DEVELOPING A FRAMEWORK TO EVALUATE INDOOR ENVIRONMENTAL QUALITY (IEQ) PERFORMANCE OF INDUSTRIAL BUILDINGS IN SRI LANKA

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ABSTRACT

Indoor Environmental Quality (IEQ) can be considered as one of the main measure of total building performance. Even though there are various methods to evaluate IEQ of buildings, it is evident that there is no holistic approach, which considers every possible parameter which results in a more pragmatic and operational, mechanism especially for industrial buildings. Similarly in Sri Lanka, there is no comprehensive framework applied in buildings to evaluate IEQ performance and the situation is same with other countries as there is less regard to IEQ factors in measuring building performance. The industrial buildings also lacks total IEQ performance methods being utilised, however there are few which are only based on IEQ measurements such as indoor air quality, thermal, acoustic and lighting comfort.

When considering the global view, are some evaluation methods or techniques which are being used. However for the industrial buildings there are no methods with a holistic approach. This creates the need to identify existing IEQ practices with respect to industrial buildings in order to develop a comprehensive evaluation framework for total IEQ performance of industrial buildings.

Therefore, this paper attempts to establish the indicators and sub indicators proposed for the framework to evaluate IEQ performance of industrial buildings based on preliminary investigation and literature survey as part of an on-going research project. The available IEQ techniques have been identified which needs to be validated in the next step of this research study.

Keywords: *Building Performance; IEQ Indicators; Indoor Environmental Quality; Industrial Buildings.*

1. INTRODUCTION

The Indoor Environmental Quality (IEQ) performance of buildings directly or indirectly affects to the building operations and its occupants (Heinzerling *et al.,* 2013). Furthermore, the occupant acceptance regarding the perceived IEQ was correlated with four main environmental factors as thermal comfort, Indoor Air Quality (IAQ), acoustic level and illumination level (Wong *et al.,* 2009). Today, the concept of an acceptable IEQ (IEQ) is considered as an integral part of the total building performance approach, however it is not fully appreciated yet (Wong *et al*., 2009). Further, it is highlighted that there is an emerging issue of impact on IEQ related factors on the industrial building occupants (Smith and Bristow, 1994).

Moreover, conventional studies on IEQ practices evaluation only address each of the main indicators separately (Wong *et al.,* 2008). According to a study by Heinzerling *et al.,* (2013), the literature findings confirm that there is no systematic evaluation technique for accurate assessment of the whole building IEQ performance. Similarly in Sri Lanka, there is no comprehensive framework applied in buildings to evaluate IEQ performance. The situation is same with other countries as there is no high regard on the IEQ factors in building performance (Mallawarachchi and Silva, 2012). The case is true for Industrial Buildings. This creates the need to identify existing IEQ practice in case of industrial buildings in order to develop a comprehensive evaluation framework for total IEQ performance for industrial buildings.

Therefore, it is important to identify each and every sub indicator which are relating to key indicators as IAQ, thermal comfort, acoustic comfort and lighting comfort for the evaluation of IEQ performance.

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Accordingly, the ultimate aim of this research paper is to identify indicators affecting to IEQ performance while the aim of the whole research is to develop an IEQ evaluation framework for the industrial buildings. The scope of this research paper is to development of a framework for evaluating IEQ performance of the industrial buildings. This study was focused and limited only to apparel manufacturing garments in Colombo metropolitan area.

2. CONCEPT OF INDOOR ENVIRONMENTAL QUALITY

Nowadays, the concept of Indoor Environment Quality (IEQ) is merging as a new and very useful index for the total building performance (Catalina and Iordache, 2011). Further, it is a well-documented fact that people spend most of their day to day time indoors and various aspects of the indoor environment affect the occupant's well-being and performance (Prakash, 2011). Furthermore, the quality of the indoor environment reflects on the health, comfort and productivity of occupants in buildings (Singh, 1996). In addition, it had been found that even though the buildings meet the recommended standards, the occupants often complained for various parameters, such as day lighting and thermal comfort which contributed to better IEQ. It also, had a positive effect on the occupant's perception of productivity and performance (Prakash, 2011).

Thermal comfort, lighting quality, acoustical quality and air quality are the most important and main factors of IEQ (Mahbob *et al.,* 2011). All these mentioned aspects of the indoor environment interact with each other and may have consequences on the overall indoor comfort and building energy consumption (Catalina and Iordache, 2011). Standards dealing with IEQ have been developed to define the acceptable ranges of these parameters and even though the requirements of these standards are met, not all building occupants are satisfied with the indoor environment (Frontczak and Wargocki, 2011).

It was also found that each of the IEQ parameters is important and a good value of IEQ improves working conditions and minimises complaints from the occupants (Catalina and Iordache, 2011). Further, increasing interest in this field has put additional pressure on the research community as architects, engineers, facility managers, building investors, health officials, jurists, and the public seek practical guidelines on creating a safe, healthy, and comfortable indoor environment (Kumarand Fisk, 2002). Because of this, there is a greater demand for improvements in the indoor environment which intern requires changes to building design, operation, maintenance, and occupancy (Fisk, 2000).

The following categories broadly influence the IEQ and these categories operate cumulatively and their cocktail effect contributing as a risk factor to the health in the indoor environment:

- Design and construction factors
  - Office design and layout, poor lighting and ventilation scheme, ergonomics
- Environmental factors
  - Odour, lighting, temperature, dust, noise, outdoor and indoor environment
- Perceptual and psychological factors
  - Hysteria and stress due to lack of privacy, or because of lack of control or claustrophobic effects due to sealed construction
- Cultural and organisational factors
  - Cleanliness, maintenance, management and their relationships with occupants (Singh, 1996)

2.1. KEY INDICATORS AFFECTING TO INDOOR ENVIRONMENTAL QUALITY (IEQ)

Overall satisfaction and perception of indoor environment, being a subjective evaluation, can be impacted by various contextual factors (Jonson and Wilhelmsson, 2012). Figure 1 indicates the main four indicators which are affecting to IEQ performance.

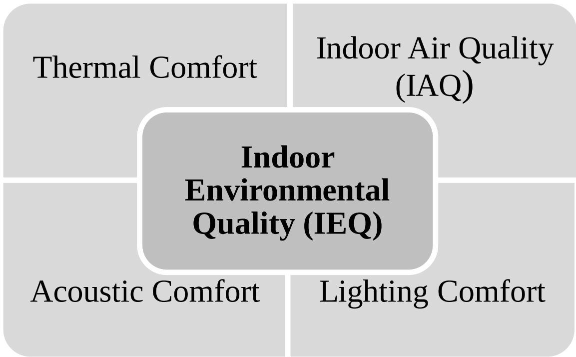

Figure 1: Main Indicators of IEQ

2.1.1. ACOUSTIC COMFORT

All sounds that are distracting, annoying, or harmful to everyday activities such as work, rest, study and entertainment can be regarded as noises (Lai *et al*., 2009). Noise and vibration in a wave motion can be a discomfort in terms of psychological and can come from outdoors, engineering services. Further, the noise pollution can create stressful feelings and health effects such as dizziness in humans (Mahbob *et al.*, 2011). The acoustic comfort also relates to the ability of the building to provide an environment with minimal unwanted noise (Ncube and Riffat, 2012).

2.1.2. LIGHTING COMFORT

Light can influence the building occupants' comfort level in several ways through vision. It is really important towards the productivity. Poor quality in lighting can cause fatigue, drowsiness, nausea, eye irritation etc. Poor lighting can be because of excessive lighting or inadequate of lights (Mahbob *et al.*, 2011). When considering the acceptable lighting level at various places, general Office illumination levels should be at least 500 lux and the colour rendering index should range from 60 to 80 lux (Ncube and Riffat, 2012). There are number of available guides and codes of practices which provide recommendations on adequate indoor lighting designs (Lai *et al.*, 2009). According to the guidelines and code of practices, an illumination level of 2000 lx with a colour rendering index not less than 90 is required for a fabric inspection factory while 500 lx with a colour rendering index range is from 60 to 80 should be maintained in a general office (Ncube and Riffat, 2012).

2.1.3. INDOOR AIR QUALITY (IAQ)

IAQ is one of the major contribution factors in determining the IEQ level (Mahbob *et al*., 2011). It was found that over the past decades, exposure to indoor air pollutants is believed to have increased due to a variety of factors, including the construction of more tightly sealed buildings, the reduction of ventilation rates (for energy saving), and the use of synthetic building materials and furnishings as well as chemically formulated personal care products, pesticides and household cleaners (Wong *et al.,* 2008). However, investigating all types of indoor air pollutants for general air quality monitoring and assessment is a very complicated matter (Mui *et al.,* 2008). There have been growing concerns in the past decade over complaints attributed to poor indoor air quality (IAQ). Various environmental parameters have been suggested for IAQ assessment (Chao e*t al.*, 2001). In a country which has a hot-humid tropical climate like, the wind or the air flow is required to accelerate the evaporation so that the discomfort of stickiness of the skin can be reduced (Nasir *et al.*, 2011). Present surveys prove IAQ play an important role and has a strong and direct correlation with work efficiency output of individual workers (Mahbob *et al.*, 2011).

2.1.4. THERMAL COMFORT

Thermal comfort can be described according to air temperature, air velocity, and relative humidity and can be expressed by the building user perception whether they want it to be cooler or warmer to be comfortable

(Mahbob *et al.*, 2011). In order to determine thermal comfort level in workplace, individual factors such as gender, activity before they enter the building and the age plays important roles that will contribute to environment satisfaction (Mahbob *et al.*, 2011). Besides, the effective temperature for thermal comfort was found to be around 26.1˚C and will differ according to race, age. However, the sex did not influence the perception of thermal comfort (Mui *et al.*, 2008). Although there are few of the studies conducted previously any of them, did not acknowledge the influence of age, gender, physical conditions and educational level towards thermal comfort perceptions. More work is required for other "non-thermal" parameters which affects thermal comfort (Kwong *et al.*, 2014). Three factors contributing to the increase in temperature in a building are as follows: (Nasir *et al.*, 2011)

- Emission of heat from the lights and electrical appliances
- Heat gain from the outside through the walls, windows and roofs of the buildings
- Heat convection by hot air from outside the building

3. IEQ EVALUATION TECHNIQUES

There are many environmental methodologies and methods for evaluating environmental performance of buildings (Sinou and Kyvelou, 2006). The assessment of any building development should touch the aspect of "Holistic Health" of the built environment which would include all aspects of people's needs and functions, in terms of physical, emotional as well as social health. Further, to minimise pollution effects from building materials, moulds, and dampness and glare that would cause adverse impact on the occupants (Kim and Kim, 2010). As a result of information arising from such studies, various models have emerged that seek to assess or measure these factors by various researchers (Kamaruzzamana *et al.*, 2011). These schemes invariably incorporate assessments relating to a number of attributes of IEQ (IEQ) and each of which carries credit points to contribute to the overall result (Kamaruzzamana *et al.*, 2011). Some of the numerous buildings' environmental evaluation tools which are corresponding to the various methodologies are recently developed, conducted detailed and thorough assessments, which seem to provide reliable results (Sinou and Kyvelou, 2006).

3.1. MULTIVARIATE REGRESSION ANALYSIS

Workplace variables inducing the largest number of health symptoms, comfort or odour concerns were investigated by multivariate regression analysis (Kim and Kim, 2010). It was realised that successful control of the indoor environment requires an understanding of the integral indoor environmental parameters and also the occupants' acceptance of the four basic IEQ components for an office environment (Wong *et al.*, 2008). Further, mathematical expressions were proposed for the overall IEQ acceptance using a multivariate logistic regression model, which can be used as a quantitative measure for an office environment design (Lai *et al.*, 2009).

3.2. IEQ EVALUATION TOOLS

Finding accurate, easy-to-use, and inexpensive measurement equipment is one of the major hurdles in IEQ performance evaluation (David *et al.*, 2013). With the explosion of wireless monitoring equipment in recent years, measuring various building parameters has become a much less labour-intensive process (Mui and Chan, 2005). However, there are still a number of operational hurdles that still make measurement, a cumbersome process (Benton *et al*., 1990). While sensor and logging device manufacturers have made products that are increasingly accurate and easy to use such as wireless, the work of creating devices with multiple sensors is still largely in the hands of the users. IEQ measurement requires a combination of devices and individual sensors to capture the state of IEQ in a space (Chiang *et al.*, 2001). Further, data logger and electronic sensors typically used in evaluation of thermal comfort (Kwong *et al.*, 2014).

3.3. GREEN BUILDING TOOLS

For enhancing building environmental performance, many voluntary assessment schemes have emerged, such as the Leadership in Energy and Environmental Design (LEED) of the US, the Building Research

Establishment Environmental Assessment Method (BREEAM) of the UK, and the Green Star of Australia GB Tool Method, CASBEE Method, HQE Method, VERDE Method, SCATS, CBE (Liang *et al.*, 2014). All such schemes invariably embrace assessments on a number of IEQ (IEQ) parameters and each of which carries certain credit points to the overall result (Lai and Yik, 2009). Table 1 presents the indicators of IEQ, which are addressed in green building tools.

Table 1: Indicators of IEQ Addressed by Various Tools

IEQ Related Parameters Involved	Tools						
	GB Tool Method	LEED Method	CASBEE Method	HQE Method	VERDE Method	SCATS	CBE
Day lighting	×	×		×			
Air Ventilation Speed				×		×	
CO2	×					×	
Relative Humidity		×				×	
Illumination		×	×			×	
Indoor Air Quality		×			×		×
Ventilation		×					
Air Temperature		×				×	
Air Quality			×				
Noise / Acoustics		×	×	×	×	×	×
Thermal Comfort			×		×		×
Lighting			×	×	×		
Visual Quality							×

4. VARIOUS PARAMETERS INFLUENCING IEQ PERFORMANCE

Some of the present surveys show acoustic and lighting stand in the lowest ranking of IEQ parameters, compared to IAQ and thermal comfort due to less complaints (Mahbob *et al.*, 2011). But, some other research studies were orientated only towards the impact of glazing on the energy consumption and thermal comfort (Catalina and Iordache, 2011) deliberated whether overall satisfaction can be described by stable relative weights of different aspects of indoor environment and concluded that generally level of thermal and air quality is more important than lighting and humidity; however, relative weights can differ between occupants, depending on their requirements (Humphreys, 2005). In another thermal comfort study conducted, it was concluded that the air temperature, wind velocity and solar irradiance were significant aspects that influenced the occupants' thermal sensations while relative humidity; acoustic, lighting and indoor air quality had no statistical importance (Hwang *et al.*, 2006). It was stated in another research that, while thermal comfort, indoor air quality and visual environment are of comparable importance, aural environment is the major determining factor (Lee *et al.*, 2012). But, correlations have the same range of magnitude, indicating that all 4 main environmental parameters are equally important for the assessments of the overall indoor environment and contribute equally much to the overall acceptability if only their acceptability levels are similar is stated in another research (Monika *et al.*, 2012). Based on the total votes, both thermal and aural environmental qualities were deemed the most important contributors whereas indoor air quality was considered the least (Lai *et al.*, 2009).

5. SUMMARY OF BUILT ENVIRONMENT RELATED FACTORS INFLUENCING IEQ PERFORMANCE

According to the Table 2, summarisation of the 20 present researches on IEQ show that, there are various sub indicators which are affecting to overall IEQ performance has been identified. But, most of the research studies were orientated only toward the specific set of indicators and none of those addressed each and every indicator affecting to IEQ.

Table 2: Indoor Environmental Quality Indicators

	Indoor Environmental Quality Indicator	**References (Shown in below)**																			
		01	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	IAQ	×													×	×			×	×	
1.	CO Concentration																		×		×
2.	CO_2 Concentration	×		×	×		×			×		×	×		×			×	×		×
3.	CO_3Concentration																		×		×
4.	Dust					×															
5.	Fresh Air Supply (Ventilation Rate)	×	×																	×	×
6.	Moisture Level																			×	
7.	Odour				×																
8.	Perceive Air Quality	×	×																		
9.	Relative Humidity (RH)	×	×	×			×	×		×		×	×		×		×	×	×		
10.	Relative Air Velocity	×								×			×		×						
11.	Smell		×													×				×	
12.	Volatile Organic Compound					×	×					×			×			×	×		
13.	Water Vapour Pressure	×																		×	
	Lighting Quality	×				×		×	×		×					×	×	×		×	
14.	Colour Rendering Index	×	×					×	×		×				×	×					
15.	Day Lighting Factors	×	×	×							×	×			×	×					×
16.	Distance from Window		×					×												×	
17.	Flicker Rates	×										×									×
18.	Glare	×	×	×			×	×							×			×		×	×
19.	Illuminance	×		×	×		×	×		×		×	×	×	×	×			×	×	×
20.	Illumination Uniformity	×																			
21.	Luminance Distribution	×					×		×												

	Indoor Environmental Quality Indicator	References (Shown in below)																			
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
22.	Rendering And Appearance (Colour Characteristics)	×																			
23.	Room Surface Reflectance	×																			
24.	Wall Colour								×					×		×					×
	Thermal Comfort	×	×	×	×	×	×	×	×	×	×		×	×	×			×			
25.	Dew Point Temperature	×																			
26.	Air Temperature	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×				
27.	Mean Radiant Temperature	×		×						×											
28.	Occupants Metabolic Rate								×												×
29.	Surface Temperature of Clothing	×																			
30.	Thermal Resistance of Clothing	×											×								×
	Acoustic Quality			×		×	×	×	×	×	×	×	×	×	×	×	×	×		×	×
31.	Sound Insulation			×								×									×
32.	Outdoor Traffic Noise											×									
33.	Equipment and Mechanical Noise											×									
34.	Overhearing Private Conversation											×									
35.	Excessive echoing of voices/sounds											×									

1- (Ncube and Riffat, 2012) **2**- (Kamaruzzamana *et al*, 2011) **3**- (Liang *et al*, 2014) **4-** (Wong, 2008) **5**- (JonssonandWilhelmsson , 2013) **6**- (Choia *et al*, 2010) **7**- (Mahbob *et al.*, 2011) **8**- (Kim and Dear, 2012) **9**- (Lee *et al*, 2012) **10**- (Monika *et al*, 2012) **11**- (Abbaszadeh *et al*, 2006)**12**- (Lai *et al*, 2009) **13**- (Chiang *et al*, 1999) **14**- (Chianga and Lai, 2002) **15**- (Frontczak M. , 2011) **16**- (Mydin *et al*, 2012) **17**- (Sulaiman *et al*, 2013) **18**- (Fadeyin *et al*,2014) **19**- (Nasir *et al,* 2011) **20**- (Steskens and Loomans, 2010)

When considering as a whole, there are some indicators which were addresses by majority of the survey studies such as CO_2 concentration, Relative Humidity (RH), relative air velocity, day lighting factors, glare, illuminance and air temperature while some other factors are addressed in only one or few research studies such as CO, CO_3, dust, moisture level, perceive air quality, illumination uniformity, rendering and appearance (colour characteristics), room surface reflectance, dew point temperature, surface temperature of clothing, thermal resistance of clothing, outdoor traffic noise, equipment and mechanical noise, overhearing private conversation and excessive echoing of voices/sounds.

6. APPLICATION OF BUILDING PERFORMANCE AND IEQ EVALUATION IN SRI LANKA

Applicability of Building Performance Evaluation concept is rare in the Sri Lankan context. When considering about the researches that have been conducted related to BPE, Linkesan (2003) has carried out a research to evaluate the performance of school buildings in Sri Lanka using a post occupancy evaluation, and (Kiritharan, 2002) has carried out a POE to evaluate the performance of residential apartments in Sri Lanka.

Even though the application of BPE techniques in the Sri Lankan context is very low; there is a high demand for it in the hotel industry. The use of Building environmental performance assessment methodologies such as LEED and BREEAM (eg: Aitken Spence hotels) are considered as a plus point of attracting customers to their industry (Konara, 2009).

The preliminary investigations which was carried out by getting opinions from the industry practitioners revealed that in Sri Lankan context, there is a requirement for evaluating basic parameters with respect to IEQ in garment industry buildings using the lux level, dust level etc., However, these surveys are not done in a serious manner and are done for the compliance of the Factory Ordinance. Normally, these surveys are conducted by the department of Labour.

According to a study by Heinzerling *et al.,* (2013), the literature findings confirm that there is no systematic evaluation technique for the accurate assessment of whole building IEQ performance. It is further verified by Adebiyi *et al.,* (2007), as there is no generally agreed model for IEQ evaluation. Consequently, a critical need exists to develop an IEQ performance evaluation framework to define acceptable IEQ levels for buildings and to provide standard way to doing continuous improvement of IEQ (Kumar and Fisk, 2002).

7. CONCLUSIONS

This study explores the factors affecting to IEQ which is a major part of total building performance. The literature review was done on the indicators and sub indicators of IEQ and current techniques regarding the evaluation of IEQ performances. According to the industrial practitioners, holistic approach to evaluate IEQ by considering each and every parameter needs to be considered, especially in the industrial sectors such as the garment manufacturing buildings as IEQ directly relate to the occupancy satisfaction and productivity of the occupants.

Based on the literature finding, development of a conceptual framework will be done by based on the four major indicators and their sub indicators. It is proposed to carry out a survey, which will indicate the relative importance of sub indicators through the opinion of industrial practitioners and AHP tool will be used to analyse the data.

It is perceived that the ultimate results study can be used for the evaluation of the IEQ of industrial buildings and also report the existing situation in the Sri Lankan context. Further the findings can be used for continuous improvement in IEQ of industrial buildings in Sri Lanka.

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