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Case Report

Mitigation Methods of Sick Building Syndrome With an Emphasis on Indoor Height Setting

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Abstract
The condition of the space environment as a result of the interaction of physical, chemical, and biological factors, in a complex way, can have acute and chronic effects on the physical and psychological health of the occupants. This was the incidence of sick building syndrome, and efforts to reduce and eliminate the syndrome were presented in this case study. The aim was to produce healthy indoor quality and sustainable use by its occupants. The methods used minimum Indonesian standards regarding procedures for planning the housing environment in urban areas. The analysis of changes in the indoor volume employed indoor height variables for a particular floor area to apply flexibility to various building layouts. The variability of changes in the pollutant exposure area and indoor air volume was expressed as a relative change. Setting indoor height was a significant determinant for maintaining healthy indoor air quality through diluting air against pollutants. An additional 0.5 m of room height could increase the air volume by 15%-20% greater than the increase in the pollutant area. It was an effective method both at the design and building renovation stages. The physical and thermal mitigation was generally performed at the building use stage. Some of the conducted approaches included air conditioning (AC), electric or manual ventilation, and chemical-phytotechnological mitigation indoors by adding chemicals to space. The methods of indoor depollution during the use of buildings are still necessary using physical and chemical-phytotechnological methods by placing decorative plants.
Keywords: Air quality, Healthy, Indoor, Pollution, Prevention, Resilient buildings

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1. Introduction

The indoor space in a building can be considered an ecosystem whose factors interact and produce the quality of the indoors. There is physical infrastructure, including room air, chemicals attached to building materials, personal use, and the presence of living things, occupants, and decorative plants, if any. All indoor ecosystem factors have the potential as a source of pollution, transport of pollutants, and receivers of pollutants, acting as recipients and processing eliminations. The indoor ecosystem's quality during the building's use can produce sick building syndrome (SBS) (1-3), which can be prevented at the design stage (4) and the stage of its use.

It is well known that SBS is a condition of the indoor environment as a set of factors that can have an acute effect on the health of occupants in various ways (5-7). The occurrence of this condition is usually preceded by pre-SBS such as allergy symptoms and/or unpleasant odors in the room (8). Unhealthy symptoms can appear without knowing the place, time, and quality of the building, thus it should be a concern for all building occupants.

A set of spatial environmental factors can be categorized into environmental tricomponents, namely, pollutant sources, pollutant transports, and pollutant receivers. Pollutant sources (9-11), which have the main characteristics of emitting pollutant potential, are building materials (e.g., cement, wood, and paint), building infrastructures (e.g., furniture, lighting, and carpets), and occupants' activities (including people, cooking, and sanitation services). The passage of pollutants, the main characteristic of moving pollutants from one place to another in indoor space, is air. Pollutant receivers (12-14) have the main characteristics of accommodating, diluting, and processing pollutants. Pollutant receivers include indoor air (water in bathroom tubs, aquariums, and decorative plant pots), the soil in decorative plant pots, and decorative plants themselves.

The aforementioned three environmental components interact sequentially in an indoor space. As the building operates and is in equilibrium with the outdoor air, various outdoor contaminants undergo transfer and interact with the indoor air. Therefore, measuring indoor health can be approached with two indicators (15, 16), namely, the indoor/outdoor (I/O) and bacteria/fungi (B/F) ratios. The I/O ratio shows the ratio of indoor and outdoor microbial colony concentrations, while the B/F ratio is the ratio of bacterial and fungal colonies. When both are less than one, it indicates that contamination from an outdoor source and prolonged repetition can cause SBS.

To keep the indoor space healthy, in an interactive circle of environmental factors, mitigation measures are needed, including prevention through the design of indoor space and its infrastructure at the new development plan stage, control of the operation and maintenance of building infrastructure at the building use stage, and restoration through the renovation of indoor space at the stage of building use. Thus, this topic aims to prepare the methods of indoor depollution using preventing, controlling, and remediating SBS. These efforts can be minimized through an approach to reducing pollutant concentrations by using an indoor air dilution mechanism. A novel technical method is increasing the room's height so that the air volume increases as a diluent for pollutants. This indoor height setting approach is a new proposal in the architectural design of buildings that prioritizes occupant health and sustainable building use.

2. Materials and Methods

Mitigation in this paper covers two stages of building construction, namely, the design and building use stages. Mitigation at the building design stage is an effort to prevent the occurrence of SBS, which involves architects and contractors and can affect potential occupants. Mitigation at the building use stage is an SBS control measure, which requires explicitly building occupants and recovery from SBS events involving occupants, architects where appropriate, and contractors.

This case study is specifically based on the application standards in Indonesia, namely, SNI 03-1733-2004 on procedures for planning the housing environment in urban areas (17). The standard has set a minimum indoor height, which is 2.5 m. However, it can be explored for standards that apply anywhere because it only adjusts to the minimum indoor height standard.

The analysis of changes in the indoor volume can use indoor height variable (h) for a certain floor area fA, which is equal to ceiling area cA (Fig. 1) so that it is flexible to various building layouts.

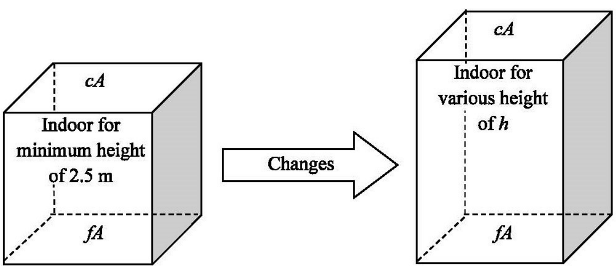

Fig. 1. Indoor Schematic Dimensions

In the context of indoor pollution, where every part of the building becomes a source of pollution (9-11), the area of exposure to pollutants is the same as the indoor area (Ia), namely, the floor area plus the ceiling area and the total wall area (twa), namely:

$$Ia = cA + fA + twa \quad (1)$$

In addition, indoor volume (Iv) is the volume of the indoor air as a pollutant transport medium as follows:

$$Iv = fA * h \quad (2)$$

The variability of changes in the pollutant exposure area and the indoor air volume is expressed as a relative change, which is formulated from the combination of Eqs. (1) and (2) as follows:

Relative change indoor area ***(rca)*** =

$$[\{Ia(h) - Ia(std)\}/(Ia(std)]*100\% \quad (3)$$

Relative change indoor volume ***(rcv)*** =

$$[\{Iv(h) - Iv(std)\}/(Iv(std)]*100\% \quad (4)$$

For Eqs. (3) and (4), notations (h) and (std) are the independently defined height and the minimum standard height, respectively.

This mitigation method applies to all types of building materials which are the preferences of building users. This case study prepares two mitigation methods (i.e., physical and chemical-phytotechnological methods). Both of them were formed based on the latest literature review and field observations. The physical method compares the built's indoor height and its modifications and thermal comfort by using an air conditioner, fan, air exhaust, and natural and manual ventilation. At the same time, the chemical-phytotechnological method works by spraying chemicals for air fresheners, mosquito repellents, and disinfectants, as well as using decorative plants to absorb indoor pollutants.

The criteria for reducing SBS are based on decreasing pollutant concentrations by diluting the indoor air volume as a result of increasing indoor height and based on pollutant removal using chemical cleaning agents and the provision of decorative plants.

3. Results and Discussion

3.1. Indoor Height

This approach can be implemented at the building design and building use stages. The role of designers, occupants, and contractors is a success factor for the prevention and recovery of SBS.

For a particular area, the height variability of the indoor space directly influences the dilution of the pollutant concentration. This is because the air volume for the high room is more than the air volume for the low room. Therefore, the large volume of air becomes a diluent for pollutant concentrations. However, increasing the indoor space height certainly increases the walls' area, which is also a source of pollutants. Thus, the advantages of mitigating space height should be proven below.

An illustration is provided for a cube indoor with a height, between floor and ceiling, as high as 2.5 m for the Indonesian standard (17). Furthermore, the room's height is increased every 0.5 m until it reaches an additional 100% (i.e., twice the height of the standard room). The area of indoor is the sum of the area of 4 walls, floors, and ceilings, all of which are sources of indoor pollution. The volume of indoor becomes the volume of air as a diluent for pollutants. The results of the calculation of the area and indoor volume are presented in Table 1.

Table 1 provides the relative additional area, which then becomes the additional area of the pollutant (the relative additional volume), which then becomes an additional volume of air. These calculations demonstrate that the additional air volume is greater than the additional pollutant area due to the addition of room height for the same floor area. In this condition, the addition of room height reduces the concentration of pollutants through the dilution process.

The readers are welcome to practice calculations for their residence, school room, workspace, and other forms of indoor space for the same indoor area. For example, using the same method, according to Eqs. (3) and (4) which resulted in Table 1, can produce the same results. Thus, the height of indoor space is a determinant of indoor quality improvements through the dilution of pollutant concentrations.

3.2. Remediation Stage

This is used for three criteria; the space has been built and used, the occupants have experienced at least pre-SBS, and the need to restore environmental conditions without expanding the floor area. Fig. 2 displays an example of a 2.5-m high cubical room (17) using a flat ceiling and renovated into a ceiling integrated into the roof.

Based on the data, the additional area of the pollutant producing area is {(43.1-37.5)/37.5}*100% = 15%, and the additional air volume is (21.9-15.6)/15.6}*100% = 40%. The additional air volume is greater than the additional pollutant area, representing the similarity of results with those of the pollutant dilution approach for the prevention stage in the design of new buildings.

In practice, space height mitigation can use several options to dilute pollutant concentrations. First, to design buildings that use ceilings, it is necessary to compare several heights of space. Second, for building renovations, the ceiling should be raised to a higher level than can be achieved, or a ceiling integrated into the roof should be used for this purpose. Moreover, an additional 0.5 m of room height can increase the air volume by 15-20%, which is greater than the increase in the pollutant area.

It is important to consider the additional energy as a result of the increase in indoor height, especially electricity, when the light bulb is placed on the ceiling. Occupants require a large number of light bulbs to provide adequate illumination. To save electricity, a viable solution is to identify the light bulb on the wall in a low and accessible position. This design also simplifies the operation and maintenance of electrical facilities by occupants.

3.3. Thermal Control

This approach is generally performed at the building use stage, which is the main role of the occupants in controlling

Table 1. Variability of the Area and Volume of Indoor Space

Indoor Height (m)	Floor and Ceiling Area (m^2): A	Wall Area (m^2): B	Indoor Area (m^2): A + B	Relative Additional Area (%): Eq. (3)	Indoor Volume (m^3)	Relative Additional Volume (%): Eq. (4)
2.5	2.5*2.5*2 = 12.5	2.5*2.5*4 = 25	37.5	0	15.6	0
3	2.5*2.5*2 = 12.5	2.5*3*4 = 30	42.5	13	18.8	21
3.5	2.5*2.5*2 = 12.5	2.5*3.5*4 = 35	47.5	27	21.9	40
4	2.5*2.5*2 = 12.5	2.5*4*4 = 40	52.5	40	25.0	60
4.5	2.5*2.5*2 = 12.5	2.5*4.5*4 = 45	57.5	53	28.1	80
5	2.5*2.5*2 = 12.5	2.5*5*4 = 50	62.5	67	31.3	100

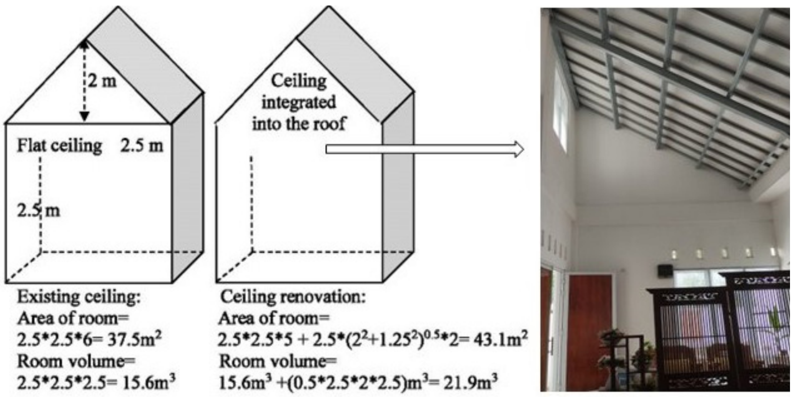

Fig. 2. Renovation of the Room Height

the quality and comfort of the indoor space.

In Indonesia, in particular, air conditioning (AC) has been widely used in the tropics. The use of AC (18) with temperatures of 14-18°C makes the air temperature gradient between the floor and ceiling as high as 2.8 m in the range of 1.5°C. The air temperature gradient represents that the temperature of the floor is hotter than the ceiling. The temperature gradient is smaller than without AC, which is in the range of 4°C. The experimental results of cooling air conditioners in a room as high as 2.45 m (19) demonstrated the fact that the temperature gradient is around 1°C. The small temperature gradient is potentially due to the short height of the room. Both experiments yielded the same findings that room cooling produces a small temperature gradient.

The use of AC is a thermal mitigation of air at a constant temperature level desired by occupants, aiming at providing comfort for occupants; this comfort can at least prevent one factor of SBS. However, in practice, the use of AC is accompanied by closing the ventilation. The closed indoor space has the potential for preventing a decrease in the concentration of pollutants (20, 21) so that the intervention for reducing pollutants is minimal. This weakness should be compensated by scheduled maintenance as part of the air intervention as a pollutant-receiving medium.

Thermal control of the indoor space can also be performed by fans, air exhaust, and natural ventilation using structural windows and manually opening and closing windows and doors, resulting in space air movement and ambient air exchange. Some researchers (22) have proven that the use of natural ventilation produces a better effect than the use of AC, implying that the concentration of room pollutants decreases due to the dilution of the ambient air because room air quality is in equilibrium with the ambient. Mitigation management in these ways can be mentioned to be practical and spontaneously prevent thermal discomfort and pollutant accumulation.

3.4. Chemical Use

This is generally outperformed at the building use stage, which is the main role of the occupants in controlling the quality of built infrastructure and the comfort of the indoor space.

Chemical mitigation in indoor environments by adding chemicals to space has so far been commonly conducted by people. An example is spraying the air freshener with the intention to remove the musty odor as one of the symptoms of pre-SBS in addition to the use of insect repellent, whether electrically, burning, or spraying aerosols. However, several studies (23-25) are concerned about the use of these chemicals because they are harmful to the health of occupants. In practice, people find it difficult to change habits unless they attempt to reduce the use of chemical substances. Thus, the amount, according to the instructions, for use is normal and does not endanger the health of the occupants. In addition, chemical mitigation should be precise at the time of use, namely, when the room air is in a stable condition from movement due to temperature fluctuations. The timing of mitigation at night is appropriate in the use of mosquito repellent.

The next alternative is the use of disinfectants in daily activities both in conditions with and without the COVID-19 pandemic. Disinfection is a chemical mitigation method for the elimination of microbial contaminants or pathogens, which are in inanimate objects. The buildings and infrastructure should be sterilized using disinfectants (26) and antiseptics to eliminate pathogenic microbes in living things, especially humans. From the point of view of room aroma, the application of disinfectant for daily use indoors is to support pre-SBS mitigation.

3.5. Applied Phytotechnology

Phytotechnological mitigation aims to empower plants for indoor quality management and processing of the release of pollutants. The application of phytotechnology is within the framework of performing the three main tasks of plants, namely, resources, repression, and remediation (27, 28). Plants provide the sources of life for all living things in the form of oxygen. Plants can also prevent indoor pollution in the form of the ability to process contamination. In fact, plants can remediate the quality of the polluted indoors in the form of the ability to extract contaminants from the environment. The application of decorative plants is important and recommended because of its ability to eliminate chemicals from the use of air fresheners and insect killers (29-32).

In addition to the aspects of comfort, beauty, aroma, and others, plants are highly significant for preventing, processing, and restoring SBS. The application of plants as the managers and processors of room air quality makes them decorative plants for indoor health. The application of decorative plants for building spaces requires social preference studies (33-35) and is related to ambient air quality (36-38). However, practically, several types of decorative plants have been used according to the preferences of occupants (39, 40). Likewise, they can be placed in any room based on occupants' preferences. The use of decorative plants is promising as SBS prevention, especially for tropical areas, which are longer exposed to sunlight than non-tropical areas.

4. Conclusion

The preventive mitigation of indoor pollutants is effective during the design phase. For example, with the indoor height approach, the decrease in pollutant concentrations by air dilution can reach about 40% for every 1-m increase. Correspondingly and in the condition of the existing building, the modification of the integrated roof ceiling can improve the air quality of the room depending on changes in the height of the achieved room. This effort can be further increased at the building use stage, where residents regularly clean the space and provide decorative plants where possible. With these preventive and operational efforts, it is hoped that SBS incidents can be reduced to a minimum and become a sustainable healthy building.

The limitations of this study are based on the standards set as technical guidelines that must be followed (the top-down approach), which have not been integrated with the social aspects of building users (the bottom-up approach). However, the implications of the results of this study stimulate the evaluation of building standards by interested parties in addition to socialization for residents to try their best to prevent the emergence of SBS.

Further empirical studies should be conducted by including population demographic considerations, which have social aspects related to the development and distribution of the population in need of housing, economic elements such as the ability to procure houses, technical aspects regarding progress in housing development, urban building arrangements, and environmental factors related to the availability of land for settlements.

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Competing Interests

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

Ethical Approval

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

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