Abstract

Indoor air quality (IAQ) influences human health, productivity and wellness. Green buildings are believed to have better IAQ. The ‘sick building syndrome’ (SBS) describes a set of nonspecific symptoms experienced by occupants due to time spent in a building with poor IAQ. Thus this study was undertaken to assess the IAQ in green buildings and compare it with that of conventional buildings. The prevalence of SBS in both types of buildings is also studied. In five pairs of green and conventional buildings measurements of comfort parameters (temperature & relative humidity) and indoor air pollutants using monitors was done. 148 employees which included 84 from green buildings and 64 from conventional buildings were surveyed for SBS using an interviewer-administered questionnaire. The analysis was done using SPSS16 and included Mann Whitney for IAQ pollutant concentrations and Chi-square for the SBS prevalence. Similar indoor air quality was found in both types of buildings. The mean of temperature, CO2 and formaldehyde was statistically lower in green buildings. The SBS prevalence was found to be 38.1% in green buildings and 53.1% in conventional buildings. Thus to conclude the poorly maintained green building does not have any added advantage for occurrence of SBS.

Keywords: Conventional buildings, green buildings, indoor air quality, sick building syndrome

Introduction

Rapid urbanization in most of the cities of India is affecting the environment particularly the air quality both outdoors and indoors. Indoor air pollution (IAP) is one of the leading health risk factors around the world. In India, IAP is a serious threat to outdoor air pollution. According to a United Nations Environment Programme (UNEP) report, the estimated contribution of IAP to ambient air pollution in India varies between 22 and 52%. However, the literature available on IAP in the Indian context focuses on the rural population and is majorly associated with chimneys and other forms of cooking fuels used.

IAP in modern building can be due to construction materials and furnishing of buildings to more airtight buildings with poor ventilation, and the wrong use of air conditioning. Evaporation of chemical vapors from building materials or furniture is a potential cause of indoor air problems in modern buildings. Commercial buildings have types of equipment such as photocopy machines, scanners, and printers that can be a source of pollution.

Sick building syndrome (SBS) is defined as a condition occurring in those who live or work in a modern building and who suffer from symptoms such as headache, fatigue, lack of concentration, and irritation of the skin and mucous membranes. Indoor environmental particularly ventilation and air conditioning are important factors playing a role in the causation of SBS.

One solution to IAP and thereby conditions like SBS could be the sustainable construction practices. Green buildings can contribute to sustainable construction using energy-efficient and

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affordability principles. Green buildings promote innovations such as the use of fly ash, LED lighting, composting toilets, rainwater harvesting, and so on designed to improve human lives and health while protecting the environment. Green construction implies resource-efficient principles, a reduction in environmental degradation, and pollution along the building lifecycle.

With this background, the present study was undertaken to measure the levels of indoor air pollutants (PM$_{10}$, PM$_{2.5}$, CO, CO$_2$, NO$_x$, SO$_2$, ozone, NH$_3$, formaldehyde, total volatile Organic Compound), and climatic factors (temperature and relative humidity) and assess its compliance with the international indoor air quality (IAQ) standards in green as well as conventional buildings. Moreover, the prevalence of SBS and its relation to IAQ was also studied.

**Material and Methods**

The present cross-sectional study was carried out at nonindustrial, commercial office buildings of Mumbai. First, an Indian Green Building Council (IGBC) certified, centrally air-conditioned green building was chosen and then it was paired with a conventional building in the vicinity of about 2 km. The pairs were matched with central air conditioning, a number of floors and their area. A total of ten commercial buildings including five green and five conventional buildings were chosen for the study. The calibrated digital monitors were used for IAQ testing. These monitors were placed at a meter away from the floor while recording the readings.

For the SBS survey, 148 employees, working in the building for at least 4 months prior to the study and spending more than 6 h/day, participated which included 84 from green buildings and 64 from conventional buildings. After obtaining informed consent, the participants were given an interviewer-administered questionnaire. The recall period for the survey was 3 months. The occurrence of symptoms was further categorized into “often” or “sometimes”, or “never” depending on the frequency of symptoms which were scored as “1”, “0.5”, or “0”, respectively. For every participant, a sum of scores from all the symptoms was calculated and reflected as an SBS score. For the question concerning improvement in symptoms when away from the office, “improvement” was coded as 1 and ‘no improvement’ was coded as 0. A study participant was labeled as a case of SBS if he had an SBS score of one or above and his symptoms resolved while away from the office.

The statistical analysis was carried out using SPSS 16. For IAQ, the mean concentration of each parameter was computed for both the building groups and reported as a summary statistic. Mann-Whitney was used to test a statistical difference in pollutant concentration. The frequency of SBS was computed for building groups and compared using the Chi-square test.

**Results**

A total of ten commercial buildings were tested for their IAQ. Out of these ten, five were green and the other five were conventional buildings. Six of the ten buildings were single firm and four were multifunctional buildings. The age of the buildings was also considered. Four out of ten buildings were as new as three years old or less. The average pollutant concentration in green and conventional groups is presented in Table 1.

The green building group’s temperature was statistically lower than conventional. On average, conventional buildings were less humid and had more oxygen to breathe with 42.09% humidity and 20.83% oxygen.

Six out of eight pollutants tested performed better in conventional buildings, i.e. their mean concentration was lower than the pollutants in green buildings. These six pollutants were PM$_{10}$, PM$_{2.5}$, O$_3$, NO$_2$, SO$_2$, and NH$_3$. PM$_{10}$ concentration was 15.33 µg/m$^3$ and 14.34 µg/m$^3$, and PM$_{2.5}$ was 14.62 µg/m$^3$ and 13.84 µg/m$^3$ in green and conventional buildings, respectively. Mean ozone concentration in green buildings was 0.0160 ppm, which is almost twice that in conventional i.e. 0.0084 ppm. Green buildings also showed higher NO$_2$ and SO$_2$ concentrations than conventional buildings.

Table 2 provides a comparison of health symptoms in the two-building groups. There were more complaints from conventional occupants. The top three common symptoms in

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Table 1: Mean of the tested air parameters in green and conventional building groups and the statistical significance of their difference

| Parameters          | Standard Buildings | Green Buildings | Conventional Buildings | P     |
|---------------------|--------------------|----------------|------------------------|-------|
| Temperature (°C)    | 22.8-26.1          | 24.18          | 24.82                  | 0.035*|
| Relative Humidity (%) | 30-65             | 49.9          | 42.1                   | 0.186 |
| CO$_2$ (ppm)        | < 1000             | 824           | 1155                   | 0.049*|
| PM$_{10}$ (µg/m$^3$) | < 100              | 15.3          | 14.3                   | 0.769 |
| PM$_{2.5}$ (µg/m$^3$) | < 25              | 14.6          | 13.8                   | 0.799 |
| O$_3$ (%)           | > 19.5             | 20.64         | 20.83                  | 0.515 |
| O$_3$ (ppm)         | < 0.1              | 0.016         | 0.008                  | 0.283 |
| NO$_2$ (ppm)        | < 1                | 0.128         | 0.068                  | 0.004*|
| SO$_2$ (ppm)        | < 2                | 0.11          | 0.06                   | 0.638 |
| NH$_3$ (ppm)        | < 25               | 0.08          | 0.06                   | 0.723 |

*Statistically significant

Table 2: Distribution of sick building syndrome symptoms in occupants of green and conventional buildings

| Symptom       | Green Buildings (%) | Conventional Buildings (%) |
|---------------|---------------------|---------------------------|
| Sore throat   | 27.4                | 26.6                      |
| Hoarseness    | 16.7                | 26.6                      |
| Nausea        | 2.4                 | 6.2                       |
| Headache      | 44                  | 43.8                      |
| Cough         | 33.3                | 28.1                      |
| Runny Nose    | 32.1                | 35.9                      |
| Mental Fatigue| 25                  | 40.6                      |
| Lethargy      | 20.2                | 48.4                      |
green buildings were cough (33.3%), runny nose (32.1%), and sore throat (27.4%). On the contrary, the top three frequent symptoms of conventional buildings were lethargy (48.4%), headache (43.8%), and mental fatigue (40.6%).

For the SBS survey, 148 employees participated which included 84 from green buildings and 64 from conventional buildings. The SBS prevalence was found to be 38.1% (32 out of 84) in green buildings and 53.1% (34 out of 64) in conventional buildings. However, the difference in the prevalence of SBS in the two groups was statistically nonsignificant ($P = 0.068$).

**Discussion**

The present study compared the IAQ parameters between commercial green and conventional buildings of Mumbai. Green buildings outperformed conventional buildings significantly, for three parameters: temperature, carbon dioxide, and formaldehyde. The remaining ten parameters performed well in conventional buildings. There was no statistically significant difference in the mean concentration of most of the pollutants between the two groups. This could be since indoor environmental quality is given only 12% weight in the rating system of green buildings\(^5\) and thus once certified less importance is paid to maintain their “greenness”. This could be a reason for having statistical insignificance between IAQ of green and conventional groups with respect to most of the parameters.

However, NO\(_2\) levels were significantly higher in green buildings which may be due to the proximity of a few green buildings to highways and vehicular traffic. The earlier studies have also reported a significant correlation between indoor pollutant concentration and outdoor pollutant concentration.\(^6\) Similarly, increased ozone levels in green buildings can be partly attributed to the air filters used to purify the indoor air which releases ozone\(^7,\)^\(^8\) on reacting with certain pollutants and partly to the use of machines like photocopiers.\(^11,\)^\(^12\)

Higher ammonia levels in green buildings as compared to conventional buildings can be partly attributed to its proximity with the Mithi river which has been reduced to a filthy ‘nullah’ with increased ammonia levels. The lower formaldehyde levels in conventional buildings can be the due release of formaldehyde in the warmer environments from the products used in conventional buildings\(^13,\)^\(^14\) whereas green buildings are constructed using green products that emit little or no formaldehyde.

More proportion of employees working in conventional buildings had symptoms suggestive of SBS as compared to green buildings. Moreover, the symptoms commonly reported by employees working in conventional buildings were strongly related to poor ventilation while the symptoms reported by the employees working in green buildings were largely respiratory. Consequently, it can be said that indoor air plays a role in the occurrence of SBS as reported by earlier studies also. However, the generalization of results should be done with precaution due to the limitation of the study to address seasonal variation in measuring IAQ and some recall bias while reporting symptoms of SBS.

**Declaration of patient consent**

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published, and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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**Conflicts of interest**

There are no conflicts of interest.

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