LEaRN Evaluation Module 2: The development of a tool for evaluating the indoor environment quality in learning spaces

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Indoor environment quality (IEQ) is the combined impact of acoustics, lighting, thermal comfort and air quality on occupants inhabiting indoor spaces. It is the product of how indoor environments are designed, constructed, occupied and maintained. When IEQ is at substandard levels inside learning spaces, it can impact on how students and educators feel about that environment and/or perform in their day-to-day tasks.

One of the barriers to IEQ evaluation is access to a tool, which communicates succinct and targeted information to a multi-disciplinary audience about the IEQ performance of learning environments. Such tools exist for commercial buildings because of the quantifiable financial gains of operating a business inside an office with good IEQ. Because of the complex myriad of factors that impact on effective teaching and learning and the nature of education, it is impossible to directly attribute quantifiable financial gains or specific student outcomes to the IEQ of the learning environment.

To overcome this barrier, the Learning Environments Applied Research Network (LEaRN) has developed a new post occupancy evaluation tool for assessing IEQ performance inside learning spaces. This paper is a discussion of LEaRN Evaluation Module 2 and the outcomes of evaluating IEQ performance inside two Catholic Education Melbourne (CEM) schools over an eight-month evaluation period in 2012 to 2013.

Introduction

The LEaRN Evaluation Tool is composed of three modules that can be used to evaluate general-purpose teaching and learning spaces in primary and secondary schools. Each module has a different focus. Module 1 focuses on the process of design and the performance of the design team; Module 2 focuses on indoor environmental conditions and sustainability; and Module 3 focuses on the alignment of teaching and learning activities and the design of the learning environment. These modules may be used independently or all three may be applied to generate an evaluation that integrates a range of different perspectives on the quality and performance of educational facilities. This paper is about LEaRN Evaluation Module 2. This paper is a discussion of LEaRN Evaluation Module 2 and the outcomes of evaluating IEQ performance inside two Catholic Education Melbourne (CEM) schools over an eight-month evaluation period in 2012 to 2013.

Literature Review

Post occupancy evaluation

Post-occupancy evaluation (POE) was defined by Zimring and Reizenstein (1980, p. 429) as “the examination of the effectiveness for human users of occupied designed environments” and by Preiser (2002, p. 42) as “a process of systematically evaluating the performance of buildings after they have been built and occupied for some time”. The information gained through evaluation may be valuable to a range of stakeholders, including those engaged in new building projects and those occupying existing facilities who wish to get the most out what they already have.

The focus of evaluation in education has begun to shift in keeping with recent developments in learning environment design. The creation of innovative learning environments appears to have encouraged researchers to search for novel evaluation methodologies and methods that can be used to assess the effectiveness of educational facilities in supporting the learning process. This renewed interest in evaluation at the intersection of the physical and the social represents a return to the origins of POE in environmental psychology. It also supports Preiser and Nasar’s (2008) view that a new

perspective on building evaluation is currently being developed that favours 'bottom up' approaches to evaluation, which value the opinions of the user.

Based on recent research conducted in the higher education sector, evaluation tools/approaches appear to be required that can be readily modified to accommodate the specific physical settings and social contexts within which they are to be applied – as well as the various interests of those commissioning the evaluation (Cleveland and Fisher, 2012).

Across all educational sectors, it appears that new POE methodologies are required if a deeper understanding is to be attained regarding how effectively learning environments can support the educational programs and practices of the 21st century. In particular, the development of formative evaluation methodologies, which can support the evaluation of educational facilities throughout their lifecycle, appears to be warranted. In recognition of this need and to address the shortcomings of existing school learning environment POE tools, academics at the University of Melbourne's Learning Environments Applied Research Network (LEaRN) developed the LEaRN Evaluation Tool.

Indoor Environment Quality

Indoor Environment Quality (IEQ) is an environmental issue concerned with the levels of lighting, thermal comfort, air quality and acoustics inside a space. The IEQ performance inside a building can be impacted by how the building has been designed, constructed, maintained and/or operated by the occupants (Vittori, 2002).

LEaRN Evaluation Module 2 is concerned with evaluating the IEQ performance inside *learning environments.* In contemporary educational discourse, learning environments are not merely 'classrooms' but are a complex assemblage of interconnected spaces overlaid with environmental, pedagogical, socio-cultural, curricular, motivational, and socio-economic issues (Higgins et al., 2005). They are inclusive of the building structure, interior design, furniture, loose items, and information and communication technology and can be differentiated by their relative degree of openness, from traditional classrooms to permanently open-plan spaces (Cleveland, 2011; Dovey and Fisher 2014).

The risks of poor IEQ are exacerbated inside learning environments because of the amount of time that students spend at school. It is estimated that a student will spend 15,000 compulsory hours in the physical school environment during their formative years and 90% of this time indoors (Johnson et al., 2010; Rutter, 1979; USEPA, 2008).

A sizable body of international research indicates that IEQ has a direct impact on effective teaching and learning (Landrigan, 1998; Faustman et al., 2000; HMG, 1999; Fisk, 2000, 2002; Wakefield, 2002; Cox-Ganser et al., 2005; Mendell et al., 2005). The two significant conclusions that may be drawn from the review of this literature are that poor IEQ can lessen the effectiveness of good pedagogy and exposure to poor IEQ in childhood can have adverse implications for adulthood.

Despite the importance of IEQ performance in learning environments, there has been an underwhelming amount of research undertaken in this area (Luther, 2013). A review of 488 papers, reports and journal articles in the Cooperative Research Centre for Construction Innovation in Australia (Bell, 2004) highlighted that up to 2004, IEQ research has focused on commercial environments (Soccio, 2014).

The prominence of IEQ research for commercial environments is demonstrated by the number of protocols that exist for measuring IEQ performance inside commercial buildings. In 2010 ASHRAE, CIBSE and the USGBC worked in collaboration to develop the *Performance Measurement Protocols for Commercial Buildings* (Heinzerling, 2012). In commercial environments, research on IEQ has been driven by demand. There are various cases that highlight the financial gains of operating a business inside offices with good IEQ. For example, employees are generally more productive and have fewer days off work due to illness (Ahmed, 2010; Fisk, 2000; Fisk, 2002; Kim & de Dear, 2012;

Mendell, et al., 2005). Good IEQ can also reduce a building's operation costs and carbon emissions (Humphreys & Nicol, 2007; Olesen, 2012). The annual financial gains from having good IEQ inside the workplace are estimated to be US$700 per employee for a company and $20 billion across the US economy (Fisk & Seppanen, 2007; Fisk, 2011). A 2004 report estimated poor IEQ cost the Australian economony AUD$12 billion annually (Building Commission Victoria, 2004).

The benefits of providing good IEQ inside schools cannot be quantified in terms of financial gains or losses. Instead the impact of IEQ inside an educational environment may be quantified using the results from standardised student testing of numeracy and literacy (HMG, 1999; HMG, 2003). However, standardised testing cannot be used to quantify the impact of the physical learning environment on effective teaching and learning (Shermiran, et al., 2011). This is because of the complexity of the school environment. In addition to myriad pedagogical, socio-cultural, curricular, motivational, socio-economic and environmental factors identified as contributing to how well students learn (Higgins, et al., 2005).

Methodology

LEaRN Evaluation Module 2 was developed to fill a gap in knowledge and provide a multidisciplinary audience with succinct and targeted information about the IEQ performance inside Australian primary and middle school classrooms. More details about the development of LEaRN Evaluation Module 2 can be accessed in Soccio (2016).

LEaRN Evaluation Module 2 was used inside two learning environments in two Catholic Education Melbourne (CEM) primary schools, over an eight-month monitoring period from July 2012 to February 2013. Convenience sampling (Bryman, 2004) was used to select the schools. At part of the assessment, objective, descriptive and subjective data about IEQ performance was collected inside each of the learning environments (ASHRAE, 2010).

Descriptive data was collected using overt observation of the learning environment. The purpose of this data was to establish the relationship between IEQ and the day-to-day teaching and learning activities. Subjective data was collected during a workshop with students, where the emphasis was on their experience and perceptions of 'comfort' inside the learning environment. The purpose of this data was to establish what aspects of IEQ could be improved. The workshop was designed using the theory of Culture Probes (Gaver et al, 2004; Loi, 2004, 2007). Refer to Soccio (2012) for specific details about the design of the workshop.

Objective data was collected over eight months using periodic or continuous sampling with environmental monitoring equipment. The equipment was of scientific quality and a mix of hand held devices and fixed sensors. Refer to Soccio, (2014) for specific details on how the data was collected. Objective data was collected about 16 IEQ components: four each for acoustics, lighting, air quality and thermal comfort. These were identified in the literature as being individually and collectively important for facilitating effective teaching and learning. Below is a description of each component and how it is believed to impact on effective teaching and learning. In order to promote 'whole building' approaches to design, there is no hierarchy amongst these components.

- Carbon dioxide is not an air contaminant, but indicates the performance of ventilation rates. Inadequate ventilation (i.e. oxygen) inside a learning environment can cause the occupants to experience difficulty in breathing, dizziness, headaches, and eye/throat irritation. Such discomfort can impair concentration levels, along with general health and wellbeing.

- Vertical illuminance inside a learning environment relates to the amount of light emitted onto vertical surfaces (such as display boards and writing surfaces). Inadequate illuminance can cause students' to experience headaches as they strain their eyes to read content or see examples. Vertical illuminance can reduce the contrast between computer screens and the rest

of the room, which may increase the length of time that students can work without experiencing fatigue.

- Relative humidity is concerned with the moisture content in the air. Low levels of relative humidity are associated with students having dry and irritated eyes, itchy skin and an irritated mucus membrane, which can lead to students' having respiratory problems. High levels of relative humidity can promote microbial growth in the learning environment, which can impact on air quality/

- Ambient temperature is the temperature of the air inside the learning environment. Thermally induced stress triggered by high and low ambient temperatures inside the learning environment can reduce students' problem solving capacity and ability to concentrate.

- Signal to noise ratio (SNR) is the sound level of a teacher's voice above the noise level inside an occupied learning environment. It can impact on the ability of students to comprehend verbal instructions and teacher voice fatigue.

- Background noise is from sources outside the learning environment (commonly playgrounds, traffic, plant and adjoining classes). Inside a noisy learning environment students can experience issues with comprehension, stress and anxiety.

- Mechanical noise is from sources inside an unoccupied learning environment (commonly heating and cooling, lights, IT equipment) Inside a noisy learning environment students can experience issues with comprehension, stress and anxiety.

- Horizontal illuminance inside a learning environment is the amount of light emitted onto horizontal surfaces (such as desks and books). Inadequate illuminance can cause headaches; eyestrain and fatigue, while over illumination may contribute to student hyperactivity and aggression.

- Access to daylight inside learning environments has the potential to influence student behaviour, academic performance, health and wellbeing. Too much daylight can cause discomfort glare and disability glare, which can both impair students' abilities to learn effectively. The size and orientation of windows (for daylight access) can impact on the ambient temperature inside the learning environment.

- Lighting control relates to level of control that occupants have over the lighting levels inside the learning environment. Lighting control reduces the effects of glare, optimises the performance of audio-visual equipment and allows for maximum flexibility of learning and teaching activity.

- Radiant heat/cold is the temperature of materials that occupants may be located on or near when participating in activities in the learning environment. Coming into contact (direct or indirect) with a hot or cold surface can increase/decrease the body temperature and may lead to thermally induced stress, which can reduce students' problem solving capacity and ability to concentrate.

- Air velocity is a measurement of airflow speed. Inside a classroom with high ambient temperatures and high levels of relative humidity, airflow can assist in cooling the occupants down by evaporating perspiration on the skin. However, inside a classroom with lower ambient temperatures, airflow with the same velocity may be unfavourably described as a 'draught'. Draughts can cause local discomfort for students occupying classrooms. This local discomfort may reduce the student's ability to concentrate.

- Reverberation time relates to the levels of sound absorption/reflection inside a learning environment. Long reverberation times are associated with lowered rates of speech intelligibility/comprehension amongst students.

- Airborne microbial is microorganisms being carried in the air, more commonly known as mould or fungi. The presence of airborne microbial inside a learning environment can cause irritation to occupants' eyes, skin, nose, throat and lungs, triggering health issues such as asthma attacks and pneumonitis.

- Total volatile organic compounds (TVOC) are a class of gaseous pollutants that are emitted from range of mostly man-made products and processes under normal atmospheric conditions. The symptoms that researchers generally associate with exposure to TVOC included skin and eye irritation, fatigue, dizziness, headaches and nausea. In a learning environment exposure to high levels of TVOC discomfort can impair occupant health and wellbeing.

- Particulate matter (PM10) describes airborne particles that range in size from 10 micros or less, which when breathed-in can cause respiration irritation that may trigger discomfort or asthma attacks. Inside a learning environment the sources of particulate matter are generally associated with the condition of the filters used inside air handling units.

Data analysis and visualisation

LEaRN Evaluation Module 2 uses 'scaling tables' to give the objective data meaning. After processing (i.e. isolating the data for the summer months when the space was occupied), the data set for each characteristic is given a 'score' between one and ten which corresponds with a certain level of performance. The scaling tables were developed using the advice outlined in current Australian and International Standards, School Building Guidelines and Rating tools about the recommended performance levels required for achieving comfort. At least one scaling table exists for each characteristic. Using the scaling tables eliminates the need for individual units (e.g. Degrees Celsius, Lux, Decibels) to be used when summarising the performance of each IEQ component, making it possible to compare characteristics that are otherwise incomparable. For example, the quality of the classroom acoustics can be compared with the air quality because once the data has been inputted into the scaling table it is converted into a value that is relative to performance.

Each scaling table uses the same basic template – depicted in Table 1. This table illustrates that a score of five is awarded to components when they achieve only the 'minimum standards', while a score of ten is awarded to components that to go beyond best practice and achieve 'next practice'. As an example, Table 2 shows the scaling table developed for carbon dioxide. For information about the development of the scaling tables refer to Soccio (2014).

Table 1: LEaRN Scaling Table template

Levels of performance relative to 'score'	
'Score'	*Range of values*
10	Achieves Next Practice
9	Achieves Best Practice
8	Achieves Excellent Practice
7	Achieves Good Practice
6	Achieves Acceptable Practice
5	Achieves Minimum standards

Table 2: LEaRN Scaling Table for carbon dioxide.

Component: Carbon dioxide Measured in parts per million (ppm)		
'Score'	Range (Lower)	Range (Upper)
10	400*	600
9	601	700
8	701	800
7	801	900
6	901	1000
5	1001	1100

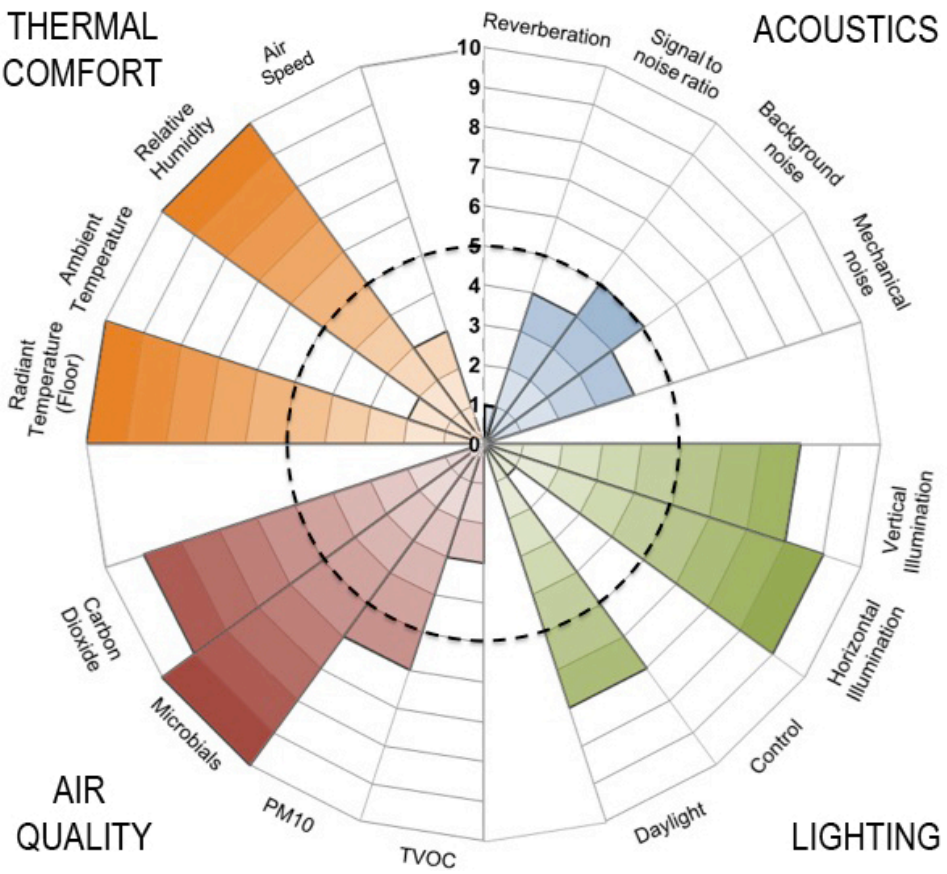
4	Below Minimum standards	4	1101	1200
3	Unsatisfactory practice	3	1201	1300
2	Problematic practice	2	1301	1400
1	Unacceptable Practice	1	1401+	
0	No data set	0	0	0

** Indoor carbon dioxide concentration levels cannot be lower that outside levels.*

The overall IEQ results for LEaRN Evaluation Module 2 are shown in an info-graphic (Figure 1). The info-graphic used shapes and colour to represent numbers in order to make the information more interesting and memorable than numbers would alone (Case, 1996).

Each of the four IEQ parameters measured by LEaRN Evaluation Module 2 is represented in one quarter of the radial diagram. The scores assigned to each component by the scaling tables generate the shape of the info-graphic. The performance of each parameter is communicated through the amount of area that is shaded – with more area shaded indicating better performance. The use of colour gradation highlights the performance of individual characteristics, with the more vibrant shades of colour reflecting better performance.

Figure 1: Example the info-graphic used to communicate the findings, where the dashed circle at the centre represents the minimum requirements set by national and international standards/benchmarks



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Results

Learning Environment 1

The info-graphics in Figures 2 and 3 highlight a range of IEQ issues in Learning Environment 1 over summer and winter, based on the objective data collected during school days (Monday to Friday) during hours of operation (7:30am-4:30pm). The descriptive and subjective data was used for deductive reasoning about the probable cause of the IEQ issues. Below is a discussion the key findings. NB: Some of the IEQ characteristics were not tested due to budget constraints and capital works programs, which could have skewed the results.

Figure 2 is the info-graphic summarising IEQ performance inside Learning Environment 1 during Summer (Dec 2012 and Feb 2013)

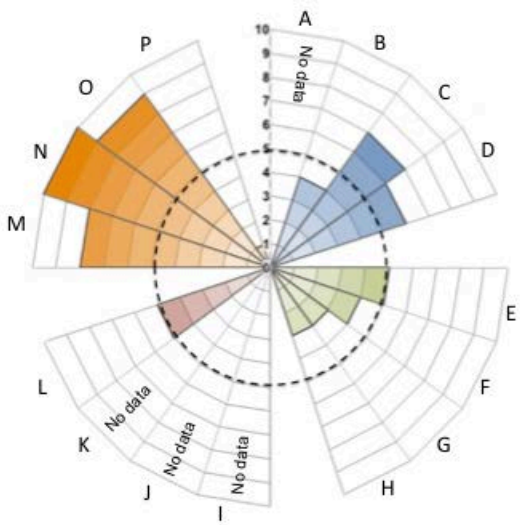
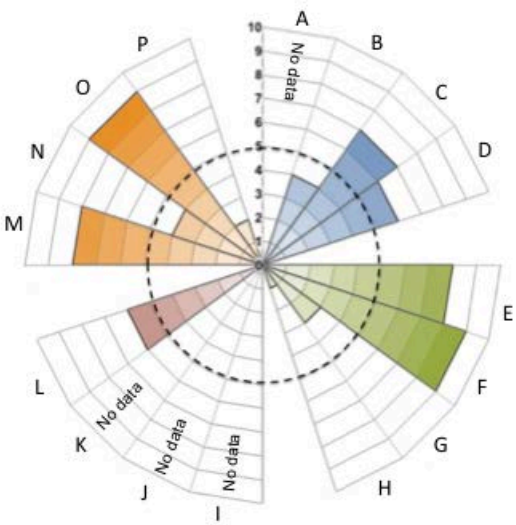


Figure 3 is the info-graphic summarising IEQ performance inside Learning Environment 1 during Winter (July and August 2012)



THERMAL COMFORT	AIR QUALITY	LIGHTING	ACOUSTICS
M: Radiant temp (floor) **N:** Ambient temp **O:** Relative humidity **P:** Air speed	**I:** TVOC **J:** PM10 **K:** Airborne microbial **L:** Carbon dioxide	**E:** Vertical illumination **F:** Horizontal illumination **G:** Lighting control **H:** Access to daylight	**A:** Reverberation time **B:** SNR **C:** Background noise **D:** Mechanical noise

Lighting

Because of the central location of the learning environment within the building, there were no windows making artificial light the main source of horizontal and vertical illumination. Limited daylight is accessed through skylights and some 'borrowed daylight' from the adjoining spaces. There is a notable contrast in the distribution of the horizontal illumination across the space. Directly beneath the skylights, the lighting level can be three times higher than elsewhere in the room. The difference is accentuated when the artificial lights are off and the daylight entering the learning environment becomes a source of glare.

The skylights are positioned directly above the wall surface used to mount the interactive whiteboard/data projector. At a certain time of the day, depending on the season, direct sunlight enters the learning space through the skylights and rebounds off this wall, making it very difficult to see projected images. High levels of vertical illumination can make it difficult for teachers to use smart boards and projectors. This is why the position of the projector directly beneath the skylights is problematic. There are also no options for shading the skylight to afford the learning environment to be 'blackened out'.

During the workshop, students identified limited access to daylight in the learning environment as a problem, suggesting that it made them "feel uncomfortable". They proposed that the number of skylights be increased. Students suggested that this change was required in order to: "improve the lighting"; to "make the space feel warmer"; to "be able to see the sky"; "to make the space more interesting"; and to "save on electricity" (by negating the need to switch-on lights).

Air Quality

Of the air quality components, only carbon dioxide (CO_2) levels were evaluated. The average level of CO_2 in winter was 905ppm and in summer was 1080ppm, which are within the upper end of the acceptable range (400-1100ppm). The build-up of CO_2 may be the result of the learning environment having no directly accessible operable windows. It should also be noted that the school assembly is regularly held inside the learning environment and having a large population in a restricted space can also result in higher CO_2 levels.

Acoustics

The average level of background noise inside the learning environment (without mechanical equipment operating) was 36dB(A). While this space does not directly overlook the busy road on which the school is situated, the sounds of the traffic can still be heard but does not contribute significantly to the overall background noise. The Heating Ventilation Air Condition (HVAC) system is the only mechanical equipment used inside the learning environment. When in operation, the HVAC system contributes an additional seven decibels to the background noise, raising it to 43dB(A), which is the equivalent to doubling the sound.

The school administration are aware of the mechanical noise generated by the HVAC system and plan to instruct their architect to be "more selective" in future capital works programs. The noise generated by the HVAC system prevents it from being used during school assemblies (compounding issues arising for thermal comfort). This anecdotal evidence is supported by the data collected about signal to noise ratio (SNR), which was eight decibels. This was below acceptable levels (15 decibels) and may be attributed to the combination of teachers' low voice projection, the background noise and the high ceiling heights (approximately six meters) inside the learning environment.

Thermal comfort

Students and teachers working inside the learning environment often feel 'cold' all year round. During winter, the average air temperature was 17.4°C and the temperature range between 12°C and 22.4°C. Over the occupied winter period, the air temperature inside the learning environment was (on average) above 20°C only once every four days. Increasing the occupants' thermal discomfort was a draught (greater than 0.1m/s), from cold air flowing through the learning environment via two staircases with external access. The HVAC system was ineffective at heating the learning environment, due to the location of the units at top of the six-meter tall ceilings. During winter, a thermal image revealed a large pocket of hot air sitting below the ceiling inaccessible to occupants. During the workshop, the students made reference to the "slow response time" of the HVAC system and suggested, "tripling the number of air-conditioning units" would improve their experience of the thermal comfort.

Recommendations

From the IEQ evaluation, the following recommendations were made to improve IEQ performance:

1. Relocate the projector and screen away from directly beneath the skylights to improve the quality of projected image; or provide an automatic blinds that will afford the space to be darkened, when the projector is in use.
2. Install reverse cycle ceiling fans, to mix and circulate (to ground level) the air supplied by the HVAC during winter (when hot air rises).
3. Install airlocks at both staircases to prevent draughts.

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Learning Environment 2

The info-graphics in Figures 4 and 5 highlight a range of IEQ issues in Learning Environment 2 over summer and winter, based on the objective data collected during school days (Monday to Friday) during hours of operation (7:30am-4:30pm). The descriptive and subjective data was used for deductive reasoning about the probable cause of the IEQ issues. Below is a discussion the key findings. NB: Some of the IEQ characteristics were not tested due to budget constraints and capital works programs, which could have skewed the results.

Figure 4 is the info-graphic summarising IEQ performance inside Learning Environment 2 during Summer (Dec 2012 and Feb 2013)

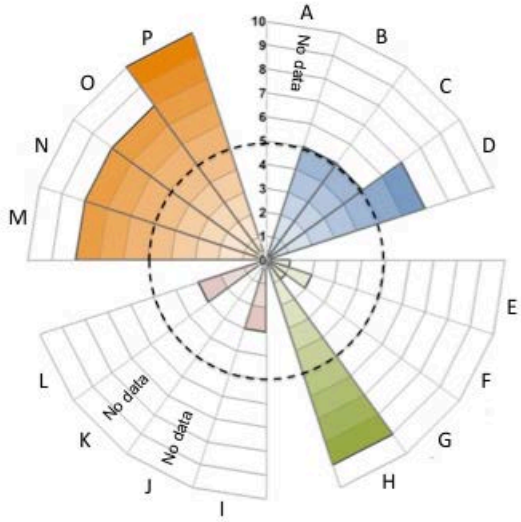
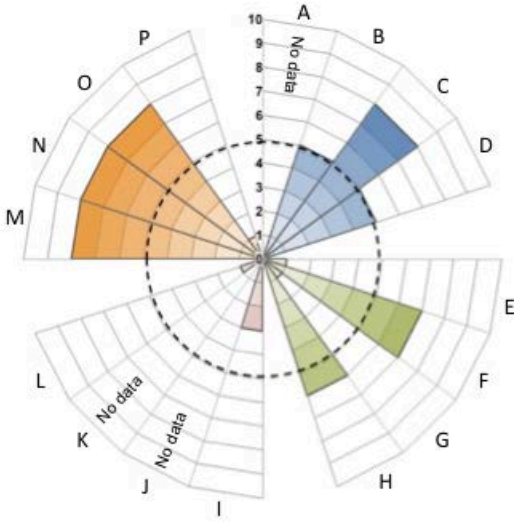


Figure 5 is the info-graphic summarising IEQ performance inside Learning Environment 2 during Winter (July and August 2012)



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Air quality

The data collected on carbon dioxide (CO_2) levels indicates that the learning environment does not have adequate ventilation. The average level of CO_2 in winter was 1607ppm, which is 2-3 times higher than the acceptable range of 640-840ppm. In summer the average CO_2 level was 1258ppm, which is also well above the acceptable range. In winter, over 20% of the data points collected recorded CO_2 levels above 2000ppm, which is problematic.

The build up of CO_2 may be the result of the teachers and students not using the operable highlight windows intended in the design for increased airflow and ventilation. There are no operable windows at floor level – only sliding doors. These operable windows were not in use during any of the site visits. During the summer site visit, the sliding doors were opened to provide ventilation after the teachers received advice from students that they were 'hot'. It was noted that without the highlight windows open, the sliding doors on only one side of the room could not achieve the desired air movement (required via the stack effect). During winter, the cold external temperatures made it counter-intuitive for the teachers to open the windows – however this meant that the space heaters only recirculated existing air.

A second reason for the high levels of CO_2 was hypothesised from the descriptive data collected during a one of the site visits. On this occasion, the outside weather was so inclement that the students

were not allowed (by teachers) to take their recess and lunch breaks outside. They were to remain inside; due to the school having no weather protected outdoor play areas. The students were given permission for "restricted indoor play". This involved the students being more quite active. On this day, the objective data collected about CO_2 spiked significantly (due to the increased breathing rates) during this period and remained high across the afternoon. It is possible that this scenario occurs frequently in winter.

An air sample found a low level of total volatile organic compounds (TVOCs). This may be due to the space being part of a relatively new capital works project. The TVOCs are associated with new furniture and finishing. Microbials and PM10 were not evaluated.

Lighting

During the school day (7:30-4:30pm), daylight is the main source of horizontal and vertical illumination. Daylight enters the learning environment through highlight windows, glass sliding doors and floor to ceiling window glazing. In summer, the average level of horizontal illumination was 670lux. This is slightly higher that the acceptable range of 230-559lux. The average level of vertical illumination is nearly four times greater than the acceptable range (185-199lux) with 10% of the data points collected in summer recording vertical illumination at or above 900lux.

Very high levels of vertical illumination make it difficult for teachers to use smart boards, particularly when the windows in the learning environment are not fitted with blinds. An assessment of lighting control found that the teachers had very limited control of the lighting level inside the learning environment and that 'switching off' the artificial lights accounted for only a 29% reduction in the illumination level on the smart board. The teachers currently address the problems created by high levels of vertical illumination and limited lighting control by "swivelling the board away from a specific glare spot" or by "taking the class into the conference room and using the projector". Both solutions are considered undesirable.

Despite these issues, the students were generally in favour of the learning environment having such high levels of daylight. The students liked that for the majority of the year their learning environment could be illuminated using only daylight. They were impressed that the school "saved electricity and the environment" by using the daylight instead of artificial lights. The students like how "bright" the learning space was and that they could "see outside to the playground" and "what the weather was like outside".

Acoustics

During the first site visit (in winter), the level of background noise inside the learning environment was within acceptable levels 34dB(A). At a subsequent visit, ground works had begun for a new building on an adjoining site, which increased the background noise inside the learning environment by 5dB, to 39dB(A).

The mechanical equipment inside the learning space, which contributes to the level of mechanical noise was the heaters, the wireless modem (which made a buzzing noise) and the ceiling fans. With the mechanical equipment on, the background noise level increased to 51dB(A), which is well above the recommended levels.

During the workshop the students commented that the learning environment "got very noisy". One student suggested addressing the acoustical issues from multiple classes working together, by returning the open-plan space into a more traditional configuration of a series of small rooms, which they described as being "more like the meeting and conference rooms, which are quiet". The students described the space heaters as being "noisy but essential". The ceiling fans were referred to as "distracting". On a later inspection of the ceiling fans, one was found to have a problem that resulted in an irregular clicking noise.

Thermal comfort

During both winter and summer, thermal comfort was generally within the acceptable range, according to the quantitative targets set by the scaling tables. In winter, the average air temperature inside the learning environment was 19.4°C. The temperature range 14.4°C to 23.8°C, though the occupants only experienced these extremes on less than 3% of the school days during the occupied winter monitoring period. In summer, the average air temperature inside the learning space was 24.6°C. The maximum temperature was 31°C; however this was only experienced by the occupants on less than 1% of occasions during the occupied summer monitoring period. Temperatures of over 26°C were experienced during one in every four days.

Despite thermal comfort levels falling within the acceptable ranges, students in the workshop identified the room temperature as being "too hot in summer and too cold in winter" and suggested that additional HVAC units be installed.

There are a number of reasons why this may have been the case. One probable reason is the use of 'predicted mean vote' (PMV) to calculate thermal comfort. It recognition that everyone is different, the PMV leaves a small 'percentage of people dissatisfied' (referred to as the PPD rate). In the LEaRN Evaluation Module 2, the range of air temperatures deemed to be within the acceptable range were calculated using a PPD value 7-20. This means that between 80-93% of the occupants will be satisfied, leaving up to 20% dissatisfied. This percentage may be higher, as in calculating the PMV, a range of assumptions were made about the learning environment, which may have been incorrect. These assumtions were: 1) the type of activity occupants are engaged in, 2) the weight (or insulation) value of their clothing, 3) the amount of air movement, 4) the levels of relative humidity and 5) the radiant heat. More research is required here to better understand what the correct assumptions are.

Additionally, students and educators experience learning environment IEQ as empiricists where their perception of 'quality' is biased by the human sensory system (Kim, et al., 2013). Human sensors have limited capacity to experience and differentiate between IEQ components and their varying levels of performance (IPMVP, 2002). Consequently, a subjective evaluation may only capture the occupants' understanding of "what is observable" (Castree, 2005, p.214) or of concern to them at a specific point in time (IPMVP, 2002; Markie, 2013). This could mean that the high levels lighting inside the learning environment combined with the low levels of fresh air, resulted in occupants believing the space was too warm (and relating this response to air temperature). The teachers raised this issue in a discussion about light, suggesting that window blinds could make the space "feel cooler" by darkening the space on hot days. Window treatments that blocked out or reduced some of the daylight could also assist with reducing the radiant heat. Because of the high percentage of glazing, there is some radiant heat gain inside the space. This is particularly notable where the glass doors to the outside of the building are not protected by an eave and direct sunlight enters the space, heating up the floor and furniture.

Recommendations

From the IEQ evaluation, the following recommendations were made to improve IEQ performance:

1. Install window treatments. At ground level these should be manually operated. Automatic window blinds could also be installed over the highlight windows.
2. Encourage the occupants to use the operable highlight windows to create a stack effect, where fresh air is pulled into the space, through lower level openings, as hot air is expelled. This will improve cross ventilation and reduce the build up of CO_2 inside the learning space.
3. Ensure routine maintenance for the upkeep of mechanical systems.

Conclusion

The purpose of this paper was to present the results from IEQ evaluations of two learning environments in CEM primary schools, undertaken using LEaRN Evalution Module 2. As context for why IEQ is an important issue in learning environments, this paper has summarized some of the literature around POE and IEQ and stated how poor IEQ may impact on effective teaching and

learning. From the IEQ evaluations of Learning Environments 1 and 2, the following recommendations should be considered in future school capital works programs:

1. For design teams to specify 'quiet' HVAC units that do not add significantly to the sound level inside the learning environment, when in operation.
2. For the design team to specify the location for HVAC units based on optimum performance. In Learning Environment 1 it was hypothesised by the teachers that the HVAC units were installed at ceiling level, as this was "easiest" for installation (with the condenser unit sitting on the roof), rather than "most effective" for heating and cooling. Thermal imaging supports this theory.
3. For design teams to consider spatial configurations that afford learning environments to be both 'opened-up' and 'closed down' for acoustic separation (when required). Acoustical barriers should not interfere with the visual connection between adjoining spaces (i.e. glass should be used wherever possible).
4. Windows should be fitted with appropriately designed sun-shading devices and/or window treatments.
5. Specify projectors with high quality image projection.
6. Afford occupants the maximum levels of control over IEQ. It was noted that occupants perceive their IEQ more favourable, when they have a higher level of control over their environment.
7. Note that activity on or nearby adjoining sites can have a significant impact on IEQ. Physical sound barriers and appropriate landscaping should be planned for sites were the activity on or nearby adjoining sites may result in ongoing noise – such as from increased road traffic.
8. For new schools, map IEQ risks to learning environments (i.e. roads, orientation, prevailing breezes) on the master plan, to encourage integration of holistic solutions as the design phase.

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References

ASHRAE. (2010). *Research Strategic Plan 2010-2015:Navigation for a Sustainable Future*. www.ashrae.org. Accessed (11/9/2013).

Bell, J. (2004). Indoor environments: design, productivity and health: literature database. Cooperative Research Centre for Construction Innovation Report: 2001-005- B. Brisbane, Australia.

Bryman, A. (2004). *Social Research Methods* (2nd Ed.). Oxford: Oxford University Press

Building Commission Victoria. (2004). Buiness Outlook & Evaluation – Indoor Environment Quality: A positive campaign now or damage control in the future? Available at http://www.businessoutlook.com.au (Accessed Feb 3, 2014). Victoria, Australia.

Castree, N. (2005). *Nature*, p.214. London: Routledge.

Cleveland, B. (2011). *Engaging spaces: Innovative learning environments, pedagogies and student engagement in the middle years of school.* Unpublished PhD, The University of Melbourne, Melbourne.

Cleveland, B., & Fisher, K. (2012). The evaluation of physical learning environments: a critical review of the literature [accepted to Learning Environments Research]. University of Melbourne.

Cleveland, B., & Soccio, P 2013. Research report. Development and pilot testing of the School Spaces Evaluation Instrument (SSEI): Module 2 – Technical Performance Evaluation/Indoor Environment Quality (IEQ) & Module 3 – Alignment of Pedagogy and Learning Environments (CEOM). Melbourne: The University of Melbourne.

Cox-Ganser, M., White, S., Jones, R., Hilsbos, K., Storey, E., Enright, P., Rao, C., & Kreiss, K. (2005). Respiratory morbidity in office workers in a water-damaged building. *Environ Health Perspect*, vol. 113(4), 485-490.

Dovey, K., Fisher, K., (2014) Designing for adaption: the school as socio-spatial assemblage. The Journal of Architecture. 19(1), 43-63.

Faustman, E. M., Silbernagel, S. M., Fenske, R. A., Burbacher, T. M., Ponce, R. A. (2000). Mechanisms underlying children's susceptibility to environmental toxicants. *Environ Health Perspec,* 108 Suppl. 1: 13-21.

Fisk, W. (2000). Estimates of potential nationwide productivity and health benefits from better indoor environments, *Air Quality Handbook*, New York: McGraw-Hill.

Fisk, W. J. (2002). How IEQ affects health, productivity. *ASHRAE Journal*. 44(5), 56, pp.58–60.

Fisk, W. (2011). Benefits and costs of improved IEQ in U.S. offices. *Indoor Air*. 21(5), pp.357-367.

Fisk, W., Seppanen, O. (2007). 'Providing better indoor environmental quality brings economic benefits' : Proceedings of Clima 2007: well-being indoors. FINVAC, Helsinki, Finland, 10–14 June 2007.

Gaver, B., Boucher, A., Pennington, S. & Walker, B. (2004). Cultural Probes and the value of uncertainty. *Interactions*, 115, 53-56.

Heinzerling, D. (2012). *Commercial Building Indoor Environmental Quality Evaluation: Methods and Tools,* Unpublished masters thesis, Department of Architecture, University of California, Berkeley.

Higgins, S., Hall, E., Wall, K., Woolner, P., McCaughey, C. (2005). *The Impact of School Environments: A literature review.* Available at: www.design-council.org.uk/ (Accessed 1 July, 2009).

Humphreys, M., Nicol, J. (2007). Self-assessed productivity and the office environment: monthly surveys in five European countries. *ASHRAE Transactions,* 113 (1), p.606.

Heschong Mahone Group [HMG]. (1999). Daylighting in schools: an investigation into the relationship between daylighting and human performance. A report submitted to Pacific Gas and Electric.

Heschong Mahone Group. (2003). Windows and Classrooms: A Study of Student Performance and the Indoor Environment, Sacramento, CA: PIER Buildings Program.

IPMVP. (2002). *International Performance Measurement and Verification Protocol Volume II: Concepts and Practices for Improved Indoor Environment Quality*, IPMVP Inc.

Johnson, P., & Kritsonis, W. (2010). Greener schools, greater learning, and the LEED value. *National Journal for publishing and mentoring Doctorial student research,* 7(1), 332-356.

Kim, J., & De Dear, R. (2012). 'Identifying substantive IEQ factors for efficient building management'. In: The 46th Annual Conference of the Architectural Science Association, ANZAScA, Gold Coast, Australia.

Kim, S., Paulos, P., Mankoff, J. (2013). 'inAir: A Longitudinal study of Indoor Air Quality Measurements and Visualizations', CHI 2013: Changing Perspectives. Paris, France. April 27-May 2, 2013, pp.2745-2754.

Landrigan, P. (1998). Environmental hazards for children in USA. *International Journal of Occupational Medicine and Environmental Health*, 11, 189-194.

Loi, D. (2004). Document/reflect/create - Cultural Probes in teaching and learning environments. Paper presented to *PDC 2004: The eighth biennial Participatory Design Conference.* Toronto, Canada.

Loi, D. (2007). Reflective Probes, Primitive Probes and Playful Triggers. Paper presented at *EPIC07: Ethnographic Praxis in Industry Conference*. Keystone, CO.

Luther, M. (2012). 'Review of measurements in schools to improve IEQ'. Paper presented at 10th International Conference of Healthy Buildings. Queensland University of Technology, Brisbane, Queensland. July 8-12.

Mendell, M., & Heath, G. (2005). Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. *Indoor Air*, 15, 27-52.

Olesen, B. (2010). Why specify indoor environmental criteria as categories?.*Adapting to change: new thinking on comfort*, London: Network for Comfort and Energy Use in Buildings.

Preiser, W. F. E., & Nasar, J. L. (2008). Assessing building performance: Its evolution from post-occupancy evaluation. *International Journal of Architectural Research, 2*(1), 84-99.

Preiser, W.F.E. (2002), "Toward universal design evaluation", 17th Conference International Association for people-environment studies; culture, quality of life and globalization: problems and challenges for the new millennium, Corunna, Spain.

Soccio, P 2012, 'Using Playful Triggers in the classroom as a tool for reflection about sustainability', proceedings at the *Australian Association for Educational Education National Conference*, Melbourne Convention Centre, Melbourne, 30 September - 3 October 2012

Soccio, P 2014. Communicating succinct and targeted information, to a multidisciplinary audience about the indoor environment quality inside Australian primary and middle school classrooms,Unpublished PhD, The University of Melbourne, Melbourne

Soccio, P. (2016). A New Post Occupancy Evaluation Tool for Assessing the Indoor Environment Quality of Learning Environments, Book chapter in Imms, W., Cleveland, B., Fisher, K. (2016), Evaluating Learning Environments Snapshots of Emerging Issues, Methods and Knowledge, Sense Publishers: The Netherlands

USEPA (2008). Mold Remediation in Schools and Commercial Buildings. http://www.epa.gov/mold/moldguide.html (Accessed 04/09/12).

Vittori, G. (2002). Green and Healthy Buildings for the Healthcare Industry White Paper. In: CleanMed, Center for Maximum Potential Building Systems. Austin.

Wakefield, J. (2002). Learning the Hard Way: The poor environment of America's Schools. *Environmental Health Perspectives*, 110 (6), pp.298-305.

Zimring, C. M., & Reizenstein, J. E. (1980). Post-occupancy evaluation: An overview. *Environment and behavior, 12*(4), 429-450.