IMPROVING INDOOR AIR QUALITY FROM EFFECTIVE VENTILATION SYSTEMS IN OFFICE BUILDINGS IN SRI LANKA

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ABSTRACT

Indoor air quality (IAQ) becomes a major consideration in indoor environments as it directly affects occupants' health and comfort. Sick building syndrome (SBS) and adverse perception on IAQ had become significant issues of poor IAQ in Sri Lankan context. These IAQ problems arise due to poorly designed, maintained, or operated ventilation systems. Further, different types of ventilation systems such as natural ventilation and mechanical ventilation have different impacts in IAQ. Yet, it is important to identify IAQ issues in order to improve IAQ through effective ventilation systems. Therefore, this research was aiming to identify IAQ issues with the intention of improving IAQ from effective ventilation systems in office buildings in Sri Lanka. A quantitative research approach based on questionnaire survey and observation were used in order to achieve the objectives. A statistical analysis was carried out to obtain findings of the research. The study revealed that occupants in naturally ventilated buildings were healthier compared to occupants in MVAC buildings.

Keywords: *Indoor Air Quality; MVAC, Natural Ventilation; Sick Building Syndrome.*

1. BACKGROUND

Indoor Air Quality (IAQ) has become a significant environmental issue in office buildings (Mui and Chan, 2006). The number of related complaints has increased in recent years with increased building tightness, the growing use of synthetic materials, and energy conservation measures that reduce the amount of outside air supply (Pan *et al.*, 2006). Mui and Chan (2006) explained that, modern office equipment (photocopiers, laser printers and computers), cleaning products, and outdoor air pollution can also increase the level of indoor air contamination. Therefore, IAQ tends to become more polluted with the modern developments.

A study by European Federation of Asthma and Allergy Association (2001 cited Dijiken *et al*., 2006) stated that, building components, occupants, finishing, furnishings, building services and equipment contribute to the release of pollutants to indoor air. Poor IAQ in buildings leads to sick building syndrome (SBS) and cause adverse effect to occupants (Cheong *et al*., 2006). According to Charted Institute of Building Service Engineers (CIBSE) (2006) SBS symptoms may include fatigue, feeling heavy- headed, headache, sleepy, difficult to breath, dry nose, blocked nose, hoarse, dry throat, dry lips and dry skin. Even though these symptoms may not be obviously related to a particular cause, they become less severe or disappear when they leave a particular environment (CIBSE, 2006). According to CIBSE (2006), if a significant proportion of occupants experience these symptoms then, occupants are suffering from SBS. According to Wargocki *et al.* (2000), ventilation flow rate can be increased to improve indoor air quality and to decrease the SBS symptoms. Increased risk of SBS and elevated prevalence of general SBS symptoms were associated with low outdoor-air flow rates, presence contamination in office rooms, and unacceptable temperature and humidity levels (Sundell, 1994). According to Cheong *et al*., (2006) symptoms of SBS can be minimized using proper ventilation.

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Johnson (2000) defined that ventilation as the process of exchanging air between the outdoors and the conditioned space for the purpose of diluting the gaseous contaminants in the air and improving or maintaining air quality, composition and freshness. Ventilation systems are widely used to improve IAQ, besides eliminating contamination sources and purifying the air (Fanger, 2006; Yu *et al*., 2009). Furthermore, a study by Modera and Andrew (1995 cited Dols and Persy 1995) showed that effective ventilation systems should designed to provide sufficient level of outdoor air to the building, to remove contaminants generated within the space, to provide comfortable environment to the building occupants. Therefore, the purpose of ventilation system is to provide acceptable microclimate in the space being ventilated (Awbi, 2003). Air quality benefits provided by ventilation systems include improving relative humidity and reducing volatile organic compounds (VOCs) as well as removing carbon dioxide from the air and producing oxygen (Smith and Pitt, 2009). Effectiveness of building ventilation system is a primary determinant of IAQ in buildings as it impacts indoor contaminant concentrations and occupants comfort (Persily *et al.*, 2006).

The designers and operators of ventilation systems should be familiar with the comfort requirements and the quality of air necessary to achieve acceptable indoor climate (Awbi, 2003). Designers should minimize uncontrolled air leakage into a building, minimize demand by over-design, giving preference to natural ventilation, choose efficient primary plant, consider energy recovery, distribute air effectively, and use effective controls (Charted Institute of Building Service Engineers (CIBSE), 2004). A study by Modera and Andrew (1995 cited Dols and Persy, 1995) showed that, the design of building ventilation systems should be based on ventilation standards that specify minimum levels of ventilation for occupant health and comfort. Ventilation for acceptable indoor air quality standard 62.1-2007 by American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) is a voluntary standard for minimum ventilation rates (ASHRAE, 2007). This is the most widely used ventilation standard in Sri Lankan context. Designers and operators need to have a better understanding about ventilation system standards in order to have an effective ventilation system.

Ventilation requirement can be provided with different types of ventilation systems. It is generally accomplished by natural ventilation and mechanical ventilation (Merritt and Ricketts, 2000). Stavrakakis *et al.* (2008) stated that, the proper design of natural ventilation must be based on detailed understanding of airflow within enclosed spaces, governed by pressure differences due to wind and buoyancy forces. Natural ventilation includes many benefits over mechanical ventilation such as low cost, flexibility, maintainability and fewer symptoms of SBS (Hummelgaard *et al*., 2007; Xuea *et al*., 2004). Mechanical ventilation and air conditioning (MVAC) system is a type of mechanical ventilation system most commonly used in multi-storey buildings to enable effective ventilation with cooling and dehumidification (Franssona *et al.*, 2007). Therefore, this research was conducted to identify IAQ issues with the intention of improving IAQ through effective ventilation systems in office buildings in Sri Lanka.

2. RESEARCH METHODOLOGY

Surveys are normally used where the views or opinions of many need to be evaluated in order to achieve a conclusion. Therefore, survey research has been selected as the most suitable research approach. Structured questionnaire was selected as the best data collection techniques. Statistical analysis of percentage, mean average and Chi-Square test was used for data analysis.

Questionnaire survey was focused on occupants overall assessment on indoor air quality, their perception of personal control and frequency of occurring symptoms of naturally ventilated office buildings as well as office buildings with MVAC systems. Data was collected from fifty occupants from naturally ventilated buildings and fifty occupants from MVAC buildings. Employees who perform sedentary work were given the questionnaire in each building and personal survey method was conducted. Sedentary office workers usually spend total working hours (8 hours) at their work desk. Therefore, those office workers become more sensitive to their working environment and variations in working environment directly affect them.

CHI- SQUARE ANALYSIS

The Chi-Square ($\chi 2$) test, also called Pearson's Chi-square test is used to discover if there is a relationship between two categorical variables. The Chi-Square test is performed to test whether two variables can be considered statistically independent. In this research Chi-Squared test was used to determine whether there is a relationship between conditions of the working environment (naturally ventilation/ MVAC) to occurrence of symptoms of SBS for occupants.

Hypothesis

Ho: Prevalence of symptoms are not associated with condition of the office environment (Natural ventilation /MVAC), and

H_1: Prevalence of symptoms is associated with condition of the office environment (Natural ventilation /MVAC)

Decision Rule

Reject H_o if $p < 0.05$

3. RESEARCH FINDINGS

3.1. PREVALENCE OF SYMPTOMS OF SBS

Survey was carried out in five naturally ventilated buildings and five mechanically ventilated and air conditioned buildings. The gender of the respondents was 54% female and 46% male for naturally ventilated offices and 48% female and 52% male for mechanical ventilation and air conditioned (MVAC) offices. Structure questionnaire survey was focused on ten symptoms of SBS. A five point Likert scale was used to collect occupant's responses, scale was as follows.

1 – No, never
2 - Yes, rare
3 - Yes, sometimes
4 - Yes often (every week)
5 - Yes, daily

Analysis was carried out to identify frequency of occurring symptoms for building occupants under three types of time periods; “at least rare”, “at least sometimes” and at “least often”. “At least rare” represents four optional answers in the Likert scale {(2-Yes, rare), (3-Yes, sometimes), (4 – Yes, often (every week)), and (5 - Yes, daily)}. This gives the number of respondents who get each symptom at least rarely. This can be illustrated as in Figure 1.

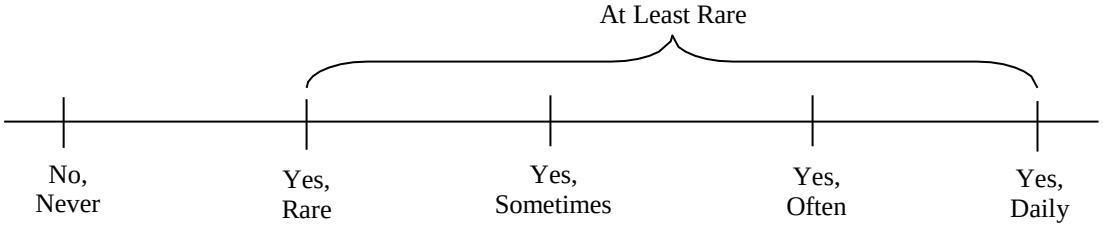

Figure 1: Time Scale of "At Least Rare"

“At least sometimes” represents three optional answers in the Likert scale {(3-Yes, sometimes), (4 – Yes, often (every week)) and (5 - Yes, daily)}. This gives the number of respondents who get each symptom at least sometimes. This time scale can be illustrated in Figure 2.

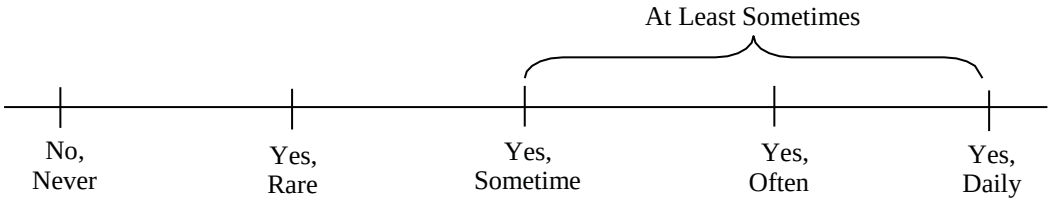

Figure 2: Time Scale of "At Least Sometimes"

"At least often (every week)" represents two optional answers in the Likert scale {(4 - Yes, often (every week)) and (5 - Yes, daily)}. This gives the number of respondents who get each symptom at least weekly.

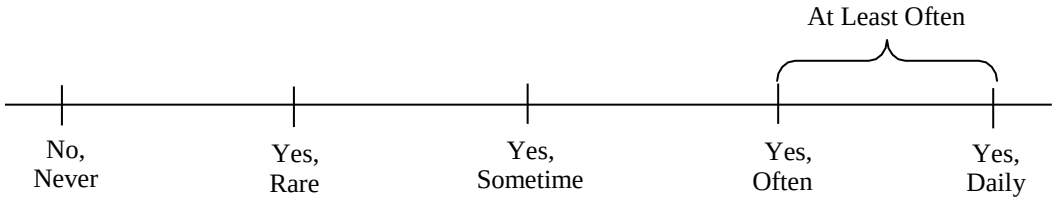

Figure 3: Time Scale of "At Least Often"

When addressing IAQ issues firstly symptoms which occur at least often should be treated. Finally, mitigation strategies can be taken to avoid symptoms occur at least rarely.

FREQUENCY OF OCCURRING SYMPTOMS – "AT LEAST RARE"

Table 1 shows prevalence of SBS symptoms based on occupants who reported they had symptom "At least rare". Furthermore, the prevalence of symptoms of SBS was also compared between occupants in two building type in Table 1. The arrows indicate whether the symptoms prevalence in naturally ventilated offices was higher (↑) or lower (↓) than in buildings with MVAC systems.

Table 1: Prevalence of Symptoms among Occupants Experienced "At Least Rare"

"At least rare" (Summation four optional answers for Yes; "yes, rare", "yes, sometimes", "yes often", and "yes, daily".)				
No	**Symptom**	**Natural ventilation offices (n= 50)**	**MVAC offices (n=50)**	**Natural ventilation Vs MVAC offices**
1	Fatigue	41	30	↑
2	Feeling heavy- headed	35	37	↓
3	Headache	33	41	↓
4	Sleepy	29	40	↓
5	Difficult to breath	28	45	↓
6	Dry nose	27	42	↓
7	Blocked nose	25	38	↓
8	Hoarse, dry throat	22	41	↓
9	Dry lips	21	48	↓
10	Dry skin	22	46	↓

The prevalence of overall symptoms occurring "At least rare" was higher in mechanically ventilated offices. Prevalence of all symptoms was higher in buildings with MVAC except fatigue.

CHI- SQUARE ANALYSIS – "AT LEAST RARE"

Hypothesis

Ho: Prevalence of symptoms are not associated with condition of the office environment (Natural ventilation /MVAC), and

H_1: Prevalence of symptoms are associated with condition of the office environment (Natural ventilation /MVAC)

Decision Rule

Reject H_o if $p < 0.05$

Table 2 shows the P value of Chi- Square analysis between naturally ventilated buildings and MVAC buildings.

Table 2: Chi Square Analysis - "At Least Rare"

Chi- Square Analysis - "At least rare" (Represent four optional answers for Yes; "yes, rare", "yes, sometimes", "yes often", and "yes, daily".)		
No	**Symptom**	**P - value**
1	Fatigue	0.015
2	Feeling heavy- headed	0.656
3	Headache	0.068
4	Sleepy	0.017
5	Difficult to breath	0.000
6	Dry nose	0.001
7	Blocked nose	0.021
8	Hoarse, dry throat	0.000
9	Dry lips	0.000
10	Dry skin	0.000

Chi- Square Analysis shows that prevalence of symptoms occurring "At least rare" was significantly higher in buildings which has MVAC systems for "sleepy" (P = 0.017, χ^2- test), difficult to breathe (P = 0.000, χ^2- test), dry nose (P = 0.001, χ^2- test), blocked nose (P = 0.021, χ^2- test), dry throat (P = 0.000, χ^2- test), dry lips (P = 0.000, χ^2- test) and dry skin (P = 0.000, χ^2- test). Fatigue (P = 0.015, χ^2- test) was significantly higher in naturally ventilated buildings. No significant differences were observed when comparing the prevalence of the feeling heavy- headed (P = 0.656, χ^2- test) and headache (P = 0.068, χ^2- test).

According to the analysis P values of fatigue, sleepy, difficult to breathe, dry nose, blocked nose, dry throat, dry lips and dry skin were lower than 0.05 which is the pre specified significance level. Therefore, null-hypothesis can be rejected. Alternative hypothesis is accepted which is the "prevalence of symptoms is associated with condition of the office environment".

FREQUENCY OF OCCURRING SYMPTOMS – "AT LEAST SOMETIMES"

Table 3 shows the prevalence of symptoms of occupants who reported that they felt a symptom "At least sometimes".

Table 3: Prevalence of Symptoms among Occupants Experienced "At Least Sometimes"

"At Least Sometimes" (Represent three optional answers for yes; "yes, sometimes", "yes often", and "yes, daily")				
No	**Symptom**	**Natural ventilation offices (n= 50)**	**MVAC offices (n=50)**	**Natural ventilation Vs MVAC offices**
1	Fatigue	14	12	↑
2	Feeling heavy- headed	7	15	↓
3	Headache	5	20	↓
4	Sleepy	2	12	↓
5	Difficult to breath	1	10	↓
6	Dry nose	1	11	↓
7	Blocked nose	3	13	↓
8	Hoarse, dry throat	3	13	↓
9	Dry lips	5	35	↓
10	Dry skin	8	28	↓

The prevalence of overall symptoms occurring "at least sometimes" was also higher in mechanically ventilated offices except fatigue.

CHI- SQUARE ANALYSIS – "AT LEAST SOMETIMES"

Hypothesis

Ho: Prevalence of symptoms is not associated with condition of the office environment (Natural ventilation /MVAC), and

H_1: Prevalence of symptoms is associated with condition of the office environment (Natural ventilation /MVAC)

Decision Rule

Reject H_o if $p < 0.05$

Table 4 shows the P value of Chi- Square analysis between naturally ventilated buildings and MVAC buildings.

Table 4: Chi- Square Analysis - At Least Sometimes

Chi- Square Analysis – "At least sometimes" (Represent three optional answers for yes; "yes, sometimes", "yes often", and "yes, daily".)		
No	**Symptom**	**P - value**
1	Fatigue	0.648
2	Feeling heavy- headed	0.530
3	Headache	0.001
4	Sleepy	0.004
5	Difficult to breath	0.004
6	Dry nose	0.002
7	Blocked nose	0.012
8	Hoarse, dry throat	0.006
9	Dry lips	0.000
10	Dry skin	0.000

Chi- Square Analysis shows that prevalence of symptoms occurring "At least sometimes" was significantly higher in buildings which has MVAC systems for headache (P = 0.001, χ^2- test), sleepy (P = 0.004, χ^2- test), difficult to breathe (P = 0.004, χ^2- test), dry nose (P = 0.002, χ^2- test), blocked nose (P = 0.012, χ^2- test), dry throat (P = 0.006, χ^2- test), dry lips (P = 0.000, χ^2- test) and dry skin (P = 0.000, χ^2- test).

Fatigue and feeling heavy headed have P values higher than 0.05. This tells that there is no statistically significant association between condition of office environment and prevalence of these two symptoms.

FREQUENCY OF OCCURRING SYMPTOMS – "AT LEAST OFTEN"

Table 5 shows the prevalence of occupants who reported that they felt a symptom "at least often".

Table 5: Prevalence of Symptoms among Occupants Experienced "at least often (every week)"

No	Symptom	At least Often (Every Week) (Represent two optional answers for Yes; "yes, often" and "yes, daily".) Natural ventilation offices (n= 50)	MVAC offices (n=50)	Natural ventilation Vs MVAC offices
1	Fatigue	6	5	↑
2	Feeling heavy- headed	3	6	↓
3	Headache	3	11	↓
4	Sleepy	1	5	↓
5	Difficult to breath	1	1	-
6	Dry nose	0	4	↓
7	Blocked nose	2	4	↓
8	Hoarse, dry throat	2	3	↓
9	Dry lips	5	24	↓
10	Dry skin	7	20	↓

The prevalence of eight symptoms among all ten symptoms, were higher in mechanically ventilated offices.

CHI- SQUARE ANALYSIS – "AT LEAST OFTEN"

Hypothesis

Ho: Prevalence of symptoms is not associated with condition of the office environment (Natural ventilation /MVAC), and

H1: Prevalence of symptoms is associated with condition of the office environment (Natural ventilation /MVAC)

Decision Rule

Reject Ho if $p < 0.05$

Table 6 shows the P value of Chi- Square analysis between naturally ventilated buildings and MVAC buildings.

Table 6: Chi- Square Analysis - At Least Often

Chi- Square Analysis – "At least often" (Represent three optional answers for yes; "yes, sometimes", "yes often", and "yes, daily")		
No	**Symptom**	**P - value**
1	Fatigue	0.749
2	Feeling heavy- headed	0.295
3	Headache	0.021
4	Sleepy	0.092
5	Difficult to breath	1.000
6	Dry nose	0.041
7	Blocked nose	0.400
8	Hoarse, dry throat	0.646
9	Dry lips	0.000
10	Dry skin	0.003

Chi- Square Analysis shows that prevalence of symptoms occurring "at least often" was significantly higher in buildings which has MVAC systems for headache (P = 0.021, χ2- test), dry nose (P = 0.041, χ2- test), dry lips (P = 0.000, χ2- test) and dry skin (P = 0.003, χ2- test).

Other symptoms have P values higher than 0.05. This tells that there is no statistically significant association between condition of office environment and prevalence of these symptoms "at least often".

OUTCOME OF PREVALENCE OF SICK BUILDING SYNDROME (SBS) SYMPTOMS

Occupants in Buildings experienced acute health and comfort effects that appear to be linked to time spent in a building. Findings of the questionnaire survey showed that prevalence of symptoms were high in MVAC buildings compared to naturally ventilated buildings. Out of ten symptoms only fatigue was high in naturally ventilated buildings. Dry nose, dry skin, dry lips and headache were the symptoms that most of occupants experienced often. Apart from this sleepy, difficult to breathe, dry throat and blocked nose were the symptoms that occupants experienced sometimes. These symptoms occur due to poor indoor air quality, therefore it can be stated that office buildings in Sri Lanka have many IAQ issues.

3.2. OCCUPANTS' LEVEL OF CONTROL

Occupants in buildings with MVAC systems felt they can have a significantly higher ability to adjust the temperature at their workplaces. Seventy percent of the occupants in MVAC office buildings felt they have an ability to control the indoor environment at their workplaces. Only sixty six percent of the occupants in naturally ventilated buildings felt they have an ability to control the indoor environment at their workplaces.

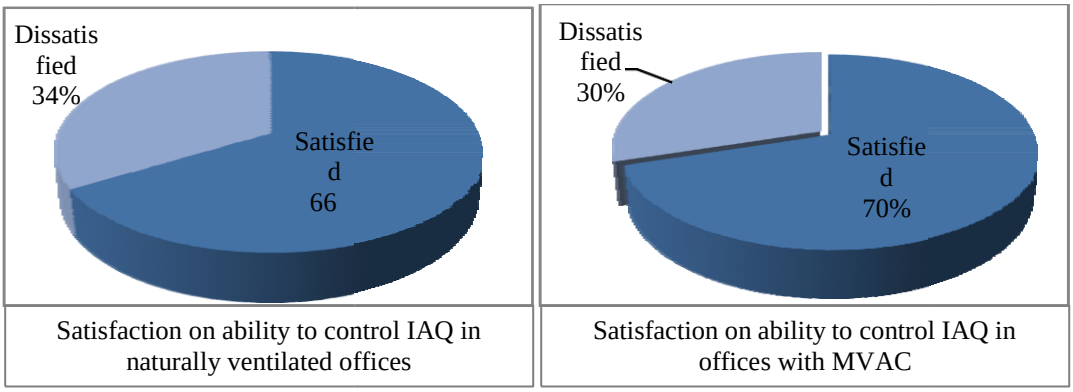

Figure 4: Satisfaction on Ability to Control IAQ

Occupants in MVAC environments can adjust thermostat and flow of air to meet their comfortable requirements. Occupants in naturally ventilated buildings can open or close doors and windows to control flow of air to some extent. However, they can hardly control the temperature. Therefore, occupants in MVAC office buildings were more satisfied on their ability to control IAQ when compared to occupants in naturally ventilated offices.

3.3. OCCUPANTS' SATISFACTION ON IAQ

Seventy percent of the occupants in the naturally ventilated buildings were replied that they were satisfied with the IAQ, whereas only sixty three percent were satisfied in the mechanically ventilated offices. Even though the difference is not significant, occupants in naturally ventilated buildings were more satisfied on IAQ when compared to buildings with MVAC. Usually occupants in controlled environments such as air conditioned environments have higher expectations on IAQ. Therefore, occupants in MVAC environments have higher expectations compared to occupants in naturally ventilated environments. When their expectations are failed to meet they get dissatisfied very easily. Figure 5 illustrate these results.

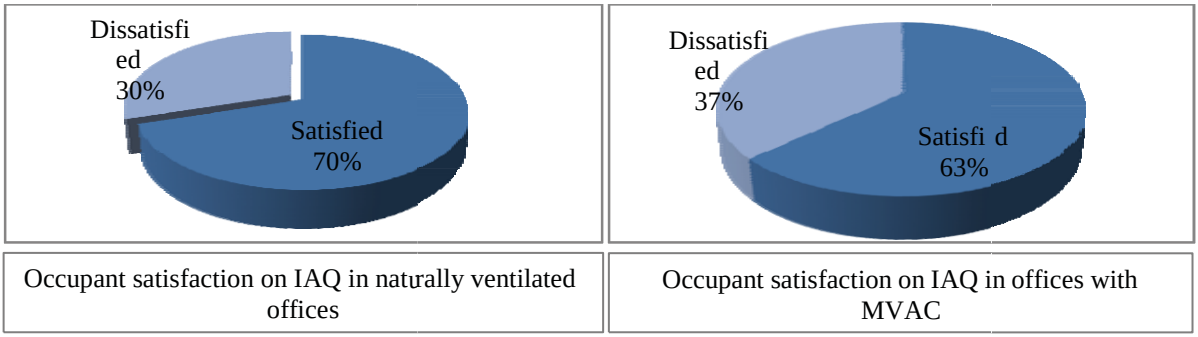

Figure 5: Occupant Satisfaction on IAQ

4. CONCLUSIONS

It was clear that occupants in office buildings in Sri Lanka suffer due to poorly maintained IAQ. According to research findings occupants in naturally ventilated buildings healthy than occupants in MVAC buildings as they experience less symptoms of SBS. Further, findings showed that occupants in naturally ventilated buildings were more satisfied on IAQ compared to MVAC buildings. Occupants in MVAC buildings have adverse perceptions on too low room temperature, stuffy (bad) air and dry air. Occupants in naturally ventilated buildings feel adverse perception about high room temperature, varying room temperature and draught. As Sri Lanka has a tropical climate, natural ventilation could not be able to reduce air temperature significantly. Therefore, it is important to address IAQ issues with the intention of improving IAQ by effective ventilation systems.

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