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Advanced Ventilation and Filtration Strategies for Indoor Air Quality and Thermal Comfort

T4.1 development and validation of
multi-zone ventilation and thermal comfort model

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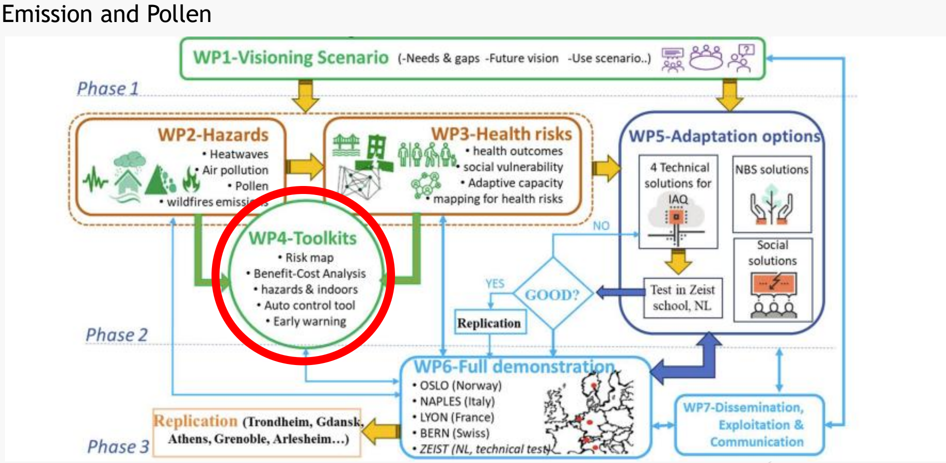
Health riskADAPT

Coordinator: NILU (Oslo, NO)

Health riskADAPT- User-driven Health risk Assessment Services and Innovative ADAPTation options as Transformative Solutions against Threats from Heatwaves, Air Pollution, Wildfire Emission and Pollen



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TNO innovation for life

Goal of the study: simulation and validation of indoor PM2.5

Indoor PM2.5 depends on:

Mechanical ventilation:
- Ventilation system flow
- Filtering of outdoor air

Infiltration:
- Outdoor wind speed
- Cp pressure coefficients
- Airtightness of the dwelling
- Windows open or closed
- Thermal driving forces (stack effect)

Indoor sources (smoking, cooking, candles)

Indoor deposition & filtering

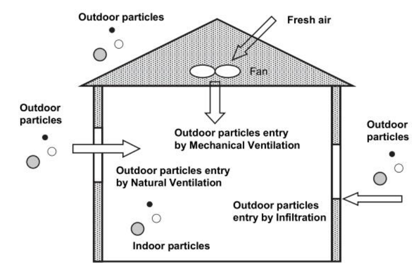

Fig. 1. The pathways of outdoor particles entering into indoor environment.

C. Chen, B. Zhao / Atmospheric Environment 45 (2011) 275–288

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$PM_{2.5}$ mass balance for each zone

$$\frac{dC_{in}}{dt} = F \cdot (1 - E_f) \cdot C_o + I \cdot P \cdot C_o - (F + I + k) \cdot C_{in} + \frac{S}{V}$$

- C_{in} indoor particle concentration (µg/m³)
- F ventilation flowrate (m³/s)
  - E_f filtration efficiency (-)
- C_o outdoor particle concentration (µg/m³)
- I infiltration flowrate (m³/s)
  - P penetration factor (-)[1]
- k deposition rate on indoor surfaces (m³/s)[1]
- S indoor particle generation (µg/s)
- V zonal volume (m³)

Ventilation F and infiltration I estimated by CO_2 measurements

Ventilation unit with heat recovery in all 4 dwellings

[1] penetration factor = 0.73, deposition rate= 0.4 ACH based upon H. Zhao and B. Stephens, "Using portable particle sizing instrumentation to rapidly measure the penetration of fine and ultrafine particles in unoccupied residences," *Indoor Air*, vol. 27, no. 1, pp. 218-229, 2017

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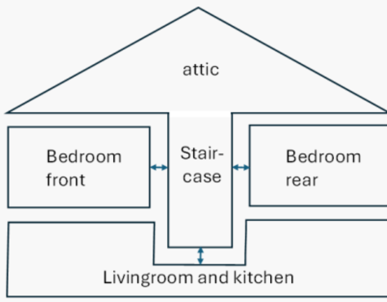
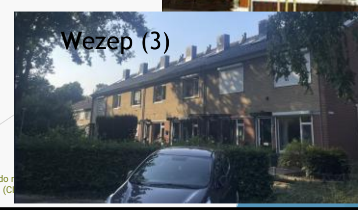
PM2.5 and ventilation monitoring and modelling of 4 dwellings: 3 Wezep and 1 Delft

Window open/closed contact

$PM_{2.5}$, CO_2, RH & T AirVisual Pro sensor

Occupant presence based on PIR movement sensor





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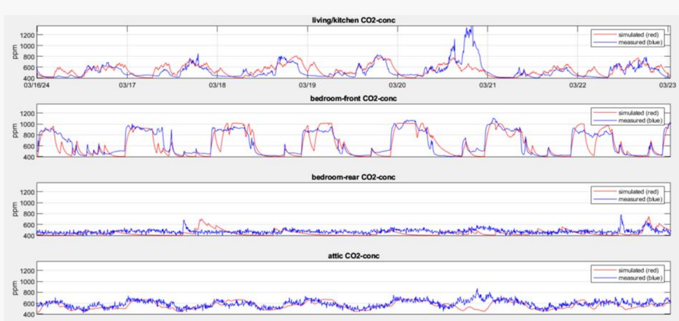
Estimate combined ventilation and infiltration flow per zone over 1 year

- Source strength Adults 19 dm^3 CO_2/h
- Source strength Children 13 dm^3 CO_2/h



The combined mechanical and infiltration flow is used to simulate the indoor PM 2.5 with TNO's AirMAPs: Multizone Airflow Network Model

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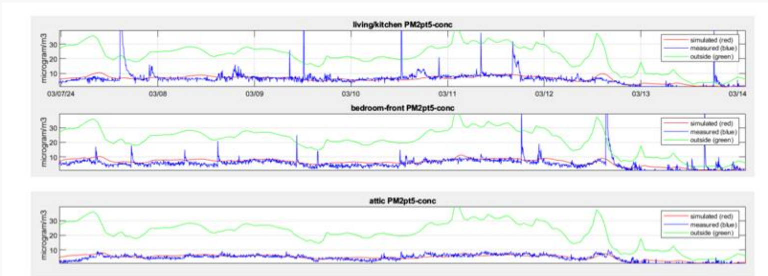
$PM_{2.5}$ 1 week in March (windows closed)

Delft:
fine F7 filter
E_f = 70% (PM2.5)
(ePM1 55%)



Underestimation in sim

Wezep: coarse G3 filter
E_f = 10% (PM2.5)
(about ISO Coarse 50%)

Underestimation in simulations possible due to:

- estimated airtightness
- estimated outdoor CO_2 level
- unknown particulate matter sources (small sources over a longer period)

Simulated indoor PM2.5 values follow measurements except of intermittent indoor sources

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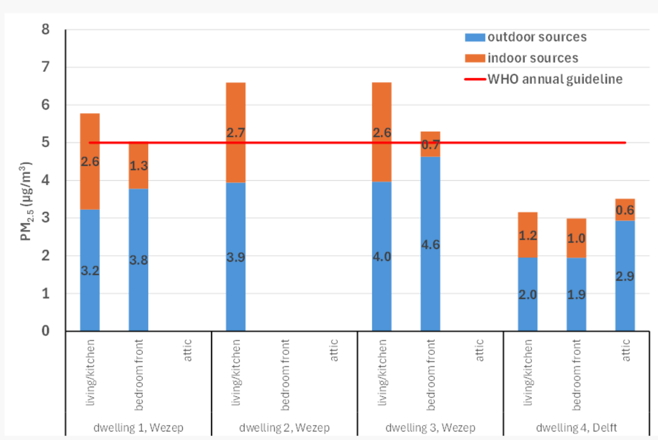
With fine filter $PM_{2.5}$ below WHO annual



Coarse G3 filter | fine F7 filter

F7 filters costs about 20 Euro annual more then G3

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Conclusions

- The simulated CO_2-levels show a moderate to good agreement with the measured values
- The simulated $PM_{2.5}$ levels (excluding indoor sources, because those are not simulated) correspond reasonable to the measured levels
- Be aware of correct assumptions on airtightness and outdoor CO_2 levels an unknown particulate matter sources (small hard to detect sources over a longer period)
- For the dwellings with G3 filter the yearly average $PM_{2.5}$ levels are equal or higher than maximum values recommended by the World Health Organization (WHO)
- For the dwelling with F7 filter the recommended level is not exceeded.

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Next steps towards November 2028

- Effect of high High-efficiency particulate filtration filter on indoor $PM_{2.5}$
- Long term health care building – nursing home
- More focus on thermal modelling, address combined heat and pollutant stress.

This integrated approach supports evidence-based design for resilient, low-energy buildings that safeguard occupant health under evolving environmental challenges.

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