Using the EduTool:IEQ to evaluate the IEQ performance inside classrooms

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The EduTool:IEQ is a post occupancy evaluation tool used for assessing the indoor environment quality (IEQ) inside primary and middle school classrooms. The quality of the indoor environment inside classrooms is an important issue, as poor IEQ can trigger health and learning difficulties for students. This paper describes the methodology used by the EduTool:IEQ to assess the IEQ performance inside primary and middle school classrooms. The four stages involved in undertaking an assessment using the EduTool:IEQ are described. Particular attention is given to describing why the EduTool:IEQ is an important tool for design professionals. The paper concludes with a discussion of three case studies. The case studies demonstrate the feasibility of using the EduTool:IEQ Info-graphic to communicate succinct information about IEQ performance to design professionals. This information could enable targeted remedial works to be undertaken, to improve IEQ performance.

Indoor Environment Quality, Classroom, Design Professional, Info-graphic, Health

Introduction

The EduTool:IEQ is a new post occupancy evaluation (POE) tool, developed to provide design professionals with succinct and targeted information about the indoor environment quality (IEQ) inside primary and middle school classrooms. POE “systematically evaluates the performance of buildings after they have been built and occupied”[1]. Guiding the POE process using tools can regulate the feedback loops used to inform the future work of design professionals [2]. In this paper ‘design professionals’ is the term used to describe the broad group of professionals involved in designing and building classrooms. This may include architects, interior designers, educational facility planners, engineers or builders.

Classrooms are complex environments overlaid with environmental, pedagogical, socio-cultural, curricular, motivational, and socio-economic issues [3]. IEQ is an environmental issue concerned with the levels of lighting, thermal comfort, air quality and acoustics inside classrooms [4, 5]. The IEQ performance inside a classroom can trigger health and learning
difficulties for students [7, 8, 9]. Young students are particularly vulnerable because of the
dynamic state of growth their bodies and minds are undergoing [10].

The *EduTool:IEQ* was developed as part of a PhD in Architecture [11]. A review of existing
POE tools revealed that there is not an existing POE tool for objectively evaluating the IEQ
performance inside primary and middle school classrooms, against the needs of young
students’ and educators’ to engage in effective teaching and learning [4, 12]. Therefore the
development of the *EduTool:IEQ* fills a gap in knowledge.

This paper begins with justification for the research, using a summary of the literature to
describe why a new POE tool for evaluating IEQ performance inside classrooms is necessary.
This is followed by a description of the four stages involved in using the *EduTool:IEQ*. The
stages are data collection, data processing and analysis, and data reporting. The paper
concludes with an overview of three case studies, to demonstrate how the findings from an
evaluation may be communicated to design professionals across three scales of information.
There was not the scope in this paper to describe the research that lead to the development of
the *EduTool:IEQ*. These details can be found in existing publication [11,13].

**Justification for the research**

Students can spend up to 15 000 hours at school, during their formative years and 90% of
their time inside classrooms [14, 15, 16]. Experts in the field of education and training argue
that the quality of the environments in which students learn, can have positive and negative
impacts on how well they learn [7, 8, 9, 17, 18]. Effective teaching and learning is important,
because the level of skills and knowledge that students gain at school can influence the type of
opportunities and ‘quality of life’ they have access to as adults [10, 19].

Young students attending primary and middle schools are particularly vulnerable inside
classrooms with poor IEQ. This is because – unlike older students and adults –the bodies and
minds of younger students are still in a “dynamic state of growth” and high concentrations of
environmental contaminants (often found in the air) can cause irreversible damage to their
nervous, immune, respiratory, endocrine, reproductive and digestive systems [10]. Younger
students are also in the process of developing reading, writing and listening skills. These skills
form the foundations of comprehension, which is an important life-skill used to “interpret,
integrate, critique, infer, analyse, connect and evaluate ideas” [20]. There are examples in the
literature, which suggest that classrooms with poor IEQ can slow student progress in learning
comprehension [7, 8, 17, 21, 22]. Therefore in order to reach their full potential, students need
to learn inside classrooms with good IEQ.
IEQ performance inside a classroom can be the product of how a building has been designed, constructed, maintained and/or operated by the occupants [23]. Design professionals can have a hand in improving the IEQ performance of classrooms through making well-informed decisions during the design phase. A new POE tool that provides design professionals with feedback about the IEQ performance inside their buildings, may broaden their understanding of the specific impact that design decision can have on IEQ [2]. The assertion that design professionals need to ‘broaden’ their understanding of IEQ comes from opinions expressed in the literature, about the scope that exists to make improvements to how IEQ education is taught to architecture and engineering students at tertiary institutions [24, 25, 26].

Methodology

IEQ is a system that is informed by sub-systems and components [25]. The sub-systems and components that are of interest to the EduTool:IEQ are those with the greatest potential to impact on effective teaching and learning, inside primary and middle school classrooms. Through a literature review, acoustics, thermal comfort, air quality and lighting were chosen for inclusion in the EduTool:IEQ. Other sub-systems such as aesthetics were excluded, because they cannot be evaluated objectively [27]. In addition, there are other existing POE tools (for use in schools), which investigate the impact of aesthetics, space planning and ergonomics on effective teaching and learning [11, 28].

The literature review identified over 40 components – specific to acoustics, thermal comfort, air quality and lighting – with the potential to impact on effective teaching and learning [11]. Using causality theory (and causal chaining) this group of components was reduced to 16, with four components chosen for each sub-system [11, 17]. There is no hierarchy amongst these components. This decision was influenced by arguments made in the literature, about the need for design professionals to conduct their practice with a whole building approach, which “takes full advantage of the symbiotic nature of design so that the design elements work to reinforce each other and thereby maximise the ability of the overall building design to fulfil its design objectives effectively and with greater efficiency and also lower capital and operating costs”[6].

The EduTool:IEQ is designed to communicate to design professionals information about IEQ performance inside a classroom, across three scales. At the macro scale a design professional may focus on overall IEQ; at the mezzo scale they may focus on the performance of the sub-systems; and at the micro scale they may focus on the performance of individual components. This level of analysis is facilitated through how the EduTool:IEQ has been designed for use. An IEQ assessment conducted using the EduTool:IEQ involves four unique stages.
The first stage is data collection. The EduTool:IEQ prescribes the objective and descriptive methods that an assessor should use to collect data about the 16 components. Objective data is collected using environmental monitoring equipment. Below is a summary, which describes how data about the 16 components is collected using environmental monitoring equipment:

‘Continuous samples’ may be used to generate hourly, daily, weekly, monthly or seasonal profiles about the performance of an IEQ component. The EduTool:IEQ uses continuous sampling to evaluate: ambient temperature, relative humidity, carbon dioxide and vertical illumination. During the 12 month-monitoring period, data about these four IEQ components was continuously collected at 15-minute time-intervals from a fixed location in the classrooms.

‘Periodic spot samples’ may be used to generate weekly, monthly or seasonal profiles about the performance of an IEQ component. The EduTool:IEQ uses periodic sampling to evaluate: background and mechanical noise, signal to noise ratio (SNR), daylight and horizontal illuminance, lighting control, radiant floor temperature and airflow. During the 12 month-monitoring period, data was collected seasonally about these eight IEQ components at multiple, uniformly distributed locations in the classrooms (using 1500mm grid) [29].

‘Once off spot samples’ may be used to generate a ‘worst-case-scenario’ (per season or annum) about the performance of an IEQ component. The EduTool:IEQ uses once off spot samples to evaluate: total volatile organic compounds (TVOC), particular matter (PM10), airborne microbial and reverberation times. During the 12 month-monitoring period, data was collected about these four IEQ characteristics from a fixed location in the classrooms. The timing of the data collection corresponded with conditions equal to worst-case scenarios [29].

Descriptive data is collected using overt observation about the physical conditions inside the classroom. Here the assessor needs to make value judgments about cleanliness and efficiency of operating systems (in particular lighting and HVAC), along with observations about how the occupants’ behaviour may have influenced the objective data collected.

In the second stage the data collected about the 16 IEQ components is processed, however only the objective data is used. Processing the data involves calculating a single quantitative result (QR) for each of the 16 components. In order to do this, it is first necessary to define the ‘period of occupancy’ under investigation. The QR is a calculation that takes the average of all the data points collected during the period of occupancy. Inside the 10 classrooms evaluated with the EduTool:IEQ, the period of occupancy was: ‘school hours’ (7:30am to 4:29pm) on ‘weekdays’ (Monday to Friday) during ‘term time’. For each component, two
QRs were calculated. One indicative of performance in winter and the other was indicative of the performance for summer. Having two QRs allows for comparisons to be made.

In Stage 3 the QRs calculated for each component are analysed, to determine (in qualitative terms) their level of performance. To do this the researcher developed ‘scaling tables’, which are type of environmental index that quantifies and numerically benchmarks the QR against different levels of practice. The scaling tables are a culmination of the performance-based advice published about IEQ in over 70 sources\(^1\). A QR awarded a score of 10/10 is an example of ‘next practice’ (which is a level of performance that goes beyond current best practice). A QR awarded a score of 1/10 is an example of ‘unacceptable practice’. A QR awarded a score of 5/10 achieves the minimum required level of practice (Table 1).

<table>
<thead>
<tr>
<th>Score</th>
<th>Performance thresholds</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Achieves Next Practice</td>
</tr>
<tr>
<td>9</td>
<td>Achieves Best Practice</td>
</tr>
<tr>
<td>8</td>
<td>Achieves Excellent Practice</td>
</tr>
<tr>
<td>7</td>
<td>Achieves Good Practice</td>
</tr>
<tr>
<td>6</td>
<td>Achieves Acceptable Practice</td>
</tr>
<tr>
<td>5</td>
<td>Achieves Minimum Practice</td>
</tr>
<tr>
<td>4</td>
<td>Below Minimum Practice</td>
</tr>
<tr>
<td>3</td>
<td>Unsatisfactory Practice</td>
</tr>
<tr>
<td>2</td>
<td>Problematic Practice</td>
</tr>
<tr>
<td>1</td>
<td>Unacceptable Practice</td>
</tr>
<tr>
<td>0</td>
<td>No data set</td>
</tr>
</tbody>
</table>

Table 1 is an example of the scaling table for carbon dioxide.

<table>
<thead>
<tr>
<th>Score</th>
<th>Range Carbon dioxide levels (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.01 - 600</td>
</tr>
<tr>
<td>9</td>
<td>601 - 700</td>
</tr>
<tr>
<td>8</td>
<td>701 - 800</td>
</tr>
<tr>
<td>7</td>
<td>801 - 900</td>
</tr>
<tr>
<td>6</td>
<td>901 - 1000</td>
</tr>
<tr>
<td>5</td>
<td>1001 - 1100</td>
</tr>
<tr>
<td>4</td>
<td>1101 - 1200</td>
</tr>
<tr>
<td>3</td>
<td>1201 - 1300</td>
</tr>
<tr>
<td>2</td>
<td>1301 - 1400</td>
</tr>
<tr>
<td>1</td>
<td>1401+</td>
</tr>
<tr>
<td>0</td>
<td>No data</td>
</tr>
</tbody>
</table>

The decision to condense the performance of each IEQ component into a single number was based on the widespread adoption of green building rating tools (LEED, BREAAM and NABERS). These use reward systems that are logical, intuitive and non-industry specific to rate building performance. The overall legibility of these scales makes the tools attractive to clients and designers [5]. They create opportunities for comparisons to be made, between buildings, from which conclusions may be drawn about the effectiveness of design solutions.

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\(^1\) The sources were either user-manuals of building evaluation tools (LEED, BREEAM, Green Star), national and international building standards (ISO, AS, ANSI etc) and building guidelines.
In Stage 4, the results of the evaluation are reported using the *EduTool:IEQ Info-graphic*, which is a data visualisation method. Designer professionals are often more attracted to information that is communicated graphically, than textually or numerically [30]. Therefore, presenting technical information using data visualisation complements the natural tendencies of design professionals [30]. In the theory on info-graphics, the kind of shapes that are generated using numbers can have a greater impact on their audience compared with numbers alone. This is because shapes are able to be “experienced rather than read” [31].

The three scales of information summarised above (macro, mezzo and micro) are present in the *EduTool:IEQ Info-graphic*. At the macro scale, the uniformity and total number of shaded cells can be used to explain the overall IEQ performance inside the classroom. At the mezzo level, the performance of the four sub-systems can be individually assessed and compared. At the micro level it is possible to investigate the performance of individual components. The dashed ring in the centre of the info-graphic is the threshold of minimum practice. From interpreting the *EduTool:IEQ Info-graphic* and the descriptive data (collected in Stage 1), a design professional may use deductive reasoning to identify the cause of poor IEQ performance inside the classroom and may be able to recommend the required remedial work.

Figure 1a: WET SEASON IEQ (Tropical climate)  
Figure 1b: DRY SEASON IEQ (Tropical climate)

Figure 2a: SUMMER IEQ (Arid climate)  
Figure 3a: WINTER IEQ (Arid climate)
Figures 1, 2 & 3: IEQ performance in three case studies across two opposing seasons shown with info-graphics.

Clockwise: Reverberation; SNR, Background noise; Mechanical noise; V.Illumination, H.Illumination, Control, Daylight, TVOC, PM10, Microbial, CO₂, Radiant Temp, Ambient Temp, Relative Humidity, and Airflow.

Case studies and key outcomes

Figures 1a & 1b; 2a & 2b; and 3a & 3b are examples of the Edutool:IEQ Info-graphic. They display the results from IEQ assessments undertaken in three case studies. There is not the scope in this paper to provide a detailed analysis of the results. These examples demonstrate how the Edutool:IEQ Info-graphic can be used to communicate information about the IEQ performance inside classrooms across the macro, mezzo and micro scales.
At the macro scale, the occupants of the tropical classroom experienced the most favorable IEQ, during the dry season (Figure 1b). In contrast, the occupants inside the temperate classroom experienced the least favorable IEQ during summer (Figure 3a).

At the mezzo scale, air quality was a sub-system that performed consistently well. In contrast, acoustics was a sub-system that regularly performed poorly. The occupants of the tropical classroom experienced the most favourable acoustics during the dry season. The classroom acoustics were less favourable in the wet season due to the monsoonal rains, which increased the overall levels of background and mechanical noise inside the classroom. The acoustical performance inside the tropical classroom may be attributed to the use of acoustic treatments on the walls and floor. In contrast the arid classroom had no acoustical treatment and this is reflected in the results of the Edutool:IEQ Info-graphic.

At the micro scale, airflow was one of the components that regularly performed poorly. What cannot be determined from the Edutool:IEQ Info-graphic was the cause (i.e. too much or too little airflow). This highlights the important role of descriptive data. In the tropical classroom, descriptive data explains that the poor performance of airflow is caused by the absence of ceiling fans and operable windows. Air diffusers in the ceiling provide refrigerated cooling. Approximately 40% of the students (when seated at their desks) experience airflow equal to 0.1m/s, while the required amount is 0.3m/s. In an interview, the teacher commented that she felt “very little breeze from the air conditioning vents”, which made the classroom feel “quite warm and stuffy in the wet season”.

The occupants inside the temperate classroom experience problems with glare, as a result of large areas of window glazing (equal to 42% of the floor area). The occupants cannot control the amount of daylight entering the classroom because the operable blinds were broken. In contrast, the occupants of the tropical classroom have a high level of control over the lighting levels inside the classroom. This is in part because there is less access to daylight (with window glazing equal to 11% of the floor area). While the design of the classroom meets the code requirements for daylight access, the window treatments prevent the required levels of daylight (as per the standards) from entering the classrooms.

Conclusion

This paper describes the IEQ performance inside classrooms as being a trigger for health and learning difficulties for students. Design professionals can have a hand in improving the IEQ performance inside classrooms through making well-informed design decisions, which are informed by the feedback loops provided by POE tools. The EduTool:IEQ is new POE tool that communicates succinct information to design professionals about the IEQ inside
classrooms. The information is ‘succinct’ because it communicates the findings across three scales. This paper describes the methodology of the EduTool:IEQ and briefly discusses the findings from three case studies, to demonstrate the type of information design professionals can access about classroom IEQ. The findings provided by the EduTool:IEQ can enable targeted remedial works, that will improve the classroom IEQ, to be undertaken.

References


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Title:
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Date:
2014

Citation:

Persistent Link:
http://hdl.handle.net/11343/162201

File Description:
Accepted version