New methods of designing high-rise residential towers with the ventilation effectiveness study: traditional Korean muntins, "Sal"

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Abstract
This research focuses on improving indoor air quality (IAQ) in high-rise residential complexes in South Korea, addressing the challenges posed by the typical plan types in these buildings. Simulation studies were conducted to identify the limitation of single-sided ventilation of different plan types. Based on the results, design alternatives were proposed to enhance IAQ while minimizing modifications to the existing plan types. Korean traditional muntins (or “Sal’s”) are an important element of traditional Korean architecture. The ventilation effectiveness of a building using a modified Sal pattern has the potential to introduce fresh air indoors. This research found that a modified Sal pattern improved ventilation effectiveness and was more effective in controlling IAQ. Furthermore, the proposed Sal pattern was shown to reduce pressure differences between the inside and outside of a building, resulting in improved indoor living conditions. We demonstrated the ventilation effectiveness of three Sal design options and provided several recommendations for Sal use in apartment buildings. By combining existing ventilation models with the indoor air pollutant concentration level, we established the potential effectiveness of using this design element on existing apartment buildings in South Korea was proven.

Highlights
- Investigated the window frame design for natural ventilation (NV) in high-rise residential complexes.
- Proposed window frame design guidelines.
- Conducted computational fluid dynamics (CFD) simulations for NV effectiveness.
- Illustrated the indoor air quality improvement level by reducing the amount of formaldehyde.

Introduction
Environmental, social, and governance (ESG) issues have been increasing in the real estate and development industries. With this trend, many Asian countries have attempted to reduce their carbon footprint by suggesting design alternatives. The greatest challenges have been found with the typical plan types used in high-rise residential complexes as these designs have burdened a growing number of households with the socioeconomic consequences of urban housing development. These plans were generated by the authorities in the 1980s in response to the population explosion and the polarization in terms of housing affordability. During that period, architects focused on financial factors rather than other ESG issues. Thus, a plan for sustainable and healthy buildings has yet to be comprehensively discussed. However, many health issues, such as sick building syndrome (SBS), allergies, and asthma, could be addressed through design actions to improve indoor environmental quality (IEQ). Increasing natural ventilation could provide a useful strategy for minimizing long-term influences.

Natural ventilation is a widely used passive design strategy for reducing building energy consumption (Montazeri and Blocken 2013). The energy cost of naturally ventilated and mixed-mode buildings is 40% less than their counterparts. Natural ventilation is also widely used to improve an existing building’s IEQ (Willmert, 2001). There are two main ventilation strategies for buildings: cross-ventilation and single-sided ventilation. The cross-ventilation rate is often estimated by the standard orifice flow equation which calculates the airflow rate proportional to the square root of the pressure difference. Therefore, cross ventilation has a greater potential to achieve the pressure gradient around facades (Mohamed, 2011). However, in reality, it is difficult to achieve cross-ventilation due to internal walls, partitions, and other obstacles. Hence, single-sided ventilation is prevalent in many naturally ventilated buildings (Wang and Chen 2012). High-rise residential buildings are especially likely to utilize both forms of ventilation (Etheridge and Ford, 2008).

The phenomenon of high-rise construction in residential towers has led to a prevalence of development styles that emphasize a central core over plate-like residential structures (Kim and Nam, 2008). Site constraints and unit number optimization are other factors contributing to the prevalence of single-sided ventilation in apartment towers (Mohamed, 2011). While the former provides numerous benefits in terms of space efficiency and design flexibility, it also presents challenges in ensuring adequate ventilation for individual units.

This is particularly concerning due to the potential for volatile organic compounds and formaldehyde to accumulate within enclosed spaces, leading to indoor air pollution and associated health risks (Park, 2008). These risks have become a significant issue, as evidenced by the emergence of SBS and related concerns. Previous comparative studies on apartment plan types have discussed feasibility perspectives but were limited to...
certain metrics, such as daylighting and energy use. To date, a comprehensive study that considers various performance metrics has yet to be conducted. Especially important, the impact of indoor pollutants levels on occupants’ health has not been directly connected to performance metrics.

This research combined existing ventilation models such as the single-sided empirical formula (Swami and Chandra, 1988) and the CFD to assess the impact of the proposed design as the main ventilation strategy for healthy buildings. The results were achieved by quantifying their impact on indoor air pollutant mitigation over time. This work mainly focused on indoor pollutants causing SBS and other respiratory diseases, such as radon, toluene, and formaldehyde. The most widely adopted method for reducing such pollutants, the bakeout, obviously leads to an uncomfortable thermal environment for occupants, due to the need to exceed comfortable indoor temperatures during occupied periods.

There are many challenges to achieving a proper ventilation rate for high-rise residential buildings such as building height and orientation, noise pollution, occupant behavior, and facade design. The ventilation performance of existing single-sided ventilated high-rise residential buildings can be enhanced through appropriate facade design strategies. There are many different facade treatments, including external wind catchers, double-skin facades, and detachable window frames. Several researchers have studied the effectiveness of using lattice window frames, which are adopted from traditional architecture in hot and humid climates (Elwan and Dewair, 2019).

Most Korean windows are made of wood, and window paper is the primary material used for the surface of the window frame. Korean-style window bars are characterized by a central void with one or two comparable openings placed along the vertical center line. Muntin shapes consist of non-repetitive patterns arranged around the perimeter of the void, balancing complexity and simplicity to create a harmonious use of space. These patterns represent the beauty of empty space. There are several basic types of muntin patterns, including Wanja-Sal, Aja-Sal, and Kkot-Sal; the names vary depending on the function, purpose, and location.

"Wanjasal" is a muntin pattern in which each muntin is in the shape of a "[,]" character. Unlike "aja-mun" which features straight lines, this pattern has protrusions at right angles, creating a dynamic pattern. "Ajasal" is a pattern in which the muntins do not protrude at right angles, unlike "wanja-sal," but rather in straight lines. Depending on the arrangement of the straight lines, patterns of various sizes of square or rectangular shapes are created. Compared to "wanja-sal," this pattern is more static and stable. "Kkotsal-mun" has most commonly been used in the windows of major buildings such as palaces and temples. It is the most colorful and elaborate muntin pattern, often featuring flowers and leaves carved into the muntins. However, in some temples and Buddhist halls, a single wooden board was used as the window frame, and the pattern was carved into the board (Lee et al, 1999).

Window muntins, with their various functions and folkloric meanings, not only play a structural role in improving the durability of window frames but also provide additional shading and regulate sunlight to a certain extent.

In traditional architecture, the proportion of the window muntins in a window is significant. While some windows only have densely arranged muntins to promote ventilation and air circulation, muntins are generally used with window frames. The area ratio of the muntins in a window often exceeds 30%, and their projecting shape helps to reduce direct sunlight penetration. The percentage of open area in the windows and doors represents a modulation system of the outdoor environment. (Chang, 2003)

Methodology

The Banpo redevelopment project, which is part of the development plans for a high-rise residential complex in Seoul, was selected for this research. The development of a residential complex is comprised of approximately 5,400 housing units. This project features the arrangement of numerous residential flats and high-rise residential tower configurations and thus allowed for the testing of diverse environmental conditions within each tower and its interior spaces. We selected six different tower types in an existing residential complex in Banpo, Seoul, Korea, and conducted simulation studies using different plan
layouts. After analyzing the performance of the existing models, we proposed an alternative means of enhancing the typical plan of the towers selected to improve performance, with maximized ventilation potential for future adaptation. We designed the Korean traditional window frame as a movable window unit to improve the mass flow rate and further assess its impact on IAQ.

**Comprehensive Simulation Analysis**

This section describes the comprehensive simulation study for daylighting, energy, and natural ventilation in high-rise residential buildings involving six tower types. It was mainly used for selecting the reference tower types after assessment of the potential improvements. Table 1 depicts the six different typical floor plans used for the performance assessments, including a narrow-a shaped-, box- and a U-shaped building.

<table>
<thead>
<tr>
<th>Table 1: Selected Building Types and Typical Plan.</th>
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</thead>
<tbody>
<tr>
<td>T1</td>
</tr>
<tr>
<td>T3</td>
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<tr>
<td>T5</td>
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</tbody>
</table>

The majority of Korean apartment buildings are in the T2 form, which is the most commonly used form. This form is favored because it facilitates natural ventilation and south-facing arrangements for good natural lighting. However, to accommodate a larger number of units on limited land, various forms ranging from T1 to T6 are being deployed that differ from the standard T2 form. In this process, many flat types are unable to take advantage of natural ventilation and natural lighting, resulting in the need for environmental analysis to classify and improve these flats according to their form.

**Daylighting and Energy Analysis**

In the first part of the comprehensive simulation study, we conducted daylighting and energy simulation using Radiance and EnergyPlus. The simulations were run using the TMY3 weather file from the nearest airport (Incheon Airport). The results revealed that several towers required improvements to reduce cooling demand while maintaining the desired level of daylighting autonomy throughout the year. Table 1 shows the results of the simulation per tower type.

<table>
<thead>
<tr>
<th>Table 2: Results of the Simulations.</th>
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<tr>
<td></td>
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<tr>
<td>sDA</td>
</tr>
<tr>
<td>cDA</td>
</tr>
<tr>
<td>EUI</td>
</tr>
<tr>
<td>Cooling</td>
</tr>
<tr>
<td>Heating</td>
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</table>

T1, T2, and T4 resulted in the highest energy consumption throughout the year with relatively higher cooling load compared to T5 and T6. Conversely, T3, T5, and T6 showed lower energy consumption than the other three options, attributed to the distributed volume across each facade. Narrow-shaped corridor buildings consumed more energy but provided increased daylighting opportunities throughout the year. Consequently, we selected for further evaluation of ventilation effectiveness two main options that resulted in higher energy consumption (including cooling) and one option with the highest cooling among the groups.

**Natural ventilation analysis**

As a result of our comprehensive simulation study (described in the previous section), three mixed plan types (T2, T3, and T4) were selected and tested to enhance the performance of the buildings within the given context. CFD simulations were conducted to obtain the pressure values on the building facades, and the NVP was calculated based on the pressure differences on the given plan of tower buildings. By considering the best and worst-case scenarios of wind pressure and speed we conducted CFD simulations with contextual buildings to identify the rooms that are most susceptible to these effects. The corner rooms, being more exposed to higher pressure differences and higher wind speeds, were found to be more effective in reducing discomfort for the occupants, while the side rooms require radical design interventions to improve the ventilation rate under the given wind conditions.

Figure 2 shows the hours in which natural ventilation is available for the side and the corner rooms, per the plan drawings.

![Figure 2: Natural ventilation hours per room condition.](https://doi.org/10.26868/25222708.2023.1494)
The NVP results for rooms in the selected towers can be seen in Figure 2. The calculated hours were dramatically different for the same building format with varying ventilation conditions. For example, the rooms located on the lowest-pressure-available facade resulted in an average of 427 hours less available ventilation potential throughout the year, as compared to the highest-pressure-available locations. To overcome the limited amount of pressure on facades, a new Korean window frame for single-sided natural ventilation is introduced and discussed in the next section.

**Health metric**

This section discusses the metrics for calculating ventilation effectiveness based on the pollution level. We employed the mass balance equation to convert the pollution concentration into the ventilation rate. The normalized form of the mass balance equation for a pollutant in a system is as follows:

\[ \frac{V}{Q} \cdot \frac{dC}{dt} = C_0 - C_i + \frac{M}{Q} \]  

where:

- \( V (m^3) \) = Volume
- \( Q (m^3/s) \) = Ventilation rate
- \( C (mg/m^3) \) = Contaminant concentration
- \( C_0 (mg/m^3) \) = Initial contaminant concentration
- \( C_i (mg/m^3) \) = Indoor contaminant concentration
- \( M (mg/s) \) = Contaminant concentration incidence rate

Equation 1 can be used to estimate the concentration of a pollutant in the incoming air.

In this study, we used the reference data of indoor pollutant concentration over time, obtained from Kwon et al. (2009). The concentrations of indoor pollutants in an apartment bedroom are illustrated in Figure 3, according to the duration of confinement.

![Figure 3: Relationship between enclosure duration and indoor air pollution in apartment bedrooms.](image)

**Design Strategy**

Traditionally, ventilation studies have primarily focused on typical wind catcher applications, (such as louvers) installed on existing opening areas. However, this approach often led to a compromise in terms of daylight availability and quality views. This study proposes a new design element and strategy aimed at effectively reducing indoor pollutant levels in existing high-rise apartment plans. The proposed design elements are implemented on the existing operable windows as depicted in Figure 4.

![Figure 4: 3D Modeling for Installation of ‘Sal’ layer.](image)

In high-rise apartments in Korea, the use of sliding windows is a common practice. The product development of the SAL FRAME, designed as a detachable double skin, serves as a prototype model that facilitates easy construction and recycling. To facilitate ventilation, the maximum opening ratio is typically 50% of the total opening area. The installation of a ‘Sal’ frame at the midpoint between the window and the outdoor environment may serve as a wind catcher and contribute to the overall effectiveness of the ventilation system. These findings suggest that the design and implementation of window systems can play a crucial role in promoting natural ventilation and improving indoor air quality in high-rise residential buildings. Table 3 explains the construction details for the CFD simulations and the selection of materials and boundary conditions for the proposed window frames.

**Table 3: Construction and simulation detail.**

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor/Ceiling (U-Value W/m2K)</td>
<td>Reinforced concrete (0.38)</td>
</tr>
<tr>
<td>Wall (U-Value W/m2K)</td>
<td>Reinforced concrete with high insulation (0.32)</td>
</tr>
<tr>
<td>Window Frame (U-Value W/m2K)</td>
<td>Aluminium (0.23)</td>
</tr>
<tr>
<td>Ambient Temperature</td>
<td>20 °C</td>
</tr>
<tr>
<td>Turbulence Model</td>
<td>LVEL K-Epsilon</td>
</tr>
<tr>
<td>Solar Radiation</td>
<td>241 degrees Solar Altitude: 57 degrees Solar Intensity: 438 W/m2</td>
</tr>
</tbody>
</table>

FloVENT® (Mentor Graphics 2014) is used for simulation of room models in different scenarios. The first experiment is conducted to investigate the effect of ambient temperature changes and air stagnation. Another experiment is conducted to find the relationship between the airflow rate and IAQ. FloVENT is capable of integrating solar irradiance into CFD simulation and its grid follows a structured Cartesian which is known for its stability and numerical efficiency. We adopted a finer resolution to optimize the solutions.

The design elements are developed to increase the indoor ventilation rate in single-sided operable windows by utilizing the traditional Korean window frame, Sal, as means of increasing the pressure difference mapped on...
the window frame. This suggests a novel guideline to effectively introduce more indoor airflow in single-sided ventilation plans while maintaining the aesthetics and quality views. Figure 5 illustrates the unit dimension of the proposed window frames with the applications in the existing window frames in selected residential towers.

**Figure 5. 3D Model of window and dimension.**

The main design components of Sal for this study are the open ratio (OR) and frame ratio (FR). The OR represents the proportion of void areas about the given window area, while the FR indicates the amount of frame designed within the window frame per the given window area. Figure 6 illustrates our design strategies for single-sided ventilation using Sal with the existing window in the side room of T3.

**Figure 6: Illustration of the OR and FR.**

To achieve proper ventilation and natural lighting, it is essential to guarantee a minimum opening ratio of around 20% to 25%. Therefore, this study began by defining the scope of application as 80% area of the total opening area, excluding the minimum frame area of 20% to 25% based on the existing window. The research investigated changes in the area and shape of the window opening to determine the optimal design for the remaining 80% of the opening. By analyzing the impact of various window opening configurations, this study aims to guide for improving energy efficiency, indoor air quality, and occupant comfort in buildings. Further research is necessary to evaluate the performance of different window designs in various contexts and building types.

We selected design options from three representative patterns of traditional Korean window frames, namely Ajasal, Gwijasal, and Kkotsal, to maximize the ventilation effect. Beginning with simple patterns, we simulated various combinations of frame placement based on their effect and selected those that were the most effective. We varied the spacing, opening ratio, and frame thickness of the patterns to develop the optimal ventilation effect. Our goal was to derive a frame pattern that could achieve the best ventilation effect.

**Result Analysis**

**Parametric simulation of OR**

Before implementing a different Sal design in the existing apartment plan, we conducted a parametric analysis on the single-sided ventilation with varying aperture ratios which is equivalent to the OR in this study. The CFD simulation revealed an enhancement in ventilation rate and wind speed by adding lattice pattern window frames to the baseline open configuration. In the initial setup, the indoor room temperature was approximately 1.2°C higher than the external temperature.

**Table 4: Result of parametric study on OR.**

<table>
<thead>
<tr>
<th>OR</th>
<th>Q (m³/s)</th>
<th>ACH (h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1.2</td>
<td>30</td>
</tr>
<tr>
<td>80</td>
<td>1.8</td>
<td>45</td>
</tr>
<tr>
<td>60</td>
<td>2.2</td>
<td>60</td>
</tr>
<tr>
<td>40</td>
<td>2.8</td>
<td>80</td>
</tr>
<tr>
<td>20</td>
<td>3.2</td>
<td>100</td>
</tr>
</tbody>
</table>

When we installed the Sal with an 80% porosity level, the results showed a significant improvement in the penetration of wind velocity into the room. With the same inlet wind velocity at 1 m/s, the proposed design options showed more effective external air penetration into the room, both for higher wind velocities and well-mixed indoor air temperature. Void levels ranging between 60% and 80% showed the most considerable improvements in mass flow rate and inlet velocity (see Table 4). In the case of a 20% to 40% void level, Sal proved to be less efficient as a cooling strategy (as compared to the previous cases), but the air speed at the inlet increased up to 0.23m/s, near the 1.5 m height level opening of the Sal. The airflow expansion due to the window frame yielded a higher air exchange rate, but the average air velocity and temperature difference between the indoors and outdoors were not distinguishable. Figure 7 shows the calculated flow rate (Q) and air changes per hour (ACH) for this parametric study, indicating that at 60% the Q increased within the range of 40% to 80% with the grid pattern design options.
Performance simulation of the Sal designs

In this section, we compare the results of the simulations for three newly proposed Sal designs by adapting the traditional patterns discussed in the methodology section. The simulation results described in the previous section show the effective range of the OR for the proposed Sal designs was between 40% to 80%. Therefore, we created design options with an OR ranging from 50% to 80% and an FR range of 10% to 50% for the final simulation. To achieve this ratio, we modified the thickness of the Sal frames by increasing them by 5mm per option. After conducting a parametric simulation study, the Q and ACH were output to evaluate the performance of each option.

1) Ajasal

Ajasal was the first option; it included two large void areas in the middle and narrow openings around those voids (see Figure 8). The Ajasal with a 15 mm frame thickness of 15 mm showed the best results of all the options yielding an ACH higher than 3. However, due to the large void spaces in the middle of the Ajasal, the wind speed decreased faster than for the other options after the air was compressed through the proposed design. Therefore, air stagnation near the ceiling areas was observed. Also, flow rate change was not distinguishable between the different OR/FR options, due to the densely populated periphery pattern and relatively large voids in the middle.

Table 5: Results of the Ajasal Parametric Study.

<table>
<thead>
<tr>
<th>THK</th>
<th>OR</th>
<th>FR</th>
<th>Q</th>
<th>ACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>10mm</td>
<td>80</td>
<td>10</td>
<td>0.57</td>
<td>2.95</td>
</tr>
<tr>
<td>15mm</td>
<td>75</td>
<td>25</td>
<td>0.61</td>
<td>3.05</td>
</tr>
<tr>
<td>20mm</td>
<td>50</td>
<td>50</td>
<td>0.41</td>
<td>2.11</td>
</tr>
</tbody>
</table>

2) Gwijasal

Gwijasal features a unique pattern that contains several voids areas along with high density horizontal and diagonal frames (see Figure 9). Due to its unique pattern, we were able to vary more of the options by increasing the thickness of the window frame from 10mm to 30 mm. The 20 mm option, which covered areas and aluminum window frames, showed the highest ventilation rate at 0.69 and ACH at 3.68. This was mainly because the density of the proposed pattern was the lowest among the other options, and thus it was possible to create more narrow space for the air compression near the Sal pattern by increasing the thickness of the frame by 5mm more than for the Ajasal.

Table 6: Results of the Gwijasal Parametric Study.

<table>
<thead>
<tr>
<th>THK</th>
<th>OR</th>
<th>FR</th>
<th>Q</th>
<th>ACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>10mm</td>
<td>80</td>
<td>20</td>
<td>0.59</td>
<td>3.08</td>
</tr>
<tr>
<td>15mm</td>
<td>75</td>
<td>25</td>
<td>0.65</td>
<td>3.37</td>
</tr>
<tr>
<td>20mm</td>
<td>65</td>
<td>35</td>
<td>0.69</td>
<td>3.98</td>
</tr>
<tr>
<td>25mm</td>
<td>60</td>
<td>40</td>
<td>0.49</td>
<td>2.53</td>
</tr>
<tr>
<td>30mm</td>
<td>50</td>
<td>50</td>
<td>0.47</td>
<td>2.44</td>
</tr>
</tbody>
</table>

3) Kkotsal

The last option was the Kkotsal, which was designed with regularly populated voids; these were very similar to the preliminary lattice design we investigated in the previous section (see Figure 10). The results were interesting, this option was the only one that included regularly populated grids on the window, leading to the highest wind speeds penetrating into the room. This was mainly because the density of the proposed pattern was the lowest among the other options, and thus it was possible to create more narrow space for the air compression near the Sal pattern by increasing the thickness of the frame by 5mm more than for the Ajasal.
In summary, the performance of Sal was mainly defined by the OR and FR and the pattern arranged in the given window opening areas. We have found that the OR was the main difference affecting the ventilation performance. When the OR ranged between 60% and 80%, the proposed Sal frame outperformed the other options. It was also recommended that the FR should not exceed 40% in order to achieve a higher ventilation rate than that of the baseline. Among the three options, the regularly populated pattern, Kkotsal, resulted in the highest air compression capability when air passed through the designed pattern. Overall, all three options resulted in an average ventilation improvement of 1.75 ACH compared to the baseline, before applying to the operable areas.

**Indoor air quality improvement potential**

The ACH requirements for Korean apartments can vary depending on the type of apartment and its intended use. However, in general, the Korean government has established regulations that require apartments to have a minimum ACH of 0.5 per hour. In specific cases where there is a significant level of indoor air pollution (such as in newly constructed or renovated apartments that may have elevated levels of formaldehyde), higher ACH rates may be necessary to adequately remove pollutants.

To evaluate the actual performance of Sals on existing plans with single-sided ventilation, we conducted tests to measure indoor air pollutant levels and the change rates per hour. We compared two design options: one before and one after the application of the Sal frame. This involved replacing four different operable windows (see Figure 11). To evaluate the shift in formaldehyde concentrations, we considered several parameters, including the typical floor plan of the T3 building, wind information, the concentrations indoor and outdoor (see Methodology section), and ACH. Figure 11 depicts the position of Kkotsal and the total volumes used to calculate the indoor air pollutants’ flush-out rate.

<table>
<thead>
<tr>
<th>THK</th>
<th>OR</th>
<th>FR</th>
<th>Q</th>
<th>ACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>5mm</td>
<td>80</td>
<td>20</td>
<td>0.73</td>
<td>4.11</td>
</tr>
<tr>
<td>10mm</td>
<td>70</td>
<td>30</td>
<td>0.71</td>
<td>4.26</td>
</tr>
<tr>
<td>15mm</td>
<td>60</td>
<td>40</td>
<td>0.88</td>
<td>5.43</td>
</tr>
<tr>
<td>20mm</td>
<td>80</td>
<td>50</td>
<td>0.61</td>
<td>8.91</td>
</tr>
</tbody>
</table>

Table 7: Result of Kkotsal parametric study.

The bedroom volume in the given plan was 90 m³, and the ACH was calculated via CFD simulations: Ajasal at 0.45 ACH, Gwijjasal at 0.52 ACH, and Kkotsal at 0.66 ACH. We referred to the indoor air formaldehyde level accumulated from the chart and provided in Figure 5. The mass balance equation was used to calculate the updated concentration level of formaldehyde.

### Discussion

Sal window frames are a traditional Korean architectural feature that historically has been used to enhance natural ventilation in buildings. We adapted this feature to apply the operable areas in high-rise residential in Seoul, in order to increase NVP for single-sided ventilated rooms. These window frames consist of small, densely placed aluminum frames that allow air to flow through the window while blocking out other unwanted objects. Studies have shown that the proposed Sal window frames can be highly effective in promoting natural ventilation in buildings. Several recommendations are offered here for the design and application of Sal as an additional layer for existing windows. The recommended opening ratio to maximize Sal’s performance is between 60% and 80%, and the FR is less than 40%. In terms of choosing a Sal, the Ajasal, or the Gwijjasal allows for more visibility, but with a reduced ventilation rate as compared to the Kkotsal. The kkotsal outperformed the other Sals but had the potential to block the views. The gwijjasal requires the same OR for a similar performance to that of the Ajasal,

![Figure 11: Reference bedroom in plan configurations.](image-url)
but the indoor air stagnation was reduced due to the relatively evenly populated void areas and those video’s size. Therefore, when designing Sals, Ajasal is recommended for the quality views it affords. This is also true for Gwijjasal, but Gwijjasal reduces air stagnation. Kkotsal is recommended when it is desirable to maximize ventilation effectiveness with an elevated flow rate.

With the increasing concern regarding preventing outdoor PM from penetrating into the indoors, an important future research area would be the addition of one more layer to the proposed Sal. This is a thin Korean paper called changhoji. It has been suggested that the use of traditional window frames with changhoji paper screens could lead to improved indoor air quality and energy savings through the natural ventilation such a design would allow (Park, 2008). Furthermore, recent studies have shown that when designing Sal, the paper used for window screens, has a filtering effect on fine dust. To further enhance this effect, we have considered the installation of Hanji on the open parts of our designed window screens, either as an additional layer or as a standalone addition. This would help to improve indoor air quality by filtering out fine dust while still allowing for natural ventilation through the open windows. However, there may be limitations in terms of the view perspective, and it is uncertain whether it would be marketable as a product. Nonetheless, this design method is worth considering in the future.

Conclusion

In conclusion, the parametric study simulation of the natural ventilation effectiveness of a newly designed window frame adopting traditional Korean muntins (in this case - Sal’s) has shown promising results. The use of Sal in window design would enhance natural ventilation in indoor spaces by increasing the airflow rate and reducing stagnation within the room. This study has shown that the effectiveness of natural ventilation is influenced by various factors, such as the size and shape of Sal. Therefore, it is essential to carefully consider these factors when designing and positioning Sal window frames in existing high-rise residential buildings.

Overall, the results of this study suggest that incorporating traditional design elements into modern building practices can lead to improved natural ventilation and indoor air quality. This finding has significant implications for sustainable building design and human health. However, further research is needed to validate these findings and optimize the design parameters for specific building types and contexts with diverse materials properties.

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Buildings 139: 762–79.
http://dx.doi.org/10.1016/j.enbuild.2017.01.070.