A Comparative Study on Sick Building Syndrome by Apartment Unit Plan with and without Cross Ventilation

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Abstract

The purpose of this study is to examine the effects of different types of apartment unit plan on symptoms related to SBS. The apartment floor plans covered in this study are divided between two types: plans with and without cross ventilation. The major methodology for the study was a survey that used an array of question items selected from preceding research related to SBS and preliminary study. The survey was conducted in August and September 2012 (summer), a season reported to show a higher rate of occurrence of SBS, and surveyed a total of 120 households, 60 households for each apartment plan type. The conclusion drawn from the findings of the survey is as follows. First, SBS symptoms were reported to occur from one and a half to two times more frequently among occupants of apartments without a cross ventilation floor plan than among those with a floor plan allowing cross ventilation. Second, narrow and enclosed spaces with built-in closets, such as entryways or bathrooms, were found to be more commonly associated with SBS symptoms. Even the living room was cited as among the areas associated with SBS symptoms by occupants of apartments with a floor plan lacking cross ventilation. Third, a majority of occupants were found to use "bake-out" to reduce the effects of SBS, but their satisfaction with this measure was low. As for "natural ventilation," the level of satisfaction was reported to be higher among the occupants of cross ventilation plan apartments, but relatively lower among their counterparts.

Keywords: apartment buildings; apartment unit plan; sick building syndrome

1. Introduction

1.1 Background and Objectives of the Study

Health issues are often a focus of public interest since well-being or the value of leading a happy and healthy life has emerged as a buzzword. The development of technology and economic growth are allowing people to reside in more hygienic environments and affluent settings than they may have in the past. At the same time, however, technological advancement and material prosperity have triggered a range of problems.

Given the fact that environmental pollution may negatively impact human health, this issue has emerged as a top priority to be addressed.

A special feature "Counterattack from the Environment—Homes attack residents" was televised on the Seoul Broadcasting System on January 3, 2004, sensitizing a number of people to the importance of the indoor environments in which modern people often spend the bulk of their time. It was reported that a growing number of people suffer pain and discomfort due to chemical materials present in the residential environment where they eat, recreate and sleep on a daily basis. Even healthy people may experience physical disorders after moving into a newly constructed house and live in daily pain and discomfort due to sick building syndrome (SBS), also known as sick house syndrome. This sick building syndrome has been reported to be the result of exposure to harmful indoor chemical substances.1

These circumstances have aroused the attention of the construction industry, as well as of manufacturers of building materials such as adhesives, paint, wood-based composite materials, furniture and interior finishing. A related law, the Indoor Air Quality Control in Public Use Facilities, etc. Act, has been in effect in South Korea since March 2004, demonstrating the South Korean government's awareness of the gravity of indoor air pollution.

Existing studies on SBS have relied upon the single method of general surveys targeting all residents of housing in general, and none have addressed the
relation between symptoms of SBS and residential unit plan.

Therefore, this study aims to examine the impact of apartment unit floor plan on symptoms related to SBS by conducting a survey targeting residents experiencing SBS symptoms and then comparing and analyzing unit plans designed with or without cross ventilation. 

1.2 Scope and Methods of the Study

The scope of the study was limited to apartment units with and without cross ventilation. For the preliminary study, apartment units one or two months after a pilot survey were selected. As the study progressed, the survey targeted units at three or four months after inspection. The unit size was roughly 84 m² and their orientation was south-eastwards.

The survey for this study was conducted on a total of 180 households residing in apartment buildings newly erected by companies A, B, and C. Apartments were subdivided into two groups: unit plans with and without cross ventilation; thus 30 households were selected for each respective subunit. The analytic frames are as follows.

The survey was conducted over approximately one month from August 4 to September 3, 2012, a period reported to show a higher rate of occurrence of SBS. In order to analyze symptoms associated with SBS by apartment unit plan, a total of five items were investigated: pattern of symptoms of SBS by family member; spaces associated with symptoms of SBS; presumed causes for SBS; remedial measures for SBS and related satisfaction; and occupants’ awareness of mechanical ventilation systems. Through a comparative analysis of these items, this study concentrated on identifying the relationship between symptoms of SBS according to apartment unit plan, time spent in the unit, and within particular areas of the unit, and sought to offer countermeasures.

2. Summary of Sick Building Syndrome

SBS refers to a variety of symptoms of which people have suffered after moving into a newly built house. One major contributor to SBS is formaldehyde, a volatile chemical commonly used as a raw material in preservatives, adhesives or spray paint for interior design. For example, immediately upon moving into a newly built house, allergic diseases such as atopic dermatitis and asthma can be exacerbated or skin irritations of unknown provenance may occur. There are wide variations in the manner and severity to which individuals may be affected. For young children and older people with weakened immune systems, symptoms may be exacerbated. In the case of those suffering preexisting allergies, allergy symptoms may be aggravated. 

The causes of problems with SBS can in general be divided among four categories. The first is the home itself. The traditional house of the past had a high infiltration rate and less indoor-generated chemical contaminants. In order to minimize adverse thermal conditions, however, homes have been made more airtight and better insulated through the application of aluminum or plastic sashes, double-paned glass, glass walls and/or insulation such as foamed polystyrene. These result in reduced air leakage, leading to a drop in air exchange rate, which makes it difficult to exhaust indoor air pollutants from the structure. What is more, a number of newly developed chemical components have been used as construction materials to heighten existing materials’ performance in terms of decoration (design), durability (chemical stability, preservatives and moth-proofing), safety (fire and disaster prevention), convenience and economic efficiency.

The second category relates to lifestyle. When houses are in extremely close proximity, it is considered more difficult to leave windows open due to privacy and/or noise issues. In addition, the introduction of air conditioning and heating systems has led people to acquire the habit of living with windows closed. Along with building materials, improved standards of living have allowed household items high in chemical substances to enter the home, such as furniture, air freshener, insect repellent, cosmetics, and hairspray.

The third is air pollution. The use of fossil fuel has resulted in a severe increase in air pollution. For example, black carbon emissions from diesel engines are combined with pollen, thus putting people at risk of developing or exacerbating allergies. Attention should be directed to the fact that outdoor air may actually be more polluted than indoor air in certain areas such as roadsides, near industrial complexes or in farmlands due to the increase in the use of agricultural pesticides.

The fourth category spans the human body. Chemical materials can enter the human body through the respiratory system or food and accumulate to levels triggering multiple chemical sensitivity. However, the amount of a compound causing the development of disease can vary by individual. Chemical materials released into the air or sea are gradually transferred to and accumulated within the human body through the food chain. This results in an increased rate of allergy sufferers.

| Concentration (ppm) | Effects on the Body |
|---------------------|---------------------|
| 1 or less           | Irritation of eyes, nose and throat |
| 0.25-5              | Severe asthma attack among people with bronchial asthma |
| 10-20               | Cough, chest tightness, dull feeling in head, rapid heartbeat |
| 50-100              | Fluid accumulation in the lungs, pulmonary inflammation, death, severe pain in mouth, throat and stomach following inhalation, vomiting, diarrhea, dizziness, convulsions, unconsciousness |

Table 1. Effects of Formaldehyde on the Human Body\(^3\)
3. Investigation and Analysis of Sick Building Syndrome Symptoms by Apartment Unit Plan

This study examines differences in SBS symptoms between occupants living in units with floor plans providing cross ventilation and those in units without cross ventilation.

According to the paper "Changes in Indoor Air Pollution over Three Years after Occupancy of New Apartments" by the Ministry of Environment, the greatest volume of pollutants is released within three to four months following occupancy. Therefore, this study selected apartment buildings the construction of which had been completed by one of the three construction companies either three or four months in the past (see Table 2).

The authors' survey consists of three parts. The first relates to the general characteristics of the apartment unit, such as overall information, size, orientation, occupancy period and the number of floors. In order to acquire basic information about household members, questions were included regarding age, gender and time spent in the apartment unit.

The second part investigates SBS. Types of SBS symptoms, symptom duration, areas associated with SBS symptoms, presumed causes for the syndrome, measures to resolve SBS, and the satisfaction with the measures taken were examined.

The third area deals with questions about ventilation in the apartment unit. Occupant satisfaction with the mechanical ventilation system and hours of using the ventilation system were examined.

3.1 Types of SBS Symptoms by Family Member

3.1.1 Female Homemakers

According to the survey, female homemakers spent the greatest amount of time in the home, reporting an average occupancy reaching 20 hours per day. Among the 180 female homemakers queried, 94 (52.2%) answered "yes" to whether or not they had suffered SBS symptoms. Among the 90 female homemakers living in apartments with a cross-ventilation floor plan, 36 (40%) answered in the positive, compared to 58 (64.4%) out of the remaining 90 residing in apartment units without a cross-ventilated plan. This indicates that homes lacking cross ventilation have a higher occurrence rate of SBS compared with the contrasting type of homes (see Table 3).

Among the SBS symptoms reported (multiple responses were allowed) by 36 female homemakers in apartment units with cross-ventilation floor plans, sore eyes was the most cited (16 respondents), followed by dizziness (11), dry and fatigued eyes (9), sneezing (8), headache (7), sore throat and worsening rhinitis (6 each), frequent coughing and runny nose (5 each), itchy and dry skin (4), dry and hoarse throat (3), aggravated asthma, worsened bronchitis, and nasal stuffiness (2 each), and lethargy (1).

Out of those 36 female homemakers in apartment units with cross-ventilation floor plans who complained...
of such symptoms, the greatest number—12 respondents (33.3%)—stated that their symptoms persisted for one month or longer but less than two months. The period one week or longer but less than two weeks ranked second, cited by eight subjects (22.2%), followed by between three and four weeks and between two and three weeks, cited by five (13.9%) and four subjects (11.1%), respectively. The remaining response options—between two and three months, less than one week, between three and four months, and four months or more—were cited by three (23.1%), two (5.6%), one (2.8%), and one (2.8%) subjects, respectively.

In apartment plans where cross ventilation is unavailable, the 58 female homemakers who reported having suffered SBS symptoms experienced, in order from the most to the least cited with multiple responses allowed, sore eyes (32 respondents), dizziness (27), headache (25), sore throat (24), frequent coughing (22), dry and fatigued eyes, and sneezing (21 each), nasal stuffiness and runny nose (18 each), itchy and dry skin (12), worsening rhinitis (11), dry and hoarse throat (10), lethargy, and loss of concentration and memory (7 each), worsened bronchitis (6), worsened atopic dermatitis (5), aggravated asthma, and nausea and vomiting (4 each), and heart palpitations (2).

Among the subjects, the largest number—36 out of 58, or 41.4%—responded that their symptoms continued for one month or more but less than two months, with 13 (22.4%) and eight (13.8%) citing between two and three months and between three and four months, respectively. The number of those reporting one week or more but less than two weeks was four (6.9%), followed by two to three weeks, between four and five weeks, and four months or more, chosen by one respondent (1.7%), respectively. The results indicate that SBS occurs more frequently and lingers for a longer period with apartment units without cross-ventilated plan (see Table 4.).

### 3.1.2 Married Men

The average hours of home occupancy for married men was 14, and among the 177 respondents, 35 (19.8%) reported SBS symptoms. Out of the 89 respondents living in apartment units with a cross-ventilated plan, 11 (12.4%) complained of such symptoms, while the figure rose to 24 (27.3%) among those residing in apartments without a cross ventilated plan.

The men living in apartment units with a non-cross ventilation floor plan showed a relatively higher percentage of reporting SBS symptoms than did those with cross-ventilation floor plans (see Table 5.). With multiple responses allowed, among the symptoms reported by husbands residing in apartments with cross-ventilated floor plans, worsening rhinitis ranked first, cited by 6 out of 11 subjects, followed by sore eyes (5 respondents), dry and fatigued eyes, sore throat, nasal stuffiness, runny nose, and sneezing (2 each), and headache, frequent coughing, dry and hoarse throat, worsened bronchitis, itchy and dry skin, and lethargy (1 each).

When asked how long their symptoms lasted, the largest number—5 out of 11 subjects, or 45.6%—chose one week or over but less than two weeks, with between two and three weeks and between two and three months cited by three respondents (27.3%), respectively.

On the other hand, for apartment plans without cross ventilation, SBS symptoms reported by the 24 husbands who responded that they had suffered such symptoms were, in order from the most to the least cited, with multiple responses allowed, sore eyes (11), sneezing (9), dizziness, dry and fatigued eyes, and sore throat (8 each), frequent coughing (7), nasal stuffiness, runny nose, and worsening rhinitis (6 each), dry and hoarse throat (4), itchy and dry skin, and lethargy (3 each).
Among those reporting symptoms, the largest number—9 (37.5%) out of 24—responded that their SBS symptoms continued for one month or more but under two months, while eight (33.3%) selected between two and three months. The durations of between one and two weeks and between three and four months were in third place, cited by three (12.5%) each, followed by between three and four weeks, cited by one (4.2%) each. These figures indicate that SBS occurrence is more frequent and its duration is longer with apartment plans not allowing for cross ventilation (see Table 6).

3.1.3 Children

The average hours of home occupancy for the children in the surveyed households was 11 hours, and among the 211 children, 52 (24.6%) responded "yes" to whether or not they had suffered any SBS symptoms. Specifically, in apartments with cross ventilated floor plans, 40 (19.8%) out of the 211 subjects answered "yes" while the figure rose to 60 among the remaining 90 female homemakers who reside in apartments with floor plans lacking cross ventilation (see Table 8).

As the outcome suggests, the percentage of children reporting SBS symptoms was higher in apartments without cross ventilation floor plans (see Table 7).

As for children residing in apartments with floor plans featuring cross ventilation who reported experiencing SBS symptoms, with multiple responses allowed, the largest number—9 out of 22—identified as their symptoms sore eyes, followed by worsening rhinitis (8); sneezing (7); runny nose (6); frequent coughing (4); dizziness (3); dry and hoarse throat, nasal stuffiness, itching and dry skin, and worsened atopic dermatitis (3 each); worsened bronchitis and lethargy (2 each); headache, and nausea and vomiting (1 each).

Among the subjects, eight of the children (36.4%) reported that their symptoms continued for one month or more but under two months. Seven (31.8%) selected between one and two weeks, three (13.6%) picked between two and three weeks and between two and three months, respectively, and one (4.5%) identified between three and four weeks.

In apartment plans without cross ventilation, with multiple responses allowed, 11 of the 30 children who reported having suffered SBS symptoms complained of frequent coughing, making up the largest proportion. Nasal stuffiness ranked second, cited by nine children, followed by dry and fatigued eyes, runny nose, and worsening rhinitis (8 each); sore eyes and sneezing (7 each); itching and dry skin (6); worsened atopic dermatitis (5); dizziness and headache (4 each); sore throat, dry and hoarse throat, aggravated asthma, and lethargy (3 each); and worsened bronchitis (2).

When these 30 children were asked how long their symptoms lingered, the largest number, 12 (40%), responded two months or longer but less than three months. The next-most common response was between one and two months, between three and four months, and between one and two weeks, cited by ten (33.3%), six (20%), and two (6.7%) respondents, respectively. This outcome indicates that SBS occurs more often and its symptoms linger longer in apartment units with floor plans lacking cross ventilation (see Table 8).

### 3.2 Spaces Associated with SBS Symptoms

Among the female homemakers from the 180 households surveyed, 100 (55.6%) answered "yes" to whether or not their homes had a space they associated with SBS symptoms.

Specifically, in cross-ventilated apartment plans, 40 out of 90 female homemakers said "yes," while the figure increased to 60 among the remaining 90 female homemakers who reside in apartments with floor plans not allowing for cross ventilation. As the results...
Table 8. Duration of Children's SBS Symptoms

|                      | Cross Ventilation Plan | Non-Cross Ventilation Plan | Total |
|----------------------|------------------------|-----------------------------|-------|
|                      | Company A              | Company B                   | Company C                  | Sub-total | Company A              | Company B                   | Company C                  | Sub-total |
| Under 1 week         | -                      | 2 (20%)                     | -                          | 0 (0%)     | -                      | 18 (12%)                    | -                          | 19 (13%)  |
| 1-2 weeks            | 5 (83.3%)              | 2 (20%)                     | -                          | 7 (51.8%)  | 1 (10%)                | 1 (8.3%)                    | -                          | 2 (6.7%)  |
| 2-3 weeks            | -                      | 3 (50%)                     | 3 (13.6%)                  | -          | -                      | -                          | 0 (0%)                    | 3 (5.8%)  |
| 3-4 weeks            | -                      | 1 (16.7%)                   | 1 (4.5%)                   | -          | -                      | -                          | 0 (0%)                    | 1 (1.9%)  |
| 4-5 weeks            | -                      | -                          | 0 (0%)                     | -          | -                      | -                          | 0 (0%)                    | 0 (0%)    |
| 1-2 months           | 1 (16.7%)              | 6 (30%)                     | 1 (16.7%)                  | 8 (36.4%)  | 4 (40%)                | 2 (25%)                     | 4 (33.3%)                 | 10 (33.3%)|
| 2-3 months           | -                      | 2 (30%)                     | 1 (16.7%)                  | 3 (13.6%)  | 5 (50%)                | 6 (75%)                     | 1 (8.3%)                  | 12 (40%)  |
| 3-4 months           | -                      | -                          | 0 (0%)                     | -          | 6 (50%)                | 5 (20%)                     | 6 (11.5%)                 | 13 (28.8%)|
| 4 months and over    | -                      | -                          | 0 (0%)                     | -          | -                      | -                          | 0 (0%)                    | 0 (0%)    |
| Total                | 6                      | 10                         | 6                           | 22         | 10                     | 8                          | 12                        | 30 (52%)  |

Table 9. Spaces Associated with SBS Symptoms (Multiple Responses)

|                      | Cross Ventilation Plan | Non-Cross Ventilation Plan | Total |
|----------------------|------------------------|-----------------------------|-------|
|                      | Company A              | Company B                   | Company C                  | Sub-total | Company A              | Company B                   | Company C                  | Sub-total |
| Entryway             | 11                     | 8                           | 11                          | 30        | 17                     | 8                           | 17                         | 42        |
| Kitchen              | 6                      | 6                           | 10                          | 22        | 12                     | 7                           | 15                         | 34        |
| Living Room          | -                      | 3                           | 1                           | 4         | 14                     | 11                          | 13                         | 38        |
| Master Bedroom       | 10                     | 15                          | 13                          | 38        | 21                     | 15                          | 22                         | 58        |
| Child's Room 1       | 6                      | 8                           | 10                          | 24        | 18                     | 7                           | 17                         | 42        |
| Child's Room 2       | 6                      | 4                           | 8                            | 18        | 12                     | 8                           | 16                         | 36        |
| Bathroom 1           | -                      | -                           | 0                            | 0         | 3                      | 3                           | 1                          | 7         |
| Bathroom 2           | -                      | -                           | 0                            | 0         | 2                      | 3                           | 1                          | 6         |
| Utility Room         | -                      | -                           | 0                            | 0         | -                      | 2                           | 1                          | 3         |
| Balcony              | -                      | -                           | 0                            | 0         | -                      | 2                           | -                          | 2         |
| Number of Respondents| 39                     | 44                          | 53                          | 136       | 99                     | 66                          | 103                        | 268       |
| Number of Respondents| (Multiple Responses)   | 11                          | 15                          | 14         | 40                     | 23                          | 15                        | 22         | 60  |

indicate, the percentage of female homemakers who reported associating a certain space in their homes with SBS symptoms was higher in apartment units without cross-ventilation floor plans.

In apartments with cross-ventilated floor plans, the master bedroom was cited as associated with SBS symptoms by the largest number of respondents, 38 (multiple responses allowed), followed by the entryway (30), child's room 1 (24), kitchen (22), child's room 2 (18), and the living room (4).

In apartments where the floor plan does not provide for cross ventilation, spaces associated with SBS symptoms were, in order from the most to the least cited by respondents, the master bedroom (58), entryway and child's room 1 (42 each), living room (38), child's room 2 (36), kitchen (34), bathroom 1 (7), bathroom 2 (6), utility room (3), and balcony (2). These figures indicate that in apartment units with non-cross ventilated floor plans, a greater number of spaces were associated with SBS symptoms. Notably, living rooms were indicated more often than they were in the case of cross-ventilated floor plans (see Table 9.).

3.3 Possible Causes of SBS

Out of the female homemakers in the 180 households surveyed, 100 (55.6%) responded "yes" to whether or not they believed there were possible causes of SBS symptoms in their homes.

Among the possible causes of SBS symptoms, with multiple responses allowed, the largest number of female homemakers dwelling in apartment units with a floor plan providing cross ventilation cited built-in closets, with 38 affirmations, while 13 subjects identified building and finishing materials.

In apartments with a non-cross ventilation floor plan, all 60 female homemakers indicated built-in closets, followed by building and finishing materials (22) and a closed floor plan (21). Built-in closets, regardless of the type of plan, showed the highest rates among the possible sources. Also, the response that SBS could be triggered by a closed floor plan was only offered at a high rate in homes without cross ventilation. This leads to the assumption that non-cross ventilation floor plans do not provide adequate ventilation, thus raising the incidence of SBS (See Table 10.).

3.4 Measures against SBS and Satisfaction Levels

3.4.1 Implementation of Measures against SBS

Among the female homemakers in the 180 households surveyed, 100 (55.6%) replied "yes" as to whether or not they had taken action to address SBS. For the questionnaire item as to what measures they had taken, those 100 female homemakers responded as follows, with multiple responses allowed. Among the measures reported by female homemakers living in cross-ventilated floor plan apartments, "opening windows" was the most cited (37 responses), followed by bake-out (23), air-purifying houseplants (12), charcoal (9), other (3), and eco-friendly building materials (2). Among those with an apartment plan...
lacking cross ventilation, opening windows also ranked first, cited by 58 out of the 60 respondents, followed by
bake-out (35), air-purifying houseplants (15), charcoal
(10), and finally other (6). The percentage of female
homemakers who took the action of opening windows
in order to relieve SBS was the highest among the
measures taken with both types of plan (See Table 11.).

### 3.4.2 Satisfaction Levels for Measures against SBS

These 100 female homemakers who took measures
to address SBS were also asked whether or not they
were satisfied with their remedies, with multiple
responses allowed. Among those with apartment plans
featuring cross ventilation, all of the 37 respondents
who cited opening windows responded "yes." Among
the 23 female homemakers who chose bake-out,
twelve answered "no" while eleven indicated "yes," followed by air-purifying houseplants where six out of
twelve responded positively and the other half marked
"no." For other measures and eco-friendly building
materials, one of the three and one of the one said
"yes," respectively.

Out of the 58 female homemakers in non-cross
ventilation plans who tried opening windows, 34
indicated "yes" while 24 replied "no," followed by
the bake-out method where 25 out of 35 indicated
"no" and ten selected "yes." For air-purifying houseplants,
ten out of 15 indicated negative satisfaction, while five
answered in the affirmative, with charcoal receiving
nine votes for "no" and one for "yes." In terms of other
measures, five out of the six who tried them said
"yes" and one responded "no." Female homemakers living
in apartment units with cross ventilation plans all
reported being satisfied with opening windows, while
the satisfaction level of their counterparts was low. The
satisfaction levels for bake-out were below 50% for
both plan types (See Table 12.).
4. Conclusion

The results of the study are as follows.

First, SBS symptoms were reported to be one and a half to two times more frequent among occupants of apartments lacking a cross ventilation floor plan than among those with floor plans allowing cross ventilation. Furthermore, the occurrence of SBS among "female homemakers," the household members who spend the greatest amount of time in the home, was two or three times higher than that among married men or children. This would indicate that female homemakers living in non-cross ventilation plans are more vulnerable to SBS.

Second, the space most commonly associated with SBS symptoms by respondents was found to be the "entryway" in both types of plan, suggesting that narrowness and enclosure of a space may correlate to its association with SBS symptoms. In addition, a number of occupants of apartment units with non-cross ventilation plans even associated the "living room" with such symptoms, intimating that SBS could be causing considerable inconvenience in their daily lives.

Third, a majority of occupants were found to use "bake-out" to address SBS, but their reported satisfaction with the measure was low. As an alternative, they also attempted "natural ventilation," for which their satisfaction level was high in apartment plans with cross ventilation, but not so with non-cross ventilation plans.

Taken together, these results suggest that narrow and enclosed spaces with built-in closets such as entryways or bathrooms should be placed so as to allow outside air to pass through windows and provide natural ventilation.

Spaces not allowing outside air have recently been equipped with mechanical ventilation systems, and the authors agree regarding the effectiveness of these systems. However, taking into account occupants' perception of being burdened with the maintenance and with the management costs of ventilators, it would be desirable to provide floor plans offering natural ventilation.

In addition, the usage of construction materials with chemical contaminants associated with SBS needs to be much more strictly regulated.

Therefore, when building apartments, construction firms are encouraged to select floor plan designs offering cross ventilation over those that do not. Also, when selecting a non-cross ventilation floor plan design is inevitable, they should consider a variety of measures to mitigate SBS, including the usage of eco-friendly building materials as well as the installation of mechanical ventilation systems with reduced maintenance costs.

Acknowledgment

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Notes

1. Yu Yeong-shik (2004), Multiple Chemical Sensitivity and Allergy of Sick House Syndrome, Daihak Publishing Company, Seoul, pp.1-2.
2. In this paper, cross-ventilation floor plan refers to a flat-type apartment unit plan with operable front and rear windows (windows that can be opened/closed), while non-cross ventilation floor plan describes a tower-type apartment unit plan with operable windows in the front and on the side.
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