TAIL and PredicTAIL

– the tools for rating and predicting the indoor environmental quality in buildings

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In the absence of a standard rating scheme for indoor environmental quality (IEQ), we propose a scheme that provides a rating of the quality of the thermal, acoustic, and luminous environment, indoor air quality, and the overall IEQ, for buildings under regular use (TAIL) and under renovation design (PredicTAIL).

Keywords: IEQ, health, well-being, rating, thermal, acoustic, IAQ, visual

To ensure that occupants' health and well-being are not compromised in energy-efficient buildings, the EU Directive on the energy performance of buildings (EPBD) states that

> ***"the energy needs for space heating, space cooling, domestic hot water, ventilation, lighting, and other technical building systems shall be calculated in order to optimize health, indoor air quality and comfort levels".***

To ensure that this guidance is observed, indoor environmental quality (IEQ) in buildings undergoing energy renovation must be monitored before and after the renovation process. This requires standard methods for rating the overall IEQ in buildings and the quality of the thermal, acoustic, and luminous environment and indoor air quality (IAQ). No agreed, and standard method exists at the moment to provide such a rating. Consequently, a rating scheme called TAIL has been developed (Wei et al., 2020a, Wargocki et al., 2021). The TAIL (**Figure 1**) allows assessment of the four IEQ components: thermal environmental quality (T), the acoustic environmental quality (A), the indoor air quality (I), and the luminous (visual) environmental quality (L), as well as the overall IEQ.

The quality of the TAIL components is determined by evaluating twelve parameters in buildings under regular use (**Table 1**). Ten of them are measured, one is inspected, and one is modelled. These parameters were selected to describe components of IEQ adequately, based on a literature review of existing IEQ standards, green building certification schemes, European ▶

Figure 1. Graphical presentation of the TAIL rating scheme including four IEQ components: thermal environmental quality (T), the acoustic environmental quality (A), the indoor air quality (I), and the luminous (visual) environmental quality (L), as well as the overall IEQ in the centre.

Table 1. Environmental parameters included in the TAIL rating scheme.

Parameter	**Threshold value**			
	Quality level: I	**Quality level: II**	**Quality level: III**	**Quality level: IV**
Thermal environment (T)				
Air temperature	**Building with mechanical cooling**			
	Heating season: 22 ± 1°C Non-heating season: 24.5 ± 1°C	Heating season: 22 ± 2°C Non-heating season: 24.5 ± 1.5°C	Heating season: 22 ± 3°C Non-heating season: 24.5 ± 2.5°C	If other quality levels cannot be achieved
	Building without mechanical cooling			
	Heating season: 22 ± 1°C Non-heating season: upper limit 0.33 θ_{rm} + 18.8 + 2°C, lower limit 0.33 θ_{rm} + 18.8 – 3°C	Heating season: 22 ± 2°C Non-heating season: upper limit 0.33 θ_{rm} + 18.8 + 3°C, lower limit 0.33 θ_{rm} + 18.8 – 4°C	Heating season: 22 ± 3°C Non-heating season: upper limit 0.33 θ_{rm} + 18.8 + 4°C, lower limit 0.33 θ_{rm} + 18.8 – 5°C	If other quality levels cannot be achieved
Acoustic environment (A)				
Sound pressure level	Small office: 30 dB(A) Landscape office: 35 dB(A) Hotel: 25 dB(A)	Small office: 35 dB(A) Landscape office: 40 dB(A) Hotel: 30 dB(A)	Small office: 40 dB(A) Landscape office: 45 dB(A) Hotel: 35 dB(A)	If other quality levels cannot be achieved
Indoor air quality (I)				
Air relative humidity	Office: 30 – 50% Hotel: 30 – 50%	Office: 25 – 60% Hotel: 25 – 60%	Office: 20 – 70% Hotel: 20 – 60%	If other quality levels cannot be achieved
Ventilation rate	≥ (10 ℓ/s/p + 2.0 ℓ/s/m^2 floor)	≥ (7 ℓ/s/p + 1.4 ℓ/s/m^2 floor) and < (10 ℓ/s/p + 2.0 ℓ/s/m^2 floor)	≥ (4 ℓ/s/p + 0.8 ℓ/s/m^2 floor) and < (7 ℓ/s/p + 1.4 ℓ/s/m^2 floor)	If other quality levels cannot be achieved
CO_2 concentration	550 ppm above outdoor concentration	800 ppm above outdoor concentration	1350 ppm above outdoor concentration	If other quality levels cannot be achieved
Formaldehyde concentration	< 30 µg/m^3	≥ 30 µg/m^3	No criteria	≥ 100 µg/m^3
Benzene concentration	< 2 µg/m^3	≥ 2 µg/m^3	No criteria	≥ 5 µg/m^3
$PM_{2.5}$ concentration	< 10 µg/m^3	≥ 10 µg/m^3	No criteria	≥ 25 µg/m^3
Radon concentration	< 100 Bq/m^3	≥ 100 Bq/m^3	No criteria	≥ 300 Bq/m^3
Visible mould area	No visible mould	Minor moisture damage, minor areas with visible mould (< 400 cm^2)	Damaged interior structural component, larger areas with visible mould (< 2500 cm^2)	Large areas with visible mould (≥ 2500 cm^2)
Luminous environment (L)				
Illuminance	Office: ≥ 60% and ≤ 100% of the time with measured illuminance between 300 and 500 lux Hotel: 0% of the time with measured illuminance ≥ 100 lux	Office: ≥ 40% and < 60% of the time with measured illuminance between 300 and 500 lux Hotel: > 0% to ≤ 50% of the time with measured illuminance ≥ 100 lux	Office: ≥ 10% and < 40% of the time with measured illuminance between 300 and 500 lux Hotel: > 50% to ≤ 90% of the time with measured illuminance ≥ 100 lux	If other quality levels cannot be achieved
Daylight factor	Office: ≥ 5.0% Hotel: no criteria	Office: ≥ 3.3% Hotel: no criteria	Office: ≥ 2.0% Hotel: no criteria	If other quality levels cannot be achieved

θ_{rm}: outdoor running mean temperature research projects, and scientific publications (Wei et al., 2020b). Their ranges were defined based on recommendations and prescriptions in the current standards (EN 16798-1, 2019) and air quality guidelines (WHO, 2005, 2010), as well as other relevant documents (Level(s), 2017). According to the protocols defined by TAIL, these parameters should be evaluated at least in one season.

The quality of each of the parameters determines the quality of the four TAIL components and is presented by one of the four colours:

- Green describing a high (desired) quality level,
- Yellow describing a medium (refined) quality level,
- Orange describing a moderate (ordinary) quality level,
- Red describing a low (undesirable) quality level.

The overall IEQ level of the indoor environment is then determined based on the quality of TAIL components, where the worst quality level among the four TAIL components determines the overall IEQ in a building. This is done to ensure that none of the IEQ components is compromised. The overall IEQ level is indicated by a Roman numeral between I and IV:

- I indicating a high (desired) IEQ,
- II indicating a medium (refined) IEQ,
- III indicating a moderate (ordinary) IEQ,
- IV indicating a low (undesirable) IEQ.

The colours, Roman numerals, and levels of IEQ were selected to follow the indoor environmental categories defined by the standard EN 16798-1 (2019), one of the standards supporting the EPBD.

The TAIL rating scheme is a performance metric; it was examined in several buildings (Wargocki et al., 2021). It describes the actual IEQ in a building that is in regular use. It was developed especially for offices and hotels, but the activities are ongoing to assess whether it can also be used for other building types; this is expected to be likely. It was also defined with the premise of use in buildings undergoing energy renovations to determine IEQ before and after renovation.

However, it is expected that it can also be used to characterize IEQ in buildings that do not undergo energy renovation.

Because TAIL provides the rating of IEQ in buildings during regular use, it cannot be used during the design process to determine the consequences of different renovation options for IEQ; such as a tool was developed recently in Denmark for dwellings (Larsen et al., 2020). Therefore, TAIL was supplemented by a method that allows predicting its parameters during design; the method is called PredicTAIL (Wei et al., 2022). In the method, one-year simulations of ten of the twelve TAIL parameters are conducted to predict the quality level of the TAIL indicators and subsequently the overall IEQ level. The ten parameters that can be predicted by the PredicTAIL method are indoor air temperature, relative humidity, sound pressure level, daylight factor, illuminance, and concentrations of carbon dioxide (CO_2), formaldehyde, benzene, radon, and $PM_{2.5}$; mould cannot be predicted, and ventilation design should follow the codes so is prescribed.

To test the feasibility of the PredicTAIL method, predictions of the TAIL parameters were conducted in two buildings, an office and a hotel, located in two European cities (Wei et al., 2022). The results of only the office building are presented in this paper as an illustration of the PredicTAIL method. The building was a two-floor concrete structure building constructed in 1900 in an urban environment; the four rooms selected for the simulations were considered representative of the office rooms. Simulations of the TAIL parameters considered a base-case scenario (current state) and four renovation scenarios: two scenarios considered renovation actions expected to impact the IEQ, and the other two addressed renovation actions expected to reduce energy use in buildings. These scenarios were selected to examine whether the method would be sensitive to detect changes in IEQ due to the changes defined by the scenarios. Simulations were conducted using TRNSYS for the indoor air temperature and relative humidity, ACOUBAT for the sound pressure level, MATHIS-QAI for the indoor pollutants, and PHANIE for the illuminance and daylight factor. However, it is expected that any other validated and relevant simulation tools can be used to perform these calculations.

Figure 2 shows the results of the predicted TAIL rating for the office building.

The overall IEQ level was red (level IV, undesirable IEQ) in the base-case (current state) scenario. The thermal environment was poor due to large variations in indoor air temperatures in the shoulder season (spring/fall) (min: 16.3°C, max: 27.7°C).

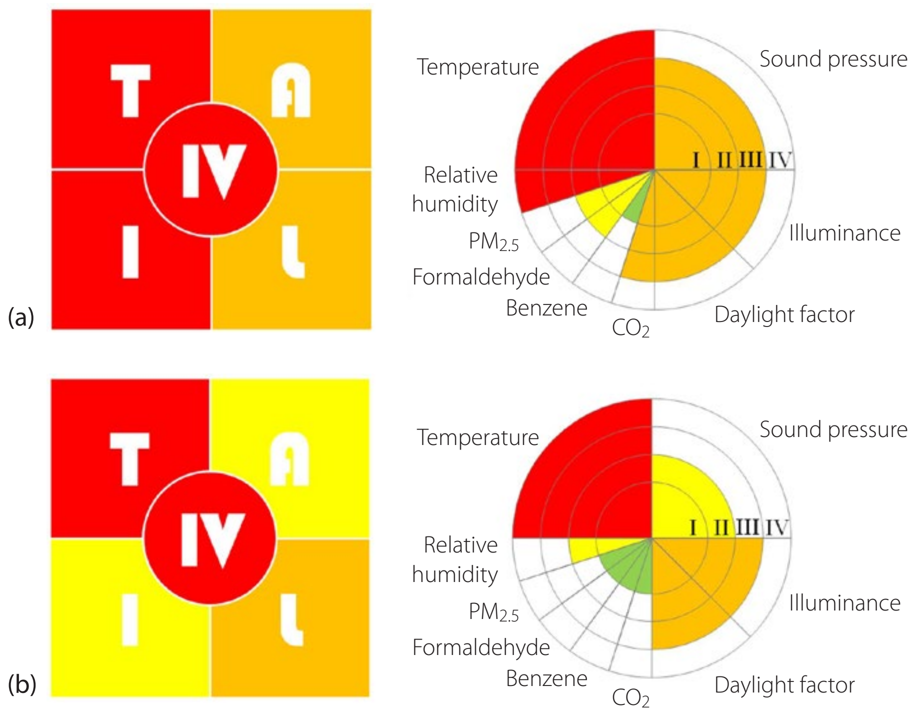

Figure 2. Predicted TAIL rating for the office building for
(a) current state (T: red, A: orange, I: red, L: orange),
(b) IEQ renovation (T: red, A: yellow, I: yellow, L: orange).

The acoustic environment was orange (moderate quality) because the building was located in an urban environment with high outdoor noise. The IAQ level was rated as undesirable due to large variations in the indoor air relative humidity (min: 10% for a few hours in the heating season, max: 92% for a few hours in the shoulder season), particularly in the shoulder season. The ventilation rate was too low, and consequently, the CO_2 concentration was rated as orange in the shared office rooms. The predicted TAIL rating for the base-case scenario indicated that apart from $PM_{2.5}$, formaldehyde and benzene, other parameters had high improvement potential because of their critical ratings for the base-case scenario. The renovation scenarios showed that increasing the ventilation rate to 10 ℓ/s/person according to the standard EN 16798-1 (2019) and installing an F7 filter on the outdoor air inlet could reduce indoor pollutant concentrations, and as a result, the green level could be reached. Improved insulation of the walls and installing double-glazed windows could improve the acoustic environment of the office building located in the urban area to the yellow level (medium quality). Moreover, the predicted TAIL rating showed that the glass curtain wall at the west facade could cause high solar gains and high illuminance levels during the daytime, resulting in moderate and low levels of the luminous and thermal environmental qualities for the office rooms oriented toward the west. As a result, specific actions not considered in the examined scenarios would be needed to improve further the hygro-thermal and luminous parameters for these office rooms next to the glass curtain wall. The prediction results showed that the PredicTAIL method was very useful in guiding design decisions that would lead to improved IEQ. It could identify the changes in IEQ as a result of renovation actions, which means that it was sufficiently sensitive within the IEQ boundaries set by the TAIL rating scheme.

Conclusions

TAIL and PredicTAIL provide a complete tool allowing characterization of IEQ in buildings. It is expected that they will become a standard method of benchmarking IEQ in buildings when applied. This requires however further validation. It is also expected that they will stimulate actions leading to the general improvement of the IEQ in buildings. ■

References

EN 16798-1, 2019. Energy performance of buildings — Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting, and acoustics — Module M1-6.

Larsen, T.S., Rohde, L., Jønsson, K.T., Rasmussen, B., Jensen, R.L., Knudsen, H.N., Witterseh, T., Bekö, G., 2020. IEQ-Compass – A tool for holistic evaluation of potential indoor environmental quality. Build. Environ. 172, 106707.

Level(s) – A common EU framework of core sustainability indicators for office and residential buildings, 2017.

Wargocki, P., Wei, W., Bendžalová, J., Espigares-Correa, C., Gerard, C., Greslou, O., Rivallain, M., Sesana, M.M., Olesen, B.W., Zirngibl, J., Mandin, C., 2021. TAIL, a new scheme for rating indoor environmental quality in offices and hotels undergoing deep energy renovation (EU ALDREN project). Energy Build. 244, 111029.

Wei, W., Mandin, C., Wargocki, P., 2020a. Application of ALDREN -TAIL index for rating the indoor environmental quality of buildings undergoing deep energy renovation. REHVA J. 22–24.

Wei, W., Wargocki, P., Ke, Y., Bailhache, S., Diallo, T., Carré, S., Ducruet, P., Maria Sesana, M., Salvalai, G., Espigares-Correa, C., Greslou, O., Zirngibl, J., Mandin, C., 2022. PredicTAIL, a prediction method for indoor environmental quality in buildings undergoing deep energy renovation based on the TAIL rating scheme. Energy Build. 258, 111839.

Wei, W., Wargocki, P., Zirngibl, J., Bendžalová, J., Mandin, C., 2020b. Review of parameters used to assess the quality of the indoor environment in Green Building certification schemes for offices and hotels. Energy Build. 209, 109683.

World Health Organization, 2010. WHO guidelines for indoor air quality: selected pollutants, WHO Regional Office for Europe. Copenhagen, Denmark.

World Health Organization, 2005. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide.