Abstract

The rating scheme for indoor environmental quality (IEQ) will be presented. It is called TAIL. It creates the framework for rating IEQ and its components: thermal acoustic and luminous environments and indoor air quality. TAIL is an integrated rating first developed for buildings undergoing deep energy renovation. It can now be used for any building, including offices, schools, and hotels. TAIL complements the existing approaches for assessing IEQ and complies with the major certification schemes. All components of the TAIL are treated equally - to achieve a high-quality level, all components of the TAIL must be at a high level, and no compromises are accepted. TAIL is based on measurements of ten parameters, observation of one, and simulations of one; 14 parameters are monitored for schools. TAIL has been used in measuring campaigns and has been shown to be an effective tool for demonstrating indoor environment quality. Because TAIL is a performance metric used in buildings under operation, a tool was developed called predictable, allowing the estimation of IEQ at the design stage. It uses similar principles as TAIL but cannot be used to rate IEQ in the building that is in use. So, it gives an indication of how the design decisions may affect the level of IEQ. Attempts were recently made to supplement the objective measurements with subjective evaluations made by the building occupants to achieve a holistic view of IEQ in a building. The results of these attempts will be presented as well.

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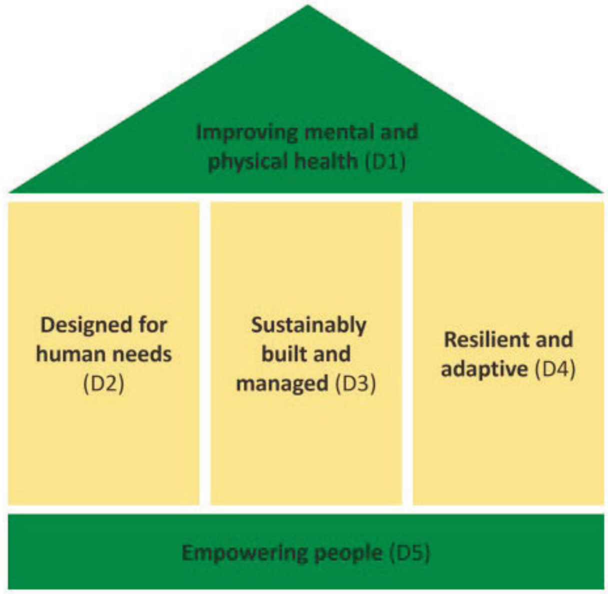
The TAIL rating schemes for offices and schools are the way to reduce carbon emissions and improve IEQ

PROLOGUE

The five-dimensions of future healthy buildings

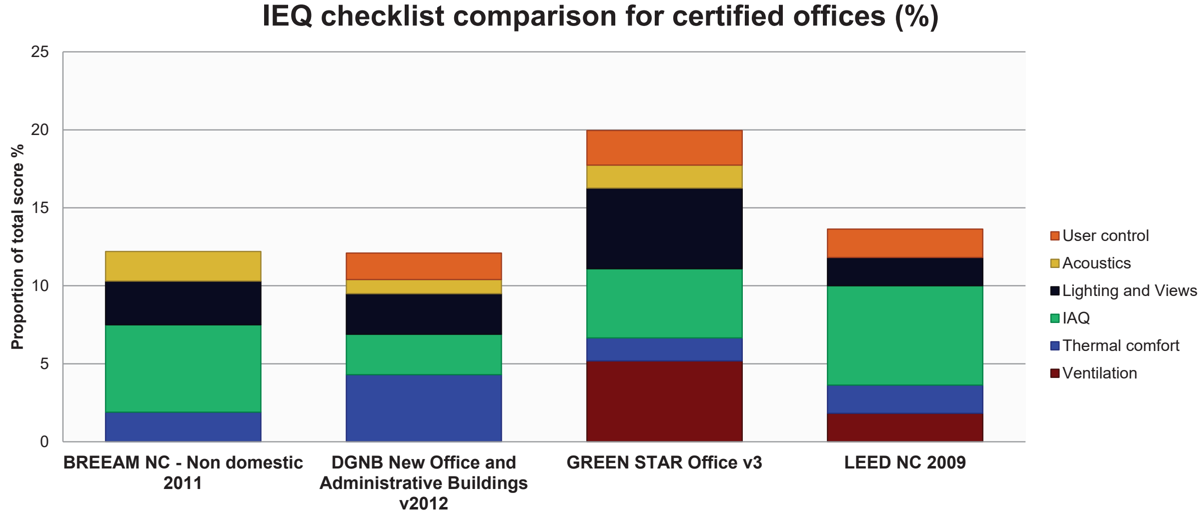


Source: Elnagar et al. (2024)

Q1: How can we document whether the building is healthy or sick?

Source: thegoldenhammer.net

IEQ certification in green buildings



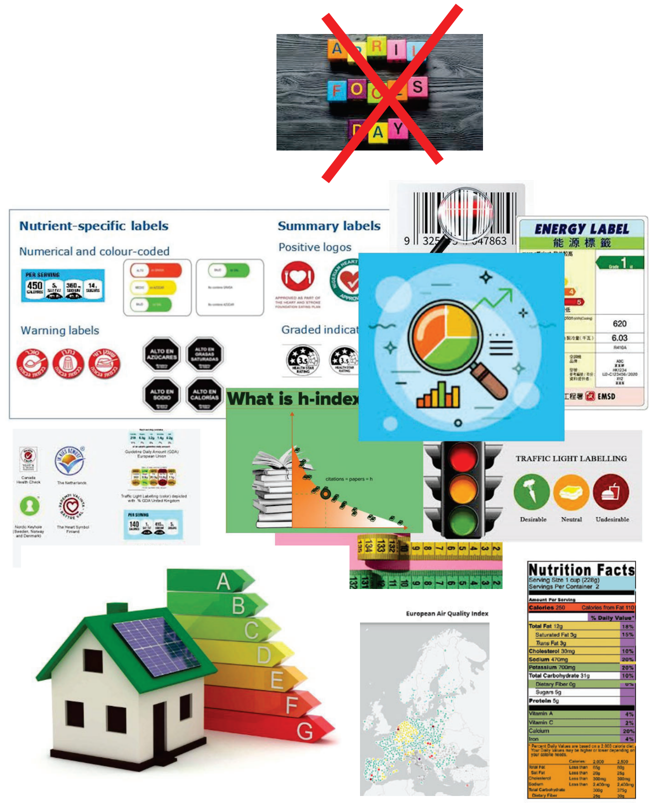
*In DGNB ventilation is incorporated in IAQ
*BREEAM has user control incorporated in diferent criterias

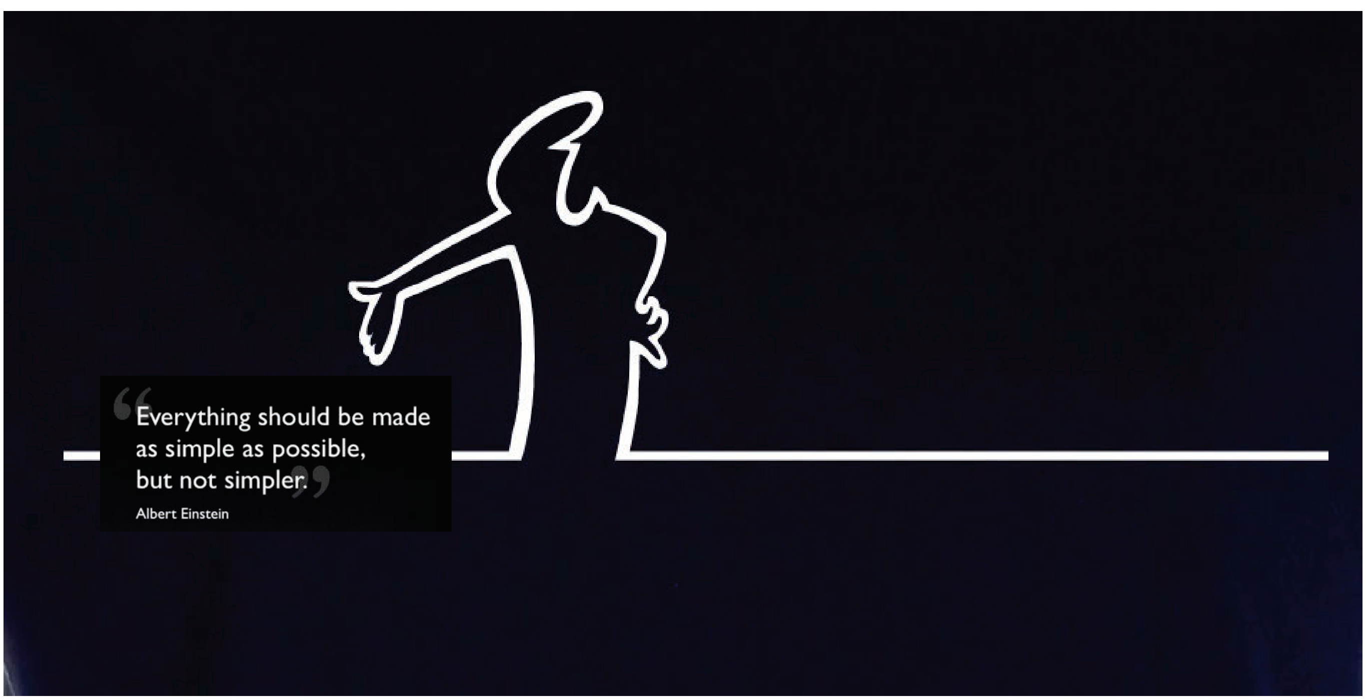
Q2: How can we document whether the green building has high IEQ?

A1-2: We cannot!

We live in a world full of labels, markers, and indicators.

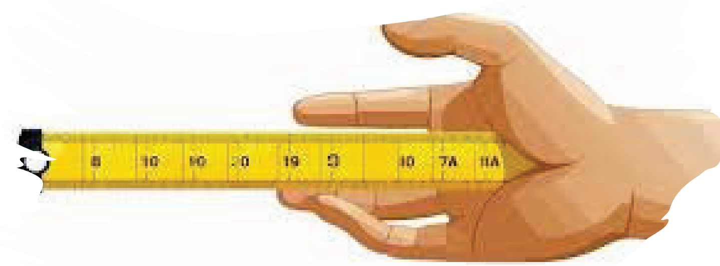
No agreed method for IEQ rating





Courtesy: La Linea

DTU



A METRIC FOR IEQ IS NEEDED

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Why? (1)

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2024/1275 | 8.5.2024

DIRECTIVE (EU) 2024/1275 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 24 April 2024

on the energy performance of buildings

(recast)

Article 13 Technical building systems

4. Member States shall set requirements for the implementation of in order to maintain a healthy indoor climate. adequate indoor environmental quality standards in buildings

5. Member States shall require non-residential zero-emission buildings to be equipped with measuring and control devices for the monitoring and regulation of indoor air quality. In existing non-residential buildings, the installation of such devices shall be required, where technically and economically feasible, when a building undergoes a major renovation. Member States may require the installation of such devices in residential buildings.

Monitoring and documentation of IEQ is of an essence

Why? (2)

- Useful data for all building stakeholders and additional incentives for improvement of IEQ
- Create benchmark, reference, building data-base
- Monitor performance – compliance and maintenance
- Input to sustainable investments, and technological advancements
- Input to control and AI
- Input to energy simulation and reduce performance gap
- Input to economic calculations
- Demonstrate invisible - occupants feel secure (no risks)
- Raising awareness

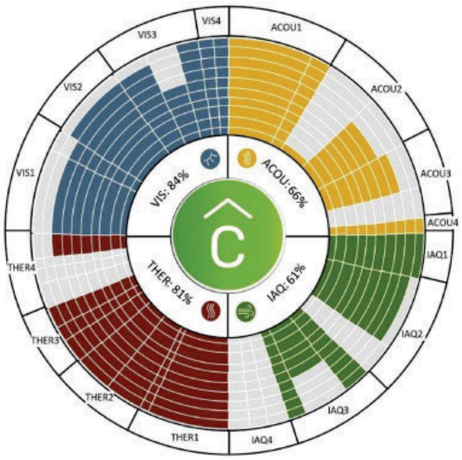
Why? (3)

Interactive poll

Name which of the following pollutants are in your room now at potentially toxic levels:

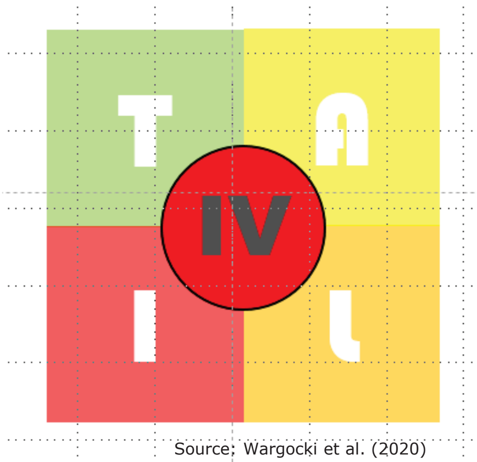
– PM2.5
– Formaldehyde
– SARS-CoV-2
– NO_2
– Radon
– Ozone
– Excessive odors
– I do not know

Examples of rating schemes but not in general use



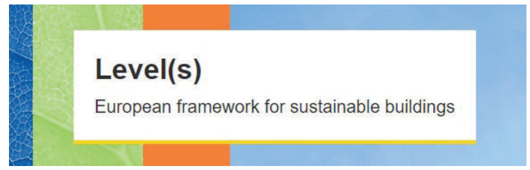
Source: Larsen et al. (2020)

IEQ-Compass
(asset rating)



Source: Wargocki et al. (2020)

TAIL
(performance rating)



A common language for assessing and reporting on the sustainability performance of buildings

Source: European Commission

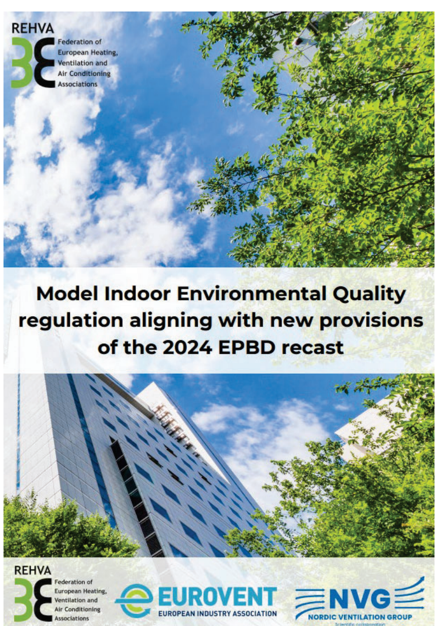


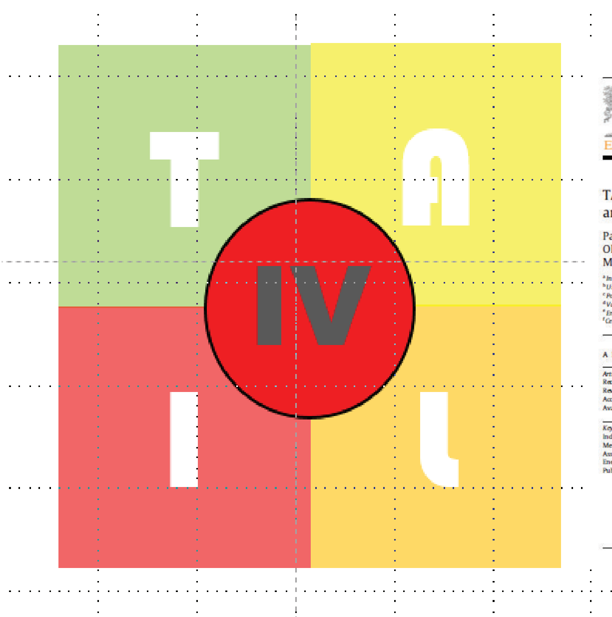
Table 5. An example of most important IEQ parameters. Minimum requirements specify design targets which compliance can be assessed with commissioning procedures. IEQ and energy performance can be assessed with continuous monitoring and inspection.

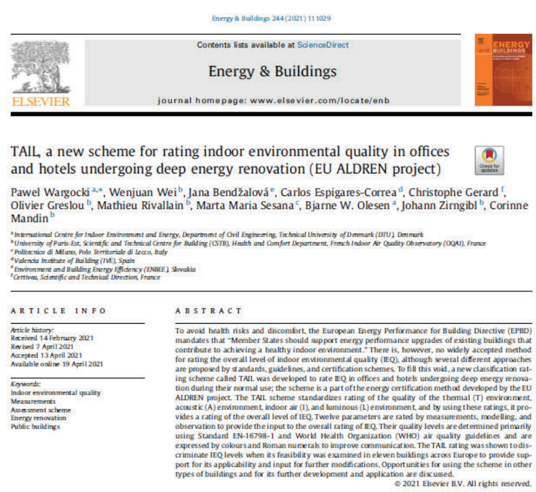
		Design	Commissioning	Monitoring[1]	Inspection	Comment
Thermal	Operative temperature	x				At representative points in the occupied zone to ensure occupant comfort
	Air velocity	x				At representative points in the occupied zone to ensure design and control of HVAC system for occupant comfort
	Air temperature			x		At 1.1 m above the floor in occupied zones
	Relative humidity			x		At 1.1 m above the floor in occupied zones
Acoustic	Sound pressure (A- and C-weighted)	x	x			Equivalent continuous sound pressure level (A- and C-weighted) at representative points in the occupied zone
	Sound reverberation time	x	x			Evaluation of noise at the design stage is found in EN 12354–5. Sound insulation parameters are not included in this document
Indoor air quality	Carbon dioxide	x		x		At 1.1 m above the floor in occupied zones, in the extract air
	PM2.5	x[2]		x[3]		At 1.1 m above the floor in occupied zones
	Formaldehyde				x	Near potential sources such as furniture and flooring
	Nitrogen dioxide				x	Near potential sources like kitchens and garages
	Carbon monoxide				x	Alarm sensors in buildings with combustion sources
	Radon	x			x	In the lowest occupied level of the building
	Ventilation rate	x	x		x	Outdoor airflow rate supplied and extracted from rooms, typically measured from supply and extract terminals
Light	Daylight provision	x				Daylight can be evaluated in accordance with EN 17037
	Glare probability	x				At workstations and near windows (EN 17037)
	Illuminance	x	x			The quality of lighting can be evaluated in accordance with EN 12464–1

[1] In addition to indoor values, monitoring of outdoor values for air temperature, humidity, CO_2 and PM2.5 is needed. The importance for IAQ is the difference of indoor-outdoor CO_2 and PM2.5.
[2] For non-residential buildings filters are specified in EN 16798-3.
[3] PM2.5 continuous monitoring is not needed if particulate matter is controlled with filters in ventilation system, and there is no significant infiltration through building envelope.

THE TAIL RATING SCHEME

The TAIL rating scheme

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TAIL, a new scheme for rating indoor environmental quality in offices and hotels undergoing deep energy renovation (EU ALDREN project)

Pawel Wargocki [a,*], Wenjuan Wei [b], Jana Bendžalová [e], Carlos Espigares-Correa [d], Christophe Gerard [f], Olivier Greslou [b], Mathieu Rivallain [b], Marta Maria Sesana [c], Bjarne W. Olesen [a], Johann Zirngibl [b], Corinne Mandin [b]

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Assessment scheme
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ABSTRACT

To avoid health risks and discomfort, the European Energy Performance for Building Directive (EPBD) mandates that "Member States should support energy performance upgrades of existing buildings that contribute to achieving a healthy indoor environment." There is, however, no widely accepted method for rating the overall level of indoor environmental quality (IEQ), although several different approaches are proposed by standards, guidelines, and certification schemes. To fill this void, a new classification rating scheme called TAIL was developed to rate IEQ in offices and hotels undergoing deep energy renovation during their normal use; the scheme is a part of the energy certification method developed by the EU ALDREN project. The TAIL scheme standardizes rating of the quality of the thermal (T) environment, acoustic (A) environment, indoor air (I), and luminous (L) environment, and by using these ratings, it provides a rating of the overall level of IEQ. Twelve parameters are rated by measurements, modelling, and observation to provide the input to the overall rating of IEQ. Their quality levels are determined primarily using Standard EN-16798-1 and World Health Organization (WHO) air quality guidelines and are expressed by colours and Roman numerals to improve communication. The TAIL rating was shown to discriminate IEQ levels when its feasibility was examined in eleven buildings across Europe to provide support for its applicability and input for further modifications. Opportunities for using the scheme in other types of buildings and for its further development and application are discussed.

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Selected 12 IEQ parameters

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

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Ranges of parameters included in TAIL: IAQ

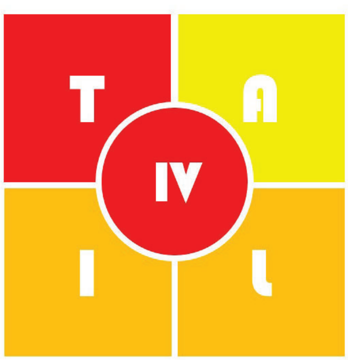
Quality of indoor air quality (I)	Green	Yellow	Orange	Red
Carbon dioxide (concentration above outdoors)[1,2]	≤550 ppm	≤800 ppm	≤1350 ppm	If other quality levels cannot be achieved
Ventilation rate[3,7]	≥(10 L/s/p + 2.0 L/s/m²floor)	≥(7 L/s/p + 1.4 L/s/m²floor) and <(10 L/s/p + 2.0 L/s/m²floor)	≥(4 L/s/p + 0.8 L/s/m²floor) and <(7 L/s/p + 1.4 L/s/m²floor)	If other quality levels cannot be achieved
Relative humidity offices[2,4] hotel rooms[2,4,5]	≥30%≤50%≥30% and ≤50%	≥25%≤60%≥25% and ≤60%	≥20%≤70%≥20% and ≤60%	If other quality levels cannot be achieved
Visible mold[6,7]	No visible mould	Minor moisture damage, minor areas with visible mould (<400 cm²)	Damaged interior structural component, larger areas with visible mould (<2500 cm²)	Large areas with visible mould (≥2500 cm²)
Benzene[7]	<2 µg/m³	≥2 µg/m³	no criteria	≥5 µg/m³
Formaldehyde[7]	<30 µg/m³	≥30 µg/m³	no criteria	≥100 µg/m³
Particles $PM_{2.5}$ (gravimetric)[7]	<10 µg/m³	≥10 µg/m³	no criteria	≥25 µg/m³
Particles $PM_{2.5}$ (optical)[7]	<10 µg/m³	≥10 µg/m³	no criteria	≥25 µg/m³
Radon[7,8]	<100 Bq/m³	≥100 Bq/m³	no criteria	≥300 Bq/m³

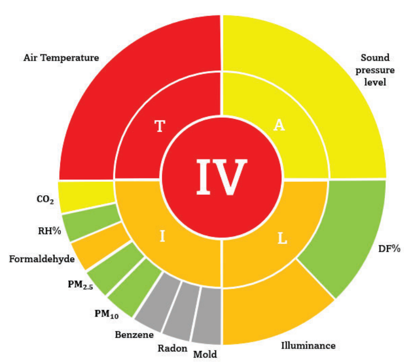
1-2 April 2025, Workshop, Stuttgart, "Indoor Environmental Quality in Sustainable Buildings" Wargocki. P. The TAIL rating schemes for offices and schools are the way to reduce carbon emissions and improve IEQ

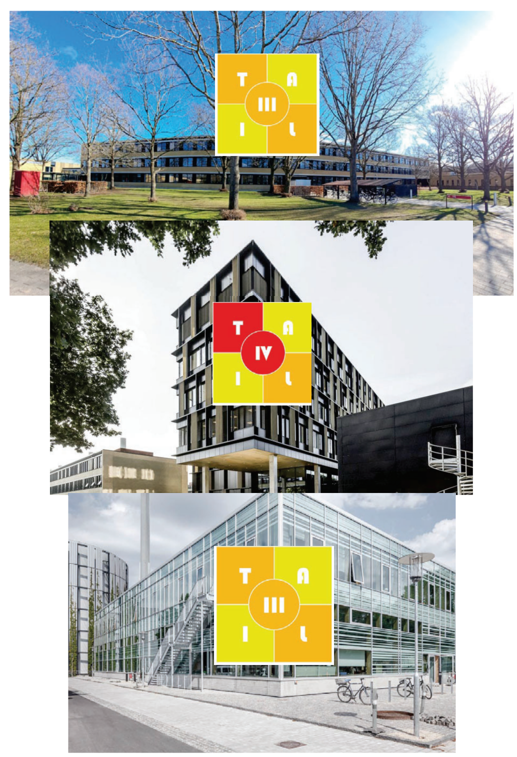
Measuring protocol

- TAIL is determined based on measurements during the heating and cooling seasons or during the same season before and after renovation.
- TAIL is determined for the working hours in offices and sleeping hours in hotels.
- 2 – 10 rooms per building are selected to be representative of different orientations, floors, and room types.
- Measurements should last 2 months for radon in radon-prone areas, 1 month for temperature and relative humidity, and 1 week for the other parameters.
- Interim rating is calculated for each parameter if it is measured in several rooms in a building.
- The final ratings of T, A, I, and L are determined according to the worst quality level among the parameters.
- The final rating of the overall IEQ is determined according to the worst quality level among T, A, I, and L.

TAIL, feasibility studies







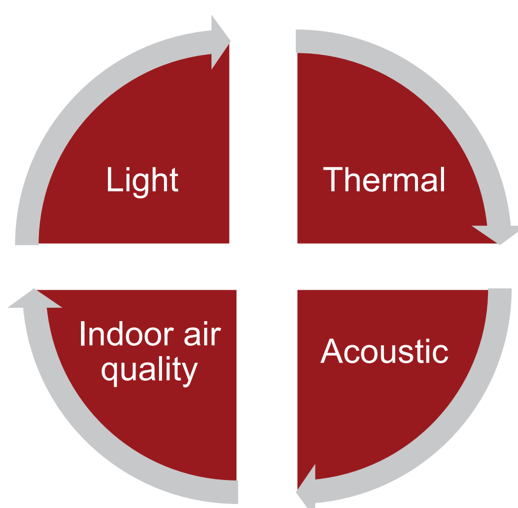
CHALLENGES

Component aggregation

- Generally assumed: equal weighting

- No compromises or trading between parameters, no averaging or weighing. All components should be treated equally

- A new approach under development (% from maximum)



No TAIL meter

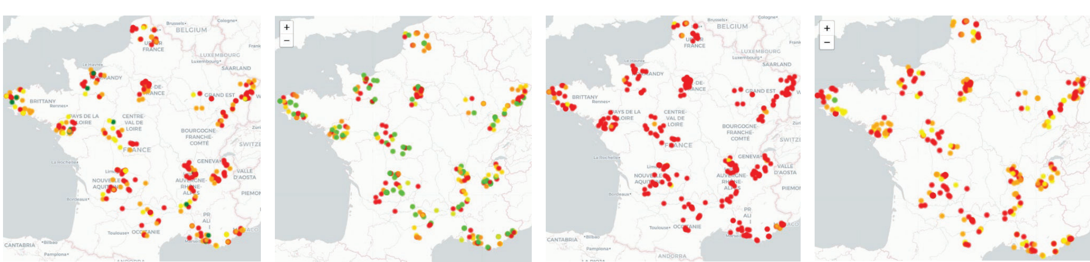
EXTENSIONS

TAIL for schools

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

Illustrate invisible, TAIL for 308 schools in France, example

High, desired	Medium	Ordinary	Low - undesired



Quality of thermal environment (T) | Quality of acoustic environment (A) | IAQ (I) | Quality of luminous environment (L)

Source: Tran et al. (2023)

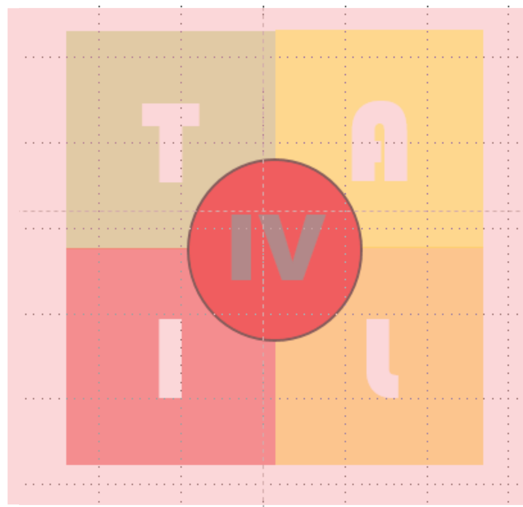
PREDICTAIL, the method for rating simulated IEQ

Four components:

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

Overall IEQ:

- I II III IV

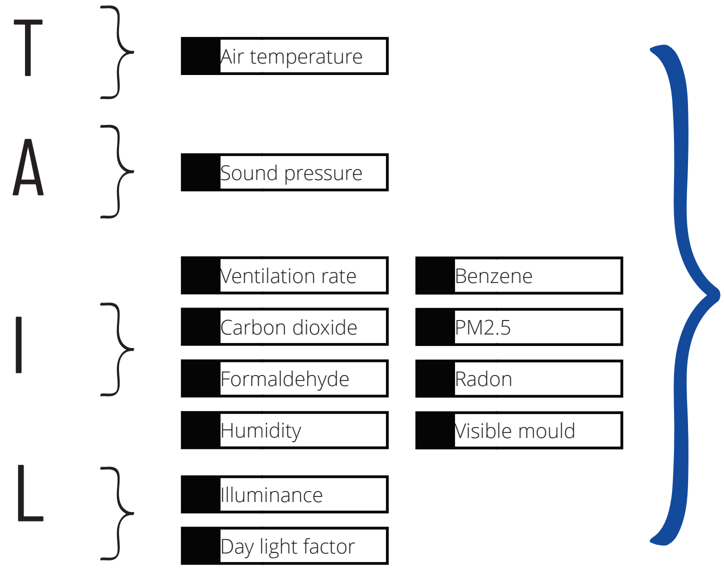


Source: Wei et al. (2021)

Subjective TAIL (OccupanTAIL)

T	Neutral	Slightly cool Slightly warm	Cool Warm	Cold Hot
A	Quiet Very quiet	Neither noisy nor quiet	Noisy	Very noisy
I	Slight odor No odor	Moderate odor	Strong odor	Very strong odor Overpowering odor
L	Neither bright nor dark	Bright	Dim	Very bright Dark

Monetizing TAIL via Harm Quantification, an example



EXPOSURE IMPACTS*

- Absenteeism
- Performance – Objective
- Performance – Self-assessed
- Employee retention
- SBS symptoms complaints
- Employee distraction
- Complaints to facility management

*Impacts that can be translated into monetary or health terms

Achieving green IAQ (I) class in TAIL…

	BD-IAP (DALYs/100,000)	Economic loss (billion RMB)	Economic loss
2017	3.70×10^3	2.88×10^3	3.5% GDP
Chinese IAQ standard (GB/T 18883-2022)	3.16×10^3	2.49×10^3	3.0% GDP
WHO guideline	707	570	0.7% GDP

EPILOGUE

The success story

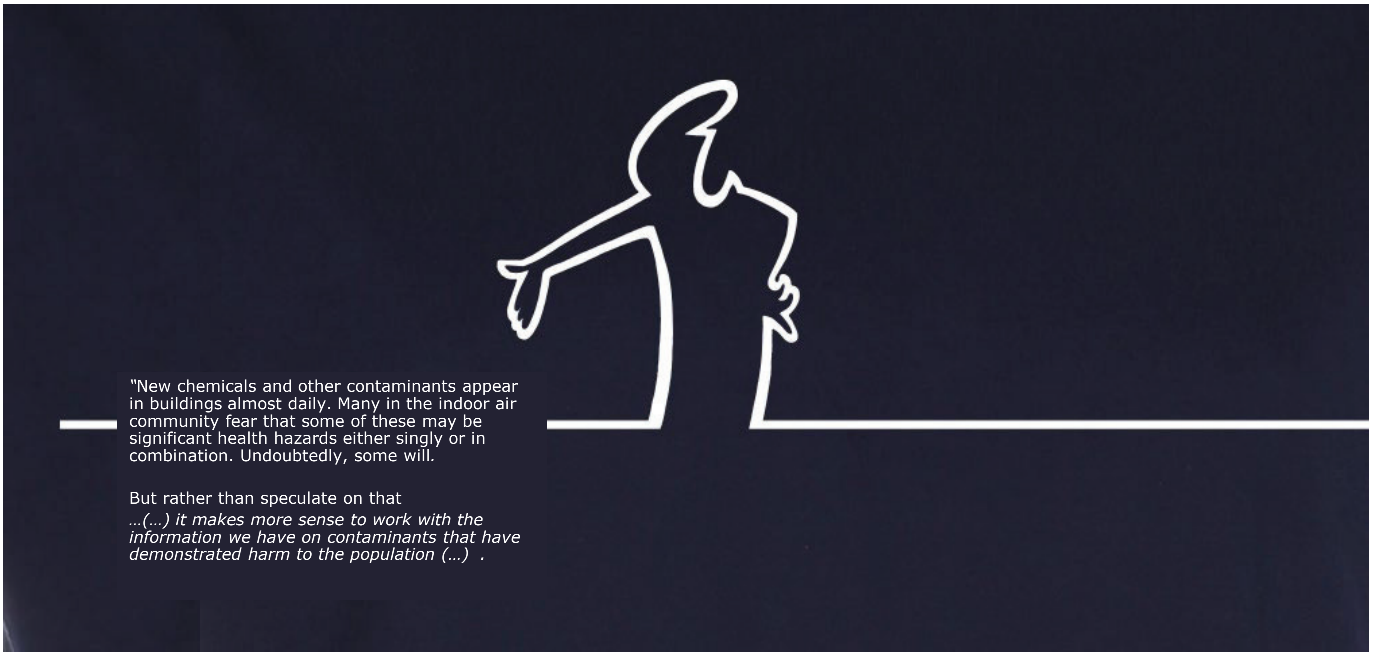
2001 2008 2024

The success story

2001 **2008** **2024**

The success story
benchmark-fix bugs-add new features-advance features that work

2001 **2008** **2024**



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Please connect with pawar@dtu.dk for questions and comments

Thank you

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READING

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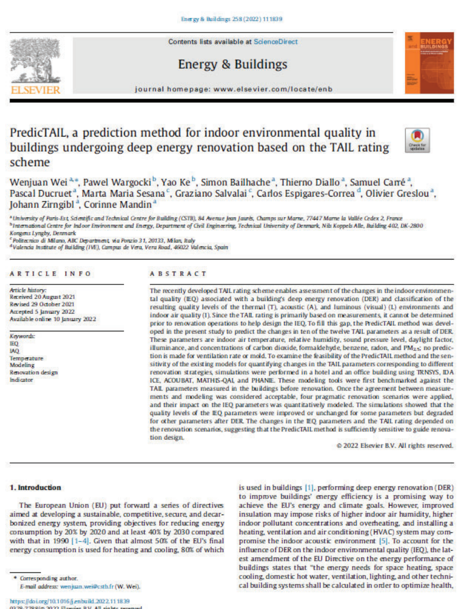
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PredicTAIL, a prediction method for indoor environmental quality in buildings undergoing deep energy renovation based on the TAIL rating scheme

Wenjuan Wei [a,*], Pawel Wargocki [b], Yao Ke [b], Simon Bailhache [a], Thierno Diallo [a], Samuel Carré [a], Pascal Ducruet [a], Marta Maria Sesana [c], Graziano Salvalai [c], Carlos Espigares-Correa [d], Olivier Greslou [a], Johann Zirngibl [a], Corinne Mandin [a]

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Review of parameters used to assess the quality of the indoor environment in Green Building certification schemes for offices and hotels

Wenjuan Wei[a], Pawel Wargocki[b,*], Johann Zirngibl[a], Jana Bendžalová[c], Corinne Mandin[a]

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ABSTRACT

Fourteen Green Building (GB) certification schemes were reviewed to examine the parameters they used to assess indoor environmental quality (IEQ). Ninety different parameters were identified. They were classified into four major IEQ components defining the thermal, acoustic and visual environments, and indoor air quality (IAQ). For the thermal environment, the most commonly used parameters were PMV, PPD, room operative temperature, room air temperature, room air relative humidity, and air speed. For the acoustic environment, the most commonly used parameters were ambient noise and reverberation time. For the visual environment, the most commonly used parameters were illuminance level, daylight factor, and spatial daylight autonomy. For IAQ, the most commonly used parameters were ventilation rate (outdoor air supply rate), TVOC, formaldehyde, CO_2, CO, PM_{10}, $PM_{2.5}$, ozone, benzene, and radon. Credits are used to rate the importance of different parameters for the overall level of IEQ in the reviewed schemes. Using these credits and the figures published in peer-reviewed papers, it was found out that the average contribution of the thermal, acoustic, luminous environment and air quality parameters to the overall IEQ rating of a building was respectively 27%, 17%, 22%, and 34%. The present work can be regarded as a reference for selecting parameters that are commonly used to characterize IEQ.

1. Introduction

The deep energy renovations of existing buildings in Europe will have to be carried out at a much higher rate to decarbonize European building stock in time to achieve the ambitious goals for significant reductions in energy use that have now been set by the European Commission. To this end, the European Commission launched many projects that would provide tools, methods and incentives for securing a higher rate of transformation of existing building stock into one with low energy use. One of these projects is the ALDREN project which was launched in November 2017. It brought together several partners from different European Union member states (http://aldren.eu/). ALDREN stands for "ALliance for Deep RENovation in buildings". The primary aim of this project was to extensively consolidate, promote, and implement harmonized procedures to overcome market barriers and support deep building renovation operations.

One important task within the scope of the ALDREN project was to provide methods for determining whether deep energy renovation has any effects on the health and well-being of building occupants. One reason for this was to address one of the conditions set by EPBD [1,2], which requires that building IEQ should not be degraded in the process of energy renovation. Specifically, EPBD stipulates that "*Member States should support energy performance upgrades of existing buildings that contribute to achieving a healthy indoor environment*" and that each long-term renovation strategy shall encompass "*an evidence-based estimate of expected energy savings and wider benefits such as those related to health, safety and air quality*". The ALDREN project therefore planned to develop a measurement protocol and a systematic method for rating IEQ that could also be used to estimate any non-energy benefits associated with improved IEQ that can add financial value. To meet these goals, the parameters that describe IEQ and their levels had to be defined to serve as a verification tool that could be used to

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