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Review Article

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Prevention of indoor air pollution through design and construction certification: A review of the sick building syndrome conditions

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ABSTRACT

Indoor quality is an important and necessary concern towards indoor use, which sustains the health of the occupants. Indoor health is the resultant of exposure to all building materials, the contents of room equipment, occupant activities, and the ability of the space to eliminate negative effects on life. This paper adequately describes sources of pollutant exposure, pollutant movement, biological processes, health impacts, all of which can cause Sick Building Syndrome (SBS). Furthermore, indoor depollution measures to counteract SBS need to be carried out at the stages of building design and construction. Based on the interests and needs, here it is necessary to propose a certification of potential SBS at the design and construction stages. Thus, SBS responsibilities can be proportionately distributed to designers, contractors, and building users.

Review

Several explanations regarding indoor boundaries are available in some literatures, which in principle are the interior of the building. The boundaries of which are on the building structure, and are directly related to the occupants, but are not related to open spaces [1-3]. The sanitation service room, kitchen room, dining room, family room, bedroom, living room, and the others are all functional rooms, all of which are included as indoor, although functional rooms are not explored in this study. Meanwhile, the part of the space that is not included in the definition of indoor is the terrace room, the space under the ceiling and roof, and open space with other external environments. People carry out activities in many indoor buildings, both at home and in other places such as schools, offices, markets and others, about 80-90% of the time in a day compared to being outside the building [4-6]. Each indoor building has a different air quality [7-9], therefore, people experience various exposures to indoor air quality. Because of the long-time people stay indoors and the difference in quality exposure, at a certain level can cause Sick Building Syndrome (SBS) [10-12]. Associated with

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human resistance and immunity, SBS can cause acute to chronic disease in humans [13-15]. Therefore, indoor quality is very important to be a serious concern in the design, construction and operation of building use.

This indoor quality assessment covers the sources of pollutants, their transport in the indoor, the live recipients of exposure, negative health impacts, and treatment methods, which are more responsibility of the occupants than the designers and contractors. Responsibility for indoor quality assessment needs to be distributed proportionally to building designers and contractors, in order to create a healthy space for the continuity of various life activities. So far, no documentation has been found regarding the declaration of indoor health status, and therefore, the objective of this assessment is to propose the need for measures in the form of potential SBS certification for a building, which is beneficial for occupants and the authorities in the event of a building accident.

Causative factors

Pollution sources

With the exception of outdoor pollutants, the enrichment of indoor substances occurs by anthropogenic emission of substances, as a result of human activities in the use of building infrastructure and space. Concentrations of substances that exceed the limit, or are less than those necessary for human health are known as pollutants. Here, pollutants are categorized as physical, chemical, microbial and particulate pollutants. Particulates are separated from the category of physical materials, because they contain a variety of chemical and microbial contaminants.

Physical parameters

Temperature, humidity, lighting, noise are important parameters of physical pollutants [16-18]. The pollution comes from lighting, kitchen equipment, TV and/or radio entertainment facilities, people's conversations, and various activities in functional spaces. For tropical areas, indoor temperature pollution can apply the facade outside the building [19-21], as a barrier against sun exposure to cool the indoor temperature. The use of Air Conditioner (AC) and fan also cools the indoor temperature, as for non-tropical areas using heaters. Humidity and noise can be controlled using building materials suitable for the function, and ventilation arrangements [22-24]. However, the use of these physical pollution control devices and materials can also emit chemical and microbiological pollutants, which require further understanding below.

Inorganic chemicals

Inorganic chemical pollutants in the indoor air include Carbon dioxide (CO_2), Carbon monoxide (CO), Methane (CH_4), Sulfur dioxide (SO_2), Sulfur trioxide (SO_3), Nitrogen Oxides (NO), Nitrogen dioxide (NO_2), and Ozone (O_3) [25-27]. CO_2 gas is the result of the respiration process of all living things in it. Each breath exhaled by an adult contains 37,000-50,000 ppm [28], or 100-140 times higher than room air. This gas can be used as a room quality indicator gas, because it is easy to measure, to represent the amount of space gases that are difficult to measure. CO_2 gas is emitted by most of the building infrastructure [29], including sanitation infrastructure, deterioration and/or degradation of building materials, furniture, and lighting. This gas emission is also from burning fossil fuels, especially kitchen and garage activities.

In addition to CO_2, incomplete combustion produces CO. Even the latest research results show that burning coal can produce CO at local ambient temperatures (15oC) [30]. In the first combustion process, CO arises spontaneously, and reaches a concentration of almost 390 ppm within 1.5 h. After extinguishing and reburning the coal, CO appears after 4 h, and reaches a maximum concentration of 80 ppm a day later. The understanding from the research results is that the first combustion of raw materials spontaneously produces CO, which can exceed the ambient CO_2 concentration. While the re-combustion produces a smaller concentration and for a longer time. Practically speaking, the first burning of coal should be kept away from, or protected from, human inhalation. Efforts to keep CO gas away, or other special forms of protection, are important, because at the same concentration, CO is a more toxic and lethal gas than CO_2, which many previous studies have proven. Even the ratio of CO_2/CO can decrease rapidly, but due to natural CO_2 absorption by decorative plants and soil [31]. CO is still a threat to human health.

Next up is methane gas (CH_4), which is colorless, odorless, and highly flammable. This methane is a major component of natural gas and biogas, which are commonly used in homes for cooking. Indoor methane also arises from the anaerobic decomposition of wet waste and/or foodstuffs [32]. Methane can also arise from prolonged moist soil floors, for example during the rainy season. The effect of CH_4 generates heat, besides being a precursor/contributor to the formation of ozone (O_3) [33].

Sulfur oxide in the form of sulfur dioxide (SO_2) is a colorless, odorless toxic gas [34, 35]. SO_2 gas arises from burning fossil fuels or other materials that contain sulfur. SO_2 gas in the air can form Sulfur trioxide (SO_3), which quickly picks up particulate water in the air and forms sulfuric acid (H_2SO_4). Sulfuric acid is a clear, colorless, and highly corrosive liquid. If there are building materials and/or furniture made of iron and rust quickly, it is necessary to watch out for the possibility of SO_x appearing in the building.

Nitrogen Oxides (NO_x) consist of Nitrogen monoxide (NO), and a smaller percentage of Nitrogen dioxide (NO_2). The level of toxicity of NO_2 is more toxic than NO [36]. The burning of fossil fuels is by far the main source through the use of motorized vehicles. Indoor sources of NO_x include kerosene heaters, stoves and gas heaters [37].

Ozone (O_3) is a colorless gas and has a characteristic pungent odor [38]. Ozone is a secondary gas, which is formed in the air through a chemical reaction between Nitrogen Oxides (NO_x) and Volatile Organic Compounds (VOCs) in the presence of sunlight. Likewise, O_3 arises in the presence of CO and CH_4. Sources of ozone in buildings are light bulbs containing mercury, and air purifiers, and electronic devices [39]. Printers and copiers have been found to be significant sources of ozone and other pollutants in the office environment. Even low-level ozone emitted by printers and copiers can react with other indoor pollutants, producing secondary pollutants and the formation of fine particulates [40].

Organic chemicals

Volatile Organic Compounds (VOCs) are commonly found in buildings, especially residential buildings [41, 42]. VOCs are one of the organic materials that are volatile and colorless and some have an odor (a group of aromatic hydrocarbons). The following are some types of materials that are included in VOCs: Formaldehyde, Benzene, Toluene, Ethylbenzene, Xylene (BTEX).

Formaldehyde contains almost 40% of which is in formalin (trade name). Formaldehyde is one of the most prominent carcinogenic pollutants in the indoor air, both in the form of gas and carried by particulates [43]. Formaldehyde is used in the manufacture of fiberboards, furniture coatings, varnishes, adhesives for wood products, curtains, oil-based paints, electronic devices, and disinfectants for floor and clothing cleaners, preservatives, household cleaners, dishwashing liquid, softeners, shoe care, shampoos, cars, candles and carpets [44]. In space formaldehyde can arise from the above products. Besides, formaldehyde is often found through combustion processes such as smoking, heating, cooking, or burning candles. In addition, building materials, furniture and wood furnishings contain formaldehyde resins such as particleboard, plywood and fibreboard. Moreover, formaldehyde is found in household products, for example air fresheners, fragrance products, and the like [45]. The concentration of formaldehyde in the room is influenced by several factors, namely, the age of the building, temperature and relative humidity, average air exchange, and season [46]. These factors can also be a reference that the level of formaldehyde in indoor air tends to be higher than outdoors. Indoor exposure to formaldehyde tends to be higher than outdoor exposure. This is due to the larger source as well as the lower rate of air exchange in the room [43].

Benzene occurs at room temperature as a clear, colorless to yellow liquid with an aromatic odor. This substance is lipophilic, being soluble mostly in organic solutions and slightly soluble in water [47]. Benzene can be found in fuel oils and products such as synthetic rubber, plastics, nylon, insecticides, paints, dyes, resin glues, furniture wax, detergents, and cosmetics.

Toluene is a colorless, highly flammable liquid that is soluble in organic solvents [47]. Toluene is an additive to petroleum and is also used as a tracer for evaporation of the petroleum [48]. Toluene appears as a component of many petroleum products. Toluene is used as a solvent for paints, coatings, rubbers, oils and resins, and can be found in soil, water, and air [49-51]. For domestic use, its concentration in indoor air can exceed that of outdoor air, with an average reported concentration of about 300 μg/day [52].

Ethylbenzene is soluble in flammable organic solvents. Ethylbenzene is found in petroleum products so that it is found in motor vehicle fuels. In addition, Ethylbenzene is present in consumer products such as paints, inks, plastics and pesticides [53]. Concentrations of ethylbenzene in outdoor air are reported to be as high as 2.7 $\mu g/m^3$, however, in indoor air it is often higher due to environmental combustion fumes and emissions from other consumer products [54].

Xylene is an aromatic hydrocarbon commonly used in the chemical industry [55], and its products include printing, rubber, paint, leather, and pharmaceuticals. Most xylene is used as an additive in fuel oil mixtures [56], as well as perfumes, cleaning agents, paints and coatings, fabricated goods, and pesticides.

Microbes

Public buildings are not sterile from invisible living things, known as microbes [56]. There are millions of microbes in the air, water, soil, floors, walls, ceilings and more. Because it is not visible to the eye, it is difficult to prove its existence to the public, and its existence is often neglected, so that the protection of health effects also receives less attention.

But generally, and as evidence of the presence of microbes in the building space is easy to show. For example, when you leave food in a food container to go stale, and wet garbage becomes smelly, and the presence of mold in a dark and hot place, or moss in a light and cold place [57].

Particulates

Particulate matter is a small solid and liquid substance that is dispersed in the air. The classification is fine particulate: $PM_{2.5}$ (diameter size up to 2.5 μm) and coarse particulate: PM_{10} (diameter size more than 2.5 μm to 10 μm).

Fine particulates generally come from burning fossil fuels, so they have a high potential for kitchen activities [58]. Fine particulates are also produced from cigarettes, building materials, insect repellent, and other household products [59, 60]. Particulates become pollutants, when the concentration of $PM_{2.5}$ in the room is more than 12 $\mu g/m^3$ [61]. Meanwhile, coarse particulates generally come from the deterioration of building materials, dust from occupant activities, and combustion residues, generally kitchen activities.

Therefore, the particulate content includes inorganic and organic substances. The content of inorganic substances includes, among others, ammonium sulfate, ammonium nitrate, sodium chloride, potassium chloride, silicon, aluminum, calcium, iron, manganese, asbestos fiber, including bacteria and fungi.

Pollutant transport

In small portions and intermittent exposure, the transport of pollutants can be through the medium of water, which is present in kitchens, sanitation services, floor cleaning, and aquariums if any. Pollutants that transport through water are of course water-soluble and/or in liquid form, for example a disinfectant solution. Likewise, intermittently and/or periodically, for contaminants that easily settle, such as particulates, their transport is through cleaning of ceilings, walls and floors. Although the portion is small and intermittent, the transport media for pollutants can also pass through solid physical objects and ornamental plants if any, manually during cleaning.

Indoor air is dynamically interacting with outdoor air, so that most and continuously is the transport of pollutants, which are volatile, through indoor air. In environmental equilibrium, the composition of indoor air is the same as ambient air of outside the building. The composition of the air [62] is mostly Nitrogen gas (N2,~78 % v/v=780,818 ppm), oxygen gas (O_2, ~21% v/v=209,435 ppm), and other gases below 1 % v/v (10,000 ppm) including CO_2.

However, volatile gases fill the room, so the exposure concentration undergoes a process of air dilution, resulting in indoor concentrations. It is the concentration of room substances that needs to be considered in relation to indoor air quality that is still acceptable to the health of the occupants.

Biological process

For completeness, visible biological life includes humans, fish in aquariums, pets, and decorative plants. All of them undergo the process of respiration as expressed in Eq. 1 [63].

$$nME + C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \mathbf{nME}$$

In Eq. 1, on the reactant side, nME is the many types (n) of Materials and Energy (ME) that are used for biological life. For example, various kinds of drinking water, food, energy sources, and other consumption materials. On the product side, equilibrium yields nME in various forms of reactant NME transformation, such as indoor pollutants that have been reviewed above. Thus, all that life produces indoor pollutants.

However, only decorative plants, which are capable of processing pollutants as described in Eq. 2.

$$\mathbf{nME} + 6H_2O + 6CO_2 \rightarrow 6O_2 + C_6H_{12}O_6 + nME$$

The process takes place in a limited time on sunny days and/or sufficient light is available, as well as the involvement of microbes and water or soil media for plant growth [64-66], which support the depollution process by decorative plants. Because of these limitations, and considering the many types of pollutants, the application of biodiversity for decorative plants is important and necessary.

Health impacts

Space contaminants can cause Sick Building Syndrome (SBS). The term is used to describe a building condition, in which occupants express discomfort living in a space. So, SBS is not an expression of a sick building, but rather the condition of the space environment as a set of factors that in various ways can have an acute influence on the physical and psychological health of the occupants [67-71]. Usually, SBS is preceded by pre-SBS, which is the appearance of allergy symptoms and/or unpleasant odors due to humidity, fragrance, deodorant, or musty. Pre-SBS is sensitive for young residents around 20-29 years old regardless of gender [72].

However, SBS actually showed a significant effect on gender [69], namely that women experienced more fatigue and/or headaches than men when they were in the room at the same time.

Temperature, humidity, lighting, noise are physical parameters, which significantly cause SBS. In summary, the occurrences of SBS were found as follows:

• Temperatures exceeding 24^{o}C give symptoms of headache, skin redness, itchy eyes and sneezing.

• A 10% increase in relative humidity from 40-50% causes coughing.

• Light intensity exceeding 600 lux gives symptoms such as dry skin, eye pain and fatigue.

• Exposure to noise levels in excess of 45 dBA produces symptoms such as headaches and dizziness [72].

Of course, the above phenomena also depend on the residence time in space, and other air parameters, which interact with each other.

For inorganic chemicals, carbon dioxide concentrations exceeding healthy limits are potentially hazardous to human health. A US National Medicine study showed that short-term effects of exposure to CO_2 pollutants include suffocation, inability and unconsciousness, headaches, vertigo and double vision, inability to concentrate, and seizures. The documented health effects of inhaling CO_2 pollutant in various concentrations are as follows: exposure to 1200-1400 ppm for 2.5-8 h causes cognitive decline and fatigue [73-75]; exposure to 2000 ppm for 3-4 h causes lung problems, increased CO_2 levels in the blood, drowsiness and dizziness [76, 77], and the higher the CO_2 concentration, the higher the health effects on human life. The effect of CH_4 generates heat, besides being a precursor/contributor to the formation of ozone (O_3). At high concentrations (more than 1000 ppm) methane can cause mood swings, slurred speech, vision problems, memory loss, nausea, vomiting, flushing and headaches[78]. The health effects of SO_x can occur in the short and long term [79, 80]. Short-term exposure to SO_x can contribute to respiratory illness by making breathing more difficult, especially for children, the elderly, and those with conditions prone to illness. Prolonged exposure can also worsen heart and lung conditions. The health effects and toxicity of NO_2 are chronic bronchitis, lung disease, and chest pain. Nitorgen dioxide (NO_2) acts as an irritant to the mucosa of the eyes, nose, throat, and respiratory tract [80]. The health effects of inhaled ozone stimulate the sensory systems in the nose and lungs and lead to activation of the nervous system. It was also found that the side effect was an increase in the levels of fatty acids, glycerol, and glucose [81]. Furthermore, the long-term effect is the incidence of asthma [82]. Short-term negative health effects, namely eye irritation, allergies and respiratory disorders and then the lungs, while in the long term can cause cancer, leukemia in children, premature birth and Alzheimer's disease [46].

For organic chemicals, benzene is a carcinogenic toxin with a high risk for human health. This substance can be exposed by mouth and inhalation, causing toxic effects on these organs [48]. General health effects of toluene include growth retardation, morbidity, mortality, liver and kidney damage and other effects. Effects of activity and sleep inhibition, performance and learning, physiology and central nervous system effects [50]. The health effects of ethylbenzene are primarily on the skin, lungs and gastrointestinal tract [47]. Exposure to xylene in air can have health effects through inhalation, eye contact or skin, and xylene vapor is absorbed rapidly through the lungs [54]. Short-term exposure causes acute effects including: inhalation of xylene is associated with shortness of breath and irritation of the nose and throat; gastrointestinal effects (eg nausea, vomiting, and gastric discomfort); mild eye irritation; and neurological effects (eg impaired short-term memory, decreased numerical ability, and changes in body balance), auditory memory, visual abstraction, and threshold vibrations in the toes. Long-term exposure to xylene can result in dizziness, fatigue, tremors, poor coordination, anxiety, inability to concentrate, sleep disturbances, headaches, irritability, depression, agitation, extreme fatigue, and impaired short-term memory. Other effects of chronic exposure include respiratory distress, impaired pulmonary function, increased heart palpitations, severe chest pain, possible renal effects, asthma-related symptoms, and muscle strength [56].

Not all microbes are contaminants that have the potential to cause disease, except for pathogenic microbes. Pathogens are microorganisms that have the potential to cause disease. It is important to remember that infection is the invasion and multiplication of pathogenic microbes in individuals or populations. To cause infection, microbes must enter our body. Microbes can enter the body through the following four portals [57]:

• Respiratory tract (mouth and nose) eg influenza virus that causes flu.

• Digestive tract (oral cavity) eg Vibrio cholerae which causes cholera.

• Urogenital tract (urinary and reproductive) eg Escherichia coli which causes cystitis (inflammation of the bladder).

• Skin surface wounds eg Clostridium tetani which causes tetanus.

To make people sick, microbes must: reach their target in the body; infect the target; multiply rapidly; obtain nutrients from the host; and survive attacks by the host immune system. The critical point of disease prevention from our body side is strengthening and maintaining our immune system. In relation to the volume of space, one of the guardians of our immune system is to stay in a comfortable and healthy space.

The particulate content makes it a pollutant that is harmful to human life [83, 84]. Particulates will enter the human body through direct exposure, which can cause allergies and eye irritation. Similarly, the transport can be through inhalation or breathing, which has an effect on the respiratory system, including various lung diseases.

Measures of pollution

Prevention of pollution is effective at the source, while also pointing to the need and importance of depollution at the design and construction stages. When the building is used, the occupants take full control of pollution prevention efforts. Therefore, a building needs to be the responsibility of the designer, contractor and occupants proportionally. In case of damage to the building during the maintenance period, according to the legality of the contract, the contractor and designer if necessary, are responsible within the limits of construction. After the maintenance period ends, all conditions and damage to the building are the responsibility of the occupants. Based on observations and experiences so far, there has been no certification of healthy buildings, and therefore the condition of the buildings is the full responsibility of the occupants. Based on the study of the facts above, it is evident that the SBS incident originates from the design stage to its use. Therefore, SBS prevention efforts can be carried out in these stages. Thus, first, the authors propose the importance and need for healthy building certification.

Second, for healthy building certification, the authors propose parameters of indoor depollution as prevention and treatment measures, which are presented in summary Table 1 and Table 2. The parameter list is a pointer based on SBS potential, and needs to be adjusted more or less according to the type of building and local conditions and regulations.

Table 1. List of potential SBS pointers at design stage

Prevention Responsibility	Parameters				Treatment	Product
	Physical	Chemical	Microbes	Particulates		
Designer	1. Indoor layout 2. Building façade 3. Lighting arrangement	1. Indoor volume 2. Ventilation arrangement 3. Selection of paint and finishing	Special spaces: 1. Kitchen 2. Sanitation services 3. Decorative plants	Materials on: 1. Ceiling 2. Wall 3. Windows and doors 4. Floor	Design adjustments, when the design stage involves potential users	SBS potential certificate for building design

Table 2. List of potential SBS pointers at construction stage

Prevention responsibility	Treatment	Product
Contractor	1. Provision of standard operating procedures for building use 2. Information on the effective start time of building use after construction is completed 3. Building safety training	SBS potential certificate for constructed building

With SBS potential certification in design and construction, both provide benefits for building users, to know the initial status of indoor quality. After the handover of the building from the contractor to the user, the user is responsible for the potential SBS from the completeness of the building contents, such as furniture selection, kitchen equipment, infrastructure replacement, room renovation and others, including maintenance. The two certifications are also useful for forensic and legal officers in the event of a building accident problem in the future, in order to assess the cause of the problem, whether it is related to design, construction and/or usage factors.

Conclusion

Sick Building Syndrome (SBS) is caused by physical, chemical, microbiological, and particulate factors, which are exposed indoors at levels exceeding the health acceptance limits of the occupants. Depollution methods for these factors can be implemented from the design stage followed by construction to the building use stage. All of them involve designers, contractors and users proportionally. It is suggested the need for potential SBS certification for buildings, which is beneficial for all parties related to buildings and their problems.

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Competing interests

The authors declare no potential conflict of interest affecting this work.

Authors' contributions

HS: conception, design, acquisition of data, analysis and interpretation of data, drafting the manuscript, and revising it, focusing on building design and construction; GS: as did HS' contribution, focusing on factors of sick building syndrome; SM: as well as the contributions of HS and GS with the addition of measures and correspondence.

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Ethical considerations

Ethical issues (including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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