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Development of the TAIL rating scheme for indoor environmental quality in schools

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Abstract. The TAIL rating scheme was developed to assess indoor environmental quality (IEQ) in offices and hotels undergoing deep renovation and was recently extended by the PredicTAIL method allowing prediction of IEQ through modeling. TAIL provides the methodology for rating the quality of the thermal, acoustic, and luminous environments, the indoor air quality, and the overall quality of the indoor environment. The present work is an extension of the use of TAIL rating scheme for school classrooms to provide necessary information for effective actions and mitigation measures to improve classroom IEQ. The TAIL was invented by examining the literature and certification schemes to identify the parameters that characterize IEQ in offices and hotels; 12 parameters were selected. A similarly pragmatic approach is followed when developing the TAIL for schools. The literature published after 2010 was surveyed to identify papers presenting measurements of IEQ in classrooms in Europe, the USA, and Australia; 75 papers were identified. Besides the 12 parameters already included in TAIL, the studies also used other parameters to characterize classroom IEQ. These parameters will be evaluated for their importance for the teaching, learning, and well-being of pupils, as well as measuring complexity, among others. Based on this assessment, the relevant parameters will be selected for inclusion in the TAIL rating for schools. The selection will be assisted using the measurements from the extensive campaign organized by the Indoor Air Quality Observatory in 308 schools and 602 classrooms in France; some of these data will be used to assess the efficacy of the TAIL for schools indicator. The relationships between the newly developed TAIL for schools, the teacher's perceptions of indoor environmental quality, and detailed building characteristics will be studied.

Keywords. Indoor environmental quality, school, classrooms, rating scheme, TAIL
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1. Introduction

Four major indoor components, i.e., thermal environment, acoustics, indoor air quality (IAQ), and lighting, characterize the indoor environmental quality (IEQ); they can be associated with occupants' perception of an environment [1,2]. It has been shown that poor IEQ impacts children's comfort, health, cognitive function, and academic achievement [3,4]. These effects can be more pronounced than for adults because children's bodies and organs are under development resulting in increased sensitivity and susceptibility [5,6]. It is therefore important to secure high IEQ in schools where children spent a substantial part of their time. To date, no standard rating system has been developed to evaluate the overall IEQ in schools based on the numerous parameters measured to assess IEQ. This leads among others to the incapability to compare different measurements and make justified decisions. There is therefore an obvious need to develop a scheme for rating IEQ in schools. Recently a rating scheme for IEQ was developed for offices and hotels; it is called TAIL [7]. The TAIL scheme is a product of the European project ALDREN (ALliance for Deep RENovation in buildings, November 2017 – October 2020, https://aldren.eu/). TAIL is an abbreviation of the four major IEQ components: Thermal, Acoustic, Indoor air quality, Lighting. The scheme allows evaluation of the quality of the components of IEQ and the overall IEQ and was shown to perform well when applied in real buildings [8]. Since TAIL is functional, it seems reasonable to investigate whether it can be also applied to evaluate IEQ in schools. This may however require modifications to account for IEQ parameters that are relevant in schools. This paper presents the first step towards adapting the TAIL scheme for assessing IEQ in schools. It presents a literature review to identify the relevant IEQ parameters to be included in the TAIL scheme for schools.

2. Materials and methods

A two-step review was performed. The first step consisted of a review of all parameters characterizing IEQ that have been measured in schools to analyse the measurement protocols to find the most effective way of measuring an IEQ parameter, taking into account the reliability, cost, and difficulty of measurement. The literature search was performed in Scopus on 24/03/2021, with the following keywords: [("indoor environmental quality" OR "IEQ" OR "thermal" OR "acoustic" OR "indoor air quality" OR "IAQ" OR "luminous" OR "visual" OR "lighting") AND ("school" OR "daycare center") AND ("Measurement")]. As there are studies that focused on only one or many components of IEQ at a time, a combination of keywords as presented here ensured that all studies of IEQ in schools and classrooms had been identified. Only studies from Europe, the United States, and Australia were selected. Only studies published in the last decade (from 2010) were considered to include the most updated measurement technologies. After removing non-relevant and duplicate articles, 75 publications on IEQ measurements in school/classroom were used for analysis.

The second step examined the relations between measured parameters and health symptoms, cognitive performance, and/or comfort. The literature search was performed in Scopus on 24/03/2021, with the following keywords: [("cognitive performance" OR "health") AND "indoor environmental quality" AND "review")]. A total of 20 publications were obtained for further analysis.

3. Results and discussion

The review shows a total of 25 IEQ parameters measured in the studies identified through the literature review. Figure 1 presents these 25 indoor parameters with their occurrence out of the 70 analysed articles. In order to be selected into the rating scheme, the parameters must have a fool-proof, simple, and deployable measurement protocol, and observed relations with health symptoms, cognitive performance, and/or comfort of occupants.

3.1 Thermal environment

Thermal comfort has an impact on children's academic performance, mental concentration, and perception [9–11]. Thermal comfort has 6 measured parameters based on the literature searches Thermal environment can be evaluated by air temperature measurement or by subjective evaluations based on questionnaires [9,11–13]. Perceived mean vote (PMV) and predicted percentage of dissatisfied (PPD) are derivative parameters that depend on air temperature, relative humidity, air velocity, mean radiant temperature, and occupant's feedback on their thermal perception, preference, metabolic rate, and clothing information. While thermal perception and preference are complex concepts to explain to children, there are studies with an innovative way of illustrating the question for children [9]. Besides, PMV and PPD being a developed model in controlled climate conditions, making results less distinctive in narrow temperature ranges [14], it is not a viable technic in extreme climate conditions [15]. This leads to the choice of thermal parameters to air temperature and relative humidity, with an example of children's learning progress enhanced with adapted thermal comfort level [16]. Air temperature and relative humidity can be measured simultaneously and continuously using a hygrometer-thermometer, preferably in 1 month and in 2 seasons (heating and non-heating season).

3.2 Acoustics

Noise in a school classroom is of concern due to its impact on children's learning and performance [17]. Studies have pointed out that acoustic quality in school is vital, as chronic exposure to high noise levels can severely hinder children's reading ability [17]; various classroom tasks involving cognitive function can also be affected [17,18]. One characteristic of a classroom is a speaking teacher and capacity of hearing and understanding of the speech of children with different physical characteristics, thus speech intelligibility is an important parameter. Children under development might find it hard to concentrate and capture every word until hearing capacity is fully matured at the age of 13-15 [19]. A bad acoustic and bad speech intelligibility can also affect teachers' vocal capacity when they tried to speak up to compensate for the bad quality [20]. There are 6 measured parameters: background noise equivalent level (dB), reverberation time (s), clarity index 50 (dB), speech transmission index (STI) (%), definition index (%) and early decay time (s). While early decay time is derived from the reverberation time, the speech transmission index parameter is dependent on reverberation time [21], so a measurement of reverberation time will not be necessary. The existing state-of-the-art instruments are capable of measuring speech intelligibility, with either an intrusive or a non-intrusive method. The intrusive method measures the receiving sound signal emitted from a source at the goal location; the result is the speech transmission index in percentage. The non-intrusive method results in the clarity index [22], which measures the response energy level within 50 m of the emitted sound. STI can be measured with a handheld device, equipped with a test sound generator and a capture microphone. Besides STI, sound pressure level (dBa) can also be measured using a sound meter, or with sophisticated instruments such as a symphony system of speaker set up around the room with various measured microphones. Sound pressure level can be measured in the occupation period of a school week, directly in the classroom.

3.3 Indoor air quality

IAQ has 7 frequently measured parameters or group of parameters: ventilation rate, concentrations of carbon dioxide, volatile organic compounds (VOC), semi-volatile organic compounds (SVOC), particulate matter, and radon, and visual mold inspection. A high CO_2 concentration, with ventilation rate as a similar indicator, is associated with children's cognitive performance [23]. Formaldehyde and benzene are the most measured VOCs; formaldehyde can trigger acute respiratory symptoms and irritation [24], and benzene is a carcinogenic compound [25]. Many VOCs can be measured through passive sampling using a porous polymer resin to capture the compound in the air followed by laboratory analyses. SVOC measurement is mostly performed through active sampling. Particles have different size ranges: the smaller the size of particles, the more harmful they are for the respiratory system [26]. $PM_{2.5}$ represents nowadays the consensus PM indicator to measure since their health effects have been largely described. They are measured preferably by gravimetric sampling (standardized method), or by an optical counter. Radon is carcinogenic [27], and can be measured using a dosimeter exposed for two months. Indoor mold can damage the respiratory system, is an asthma-induced and exacerbations factor [16]; sick building syndrome can be also related to mold exposure [35]. Bio-contaminants can be measured by many factors, with visible mold area inspection the simplest form of characterization in a studied room and in places with high relative humidity, other than deploying a specific sampling. Another aspect to consider is the sampling locations in a school, other than the classroom for some type of school. One example is nurseries, where children spend time in the dormitory, often characterized by low ventilation and high occupancy. It is a commonplace for virus spreading [28].

3.4 Lighting quality

Lighting can cause eye strain and discomfort, or a problem of glare [29,30]. Lighting measurements in literature consist of 4 parameters: artificial illuminance, natural illuminance, daylight factor, color rendering index. The color rendering index is complex to measure and its effects on occupants' perception cannot be directly observed. The daylight factor is assessed by simulation and can provide interesting information about glare and discomfort in the classroom. In the four analysed studies, there is only one [31] with a distinction between illuminance sources. In the presence of windows blinds, they can be closed to reduce glare [32]. In this study, four measurements per spot under four lighting conditions are carried out: (a) lights on, blinds open, (b) lights off, blinds open, (c) lights on, blinds closed, (d) lights off, blinds closed. Leaving out daylight factor as a simulated parameter, and just by measuring natural light and artificial light in different locations of the room, the illuminance quality of the classroom can be assessed. Another interesting point is to look at the difference of occupant's comfort level with different types of lighting (fluorescent lamps, LED, etc.), as different types of lighting can have a different interaction with occupant's eyesight.

4. Conclusion and perspectives

Based on the literature review of 25 measured IEQ parameters in school and their impact on children's health and comfort, a proposal of 13 IEQ parameters to be included in TAIL for school are summarized in Table 1, along with the measurement protocol. The next step will be a feasibility test using measurement data from the national school survey carried out in France in 2013-2017 in 308 schools/602 classrooms. Besides the measurements of IEQ indicators, building characteristics and perception were also documented. The relations between the scores from the rating scheme and the corresponding building characteristics first, and occupants' perception secondly, will be studied. This will fully complete TAIL as an IEQ rating scheme in school and classroom. Although relatively crude, it is expected that TAIL for schools will be implemented in practice as a standard tool.

5. Figures

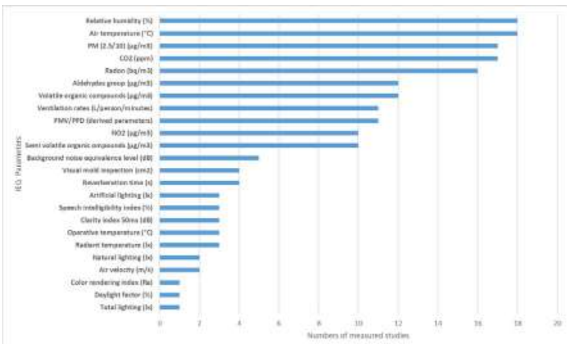

Fig. 1 – IEQ measured parameters in schools in literature.

6. Tables

Tab. 1 – Proposed list of parameters defining TAIL for schools.

Indicators	Measurement protocol (with standards)	Some documented effects on children's health, comfort and learning
Thermal environment		
Air temperature (°C)	Active measurement, 1 month duration, 1-10 minutes time interval, 0.5 °C accuracy, measurement to follow EN16798-1 standard.	Children's learning progress, mental concentration (13), occupant's thermal perception.
Air relative humidity (%)	Active measurement, 1 month duration preferably, if not Monday to Friday measurement, time interval of 1-10 minutes, calibrated sensor at 5% accuracy, comply with the EN 16798-1 standard	
Acoustic environment		
Sound pressure level (dB(A))	Active measurement, Monday to Friday, 1 min time interval, 1 db(A) accuracy, measurement to follow EN16798-1 standard.	Children's learning progress, Cognitive performance [17,33]
Speech intelligibility index (%)	Active measurement in different location in the classroom, and to follow IEC 60268-16:2020 standard	Children's learning progress, Cognitive performance [17,33]
Indoor air quality		
Ventilation rate (l/s/person)	Spot measurement at the mechanical system's supply/exhaust. Flow hood measurement to follow EN 16798-1 standard	Children's learning progress, cognitive performance [23,34]
Carbon dioxide concentration (ppm)	Active measurement using calibrated Fourier transform infrared sensor, Monday to Friday, 1-10 minutes time interval, ±50 ppm accuracy	Children's learning progress, cognitive performance [23,34]
Formaldehyde concentration (μg/m³)	Passive measurement, Monday to Friday, a suggestion of measure in 2 critical outdoor period, measurement to be comply with ISO 16000-4:2011	Cough, asthma and allergy induced [35,36]
Benzene concentration (μg/m³)	Passive measurement, Monday to Friday, a suggestion of measure in 2 critical outdoor period, measurement to be comply with ISO 16017-2:2003	Carcinogenic compound [25,37]
Particle (PM2.5) concentration (μg/m³)	Preferably with gravimetric method, if not possible optical counter, Monday to Friday, suggestion of measure in 2 critical outdoor period, measurement to be comply with CEN – EN 12341:2014	Respiratory tract damage [26,38]
Radon concentration (Bq/m³)	Passive measurement with 2 dosimeters in ground floor, 2 months duration in winter, ISO 11665-8:2013	Carcinogenic compound [27]
Visible mold area (cm²)	Visual observation in measured room, and directly adjacent location based on relative humidity.	Asthma and asthma exacerbations [39]
Luminous environment		
Natural Illuminance (lux)	Spot measurement on 3 occasions, at morning, midday and afternoon, 5 points of measurements, 1 in the middle of the room and in the 4 corners. Sensor calibrated at ± 3lx, measurement to be comply with the EN 16798-1 standard	Headache, eyestrain, glare [29,32]
Artificial Illuminance (lux)	Spot measurement with windows blinds closed, 5 points of measurements, 1 in the middle of the room and in the 4 corners. Sensor calibrated at ± 3lx, measurement to be comply with the EN 16798-1 standard	Headache, eyestrain, glare [29,32]

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