# Indoor environmental quality rating using the TAIL scheme

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## ABSTRACT

The TAIL scheme was developed to rate buildings' indoor environmental quality (IEQ). The scheme was developed to assure that occupants' health and well-being are not compromised during deep energy renovation (DER) of office buildings and hotels, but it is expected that TAIL can also be used as a general rating scheme of IEQ in any building. **TAIL** combines the quality of **T**hermal, **A**coustic and **L**uminous environment and **I**ndoor air quality to determine the overall quality of the indoor environment. The rating is based on the levels of twelve parameters characterizing IEQ, which are measured, modeled, or inspected in actual buildings. To allow the prediction of TAIL parameters during the design phase, a method was developed called PredicTAIL. It uses modeling tools for the prediction of IEQ under different design scenarios. The feasibility of TAIL and PredicTAIL was examined in the hotel and office buildings. It showed the sufficient discrimination power concerning the IEQ and its components in these buildings when using these rating schemes. TAIL and PredicTAIL create a complete method for evaluating IEQ and its components during the design and operation of a building. No such method has been available previously.

## KEYWORDS

IEQ, indicator, modeling, measurement, well-being

## 1 INTRODUCTION

European Energy Performance for Building Directive (EPBD) requires that building IEQ should not be degraded in the process of energy renovation (EPBD 2010; 2018). Specifically, EPBD stipulates that "The 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." However, there is no standard accepted method that can be used to rate indoor environmental quality (IEQ), its components, and its impact on building occupants.

Wei et al. (2020) reviewed certification schemes to identify parameters used to assess IEQ. Fourteen schemes were examined, among which ten were European and four non-European. Besides, they surveyed fourteen research articles and seven reports from European projects to verify and broaden the information collected by reviewing certification schemes. They identified 90 different parameters to characterize IEQ.

Nineteen parameters were proposed in these documents to assess the quality of the thermal environment in buildings, of which six parameters assessing the quality of the thermal environment in terms of the resulting comfort of building occupants were included in at least five documents. These were: Predicted Mean Vote (PMV), Predicted Percentage Dissatisfied (PPD), operative temperature, air temperature, relative humidity, and air speed. Thirty-nine parameters were proposed to assess the indoor air quality (IAQ) in buildings, of which thirty-five parameters were concentrations of indoor air pollutants and twenty-nine concentrations of gaseous pollutants, mainly volatile organic compounds (VOCs). Indoor air pollutants included in different GB schemes varied widely, and no rationale for their choice and inclusion was found; a few biological pollutants were considered, too. The ten most often proposed parameters were ventilation rate, total volatile organic compounds (TVOC), carbon dioxide ($CO_2$), carbon monoxide (CO), formaldehyde (HCHO), particles with a size below 10 μm (PM10) and 2.5μm (PM 2.5), ozone, benzene, and radon; the last seven of these ten parameters are listed by the World Health Organization air quality guidelines (WHO, 2010; 2021). Twenty parameters were used to assess the quality of the acoustic environment in buildings. Two parameters: ambient noise and reverberation time, were used most frequently. Twelve parameters were used to assess the quality of the visual environment. Illuminance level, daylight factor, and spatial daylight autonomy were three parameters that were proposed most frequently.

No standard set of parameters to examine IEQ in buildings was identified by Wei et al. (2020). Moreover, they did not find an agreed method for integrating the measured quality of the parameters defining thermal, acoustic, and luminous environment and indoor air quality to determine the overall quality of the indoor environment. The proposed aggregation of the components of IEQ was either by simple or weighted addition. In the latter case, different weighting coefficients were proposed and varied between 12% and 38% for thermal environment, 14% and 36% for IAQ, 16% and 25% for visual environment, and 18% and 39% for the luminous (visual) environment. Often equal weightings are used as there is no credible information in the literature on the weighting level (Piasecki and Kostyrko, 2017), and the information available is mainly based on subjective ratings and inadequate (Frontczak and Wargocki, 2011).

Finally, Wei et al. (2020) concluded that their work could be considered a reference when selecting parameters commonly used to characterize IEQ. They also proposed that developing a metric of IEQ should be considered a priority as it would supplement energy metrics and allow complete characterization of building performance. It would also lead to technological advancements. Similar conclusions were made by Steinemann et al. (2017).

Following these recommendations, the rating scheme for IEQ was developed and examined in actual buildings. The entire scheme is presented in the subsequent sections.

## 2 DESCRIPTION OF TAIL RATING SCHEME

A rating classification scheme was proposed to characterize the four major components of IEQ; it is called TAIL (Wargocki et al., 2021). T stands for the thermal environment, A for the acoustic environment, I for indoor air quality, and L for the luminous (visual) environment (Figure 1). The quality of each of the four components of TAIL is indicated by using one of the four colors: green denotes a high (desired) quality level, yellow a medium (refined) quality level, orange a moderate (ordinary) quality level, and red a low (undesirable) quality level.

Twelve parameters were chosen to describe the level of IEQ using the TAIL index:

- the temperature is used to describe the thermal environment (T),
- noise level is used to characterize the acoustic environment (A),
- ventilation rate, concentrations of carbon dioxide, formaldehyde, benzene, PM2.5, and radon, relative humidity, and visible mold are used to describe indoor air quality (I),
- illuminance and daylight factor are used to characterize the luminous environment (L).

The selected parameters match the ones that are most frequently used to characterize IEQ (Wei et al., 2020). Except for a few parameters characterizing indoor air quality, the parameters describing IEQ in TAIL refer to conditions required for comfort. The parameters documenting IAQ conditions that reduce health risk comply with the WHO air quality guidelines (2010, 2021). It was decided that the quality levels of parameters underlying TAIL are not determined by the arbitrary credits assigned to different parameters, as in many certification schemes (Wei et al., 2020). Objective measurements using calibrated instruments were chosen as the primary method for determining the levels of the parameters defining TAIL except for visible mold assessed by observations and daylight factor being modeled. The protocol for monitoring and determining the levels of the selected parameters was developed (Wargocki et al., 2021). It includes the temporal and spatial sampling strategy, a definition of the minimum number of locations (rooms) per building that shall be instrumented during the measuring campaign, details on instruments that shall be used for performing measurements and their minimum precision, and a description on how the results of measurements shall be analyzed.


Figure 1: TAIL rating scheme

Based on the quality levels of the four TAIL components, the overall (integrated) quality level of the indoor environment can be determined and indicated by a Roman numeral in the center of the graphical presentation of the TAIL rating (Fig. 1), where I denotes a high (desired) quality level, II a medium (refined) quality level, III a moderate (ordinary) quality level, and IV a low (undesirable) quality level. The Roman numerals and levels of quality of the indoor environment are aligned with the EN 16798-1 standard (2019), one of the many standards supporting EPBD by defining indoor environmental input parameters for the design and assessment of the energy performance of buildings. The overall level of IEQ is the lowest quality level among the four components to create an incentive to improve IEQ. Thus no weighting is proposed considering that information on how to aggregate the components of IEA is incomplete (Wei et al., 2020). The rationale for this choice was also that if the indoor environmental quality is to be regarded as high, the quality level of all components contributing to the overall IEQ must be high as well. The proposed method can be regarded as precautionary and protecting against the trade-offs between different components of IEQ, creating an incentive for improvement and encouraging excellence and innovation. The approach is similar to methods for determining the ambient pollution level: the air quality index in the EU (https://www.eea.europa.eu/themes/air/air-quality-index) and the Pollutant Standards Index (PSI) in Singapore (https://www.haze.gov.sg/), where the highest concentration of any pollutant determines the ambient (outdoor) air quality level.

The TAIL rating scheme and the measuring protocol were examined in six office buildings and five hotel buildings located in Southern, Central, and Northern Europe, in different climatic zones and countries. The field measurements documented the feasibility of the TAIL rating scheme and confirmed its intended attributes. The measurements indicated which parameters could be improved during the retrofit to achieve a higher overall indoor environment quality. They also indicated which IEQ parameters had good quality levels and should be at least maintained during the retrofit. It was also demonstrated that the TAIL rating scheme could also discriminate between buildings based on the indoor environment quality levels and classify them accordingly.

## 3 DESCRIPTION OF PREDICTAIL

TAIL rating scheme enables assessment of the changes in IEQ and is primarily based on measurements. Therefore, it cannot be determined prior to renovation operations to help design the IEQ. To fill this gap, the PredicTAIL method was developed (Wei et al., 2022).

The PredicTAIL method is complementary to the TAIL rating scheme. However, it enables the prediction of only ten of the twelve parameters characterizing TAIL. These parameters are indoor air temperature, relative humidity, sound pressure level, daylight factor, illuminance, and concentrations of $CO_2$, formaldehyde, benzene, radon, and PM2.5; they all can be predicted by the simulation tools. The visible mold area is not included in the PredicTAIL method because modeling of mold growth is based on the mold index, which qualitatively predicts the mold area. The ventilation rate is not simulated because mechanical ventilation depends on the system setup (input parameter) and natural ventilation depends on the occupants' window opening behavior, which remains challenging to predict.

The PredicTAIL method uses the parameters whose levels are simulated during the working hours for office buildings and the sleeping hours for hotel buildings to derive the TAIL components and the overall TAIL rating describing IEQ.

Different simulation models can be used to predict IEQ parameters. Wei et al. (2022) used the following five models: TRNSYS, IDA Indoor Climate and Energy (IDA ICE), ACOUBAT, MATHIS-QAI, and PHANIE but it is expected that other models can be used as well.

To test the feasibility of the PredicTAIL method, it was applied to two buildings, i.e., a hotel and an office. The two buildings were located in two European cities where the measurements were performed (Wargocki et al., 2021). For each building, the simulations of the IEQ parameters considered the base-case scenario and four renovation scenarios. The base-case scenario corresponded to the building before renovation (current state), as documented by the measurements. The four renovation scenarios included common renovation actions related to the reduction in energy use or explicitly focused on the IEQ parameters. The former aimed to achieve intermediate and low energy use and did not consider the IEQ aspects. The latter aimed to achieve high and low IEQ levels and did not consider energy use. Although an optimized renovation scenario should consider the influence of both energy and IEQ, separation was performed to observe the sensitivity of the PredicTAIL method; no optimized renovation scenario was eventually examined, which would attempt to reveal the lowest energy use with the highest IEQ.

The results showed that the PredicTAIL method could document the impact of different renovation actions on the IEQ parameters according to the TAIL rating; thus, PredicTAIL is a useful tool when decisions regarding renovation actions need to be made. The thermal, acoustic, IAQ and luminous models integrated into the PredicTAIL method showed that simulations by different models could be performed under a holistic modeling framework, i.e., the PredicTAIL method, and that these models are sufficiently sensitive to quantify the changes in the TAIL parameters associated with different renovation scenarios. Still, the validation of this method with a larger number of measurements is necessary to verify the direction of change in IEQ parameters predicted through the simulations.

## 4 CONCLUSIONS

In the absence of a widely used standard or an approved method for rating the overall IEQ in buildings, a rating scheme was developed called TAIL. TAIL is not just a reporting scheme but also a rating scheme for IEQ in buildings during their intended use. It is thus a performance metric. The scheme makes it possible to rate the four components describing IEQ and derives an integrated rating of IEQ based on the quality of these four components. TAIL is voluntary and does not supersede the national codes and regulations but is based on existing standards and guidelines. Rather than setting arbitrary quality levels, the TAIL rating scheme refers to the quality levels defined by Standard EN 16798-1 (2019), so they can be assumed to be widely accepted and used.

The unique feature of TAIL is that it provides a quantitative rating of the quality of the components describing IEQ and an integrated overall quality rating of the indoor environment in a building; these assessments are made when a building is in regular use. The TAIL rating scheme can thus be considered to provide new and systematized information on the indoor environmental quality in a building.

The scheme can be regarded as a relatively crude yet robust method for rating components and the overall quality of indoor environments. The TAIL rating was shown to discriminate IEQ levels when its feasibility was examined in eleven European buildings to support its applicability and input for further modifications.

TAIL was developed to classify and compare IEQ and its components before and after an energy renovation in an office building and hotel to document the impact of energy renovation on IEQ. However, it cannot be ruled out that TAIL might evolve into an overall rating scheme that will make it possible to compare the IEQ in different buildings as in energy labeling. An attempt to adapt TAIL for school buildings is ongoing (Tran et al., 2022). Therefore, the TAIL rating scheme should be considered the first step in developing a classification, an integrated index characterizing IEQ in buildings and a standardized approach at the EU level. It should also be added that TAIL is based on the levels of twelve parameters, but future modifications may also consider the inclusion of other parameters.

In the energy renovation design, the strategy is defined for improving energy efficiency and verified by energy simulations. Achieving high energy efficiency is the primary objective. Different renovation strategies and complex operations can be defined, resulting in various renovation scenarios. To assess a building's IEQ evolution associated with these renovation scenarios or any other renovations, the PredictTAIL method was developed as a predictive tool to be used as a decision tool during the design stage. PredicTAIL supplements the TAIL rating scheme that is mainly based on measurements in buildings in use: PredicTAIL provides the procedures that can be used during the design of energy renovation actions to assess their impacts on the IEQ. The PredicTAIL method determines the quality level of each IEQ parameter based on building simulation results so that renovation design can be guided to avoid unacceptable levels of any parameter.

TAIL and PredicTAIL create a complete method for evaluating IEQ and its components during the design and operation of a building. No such methods have been available and used in practice.

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