A review of pollutants and sources of concern and performance-based approaches to residential smart ventilation

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Is ventilation *the* answer to indoor air quality control in buildings?

Do we need performance-based approaches?

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Outline

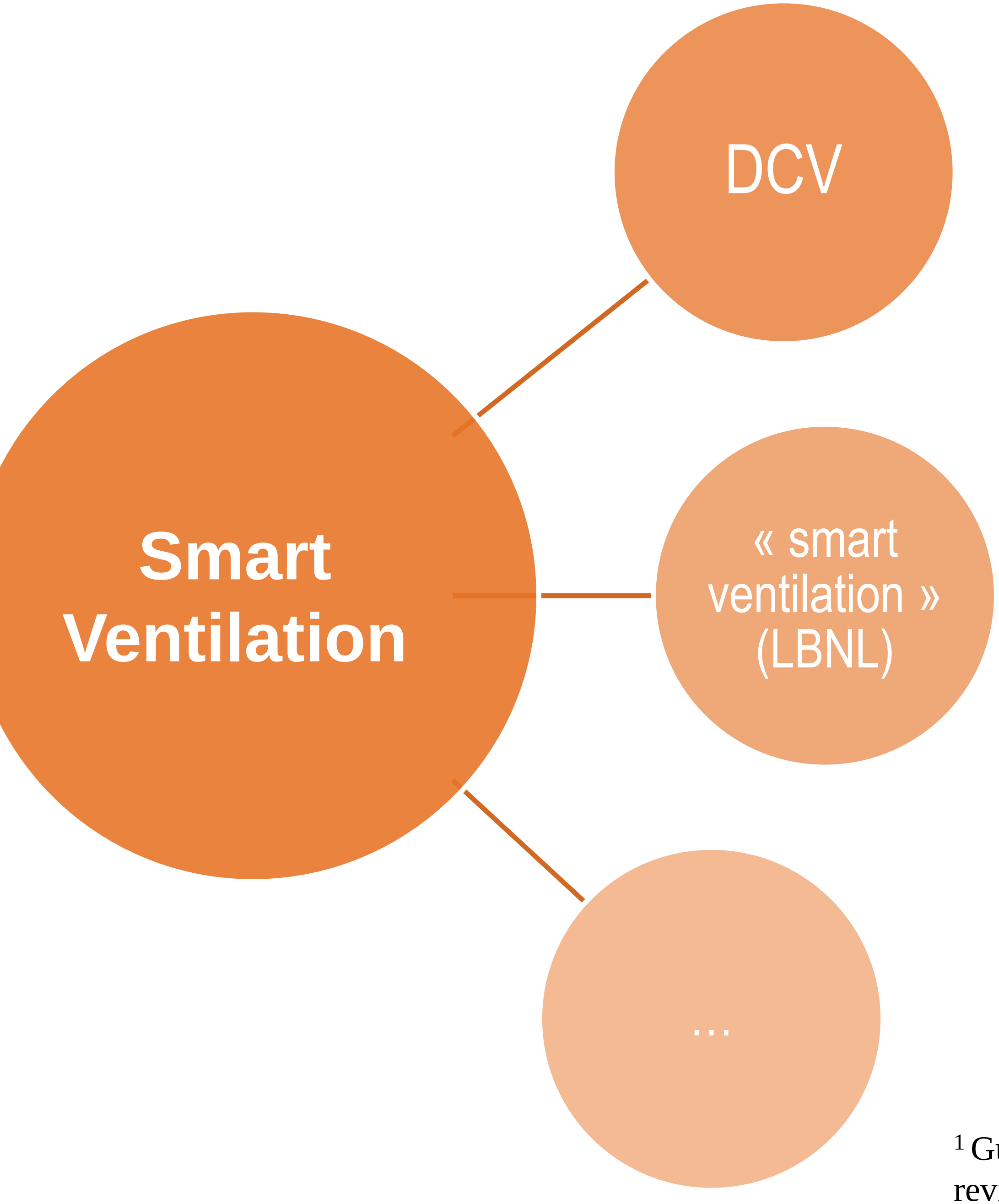
- Scope : smart ventilation strategies
- Relevant parameters for smart ventilation
- Performance-based approaches in 5 standards and regulations
- Perspectives

Our scope : smart ventilation strategies

- **Smart ventilation : modulation of ventilation airflows in response to several factors**

⇒ **reduce ventilation energy use and cost while maintaining the same indoor air quality (IAQ) as a continuously operating system, or better**

- **From a literature review (not a market survey)**
  - *In-press : Guyot, G., Sherman, M.H., Walker, I., 2017. Residential smart ventilation: a review. Lawrence Berkeley National Laboratory. In-press*



- Over 30 years old
- Widely used in countries as FR, BE, NT
- Mostly CO_2 or humidity based with a wide variety of systems and strategies
- IAQ : various results
- Energy savings : -26% + 60% [1]
- **Performance-based approaches**

- RIVEC prototype (Sherman and Walker, 2011)
- ACH = f(outdoor conditions, utility peak loads, occupancy, operation of other air systems)
- IAQ maintained, sometimes improved
- Energy savings : >40%, 500-7000 kWh/year/household
- **Performance-based approach = Equivalence principle**

[1] Guyot, G., Sherman, M.H., Walker, I., 2017. Residential smart ventilation: a review. Lawrence Berkeley National Laboratory.

Relevant parameters for smart ventilation

- **Pollutants of concerns**
  - Borsboom, W., De Gids, W., Logue, J., Sherman, M., Wargocki, P., 2016. TN 68: Residential Ventilation and Health, AIVC Technical Note 68.

Table 6: Priority pollutants in the indoor residential environment for consideration in making ventilation standards

PRIORITY POLLUTANTS FOR CHRONIC EXPOSURE (RANKED BY POPULATION IMPACT)	POTENTIAL ACUTE EXPOSURE CONCERNS
Particulate matter	Acrolein
Mould/ moisture	Chloroform
Formaldehyde	~~Carbon Monoxide~~
Acrolein	Formaldehyde
	NO_2
	$PM_{2.5}$

Relevant parameters for smart ventilation

- **Pollutants of concerns**
  - Borsboom, W., De Gids, W., Logue, J., Sherman, M., Wargocki, P., 2016. TN 68: Residential Ventilation and Health, AIVC Technical Note 68.

- **Odors, CO_2 and humidity, temperature**
  - Correlation between them / with other types of indoor pollutants ?
  - No consensus about the conclusions !

- **Occupancy**

Relevant parameters for smart ventilation

- **Also an issue of availability and reliability of sensors :**
  - Performance, size, extend of signal conditioning, reliability, robustness, maintainability, cost

- **Only some CO_2 and humidity sensors seems accurate and reliable enough with affordable costs**

- **But not only a question of sensors !**
  - also control strategies algorithms, regulation type, localization of sensors, ….

Performance-based approaches in some countries

Context

- A number of ventilation standards and national regulations with an allowance for smart ventilation strategies and/or DCV systems in residential buildings
- Simultaneously, EP regulations with the opportunity to claim credit for savings from such systems

⇒ Performance-based approaches defined and required for smart ventilation strategies

⇒ DCV strategies used at massive scale, notably in France and in Belgium, for more than 30 years

ASHRAE 62.2 2016

Compliance required in some State regulations in US and Canada

Ventilation Equivalence method	Person in charge	Calculated IAQ indicators	Credit in EP-calculation	Minimum airflow	Market
Single zone modeling $\Delta t<1h$ Constant pollutant emission rate	The manufacturer, specifier or designer	No specifically defined pollutant Yearly average relative exposure R<1 At each time-step $R_i<5$	Rare	Can be null if the total airflow rate equivalence is required over any 3-hour periods	Some DCV systems

Relative Exposure R(t)

$$R(t) = \frac{C(t)}{C_{eq}}$$

To avoid peak exposure

$$R_i = \frac{Q_{tot}}{Q_i} + \left(R_{i-1} - \frac{Q_{tot}}{Q_i}\right) e^{-Q_i \Delta t / V_{space}} < 5 \quad if\ Q_i \neq 0$$

Equation 15

$$R_i = R_{i-1} + \frac{Q_{tot}\Delta t}{V_{space}} < 5 \quad if\ Q_i = 0$$

Where Q_{tot} is the minimum constant ventilation rate calculated according to section 4.1 of the ASHRAE 62.2,
Q_i is the real-time airflow in the variable mechanical ventilation system at time step i,
Δt is the time-step used in the calculation,
V_{space} is the volume of the space.

France

Avis techniques

Performance-based approach	Person in charge	Calculated IAQ indicators	Credit in EP-calculation	Minimum airflow	Market
Multi-zone modeling Δt =15 min Conventional entry data: meteorological, homes geometries, airleakage distribution, occupancy, …)	The manufacturer	Per room, over the heating period : 1/CO_2 cumulative exposure indicator E_{2000} < 400.000 ppmh 2/Number of hours $T_{RH>75\%}$ <600 h in kitchen, 1000 h in bathrooms, 100 h in other rooms	Average equivalent exhausted airflow (m^3/h) can be implemented in the EP-calculation ~ -40%	Switch off not allowed 10-35 m^3/h according to the number of rooms in the building	> 30 years 23 DCV systems with agreements (mostly RH controlled) > 90% new homes

$$E_{2000} = \sum_{t=0}^{T} C_{CO_2>2000}(t) * t < 400\,000\ ppm.h$$

Spain

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Performance-based approach	Person in charge	Calculated IAQ indicators	Credit in EP-calculation	Minimum airflow	Market
Multi-zone modeling Δt =40 s Conventional entry data: meteorological, homes geometries, occupancy, …)	The manufacturer	Per room, over the year : 1/CO_2 cumulative exposure indicator E_{1600} < 500.000 ppmh 2/ Yearly average CO_2 concentration < 900 ppm	Yearly average ventilation airflow could be implemented in the EP-calculation	/	3 DCV systems with agreements (recent procedure)

2017 : Towards a performance-based approach for every new building equipped with any type of ventilation system, using a software and some conventional data

Belgium

No more ATG-E since 2015

Former performance-based/equivalence approach	Person in charge	Calculated IAQ indicators	Credit in EP-calculation	Minimum airflow	Market
Multi-zone modeling Δt =5 min Conventional entry data both deterministic and stochastic	The manufacturer	Per person, over the heating period, At least equal that the worst performing reference system : 1/CO_2 cumulative exposure indicator E'_{950} 2/Monthly average RH> 80% on critic thermal bridges from December 1st to March 1st 3/Exposure to a tracer gas emitted in toilets and in bathrooms	An energy saving coefficient f_{reduc} is extrapolated and can be implemented in the EP-calculation	/	34 DCV systems with agreements (mostly CO_2 controlled)

Belgium

No more ATG-E since 2015

- **2014: DCV systems considered as mature enough to be directly integrated in the EP-calculation method**

- **A study (Caillou et al., 2014b) evaluated the 35 systems gaining the ATG-E through an advanced equivalence method**

- **2016: only the energy saving coefficients f_{reduc} given in the tables of an Ministerial Order (Moniteur Belge, 2015) can be used directly in the EP-calculation**
  - Sensors accuracy requirement
  - Minimum airflows over 10% of the minimum constant airflow for each room

Type of detection in dry spaces	Type of regulation of air inlets in dry spaces	Local detection in humid spaces with regulation of air outlet Local regulation	Local detection in humid spaces with regulation of air outlet No local regulation	Other or no detection in humid spaces
CO_2-local : at least a sensor in each dry space	Local	0.35	0.38	0.42
	2 zones (night/day) or more	0.41	0.45	0.49
	Central	0.51	0.56	0.61
CO_2- partially local : at least a sensor in each bedroom	Central	0.60	0.65	0.70
CO_2- partially local : at least a sensor in the main bedroom + at least a sensor in the living room	2 zones (night/day) or more	0.43	0.48	0.53
	Central	0.75	0.81	0.87
CO_2-central : at least a sensor in the exhaust duct(s)	Central	0.81	0.87	0.93
Occupancy-local : at least a sensor in each dry space	Local	0.54	0.60	0.64
	2 zones (night/day) or more	0.63	0.67	0.72
	Central	0.76	0.82	0.88
Occupancy-partially local : at least a sensor in each bedroom	Central	0.87	0.93	1.00
Occupancy-partially local : at least a sensor in the main bedroom + at least a sensor in the living room	2 zones (night/day) or more	0.66	0.72	0.78
	Central	0.87	0.93	1.00
Other or no detection in dry spaces	No, local, per zone, or	0.90	0.95	1.00

The Netherlands

Standard NEN 8088 & a complementary performance-based approach

Standard and performance-based approaches	Person in charge	Calculated IAQ indicators	Credit in EP-calculation	Minimum airflow	Market
Correction factors are given in the standard NEN 8088 for quite a few DCV systems OR A complementary performance-based approach uses a multi-zone modeling, in a semi-probalistic approach	The person involved in EP-calculation (standard approach) OR the manufacturer (performanc-based approach)	Per person, over the heating period : Cumulative CO_2 exposure over 1200 ppm: LKI_{1200} < 30.000 ppm.h	Given correction factors directly used in the EP-calculation OR New correction factors are calculated	A function of the number of type of occupants	37 DCV systems with agreements

$$LKI_{1200} = \sum_{t=0}^{T} \left(\frac{C_{CO_2>1200}(t) - 1200}{1000} \right) * t < 30\ kppm.h$$

Equation 22

Where $C_{CO_2>1200}(t)$ is the absolute concentration at which an occupant is exposed at t time-step, if it is higher than 1200 ppm, or 800 ppm above the outdoor concentration.

Conclusions

- Performance indicators used in performance-based approaches for smart ventilation strategies are related to CO_2 exposure and condensation risk (exc. ASHRAE 62.2)

- As many smart ventilation systems types than regulations and performance-based methods, because manufacturers have to adapt their systems…

Perspectives

- **Smart ventilation strategies success is not ready to end …**
  - Two recently European published directives (Ecodesign n°1253/2014 EcoLabeling n°1254/2014) : toward a generalization of DCV and balanced heat recovery systems at the 2018 horizon

- **Can we use this background for the definition of a performance-based approach at the design stage of every new dwellings equipped with any type of ventilation system?**

Thank you for your attention !

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Towards an health performance-based approach ?

- As proposed in Sherman, M.H., Walker, I.S., Logue, J.M., 2012. Equivalence in ventilation and indoor air quality. HVAC&R Research 18, 760–773. doi:10.1080/10789669.2012.667038

$$DALY = \sum_i Concentration_i * UDE_i$$

Equation 23

$$DALY_{limit} = \sum_i Standard_i * UDE_i$$

Equation 24

Compound	UDE $\left[\frac{\mu DALYS}{year*person} * \frac{m^3}{\mu g}\right]$	Chronic Standard $\left[\frac{\mu g}{m^3}\right]$	Chronic Standard damage $\left[\frac{\mu DALYS}{year*person}\right]$
Priority Pollutants			
1,3 Butadiene	0.02	0.06	0.001
1,4-dichlorobenzene	0.03	0.91	0.024
Acetaldehyde	0.3	3.7	0.96
Acrolein	190	0.02	3.7
Benzene	0.08	0.34	0.025
Formaldehyde	6.8	1.7	11.4
Naphthalene	0.47	0.29	0.14
Nitrogen Dioxide	0.70	40	27
$PM_{2.5}$	500	15	7,500
Other contaminants			
Ammonia	0.23	200	46
Ozone	1.4	147	200
Crotonaldehyde	1.02	N/A	N/A

Table 11: Indoor air contaminants – UDE_i and $Standard_i$ values in order to implement the IAQ equivalence principle according to Equation 23 and Equation 24 , source : (Sherman et al., 2012)