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D'ici, on voit + loin !

IEA EBC ANNEX 68 IAQ METRICS:
WHAT WAS PROPOSED, WHAT WORKS, WHAT NOT, WHAT ARE THE REMAINING QUESTIONS?

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AIVC & IEA EBC Annex 86 "Energy Efficient Indoor Air Quality Management in Residential Buildings"
Part 2: IAQ and ventilation Metrics | Thursday April 8th, 2021 at 09:00-10:30 (CET)

EBC Energy in Buildings and Communities Programme

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- Results from IEA EBC Annex 68 (Subtask 1):
  - > Introduction
  - > Pollution levels in residential buildings
  - > Exposure Limit Values → List of pollutants of concern for Annex68
  - > IAQ indices → Metrics for Annex68
- What works, what not, what are the remaining questions?

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RESULTS FROM IEA EBC ANNEX 68 SUBTASK 1:

DEFINING THE METRICS TO ASSESS THE IAQ IN LOW-ENERGY RESIDENTIAL BUILDINGS

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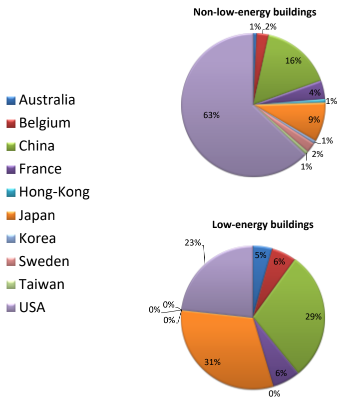
IEA EBC ANNEX 68 SUBTASK 1 (2016)

IEA-EBC Annex 68: Indoor Air Quality Design and Control in Low Energy Residential Buildings (2015-2020) www.iea-ebc-annex68.org

- Is exposure to pollutants lower in low-energy buildings compared to non-low-energy buildings?
- What are the target pollutants in low-energy residential buildings?
- How to quantify IAQ?
- How to account for energy consumption with IAQ?

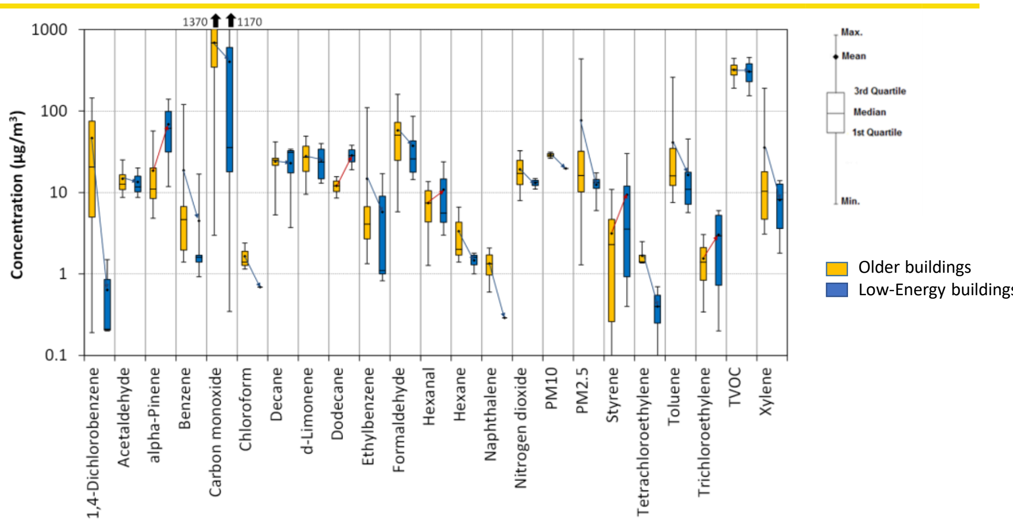
POLLUTION LEVELS IN RESIDENTIAL BUILDINGS



	Reference	# of measured pollutants	# / type of residential buildings
Australia	Cheng et al. (2010)	13	100 dwellings
Belgium	Stranger et al. (2012)	23	356 homes
China	Zhang et al. (2013) – China 1	5	1500 homes
	Guo et al. (2009) – China 2	17	94 homes
	Du et al. (2014a) – China 3	15	296 homes
	Du et al. (2014b) – China 4	4	267 homes
France	Kirchner et al. (2006a)	56	567 houses and apartments
Hong-Kong	Guo et al. (2009)	17	100 homes
Japan	Azuma et al. (2007) – Japan 1	93	Compilation of different studies
	Guo et al. (2009) – Japan 2	17	97 homes
	Park and Ikeda (2006) – Japan 3	26	810 single-family houses + 273 apartments
Korea	Guo et al. (2009)	17	96 homes
Sweden	Langer and Beko (2013)	14	157 single-family houses + 148 apartments
Taiwan	Guo et al. (2009)	17	100 homes
USA	Logue et al. (2011a)	69	18278 homes (46% from USA and 54% from other industrialized countries)

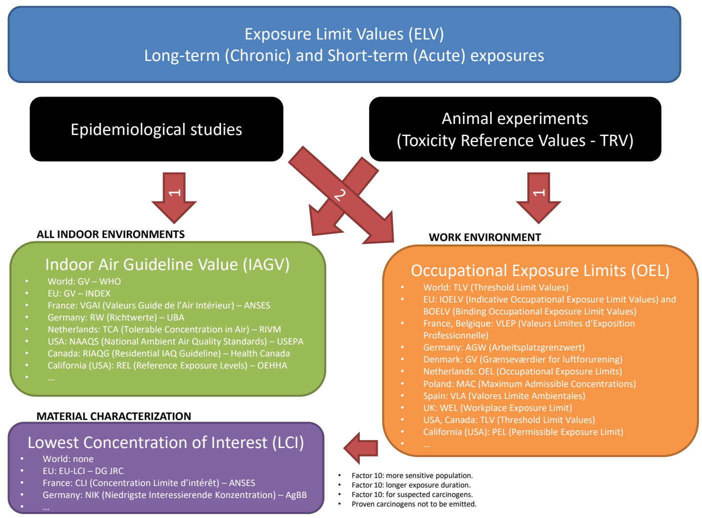
	Reference	# of measured pollutants	# / type of residential buildings
Australia	Cheng et al. (2010)	12	40 dwellings
Belgium	Stranger et al. (2012)	19	51 homes
China	Du et al. (2014b)	3	266 houses and apartments
France	Derbez et al. (2015)	22	57 houses and apartments
Japan	Park and Ikeda (2006)	26	219 single-family houses + 66 apartments
USA	Logue et al. (2011a)	31	2362 homes (9% from USA and 91% from other industrialized countries)

POLLUTION LEVELS IN RESIDENTIAL BUILDINGS



TARGET POLLUTANTS IN LOW-E RESIDENTIAL BUILDINGS

+ **Exposure Limit Values (ELV)**
  - Established nationally and worldwide by cognizant health agencies
  - Duration of exposure:
    - **long-term** effects (potentially chronic risks)
    - **short-term** effects (potentially acute risks)



TARGET POLLUTANTS IN LOW-E RESIDENTIAL BUILDINGS

+ Methodology:
  - Pollutant concentration levels: **minimum, 1^{st} quartile, median, 3^{rd} quartile, maximum and average concentrations** of pollutant in low-energy buildings.
  - Exposure limit values: **lowest** ELV among the data collected for **long-term** effects (≥ 1 year) and **short-term** effects (<1 year).
  - **Ratio** between concentration and ELV:
    - **average annual concentration and long-term ELV**
    - **peak concentration and short-term ELV**
  - **Ratios higher than 0.1:** pollutants potentially hazardous, considered as pollutants relevant for IEA EBC Annex 68.

TARGET POLLUTANTS IN LOW-E RESIDENTIAL BUILDINGS

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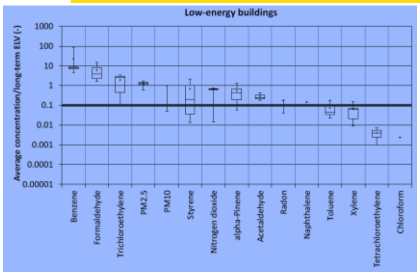

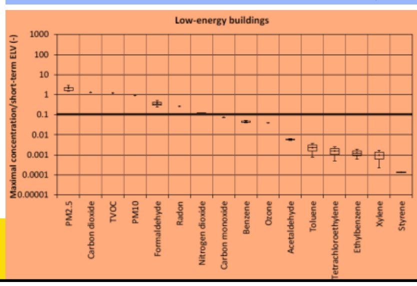

Pollutants relevant for long-term exposures			
	ELV	Averaging period	Reference study
Acetaldehyde	48	1 year	Japan [27]
Acrolein	0.35	1 year	USA-California [28]
α-pinene	200	1 year	Germany [29]
Benzene	0.2	whole life (carcinogenic risk level: 10^{-6})	France [30]
Carbon dioxide	-	-	-
Formaldehyde	9	1 year	USA-California [28]
Naphthalene	2	1 year	Germany [29]
Nitrogen dioxide	20	1 year	France [30]
PM10	20	1 year	WHO [31]
PM2.5	10	1 year	WHO [31]
Radon	200	1 year	Austria [32], Canada [35]
Styrene	30	1 year	Germany [29]
Toluene	250	1 year	Portugal [36]
Trichloroethylene	2	whole life (carcinogenic risk level: 10^{-6})	France [30]
TVOC	-	-	
Mold	200	1 year	EU [33]

Pollutants relevant for short-term exposures			
	ELV	Averaging period	Reference study
Acetaldehyde	-	-	-
Acrolein	6.9	1 h	France [30]
α-pinene	-	-	-
Benzene	-	-	-
Carbon dioxide	1000	8 h	Hong-Kong [34], Korea [38]
Formaldehyde	123	1 h	Canada [35]
Naphthalene	-	-	-
Nitrogen dioxide	470	1 h	USA-California [29]
PM10	50	24 h	WHO [31]
PM2.5	25	24 h	WHO [31]
Radon	400	8 h	Austria [32], China [38], Portugal [36]
Styrene	-	-	-
Toluene	-	-	-
Trichloroethylene	-	-	-
TVOC	400	8 h	Japan [27], Korea [37]
Mold	-	-	-

Pollutants relevant with the scope of IEA EBC Annex 68; concentration is given in µg/m³ except for carbon dioxide which is in ppm, radon which is in Bq/m³, and mold given in CFU/m³.

IAQ METRICS – ELV-BASED APPROACH

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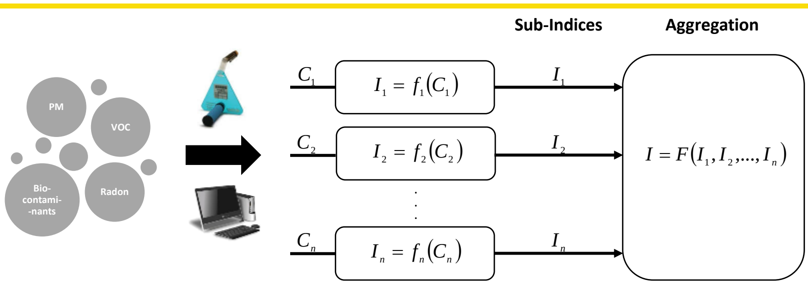


adapted from IND-QAI (Sharma and Bhattacharya, 2012)

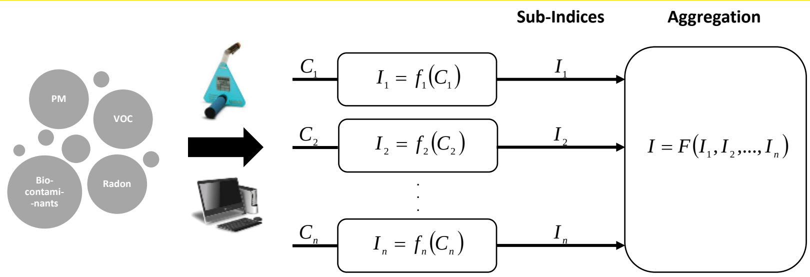
Step 1: Sub-indices

> $I_i = \frac{C_i}{ELV_i}$

> $I_i = f_i(C_i)$ or $f_i\left(\frac{C_i}{ELV_i}\right)$

	Grade for PM_{10} (µg/m³, 24h) - Chiang and Lai (2002)								
Grade	20		40		60		80		100
C_i		>350≥	X	>150≥		>50≥		>25≥	

IAQ METRICS – ELV-BASED APPROACH



adapted from IND-QAI (Sharma and Bhattacharya, 2012)

+ Step 2: Aggregation of Sub-indices

- Weighted Additive Form $I = \sum w_i I_i$
- Root-Sum-Power Form (non-linear aggregation form) $I = \left(\sum_{i=1}^{n} I_i^p \right)^{1/p}$
- Root-Mean-Square Form $I = \left(\frac{1}{n} \sum_{i=1}^{n} I_i^2 \right)^{1/2}$
- Max Operator $I = \max(I_1, I_2, ..., I_n)$
- …

IAQ METRICS – ELV-BASED APPROACH

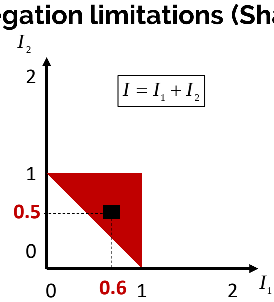
+ Aggregation limitations (Sharma and Bhattacharya, 2012):

Example:

$I_1 = \frac{C_1}{ELV_1}$ (no risk if $I_1 \leq 1$)

$I_2 = \frac{C_2}{ELV_2}$ (no risk if $I_2 \leq 1$)

$I = f(I_1, I_2)$ (no risk if $I \leq 1$)

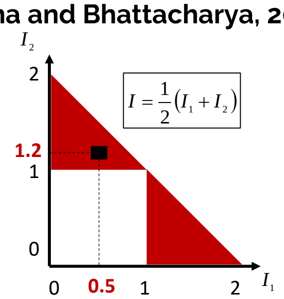


$I_1 = 0.6 \leq 1 \rightarrow no\ risk$

$I_2 = 0.5 \leq 1 \rightarrow no\ risk$

$I = 1.1 > 1 \rightarrow risk!$

Ambiguity (false alarm)



$I_1 = 0.5 \leq 1 \rightarrow no\ risk$

$I_2 = 1.2 \leq 1 \rightarrow risk!$

$I = 0.85 \leq 1 \rightarrow no\ risk$

Eclipsing

➡ **Only one unambiguous and non-eclipsing aggregation = Max (sub-indices)**

IAQ METRICS – DALY APPROACH

- **Disability-Adjusted Life-Years (DALY):**
- WHO definition:
  - > *One DALY can be thought of as one lost year of "healthy" life.*
  - > *The sum of these DALYs across the population, or the burden of disease, can be thought of as a measurement of the **gap between current health status and an ideal health situation** where the entire population lives to an advanced age, free of disease and disability.*

$$DALY_{disease} = YLL_{disease} + YLD_{disease}$$

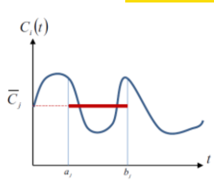
$YLL_{disease}$: Years of Life Lost due to premature death from the disease,

$YLD_{disease}$: Years of Life Disability, weighted from 0 to 1 depending on disease severity.

- $DALY^{Pollutant} = \sum_{j=1}^{n_{disease}} DALY_j = \sum_{j=1}^{n_{disease}} f_j(C_i)$ ➡ $DALY = \sum_{i=1}^{n_{pollutant}} DALY^i$

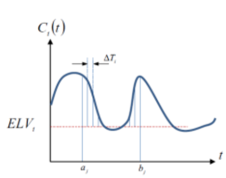
sub-indices *(Logue et al., 2011)* *aggregation*

METRICS FOR ANNEX68 – DASHBOARD

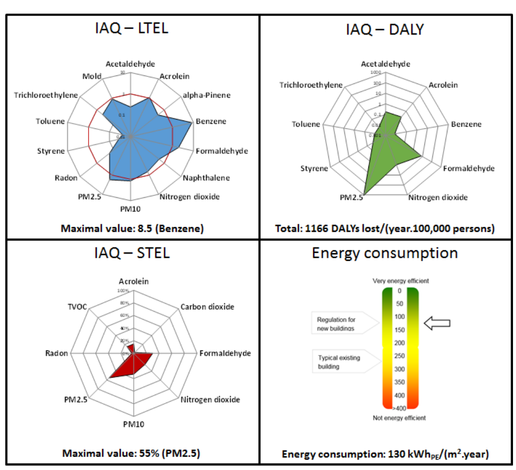


$$\overline{C_i} = \frac{1}{n}\sum_{j=1}^{n}\left[\frac{1}{b_j-a_j}\int_{a_j}^{b_j} C_i(t)dt\right]$$

$$I_p = \frac{\overline{C_p}}{ELV_p}$$



$$I_t = \frac{\sum_{j=1}^{n}(b_j-a_j)\times f_j(C_i(t)\geq ELV_t \text{ over } \Delta t_i)}{\sum_{j=1}^{n}(b_j-a_j)}$$



Data represented here are just for display and do not represent actual situation

$$DALY^p = \sum_{j=1}^{n_{disease}} DALY_j = \sum_{j=1}^{n_{disease}} f_j(\overline{C_i})$$

Energy consumption linked with IAQ:

- **Energy** needed **to condition the outdoor air** (ventilation/infiltration) i.e. heat, cool, humidify or dehumidify.
- **Energy to power the systems** like fans or air cleaning devices (electrostatic precipitation, ionization, plasma or photocatalytic oxidation)

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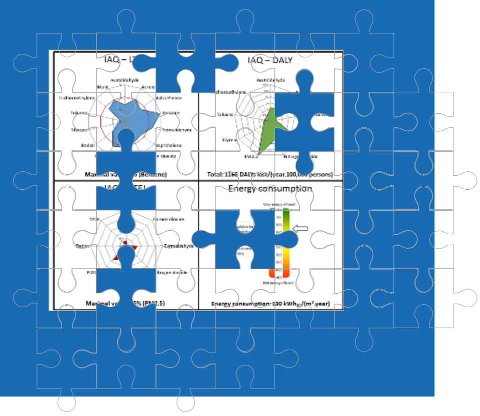
RESULTS FROM IEA EBC ANNEX 68 SUBTASK 1:

WHAT WORKS, WHAT NOT, WHAT ARE THE REMAINING QUESTIONS?



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MAIN LIMITATIONS OF ANNEX 68 (ST1) WORK

+ **Number of data:** too limited data available regarding levels of pollutants in low-energy residential buildings.

+ **Quality of data:**
  > Only aggregated pollutant concentrations (average, min, max) were often available
    - no details were provided for each building (average, min, max, ventilation system, airflow rates…).
  > Available concentration data do not correspond to long-term and short-term exposure as they are 1 week (sometimes 2 weeks) averages:
    - For long-term exposure: at least two periods (heating period and summer) need to be considered to have a more complete whole year evaluation.
    - For short-term exposure: continuous measurements (i.e. recording real-time concentration of pollutants) are needed.
      - OK for particles, CO, and CO_2.
      - VOCs: 1 week passive measurements → underestimated maximal value.

MAIN LIMITATIONS OF ANNEX 68 (ST1) WORK

- **Time of measurements:** in low-energy residential buildings, right after the construction of the building.
  - > Emissions can be higher than for the rest of the year explaining why some pollutant concentrations were found at higher levels in low-energy residential buildings than in older buildings.
- **Variability of ELVs among countries and time:**
  - > To consider this variation, the lowest ELV of all available ELVs for a pollutant was used.
- **ELVs do not account for "cocktail effect":** may cause that a pollutant produces harmful effects even at concentrations lower than its ELVs.
  - > A factor of 10 was used when the relevant compounds were pollutants for which the ratio of concentration to ELV was higher than 0.1 (instead of 1).

MAIN LIMITATIONS OF ANNEX 68 (ST1) WORK

- **DALY approach:**
  - \+ Comparison of health impact from various pollutants, including the various types of diseases induced.
  - \+ Can be monetized and integrated to economical assessment (with energy consumption).
  - \- Large uncertainty in the number of DALY losses estimated, which may reach several orders of magnitude.
  - \- Lack of reference for DALY: based on ELV? Different for outdoors/indoors?
- **Applicability of the dashboard (3 IAQ indices):**
  - > In-situ measurements: metrology for real-time measurement of VOCs currently rather expensive.
  - > IAQ simulation: relevant input data (outdoor pollution levels, pollutant source emission rates or materials' ad/desorption properties, …) are not easy to find, or do not exist at all → Annex86.

CONCLUSION

- The main findings of the Annex68 Subtask 1:
  - There are **16 target pollutants** that may cause health risks in low-energy residential buildings: acetaldehyde, **acrolein**, alpha-pinene, **benzene**, carbon dioxide, **formaldehyde**, naphthalene, **nitrogen dioxide**, **PM10**, **PM2.5**, radon, styrene, toluene, trichloroethylene, TVOC and mold.
  - There are **4 indices**: IAQ-STEL, IAQ-LTEL and IAQ-DALY for IAQ, and energy consumption. The combination of these indices provides a comprehensible signature for IAQ and energy use of a building but still need to be evaluated/tested.

- Despite our efforts and many efforts in the past, the unique scientifically-based index capable of describing IAQ level indoors is still missing. This index would have to include all the **most important pollutants**, account for both **long-term** and **short-term** exposures, **avoid ambiguity and eclipsing** and be expressed on a **scale compatible with energy consumption**.

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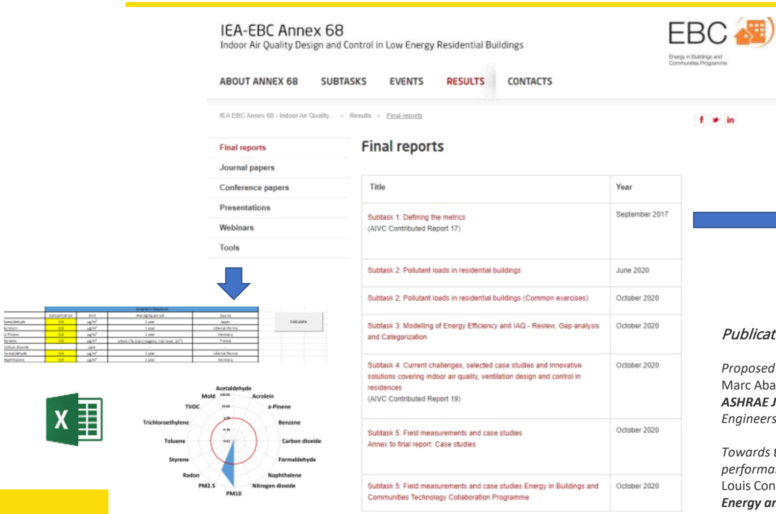
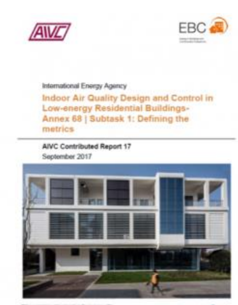
REFERENCES

https://www.iea-ebc-annex68.org/results/final-reports





Publications in Journals

Proposed Metrics For IAQ in Low-Energy Residential Buildings
Marc Abadie, Pawel Wargocki, Carsten Rode, Jensen Zhang
ASHRAE Journal, *American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2019, 61 (1).*

Towards the definition of indicators for assessment of indoor air quality and energy performance in low-energy residential buildings
Louis Cony Renaud Salis, Marc Abadie, Pawel Wargocki, Carsten Rode
Energy and Buildings, Elsevier, 2017, 152, pp.492 - 502.

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Annex 68 IAQ metrics: what was proposed, what works, what not, what are the remaining questions?

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DALY as an integrated IAQ metric: methodological updates.

Benjamin Jones
University of Nottingham, UK