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Porosity Rendering in High-Performance Architecture: Wind-Driven Natural Ventilation and Porosity Distribution Patterns

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ABSTRACT: Natural ventilation is one of the most essential issues in the concept of high-performance architecture. The porosity has a lot to do with wind-phil architecture to meet high efficiency in integrated architectural design and materialization a high-performance building. Natural ventilation performance in porous buildings is influenced by a wide range of interrelated factors including terrace depth, porosity distribution pattern, porosity ratio, continuity or interruption of the voids and, etc. The main objective of this paper is to investigate the effect of porosity distribution pattern on natural ventilation performance in a mid-rise building. One solid block and six porous residential models based on unit, row and combined relocation modules with different terrace depths (TD = 1.2, 1.5 m) were analyzed by computational fluid dynamics (CFD). The evaluations are based on grid sensitivity analysis and a validation of wind tunnel measurements. Investigations indicated that introducing the velocity into a solid block would enhance the building natural ventilation performance up to 64 percent compared to the solid case. However, it is demonstrated through simulations that the porosity distribution pattern as an architectural configuration has a significant effect on ventilation efficiency. Unit-Relocation models (U-RL) have approximately 1.64 times the mean airflow of the solid block, 1.1 times of Row-Relocation (R-RL) and 1.22 times of Combined-Relocation models (CO-RL). U-RL models are also able to achieve approximately 1.26 times the maximum air velocity inside the blocks compared to the solid case. This value is about 1.05 times of R-RL cases and 1.1 times of CO-RL cases. The results clearly indicated that porosity distribution pattern is a factor that could be modified by architects to fulfill most of architectural and environmental requirements.

Keywords: Natural Ventilation, High-Performance Architecture, Windphil Architecture, Porosity, Distribution Pattern.

INTRODUCTION

Heating, ventilation and air conditioning (HVAC) systems account for about 65 percent of the energy use in the building sector (Pérez-Lombard, Ortiz, & Pout, 2008). Natural ventilation is an effective strategy to reduce building energy consumption (Etheridge, & Ford, 2012), improve occupants' satisfaction and indoor air quality (Allard & Santamouris, 1998; Aynsley, 2014; Kubota, Chyee, & Ahmad, 2009; Liping & Hien, 2007; Tantasavasdi, Srebric, & Chen, 2001; Zhou, Wang, Chen, Jiang, & Pei, 2014).

Apartments and multi-story buildings are the prevalent building typologies due to population growth in this era. However, it is a challenging issue to control ventilation performance and also achieve comfortable living environments by means of natural ventilation in multi- story buildings. Numerous investigations have focused on different architectural solutions to overcome this problem such as modification of general geometry (Allard & Santamouris, 1998; Givoni, 1994; Hariri, Khosravi, & Saadatjoo; Heiselberg, 2004; Islam, 2013;

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Osman, 2011) and components such as roof details (Kabrhel, Jirsák, Bittner, & Zachoval, 2007; Khosravi, Saadatjoo, Mahdavinejad, & Amindeldar, 2016; Kindangen, Krauss, & Depecker, 1997; Peren, van Hooff, Ramponi, Blocken, & Leite, 2015), introducing the porosity (Hirano, Kato, Murakami, Ikaga, & Shiraishi, 2006; Saadatjoo, Mahdavinejad, & Zhang, 2017), atriums (Etheridge & Ford, 2008; Fareaa, Alkaffb, & Kotani, 2015; Kleiven, 2003) and courtyards (Khan, Su, & Riffat, 2008; Ok, Yasa, & Ozgunler, 2008; Prelgauskas, 2003; Saadatjoo, Mahdavinejad, Khosravi, & Kaveh, 2016; Tablada, Blocken, Carmeliet, De Troyer, & Herschure, 2005), application of wind catchers (Mahdavinejad & Javanroodi, 2012; Mahdavinejad & Javanroodi, 2014; Montazeri, 2011; Montazeri, Montazeri, Azizian, & Mostafavi, 2010) and other similar supplements.

This research specifically focuses on porosity as an efficient and practical ventilation approach. Despite the fact that porosity and permeability are primary features of the Iranian vernacular architecture that appeared in the form of porches, gardens, pits, etc. (Mahdavinejad & Javanroodi, 2012), this issue received relatively little attention in the modern era (P. Saadatjoo, Mahdavinejad, Najaf Khosravi, & Kaveh, 2016). Many historic building facades are characterized by protrusions and recessions (Montazeri & Blocken, 2013). It was proved that introducing the voids into the building would bring advantages in the architectural and environmental aspects compared to ordinary buildings (Fareaa, Alkaffb, & Kotani, 2015; Ismail, 1996; Mahdavinejad & Rohani, 2014; Murakamia, Kato, Ookac, & Shiraishi, 2004). Hirano and his colleagues (Hirano et al., 2006) revealed the effects of porous residential buildings on the natural ventilation performance by comparing a porous case (50 percent porosity) and a solid one. Murakami and his colleagues developed an environmental high-density porous model suitable for hot and humid regions which have approximately 3.5 times the air flow rate of the solid model (Murakamia et al., 2004). Kato and his colleagues (Kato, Song, Ooka, Uehara, & Murakami, 2004) explored the cooling load of a porous-type housing model (Honoi experimental house), a prototype housing model for hot and humid climates (Kato et al., 2004). Porosity offers the opportunity for reducing energy requirements and enhances ventilation and infiltration rate through the building (Mahdavinejad, Javanroodi, & Rafsanjani, 2013). It must be mentioned that void size influences ventilation indicators as well as the porosity ratio. According to Muhsin (Muhsin, Yusoff, Mohamed, & Sapian, 2017), enlarging the porosity size to 50 percent of the living units, natural ventilation performance in the living units is increased by up to 50.88 percent. Regarding the investigation in the context of terrace depth and ventilation performance, the buildings with terrace depth of 1.2 meter indicated better performance compared to other cases (with different TD) (Saadatjoo, Mahdavinejad, & Zhang, 2018). All in all, porosity brings advantages in the architectural, environmental, and structural aspects by controlling the indoor environmental condition, facilitating natural ventilation and controlling IAQ[1], improving solar shading performance, and providing variegated living spaces.

Given the limited amount of relevant studies in this field, this paper investigates the potential of terraced apartments in terms of harnessing natural ventilation to maintain an acceptable indoor environment. Among the numerous physical parameters that could influence natural ventilation performance in a porous building, this paper specifically focuses on porosity distribution pattern. The computational fluid dynamic is applied to investigate the effect of porosity distribution pattern on natural ventilation performance (Fallahtafti & Mahdavinejad, 2015). Regarding the air velocity and age of air distribution as primary evaluation factors in most of the research, these parameters were measured and compared to better understand the natural ventilation performance in the buildings. Previous studies suggest in hot and humid regions, the air velocity equivalent to 0.4 m/s could enhance indoor thermal comfort, 1 m/s is pleasant and up to 1.5 m/s are acceptable (Mirrahimi, Mohamed, Haw, Ibrahim, Yusoff, & Aflaki, 2016). Our case study is a mid-rise residential apartment in Qeshm, an island in hot and humid climate.

OBJECTIVES

Nowadays, most of the buildings tend to be in the form of apartment blocks. It could be argued that the omission of open spaces in apartment blocks not only degrades the spatial quality, but also deteriorates the potential of receiving natural wind and daylight. Introducing porosity into solid buildings could result in natural ventilation enhancement, incorporation of interior and exterior, and also daylight exploitation.

Architects should take into account all of these solutions at the first design steps. In another word, environmental considerations must be an important part of concept making process. But it is almost impossible due to lack of expertise in using proper technologies to evaluate and implement natural ventilation solution

(Mora-Pérez, Guillén-Guillamón, & López-Jiménez, 2015). The implementation of porosity in the form of terraces should be based on logical rules which are inferred from scientific analysis.

The main objective of this paper is to investigate the relation between terrace distribution pattern and natural ventilation performance in a mid-rise building. CFD analysis would indicate how the porosity distribution pattern influences the wind behavior in the buildings with identical porosity ratio. It follows the relocation design methodology (RL) to create porous apartment blocks. The computational model is created with a systematic procedure and validated with full-scale measurements to assure credible results. The main goal of this study is to offer a comprehensive understanding of the terrace distribution pattern associated with natural ventilation exploitation to improve building energy efficiency. The proposition of such design grammars would promote awareness of architects toward natural ventilation issue to design high performance wind-phil buildings at conceptualization stage.

DEVELOPMENT OF MODELS

Nowadays apartment blocks are prevailing building typologies due to increasing population in most of the countries. It is essential that a high-density neighborhood could establish a consolidation between space quality, energy efficiency, and structural stability. Introducing the permeability into a solid block is a promising approach that would fulfill most of those requirements. It facilitates natural ventilation, natural light exploitation, promotes indoor air quality and improves solar shading performance. It also enhances living standards due to the reduction of physiological and psychological stresses.

This principle that first emerged in the habitat residential, continued to be the prominent concept in most of the modern projects. A similar spatial scheme could be found in Ricardo Boffil's Kafka castle (1968); Simmons Hall at MIT (1999), Honoi Residential Project (2003), Big Lego House (2013), etc. Today most of the projects designed by MVRDV draw direct inspiration from Safdie's design strategy.

Despite the common buildings, these types of apartments require special design method. Although numerous design methods have been introduced during last decades (Kotsopoulos, 2007; Murakamia et al., 2004), all of them are based on two primary techniques, Relocation, and Reduction. In other words, omission, protrusions, and recessions of basic modules would lead to the generation of numerous porous alternatives. In this paper, two primary techniques (RL and RD) would be applied on the basis of defined variables (Fig. 1).

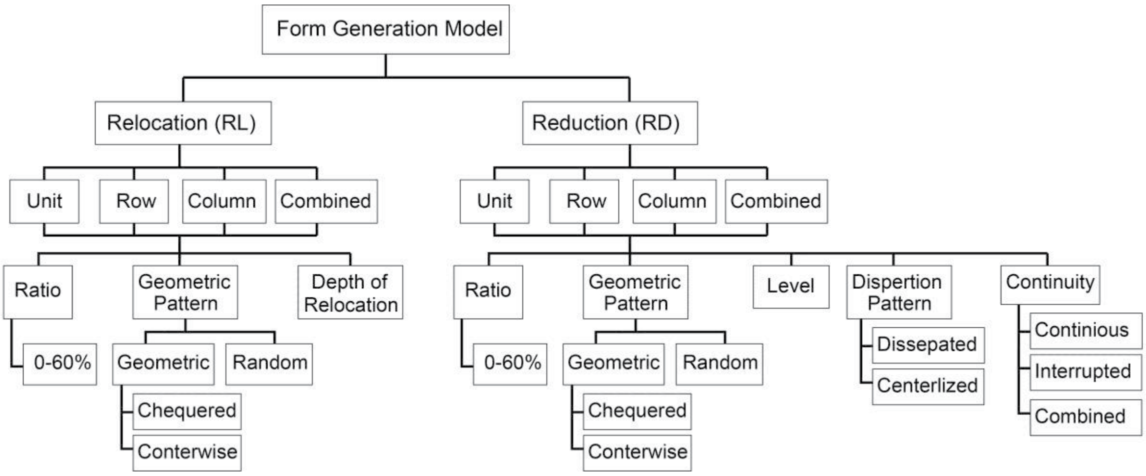


Fig. 1. Two form Generation Models and the Related Variations

In this research, form generation process structured in three phases. Firstly, primary modules are defined, then a generation method (RD-RL) and variables in subsets are selected. Finally writing an algorithm in grasshopper would result in the intended forms (Fig. 2).

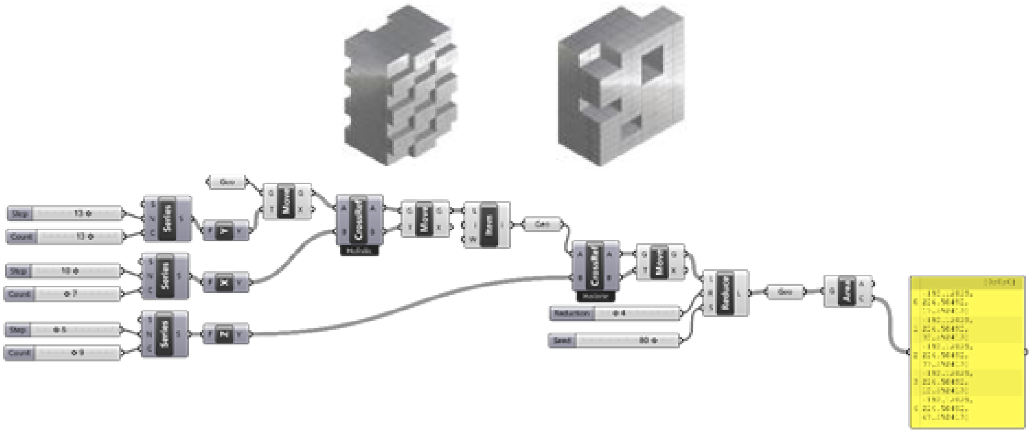


Fig. 2. Algorithm of RL and RD Method Generated in Grasshopper

RESIDENTIAL BUILDING MODELS

Outline

The present paper analyzed cases with different porosity distribution patterns. To that end, parametric devices were applied to generate physical models based on the predestinated factors. The Porosity distribution pattern is the main variable, while other parameters such as window size, location, wind direction, etc., are considered to be constant in all the cases. Then CFD analyses are conducted for predominant wind direction. Mean air velocity in the blocks and terraces were measured and reported. The Mean age of air in the residential blocks was measured as well. The achieved results would help us to compare the cases in terms of natural ventilation performance.

Residential Models

The analyzed cases are seven story buildings that consist of six residential blocks at each level. Considering the time-consuming process of CFD analysis, dimensions of the blocks are smaller than a real residential apartment. They are all 5×5×3 units without interior partitions generated by relocation method. To investigate the effect of distribution pattern on ventilation performance as the main objective of this paper, we generated row, unit and combined recessions on buildings. These recessions with constant depth (1.2 - 1.5 m) in all of the cases constitute semi-open spaces for the apartments. Other parameters such as opening size, opening position, wind direction, terrace depth, recession ratio, etc. are identical in all of the cases. Lateral units consist of two openings (double-sided ventilation) and the middle blocks include one 2×1 opening (single sided ventilation). The simulations were conducted assuming all the opening to be opened and all of the cases were analyzed for only prevailing wind direction. 35 percent of blocks have single sided ventilation and the rest of them apply double-sided ventilation. Since these simulations were to reveal the potential of natural ventilation, the walls were assumed to be only between apartments, i.e. the partitions inside each apartment were neglected (Fig. 3).

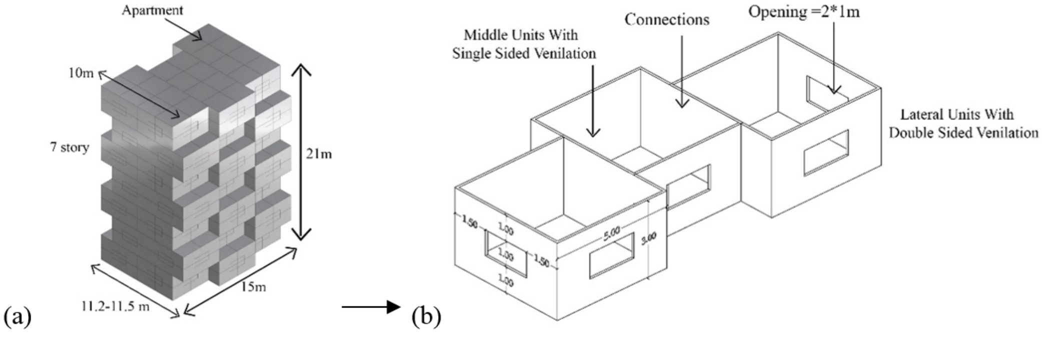


Fig. 3. Dimensions and Components of Residential Models

In this research, we analyzed 1 solid block and 6 cases with different porosity distribution pattern (Table 1). For each physical model, we modified terrace depth (TD) from 1.2 to 1.5. U-RL1[2] and U-RL2 are the cases following a unit recession, R-RL1[3] and R-RL2 consist of row terraces, CO-RL1 and CO-RL2[4] with a combined pattern include row and unit recession (Fig. 4). It must be stated that porosity distributions are not random and all of the modifications are applied on the basis of the specific geometric pattern.

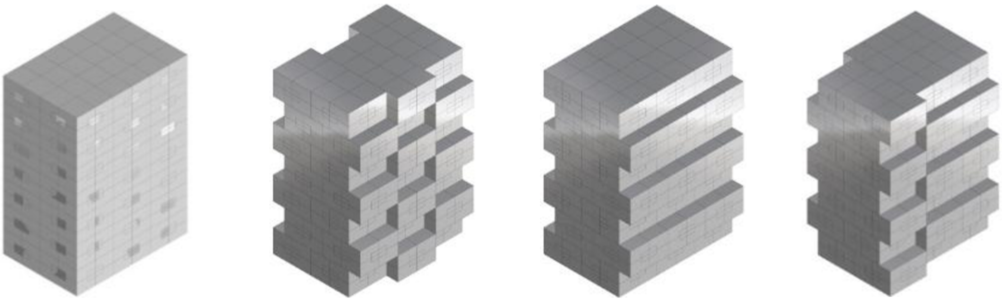


Fig. 4. Analysis Models with Different Porosity Distribution Pattern

The simulations were conducted assuming all of the windows to be opened. These models are analyzed for the prevailing wind direction. They are all located in Qeshm Island with hot and humid climate.

Table 1. Analysis Cases

Model	U-RL1, 2 R-RL1, 2 CO-RL1, 2 CO-RL1, 2
Form Generation Method	Relocation Method (RL)
Relocated Unit	Units, Columns, Rows, Combined
Ratio of Relocated Units (%)	52.38% - 57.14%
Depth of Relocated Units (m)	1.2 - 1.5 m
Number of Floors	7
Number of Residential Blocks	42
Volume of each terrace (m^3)	18 - 22.5 m^3
Unites with Single Sided Ventilation	28
Unites with double Sided Ventilation	14

Solver Settings and Analysis Domain

In this research, Reynolds-averaged Navier-Strokes Equations (RANS Equations) are solved in a geometrical domain. These equations are time-averaged equations of motion for fluid flow. The idea behind the equations is Reynolds decomposition, whereby an instantaneous quantity is decomposed into its time-averaged and fluctuating quantities. These equations can be used with approximations based on knowledge of the properties of flow turbulence to give approximate time-averaged solutions to the Navier–Stokes equations (URL1). Standard k–ε as a RANS based turbulence model was selected in CFD settings.

A single building is located in the analytic domain and surroundings are ignored. The case study is a simple cube without the internal and external details because the effect of the general form on NV[5] performance is of particular concern.

Despite the numerous criteria to define the analysis domain, AIJ standard was applied as a guideline for flow domain dimensions in our simulations (Tominaga et al., 2008). The CFD analysis domain was 430 m in the X-direction; 230 m in the Y-direction and 126 m in the Z-direction. The windward distance (from building surface to the inlet) and leeward distance (from building surface to outlet) were set as 5H and 15H, respectively, where H is the height of the building. The lateral and the distance from the top of the building to the top of the domain were set as 5H (Fig. 5).

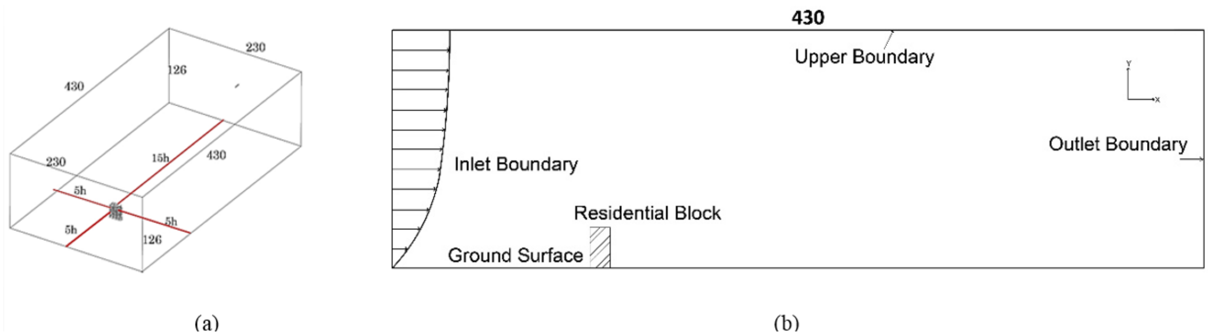


Fig. 5. Calculation Domain; a. Perspective, b. Section of the domain

Boundary Conditions

The specification of consistent boundary conditions is essential to achieve a model that is similar to the real environment. In this research, velocity profile of the inlet is defined based on the relevant Equations and reference wind speed (measured at the height of 10 meters).

Since we are going to compose a general design guideline for hot and humid regions in Iran, the simulations are conducted based on the climatic information in meteorological stations during the years 2004-2014.

Although the definition of velocity inlet direction is not a simple task, statistical information such as compass rose could be applied to define the main wind direction. Prevailing wind direction for simulations is defined based on the wind roses at the meteorological station. The inlet velocity range between 0 m/s and 20.31 m/s. The average and maximum air speed from May to September during the years 2004-2014 was elicited. The reference airspeed which is a value between the maximum and average airspeed was considered to be 8.07 m/s at the height of 10 meters (IRIMO, 2017).

This amount was then retrofitted to define the wind profile at the height of 0 to 126m by the following equitation.

$$\frac{\bar{V}_z}{\bar{V}_{z_{10}}} = (\frac{Z}{Z_{10}})^{\alpha}$$

Where V_z is mean airspeed, V_{z10} is mean airspeed at the height of 10 meters, α is a quantity depending on surface smoothness and is considered 0.36 in this research.

The lateral walls and roof of the domain are prescribed as symmetrical to enforce a parallel flow. The outlet of the domain is set at static pressure. A relative static pressure of zero is set at the outlet surface. To prevent a strong artificial acceleration, the blockage ratio was considered to be under 3 percent (0.01 in this research).

Grid Discretization and Mesh Sensitivity Analysis

The computational domain was discretized using a structured hexahedron type grid with high resolution. A growth rate of 1.5 percent in all directions was implemented for the meshes in the whole domain. The spatial domain was divided into tetrahedral elements.

In this research, the grid sensitivity test was carried out with a different number of cells; a coarser grid and a finer one (Fig. 7). The maximum size of the grids varied from 1.8 to 3 and the minimum size of the elements was between 0.008 - 0.016. A number of grids vary from 3756560 to 1323866 based on the numerous grid sizes (Table 2).

The results are compared in Fig. 6, indicating only a very limited dependence of the results on the grid resolution. Air velocity through a definite vertical profile was measured to compare the results and to figure out the dependency on grid size. The average deviation between the finest case and the other ones is between 0 - 0.081 (Fig. 6). To that end, negligible grid sensitivity is found for the other parts and the maximum grid size of 3 and minimum size of 0.016 was applied to the analysis. The number of grids in the simulations is 1323866.

Table 2. Cases for Mesh Sensitivity Analysis and their Features.

Case	Maximum Grid size	Minimum Grid Size	Inflation Rate	Number of Elements	Number of Nodes	Deviation from Base Case
G1	1.8	0.008	1.5	3756560	3834980	0
G2	2	0.01	1.5	2991724	3058748	0.34
G3	2.4	0.12	1.5	1990682	2141340	0.12
G4	2.8	0.014	1.5	1512558	1554312	0.087
G5	3	0.016	1.5	1323866	1361922	0.081

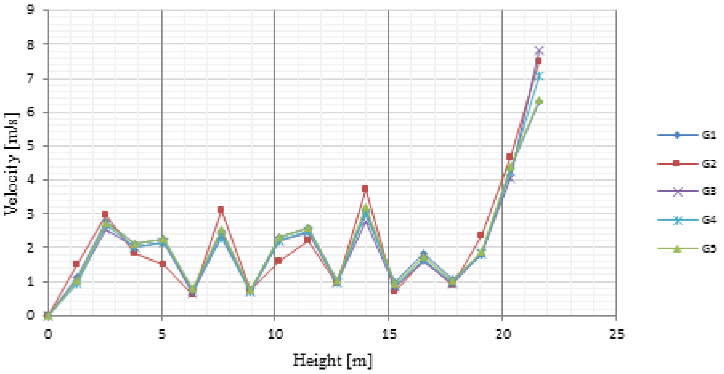


Fig. 6. Result of Mesh Sensitivity Analysis on Five Cases

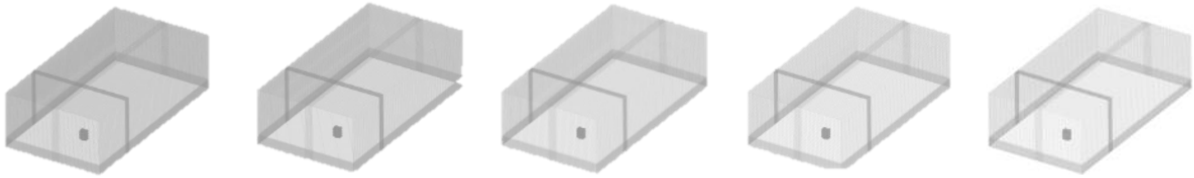

G1 G2 G3 G4 G5

Fig. 7. Five Cases for Mesh Sensitivity Analysis

Convergence Criteria

According to the previous research (Asfour, 2010; Franke, Hellsten, Schlünzen & Carissimo, 2007), the convergence of scaled residuals down to 10^{-5} is acceptable. In this research, two different convergence criteria with residuals 10^{-4} and 10^{-8} were used and the results were compared. Considering the air flow velocity and mean age of air, there is a negligible discrepancy between the results. To that end, residual of 10^{-4} has been employed to examine the turbulence models and to conduct the parametric study.

EXPERIMENTS

Comparison of Air Velocity in the Blocks

Mean and maximum air velocity in the residential blocks and terraces was measured. Graphical contours, as well as numerical values, would indicate the effect of geometrical pattern on natural ventilation performance.

The quantitative results of the simulations are illustrated in Fig. 8. To make a better comparison, the average amount of air velocity was calculated for each case with TD1.2 and TD 1.5, and presented in Fig. 9.

According to the result, introducing the porosity would enhance the building efficiency in terms of natural ventilation exploitation. The implementation of porosity into the wind-phil building could enhance its mean velocity up to 64 percent and the maximum air velocity up to 26.42 percent in the residential blocks. Meanwhile, CFD results clearly show that air flow in and around a building is drastically influenced by physical features such as porosity distribution pattern. The models with U-RL pattern has the mean air velocity value of 0.82 m/s and maximum velocity value of 3.11 m/s inside the blocks. It could be inferred from the results that U-RL cases showed better performance when compared to R-RL and CO-RL cases. These models have approximately 1.64 times the mean airflow of the solid block, 1.1 times of R-RL and 1.22 times of CO-RL models. U-RL models are also able to achieve approximately 1.26 times the maximum air velocity inside the blocks compared to the solid case. This value is about 1.05 times of R-RL cases and 1.1 times of CO-RL cases. Considering the mean and maximum air velocity in the blocks, U-RL cases have better performance than R-RL and CO-RL models.

It could be inferred from the results that the direct infiltration of the flow on building recessions and protrusions makes flow separation. This flow would go directly into the lateral residential blocks.

Velocity contours are illustrated on 3 horizontal plane and 1 vertical plane at the height of 13.5 meters (Fig. 10). These contours clearly indicate the effect of porosity distribution pattern on wind behavior in and around the building. We considered two different terrace depth (TD=1.2, TD=1.5) for each case. The simulation result for each case is illustrated separately in Fig. 11.

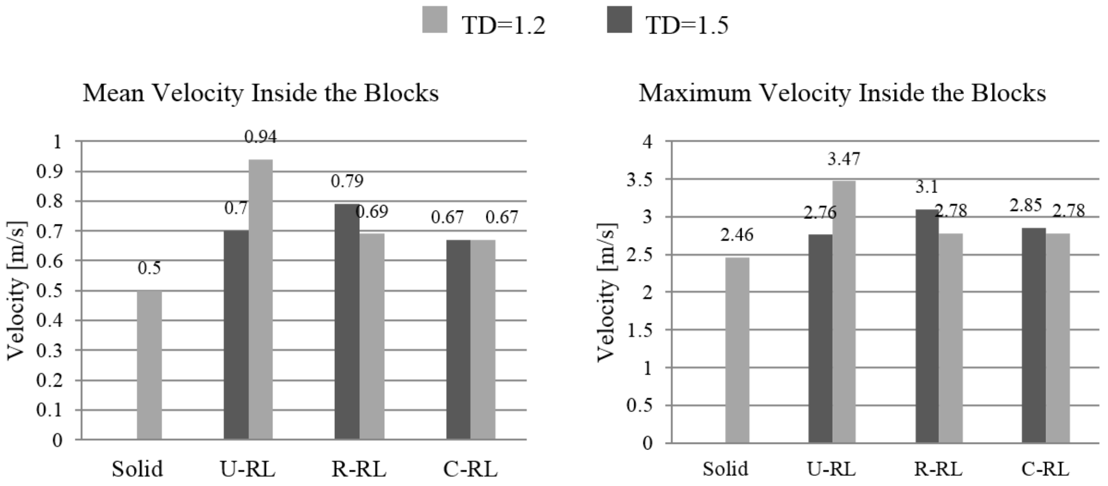


Fig. 8. Mean and Maximum Air Velocity in the Blocks of Solid Case U-RL, R-RL and CO-RL Models with Different TDs

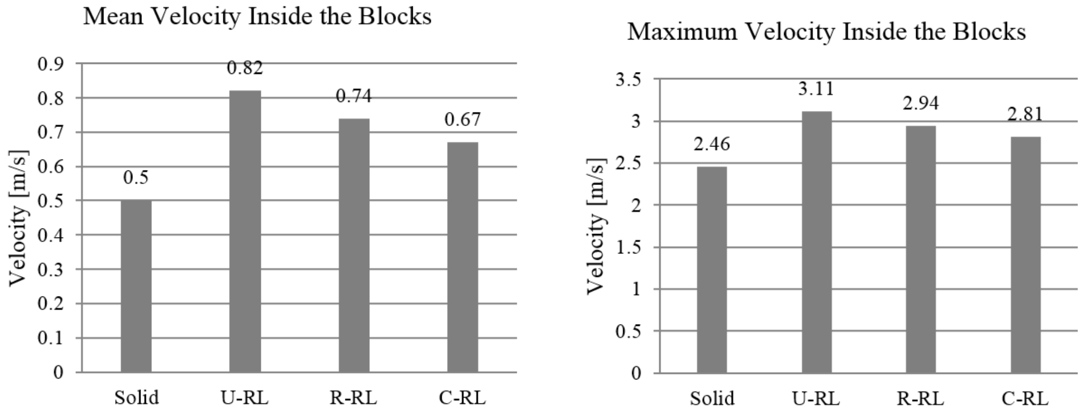


Fig. 9. Mean and Maximum Air Velocity in the Blocks of Solid Case, U-RL, R-RL and CO-RL (Average Amount of Models with Different TDs)

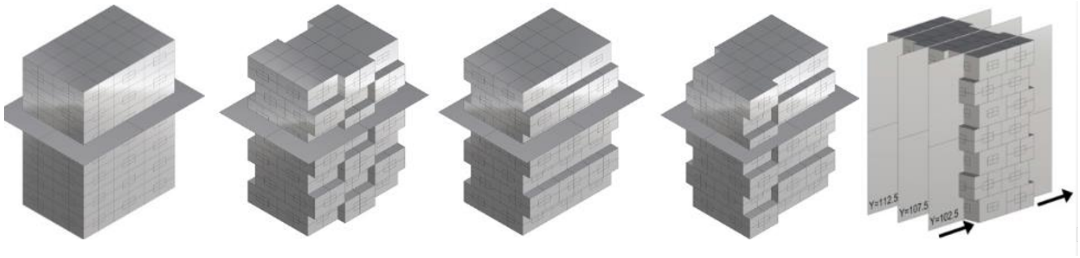


Fig. 10. The Location of Vertical and Horizontal Plane Cuts

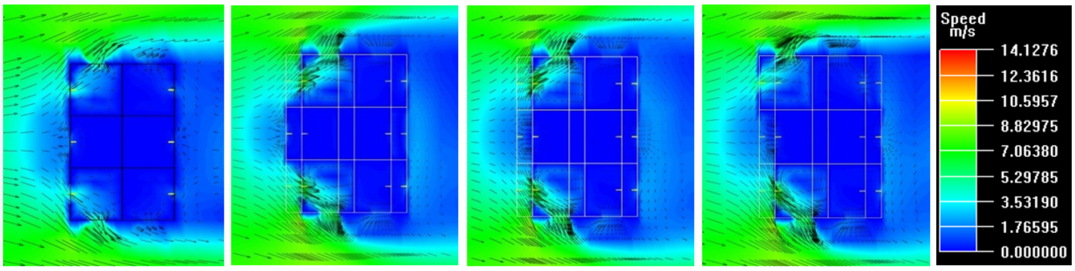


Fig. 11. Velocity Contours on Z Plane Cut, Z = 13.5
(a. U-RL with TD=1.5 m, b. R-RL with TD =1.5 m, c. CO-RL with TD =1.5 m)

Comparison of Air Velocity

Investigations indicate that mean and maximum air velocity values in the terraces is influenced by the buildings physical configurations such as porosity distribution pattern. According to the results, the R-RL pattern leads to a mean velocity increase of about 20.40 percent in terraces compared to U-RL and 2.90 percent compared to CO-RL patterns. The maximum air velocity in R-RL case is 1.7 times the maximum air velocity of U-RL and 1.24 times of CO-RL models. Despite the interior air velocity, U-RL cases indicate the lowest values for mean and maximum air velocity in terraces compared to the other cases. In row relocated models as well as combined relocated ones, large terraces provide a good context for air flow. To that end, the measured velocity amount is considerably higher than U-RL models.

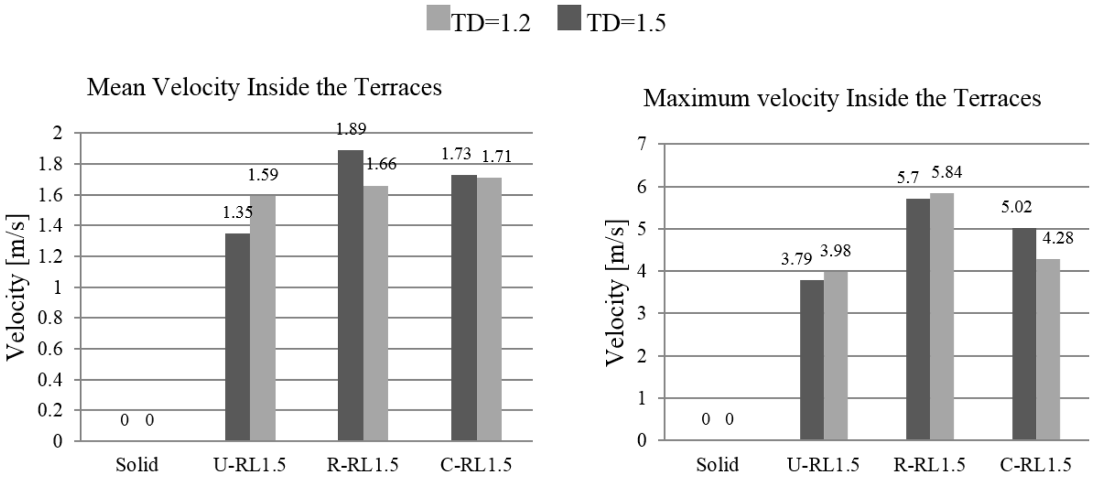


Fig. 12. Mean and Maximum Air Velocity in the Terraces of Solid Case and U-RL, R-RL and CO-RL Models with Different TDs

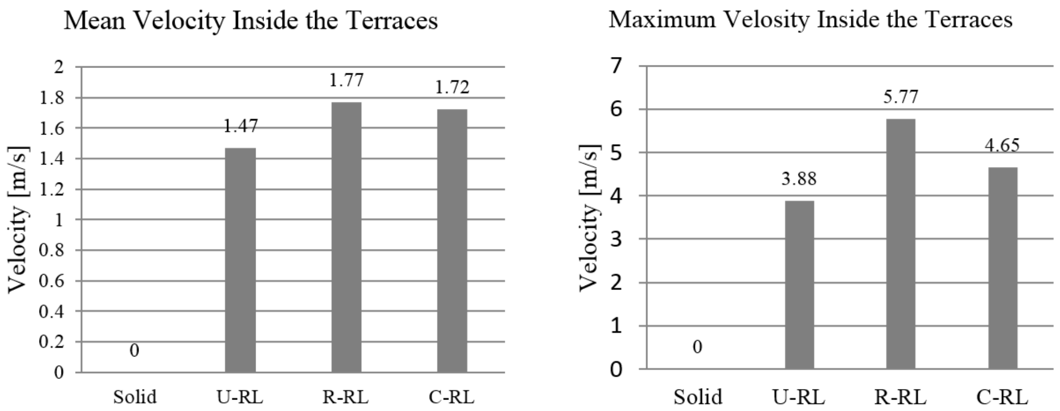


Fig. 13. Mean and Maximum Air Velocity in the Terraces of Solid Case and U-RL, R-RL and CO-RL (Average Amount of Models with Different TDs)

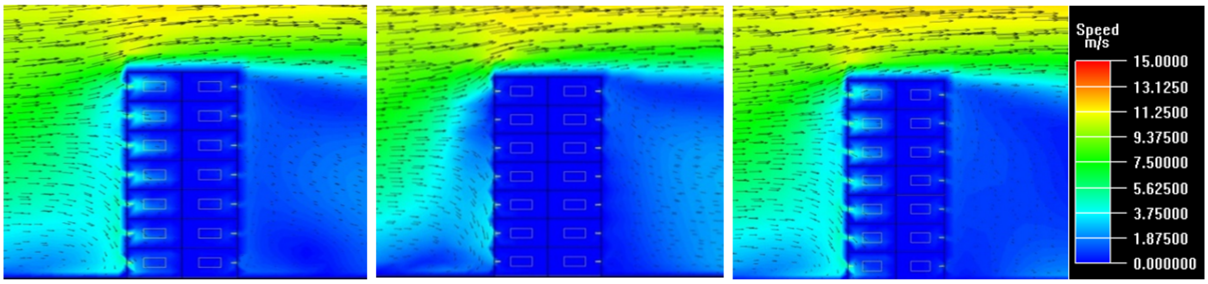


Fig. 14. Velocity Contours of Solid Model on 3 Horizontal Plane Cuts (a. Y = 102.5, b. Y = 107.5, c. Y = 112.5)

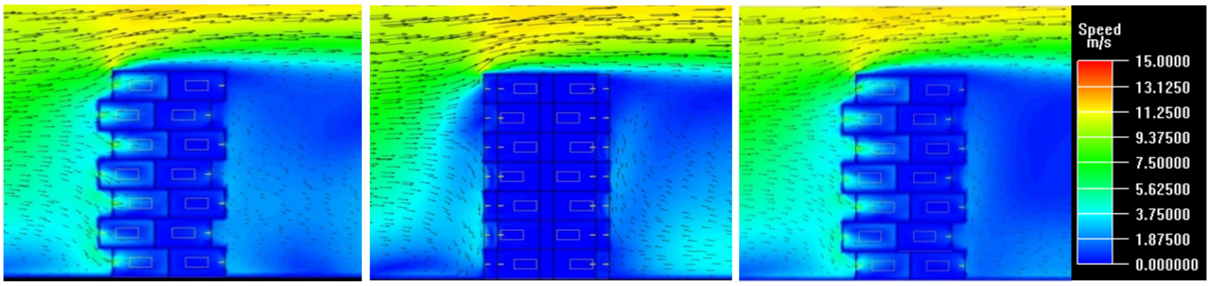


Fig. 15. Velocity Contours for U-RL Model with TD = 1.2m on 3 Horizontal Plane Cuts (a. Y = 102.5, b. Y = 107.5, c. Y = 112.5)

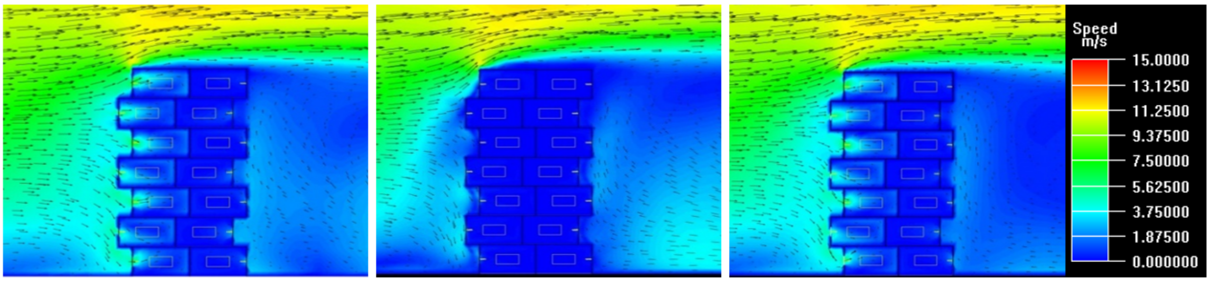


Fig. 16. Velocity Contours for R-RL Model with TD = 1.2 m on 3 Horizontal Plane Cuts (a. Y = 102.5, b. Y = 107.5, c. Y = 112.5)

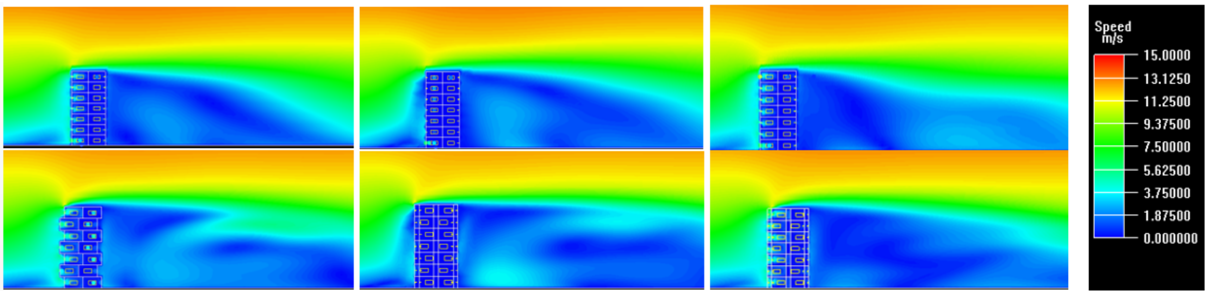


Fig. 17. Velocity Contours for CO-RL Model with TD = 1.2 m on 3 Horizontal Plane Cuts (a. Y = 102.5, b. Y = 107.5, c. Y = 112.5)

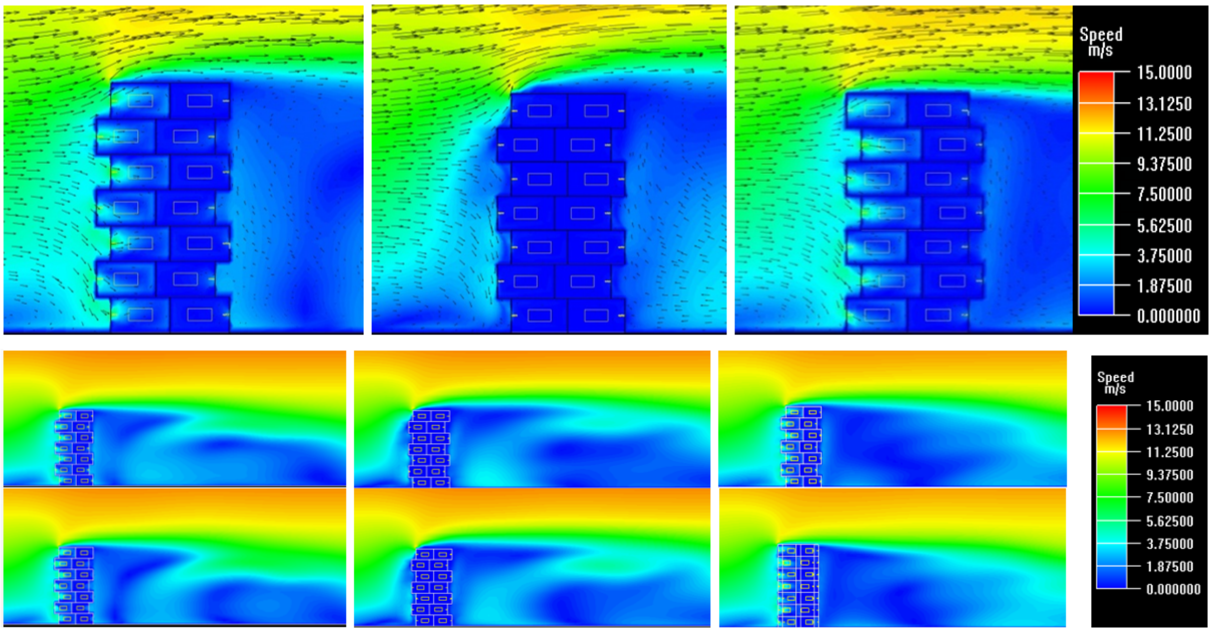


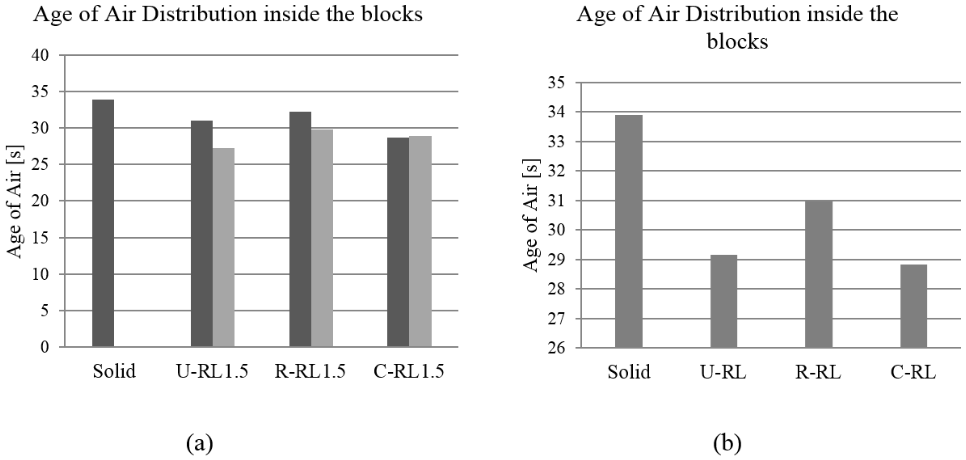
Fig. 18. Velocity Contours for Models, with TD = 1.2 m on 3 Horizontal Plane Cuts (a. Y = 102.5, b. Y = 107.5, c. Y = 112.5)

Comparison of Age of Air Distribution

The minimum age of air was measured in all 42 residential blocks. The units located in the middle row and rear side of the building showed higher values (60-70s) for the age of air distribution. The solid case has the highest value in comparison to the other cases.

The age of air value was significantly lower in U-RL and CO-RL models compared to R-RL cases. However, compared to the solid model, the age of air values was significantly reduced in all porous cases. CO-RL models obtain a minimum age of air value of approximately 28.82s.

Achieved results for age of air value are too high when it comes to reality. It must be considered that the main goal of this paper is to obtain some quantities and make a comparison between numerous physical cases. It tries to investigate the effect of building physics on wind behaviour inside and outside the building. On the other hand, the age of air is not considered as the main parameter to indicate natural ventilation performance. It was just measured to make a better comparison between seven cases.



(a) (b)

Fig. 19. Mean and Maximum air Velocity in the Terraces for Solid Case and U-RL, R-RL and CO-RL Models (a) with Different TDs, (b) Average Amount of Models with Different TDs

CONCLUSION

The results of the research emphasize on the role of porosity rendering on the level of energy efficiency in high-performance architecture. The study on porous architecture was motivated by the lack of knowledge in the field of natural ventilation in the porous type of buildings. It explores the effects that porosity distribution pattern has on the natural ventilation performance in a mid-rise building. It also compares these kind of buildings with solid blocks in terms of ventilation exploitation.

It was illustrated that porous residential blocks are effective in enhancing the natural ventilation performance up to 64 percent compared to the solid models. On the other hand, it was proved that porosity distribution patterns are important parameters to be considered for the evaluation of the airflow in the buildings.

Considering the interior air velocity, wind-phil buildings with U-RL distribution patterns have the best performance compared to others. These models have approximately 1.64 times the mean airflow of the solid block, 1.1 times of the R-RL and 1.22 times CO-RL. However, these conditions change when we consider the wind velocity inside terraces. In row relocated models as well as combined relocated ones, large terraces provide a good context for air flow. To that end, the measured velocity amount is considerably higher than the U-RL cases.

These simulation results clearly indicate that airflow pattern in the buildings with different porosity distribution patterns could be used as proper guidelines for naturally ventilated buildings. This research provides new insights that enable improved understanding of flow patterns in buildings with different porosity distribution patterns. These results are useful for establishing practical guidelines to design and evaluate the ventilation performance of terraced apartments in the hot and humid region.

END NOTE

1. Indoor Air Quality
2. Unit Relocation
3. Row Relocation
4. Column Relocation
5. Natural Ventilation

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