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Assessment of Indoor Environmental Quality (IEQ) in Air-Conditioned Lecture Halls of the Institutional Buildings: A Case Study for Sri Lanka

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ABSTRACT

On average, a higher educational student spends 3-8 years inside an institutional building during their studies, where they tend to stay with large groups of students in confined environments for longer durations. Improper design standards and occupant control in lecture halls can result in poor Indoor Environmental Quality (IEQ), which can lead to health issues such as Sick Building Syndrome (SBS). Generally, the IEQ of institutional buildings are being overlooked in many instances with respect to commercial or residential buildings, where occupants are mostly in control of their activities and indoor environments. Therefore, to assess the variations of IEQ in lecture halls, the present study has analyzed indoor air quality, thermal comfort and acoustic comfort by considering parameters indoor CO_2 level, relative humidity, and sound pressure respectively during a continuous 2-hour lecture. The study was conducted by considering University of Sri Jayewardenepura, Sri Lanka as a case study. Student responses on prevalence of SBS symptoms were collected through a questionnaire survey and an ordinal logistic regression was performed to assess whether there are co-relations between the IEQ and reported symptoms. The results of the study showed that some of the lecture halls exceeded the ASHRAE standard values indoor CO_2 levels towards the end of the lecture and some lecture halls had poor acoustic comfort due to the noise of air conditioning machinery. Results from the ordinal logistic regression showed that there is a statistically significant association on prevalence of SBS symptoms such as headache, difficulties in concentration, dry throat, cough and tiredness for the lecture halls with high occupant densities. The results of this study highlight the importance of maintaining optimum design guidelines, proper occupant control and selecting the appropriate capacity of air conditioners for the lecture halls to maintain a good IEQ.

INTRODUCTION

In the current context, air conditioning has become an essential aspect in achieving indoor comfort conditions in buildings. According to Mustapa et al. (2016), there is a trend where air conditioning (A/C) has become an essential feature of buildings to create and maintain thermally comfortable indoor conditions during working hours. People spend 60–90% of their lifetime in buildings, which also found to be increasing with the time (Antoniadou and Papadopoulos, 2017). Higher educational student spends 3-8 years average inside institutional buildings during the course of their study. Indoor Environmental Quality (IEQ) refers to the quality of a building's environment in relation to the health and wellbeing of those who occupy the space within it (The National Institute of Occupational Safety and Health, 2013). According to Reynold et al. (2001), Indoor Environmental Quality (IEQ) is an important public health issue as it can lead to widely publicized problems such as Sick Building Syndrome (SBS) and Building-Related Illness (BRI). SBS is used to describe situations in which, building occupants experience acute health and comfort effects that appear to be linked to time spent in a building, however, there is no specific illness or cause can be identified. BRI is used when symptoms of diagnosable illness are identified and can be attributed directly to airborne building contaminants (USEPA, 1991).

IEQ depends on the combination of four major environmental factors which are, Thermal Comfort (TC), Indoor Air Quality (IAQ), Acoustic Comfort (AC) and Visual Comfort (VC) (Mustapa et al, 2016). There were several indicators used in literature to assess the IEQ considering these various aspects. From the 19th Century, the indoor Carbon Dioxide (CO_2) concentration has been used as an indicator of air quality in buildings and to assess the effectiveness of outdoor air supply rate in occupied rooms. Many studies are focused on measurement of CO_2 concentrations as an indicator of the IAQ (Pereira et al., 2014, Vilcekovaa et al., 2017, Antoniadou and Papadopoulos, 2017). Vilcekovaa et al. (2017) have used indoor CO_2 concentration to determine indoor air quality factor relative humidity and air temperature to determine thermal comfort. Furthermore, illuminance and sound pressure were used as the most prominent parameters of measuring visual comfort and acoustic comfort respectively (Vilcekovaa et al., 2017).

In the modern construction practice, it has become essential to pay a special attention towards IEQ while designing buildings as poor environmental quality can cause problematic situations such as diseases, reduced productivity, reduced efficiency as well as poor satisfaction of the occupants. There are several symptoms associated with SBS. Some of these symptoms are headache, difficulty in breathing, fatigue, irritation in eyes, difficulty in concentrations etc. (WHO, 1983). These symptoms may be alleviated after the individual leaves the building (WHO, 1983). Improper thermal conditions can affect productivity and work performance through reducing the occupant productivity and generating disorders that increase maintenance costs. SBS symptoms have a negative effect on mental aspects of the occupants. Moreover, these sicknesses can increase disorders of occupants and therefore, it is of a prime importance to maintain indoor environmental quality in line with the standards for the IEQ for any type of a building (Kalz and Pfafferott, 2014).

The standards in assessing the IEQ are provided by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) to maintain healthier building indoor environments. The healthy heating (2012) considers IEQ as a combination of indoor air quality (IAQ), indoor thermal quality (ITQ), indoor lighting quality (ILQ), indoor sound quality (ISQ), indoor odour quality (IOQ) and indoor vibrations quality (IVQ). According to Pereira et al. (2014), IEQ results on four major environmental factors such as thermal comfort (TC), Indoor air quality (IAQ), Acoustic comfort (AC) and Visual comfort (VC). According to the ASHRAE standard, 1000ppm of CO_2 concentration is considered as the acceptable level for indoor environment while the acceptable level of percentage relative humidity (RH) is considered as 30%- 60%. The acceptable levels of illuminance and sound pressure, according to the ASHRAE guidelines are in the range of 150-300 lux and 30-40 dB, respectively.

Students have limited option for adjusting themselves to indoor environment since the student's classroom-based activities are restricted. A study was done by Zaki et al. (2017) on thermal comfort in university classrooms in Malaysia and Japan for mechanical cooling (A/C was switched on) and free running (A/C was switched off). Based on the results of this study indoor RH is impacted from the mode of ventilation. The lecture halls with free running mode has recorded a higher RH than mechanical cooling. In particular, there are fewer number of studies found in literature which focus on IEQ of air-conditioned lecture halls. In fact, many studies focus on other educational facilities such as secondary class rooms, kindergartens and schools. TC has been found exceedingly important in the context of educational buildings as it could generate unsatisfactory conditions for both staff and students due to thermal discomforts (Barbhiya and Barbhuiya, 2013). Due to the negative influence on learning and performance that can be caused by unsatisfactory thermal environment in class rooms where there is high occupant density, thermal condition of such buildings has to be concerned vigilantly. Therefore, scientific studies focus their attention towards IEQ of students as they have more vulnerability to environment pollutants than adults (Katafygiotou et al., 2014). Schools have compound indoor environments and it is influenced by several factors such as number of occupants, equipment used, activities and the building design. Although students spend majority of their time in buildings, it is very important to understand the environment quality in these institutional buildings (Scheff et al., 2000). According to Vilcekova et al. (2017) public knowledge of IAQ in schools is very low and the occupants were not aware about the bad impacts on their health, comforts, productivity from the exposure to the pollutants.

Among the few studies on IEQ of A/C lecture halls, one study was carried out on adaptive thermal comfort model for air-conditioned lecture halls in Malaysia and the study find out a relationship between operative temperature and behavioral adaptations of occupants (Chew et al., 2015). Suleiman et al. (2013) has done a study on IEQ of Higher Education Institutions (HEIs). According to the study, the occupant satisfaction level of majority of academic buildings lied within moderate level. Most of the correspondence suggests improving the maintenance of the building and improving the green technology in the university area. Nico et al. (2014) has done a study on evaluation of thermal comfort in university classrooms through subjective and objective approach. According to the study, architectural geometry of the environment has a great influence on thermal conditions. The present study will focus on assessing the IEQ particularly in air-conditioned lectures halls with varying occupant densities, in order to identify its influence on the prevalence of SBS symptoms by selecting a higher educational institute located in Sri Lanka as a case study.

METHODOLOGY

Five different air-conditioned lecture halls were selected as the sampling locations in the Faculty of Applied Sciences, University of Sri Jayewardenepura, Sri Lanka for the IEQ assessment. The lecture halls were selected based on the varying occupant density and dimensions which conducted continuous two-hour lectures. Figure 1 shows the schematic of the Lecture Hall 1 (L01) with the data logger setup. The orange colour lines show the furniture arrangement of the lecture hall and seating area of the students. Green colour box indicates the A/C machine. W and D indicate window and door respectively.

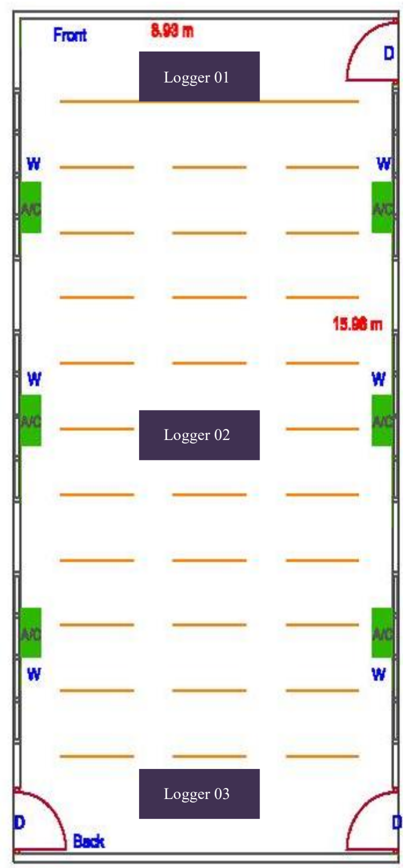

Figure 1- Lecture Hall 1 (L01)

Continuous CO_2, RH, Temperature data loggers (Perfect-Prime CO2000) was set up throughout a lecture to measure the indoor air quality and thermal comfort. Equipment was set up before the start of the lecture and was removed after the end of the lecture. Three data loggers were set up in the height of 1.1m to get the measurements in occupant zone of a seating person in the front, middle and back of the lecture hall. (Mustapa et al., 2016). In addition to these equipment, digital sound noise meter were used to measure the noise level. The lecture halls were categorized based on the occupant density, which is the number of students for a unit area. Table 01 shows

Table 1 – Occupant Densities of the Selected Lecture Halls

Lecture hall	Floor Area (m^2)	Average Occupant Density (per square meter)
L01 (n=30)	142.52	0.208
L02 (n=13)	34.8	0.383
L03 (n=14)	78.15	0.176
L04 (n=22)	107.28	0.207
L05 (n=47)	170.66	0.278

a summary of the floor area, average number of students per each lecture and occupant densities of the lecture halls respectively.

A questionnaire survey was performed simultaneously to identify the prevalence of SBS symptoms for the selected lecture halls. The occurrences of SBS syndrome symptoms (blocked or stuffy nose, cough, difficulties in concentration, dry throat, dry/itching/ irritated skin, dryness in the eye, fatigue/lethargy/tiredness, headache, heavy headed, itchy or watery eye and nausea/dizziness), type of clothing, satisfaction on the quality of the lecture hall, were obtained by using the questionnaire. Questionnaire was distributed to students who attended the lectures in each hall individually. Sample sizes of L01, L02, L03, L04 and L05 are 52, 56, 61, 48 and 35 respectively. Daily attendance of students during each lecture series was taken. The length and width of each lecture hall was measured to calculate areas. These two parameters were used to measure occupant density and average occupant density of each lecture hall which was used as the major indicator to assess the correlations of the IEQ parameters and the lecture hall. One way ANOVA and Tukey HSD tests were performed to identify whether there are significant differences among IEQ parameters in the three positions considered.

An ordinal logistic regression was performed for each of the lecture halls to assess the significance of the prevalence in selected 11 SBS syndromes based on the results of the questionnaire survey. The odds ratios were calculated in reference to the symptom nausea/ dizziness for each of the lecture hall to identify the significance prevalence of various symptoms for each of the lecture hall. An odds ratio (OR) is a measure of association between an exposure and an outcome. The OR represents the odds that an outcome will occur given a particular exposure.

OR>1 Exposure associated with higher odds of outcome
OR=1 Exposure does not affect odds of outcome
OR<1 Exposure associated with lower odds of outcome

At the 95% Confidence Interval (CI) ≥1 and OR>1, the prevalence of the symptom for a particular lecture hall to is considered to be statistically significant (Zamani et al, 2013).

Results and Discussion

Primary source of CO_2 difference is through respiration of occupants for extended periods of time. Furthermore, the difference of RH is mainly associated with the room air conditioning and the respiration of occupants. Differences in sound pressure could be associated with the behaviors of the occupant's and other external sources such as air conditioning units, microphones, and computers. Figure 2 shows summary results obtained for the five lecture halls on the indoor CO_2 concentrations and the relative humidity levels. As can be seen in Figure 2, for all the five lecture halls

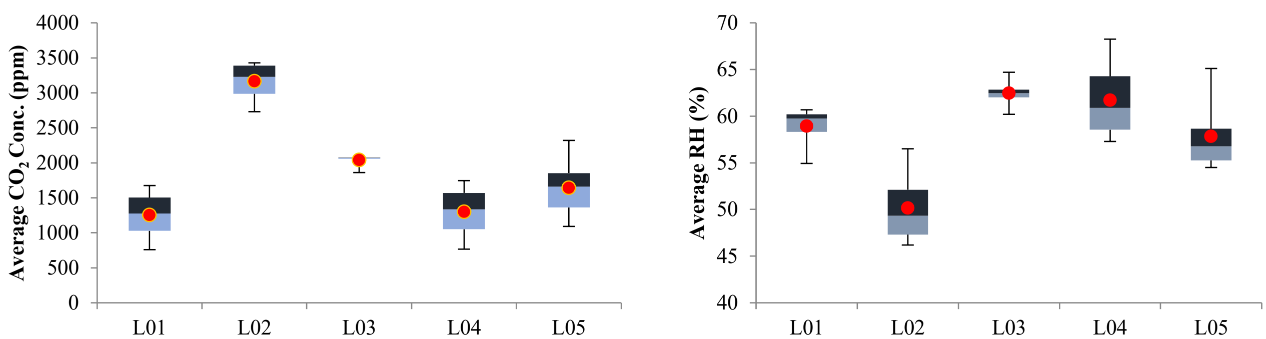

Figure 2 – Box and Whiskers Plots for the CO2 concentrations and RH levels in five lecture halls

the indoor CO_2 concentrations have been exceeded the and ASHRAE standard CO_2 concentrations of 1000 ppm. The increasing trend of CO_2 has been recorded after the first hour of the lecture of the two-hour lectures, that the data collection has performed. When assessing the RH levels of the five lecture halls, all the halls have maintained the standard ASHRAE guideline for the RH for comfortable indoor environments which ranges from 30% -60%. The average CO_2 and RH was obtained by taking the average of values for the three locations of the classroom which were front, middle and back for the two hours.

Figure 3 represents the noise levels recorded for the middle of the lecture hall L01, where noise levels were recoded slightly above the standard. The L01 lecture hall had an air conditioner which was operating with significant noise compared to other lecture halls which may have caused the increase of the noise levels of the halls with respect to the standard levels. The neutral level of acoustic comfort is ranges between 30-40dB (Antoniadou and Papadopoulos, 2017). Sound pressure is used as the indicator of acoustic comfort and the unit of sound pressure is dB (Reynold et al., 2010). According to Astolfi and Pellerey (2007) speech communication, performances of students are decreased by bad acoustic condition of classrooms. Furthermore, due to bad acoustic condition, teachers could suffer from fatigue conditions.

Even though present study has recorded quite high indoor CO_2 concentrations compared to ASHRAE standards, it has shown similar trends compared with the past studies conducted in institutional buildings in other international case studies. According to Pereira et al. (2014), CO_2 concentration was more than 5000ppm in some secondary class rooms in Portuguesa. The study focused two class rooms and the maximum recorded CO_2 concentrations were 6223 ppm and 7645 ppm. It was significantly high amount when compared with ASHRAE standards similar to the present study.

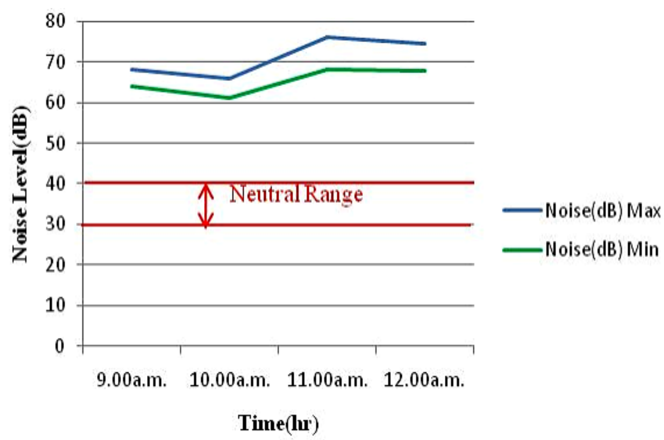

Figure 3 – The noise levels (dB) recoded for the middle of the lecture hall L01

RH levels are falling within the recommended range in every lecture hall and this could be due to the air conditioner system which maintains the thermal comfort conditions. Although RH falls within the standard range, there were some visible fluctuations. This could be due to the changes in the air condition level in the lecture halls. Most of the students tend to switch off or increase the temperature level of air condition machineries if they feel discomforts. According to Katafygiotou et al (2014), RH of the class rooms in Cyprus fell within the range in all of their seasons.

In order to reduce the energy costs associated with heating, cooling and maintaining the comfort of the indoor environment, most of the heating, ventilation and air conditioning systems (HVAC) re-circulate a significant portion of the indoor air. Therefore, it is difficult to judge how much of the air is re- circulated in the building operation and occupants' sense from air coming out of an air supply. As a result, currently, CO2 is used as an indicator in ensuring ventilation systems are delivering the recommended minimum quantities of outside air to the building's occupants (Prill, 2000). The dominant indoor source of CO_2 is through occupant respiration. The increase of indoor CO_2 concentration with respect to outdoor environment is considered to be an indicator of contamination of bio effluents and CO_2 concentration in outdoor environment varies with the location as well as time while indoor CO_2 concentration is spatially non-uniform (Seppanen et al., 1999).

TC is defined as "the condition of mind that expresses satisfaction with the thermal environment" (Antoniadou and Papadopoulos, 2017). Performance of building occupants could be significantly affected by poor TC and it could affect the psychological well-being of the occupants and productivity. Poor TC can be attributed to vast majority of complaints on IEQ amongst other parameters (Barbhuiya and Barbhuiya, 2013). According to the definitions of ISO standards 7730 and ASHRAE standard 55, TC is one of the most important parameters in IEQ. TC is an important feature of indoor environment as it is not limited to thermal sensation but also influence the energy consumption of a building in the terms of sustainability (Katafygiotou et al., 2014).

One-way ANOVA and Tukey HSD test at 95% confidence interval was conducted in this study to assess whether there is a significant difference in the recorded parameters in the 3 positions of the lecture hall (front, middle and back). According to the results there is a significant difference ($p<0.05$) in CO_2 concentration and RH in 3 positions in every lecture hall. However, there were no any significant differences ($p>0.05$) in noise levels for all lecture halls.

Ordinal logistic regression was performed in this study to assess whether there is a significance in the prevalence of SBS symptoms for each of the lecture hall by using the questionnaire surveys. Significant symptoms varied from one lecture hall to another. Headache and difficulties in concentration are statistically significant in L01 (OR>1, $p<0.05$) while headache and cough were statistically significant in L02.The prevalence of the symptoms such as difficulties in concentration, dry throat, fatigue and headache were statistically significance in L03 and there were no statically significant ($p>0.05$) SBS symptoms recorded in L04. Dry throat symptom was statistically significant in L05. The results of ordinal logistic regression are shown on Table 2.

Table 2 - Summary results for the ordinal logistic regression for 5 lecture halls

	L01				L02				L03				L04				L05			
		95% Confidence Interval				95% Confidence Interval				95% Confidence Interval				95% Confidence Interval				95% Confidence Interval		
Symptom	Significance	Lower Bound	Upper Bound	Odds Ratio	Significance	Lower Bound	Upper Bound	Odds Ratio	Significance	Lower Bound	Upper Bound	Odds Ratio	Significance	Lower Bound	Upper Bound	Odds Ratio	Significance	Lower Bound	Upper Bound	Odds Ratio
Blocked or stuffy nose	.043	0	1	1.999	.010	0	2	2.598	.223	0	1	1.625	.761	-1	1	1.164	.002	0	2	3.254
Cough	.843	-1	1	1.071	.001	1	2	3.524*	.450	0	1	1.354	.618	-1	1	1.280	.128	0	1	1.812
Difficulties in concentration	.000	1	2	3.431*	.007	0	2	2.710	.000	1	2	5.240*	.021	0	2	3.008	.003	0	2	3.078
Dry throat	.398	0	1	1.338	.029	0	2	2.264	.000	1	2	5.169*	.192	0	2	1.880	.000	1	2	3.847*
Dry/Itching/ Irritated skin	.784	-1	1	1.100	.041	0	1	2.143	.141	-2	0	0.521	.116	-2	0	0.401	.616	-1	1	1.225
Dryness in the eye	.458	0	1	1.292	.383	0	1	1.393	.004	0	2	3.076	.448	-1	1	1.451	.058	0	1	2.079
Fatigue/lethargy/tiredness	.092	0	1	1.783	.181	0	1	1.655	.000	2	3	10.48*	.102	0	2	2.197	.002	0	2	3.223
Headache	.000	1	2	3.729*	.000	1	2	3.743*	.000	1	2	4.104*	.143	0	2	2.029	.002	0	2	3.296
Heavy headed	.049	0	1	1.966	.034	0	2	2.205	.006	0	2	2.962	.462	-1	1	1.435	.068	0	1	2.026
Itchy or watery eye	.092	-1	0	0.544	.856	-1	1	0.932	.338	0	1	1.467	.434	-1	1	0.659	.809	-1	1	1.104

*Indicates statistically significant odds ratio, (CI) >1 and OR>1 at 95% confidence interval

There were no statically significant SBS symptoms recorded for L04 lecture hall and this could be due to its occupant density. Similar outcomes were recorded by the studies of Tsai et al. (2012) and Erdmann et al. (2002). According to Tsai et al. (2012), there was a prevalence of some SBS syndromes although there was a less CO_2 concentration with respect to ASHRAE guidelines.

The qualitative analysis of the lecture halls obtained from the student responses shows that, the students reported that the noise level they feel is in neutral range however, the recorded values were higher than the standard for the neutral range. Furthermore, some proportion of students in each lecture hall reported that the thermal comfort condition is cold throughout the lecture. The majority of students (L01-80.36%, L02-71.15%, L03-87.50%, L04-63.64%, L05-90.16%) in every lecture hall responded that their satisfaction level on the lecture halls is neutral and/or satisfied even with the significant variations of recommended CO_2 values, however with the RH falling within the recommended ranges. Therefore, it can be identified that, for the general satisfaction levels, maintaining the proper thermal comfort conditions in the lecture hall plays an important role.

Conclusions

The results of this study show that that there could be some possible associations on prevalence of SBS symptoms which can be attributed to the IEQ in air-conditioned lecture halls. The analysis conducted shows that, there is a significant prevalence in SBS symptoms such as headache, dry throat, difficulties in concentration, cough, and dryness in eye in some of the lecture halls which were considered for this study. Among the 5 lecture halls, one lecture hall hasn't recorded any significant symptom and the highest 15 minute moving average CO_2 concentration is 1745 ppm. The results further show that, there could be significant associations present with the prevalence of SBS symptoms with the variations of indoor CO_2 and RH levels which were significantly different for each of the lecture halls in comparison with the noise. There is a statistically significant difference of CO_2 concentration and RH in the recording position of each and every lecture hall (front, middle and back). Therefore, there is an impact of these parameters to the occupants according to their seating positions. Differences in occupant density also have an impact on the differences of the IEQ parameters in the lecture hall.

Higher education students spend prolonged periods in confined lecture halls with high occupancy rates which could lead to the exposure of poor indoor air quality during the course of their study. This study has shown the correlations between SBS symptoms and indoor CO_2 levels particularly for air-conditioned lecture halls where the air circulation is limited when compared with the naturally ventilated halls. Therefore, the results of this study provide valuable insights on prevalence of SBS on air-conditioned lecture halls, which should be taken into consideration in future lecture hall designing by selecting optimal dimensions, controlling number of occupants and maintaining appropriate capacity of air conditioning within the lecture hall.

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