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Strategies for Planning Mould Free Air Conditioned Buildings in Tropical Climates

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Abstract: Buildings constructed in tropical climatic conditions must be designed to have a very low carbon foot print that will need the buildings to be used as free running while ensuring adequate thermal comfort with passive means. However, there could be certain instances when the use of active means of thermal comfort like air conditioning will be inevitable due to special requirements. Hospital buildings or buildings with special equipment would need lower indoor temperature like 15 – 18 °C compared to the ambient temperature in tropical climates. Thus, the growth of mould on the building elements such as walls and floors of the surrounding areas will be inevitable unless special planning provisions have been used with strategically placed buffer zones that will have normal air conditioning which maintains indoors with relatively lower levels of moisture content. Mould created on various building elements can produce spores, air-borne particles and gases which are harmful to the humans and built environments. In order to identify the magnitude and the causes for mould growth, a comprehensive research was carried out with a case study in a hospital building planned without attention to much detail and hence led to a severe growth of mould, where several concerns were raised by the occupants of the building, related to sick building syndrome. This will shed light on special planning precautions that must be taken by the architects and engineers who plan buildings with specially air conditioned spaces in large buildings located in countries with tropical climatic conditions.

Keywords: Mould growth, condensation, air conditioned buildings, air quality

1. Introduction

World Health Organization [1] defines mould as all species of microscopic fungi that grows in the form of multi cellular filaments, called hyphae. Studies conducted in many countries indicate that significant percentage of indoor environment in buildings has shown signs of dampness and mould growth [2] [3] [4] [5] [6] especially in higher scale where low income levels prevail [7] [8]. Fungi are ubiquitous eukaryotic organisms, which may be transported in to buildings by sticking on the surface of materials or active and passive ventilation. Mould growth in building elements is a consequence of an interaction between environmental factors (temperature and humidity), material properties, and the characteristics of mould fungi. [9]

Fungi also need nutrients such as proteins, lipids, and carbohydrates. Fungi can also grow on inert materials like ceramic tiles obtaining nutrients from dust particles and soluble components of water [1]. Indoor fungal growth is mainly due to moisture but other factors such as temperature and nutrients can affect the rate of growth and the production of allergens and metabolites [10].

Mould creates an unpleasant impression and people are always reluctant to enter into such buildings. Indoor mould growth is a severe problem since Bacteria [11] [12] [13] such as Streptomycetes [14] and Viruses [15] can grow in the same areas as moulds grow. Spores which are products of replication of mould and fungal fragments that can stay airborne for long periods of time are prone to be deposited in the respiratory system [16] and respiratory tract [17] which is known to contain harmful allergens [18] and mycotoxins [19]. There is sufficient evidence to suggest the association of mould and building dampness with upper respiratory tract symptoms, Wheeze, Cough, and Asthma by the findings of the Institute of Medicine [2] and other studies conducted in different geographical regions [20] [21] [22] [23]. The study covered in the paper is based on a detailed investigation carried out in a Hospital building in Sri Lanka where mould growth has been a severe problem for the occupants. The extent of mould growth and the related environmental parameters were determined on which the remedial measures were based.

2. The Case Study

The study was carried out in a four storied building, used as a hospital which was constructed in 1997. A temporary roof covers the 4th floor slab of this building. It was reported that frequent repair work in the form of repainting has been carried out on regular basis due to mould growth inside the building. Thus a detailed investigation on mould growth and related air quality parameters was carried out inside building.
The investigation work included the identification of activity spaces of the building, monitoring of thermal and air quality parameters, observing the mould growth and ventilation conditions. The activity spaces were categorized in to four main areas depending on the usage and the ventilation as follows:

- Naturally ventilated areas
- Air conditioned areas
- Specially air conditioned low temperature areas
- Wash rooms

2.1 Mould growth

Figures 1 – 4 show the activity spaces and the extent of mould growth in those spaces which was determined by observation. Since the literature highlights the air quality issues related to mould growth, a comprehensive set of measurements was taken to quantify the concentrations of CO2, NO2, VOC, CO, PM2.5, the indoor temperature and relative humidity (RH). These readings were recorded over a period of four days at four different locations. The locations where the readings were taken are indicated in the Figures1 – 4.

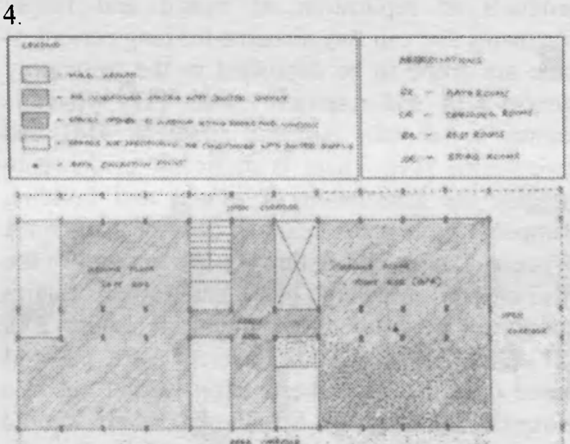

Figure 1: Activity spaces and the extent of mould growth in ground floor

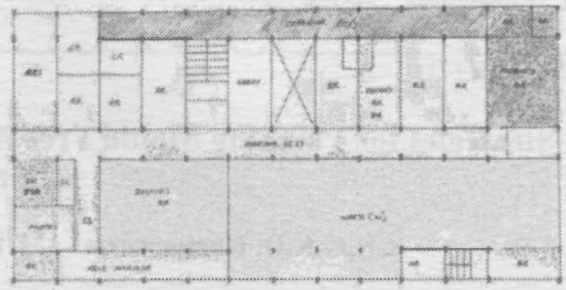

Figure 2: Activity spaces and the extent of mould growth in the first floor

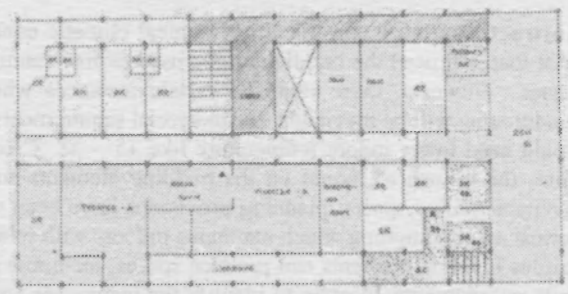

Figure 3: Activity spaces and the extent of mould growth in the second floor

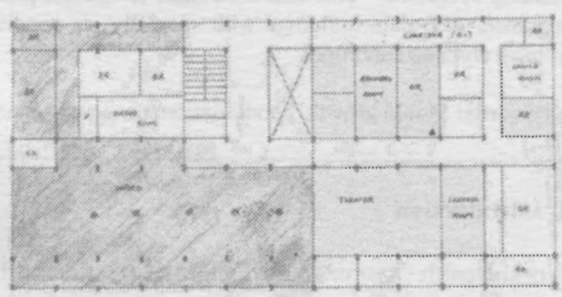

Figure 4: Activity spaces and the extent of mould growth in the third floor

The mould growth could be seen on the ducts, walls, ceilings, pipes, ceiling fans etc. Further to that Mould growth exists even in very important laboratories where critically sick patients are treated. The severity of mould growth in this building is shown in Figure 5 and 6.

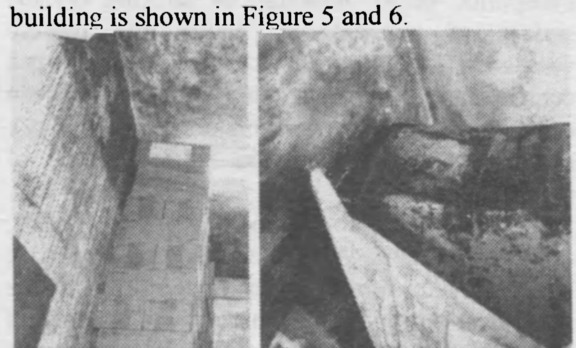

Figure 5: Severe mould growth (a) ICU store room S2 at second floor (b) A duct in S5 at second floor

2.2 Air Quality

In order to monitor the indoor environment air quality parameters CO2, NO2, CO, VOC and PM2.5 were measured at the selected locations in all four floors and compared those with the threshold values indicated in the standards that are shown in Table 1.

The Indoor Air Quality Monitor (IQM60 Environmental Monitor V5.0) was used to measure TVOC (total VOC), CO, CO2, NO2, Temperature and RH (relative humidity) moreover PM2.5 was measured using Haz-Dust Particulate Air Monitor as shown in Figure 6.

Figure 6: A data collection point at ICU in 2nd Floor

Table 1: Threshold values for indoor air quality (IAQ) pollutants recommended by several organizations

Pollutant Name	Threshold Limit	Organization
CO_2	1000 ppm	ASHRAE [24]
NO_2	0.053 ppm 24-hour mean	ASHRAE [24], US EPA [25]
CO	9 ppm	ASHRAE [24]
VOC	0.75 ppm	OSHA [26]
$PM_{2.5}$	25 µg/m³ 24-hour mean	WHO [27]

Air quality parameters were measured in all four floors and the variations for each IAQ parameter showing the most critical values are presented in the paper with possible impacts and causes.

2.2.1 Carbon Dioxide

CO_2 is a colour-less and odour-less gas. Despite the fact that it is non-toxic, if CO_2 concentration is too high, it can be unpleasant and perhaps unhealthy for the building occupants. Indoor Carbon dioxide at levels that are unusually high may cause occupants to feel drowsy, get headaches, or function at lower activity levels. Humans are the main indoor source of carbon dioxide. Indoor CO_2 levels could be an indicator of the adequacy of outdoor air ventilation relative to indoor occupant density and metabolic activity [28].

Chart 1shows the variation of the highest CO_2 concentration which has exceeded the recommended threshold of 1000 ppm. This variation was recorded in the Cath lab in the third floor of the building where patients and the medical staff are affected by the adverse effects. Since CO_2 is a direct indication of ventilation, an improved air conditioning system is proposed to supply fresh air to dilute the high CO_2 concentration.

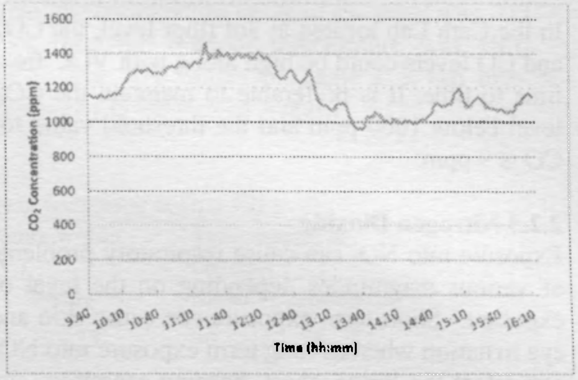

Chart 1: CO_2 Concentration variation in Cath Lab (3rd floor)

2.2.2 Carbon Monoxide

Carbon Monoxide directly interfere with the oxygen carrying red blood cells of the human body, significantly reducing the supply of oxygen to the heart and other organs, by creating a permanent bond with red blood cells called Carboxyhemoglobin. Exposure to CO may contribute to cardiovascular mortality and may also an early cause of heart attacks. Patients with coronary artery disease are considered as most sensitive to CO exposure, with aggravation of angina occurring in patients. Exposure to CO can develop a range of symptoms, such as headaches, weakness, dizziness, nausea, disorientation, confusion and fatigue in healthy people [29], [30].

As shown in Chart 2 Carbon Monoxide was also found to be in excess of the threshold value in the Cath lab located in the third floor which could be due to the activities going on inside the laboratory. Since high CO could cause serious problems for the patients and the staff, proper extraction of toxic gases should be done with a good exhaust system coupled with pumping of fresh air to dilute the higher concentration of CO.

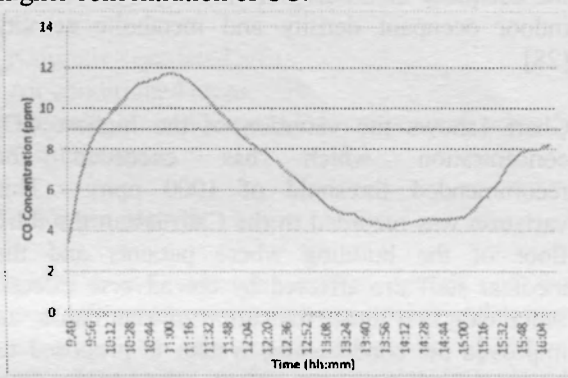

Chart 2: CO Concentration variation in Cath Lab (3^{rd} floor)

In the Cath Lab located at 3rd floor level, the CO2 and CO levels could be high along with VOC from time to time. It is preferable to maintain the CO2 level below 1000 ppm and the threshold value for CO is 9 ppm.

2.2.3 Nitrogen Dioxide

Exposure into NO_2 can cause respiratory problems of various magnitudes depending on the level of exposure. Short term exposure can cause skin and eye irritation whereas long term exposure into NO_2 can affect the lungs, chest, burning sensation, etc. Frequent exposure into high concentrations could lead to increased incidents of acute respiratory illnesses, where the children are the main victims [31]. Chart 3 shows the variation of NO_2 in the 2^{nd} floor ICU.

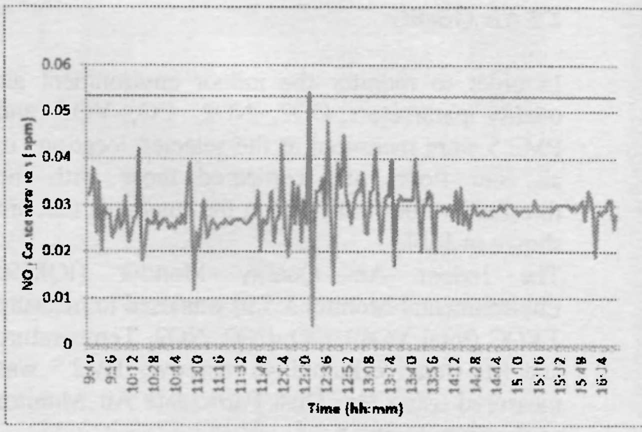

Chart 3: NO_2 Concentration variation in ICU-S4 (2^{nd} floor)

2.2.4 Volatile Organic Compounds

In indoor environments, there can be many different VOC substances in varying concentrations. There are six major classes of VOCs such as aldehydes (formaldehyde), alcohols (ethanol, methanol), aliphatic hydrocarbons (propane, butane, hexane), aromatic hydrocarbons (benzene, toluene, xylene), ketones (acetone) and halogenated hydrocarbons (methyl chloroform, methylene chloride) [1]. Formaldehyde is highly reactive and can irritate body surfaces containing moisture such as eyes and upper respiratory tract. Materials containing formaldehyde release formaldehyde gas into the air. Short term effects include eye, nose, throat and skin irritation, headaches and allergic sensitization. Long term exposure to VOCs can cause carcinogenic effects [32].

The highest values for the VOC were recorded in the ICU of the third floor where lot of chemicals are used for the patient care and cleaning. The medical staff who works there complained of various sick building symptoms which could be linked up with high VOC contents. This can obviously affect the patients as well since most of them are having heart related sicknesses. A properly designed mechanical ventilation system to extract the toxic gases is proposed for the timely dispersion of VOCs. Variation VOC concentration in the 2^{nd} floor ICU is shown in Chart 4.

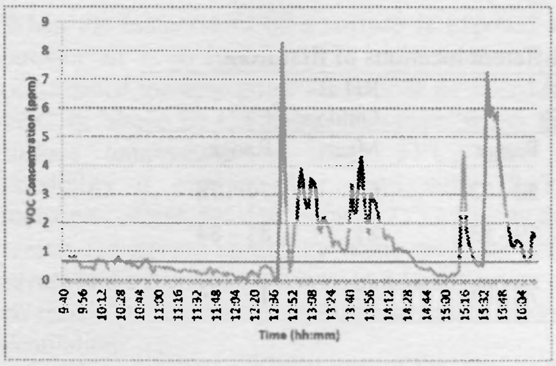

Chart 4: VOC Concentration variation in ICU-S4 (2^{nd} floor)

In the Intensive Care Unit (ICU) at the 2nd floor level, CO2, NO2 and CO levels are acceptable. VOC and PM2.5 have indicated many peaks that could be due to the various chemicals used in the ICU. A similar observation was reported in the operation theatre of the 2nd floor as well.

2.2.5. Particulate matter

The particles with an aerodynamic diameter less than or equal to 2.5 micro meters is defined as $PM_{2.5}$. Particulate matter resulting from combustion can affect the lungs directly.

Smaller particles can create more serious problems since they can penetrate deeper into the lungs and create respiratory problems. The outdoor air which enters into the building can also be a significant source of indoor airborne particulate matter [30], [28], [33]. Variation of Particulate matter in 2^{nd} floor ICU where it was recorded highest is shown in the Chart 5.

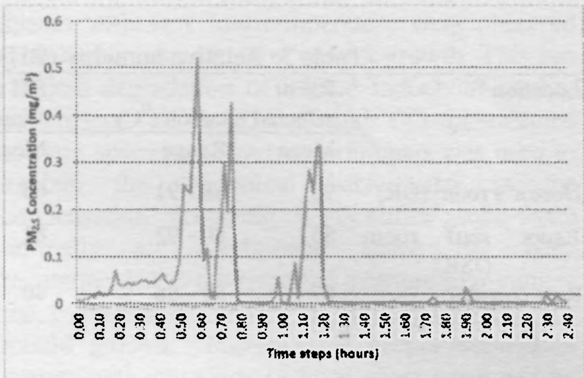

Chart 5: $PM_{2.5}$ Concentration variation in ICU-S4 (2^{nd} floor)

2.3 Temperature and humidity

The indoor temperature and the relative humidity values were recorded in all four floors. Four locations were selected in the first floor level to present the temperature differences occurring in the adjacent rooms which will form condensation and resulting mould growth. The locations are Doctor's room (DR), junior staff room (JSR), the rear corridor and the ward. The temperature and RH of the ward were recorded continuously. In Table 2 and Table 3 the temperature and humidity of the ward and the outdoor are given respectively together with the other locations for comparison purposes. For example, in doctors' room (DR), the temperature range is 23^0C – 25^0C. At the same time, the temperature range of the ward was 20^0C – 23^0C and the outdoor temperature was 28^0C – 31^0C. The RH values of Table C.3 can also be compared in the similar manner.

Table 2: Temperature at different locations at first floor

Location	Temperature at selected location (^0C)		Temperature within Ward (^0C)		Temperature at Outdoor (^0C)	
	Mean	Range	Mean	Range	Mean	Range
Doctor's room (DR)	24	23 - 25	21	20 - 23	30	28 – 31
Junior staff room (JSR)	24.5	24.5 - 25	21.5	19 – 22.5	27	26.5 – 27
Rear corridor	25	-	22.5	22.5 - 23	27	27 – 27.5

Table 3: Relative humidity (RH) at different locations of first floor

Location	RH at selected location (^{0}C)		RH within Ward (^{0}C)		RH at Outdoor (^{0}C)	
	Mean	Range	Mean	Range	Mean	Range
Doctor's room (DR)	78	68 - 91	65	52 - 73	64	70 – 78
Junior staff room (JSR)	85	80 - 92	81	79 - 83	81	81 – 84
Rear corridor	87	84 - 88	80	79 - 83	86	84 – 88

2.4 The identified causes for mould growth

The growth of the mould can be isolated to few locations in the building. One notable feature has been the absence of mould growth in areas that can be identified as specially air conditioned with low temperature (SACLT). The very low temperature in these areas means low moisture content in air (as low as 10 – 11g/kg of air) and hence the prevalence of dry conditions along with low due point.

Mould growth has not been very severe in areas that have normal air conditioning as well. The areas that are not air conditioned but located close to SACLT areas have shown severe growth of mould as indicated in Figure 2and 3. This observation indicates that in the naturally ventilated areas adjacent to SACLT areas, the prevalence of extremely low temperatures could lead to condensation on floor slabs and walls. The prolong prevalence of moist environment has promoted the growth of mould.

The temperature of SACLT areas can be as low as 18^{0}C during night time. Since 24 hour air conditioning is provided, the surrounding walls and slabs of these areas can also reach similar temperatures. The moisture content in this location varies between 14 g to 18g per kg of air in general and sometimes reaching even up to 20g/kg of air [34]. When there is 18g/kg, the dew point is 23^{0}C and when it is 14g/kg, the dew point is 19^{0}C. These values can be obtained from the Chart 6(solid line). When the temperature of a surface is above dew point temperature, condensation will not occur. A surface maintaining a temperature lower than the dew point runs the risk of forming moisture.

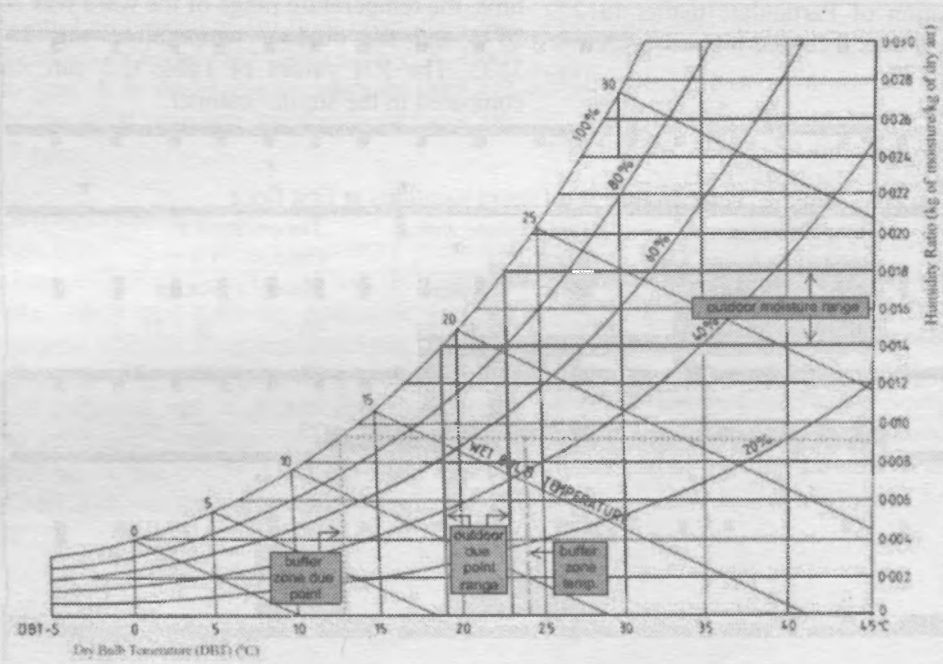

Chart 6: Psychometric chart for outdoor and buffer zone

When the temperature of a surface is exposed to outdoor air is as low as 18^{0}C, condensation can occur since the dew point of outdoor air could be 19^{0}C or above in Colombo. However, when the surface temperature is about 24^{0}C, such a possibility is remote since even with 18g/kg moisture content, the dew point is 23^{0}C. This is the reason for having mould on some areas as very severe and some other areas as to a lesser extent or no mould problem at all even when under natural ventilation.

2.5 Remedial measures

When the temperature of an air conditioned space is 240C with about 50% RH, as indicated by the broken line in Chart 6, the moisture and the dew point are around 9g/kg and 130C respectively. This indicates that when a normally air conditioned space is next to SACLT area, there is no chance of condensation since the dew point temperature(130C) is less than the lowest likely temperature(180C) that could occur in the slabs and the walls.

The dew point of normal air (outdoor) even with 20g/kg is about 250C. With a more likely maximum of 18g/kg for outdoor air, the dew point is about 230C. When the indoor is maintained at about 240C, the surface temperature of the slabs and walls would be in the range of 240C – 250C. This means that under normal conditions prevailing in Colombo, it is highly unlikely to form moisture except in a few days where the moisture content in outdoor air reaching unusually high values like 20g/kg. Hence, there will not be any prolonged condensation problem when a naturally ventilated area is located next to normally air conditioned area.

This means the solution to the mould growth in the building lies with the formation of buffer zones between SACLT areas and naturally ventilated areas. The buffer zone should be a normally air conditioned area.

3 Conclusion and Recommendations

Mould growth in buildings has been identified to cause building related health problems which could be termed as Sick Building Syndrome. A detailed study covered in this paper highlighted the causes for the mould growth, and remedial measures. Condensation created by the temperature gradient of the adjacent activity spaces of the building, has created dampness in some parts of the building which in turn cause mould growth. The case study has revealed that the activity spaces, adjacent to the spaces with very low temperature were observed with higher magnitude of mould growth. This has resulted degradation of related indoor air quality parameters, VOC, PM2.5 and CO in selected activity spaces. Psychometric chart was used to explain the theoretical background to the condensation occurring. A buffer zone with normally air conditioned space has been recommended as the remedial measure to minimize the condensation which in turn will reduce the mould growth. Moreover, a proper ventilation system with extraction of toxic gases generated by various activities would result better air quality insider the building.

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