AIVC April Workshop

Jelle Laverge
Operating Agent
IEA-EBC Annex 86

Series of four webinars

Organised in collaboration with IEA-EBC Annex 86 'Energy efficient IAQ management'

April 1, Building ventilation: How does it affect SARS-CoV-2 transmission?

April 8, IAQ and ventilation Metrics

April 13, Big data, IAQ and ventilation -part 1

April 21, Big data, IAQ and ventilation -part 2

Register at www.aivc.org

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Introduction: context of the webinar

- The IEA-EBC ExCo approved the start of the preparation year of 'Annex 86' in June 2020
- AIVC TechNote 68 'Ventilation and Health'
- AIVC CR 17 and 19

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EBC

Energy in Buildings and Communities Programme

IEA-EBC Annex 86

Energy Efficient IAQ Management in residential buildings

ExCo meeting November 2020

EBC

Energy in Buildings and Communities Programme

Scope and Goals

Provide a framework to improve energy efficiency of IAQ management for

Residential buildings

both new construction and refurbishment

To select metrics to assess energy performance and indoor environmental quality of an IAQ management strategy and study their aggregation
To improve the acceptability, control, installation quality and long-term reliability of IAQ management strategies by proposing specific metrics for these quality issues
To set up a coherent rating method for IAQ management strategy that takes into account the selected metrics
To identify or further develop the tools that will be needed to assist designers and managers of buildings in assessing the performance of an IAQ management strategy using the rating method
To gather existing or provide new standardized input data for the rating method
To study the potential use of smart materials as (an integral part of) an IAQ management strategy
To develop specific IAQ management solutions for retrofitting existing buildings
To benefit from recent advances in sensor technology and cloud-based data storage to systematically improve the quality of the implemented IAQ management strategies, ensure their operation and improve the quality of the rating method as well as the input data
To improve the availability of these data sources by exploring use cases for their providers
To disseminate about each of the above findings.

EBC
Energy in Buildings and Communities Programme

Partners

42 institutes from 24 countries

Active participation by companies encouraged!

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

EBC
Energy in Buildings and Communities Programme

Workplan

6 Subtasks

ST 1 and 2: methodology

ST 3 and 4: application to technology

ST 5: new opportunities through IoT

ST 6: dissemination and management

Subtask 1 Metrics and development of an IAQ management strategy rating method
This subtask is devoted to the development of a general rating method for the benchmarking of the performance of IAQ management systems. In addition to relevant metrics, a set of appropriate tools, consistent modeling assumptions and monitoring protocols are also proposed.

Subtask 2 Source characterization and typical exposure in residential buildings
This ST creates consistent input values for the assessment method developed in ST 1 and control strategies in ST 4. It starts from information available in literature, adding new experimental results where needed and reviewing and developing models (empirical, semi-empirical or physical models) for characterizing relevant residential sources.

Subtask 3 Smart materials as an IAQ management strategy
This ST identifies opportunities to use the building structure and (bio-based) building materials (focussing on hemp concrete) and the novel functional materials inside it to actively/passively manage the IAQ, for example, through active paint, wallboards, textiles coated with advanced sorbents or hemp concrete, and quantifies their potential based on the assessment framework developed in ST 1.

Subtask 4 Ensuring performance of smart ventilation
This subtask focuses on practical conditions that assure reliable, cost effective and robust implementation of smart ventilation. This includes both installation and operation. A poor performance of smart ventilation systems can not only lead to waste of energy and aggravated IAQ. It can also create a bad reputation of smart ventilation among relevant stakeholders - designers, installers as well as occupants. This, in the end, can lead to adoption of more primitive, less efficient (in terms of energy use) and less effective (in terms of IAQ) forms of IAQ management. The subtask defines a smart ventilation according to the AIVC

Subtask 5 Energy savings and IAQ: improvements and validation through cloud data and IoT connected devices
This subtask is exploring the potential of the new generation of IoT connected devices (both standalone and embedded in eg. AHU's) for smart IAQ management. What can we learn from big data? Can we benchmark system energy and IAQ performance based on this data? How can we make sure that the data is available and can be accessed? Can we update what we think we know about what happens in dwellings based on what we see in big data rollouts? What are the best protocols and ontologies? How to create viable services out of the data/business plans? How can we integrate data with smart grids?

Subtask 6 Dissemination, management and interaction
The final subtask assures the close alignment of the activities within the annex and the interaction with the AIVC. This subtask includes the outreach of the annex, eg. by managing the dedicated section of the IEA EBC webpage. It uses the different platforms that the AIVC provides to interact with the broader target audience. This task will also ensure the continuation of the link with (the results from) other ongoing and ended annexes, especially annex 68.

EBC

Energy in Buildings and Communities Programme

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AIVC

IAQ and Ventilation Metrics

webinar

2021.04.08

Objectives:

- To discuss the road towards a robust comprehensive IAQ metric for the assessment of the performance of ventilation
- To set the starting stage for subtask 1 of IEA EBC Annex 86

09:00 | Introduction, ***Jelle Laverge – EBC Annex 86 Operating Agent, Ghent University, Belgium***

09:10 | Annex 68 IAQ metrics: what was proposed, what works, what not, what are the remaining questions? ***Marc Abadie – University of La Rochelle, France***

09:30 | DALY as an integrated IAQ metric: methodological updates, ***Benjamin Jones – University of Nottingham, UK***

09:50 | TAIL a new rating scheme of indoor environmental quality, ***Pawel Wargocki – DTU, Denmark***

10:10 | Questions and Answers

10:30 | Closing & End of webinar

IAQ and Ventilation Metrics

webinar
2021.04.08

Marc Abadie
La Rochelle Université,
France

Benjamin Jones
University of Nottingham,
UK

Pawel Wargocki
Danmarks Tekniske
Universitet, Denmark

Webinar management

Maria Kapsalaki
(INIVE, BE)

Valérie Leprince
(INIVE, BE)

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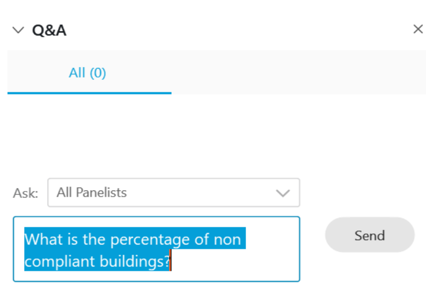
webinar
2020.04.08

How to ask questions during the webinar

Locate the **Q&A box**

Select **All Panelists** | Type your question | Click on Send



Note: Please DO NOT use the chat box to ask your questions!

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webinar
2020.04.08

<u>NOTES:</u>

- The webinar will be **recorded and published** at www.aivc.org within a few days, along with the presentation slides.
- After the end of the webinar you will be redirected to our **post event survey**. Your feedback is valuable so take some minutes of your time ti fill it in.

Organized by: www.aivc.org **Facilitated by** INIVE

D'ici, on voit + loin !

IEA EBC ANNEX 68 IAQ METRICS:

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

Marc Abadie – University of La Rochelle (France)

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)

CONTENTS

- 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?

RESULTS FROM IEA EBC ANNEX 68 SUBTASK 1:

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

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?

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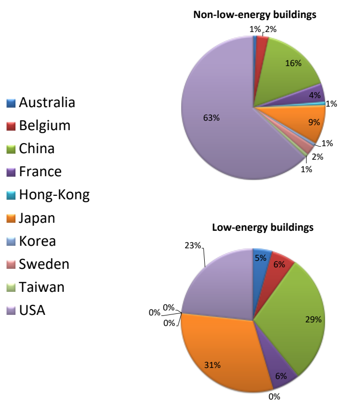
POLLUTION LEVELS IN RESIDENTIAL BUILDINGS



	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)

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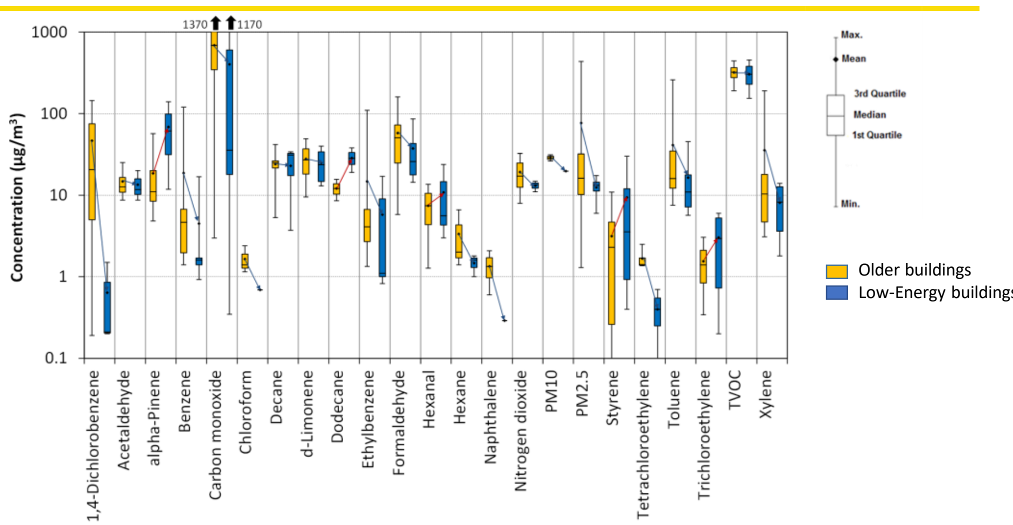
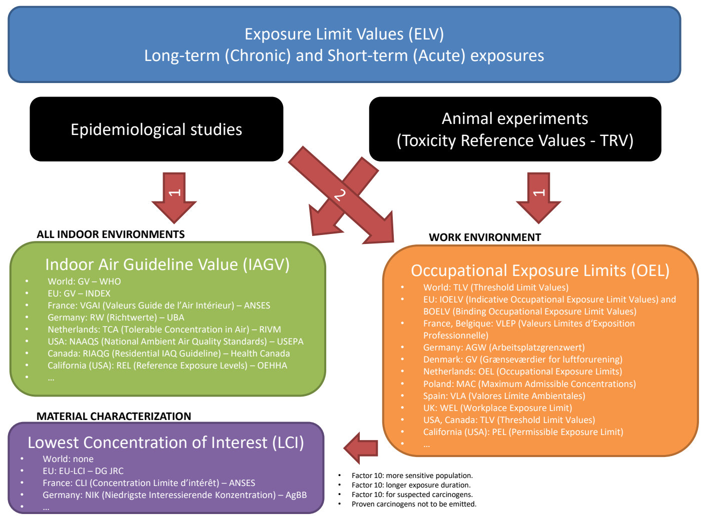
POLLUTION LEVELS IN RESIDENTIAL BUILDINGS



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, 1st quartile, median, 3rd 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.

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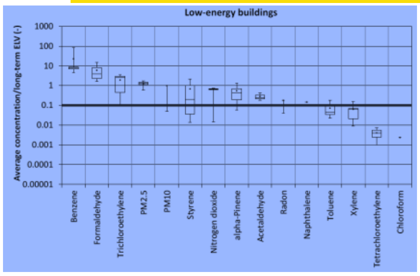
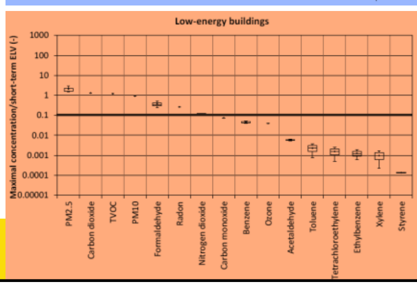
TARGET POLLUTANTS IN LOW-E RESIDENTIAL BUILDINGS





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.

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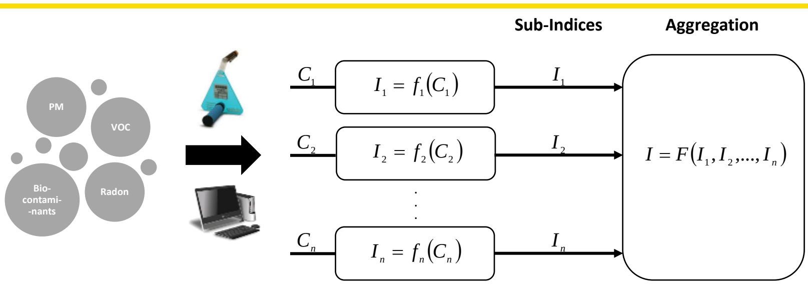
IAQ METRICS – ELV-BASED APPROACH



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

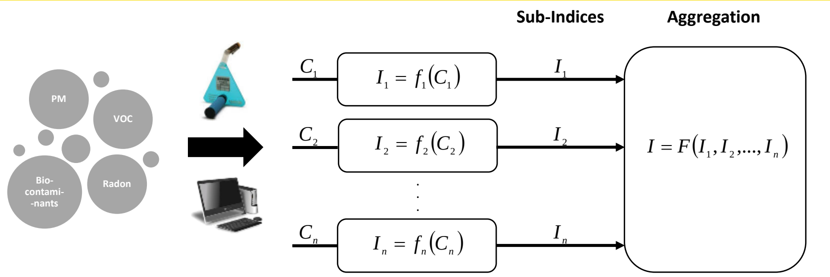
Step 1: Sub-indices

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

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

	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

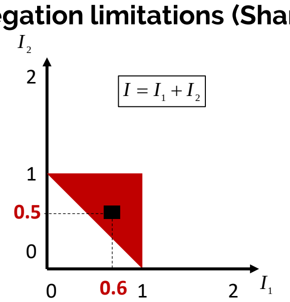
+ Aggregation limitations (Sharma and Bhattacharya, 2012):

Example:

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

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

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

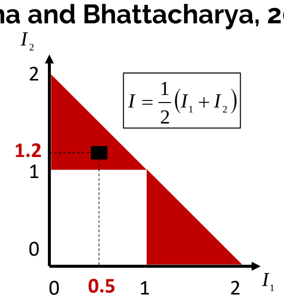


$I_1 = 0.6 \le 1 \rightarrow no\ risk$

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

$I = 1.1 > 1 \rightarrow risk!$

Ambiguity (false alarm)



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

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

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

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.*

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

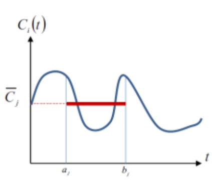
$YLL_{disease}$: Years of Life Lost due to premature death from the disease,

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

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

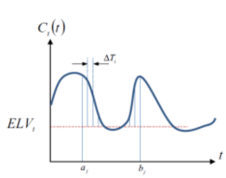
sub-indices (Logue et al., 2011) aggregation

METRICS FOR ANNEX68 – DASHBOARD

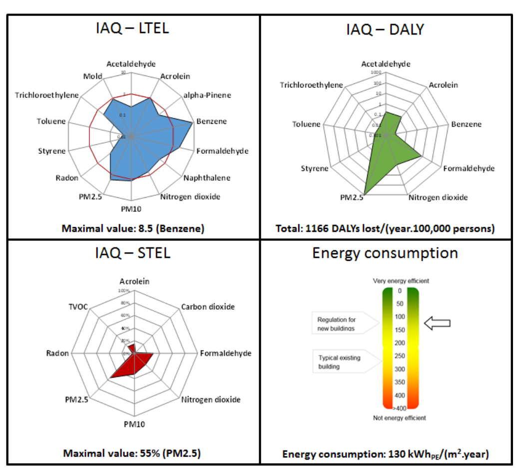


$$\overline{C_i} = \frac{1}{n}\sum_{j=1}^{n}\left[\frac{1}{b_j-a_j}\int_{a_j}^{b_j} C_i(t)dt\right]$$

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



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



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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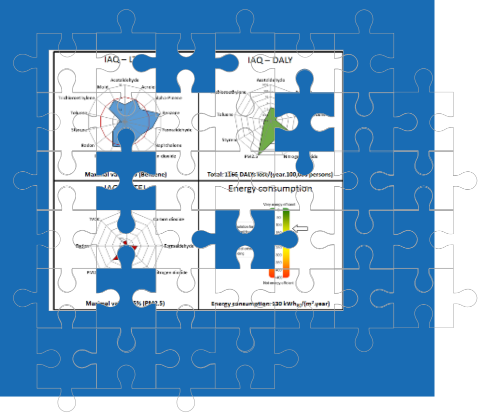
RESULTS FROM IEA EBC ANNEX 68 SUBTASK 1:

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.

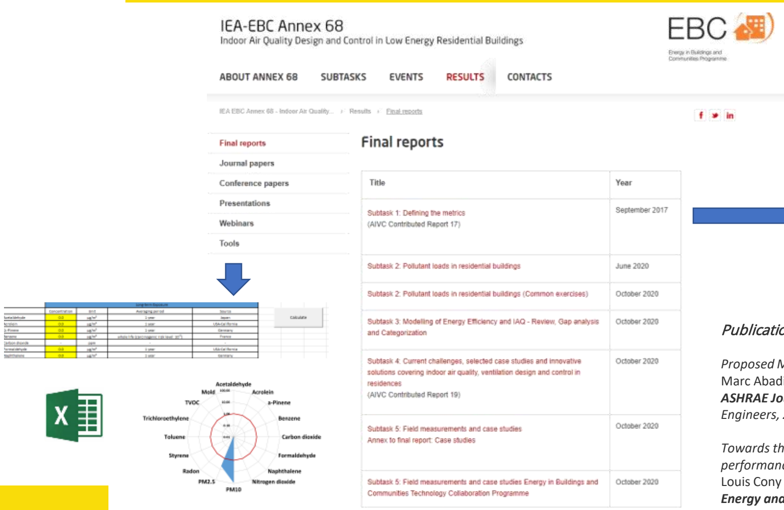
CONCLUSION

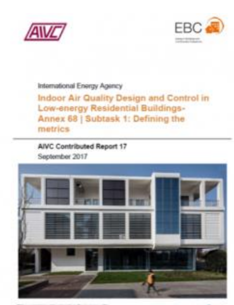
- The main findings of the Annex68 Subtask 1:
  - There are **16 target pollutants** that may cause health risks in low-energy residential buildings: acetaldehyde, **acrolein**, alpha-pinene, **benzene**, carbon dioxide, **formaldehyde**, naphthalene, **nitrogen dioxide**, **PM10**, **PM2.5**, radon, 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**.

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.

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

Marc Abadie
University of La Rochelle, France

DALY as an integrated IAQ metric: methodological updates.

Benjamin Jones
University of Nottingham, UK

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Disability Adjusted Life Years (DALYs) as an integrated IAQ metric of harm

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Thought experiment

Perfectly mixed pollutant. Two people. Different activities. Different ages.
Which person is harmed the most?

8 years old

80 years old

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The olfactory paradigm

Section 1

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The Olfactory Paradigm

"…the committee chair [of ASHRAE Standard 62-1989 (ASHRAE, 1989)] noted that the minimum ventilation requirement of 7.5 L/s per person is based on body odour control (Janssen 1989). This minimum was increased to 10 L/s per person in many building types to account for contaminants other than human bioeffluents, such as building materials and furnishings, though no specific methodology for determining the increase is noted."

Persily, A. 2006. What we Think we Know about Ventilation. *International Journal of Ventilation* 5(3): 275-290.

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Thinking about IAQ

Section 2

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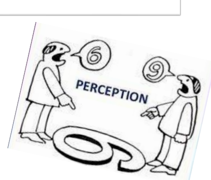
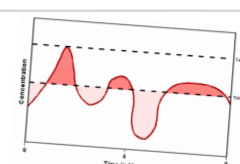
How do we advance?

(As discussed by AIVC Workshop on IAQ Metrics in 2017, 3 articles, and IEA Annex 68)

Measurements

- **Perceived air quality**
  - Good as a rule of thumb but not as a population-scale generic metric. Has limitations: Can't smell CO, for example.
- **Ratings systems**
  - Helpful to someone sensitive to specific contaminants, and/or home buyers.
- **Sub-indices**
  - Measure range of pollutants to gain a comprehensive picture. Combine all indices into a single measure. E.g. TVOC
- **Exposure limit values**
  - Ratios of maximum concentration to their respective ELV concentrations give a quick indication of risk, where a ratio ≪1 might be acceptable but one approaching or exceeding unity may be problematic.





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How do we advance?

Pollutant	Indoor/occupational		Threshold	By
	Value	Exposure Time		
Criteria pollutants: Particulate matter ($PM_{2.5}$)	25 µg/m³	24 hrs	Guideline	WHO
	35 µg/m³	24 hrs	Standard	US EPA
	65 µg/m³	24 hrs	Standard	ASHRAE
Sulphur Dioxide (SO_2)	0.012 ppm	1 year	Guideline	WHO
	0.030 ppm	1 year	Standard	US EPA
Nitrogen Dioxide (NO_2)	0.1 ppm	1 hrs	Guideline	WHO
	1 ppm	15-min	Standard	NIOSH/US EPA
Ozone (O_3)	200 µg/m³	8 hrs	ELV/Standard	OSHA/US EPA
	120µg/m³	8 hrs	Guideline	WHO

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Metrics: remarks

- Some standards regulating IAQ rely on non-health based metrics, including carbon dioxide concentrations in indoor spaces and, perception of IAQ.
- Although threshold-based values are useful, they provide insufficient information with which to make any but the most basic judgments (above or below a threshold).
- CO_2 concentrations, perception, and threshold-based metrics are considered helpful, however, in a cursory way.
- The well-being of individuals is address considering two parameters: mortality & morbidity. Any single summary measure of health and well-being needs to account for both these aspects, in this case, **HALYs** are a more robust metric over threshold values.

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Health adjusted life years

Section 3

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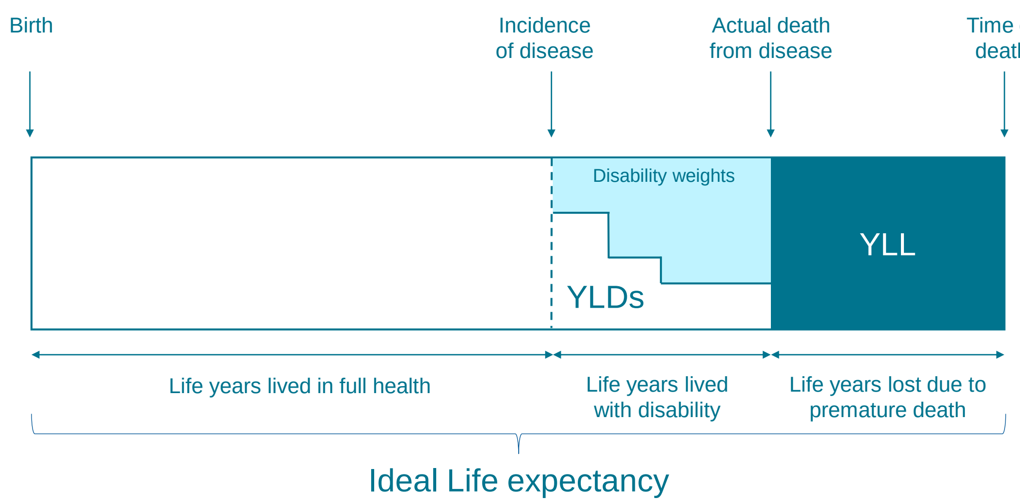
Health Adjusted Life Years (HALY)

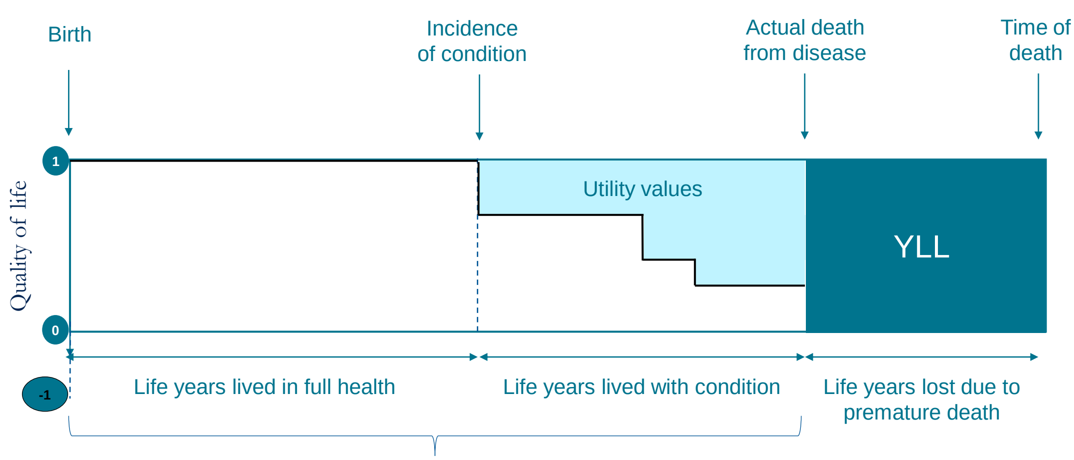


HALY: population health summary measures typically used in estimates of the burden of disease. They measure the combined effects of mortality and morbidity in populations, allowing for comparisons across illnesses or interventions as well as between populations. **YLL:** years of life lost; **YLD:** years of life with disability.

Health Adjusted Life Years (HALY)

QALY	DALY
Measures the quality of life in health gain	Measures health loss in the quality of life
Accounts for healthy years lived	Accounts for lost of healthy years
QA quality of life /	**DA** morbidity
LY quantity of life	**LY** mortality
Not for specific health outcomes	Measure for specific health outcomes
Allows to measure the effectiveness of intervention by increasing quality of life	Allows to measure the effectiveness of intervention at reducing the disease burden due to a condition
Cost to health: Has been allocated to economic values at the national level (i.e. UK)	Cost to health: Has not been allocated to economic values at the national level
Uses life tables; Can account for discount rates; Can account for age-adjustment	
Do not consider comorbidity (an individual experiencing multiple illnesses)	

Quality Adjusted Life Years (QALY)

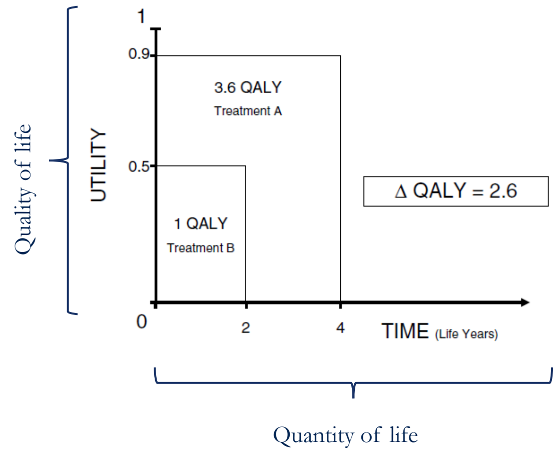


QALY = *length of life years × quality of life*

Provide a comprehensive measure of health in social well-being and physical health dimensions by combining both quantity and quality of life.

Quality Adjusted Life Years (QALY): example

Treatment	Cost (£)	QALYs
Treatment A gives 2 years of life with a utility value 0.5	1000	2 years×0.5 = 1
Treatment B gives 4 years of life with a utility value 0.9	1500	4 years×0.9= 3.6
ΔAB	500	2.6
Ratio	$\frac{500\ £}{2.6\ QALYs} = 192\ £\ per\ QALY\ gained$	



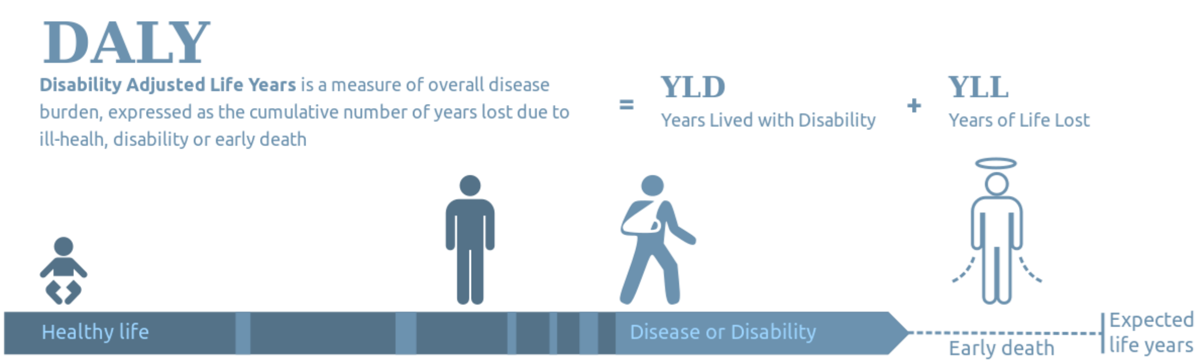
- A decision can be taken on the relative success of different treatments (£20,000-£30,000 per QALY is suggested by NICE to be the limit for an intervention to be cost-effective)

https://en.wikipedia.org/wiki/National_Institute_for_Health_and_Care_Excellence

Pietro & Sacristan (2003). doi.org/10.1186/1477-7525-1-80

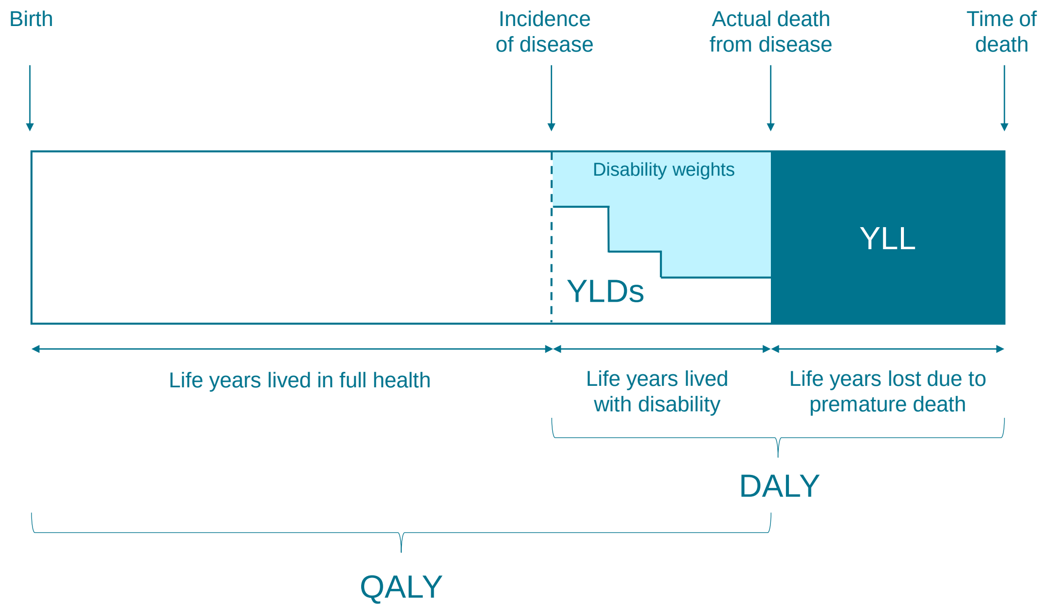
Friday, April 9, 2021 NICE National Institute for Health and Care Excellence 13

Disability Adjusted Life Years (DALY)



One DALY = one lost year of healthy life

Disability Adjusted Life Years (DALY)



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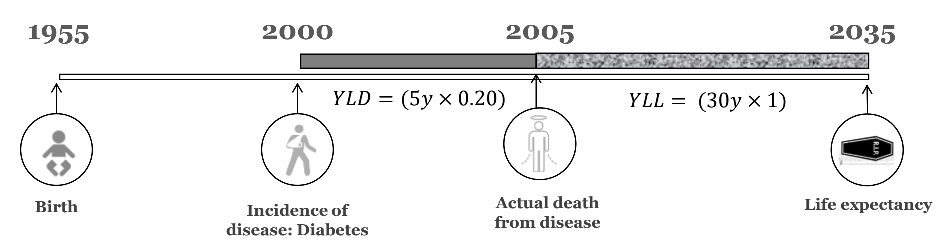
Disability Adjusted Life Years (DALY): a simplified example

Onset Diabetes:

with out any

treatment

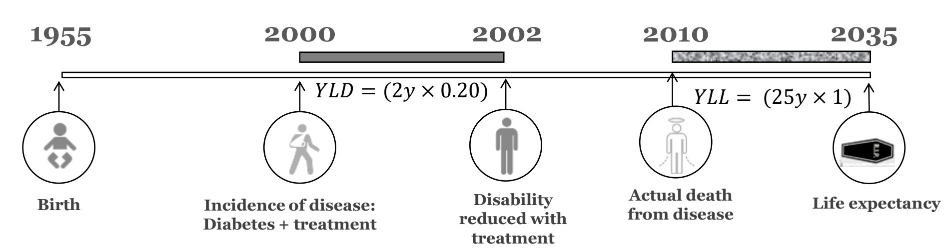
$DALY = 31 \; years$



Onset Diabetes:

with treatment

$DALY = 25.4 \; years$



$Adverted \; DALYs = 5.6 \; years$

A value can be proposed on the relative success of the hypothetical treatment (£ per aDALY; limit for an intervention to be cost-effective)

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Remarks on QALYs & DALYs

- DALY
  - Is still a methodological and thought experiment.
  - Used as the preferred metric to estimate health impacts in the Global Burden of disease studies.

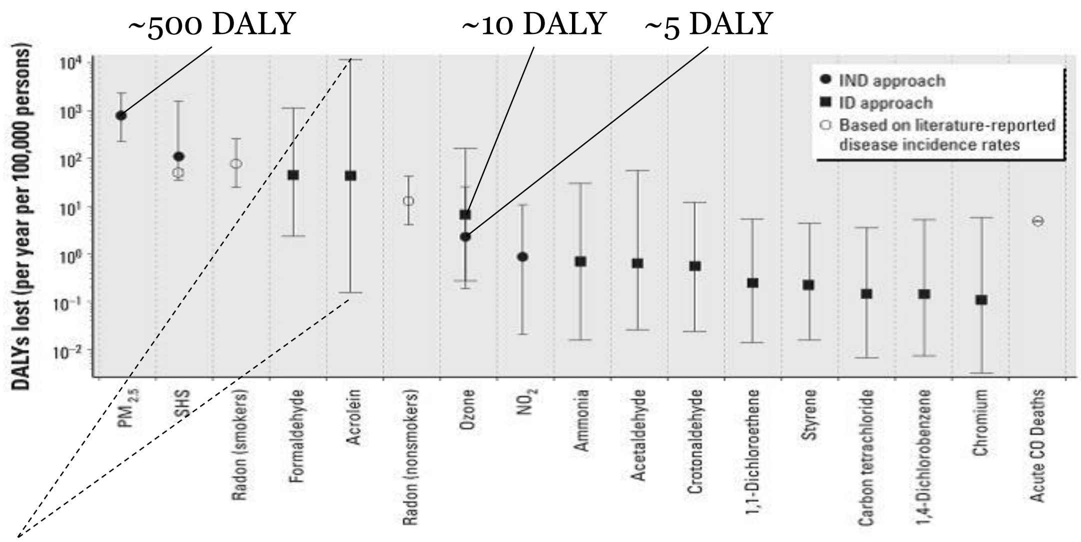
- QALY
  - UK, Ireland and Thailand have explicit *Cost-Effective Thresholds* per QALY.
  - Sweden, Portugal, Poland, Norway, the Netherlands, Hungary, South Korea, Japan, Hungary, the Czech Republic, Canada, Brazil, Belgium and Australia use not-official *Cost-Effective Thresholds* per QALY.
  - A general cost-effectiveness (C/E) threshold is stated in the literature as 100,000$ USD per QALY.
  - WHO 1 – 3 GDP per capita.

(Cameron et al., 2018 - doi.org/10.1080/16549716.2018.1447828)

DALY impact assessment of indoor air quality

- Lawrence Berkeley Laboratories and the AIVC (see AIVC TN68).
- Reviewed 77 studies reporting on indoor air pollutant concentrations in the U.S. and other countries with similar lifestyles, such as the UK.
- Considered 267 chemical air pollutants in total.
- Calculated the annual health impact of pollutants considering the total intake in houses in addition to intake in other environments.
- The in-house inhalation of air with the mean exposure from the studies was considered relative to a theoretical case of no inhalation.
- The inhalation is weighted to the U.S. population and so there would be differences for other populations, but there are likely to be some similarities in other countries, such as the UK, that have similar lifestyles.

Disability Adjusted Life Years (DALY): An impact assessment approach for indoor air quality



Note the magnitude of confidence intervals

Commonly found indoor air pollutants.

Logue et al. (2012). doi.org/10.1289/ehp.1104035

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Summary

Section 4

Thought experiment

Perfectly mixed pollutant. Two people. Different activities. Different ages.
Which person is harmed the most?

8 years old

80 years old

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Thought experiment

In a household.
Perfectly mixed pollutant: $PM_{2.5}$.
1 year of exposure.

Onset of disease: Asthma for 1 year; then death.
Life expectancy 80 and 82.5 years, male and female.

$$DALY_{PM_{2.5}} = (1 \times 0.2) + (80 - 9)$$
$$DALY_{PM_{2.5}} = 71.2\ years$$

$$DALY_{PM_{2.5}} = (1 \times 0.2) + (82.5 - 81)$$
$$DALY_{PM_{2.5}} = 4.4\ years$$

8 years old (male)

80 years old (female)

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What next for health based metrics?

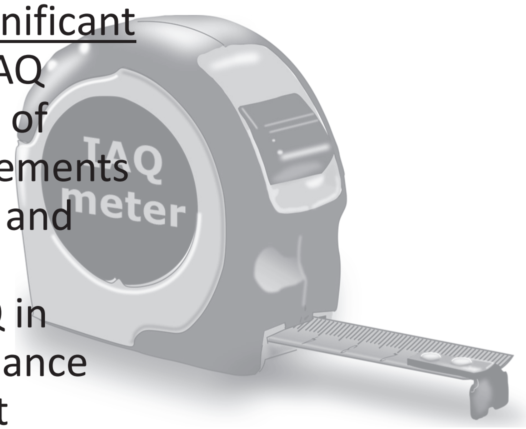
- Annex 86 and ASHRAE 62 are beginning the transition but…
- They're still some way off being useful and accepted as *best practice*
- They must be robust to avoid litigation
- They must be combined with appropriate diagnostics
- They must not be a barrier to innovation
- They must also consider energy
- How/can/should we consider mental health?
- Sanctions for non-compliance must be defined and methods of identification derived
- It will require multidisciplinary study and collaboration
- We must involve stakeholders to ensure their support

End

Disability Adjusted Life Years (DALYs) as an integrated IAQ metric of harm

….is IAQ metric necessary?

- Lack of IAQ metric or disagreement what should constitute IAQ metric is a significant barrier holding back innovation of IAQ conducive technologies, emergence of undocumented methods of measurements of IAQ claiming their high efficiency and authenticity, this all resulting in undervaluing the importance of IAQ in different credit schemes and compliance metrics related to built environment



Source: Steinemann et al. (2016)

More and more pollutants present for which no toxicological data exist

"New chemicals and other contaminants appear in buildings almost daily. Many in the indoor air community fear that so me of these may be significant health hazards either singly or in combination. Undoubtedly some will.

But rather than speculate on that …(…) it makes more sense to work with the information we have on contaminants that have demonstrated harm to the population (…) .

Sherman (2013)

TAIL

A NEW RATING SCHEME FOR INDOOR ENVIRONMENTAL QUALITY (IEQ)

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Background - ALDREN project

- Horizon 2020 Coordination and Support Action (CSA)
- Alliance for Deep RENovation in buildings (ALDREN). Implementing the European Common Voluntary Certification Scheme, as back-bone along the whole deep renovation process
- Main objective: To consolidate, promote and implement an extended harmonized procedure based on the European Voluntary Certification Scheme for non-residential buildings (EVCS) and a set of relevant instruments in order to support building deep energy renovation operations all along the process tackling its organizational, financial and technical components issues.
- Focus: offices and hotels undergoing deep energy renovation
- Duration: November 2017-September 2020
- Project number ALDREN 754159

ALDREN ALliance for Deep RENovation in buildings
www.aldren.eu

Specific goals of the ALDREN project (the packages)

- Development of a harmonized energy performance rating method based on the European Voluntary Certification Scheme (EVCS) mandated by the new Energy Performance of Buildings Directive (EPBD).
- Reduction of the gap between predicted (modeled) and actual energy performance of buildings to increase their reliability and compliance.
- **Inclusion of indoor environmental quality (IEQ) in the scope of deep energy renovation to promote solutions supporting comfort and health and to ensure that renovations will not be detrimental to indoor environmental conditions.**
- Linking the building rating in terms of energy, sustainability and IEQ with the private and national financing instruments to emphasize enhanced building value and thus create strong incentives for investment.
- Developing a building passport that integrates, illustrates and documents the different phases of a deep renovation process for proper documentation and dissemination and renovation roadmap (renomap).

A need for inclusion of IEQ in the scope of deep energy renovation

- To satisfy the mandate of the EU Energy Performance of Buildings Directive (EPBD)
- To guarantee that IEQ is not degraded during renovation
- To document any improvements in IEQ after renovation
- To estimate potential additional benefits from renovation including benefits for health and well-being, as well as the financial benefits from improved productivity and increased value of a building on a market

DIRECTIVE (EU) 2018/844 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency

Article 2a. Long-term renovation strategy

1. Each Member State shall establish a long-term renovation strategy to support the renovation of the national stock of residential and non-residential buildings, both public and private, into a highly energy efficient and decarbonized building stock by 2050, facilitating the cost-effective transformation of existing buildings into nearly zero-energy buildings. Each long-term renovation strategy shall be submitted in accordance with the applicable planning and reporting obligations and shall encompass:
(…)

(g) **an evidence-based estimate of** expected energy savings and **wider benefits, such as those related to health, safety and air quality.**

Review of current certification schemes and standards

13 Green Building Certifications
- Level(s)
- OsmoZ
- HQE
- BREEAM
- KLIMA
- DGNB
- ITACA
- CASBEE
- LEED
- WELL
- NABERS

European standard EN16798

7 European projects

14 Research articles

IEQ
- Thermal environment — 19 indicators
- Indoor air quality — 39 indicators
- Acoustic environment — 20 indicators
- Visual environment — 12 indicators

Nearly 100 indicators!

Wei et al. (2020) Energy and Buildings

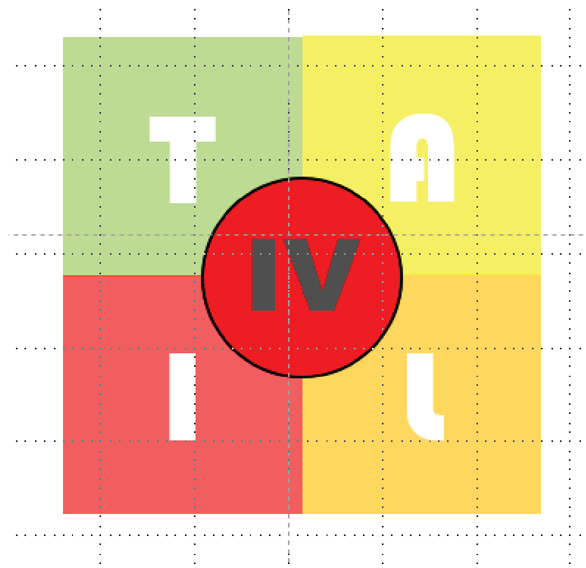
TAIL, a new proposed rating scheme for IEQ

Four components:

- **T**hermal environment
- **A**coustic environment
- **I**ndoor air quality
- **L**ight – Luminous (visual) environment

Overall IEQ:

- I II III IV

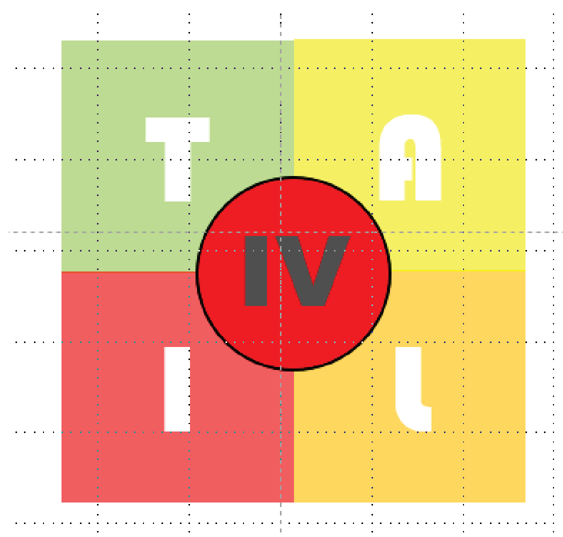


Wargocki et al. (2021) submitted to Energy and Buildings

TAIL, a new proposed rating scheme for IEQ

- Colors: green, yellow, orange, red
- Roman numbers: I, II, III, IV

- Compliant with the Standard EN16798-1(2019) supporting EPBD
- Category I: High level of expectation and recommended for spaces occupied by sensitive and fragile people with special requirements like some disabilities, sick, very young children and elderly persons, to increase accessibility
- Category II: Normal level of expectation
- Category III: Moderate level of expectation
- Category IV: Low level of expectation. Poor quality. Unacceptable regarding health



Criteria for selection of parameters defining TAIL components

- Parameters that may be changed due to the process of deep energy renovation (no deliberate action to change IEQ is proposed)
- Parameters that are included in existing building certification schemes and/or prescribed by the current standards (to allow quick adoption of procedures developed by ALDREN)
- Parameters that can be measured and/or modeled (to allow verification and rating of actual IEQ performance)
- Parameters that have been shown to affect productivity, as well as health, well-being and comfort of building occupants (to allow estimation of economic benefits of potential improvement of IEQ)
- No parameters that directly measure comfort, well-being, health or productivity

Parameters selected to define TAIL components

	IEQ parameter	Measured	Modelled	Visual inspection
T	Indoor temperature (°C)	×	(×)	
A	Noise level (dB(A))	×		
I	Carbon dioxide, CO_2 (ppm)	×	(×)	
	Ventilation rate (L/s)	×	(×)	
	Formaldehyde (µg/m³)	×		
	Benzene (µg/m³)	×		
	Particulate matter, $PM_{2.5}$ (µg/m³)	×		
	Radon (Bq/m³)	×		
	Indoor air relative humidity (%)	×	(×)	
	Visible mold (cm²)			×
L	Daylight factor (%)		×	
	Illuminance (lux)	×		

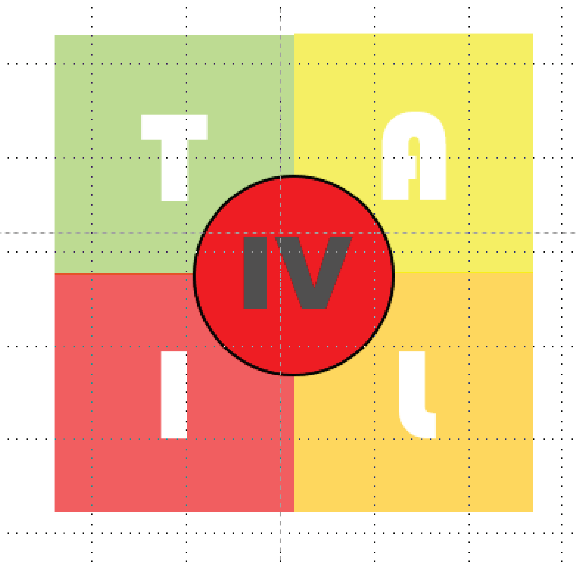
TAIL parameters in Standards, Environmental Assessments Frameworks and Green Building Certifications

	TAIL IEQ parameters	EN16798	Level(s)	WELL	HQE	OsmoZ	BES	LEED	BREEAM	KLIMA	CASBEE	NABERS	DGNB	LiderA	ITACA
T	Indoor temperature (°C)	x	x	x	x		x			x	x	x	x	x	
A	Noise level (dB(A))	x		x	x	x	x	x	x	x	x	x			
I	CO_2 (ppm)	x	x	x		x	x	x		x		x			
	Ventilation rate (L/s)	x	x	x	x	x	x	x	x		x	x	x		x
	Formaldehyde (µg/m^3)	x	x	x	x	x	x	x	x	x		x	x		
	Benzene (µg/m3)	x	x	x	x	x									
	$PM_{2.5}$ (µg/m3)	x	x	x	x	x		x							
	Radon (Bq/m3)	x	x	x	x		x								
	Indoor air relative humidity (%)	x	x	x						x					
	Visible mould (cm^2)		x	x											
L	Daylight factor (%)	x	x		x	x			x		x		x		x
	Illuminance (lux)	x	x	x			x	x	x		x			x	
	Number of parameters	*11*	*11*	*11*	*8*	*7*	*7*	*6*	*5*	*5*	*5*	*5*	*4*	*2*	*2*

Rating protocol, overall design (example for T)

Quality of the thermal environment (T)	Buildings with mechanical cooling		Buildings without mechanical cooling	
	Heating season	Non-heating (cooling) season	Heating season	Non-heating (cooling) season
Green	22±1 °C	24.5±1 °C	22±1 °C	upper limit $0.33\Theta_{rm}+18.8+2$ °C lower limit $0.33\Theta_{rm}+18.8-3$ °C
Yellow	22±2 °C	24.5±1.5 °C	22±2 °C	upper limit $0.33\Theta_{rm}+18.8+3$ °C lower limit $0.33\Theta_{rm}+18.8-4$ °C
Orange	22±3 °C	24.5±2.5 °C	22±3 °C	upper limit $0.33\Theta_{rm}+18.8+4$ °C lower limit $0.33\Theta_{rm}+18.8-5$ °C
Red	If other quality levels cannot be achieved		If other quality levels cannot be achieved	

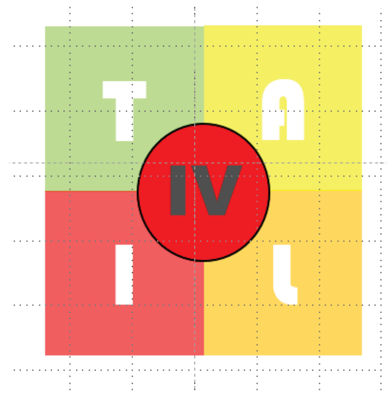
Rating protocol, determination of the overall level of IEQ



Measurements (the rating)

- Measurement to be performed before and after deep energy renovation (DER) at the **same season**, or ideally in summer + winter before and summer + winter after
- Measurements are performed 5 days (MO-FR) in offices and 7 days (MO-MO, or TU-TU, etc.) in hotels
- Measurements only offices/workplaces in office buildings and only in rooms in hotels
- Before renovation: results from previous surveys can be used provided that the same or similar methods were implemented

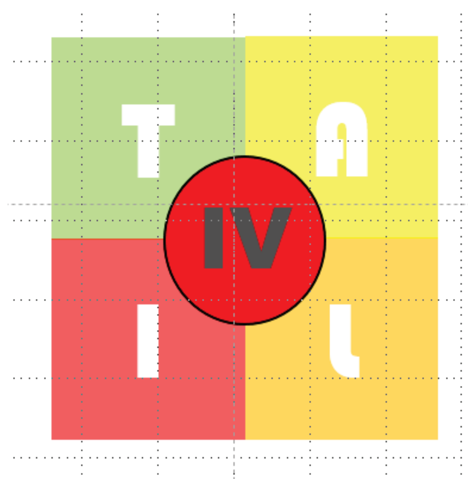
Summary



- The framework for rating of IEQ and its components is proposed.
- TAIL – a rating scheme describing IEQ level in offices & hotels that undergo deep energy renovation – allows rating of IEQ level before and after renovation.
- TAIL integrates all IEQ components. Based on actual measurements and measuring results. No arbitrary credits are given.
- TAIL treats all IEQ components equally. No weightings are used.
- TAIL complements the existing approaches for IEQ ratings and addresses EPBD mandate.
- TAIL is compliant with major certification schemes, EN16798-1 and the Level(s) which is EU's common assessment and reporting scheme on the sustainability of buildings.
- Even though TAIL may be perceived as fairly crude, it is expected to increase the interest of investors in IEQ.

TAIL perspectives

- Short-time frame: validation of the TAIL concept by measurements in buildings undergoing deep energy renovation, development of a prediction tool (predicTAIL).
- Medium-time frame: sensitivity analysis to distinguish differences in IEQ across buildings using TAIL, verification against modeling and occupant responses and against long-time measurements with more sophisticated instrumentation.
- Long-time frame: extension to new and existing and other public (schools) and residential buildings, increasing number of parameters underlying TAIL, inclusion of occupant ratings (occupanTAIL), extension to include occupant control and preferences, monetizing TAIL and developing instrument measuring TAIL as well as inclusion the aspects of building resilience (resilienTAIL)



Thank you

ALDREN ALliance for Deep RENovation in buildings

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 754159.