A FRAMEWORK FOR THE EVALUATION OF INDOOR ENVIRONMENTAL QUALITY (IEQ) PERFORMANCE IN APPAREL INDUSTRY BUILDINGS IN SRI LANKA

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ABSTRACT

In the modern world, many people spend large portion of their time in built environments. Accordingly, significance of built environments' performance is increasing over past two decades. It draws the attention towards the concept of Indoor Environmental Quality (IEQ) to determine how well built environments are performing as IEQ performance directly affects occupants' health, comfort, satisfaction and ultimately for a productive work environment. Moreover, IEQ concept can be considered as an integral part of total building performance approach.

Today in Sri Lankan industrial sector, especially apparel manufacturing sector grows upward in speedily. For this rapidly development, performance of the built environment is vital as it is having direct relationship with occupants' productivity. At the present, various approaches to evaluate IEQ performance has being developed. However, it is evident that there is no holistic approach. Similarly in Sri Lanka, there is no comprehensive framework applied in industrial buildings to evaluate IEQ performance. This necessitates the important of developing a holistic IEQ evaluation approach which would greatly benefit to the industrial sector.

Survey methodology is used in the research and RII is employed as a data analysing tool to validate the IEQ indicators which have been identified in literature review and modified in preliminary survey. Further, it is established the most significant indicators based on their importance towards IEQ performance in apparel industry buildings with AHP tool. The developed framework comprised with four main IEQ indicators as thermal comfort, indoor air quality, acoustic quality and lighting quality. This framework focused on holistic approach to measure IEQ performance which will allow acceptable built environment while processing continuous improvements.

Keywords: *Building Performance; Built Environment; Indoor Environmental Quality (IEQ); IEQ Indicators; Industrial Buildings.*

1. INTRODUCTION

The indoor environment quality (IEQ) performance of buildings directly or indirectly affects the buildings operation and its occupant's satisfaction and productivity (Heinzerling *et al.*, 2013). At present, the concept of an acceptable IEQ is considered as an integral part of the total building performance approach, however it is not fully appreciated yet (Wong *et al.*, 2008).

According to Sinou and Kyvelou (2006), there is an emerging issue of poor IEQ related factors negatively impact on industrial building occupants. As the investments on industrial buildings become popular and large numbers of people were attached to the industrial work settings, it was arisen the demand for IEQ improvement to reduce impact of poor IEQ conditions on building occupants (Bannet, 1984).

According to Sinou and Kyvelou (2006), nowadays several methods are in practice for evaluating IEQ performance of buildings. 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

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framework to define acceptable IEQ levels for buildings and to provide standard way of doing continuous improvement of IEQ (Kumar and Fisk, 2002).

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 no high concentration on some IEQ factors in building performance (Mallawaarachchi and Silva, 2012). Industrial buildings also have not been considered the evaluation of total IEQ performance, even though some of buildings have concentration on few IEQ measurements. Therefore, this research focused to develop a framework to evaluate for total IEQ performance of industrial buildings in Sri Lanka.

2. LITERATURE REVIEW

People spend almost 90% of life time in built environment when the world is in the developed part of it (Klepeis *et al.*, 2001). Main relationship between buildings and people is that, buildings are for people and people are the facilitators of built environments (Barrett, 1992 cited Amaratunga and Baldry, 1998). Furthermore, Barrett (1992 cited Amaratunga and Baldry, 1998) emphasised that, the environments create by buildings provides the temperature, humidity, lighting and ventilation which necessary for people to live and work productively.

In the present, the concept of IEQ is growing as a new and very useful concept of the building performance and quality (Catalina and Iordache, 2011). It is because of people spending most of their time in built environments and various aspects of the indoor environment affect its occupant's wellbeing and performance (Prakash, 2005). Further, the quality of the indoor environment reflects on the health, comfort and productivity of occupants in built environment (Singh, 1996).

Thermal comfort, lighting quality, acoustic quality and indoor air quality are the most important indicators of IEQ (Mahbob *et al.*, 2011). All these four indicators of the indoor environment interact with each other and make impact on the overall indoor comfort and energy consumption of the building (Catalina and Iordache, 2011). Figure 1 illustrated the main indicators relating to the concept of IEQ performance.

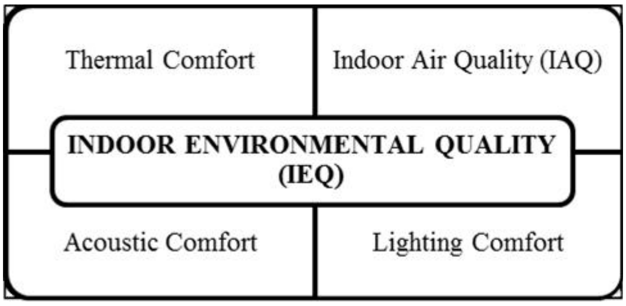

Figure 1: Main Indicators of IEQ

Industrial sector, basically apparel manufacturing industry has an important place in economy of Sri Lanka while it has become the largest export industry in Sri Lanka since the year 1986. It is also the largest net foreign exchange earner of the country and also the biggest industry in Sri Lanka (Dheerasinghe, 2006). Moreover, apparel manufacturing industry is the leading manufacturing industry in Sri Lanka up to now and it has emerged as the country's main export earner and the largest single employment provider (Saheed, 2005). There are 830 garment factories in Sri Lanka, of which 157 are small, 438 are medium, and 235 are large. The industry produces around 500 million units of garments per annum of which woven garments account for 55% and knitwear 45 % (Saheed, 2005).

Heerwagen (2000) stated that, there is a direct effect of IEQ on factory workers performance. According to the present surveys, IEQ plays an important role and it has a strong and direct correlation with work efficiency and also earlier scientific studies conclude that 16% of worker's performance can be increased, if the building occupants are comfortable with their indoor environment (Mahbob *et al.*, 2011). Most of the industrial building owners and responsible persons such as health and safety executives, maintenance engineers applied some techniques to evaluate the building performance and yet, those methods are conducted in their own customized ways (Rathnayaka, 2010). Furthermore, Rathnayaka (2010) stated that, maximum benefits of those evaluations are doubtful, due to that reason.

3. RESEARCH METHODOLOGY

The quantitative approach with the survey methodology was selected for this research and three steps were adopted to develop the IEQ performance evaluation framework.

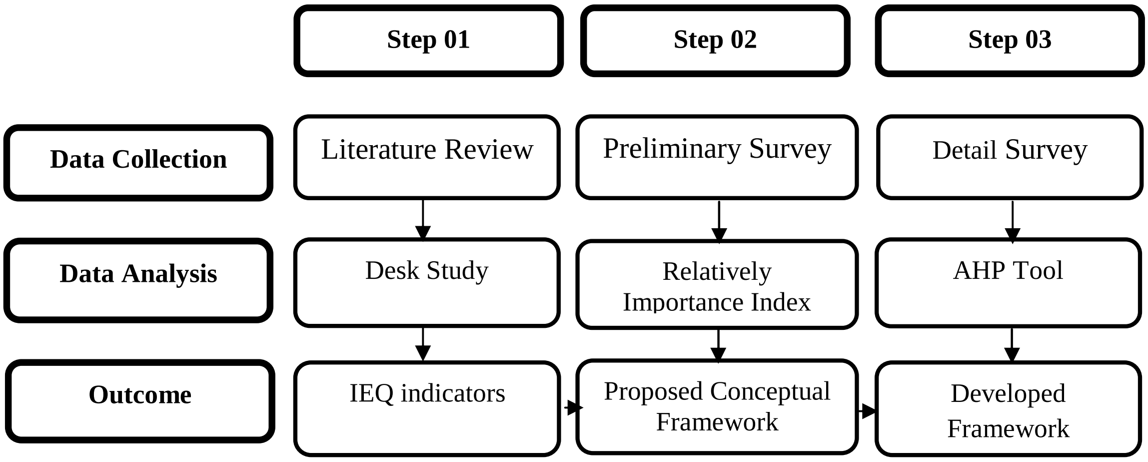

Figure 2: Steps in the Research Methodology

Step 1 - A comprehensive literature review was carried out in order to explore the concept of IEQ, IEQ performance evaluation techniques and tools, current IEQ performance condition in Sri Lankan apparel manufacturing sector and IEQ related indicators through referring books, journal articles and unpublished dissertations.

Step 2 - Preliminary survey was carried out among ten (10) industry experts and analysed using Relatively Importance Index (RII) in order to serve the most significant IEQ indicators to derive with a conceptual framework for the development of holistic framework to evaluate IEQ performance in apparel manufacturing industry in Sri Lanka.

Step 3 - Based on the Analytical Hierarchy Process (AHP) tool which provided the facility of prioritization of factors, the questionnaire was prepared by using the data gathered from preliminary questionnaire survey. Since the data collection was mainly aim at professionals in garment manufacturing field in Western Province, questionnaires were distributed among 30 respondents as large size of sample may be impractical as there is a great tendency to provide arbitrary answers (Wong and Li, 2007). Moreover, AHP survey with 30 number of respondants sample size has been conducted in previous researches (Sato, 2003).

Detail questionnaire survey was carried out among thirty (30)IEQ related industry experts and analysed using Analytical Hierarchical Process (AHP) in order to validate and prioritize the preliminary survey findings. The Proposed developed framework consisting of four IEQ main indicators and its twenty seven sub indicators (Figure 3) were developed using the literature review and preliminary survey findings.

4. GENERIC FRAMEWORK FOR EVALUATING IEQ PERFORMANCE

Indicators which are related to IEQ were identified referring twenty researches which were done based on the IEQ performance evaluation which had been discussed in literature review. In this identification, sub indicators were identified basically in major four key indicators, namely indoor air quality, lighting quality, thermal comfort and acoustic quality. It had listed 12 indicators which are related to indoor air quality, 11 indicators which are related to lighting quality, 6 indicators which are related to thermal comfort and 5 indicators which are related to acoustic quality. Hence, altogether 34 indicators were identified (Refer Table 1).

Apart from the IEQ indicators which were identified in the literature review, respondents had identified 15 additional indicators and seven (7) indicators were removed, two (2) indicators were combined as one and three (4) indicators were modified while three (3) were split in to two. In order to identify the importance of the indicators for evaluating the IEQ performance, it was necessary to rank the indicators according to their importance and remove the indicators which are having a less importance. To determine the relative importance of IEQ indicators, the results obtained from preliminary survey were transformed to importance indices based on the RII value. Table 2 shows the RII values and the ranking position of each identified IEQ indicators according to their level of importance in evaluating total IEQ performance.

Table 1: RII Prioritization of IEQ Sub Indictors

	Indoor Environmental Quality (IEQ) Indicator	**RII**
	Indoor Air Quality (IAQ)	
1	Fresh Air Supply	0.92
2	CO_2 Concentration	0.88
3	Relative Humidity (RH)	0.84
4	Perceive Air Quality	0.80
5	Hazardous Chemical	0.80
6	Fabric Dust	0.76
7	Micro Organism (Fungus, Bacteria etc.)	0.72
8	Ventilation Rate	0.68
9	Natural Odour	0.48
10	Chemical Organ Odour	0.48
11	Volatile Organic Compound	0.48
12	Water Vapour Pressure	0.48
13	Relative Air Velocity (Mean)	0.48
	Lighting Quality	
1	Illumination Uniformity	0.84
2	Lighting Power Density (LPD)	0.80
3	Light Intensity	0.80
4	Natural (Day) Lighting	0.76
5	Direct Glare	0.76
6	Flicker Rates	0.68
7	Indirect (Reflected) Glare	0.68
8	Wall Colour	0.48
9	Nr of Lights according to the SqrFeets	0.48
10	Colour Variation	0.48
11	Distance between the Floor Level and Light Source	0.48
12	Direction of the Occupant Regarding Light Source/Bulb	0.44
	Thermal Comfort	
1	Operative Nature (light, medium, low work load of the occupant)	0.72
2	Machine Nature	0.72
3	Dry Bulb Temperature	0.68
4	Building Conductivity	0.68
5	Factory Layout	0.68
6	Wet Bulb Globe Bulb Temperature Index (WBGT Index)	0.64

	Indoor Environmental Quality (IEQ) Indicator	RII
7	Occupants Metabolic Rate	0.64
8	Wet Bulb Temperature	0.48
9	Mean Radiant Temperature	0.48
10	Construction Material	0.48
11	Air Temperature	0.44
	Acoustic Quality	
1	Equipment and Mechanical Noise	0.76
2	Sound Absorption	0.68
3	Outdoor Traffic Noise (Insulation)	0.68
4	Overhearing Private Conversation	0.68
5	Building Size	0.64
6	Plant Room and Other Related Noises	0.64
7	Sound Pressure Level	0.48
8	Excessive Echoing of Voices/Sounds	0.44
9	Used Material for The Construction	0.44

The insignificant factors were disregarded which have the RII value lesser than 0.5. To gain a better result from AHP analysis, it was removed the 8th indicator of IAQ as it was advised to limit the main and sub factors in number seven on the basis of Miller's theory (Perera and Sutrisna, 2010).

According to the result of RII analysis, six indicators under the key indicator of IAQ, five indicators which were under the key indicator of lighting quality, four indicators which were under the key indicator of thermal comfort and three indicators which were under the key indicator of acoustic quality were identified as less importance indicators.

5. DEVELOPED FRAMEWORK FOR IEQ EVALUATION

Each IEQ related sub indicator was prioritized by using the AHP tool with the data which was obtain through the AHP questionnaire survey which was contained pairs of key and sub indicators. Those indicators were compared based on their relative importance with the intention of improving the effectiveness of IEQ performance evaluation framework for the apparel manufacturing facility. The ultimate objective of the adaptation of AHP tool was to obtain performance scores for each and every indicator for the prioritisation. This tool is consisted three interrelated steps as air wise calculation, normalised calculation and finally, consistency calculation as the judgment of the respondents may not be consistent.

Performance scores or the relative weights were obtained through the normalisation of pair-wise comparisons. Indicators which were used to develop the conceptual framework were developed with the results obtained in preliminary survey by using RII calculation to conduct the pair wise comparison. Therefore, it can be developed the generic framework for evaluate IEQ performance of apparel manufacturing facility can be developed with final data findings of the AHP tool. Indicators which were prioritized are presented in Table 2. Validity and consistency of the data set which was used to develop the framework has been confirmed by the lower consistency ratio than the given acceptable value of 1.0. Based on that fact, it can be justified that, this framework can be utilised for evaluating the IEQ performance of apparel manufacturing facility.

In Table 2, first column named 'Rank' indicates the relevant ranks of IEQ sub indicators under relevant main indicators according to their performance scores. Overall performance scores were obtained by multiplying the performance score for relevant sub indicator by the performance score which is allocated for the main indicator of relevant sub indicator. 'Overall Rank' was prioritized by referring overall performance scores. The overall performance scores of the all IEQ sub indicators were added up to 1.00

while overall performance scores of the IEQ sub indicators within the relevant main indicator were added up to the performance score of relevant main indicator.

Table 2: Prioritized IEQ Indicators

Rank	Indoor Environmental Quality (IEQ) Indicator	Performance Score	Overall Performance Score	Overall Rank
1	**Indoor Air Quality (IAQ)**	**0.368**		
1.1	Fresh Air Supply	0.302	0.111	1
1.2	CO_2 Concentration	0.151	0.055	5
1.3	Relative Humidity (RH)	0.116	0.043	9
1.4	Perceive Air Quality	0.117	0.043	8
1.5	Hazardous Chemical	0.178	0.066	4
1.6	Fabric Dust	0.091	0.033	14
1.7	Micro Organism (Fungus, Bacteria etc.)	0.045	0.017	23
2	**Lighting Quality**	**0.296**		
2.1	Illumination Uniformity	0.071	0.021	20
2.2	Lighting Power Density (LPD)	0.124	0.037	11
2.3	Light Intensity	0.183	0.054	6
2.4	Natural (Day) Lighting	0.150	0.044	7
2.5	Direct Glare	0.106	0.031	15
2.6	Flicker Rates	0.291	0.086	2
2.7	Indirect (Reflected) Glare	0.074	0.022	19
3	**Thermal Comfort**	**0.229**		
3.1	Operative Nature (light, medium, low work load of the occupant)	0.296	0.068	3
3.2	Machine Nature	0.157	0.036	12
3.3	Dry Bulb Temperature	0.130	0.030	16
3.4	Building Conductivity	0.120	0.027	17
3.5	Factory Layout	0.150	0.034	13
3.6	Wet Bulb Globe Bulb Temperature Index (WBGT Index)	0.098	0.022	18
3.7	Occupants Metabolic Rate	0.049	0.011	25
4	**Acoustic Quality**	**0.107**		
4.1	Equipment and Mechanical Noise	0.348	0.037	10
4.2	Sound Absorption	0.194	0.021	21
4.3	Outdoor Traffic Noise (Insulation)	0.124	0.013	24
4.4	Overhearing Private Conversation	0.067	0.007	27
4.5	Building Size	0.166	0.018	22
4.6	Plant Room and Other Related Noises	0.102	0.011	26

Among four main indicators ‘IAQ’ main indicator obtained the highest performance score (0.37) and ‘Lighting Quality’ (0.30) obtained the second highest performance score while ‘Thermal Comfort’ (0.23) and ‘Acoustic Comfort’ (0.11) respectively obtained the third and fourth highest scores. Overall rank in accordance with the overall performance scores of the IEQ sub indicators are presented in the Table 2.

According to the figures presented in the Table 2 ‘Fresh Air Supply’, ‘Flicker Rate’, ‘Operative Nature (light, medium, low work load of the occupant)’, ‘Hazardous Chemical’, ‘CO_2 Concentration’ and ‘Light Intensity’ indictors have obtained the highest overall performance scores exceeding 0.05. Therefore the foresaid IEQ sub indicators can be identified as the most significant indicators to evaluate the overall IEQ performance of the apparel manufacturing factory. According to the presented figures the highest important indicator which is ‘Fresh Air Supply’ is approximately sixteen times greater than the least important sub indicator which is ‘Overhearing of Private Conversation’. It shows the criticality of the highest important indicator when comparing with the least important indicator.

Further, sub IEQ indicators which are obtain performance scores lower than 0.03 can be identified as moderately important indicators which are ‘Natural (Day) Lighting’, ‘Perceive Air Quality’, ‘Relative Humidity (RH)’, ‘Equipment and Mechanical Noise’, ‘Lighting Power Density (LPD)’, ‘Machine Nature’, ‘Factory Layout’, ‘Fabric Dust’, ‘Direct Glare’ and ‘Dry Bulb Temperature’. Performance score below 0.03 can be identified as the least important indicators which are namely ‘Building Conductivity’, ‘Wet Bulb Globe Bulb Temperature Index (WBGT Index)’, ‘Indirect (Reflected) Glare’, ‘Illumination Uniformity’, ‘Sound Absorption’, ‘Building Size’, ‘Micro Organism (Fungus, Bacteria etc.)’, ‘Outdoor Traffic Noise (Insulation)’, ‘Occupants Metabolic Rate’, ‘Plant Room and Other Related Noises’ and ‘Overhearing Private Conversation’.

The framework was developed on the basis of findings of the literature review, findings of the preliminary questionnaire survey and then finalised with the finding of AHP survey. As IEQ performance can be identified as one of the integral parts of total building performance IEQ performance is presented as a subset of total building performance (Refer Figure 3).

Literature review identified that the main and sub indicators which are influence on IEQ performance in the built environment. Then, those indicators were modified and ranked according to the relatively importance while ignoring the less importance indicator by applying the RII tool. Furthermore, relatively higher importance indicators were prioritized with the AHP survey on the basis of importance of each indicator to the apparel manufacturing sector in Sri Lanka. Those prioritized indicators were presented in respectively under the four main indicators in the framework.

Framework illustrated that the importance of proper IEQ performance evaluation as occupants' satisfaction, increasing the productivity of occupants. The importance of IEQ evaluation was derived from the literature review as considerable number of researchers have being emphasised it. Moreover, this IEQ performance evaluation framework can be applied to measure the adequacy of current practice and through the measured results organisations can use for continuous improvements of IEQ performance within apparel manufacturing facility. This application of the IEQ framework was focused on developing this framework with the intention of mentioned application as achieving ultimate objective of this research.

This framework can be used in the design and operation stage of an apparel manufacturing facility to maintain proper IEQ performance. Industry practitioners who are engaged with IEQ performance related activities as Facilities Managers, Health and Safety Executives, Maintenance Managers/ Engineers, Sustainable Officers, Factory Inspection Engineers will be the beneficiaries of this framework.

During the evaluation of IEQ performance within the workplace the evaluator can use this framework to identify the indicators which have to be highly concerned. Moreover, this framework can be used to identify most significant indicators as this framework has being prioritized the indicators based on their importance. This can be referred to decide the indicators which should be significantly taken into consideration among various IEQ indicators.

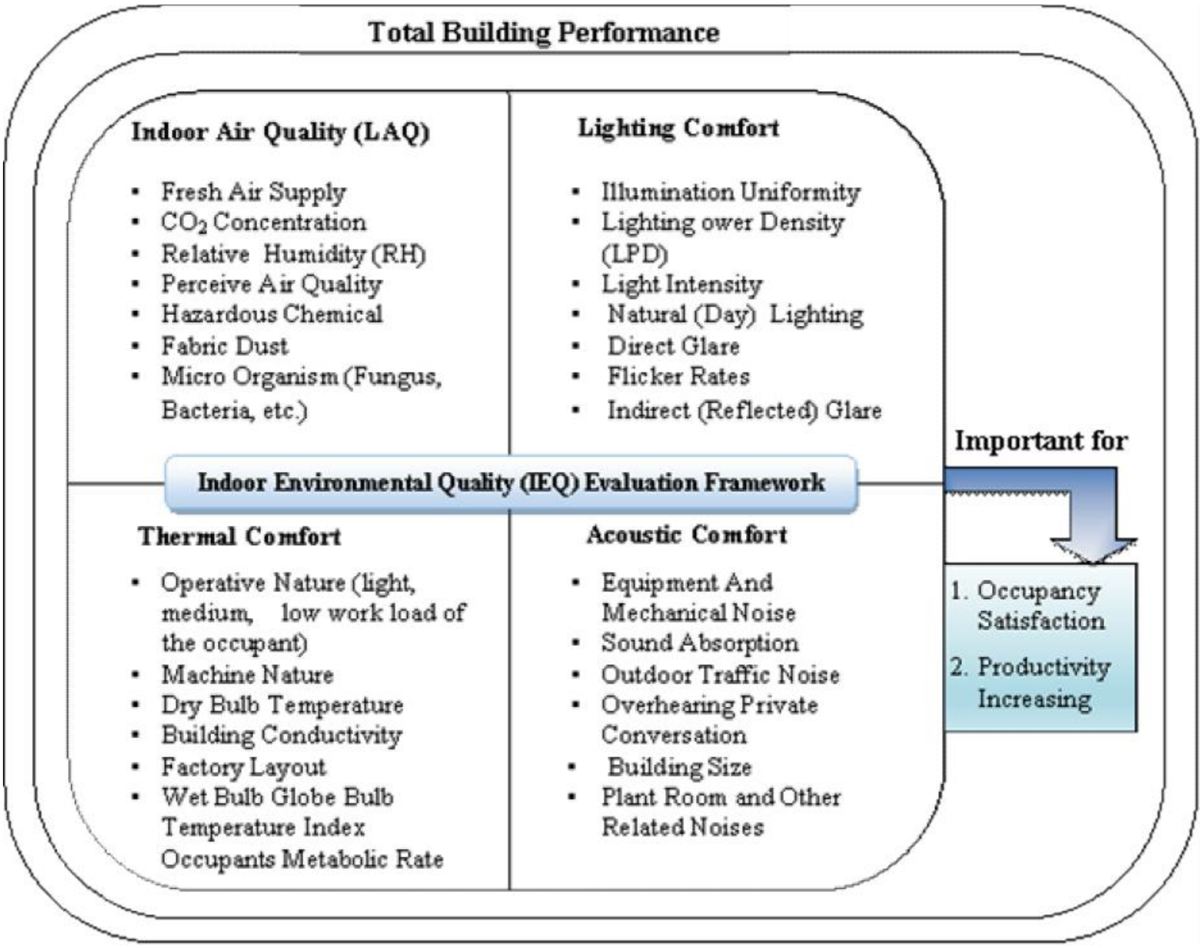

Figure 3: Developed Framework for Evaluating IEQ Performance

6. CONCLUSIONS

A conceptual framework was proposed compromising of four main indicators and fourth five sub indicators to evaluate IEQ performance of apparel manufacturing industry in Sri Lanka. With the research findings of preliminary survey and interviews, the researcher proposed a conceptual IEQ evaluation framework for the industrial buildings of Sri Lanka: Apparel industry.

Based on the AHP survey outcome, the generic IEQ performance evaluation framework had been developed with performance scores which represented the relative importance of each main and sub IEQ indicators. These performance scores provided opportunity to consider the significance of each and every IEQ main or sub indicator from another IEQ main or a sub indicator respectively. Moreover, overall performance scores of IEQ indicators were calculated as to pave the path to prioritise IEQ sub indicator of each main indicator with each other.

This research facilitate for a successful structured framework to evaluate the IEQ performance as providing a good solution and pave the path for continuous improvements action towards occupancy satisfaction and productivity with identifying significant IEQ indicators for the overall IEQ performance of the industrial buildings, basically the apparel manufacturing sector within Sri Lankan context.

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