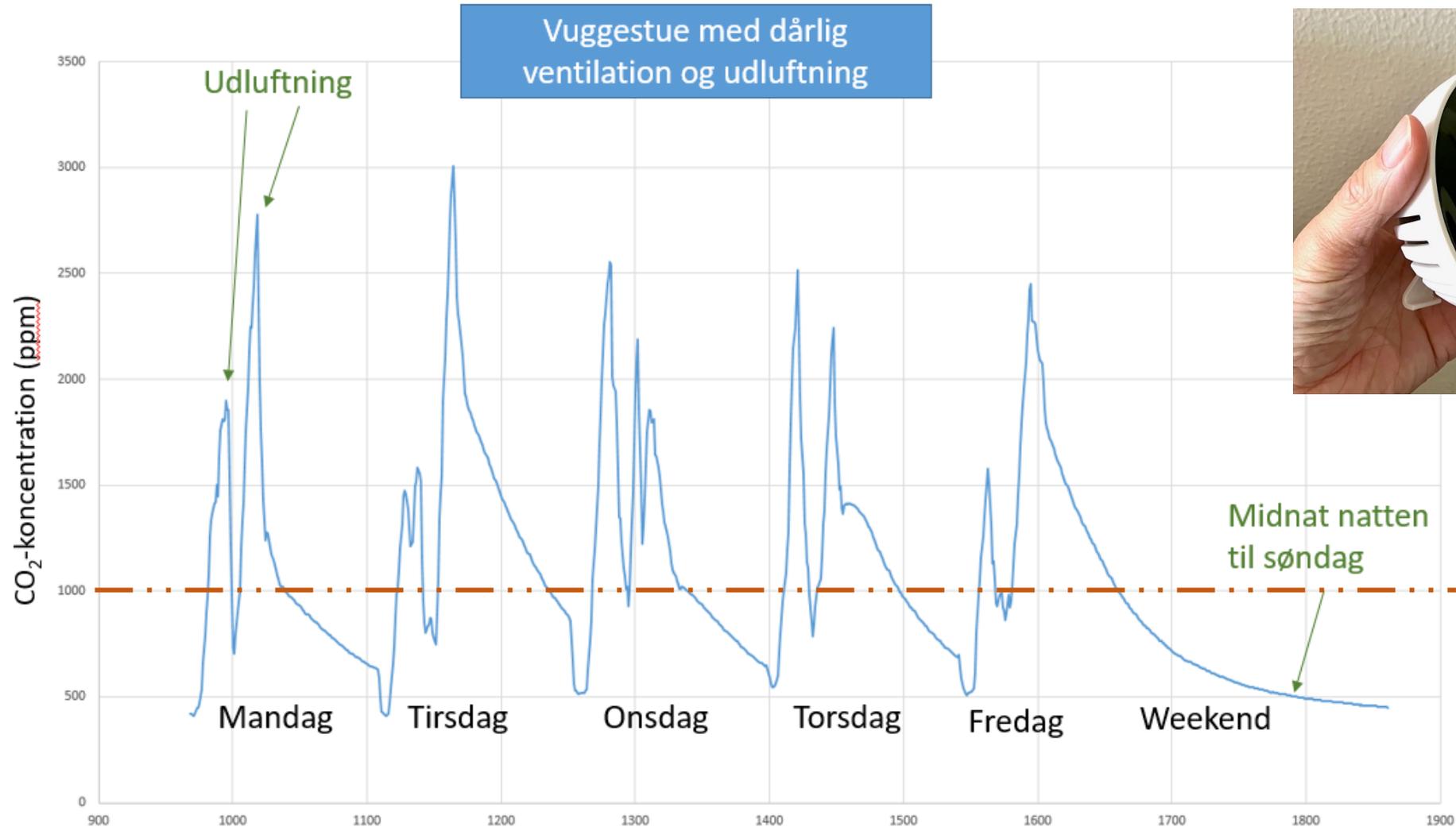


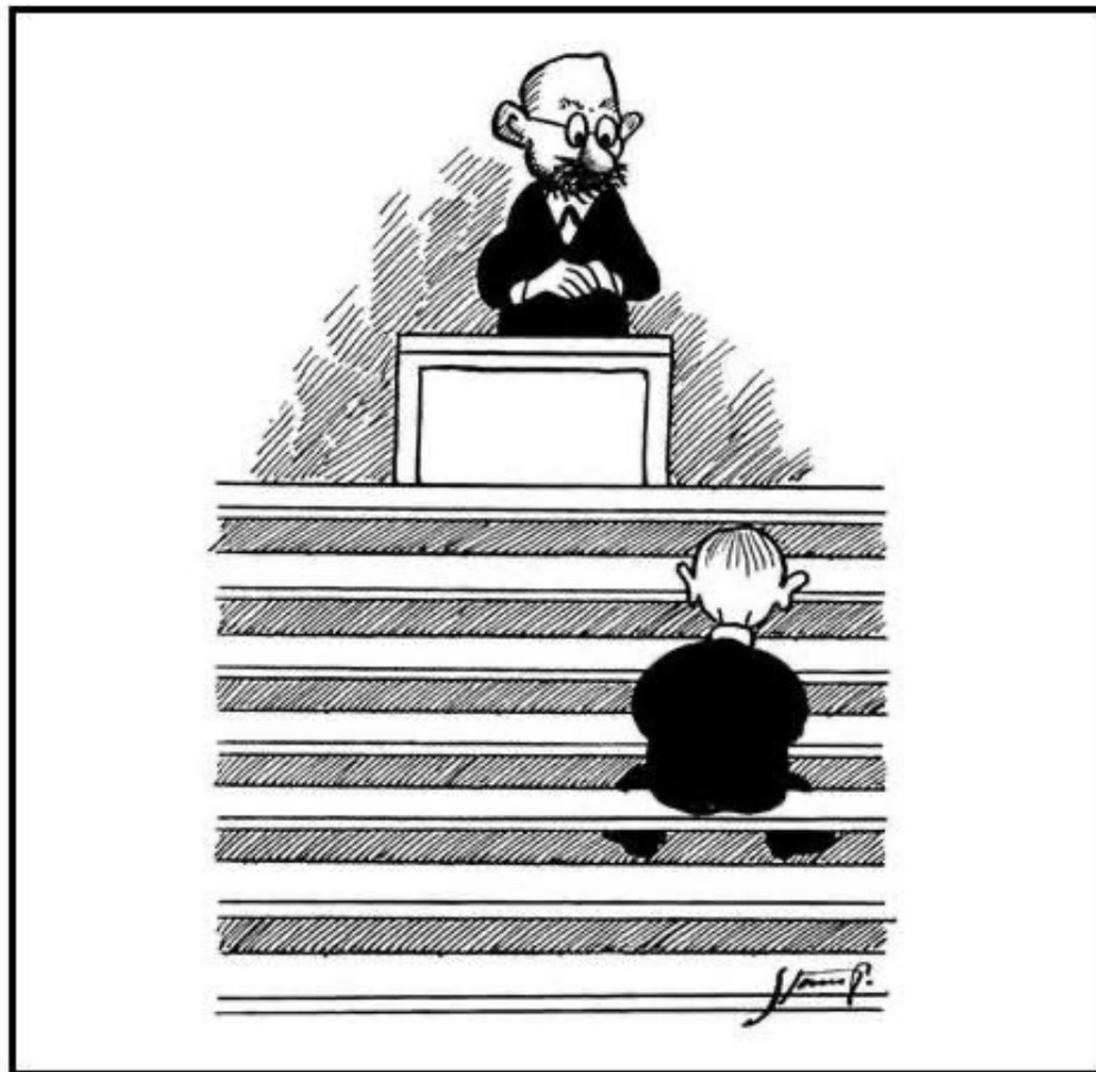
CO₂ som mål for smitterisiko og god indeluft

Forebyggelse af smitte i daginstitutioner



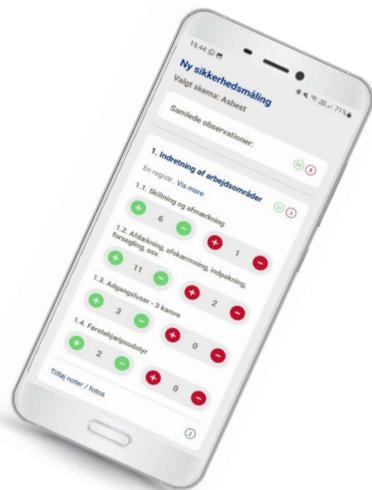
Forebyggelse af smitte i daginstitutioner





**- Ærede Tilhører - jeg maa desværre
slutte nu - men hvis De skal samme vej
- kan De høre resten i Sporvognen.**

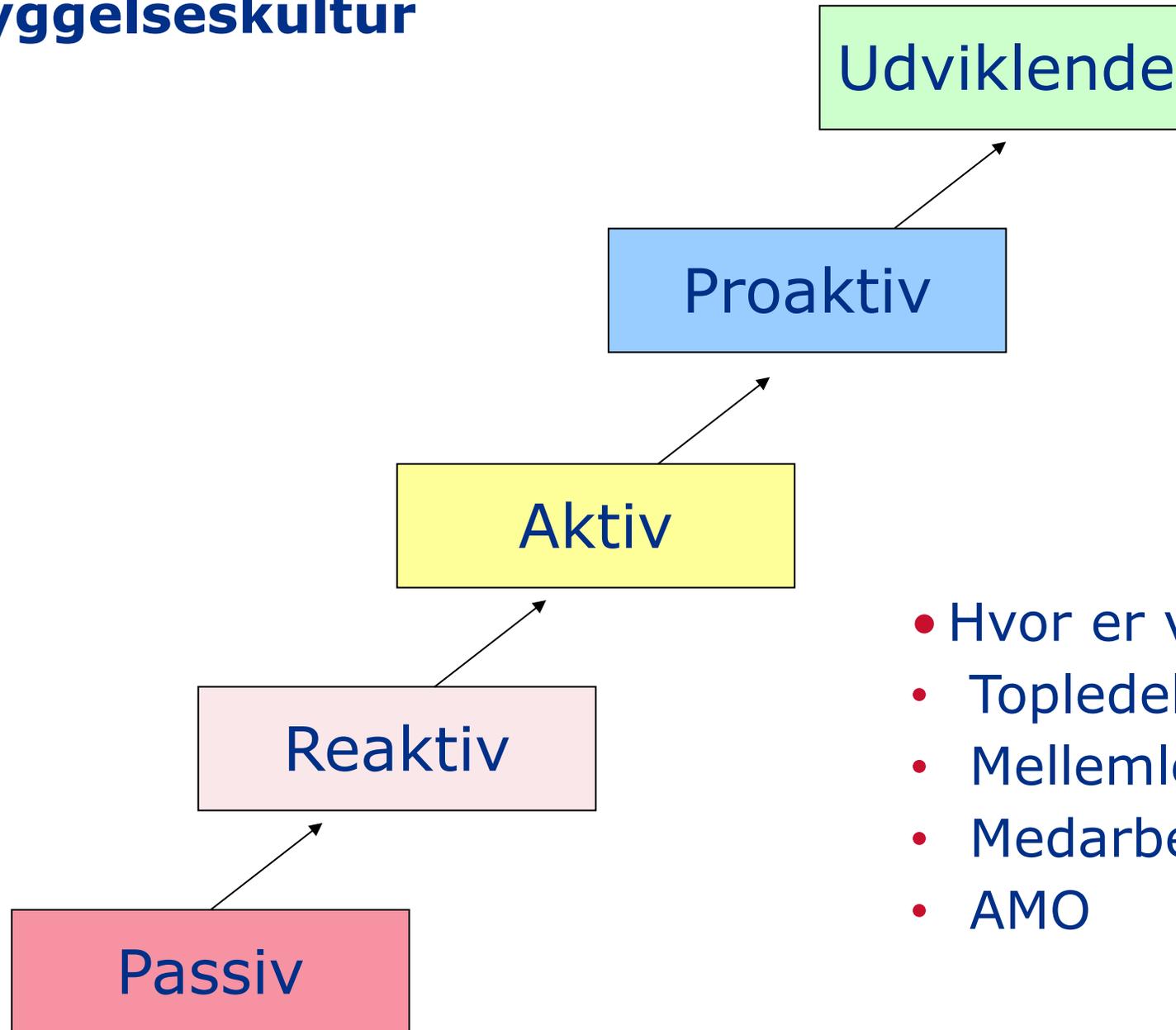
Billige sensorer og samspil med NFA's 'Safety Observer' app



10. marts 2026

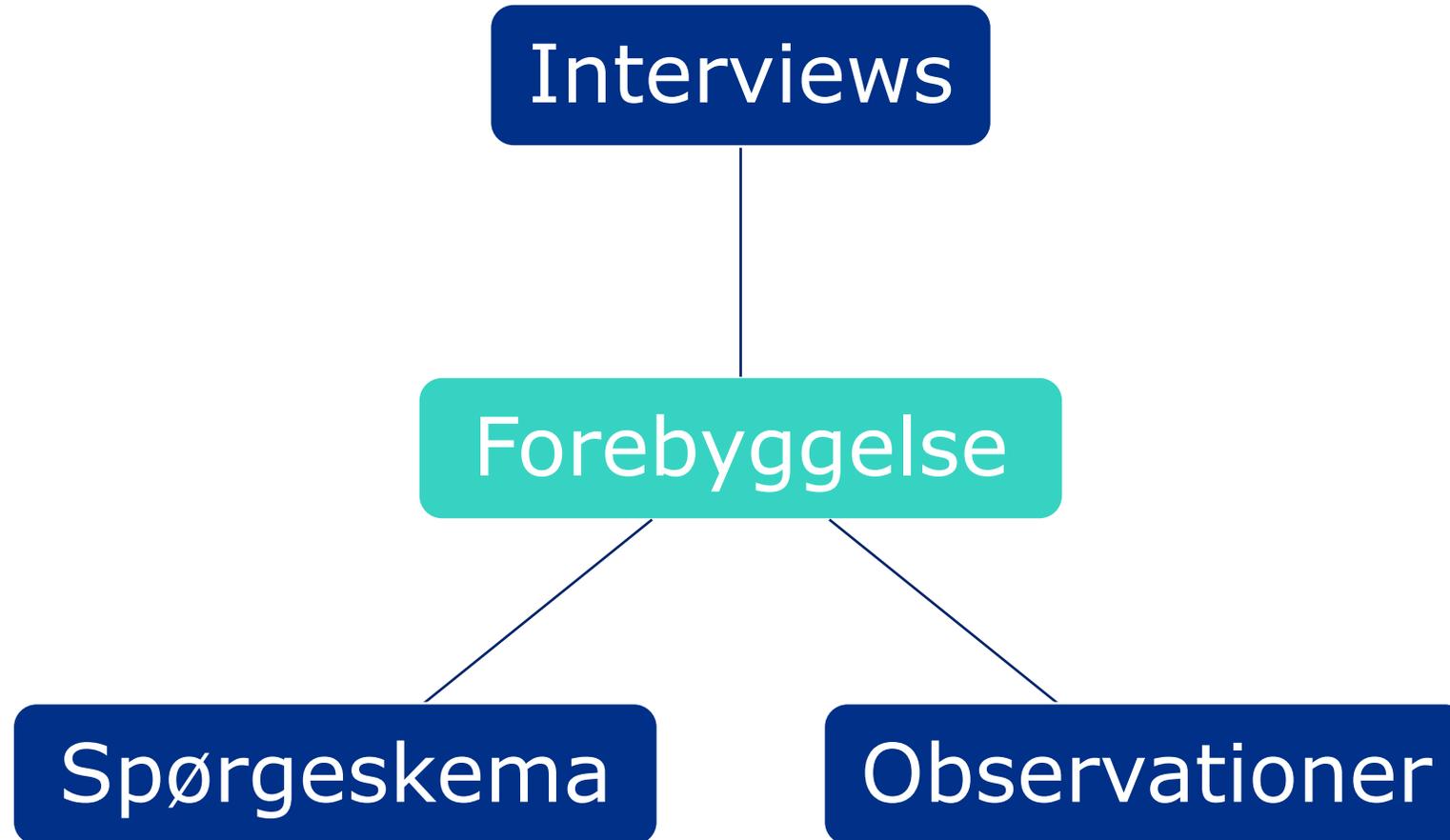


Stærk forebyggelseskultur



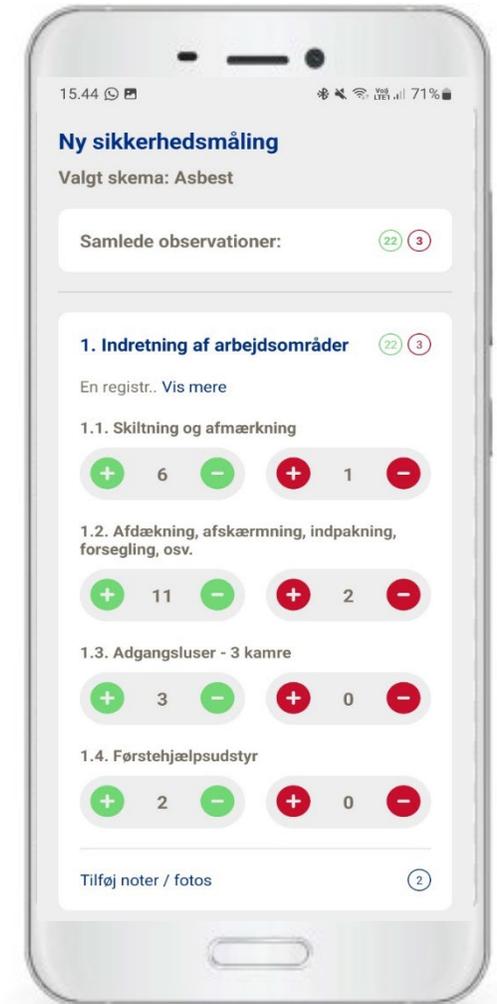
- Hvor er virksomhedens:
- Topledelse
- Mellemedelse
- Medarbejdere
- AMO

Forebyggelseskulture - forskningsmetoder

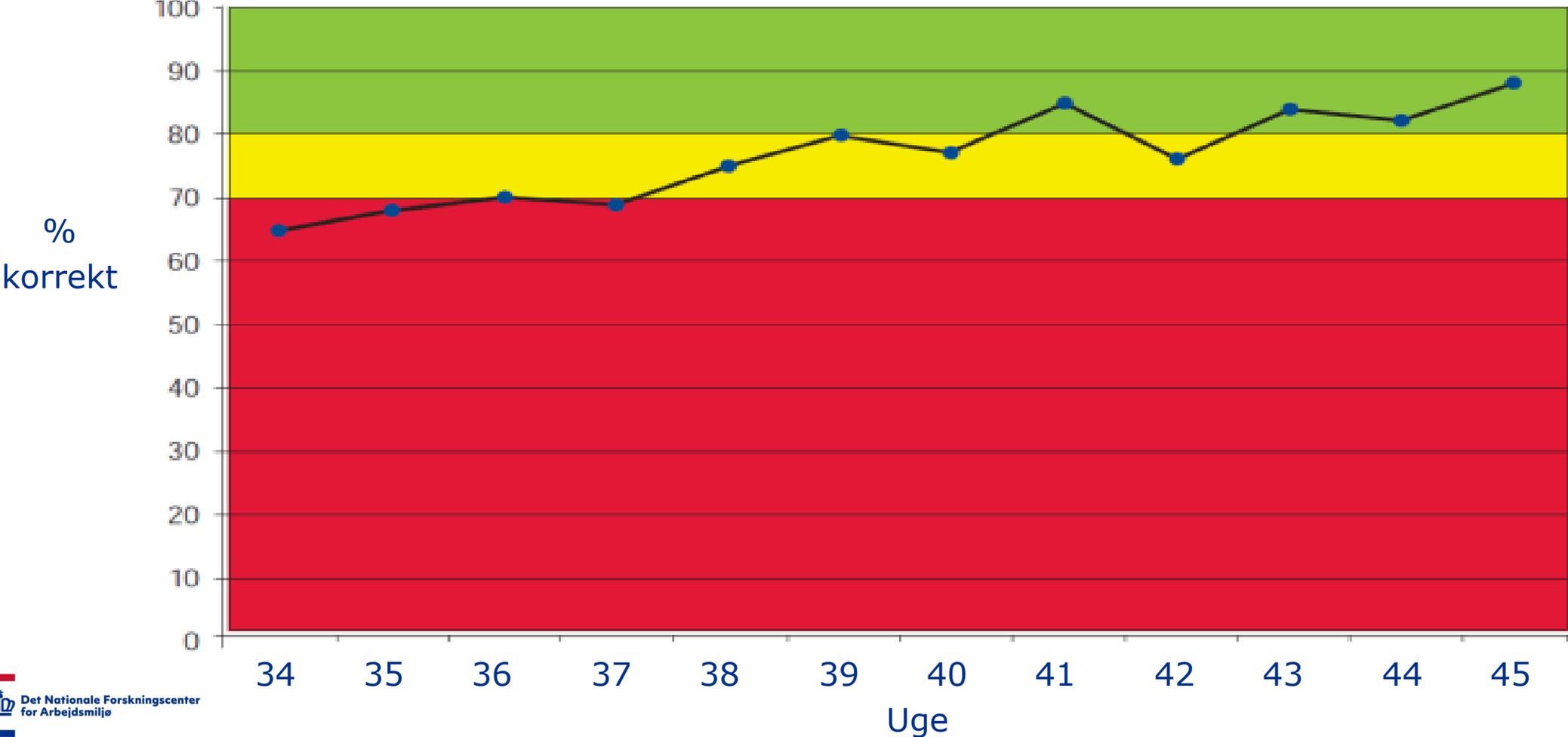


Systematiske sikkerhedsrunderinger – kemi

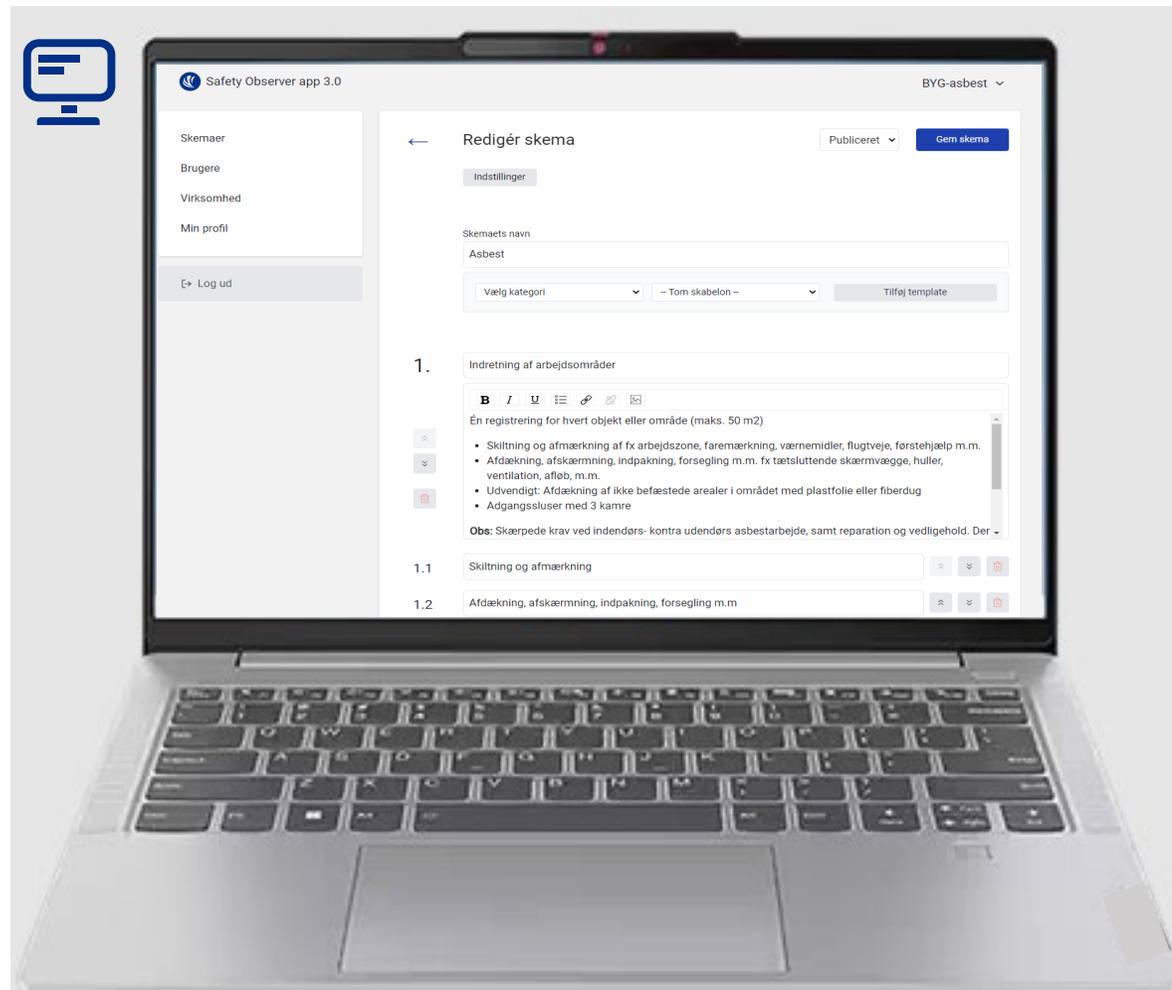
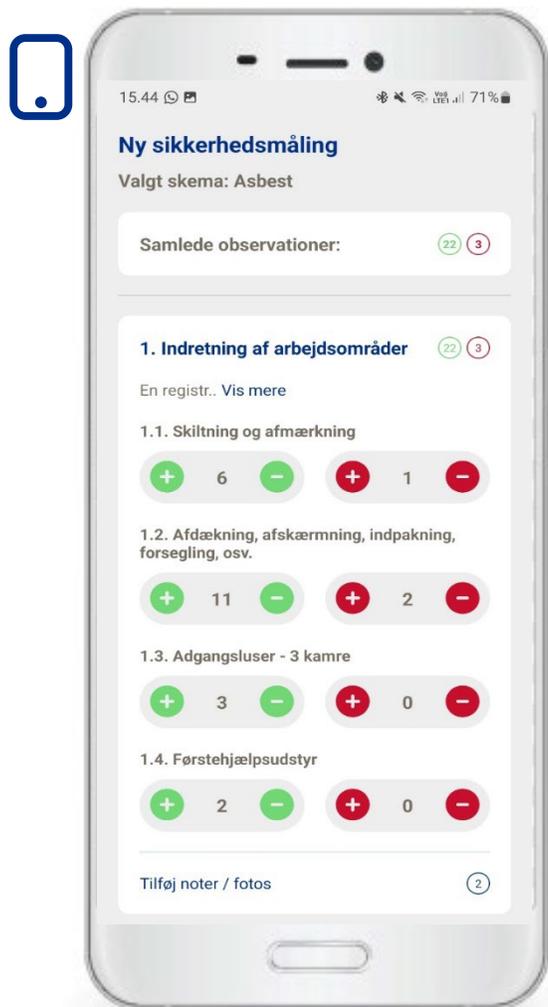
1. Indretning af arbejdsområder fx skiltning, afmærkning, sluser
2. Orden og ryddelighed fx faremærkning af affald
3. Personlige værnemidler fx støvdragt, åndedrætsværn
4. Tekniske hjælpemidler, maskiner og værktøj fx ventilation, støvsuger
5. Velfærdsforanstaltninger fx miljøvogn, skur, omklædning, spise/pause



Sikkerhedsindeks (forhold og adfærd)



NFA's Safety Observer - app og web-modul



- Gratis
- 150+ lande
- Danske menuer
- Engelske menuer



Safety Observer 3.0

- Info.: nfa.dk/safetyobserver
- Web modul: Safetyobserver.dk

NFA's Safety Observer app – skabeloner om det kemiske arbejdsmiljø

Skabeloner udarbejdet i forskningsprojekter og i samarbejde med BFA'er og virksomheder

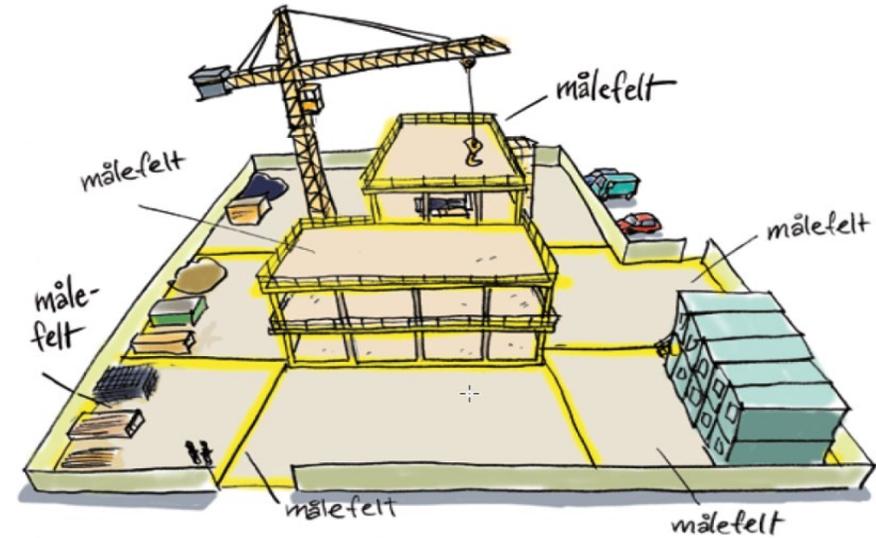
- Industri: nanomaterialer, støv, Krom-6
- Bygge og Anlæg: støv, asbest, bly, pcb
- Landbrug: håndtering af faremærket kemi
- Handel: Bager og konditor, slagter, guldsmed, urmager - videoer om kemisikkerhed



Asbest skabelon til sikkerhedsrunder med NFA's Safety Observer app

5 temaer:

1. Indretning af arbejdsområder
2. Tekniske hjælpemidler
3. Personlige værnemidler
4. Orden og ryddelighed
5. Velfærdsforanstaltninger



Fx

- Skiltning og afmærkning (fx arbejdszone, faremærkning, værnemidler, flugtveje, førstehjælp m.m.), afdækning, afskærmning, indpakning, forsegling m.m., samt mht. sluse, ventilation, afløb m.m.
- Skurvogn, miljøvogn m.m.: ordentlige og rene forhold; spise- og hvileplads i ren zone; mulighed for sikker og ren opbevaring af personlige værnemidler; separate/opdelte omklædningsfaciliteter med garderobeskab for eget tøj og arbejdstøj; bad og håndvask udstyret med varmt og koldt vand



Temaer og indtastning, noter og fotos

15.39 72%

Ny sikkerhedsmåling

Valgt skema: Asbest

Samlede observationer: 89 17

1. Indretning af arbejdsområder 33 5

2. Tekniske hjælpemidler, maskiner og værktøj 10 2

3. Personlige værnemidler 9 2

4. Orden og ryddelighed 31 7

5. Velfærdsforanstaltninger 6 1

Tilbage Næste

15.44 71%

Ny sikkerhedsmåling

Valgt skema: Asbest

Samlede observationer: 22 3

1. Indretning af arbejdsområder 22 3

En registr.. Vis mere

1.1. Skiltning og afmærkning 6 1

1.2. Afdækning, afskærmning, indpakning, forsegling, osv. 11 2

1.3. Adgangsluser - 3 kamre 3 0

1.4. Førstehjælpsudstyr 2 0

Tilføj noter / fotos 2

09.13 38%

Noter til ny sikkerhedsmåling

Tilbage

Note

Skrive eller indtale dine noter her..|



Tilføj

Nulstil

Rapport i app'en og e-mail

Safety Observer

Virksomhed: BYG-asbest
Skema: Bygasbest , 2021
Arbejdsplads: Brøndby 2 og 3
Sektion:
Område:
Kommentarer:
sammen med NFA målinger
Måling foretaget af: Pete Kines
Kl. 10:48 28. marts 2022
Antal observationer: 236
Sikkerhedsindeks: 83 %

1. Indretning af arbejdsområder

Fotos(4)

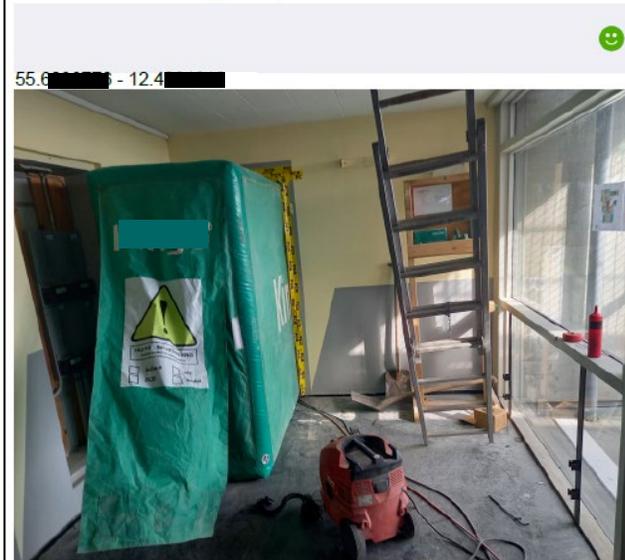
1.1. Skiltning og afmærkning	5 observationer		
1.2. Afdækning, afskærmning, indpakning, forsegling, osv.	5 observationer		
1.3. Adgangsluser - 3 kamre	1 observation		
1.4. Førstehjælpsudstyr	8 observationer		
1.5. El-sikkerhed	15 observationer		
1.6. Belysning	11 observationer		

2. Orden og ryddelighed

Fotos(2)

2.1. Oprydning	27 observationer		
2.2. Farligt affald - mærkning og håndtering	6 observationer		

Noter/fotos til 1. Indretning af arbejdsområder



Tak for jeres opmærksomhed!

Pete Kines
pki@nfa.dk