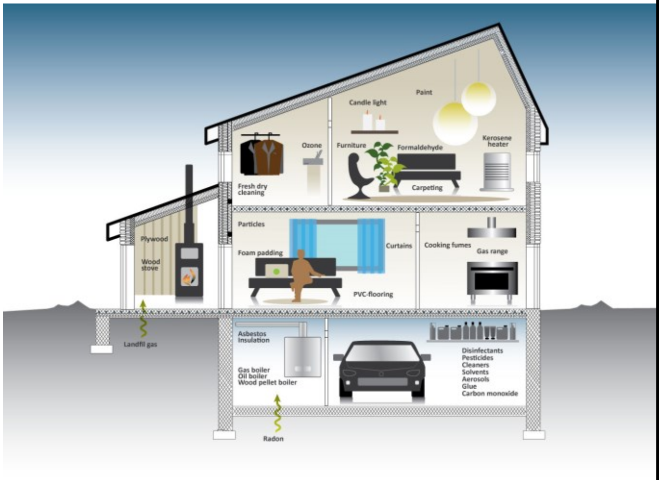
Webinar 23 November 2021

Emerging smart ventilation strategies for energy efficient IAQ management

Intro by: Prof. Carsten Rode
Technical University of Denmark



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IEA-EBC Annex 86

Energy Efficient Indoor Air Quality Management in Residential Buildings

Operating Agent:
Jelle Laverge
Ghent University

Presented by: Prof. Carsten Rode, Technical University of Denmark

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Scope and Goals

Provide a framework for energy efficiency of the IAQ management strategies in operation and to improve their acceptability, control, installation quality and long-term reliability.

Residential buildings
- new and refurbished

- Metrics to assess energy performance and indoor environmental quality of an IAQ management strategy
- Improve acceptability, control, installation quality and long-term reliability of IAQ management strategies
- Coherent rating method for IAQ management strategy that takes into account the selected metrics
- Tools to assist designers and managers of buildings in assessing the performance of an IAQ management strategy
- Gather standardized input data for the rating method
- Study use of smart materials as part of an IAQ management strategy
- Develop IAQ management solutions for retrofitting existing buildings
- Benefit from advances in sensor technology and cloud-based data storage to improve quality of IAQ management strategies & operation
- Improve availability of data sources by exploring use cases
- Disseminate about above findings

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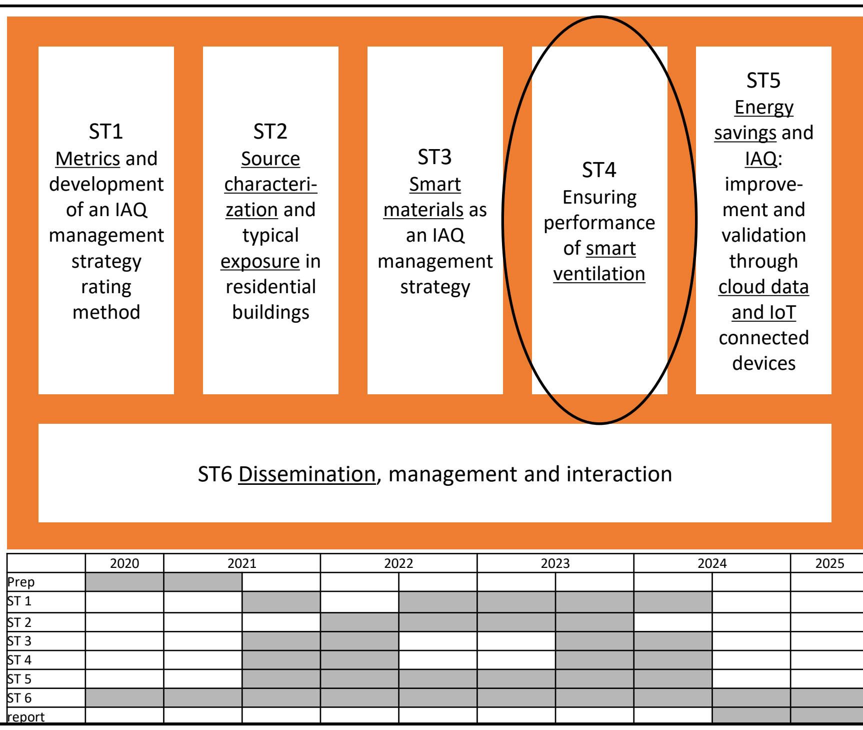

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Partners

41 institutes from 24 countries

List of annex participants per country:

Australia:	CSIRO
Austria:	University of Innsbruck
Belgium:	UGent, KUL, BBRI, University of Antwerp
Brazil:	Pontifical Catholic University of Paraná
Canada:	NRC
Chile:	PUC
China:	Nanjing University, BUCE, Tsinghua University
Denmark:	DTU, Aalborg University Copenhagen
Finland:	Aalto University
France:	La Rochelle University, ENS PSL, CEREMA, Université de Lille, UPJV, CETIAT
Germany:	TH Rosenheim
Ireland:	NUIG
Italy:	EURAC research centre
New Zealand:	BRANZ
Netherlands:	Technical University of Eindhoven, BBA/TUDelft, Zehnder
Norway:	Oslo Metropolitan University, SINTEFF
Portugal:	University of Coimbra, Polytechnic Institute of Viseu, University of Porto
Singapore:	National University of Singapore
Spain:	Eduardo Torroja Institute for Construction Sciences – CSIC
Sweden:	Chalmers University, KTH
Switzerland:	ETH
Turkey:	TTMD
United Kingdom:	University of Strathclyde, Lancaster University, University of Nottingham
USA:	Syracuse University, UMD, LBL

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EBC Annex 86 Webinars with the AIVC

https://www.aivc.org/events/webinars

1 April 2021	Building ventilation: How does it affect SARS-CoV-2transmission
8 April 2021	IAQ and Ventilation Metrics
13 April 2021	Big data, IAQ and ventilation – part 1
21 April 2021	Big data, IAQ and ventilation – part 2
12 October 2021	Smart materials for energy efficient IAQ management
23 November 2021	Emerging smart ventilation strategies for energy efficient IAQ management

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Agenda – 23 November 2021

16:00 | *Introduction IEA-EBC Annex 86 and dissemination activities*
Carsten Rode, Leader of ST6, IEA EBC Annex 86 – DTU, Denmark

16:05 | *Introduction IEA-EBC Annex 86 ST4-smart ventilation*
Gaëlle Guyot, Leader of ST4, IEA EBC Annex 86 – Cerema, France

16:10 | *Investigation of natural ventilation control with regard to indoor and outdoor environments: First results*
Evangelos BELIAS – EPFL, Switzerland

16:30 | *Implementation of a MPC for an all-air system in an educational building*
Bart Merema, KU Leuven – Belgium

16:50 | *Draft for a health related performance assessment framework for smart ventilation*
Klaas De Jonge – UGent, Belgium

17:10 | *Residential Applications of Smart Ventilation Controls*
Iain Walker – LBNL, USA

17:30 | *Questions and Answers*
Jakub Kolarik, Co-Leader of ST4, IEA EBC Annex 86 – DTU, Denmark

17:45 | *Closing & End of webinar*

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Webinaire 23/11/2021

Emerging smart ventilation strategies for energy efficient IAQ management

Introduction

Jakub Kolarik (DTU, Denmark) & Gaëlle Guyot (Cerema & Univ. Savoie Mont Blanc, France)

EBC
Energy in Buildings and Communities Programme

Webinar
AIVC Air Infiltration and Ventilation Centre

Smart ventilation definition

"Smart ventilation is a process to continually adjust the ventilation system in time, and optionally by location, to provide the desired IAQ benefits while minimizing energy consumption, utility bills and other non-IAQ costs (such as thermal discomfort or noise).(…)"

(Durier et al 2018, AIVC)

EBC
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IEA-EBC Annex 86 ST4
Ensuring performance of smart ventilation

A4.1 Rating existing smart ventilation strategies

A4.2 Quality control of implementation

A4.3 Durability of smart ventilation systems and components

A4.4 Occupant interaction

What we want in this Annex 86

- Have a precise description of the SV strategies we are talking about
  - Work on good practice examples, in order to avoid generalization
  - Identify potential of energy saving and IAQ performances
- Collect knowledge from all involved partners about how ensuring performance of such smart ventilation strategies

4 Presentations of the webinar

- 16:10 | Investigation of natural ventilation control with regard to indoor and outdoor environments: First results, ***Evangelos BELIAS – EPFL, Switzerland***
- 16:30 | Implementation of a MPC for an all-air system in an educational building, ***Bart Merema, KU Leuven – Belgium***
- 16:50 | Draft for a health related performance assessment framework for smart ventilation, ***Klaas De Jonge – UGent, Belgium***
- 17:10 | Residential Applications of Smart Ventilation Controls, ***Iain Walker – LBNL, USA***
- 17:30 | Questions and Answers, ***Jakub Kolarik, Co-Leader of ST4, IEA EBC Annex 86 – DTU, Denmark***
- 17:45 | Closing & End of webinar

EBC
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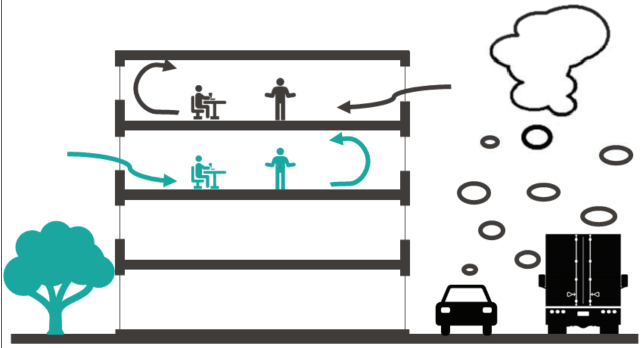
Investigation of natural ventilation control with regard to indoor and outdoor environments: First results



Evangelos BELIAS

PhD candidate

École polytechnique fédérale de Lausanne

23 November 2021

Webinar – Emerging smart ventilation strategies for energy efficient IAQ management

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The need for ventilation in buildings:

- Introduction of outdoor air to dilute the indoor air contaminants emitted by indoor sources

EPFL

Evangelos BELIAS

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Figure source: iqair.com

Outdoor air - IAQ

- Outdoor particulate matter is listed as one of the top risk factors for human health
  Source: Gakidou et al. (2017)

- People spend ~90% of their time indoors
  Source: Klepeis et al. (2001)

- It is estimated that 80% of humans' exposure to outdoor pollution takes place indoors
  Source: Nazaroff (2018)

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Figure source: COOLING POST

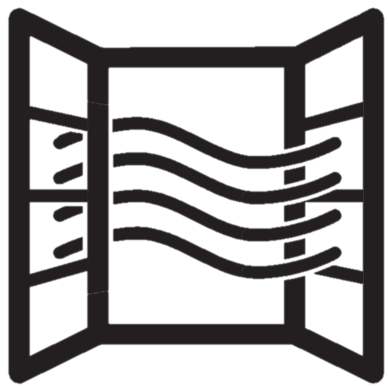
Air tightness + heat waves:

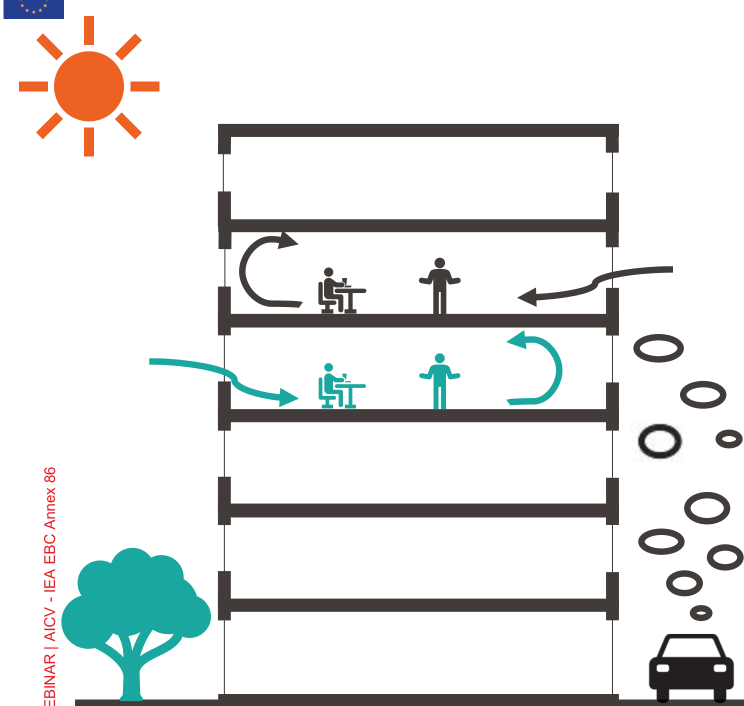
- Overheating phenomena in energy-efficient buildings, which occur not only during the summer but also during the transition periods

Sources: Mlakar and Štrancar (2011), Psomas et al. (2016)

Goal of Natural Ventilation:

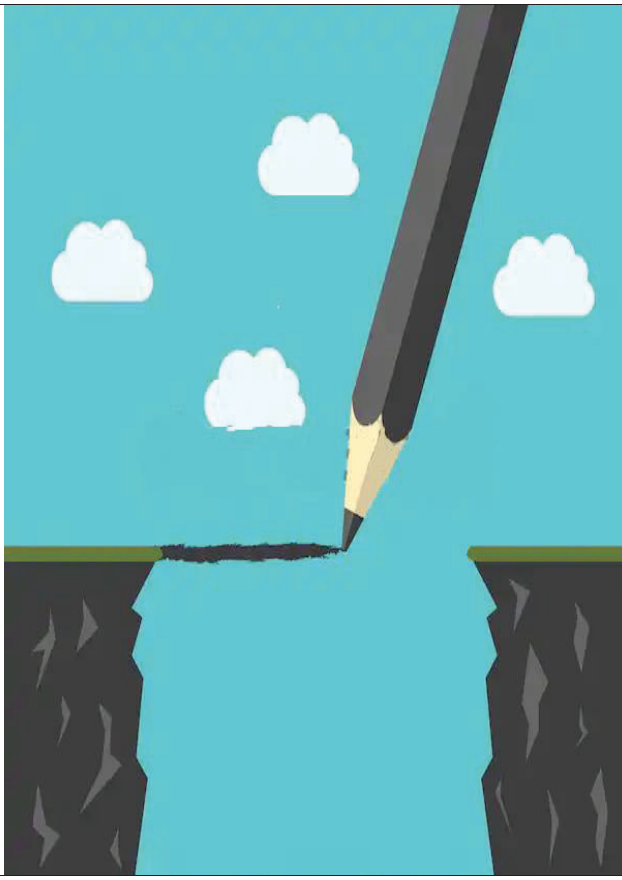
Indoor Air Quality + Thermal Environment





Existing studies

- Tradeoffs between overheating and $PM_{2.5}$ exposure in London (Taylor et al., 2014-15)
- Effect of outdoor $PM_{2.5}$ on NV applicability of office buildings in Europe & Asia (Martins and Carrilho da Graça, 2017-18 & Song et al., 2021)
- Effect of $PM_{2.5}$, PM_{10} & O_3 on NV applicability of office buildings in USA (Chen et al., 2019-20)



Knowledge gaps

- Only the effect of outdoor $PM_{2.5}$ on NV potential is mapped for Europe
- No distinction between traffic and background buildings
- No consideration of residential non-air conditioned buildings *(beyond London)*

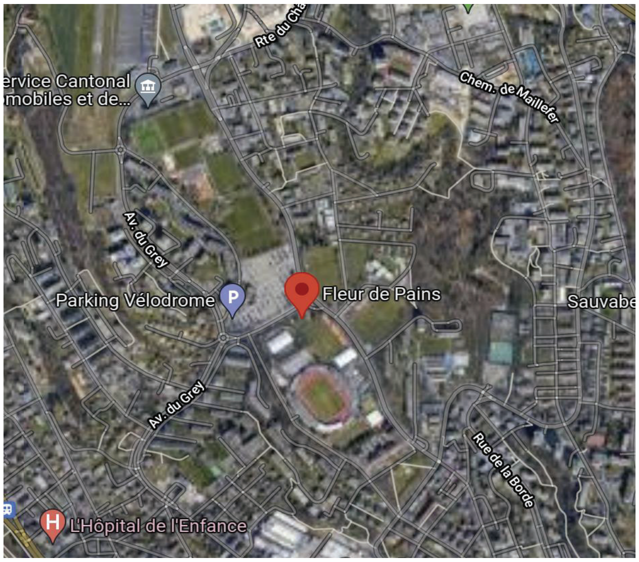
Objectives

- To quantify the outdoor air pollution penetration indoors when different NV scenarios are applied
- To investigate the tradeoffs between air pollution penetration and increased overheating
- To examine if the proximity to traffic plays a critical role in the indoor pollution levels

Methods: Investigated locations

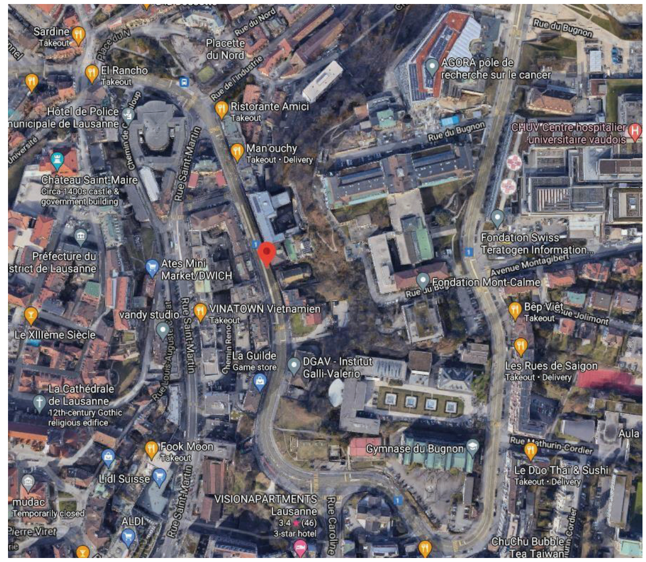
Evangelos BELIAS

Lausanne-Plaines du Loup



Background

Lausanne-César-Roux



Traffic

Methods: Selection of Representative Air Pollution Data

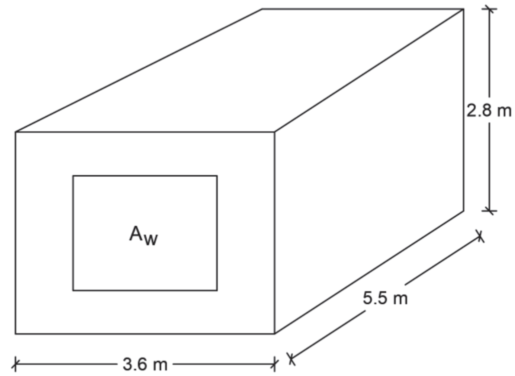
Evangelos BELIAS

- Three major air pollutants (PM_{10}, O_3, NO_2)
- Hourly concentrations for the five last years (2015-2019)
- Equivalent method for the creation of TMY
- Creation of representative year-long timeseries

Methods: Building simulation model

- **Geometry:**
  NF EN 15265 2008 & NF EN ISO 13790 2013
- **Envelope characteristics: (walls, windows, infiltration etc.):**
  Rinquet and Schwab, 2017
- **Operation, occupation, lighting, shading, appliances ventilation schedules:**
  EN 16798-1
- **Calculated NV considering wind and stack effect**

Typical apartment building built between 1960-1975

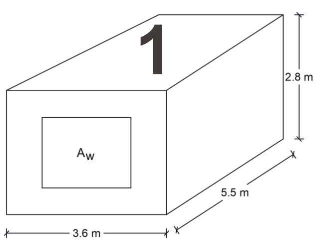


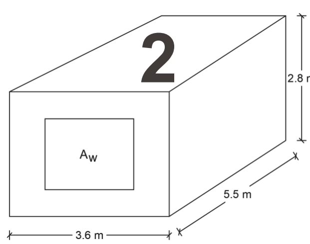
EnergyPlus

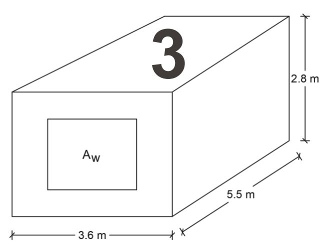
Figure Source: EnergyPlus

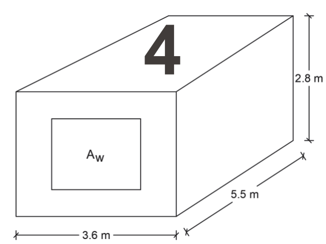
Methods: Ventilation scenarios

Continuous mechanical ventilation	Scheduled and summer comfort window opening	DCV window opening (T, RH, CO_2)	DCV window opening (T, RH, CO_2 & pollution)









No window opening	Three times per day + when T_{in} > 24 °C	Hygienic ventilation: CO_2 > 900 ppm Ventilative cooling: T_{in} > 24 °C & T_{in} > T_{out} & T_{out} > 10 °C	Hygienic ventilation: CO_2 > 900 ppm Ventilative cooling: as in 3 but only if outdoor pollution ↓

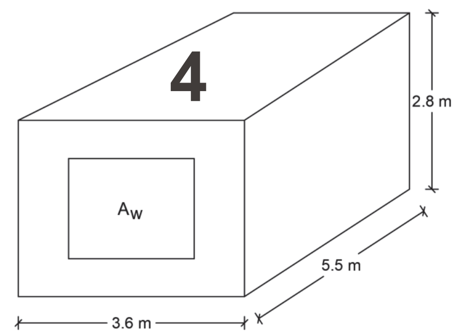
Methods: Ventilation scenario 4

- **Limits for outdoor air pollution:**
  - **PM_{10} < 20 µg/m^3**
  - **O_3 < 100 µg/m^3**
  - **NO_2 < 40 µg/m^3**

  (Limit values of WHO 2005 air quality guidelines)

- **If all apply → Ventilative cooling is permitted**

DCV window opening (T, RH, CO_2 & pollution)



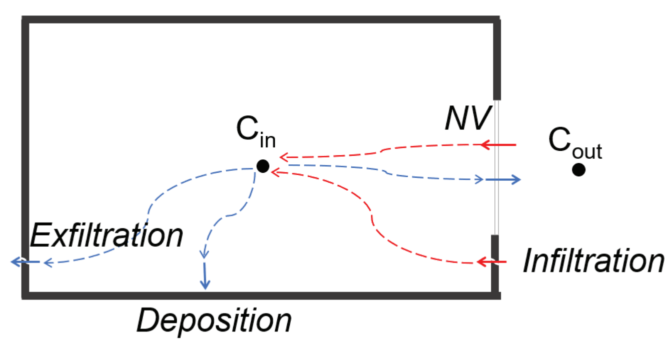
Hygienic ventilation: CO_2 > 900 ppm
Ventilative cooling: as in 3 but only if outdoor pollution ↓

Methods: IAQ modelling

- **Mass-balance model**

$$\frac{dC_{in}}{d} = \mathrm{P} \cdot \lambda \cdot C_{out} + \frac{Q_v}{V} \cdot C_{out} - \lambda \cdot C_{in} - \frac{Q_v}{V} \cdot C_{in} - k \cdot C_{in}$$

- C_{out}: Outdoor concentration [µg/m^3]
- *P:* Penetration coefficient [-]
- λ: infiltration/exfiltration rate [h^{-1}]
- Q_v: Ventilation air-flow [m^3/h]
- k: Deposition rate [h^{-1}]
- *V:* Room Volume [m^3]
- C_{in}: Indoor concentration [µg/m^3]

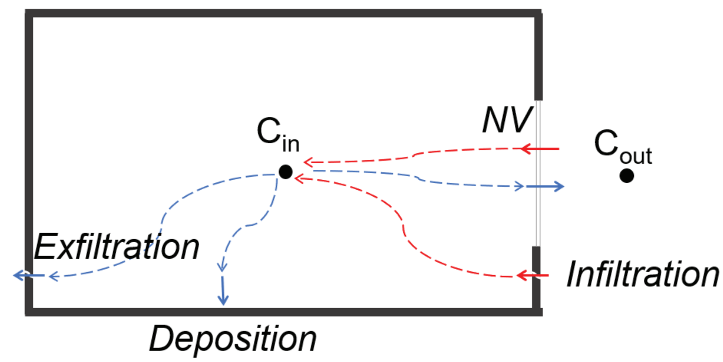


Methods: IAQ modelling

- **Mass-balance model**

$$\frac{dC_{in}}{d} = \boxed{P} \cdot \lambda \cdot C_{out} + \frac{Q_v}{V} \cdot C_{out} - \lambda \cdot C_{in} - \frac{Q_v}{V} \cdot C_{in} - \boxed{k} \cdot C_{in}$$

Pollutant	P	k
PM_{10}	0,2	1,2
O_3	0,54	1,62
NO_2	0,72	0,27

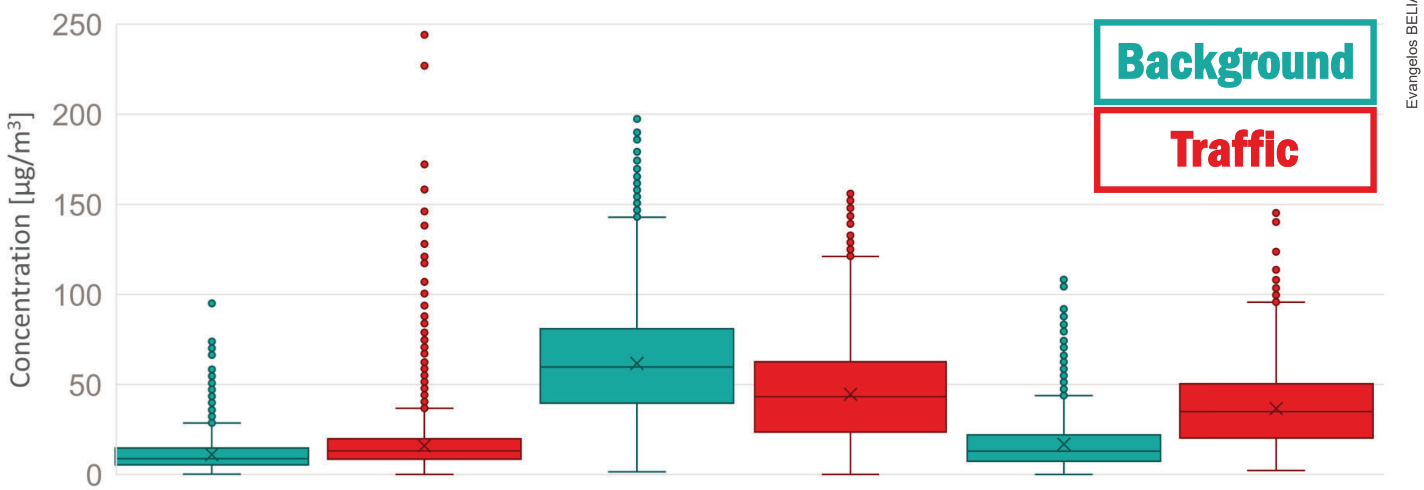


(Stratigou et al. 2020, *Zhao and Stephens 2016 & Zhao et al. 2019*)

CO_2: emission by the occupants: 0,66 l/(m^2, h) *(EN 16798-1)*

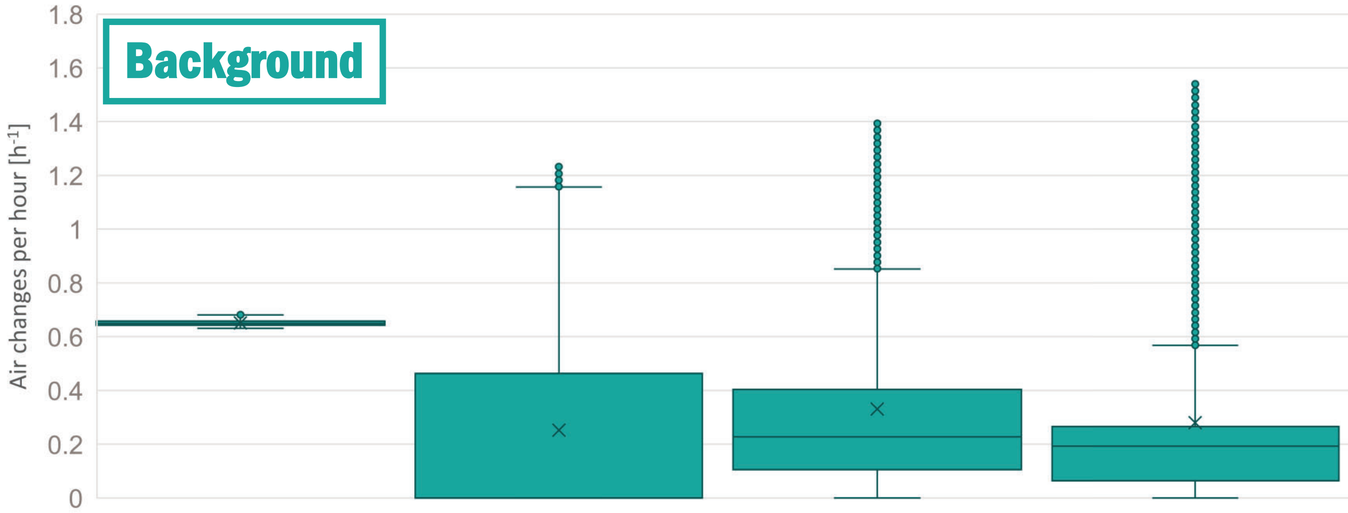
CO_2: outdoor concentration: 400 ppm

Results: Outdoor air quality



	PM_{10}		O_3		NO_2	
Max	97.56	521.8	197.38	158.5	108.2	148.1
Mean	11.1	16.0	61.7	44.5	16.8	36.5

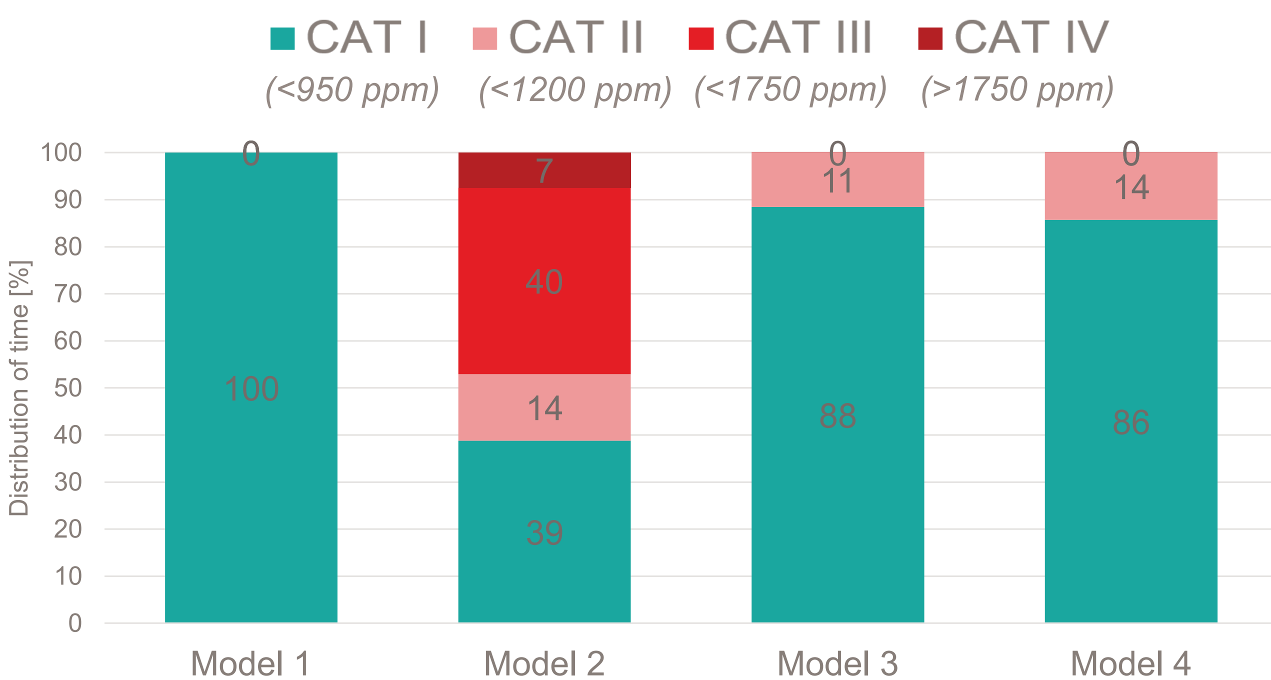
Results: Ventilation rates per model



	Model 1	Model 2	Model 3	Model 4
Mean	0.65	0.25	0.33	0.28

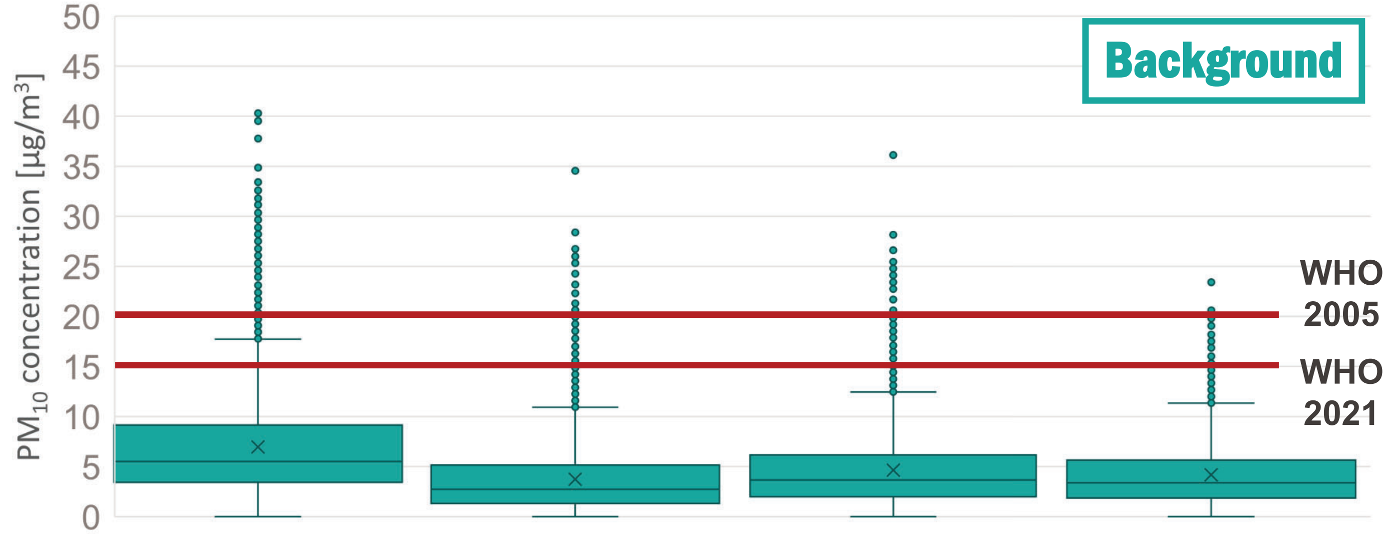
Mean infiltration rate ~ 0.14 ACH

Indoor CO_2 concentrations



EPFL

Results: Indoor PM_{10} concentrations

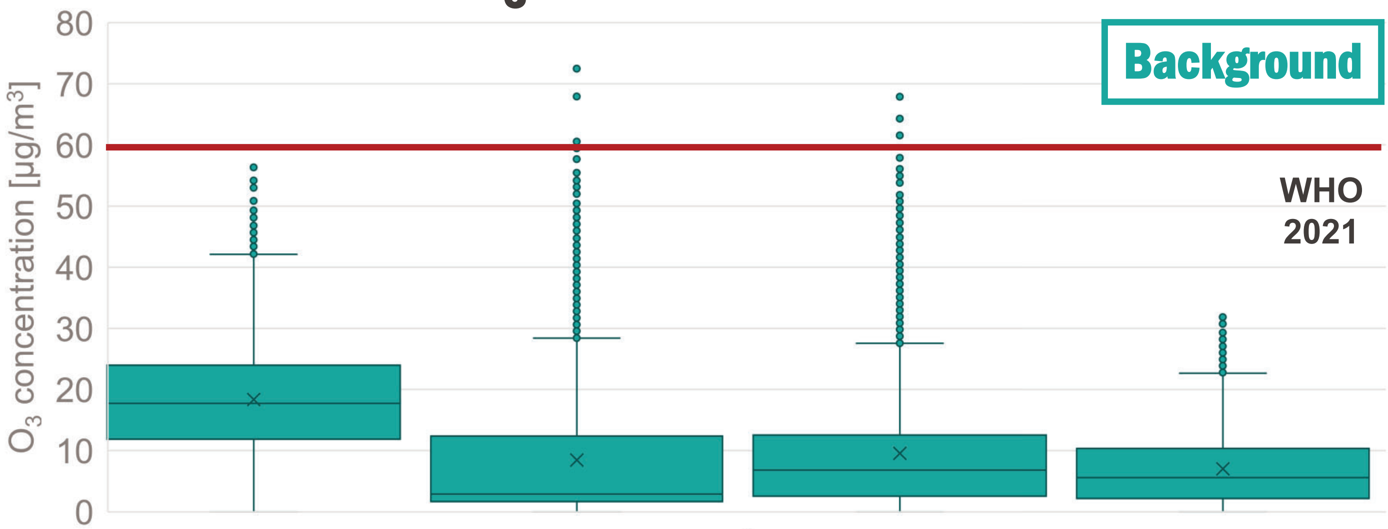


	Model 1	Model 2	Model 3	Model 4
Mean	6.96	3.76	4.65	4.18
Max	40.92	34.54	36.11	23.41

Evangelos BELIAS

EPFL

Results: Indoor O_3 concentrations



	Model 1	Model 2	Model 3	Model 4
Mean	18.35	8.47	9.57	7.04
Max	56.95	72.48	67.89	31.88

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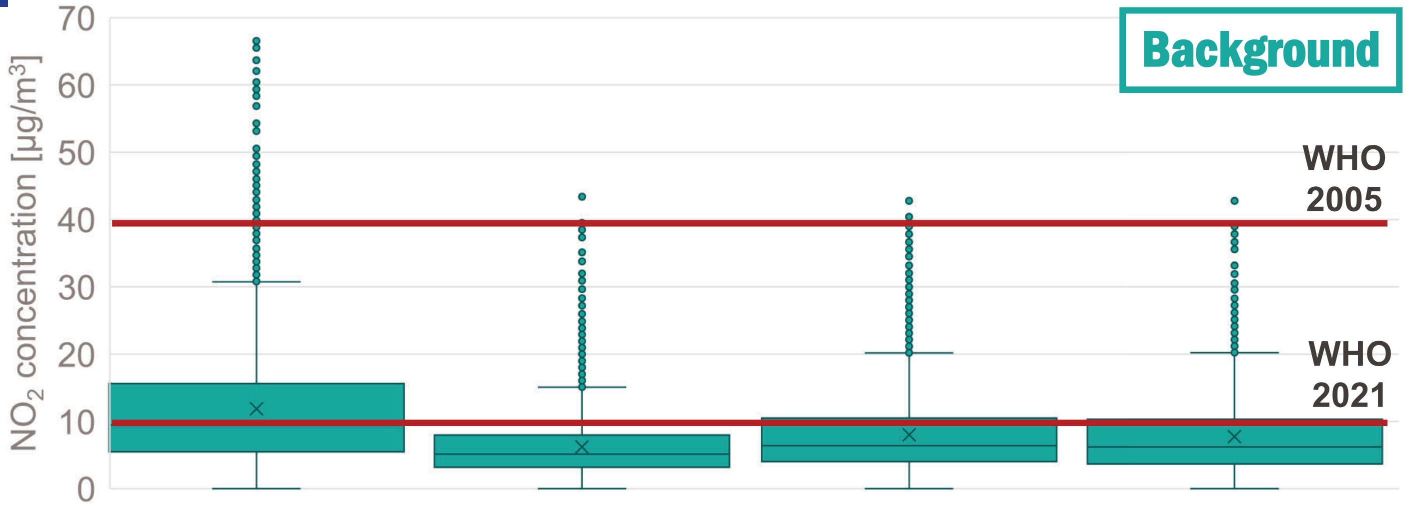
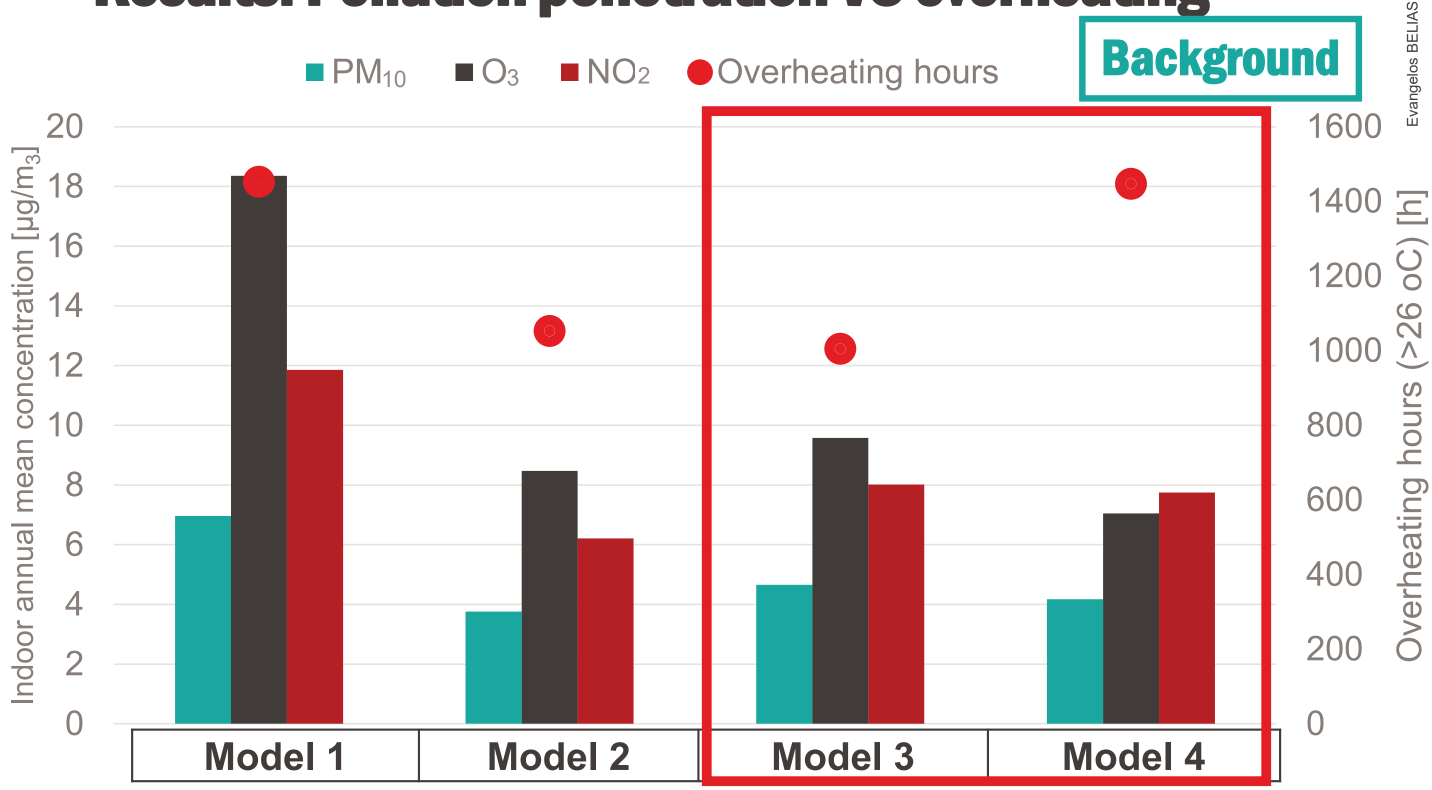
Results: Indoor NO_2 concentrations



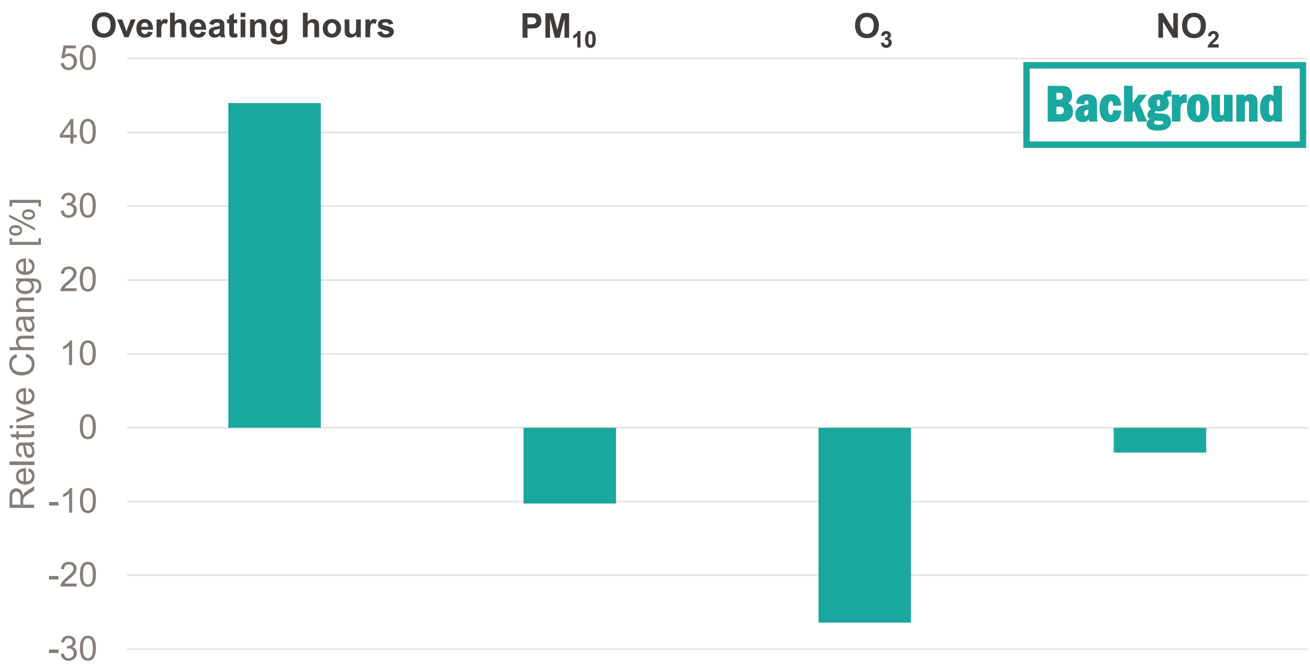
	Model 1	Model 2	Model 3	Model 4
Mean	11.86	6.21	8.01	7.74
Max	66.52	43.4	42.9	42.9

Results: Pollution penetration VS overheating

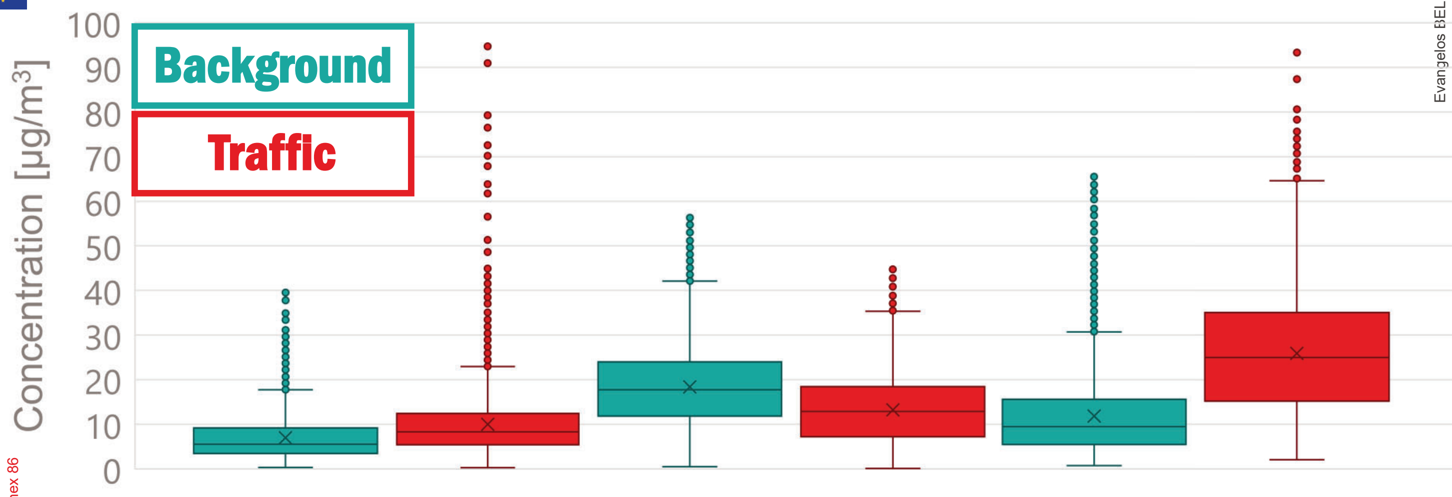


Results: Pollution penetration VS overheating

- Relative changes from model 3 to 4



Results: Background VS Traffic indoor concentrations



	PM_{10}		O_3		NO_2	
Max	40.92	202.57	56.95	45.98	66.53	93.3
Mean	6.9	10.1	18.15	13.3	11.8	25.9

Results: IAQ compliance

Evangelos BELIAS

- WHO air quality guidelines 2005:

  All models in all locations in compliance

- WHO air quality guidelines 2021:

		Model 1		Model 2		Model 3		Model 4	
		Background	Traffic	Background	Traffic	Background	Traffic	Background	Traffic
PM_{10}	Annual mean	6.96	10.02	3.76	5.21	4.65	6.59	4.18	5.64
	24-h exceedance	0	1	0	0	0	0	0	0
O_3	8h mean maximum ex	0	0	0	0	0	0	0	0
	8h mean peak season	<60	<60	<60	<60	<60	<60	<60	<60
NO_2	Annual mean	11.86	25.88	6.21	14.66	8.01	18.26	7.74	15.31
	24-h exceedance	16	203	0	49	1	66	1	10

Conclusions

Evangelos BELIAS

The DCV reduces the penetration of outdoor air pollutants

Reducing outdoor air pollution penetration increases overheating

The proximity to traffic influences significantly the IAQ

With the new WHO air quality guidelines, NO_2 becomes critical

Merci.

Questions?

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 754354, and from EPFL

KU LEUVEN

MPC framework for all-air systems in non-residential buildings

Numerical and experimental study

Bart Merema

Supervisors:

Dirk Saelens

Hilde Breesch

AIVC webinar

Table of contents

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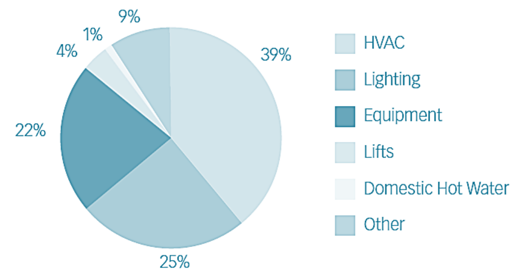
High energy use in buildings

Measures taken

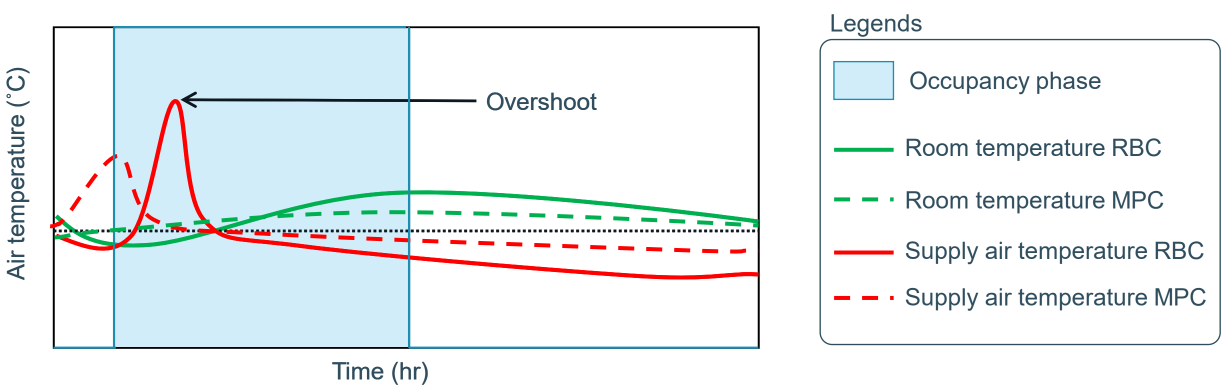
- Improved insulation layer
    - More airtight envelope
    - Better design and optimization of energy efficient HVAC systems



There is still energy waste in buildings due to inefficient operation

Smart control of HVAC systems

Reactive control (RBC) vs. predictive control (MPC)



Introduction | Methodology | Results | Conclusions

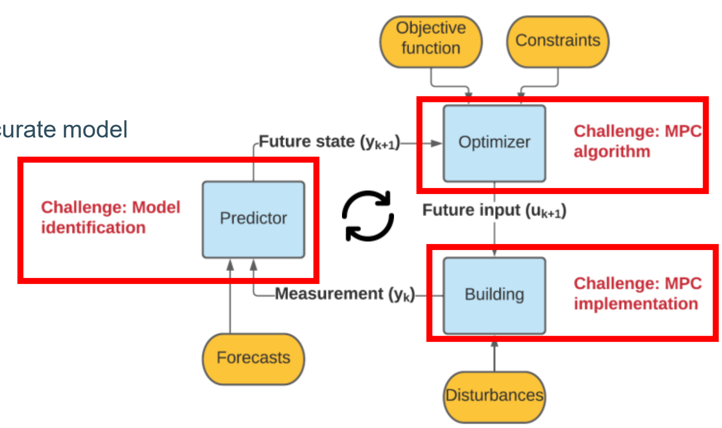
Objectives

- Proof of concept for an MPC framework in non-residential buildings with an all-air system
  - To identify suitable models for application in all-air systems
  - A robust MPC algorithm for application in all-air systems
  - To demonstrate the potential of MPC for all-air systems

Introduction | Methodology | Results | Conclusions

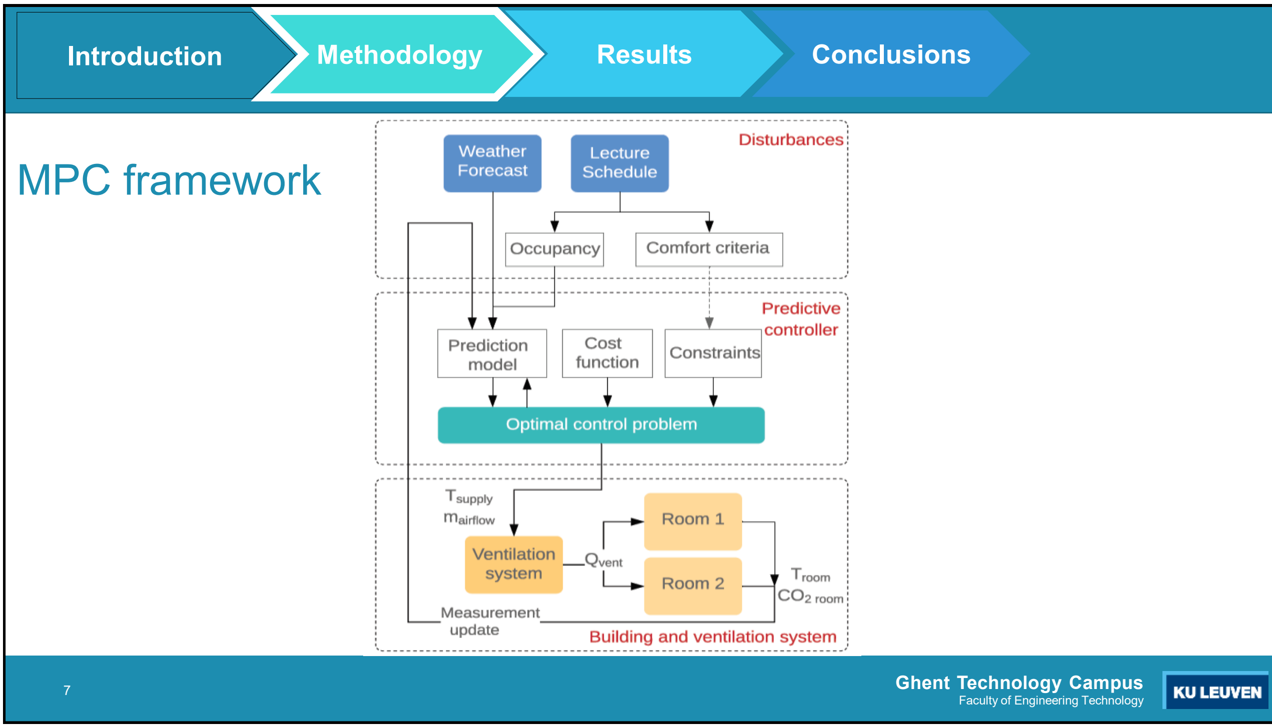
- MPC is a promising technique to optimize the control of the all-air system

Simple but accurate model



Conflicting targets

Integration with BAS



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MPC framework
Weather Forecast
Lecture Schedule
Disturbances
Occupancy
Comfort criteria
Predictive controller
Prediction model
Cost function
Constraints
Optimal control problem
T supply
m airflow
Ventilation system
Q vent
Room 1
Room 2
T room
CO2 room
Measurement update
Building and ventilation system
7
Ghent Technology Campus
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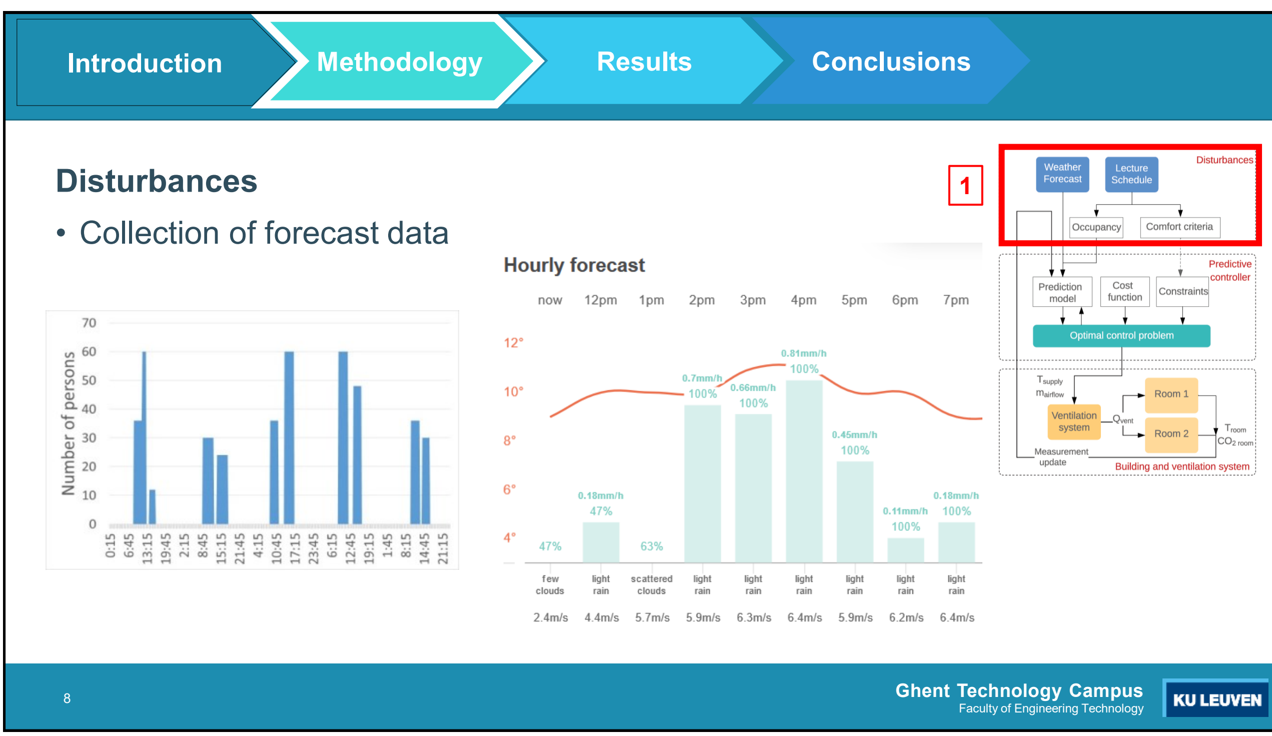

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Disturbances
• Collection of forecast data
1
Number of persons
Hourly forecast
now 12pm 1pm 2pm 3pm 4pm 5pm 6pm 7pm
few clouds
light rain
scattered clouds
2.4m/s 4.4m/s 5.7m/s 5.9m/s 6.3m/s 6.4m/s 5.9m/s 6.2m/s 6.4m/s
8
Ghent Technology Campus
Faculty of Engineering Technology
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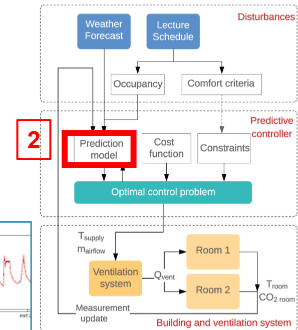
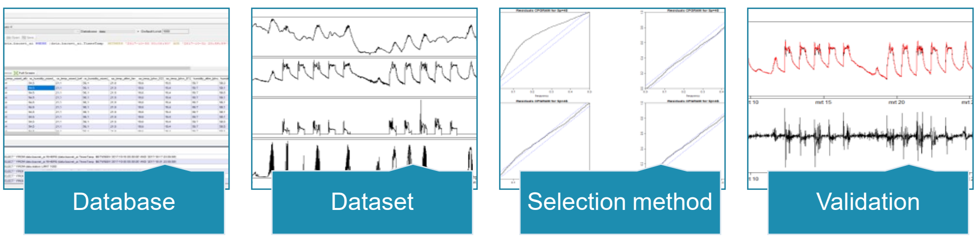
- Multi-zone RC and ARX-models for CO_2 and temperature predictions





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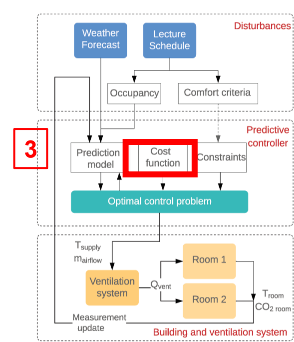
Introduction Methodology Results Conclusions

Cost function with comfort and energy parameters

$$Min: \sum_{k=0}^{Hp} w1 * (zCO_2)^2 + w2 * (zT)^2 + w3 * (Q_{elec})^2 + w4 * (Q_{thermal})^2$$



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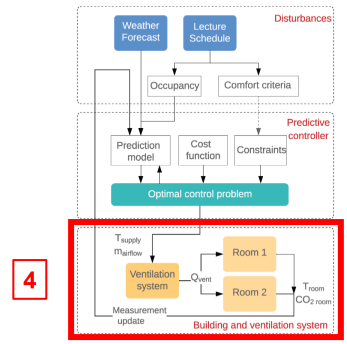
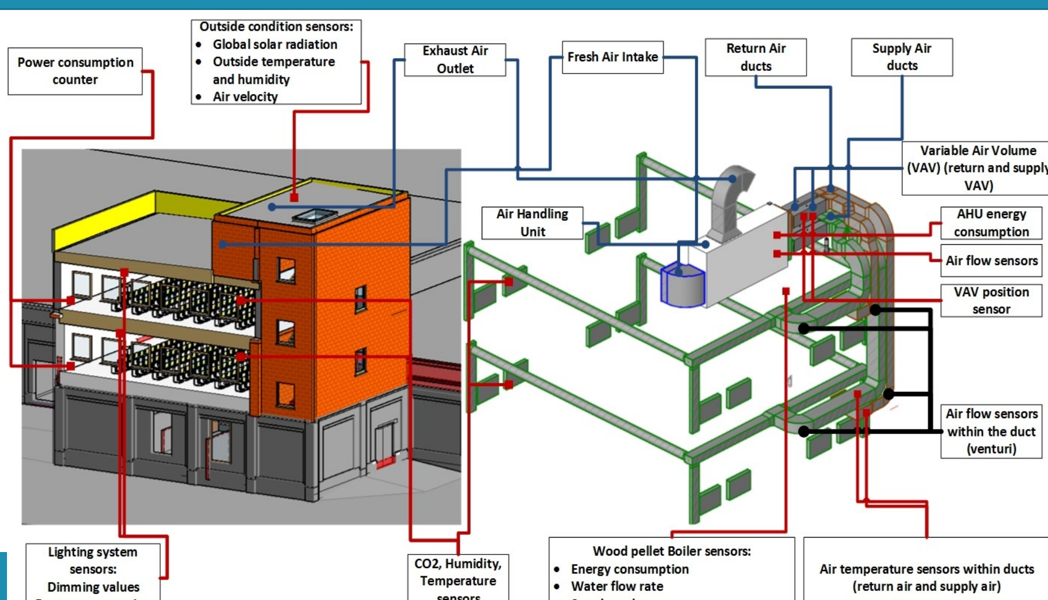
- Case study: Test lecture rooms, Ghent, Belgium
- Educational building with 2 lecture rooms
- All-air system (CO_2 + T)
- Integration of MPC through BACnet





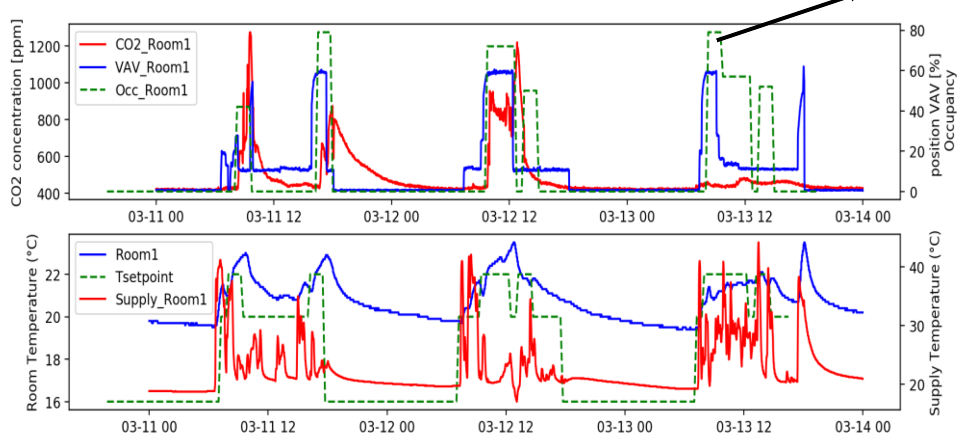
- Design of experiments: Feb-May 2020 and Sep-Dec 2020

	Horizon		Model		Timestep		Occupancy based
	2 h	4 h	RC	ARX	15 min	5 min	
Scenario 1	x		x		x		-
Scenario 2	x			x	x		-
Scenario 3	x		x		x		x
Scenario 4	x			x	x		x
Scenario 5		x	x		x		x
Scenario 6		x		x	x		x
Scenario 7	x		x			x	x
Scenario 8	x			x		x	x

13

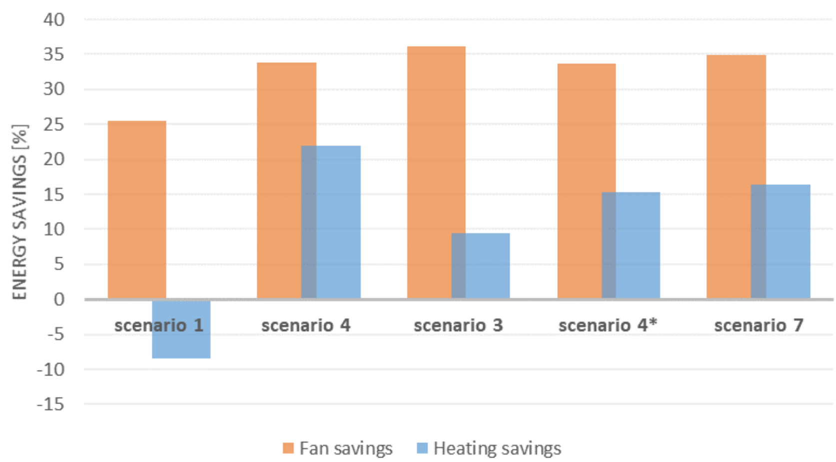
Demonstration of MPC

Expected occupancy



14

Energy savings MPC compared to RBC



	Thermal discomfort [Kh]		CO2-discomfort [ppmh]	
	RBC	MPC	RBC	MPC
Scenario 1 (RC-MPC)	11.9	6.81	1535	1607
Scenario 4 (ARX-MPC)	11.0	5.78	1460	1617
Scenario 3 (RC-MPC)	1.31	0.24	706	764
Scenario 7 (RC-MPC)	1.98	0.13	502	79

Introduction | Methodology | Results | **Conclusions**

- The developed all-air MPC can cope better with the intermittent use of the space compared to a RBC
- MPC strategies can control the IAQ and reduce the energy use
- Energy savings demonstrated for MPC compared to RBC: Fans 33-36%, heating coil 10-22%

Thank you for your attention!

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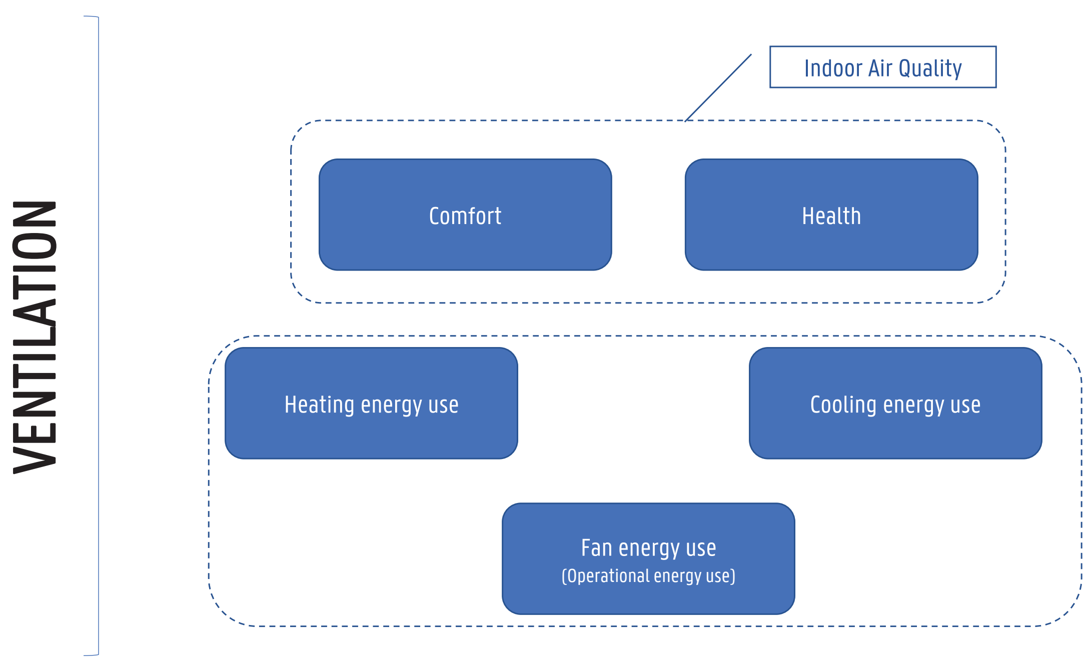
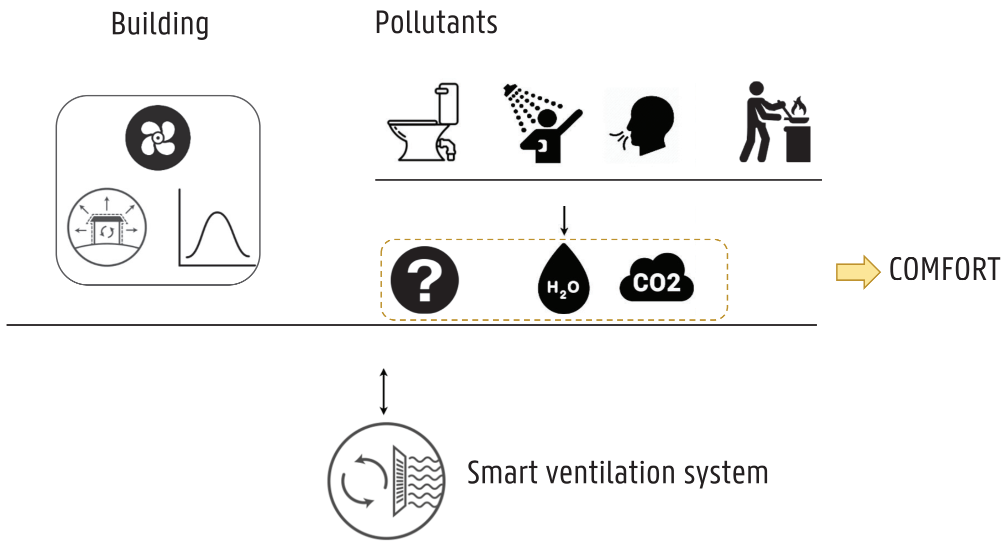
Draft for a Health-related Performance Assessment Framework for Smart Ventilation

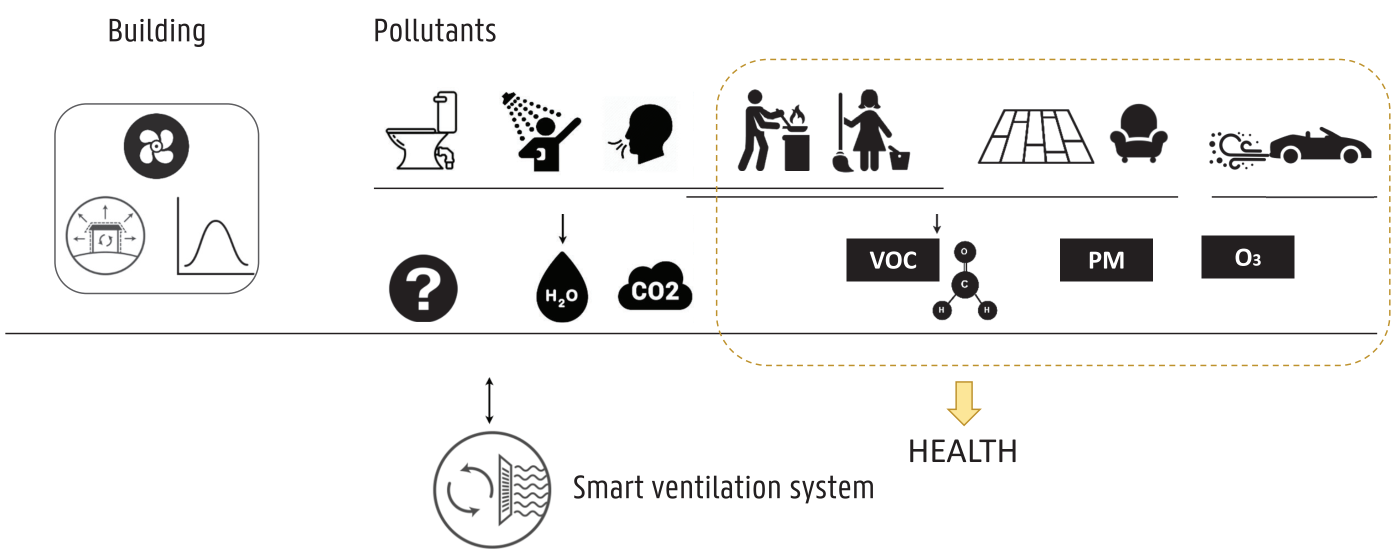
Ir.-Arch. Klaas De Jonge, Janneke Ghijsels

Prof. Dr. Ir.-Arch. Jelle Laverge

GHENT UNIVERSITY




Building
Pollutants
CO2
COMFORT
Smart ventilation system

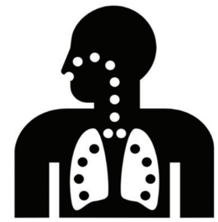

Building
Pollutants
CO2
VOC
PM
O3
HEALTH
Smart ventilation system

How to assess, score and check the performance?

Which pollutants?
Which sources?

How to assess, score and check the performance?

Key principles



Occupant-centric
- Exposure concentration (not room concentration)

Double check
1. Pass or fail: absolute limits
    - Maximum exposure concentration
    - Maximum (yearly) intake
    - Life-time average daily dose (HQ, LCR)
    - Better then reference systems
2. Scoring
    - Metrics that allow relative rating
    - Energy-use
    - Disability adjusted life-years (DALY)

Minimum performance

Relative performance

Applicable at different data resolutions

Which pollutants? Which sources?

Proposed method

1. Measurement campaign
2. Identify pollutants of interest
    - Filter based on occurrence, concentration level and health impact
3. Identify sources
    - Occupants
    - Occupant activities
    - Building - furniture

1. Measurements
2. Identify pollutants
3. Identify sources

Feedback:

New emerging pollutants?

Rising concentration levels?

New sources?

Add pollutants/sources to simulation framework

Design simulation framework

Evaluate pollutants for scoring

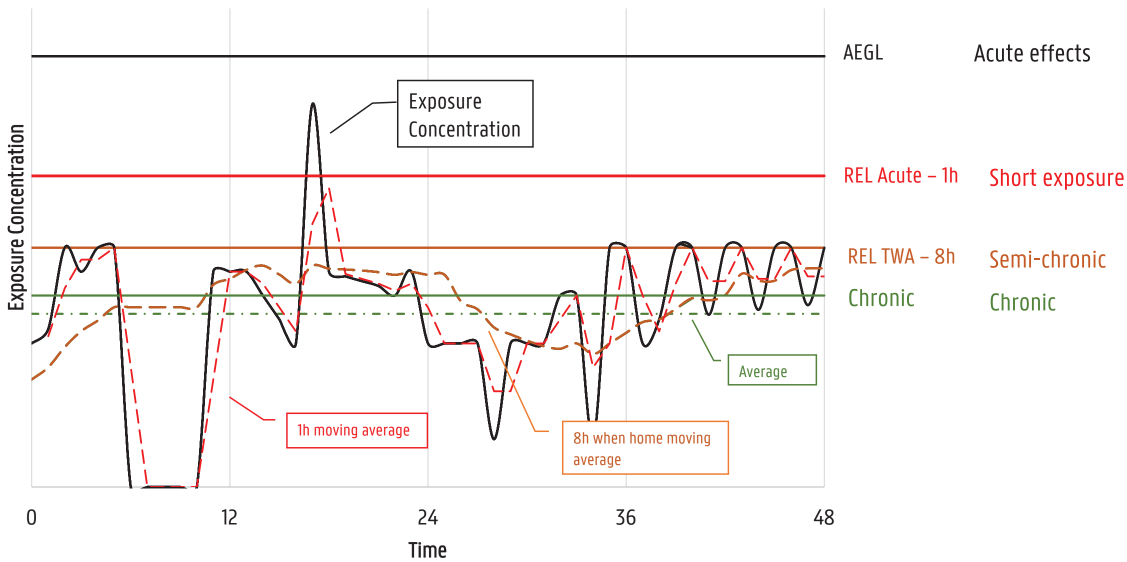
+

Identify other pollutants

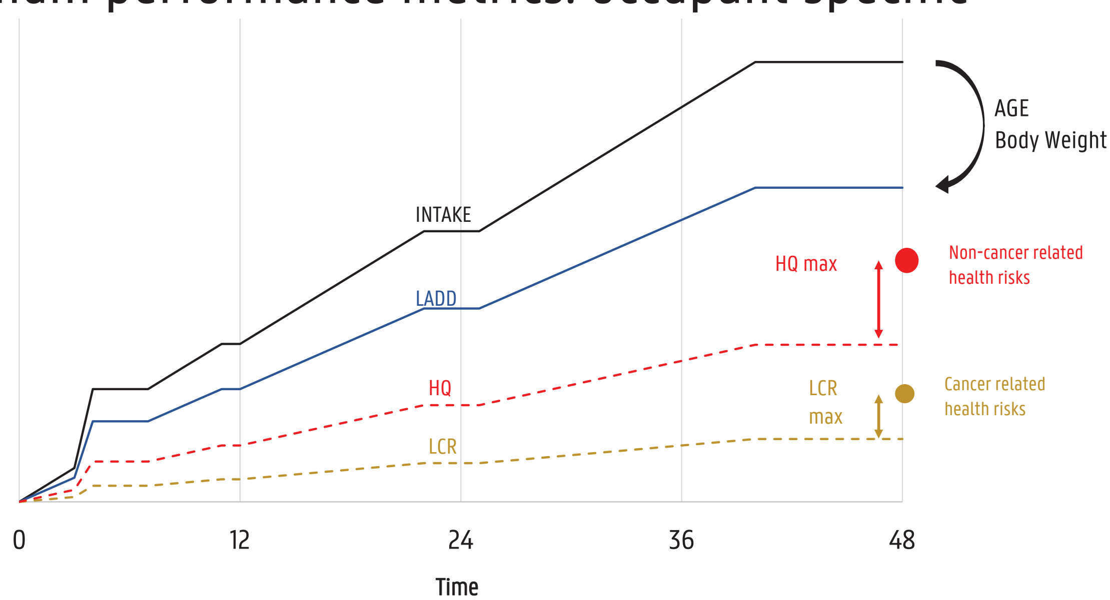
Case Belgium

DRAFT

Minimum performance metrics



Minimum performance metrics: occupant specific



Relative performance metric

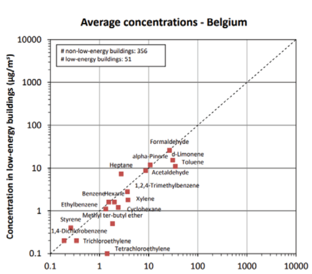
Disability Adjusted Life Year (DALY)

- Metric of harm
- Sum-able

- Based on Logue et al. (2011)
- ID & IND method

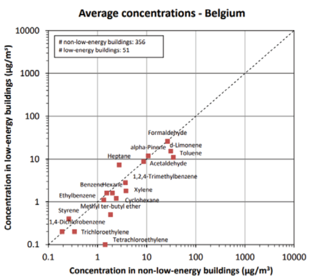
Planemad CC BY-SA 3.0

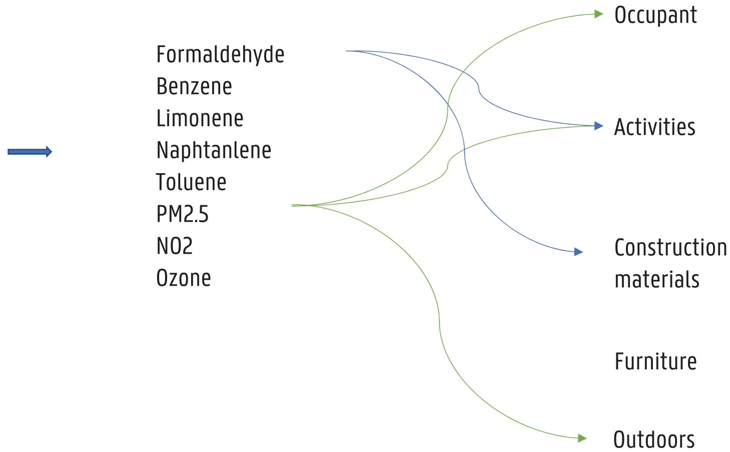
2.

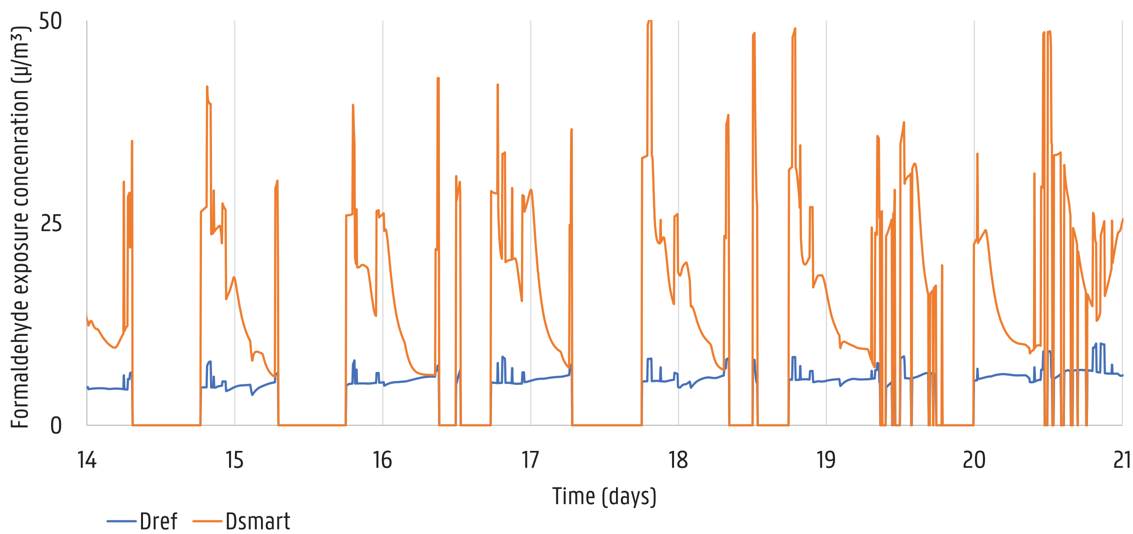


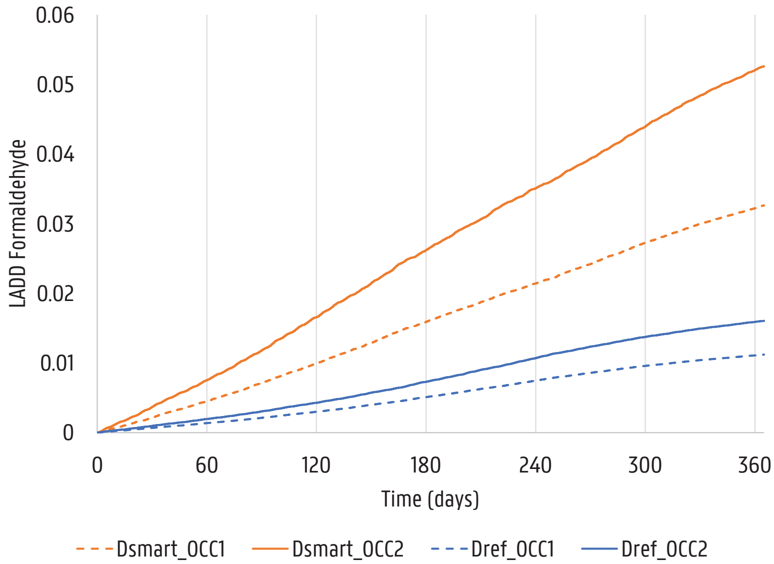
Formaldehyde
Benzene
Limonene
Naphtanlene
Toluene
PM2.5
NO2
Ozone

3.

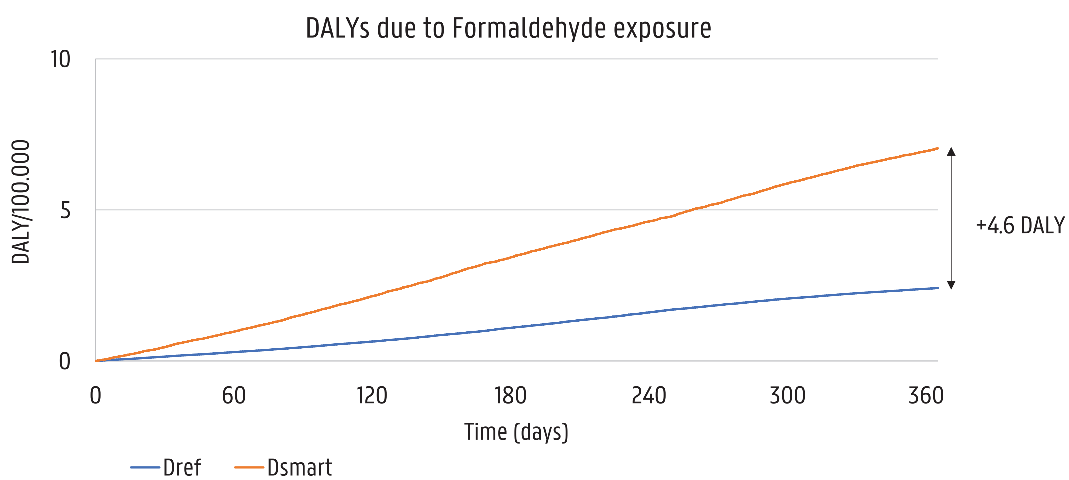

Average concentrations - Belgium
non-low-energy buildings: 356
low-energy buildings: 51
Concentration in low-energy buildings (µg/m³)
Concentration in non-low-energy buildings (µg/m³)
10000
1000
100
10
1
0.1
0.1
1
10
100
1000
10000
Formaldehyde
alpha-Pinene
d-Limonene
Toluene
Heptane
Acetaldehyde
1,2,4-Trimethylbenzene
Benzene
Hexane
Xylene
Ethylbenzene
Cyclohexane
Methyl ter-butyl ether
Styrene
1,4-Dichlorobenzene
Trichloroethylene
Tetrachloroethylene

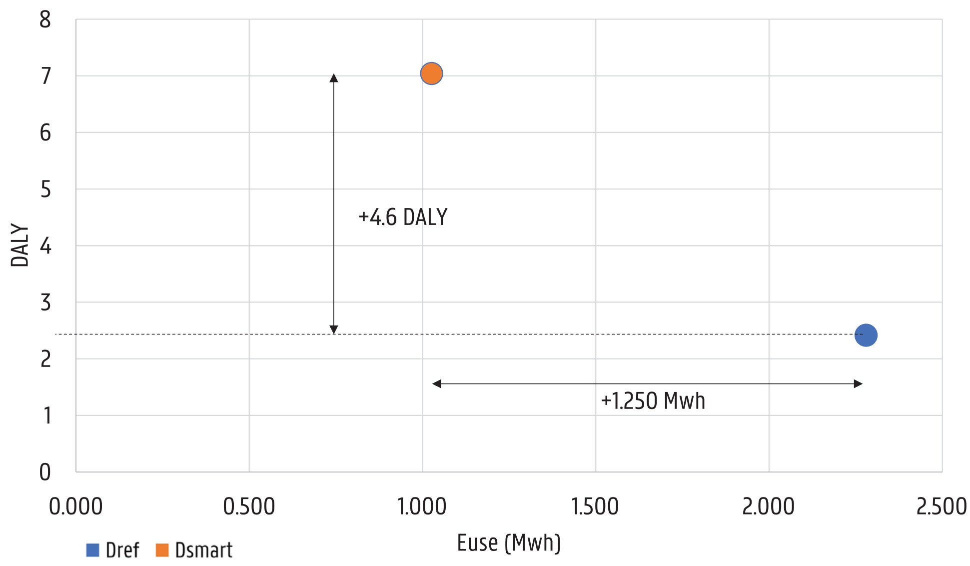

Formaldehyde
Benzene
Limonene
Naphtanlene
Toluene
PM2.5
NO2
Ozone
Occupant
Activities
Construction materials
Furniture
Outdoors


Formaldehyde exposure concenration (µ/m³)
50
25
0
14
15
16
17
18
19
20
21
Time (days)
Dref
Dsmart



	Dref	Dsmart
HQ	☑	☑
LCR	X	X





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AND ARCHITECTURE

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Ghent University – Building Physics research group
FWO – Flanders Research Foundation (1SA7619N)

GHENT
UNIVERSITY

Residential Applications of Smart Ventilation Controls

Iain Walker
November 23 2021

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Energy Technologies Area

homes.lbl.gov

1

Why are we ventilating?

Odour – Health - Moisture

1. Contaminants from the building:
   - Formaldehyde is the classic example – but many other VOCs
2. Contaminants from human activities:
   - Bioeffluents
   - Health-related: e.g., particles from cooking or water vapour and cleaning chemicals from cleaning/bathing

These are not all reduced equally by different smart ventilation systems and strategies

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2

Residential Smart Controls

AIVC VIP 38 “What is Smart Ventilation”
Definition includes controls based on:

- Weather
- Occupancy
- Contaminant sensing
- Energy supply signals

Today’s discussion: assessing applications of smart ventilation controls through simulations:

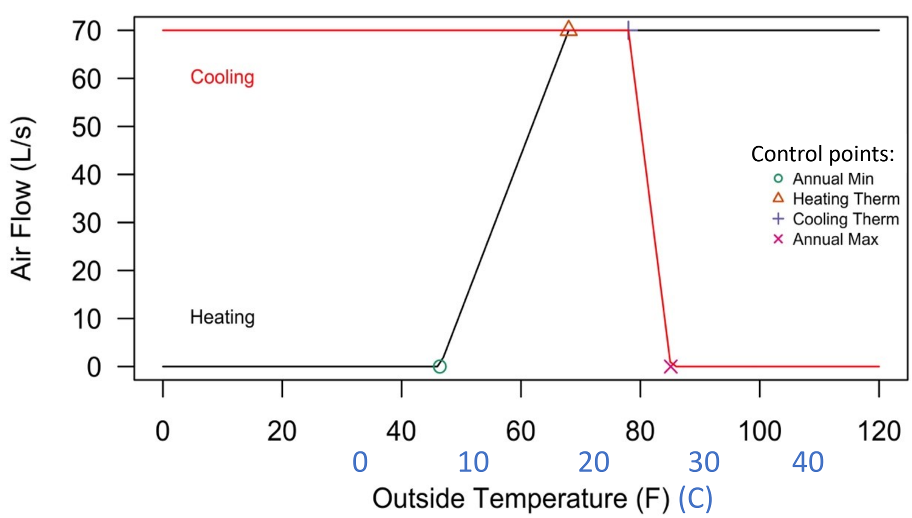
- combined CONTAM/EnergyPlus – full year, 5 minute timestep – range of climates, envelope leakage etc.

Control Strategies

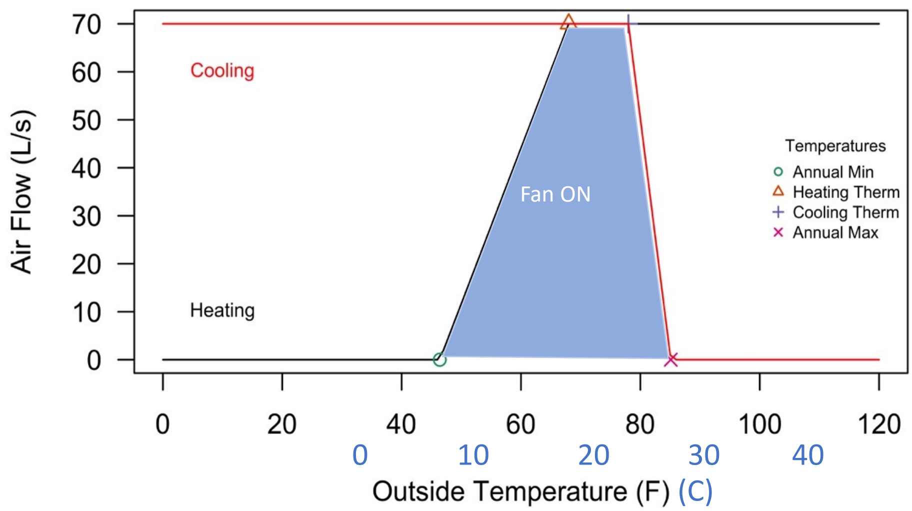
- Weather (outdoor temperature) controls
  - Pre-calculated temperatures to give the same annual exposure
  - Real time exposure calculations + temperature cutoffs
- Occupancy Controls
  - Reduce ventilation when unoccupied
- Zonal controls
  - Tracking relative exposure and dose in each zone during occupied periods
  - Flow directed to occupied zones
- Contaminant controls
  - Whole dwelling vented if any contaminant is above its threshold
  - Zone vented if it is above threshold
  - Zone vented if it is above threshold AND occupied

Weather **Controls**

Change Mechanical System Flow Rate With Outdoor Temperature

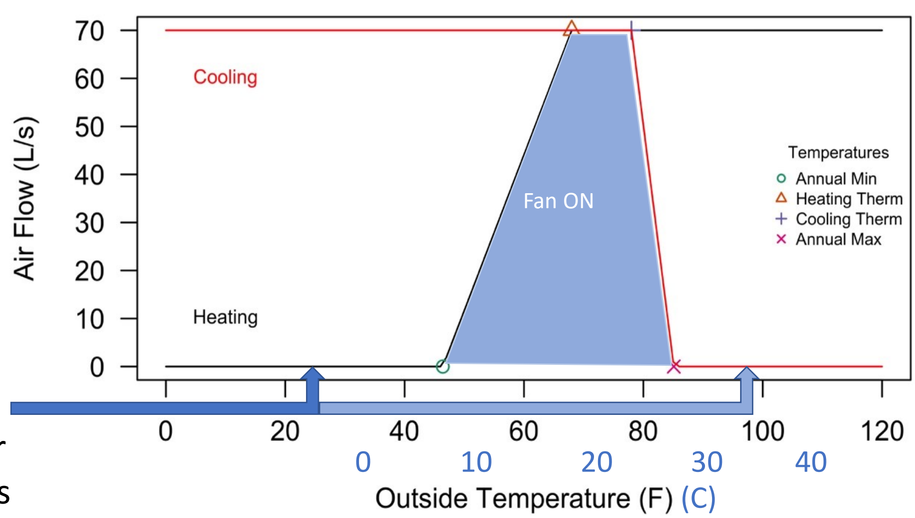


Change Mechanical System Flow Rate With Outdoor Temperature

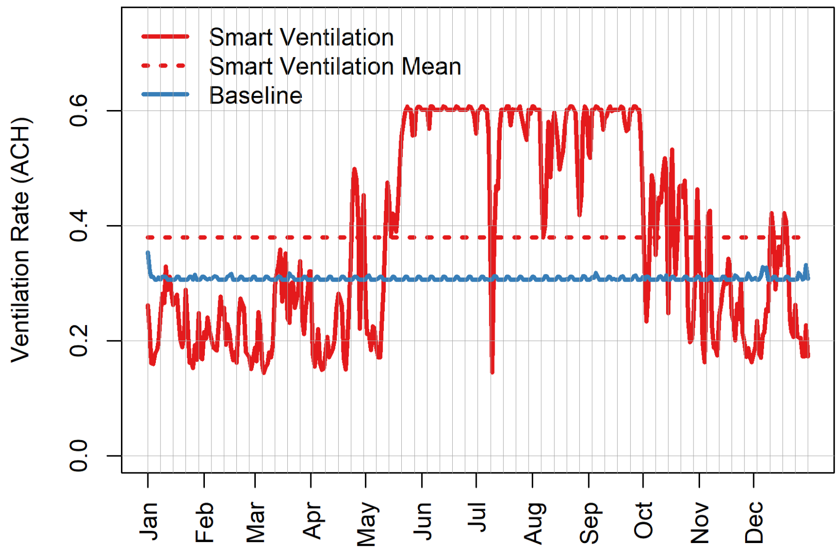


Change Mechanical System Flow Rate With Outdoor Temperature

Include some minimum other than “zero”? Controlling relative exposure to less than 5 accounts for any acute problems

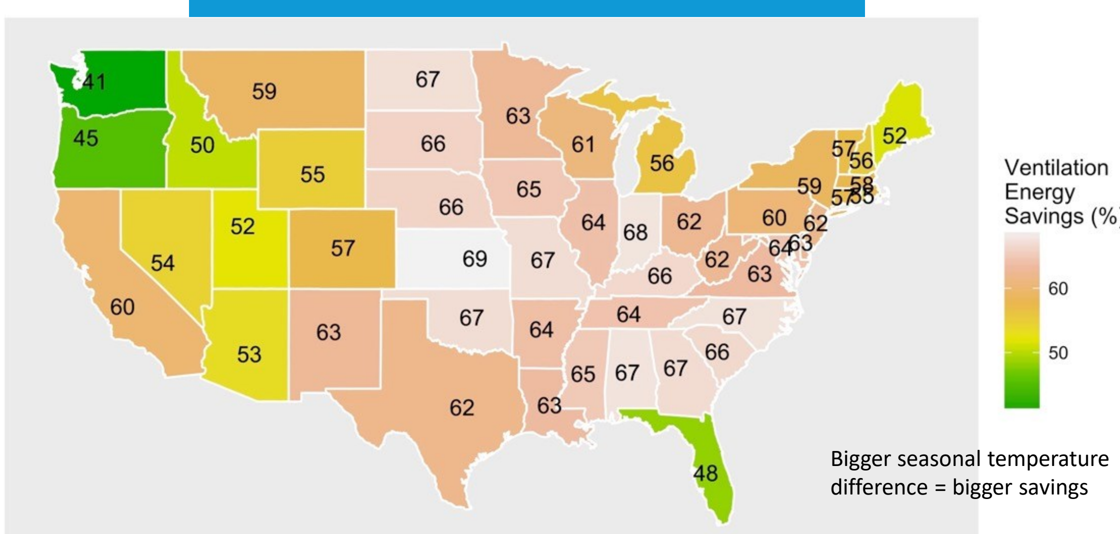


Daily Average Ventilation Rate With Outdoor Temperature Control



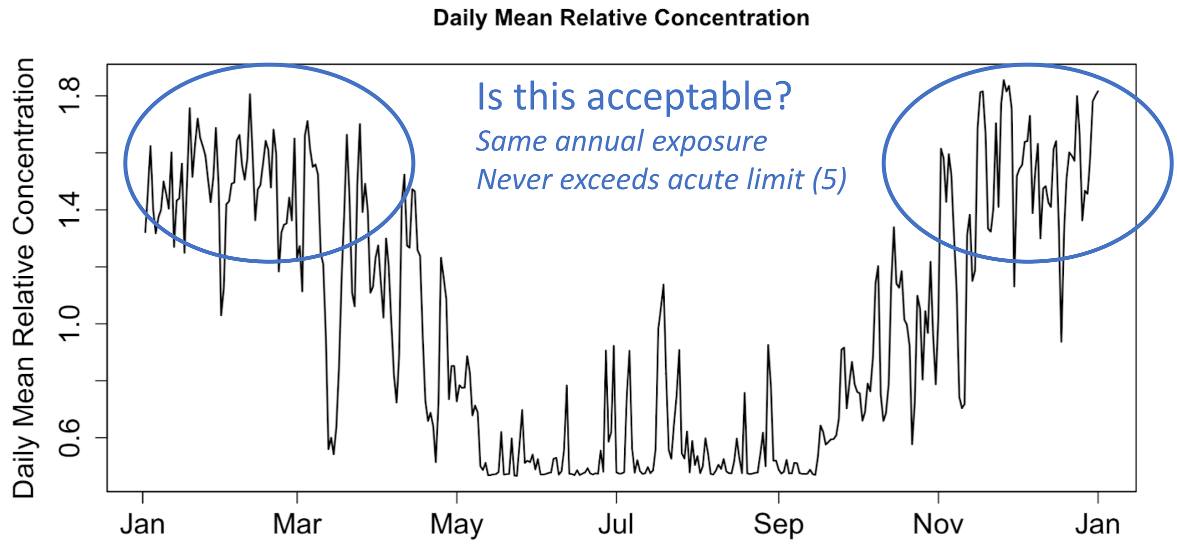
shifts ventilation from winter to summer

Ventilation Energy Savings

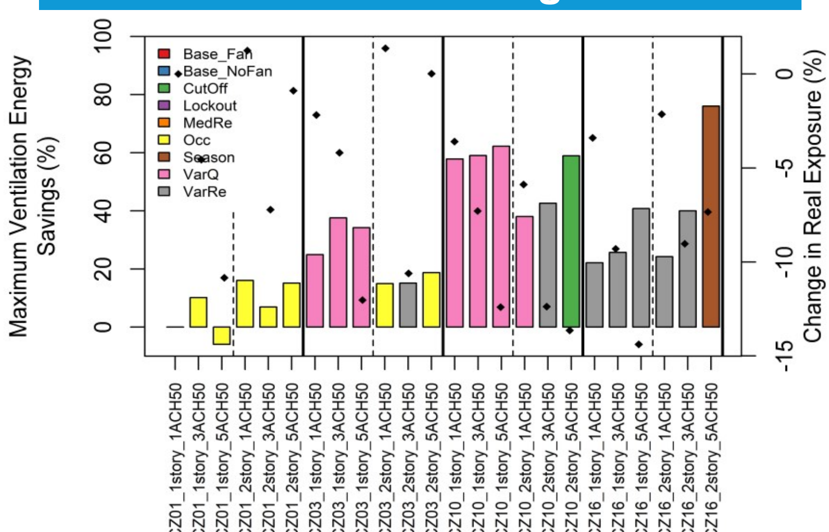


Bigger seasonal temperature difference = bigger savings

Daily Average Concentration With Outdoor Temperature Control



Optimum control depends on climate and house being ventilated



CZ 1: North Coast cool: Arcata
CZ03: Temperate: Oakland/SF
CZ10: Inland: Sacramento
CZ16: Mountains

1 & 2 Stories

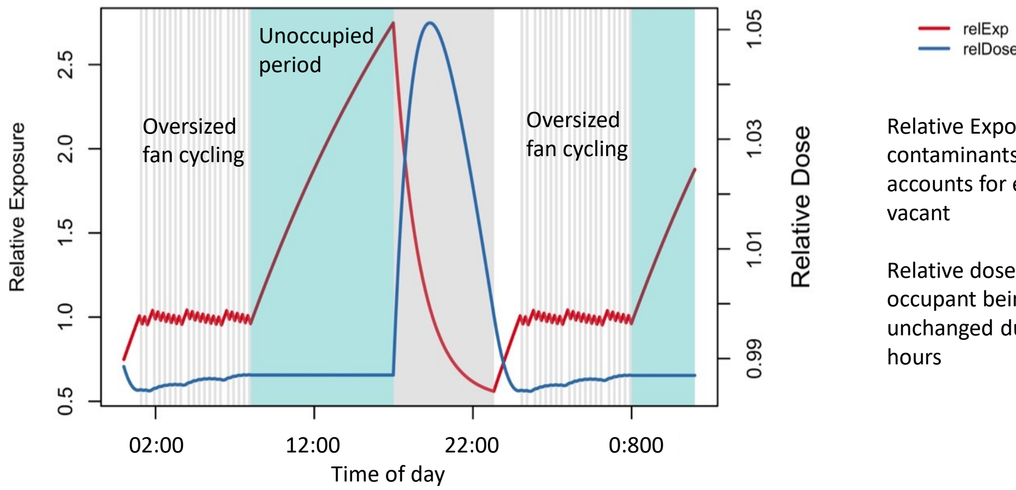
1, 3 & 5 ACH50

Occupancy Controls

Occupancy Control

- Assuming actual occupancy NOT using CO_2 or RH as a surrogate
- Include non-occupant generated contaminants:
  - E.g., Formaldehyde and other building-related VOCs or Radon

Fan off when unoccupied: generic VOC exposure



Relative Exposure tracks contaminants at all times: accounts for emissions when vacant

Relative dose based on occupant being exposed – unchanged during unoccupied hours

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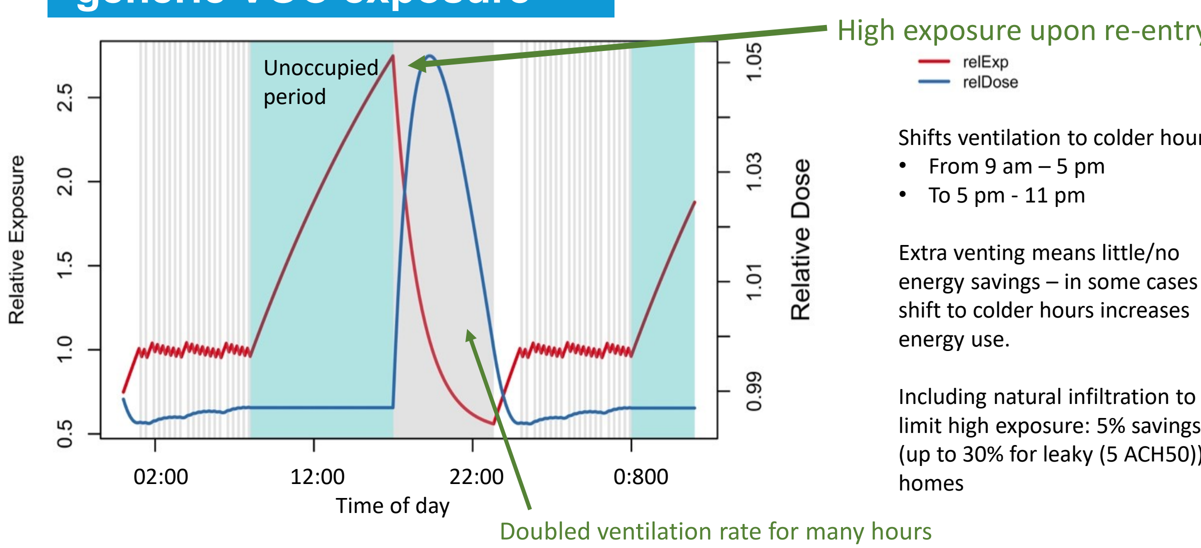
Fan off when unoccupied: generic VOC exposure



Shifts ventilation to colder hours:

- From 9 am – 5 pm
- To 5 pm - 11 pm

Extra venting means little/no energy savings – in some cases shift to colder hours increases energy use.

Including natural infiltration to limit high exposure: 5% savings (up to 30% for leaky (5 ACH50)) homes

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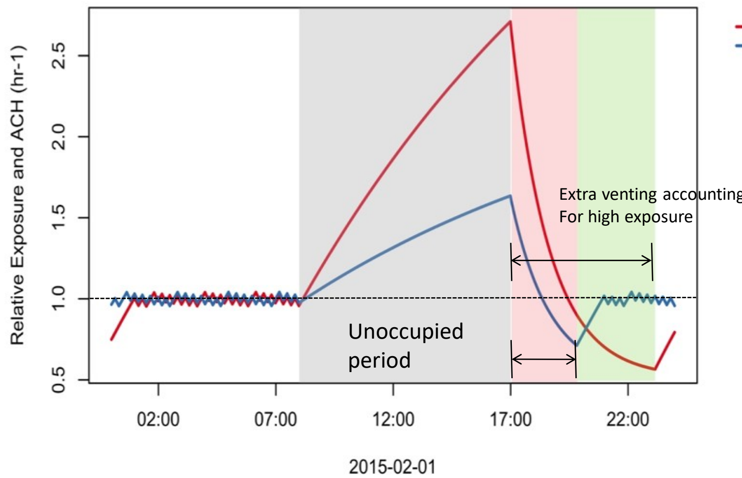
Occupancy Control – Reduced but not zero when unoccupied?

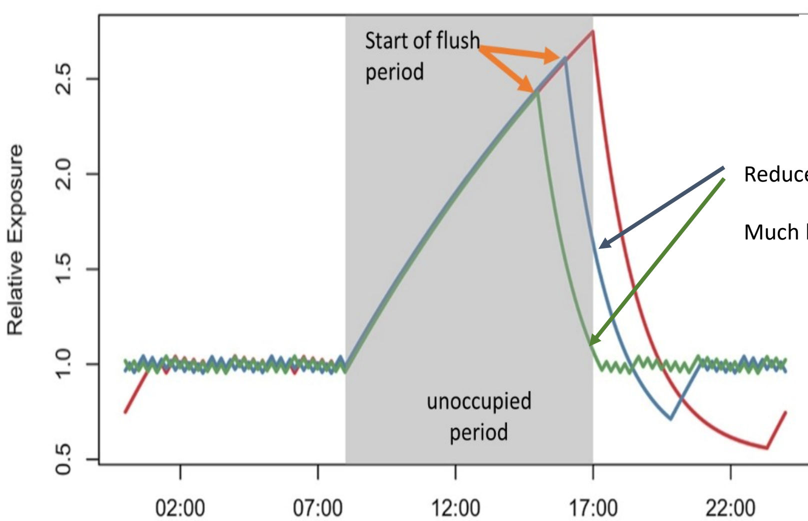


Relative exposure full reduction
Relative exposure 35% flow

Improved savings to about 5% of ventilation energy

Unoccupied period in grey, 35% ventilation recovery period in pink, full ventilation reduction recovery period in green

Occupancy Control – Pre-venting (or flushing)



Relative exposure no pre-venting
Relative exposure 1 hour pre-vent
Relative exposure 2 hour pre-vent

Reduced exposure upon re-entry

Much less ventilation required to recover

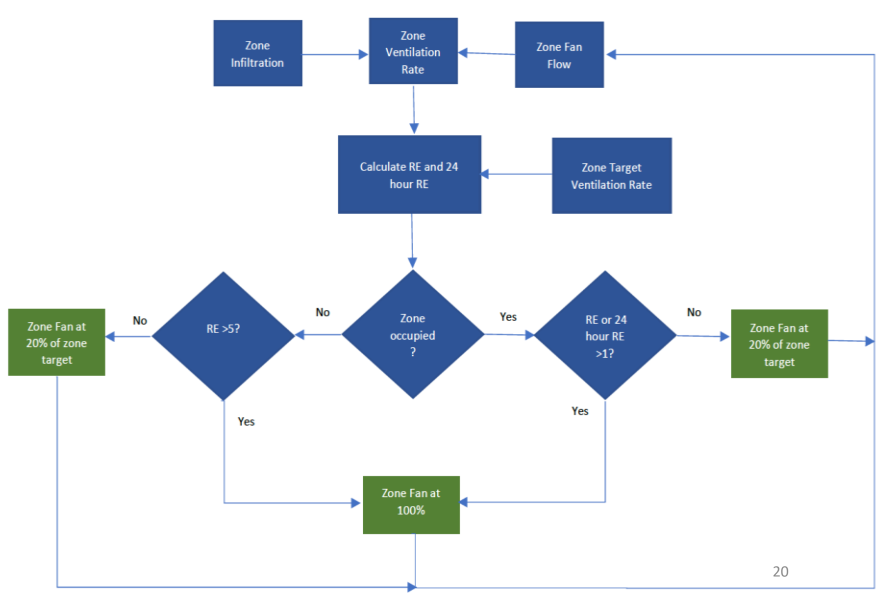
One hour pre-venting/flush improved savings to about 10% of ventilation energy

Zoning Controls

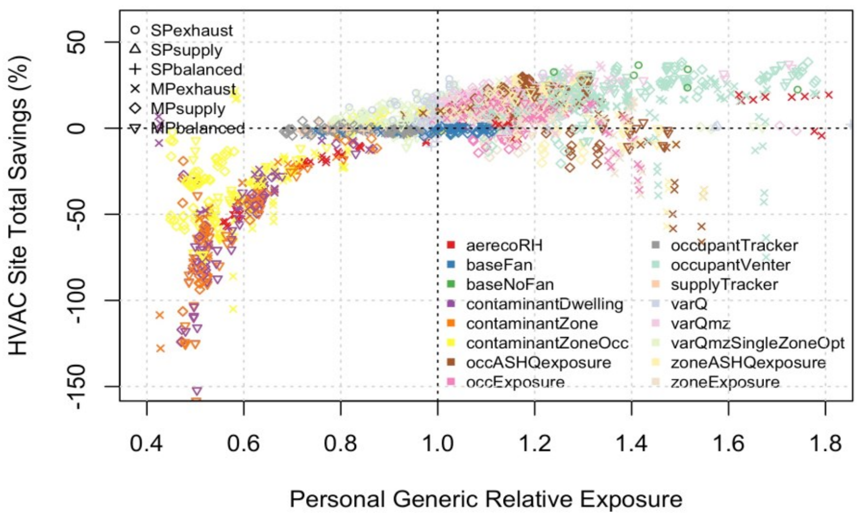
Example controller flowchart for a zonal exposure controller

This control process is for a single zone and is repeated for each zone in the dwelling.

“RE” is the relative exposure calculated for an individual zone.

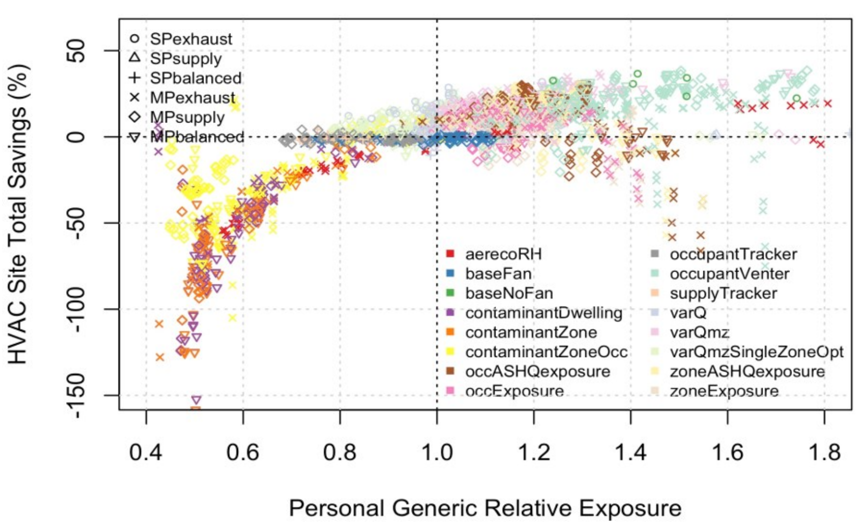


Zonal Control



Best controllers saved 10-25% of ventilation energy compared to about 7% for non-zoned versions

Zonal Control

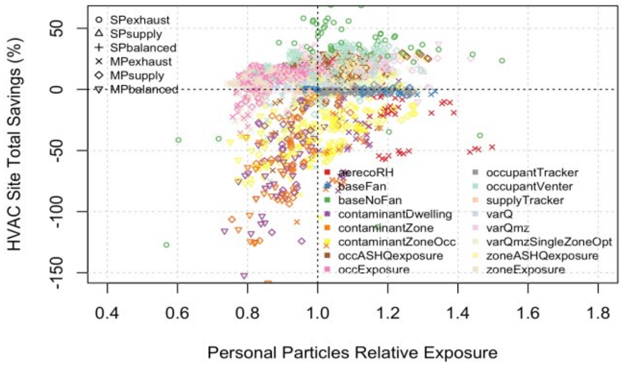


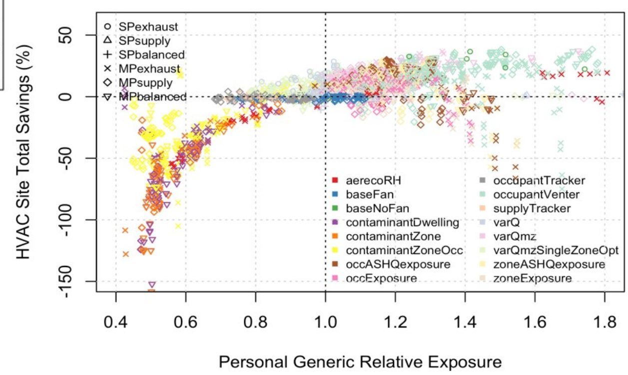
BUT.. increased contaminant concentrations for at least one contaminant:

- diversity of sources: continuous vs. periodic vs. outdoors
- diversity of removal mechanisms: outside air ventilation, deposition, filtration

People move from zone to zone – same problem as occupancy with contaminant build-up

Zonal Control - Different results for different contaminants



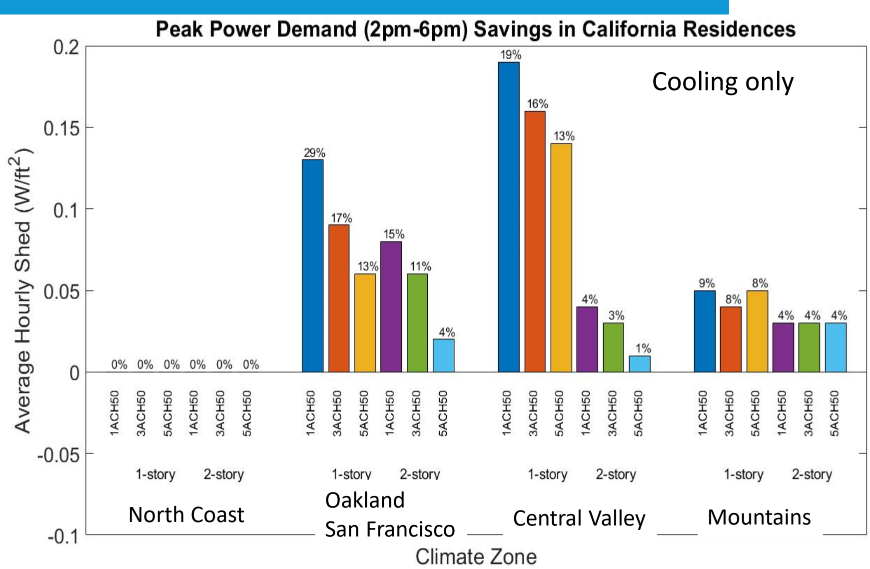


Zoning

- Zone control:
  - reduces IAQ when point-source contaminant emissions (e.g., cooking, breathing, bathing) were aligned with the location of the single-point fan
  - improves IAQ when contaminant sources (e.g., CO_2 in bedrooms with closed doors) are NOT aligned with the location of the single-point fan
  - improves IAQ when unzoned systems do not evenly serve the dwelling. E.g., two-story dwellings, where first and second levels are ventilated at substantially different rates by unzoned supply and exhaust

Peak Demand

Turning off ventilation on peak



Works best for:

- Hot climates
- Low natural infiltration:
  - Tight homes
  - Single-story homes

Note: % = cooling energy savings

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Contaminant Sensing

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Key issues for contaminant sensing

1. Can we ignore formaldehyde?
   - Even at double ASHRAE minimum rate (>0.5 ACH) to get concentrations down to 9 μg/m^3 (California OEHHA 24 hour target)
   - Need lower emitting materials
2. Are sensors good enough and affordable?
   - Particles – YES
   - CO_2 – NEARLY (best have autozero and actually sense CO_2 – but are expensive)
   - NO_2 – NO (but all-electric decarbonized homes don't need this)
   - T & RH – YES
   - TVOC – limited applicability (solvent = opening wine bottle or peeling an orange)
   - Formaldehyde – NO
3. Where should we sense?
   - In all rooms combined with occupancy sensor and pre-occupancy "learned" flushing?
     - Expensive, impractical?
   - Maybe restrict sensor-based controls to kitchens and bathrooms?
4. How to combine contaminants: if a strategy decreases particles but increases formaldehyde.. What do we do?

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Questions?

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Background papers from LBNL

Walker, I. Less, B. Lorenzetti, D. Sohn, M. (2021). Development of Advanced Smart Ventilation Controls for Residential Applications. Energies 2021, 14, 5257. https://doi.org/10.3390/en14175257

Young, M., Less, B.D., Dutton, S.M., Walker, I.S., Sherman, M.H. and Clark, J.D. (2020). Assessment of peak power demand reduction available via modulation of building ventilation systems. Energy and Buildings. 10.1016/j.enbuild.2020.109867

Less, B.D., Dutton, S., Walker, I, Sherman, M. and Clark, J. (2019) Energy savings with outdoor temperature-based smart ventilation control strategies in advanced California homes. Energy and Buildings. 194 (2019) 317 - 327. https://doi.org/10.1016/j.enbuild.2019.04.028. LBNL 2001207

Clark, J., Less, B., Dutton, S., Walker, I. and Sherman, M. (2019). Efficacy of occupancy-based smart ventilation control strategies in energy-efficient homes in the United States. Building and Environment, Vol. 156, https://doi.org/10.1016/j.buildenv.2019.03.002. LBNL 201199

Guyot, G., Sherman, M.H. and Walker, I.S. (2018). Smart ventilation energy and indoor air quality performance in residential buildings: a review. Energy and Buildings. Vol. 163, pp. 416-430. https://doi.org/10.1016/j.enbuild.2017.12.051

Guyot, G., Sherman, M.H. and Walker, I.S. (2018). Performance based approaches for smart ventilation in residential buildings. International Journal of Ventilation. Vol. 18, No. 2 https://doi.org/10.1080/14733315.2018.1435025

Turner, W.J.N., Walker, I.S. and Roux, J. (2015). Peak Load Reductions: Electric Load Shifting with Mechanical Pre-Cooling of Residential Buildings with Low Thermal Mass. Energy. DOI: 10.1016/j.energy.2015.02.011. LBNL-180912.

Less, B., Walker, I., Lorenzetti, D., Mills, E., Rapp, V., Dutton, S., Sohn, M., Li, X., Clark, J. and Sherman, M. 2020. Smart Ventilation for Advanced California Homes. LBNL-2001342. https://doi.org/10.2172/1635274

Less, B., Walker, I and Ticci, S. 2016. Development of Smart Ventilation Control Algorithms for Humidity Control in High-Performance Homes in Humid US Climates. LBNL-1007244. http://eta-publications.lbl.gov/sites/default/files/1007244.pdf

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Field Measurement of Temperature Control

- Long term monitoring of two homes
  - One with Washington State University – an energy efficient retrofitted home
  - One with University of Illinois – typical US midwest home
- Flip-flop – one week controlled one week continuous
- Measure energy use and indoor T, RH, CO2

Lubliner, M. Francisco, P. Martin, E., Walker, I. Less, B., Viera, R., Kunkle, R. and Merrin, Z. (2016). Practical Applications and Case Study of Temperature Smart Ventilation Controls. Thermal Performance of the Exterior Envelopes of Buildings XIII, ASHRAE/DOE/BTECC

Photo thanks to Mike Lubliner

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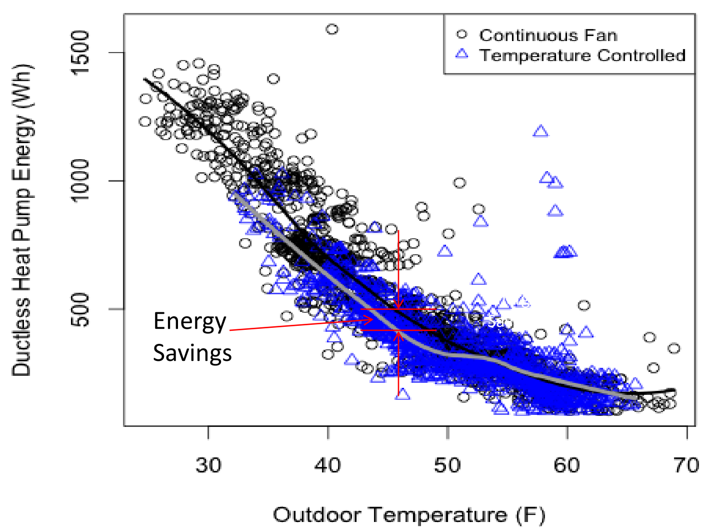
Field Measurement of Temperature Control



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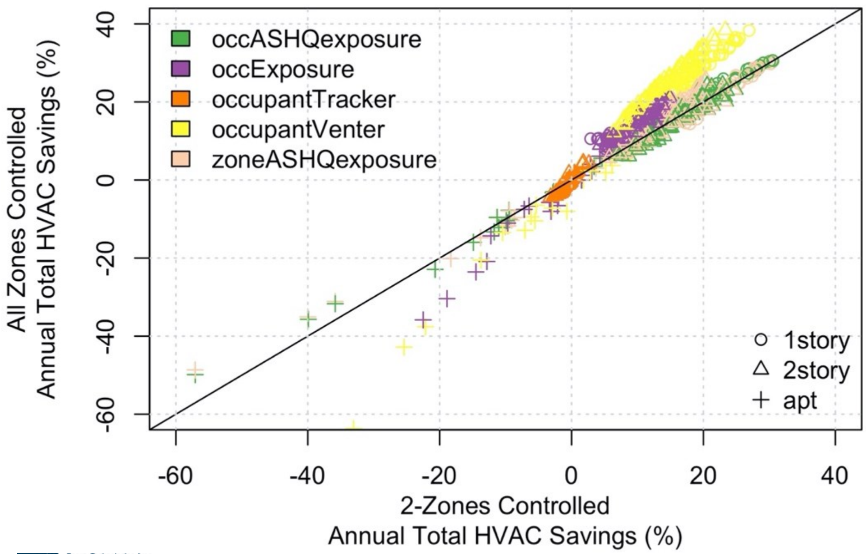
More zones does not necessarily mean more savings



Best controllers saved 10-25% of ventilation energy compared to about 7% for non-zoned versions

BUT

Most also increased contaminant concentrations by up to 20%

Example zonal controllers

occupantVenter – All zones get a minimum flow rate when unoccupied. Additional airflow is distributed to occupied zones. There is no tracking of controller estimated exposure, dose or contaminants

occupantTracker – Flows directed to occupied zones. Total airflows are unchanged. It is possible for a single occupied zone to receive the full dwelling airflow rate.

occExposure – Zones are vented if any person in the zone has an integrated relative dose greater than 1, or if the zone relative exposure is greater than 1. Personal exposure in one zone can be compensated for by increased ventilation in another zone

zoneASHQexposure – Zones are vented if the zone has an integrated relative dose greater than 1, or if the zone relative exposure is greater than 1. Controls the zone Generic contaminant concentration to be the same as the steady-state zone concentration that would occur at the uncontrolled annual ventilation rate

occASHQexposure – This is the same control strategy as occExposure, but instead of using controller estimates of relative exposure and dose, it controls the zone Generic contaminant concentration to be the same as the steady-state zone concentration that would occur at the uncontrolled annual ventilation rate