Optimization of building openings by utilizing the wind tunnel effect on a row house

The case study is Kampung Deret Petogogan, Jakarta

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***Abstract*: Energy consumption on domestic uses in Indonesia provokes designers to implement passive design concept as an effort to reduce energy consumption for household comfort without use of mechanical and electrical support. This research observed Kampung Deret Petogogan which a wind tunnel effect could not accurately provide natural comfort inside the row houses. Openings design was a key element to determine optimization of air movement indoors, including its positions, types, and dimensions. The goals were to identify the causes and determine ideal openings design to optimize indoors air circulation. First assessment involved relevant design theories that conducted as guidelines. Then the existed design openings were examined and compared with guidelines, thus the ideal design openings were generated. The final results concluded multiple solutions for optimizing indoor air circulation. An addition of wing wall, to help control the air movement. Repositioning the openings, both on walls and roofs. The selection of opening types which would be suitable based on air movement pattern. Lastly, redesign the dimension of the openings to fit the needs of natural comfort inside the houses.**

***Index Terms*: Row house, opening, air movement control, passive design**

I. INTRODUCTION

Housing in Indonesia are faced with the issue of energy consumption up to 19% from total (Outlook Energi Indonesia 2016). This value above commercial building function. The disparity between supply and demand took over more than ±17.2 million units in 2014. Therefore, it is predicted to increase up to ±930 unit yearly (RPJMN 2014-2019). This issue influenced housing designers to apply passive design concept as a sustainable solution to reduce energy consumption for household comfort without use of mechanical and electrical support. (Lechner 1975).

In tropical climate, passive design concept focuses on thermal comfort by air circulation, because environtment condition in tropical climate is hot and humid. This environment causes saturated air envelope which blocks heat discharge and can make people inside building feeling sweaty and uncomfortable. How to get rid of it just by optimizing natural air circulation from outside to inside building by utilizing the existing environmental potention (Koenigsberger 1975). Therefore, research on natural ventilation in housing is important to be carried out.

Kampung Deret Petogogan in Jakarta is one of row houses built by the government. In this project, The massing configuration enables wind tunnel effect that can be utilized because it can increase air velocity and distribute to every housing unit (Fig. 1) (Boutet 1987). However, air conditioning units are still used in some housing units which indicates unsuccessful application of passive design concept to make people inside building feel comfort.

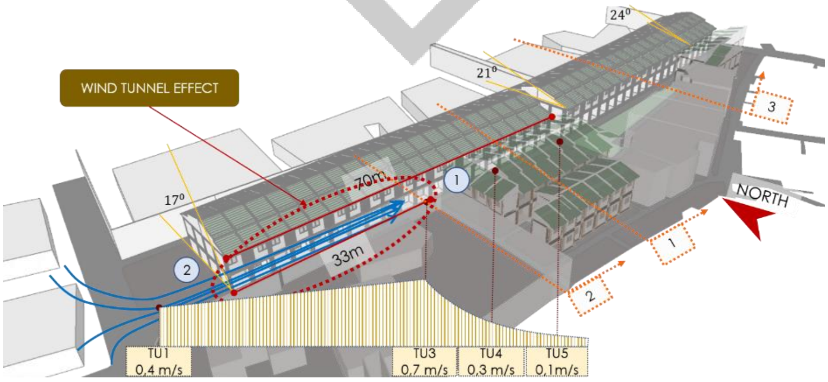


Figure 1. The wind tunnel effect in Kampung Deret Petogogan

Due to the building mass ordering and openings system, the wind tunnel effect could not optimally work. The symptoms occurred because of the air didn't thoroughly circulate inside the houses, thus generated heat which causes discomfort. This research observed building mass ordering including scale (gap and dimension between three-dimensional objects) and orientation. Moreover, assessment also conducted on openings design contained type, position, and dimension along with the technology innovations. These produced multiple variables which synthesized into resolution formula.

II. Material and Methods

Site and Existed Object Observation

Observations were operated in the entire built environment of Kampung Deret Petogogan, Jakarta. Enclosed space used for circulation were specifically examined, both front-to-front and back-to-back sides. (Fig.2)

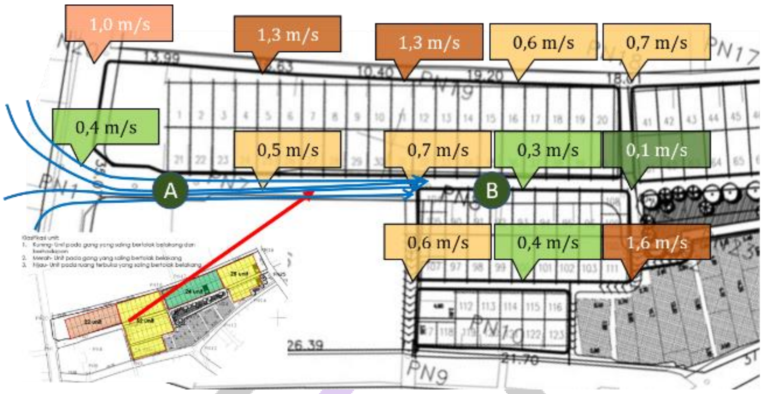


Figure 2. Observation result of air movements on site

Data inventory was measured by two devices, WBGT (Wet Bulb Globe Temperature) and Hot Wire Anemometer. Whilst air movement mapping was plotted on site plan (Fig. 3). The measurement results on site (Fig. 2) showed the increase velocity of air movements at (A) where the circulation area was shrunk. The air movement velocity reached maximum at the intersection, whereas it decreased at (B) towards the minimum point at the next intersection.

Figure 3. WBGT (wet bulb globe temperature) meter and Hot Wire Anemometer

Meanwhile, measurement and mapping on units showed no air movements from outdoor to indoor. The measurement result of air movement velocity in every room showed uncomforted thermal presence according to ET-CET diagram from Houghton and Yaglou (Fig. 4).

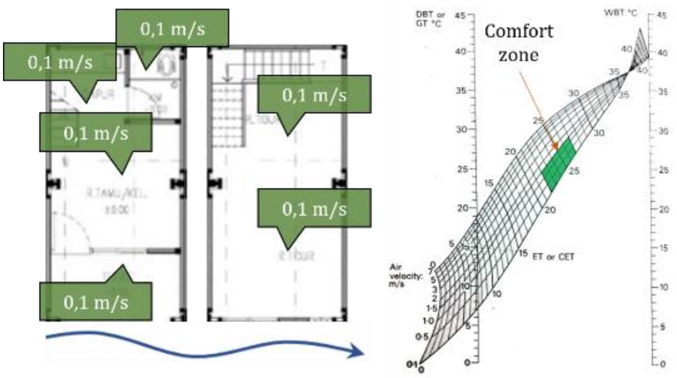


Figure 4. Observation result of air movements inside building unit

Data Analysis Method

Acquired measurement and mapping statistics were to be analyzed towards building mass order and openings in the building. Next calculation was done using Microsoft Excel and ET-CET Diagram to achieve 'air change per hour' variable. The results were further synthesized by Autodesk FlowDesign software to acknowledge why less airflow coming into the building. These steps became a design guideline to obtain a solution for applying ideal passive design, in terms of optimizing thermal comfort.

III. Results and Discussion

Analysis was conducted in the environment context which included building mass order and scale (dimensions and gaps between three-dimensional objects. Furthermore, in the building and interiors context (position, type, and dimension of openings) were also analyzed. Both contexts then were to be observed, simulated, and compared with relevant theories.

Site factor analysis

Observation results in the vicinity of Kampung Deret Petogogan stated that there were two dominant air directions existed through the row houses. The first one flowed parallel along the units while the other one streamed upward over the roof. (Fig.5)

Figure 5. Airflow pattern in around bulding

Both airflow pattern occurred because of a seamless configuration of row units. Addition of wing walls were recommended (Fig. 6) to direct more airflow into the building. (Evans 1980, Boutet 1987, and Brown 2001)

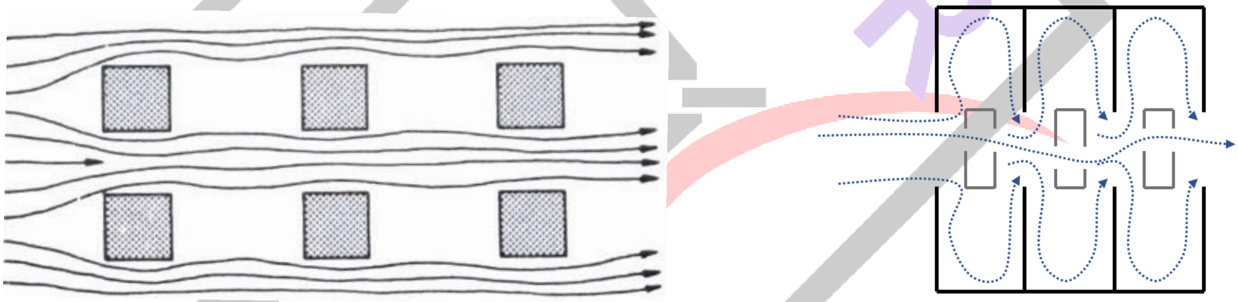


Figure 6. Airflow pattern on row houses and design recommendation

There are two recommended types of wing walls, vertical and combination. The vertical wing walls were best placed in ground floor along the arcades, whereas the combination wing walls were to be placed next to the windows or openings in upper floor. (Fig. 7)

Figure 7. Wing walls addition in accordance of the airflow pattern

Wind tunnel effect also occurred in the vicinity had effectively risen the air velocity (from unit (1) towards 33 meters eastbound). However, it had started to decrease until unit (2) which separated 60 meters in distance from unit (1). The lowest air velocity existed at 0.1 m/s. (Fig. 8)

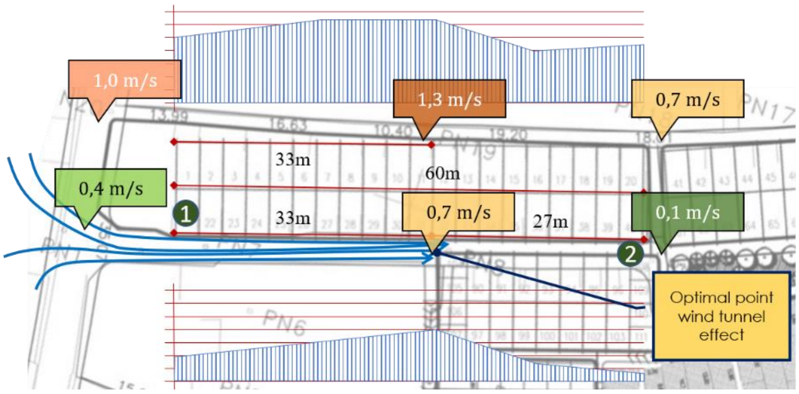


Figure 8. The wind tunnel effect in circulation between housing unit

The issue above could be solved by reordering the length of row units to optimize wind tunnel effect. The suggested total length was below 33 meters. The simulation was a proof, that airflow could be distributed evenly to every units because there was no velocity difference nor excessive length units. (Fig. 9)

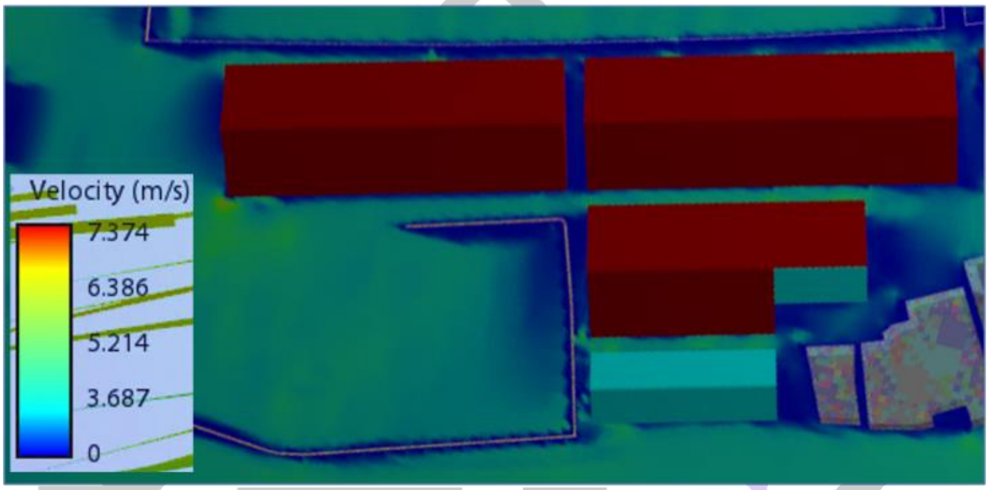


Figure 9. Redesign simulation

Analysis on openings in the building

Building openings were examined by measurement and existed mapping of environment influence. The openings indeed were needed to be attached wing walls. This section explored 4 (four) opening elements to optimize airflow, position, type, and wing wall. Openings in Kampung Deret Petogogan were only existed on one side of the units. According to Brown (2001), this affected low percentage of airflow going inside the buildings. Subsequently, the suggested position of windows or openings should be placed horizontally and vertically. Horizontal inlet and outlet openings should help optimize airflow percentage gained inside the room, while vertical openings (placed between 0 to 2 meters above the floor) supported airflow stream through living zone. (Fig. 10)

vertikal horizontal

Figure 10. Recommended position of opening

Despite of no openings situated on the roof caused less optimization of indoor thermal comfort. Roof openings were recommended to help lower the heat through cross ventilation. The most optimal opening type was a combination of continuous ridge and soffit louvers. This type can reduce the temperature in the attic up to 18.9°C at 0.4-2.4 m/s (Fig. 11). (Boutet 1987)

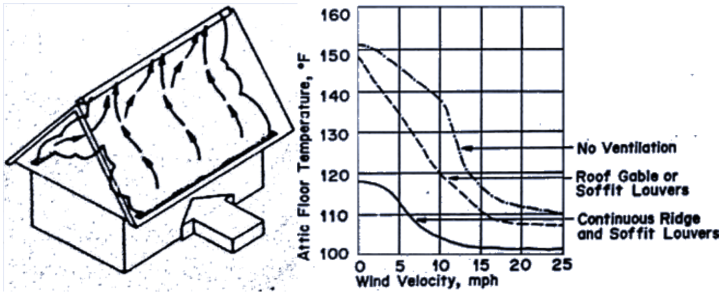


Figure 11. Roof opening, continuous ridge and soffit louvers

The roof openings can be applied in every units. The inlet should be placed on the lower side of the roof whilst the outlet should be placed on the upper side. The airflow then streams upward from the ground floor carrying the heat out of the indoor. (Fig. 12)

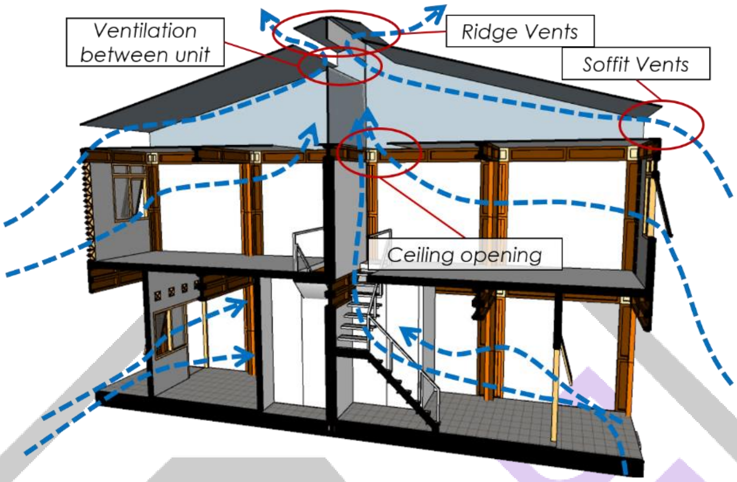
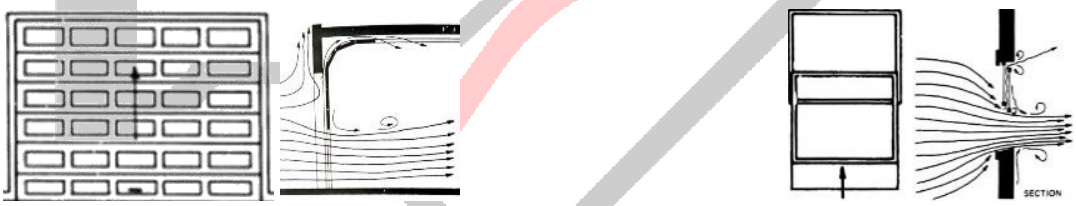
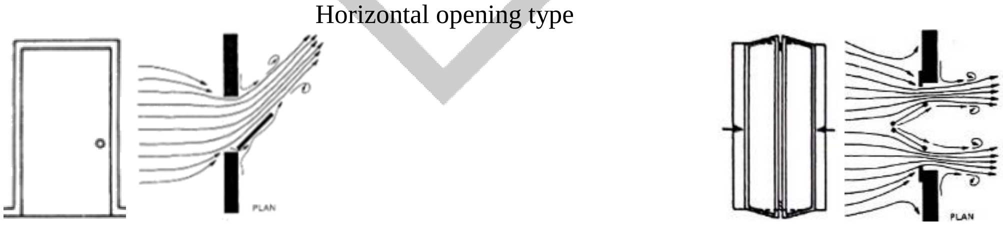


Figure 12. Roof opening application in housing unit

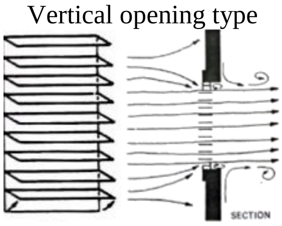
The opening types played a role both in incoming airflow direction and the velocity. There are three opening types (including windows and doors), which are horizontal, vertical, and screen (Boutet 1987). Horizontal openings determine airflow direction vertically, and vice versa. On the other hand, screen does not direct air movements (Fig.13). Opening types selection needs to be suitable with the outdoor airflow pattern and the desired direction.



Horizontal opening type



Vertical opening type



Screen type opening

Figure 13. Opening type

Existed opening types in Kampung Deret Petogogan units are single-flush door, rolling door, single-swing window, and screen. The placement of single-swing type in these particular units was not ideal, consequently directed the airflow away from living zone

(0-2m). The suitable opening types for this case should be vertical openings that direct more airflows into the living zone (0-2m). (Fig. 14)

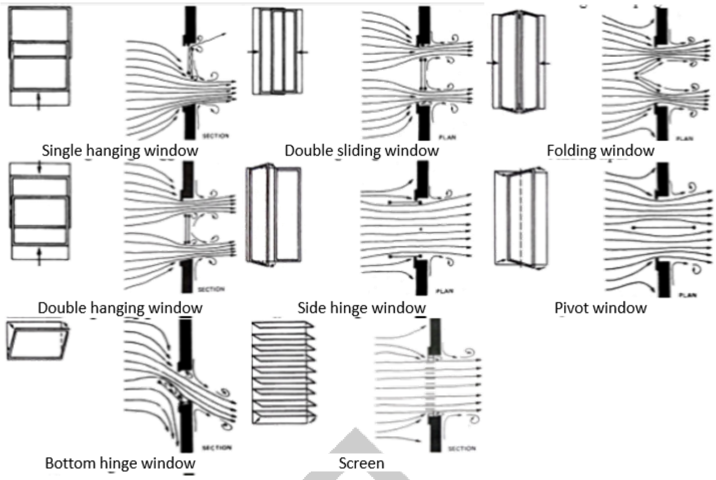


Figure 14. Recommended window types

The dimension of opening types stood as a parameter of airflow behavior between indoor and outdoor, particularly its velocity. The indoor-outdoor airflow exchange within an hour can be measured by ACH (Air Change per Hour. The amount of ACH could be obtained by a formula (1) (Latifah 2012) which consisted of inlet/opening area, air velocity, and room volume.

$$N = 60\frac{0{,}5682\ Av}{V} \quad (1)$$

Where:

[1] N= Value air change per hour (ACH)
[2] A= Area of *inlet* (m^2)
[3] v= Velocity (m/s)
[4] V= room volume (m^3)

The minimum criteria for airflow exchange per hour is regulated on SNI 03-6572 2001 (Table 1).

Table 1 Air change per hour standard

Room function	Outdoor air needs (m^3/min)/People		Air change per hour
	Smoking	**No smoking**	
Living room	-	0,3	2
Kitchen	-	3,0	20
Restroom	3,0	1,5	10
Bedroom	0,75	0,3	2

Source: SNI 03-6752 2001

Based on ACH calculation, its value can be grown by either decrease the room volume or increase the inlet area. Considering this building was built on RISHA structure system, hence transformation of inlet area is needed. The comparison below stated different cases to achieve a standard airflow exchange value.

- For Living room

$$2 = 60\frac{0{,}5682 \times A \times 0{,}5}{23{,}52}$$
$$2 = \frac{17{,}046 \times A}{23{,}52}$$
$$A = \frac{2 \times 23{,}52}{17{,}046} = 2.76m^2$$

- For Kitchen

$$20 = 60\frac{0{,}5682 \times A \times 0{,}5}{7.68}$$
$$20 = \frac{17{,}046 \times A}{7.68}$$
$$A = \frac{20 \times 7.68}{17{,}046} = 9.01m^2$$

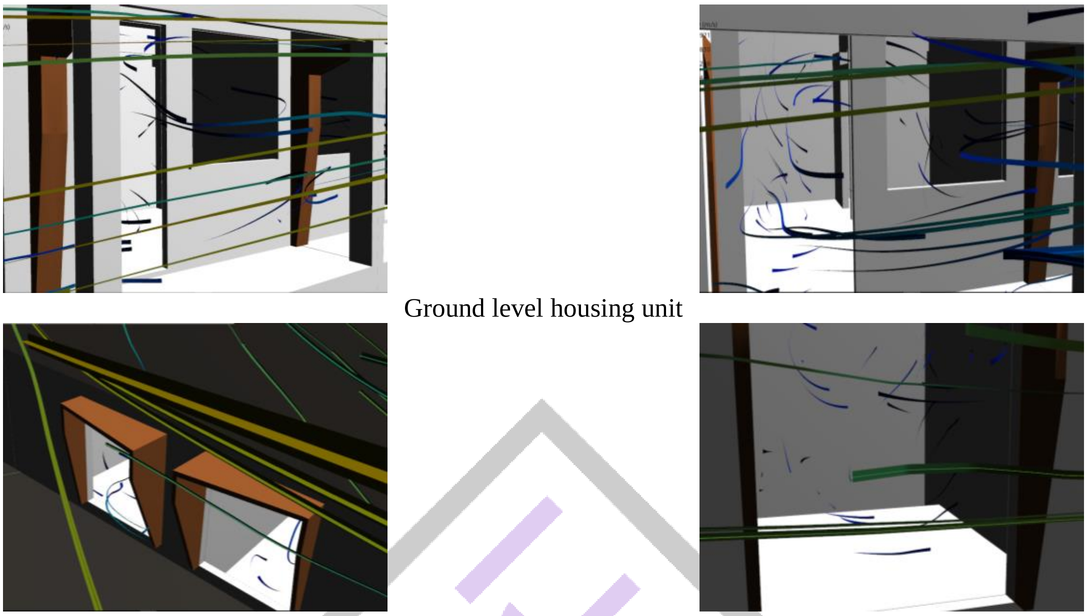
- For Restroom

$$10 = 60\frac{0{,}5682 \times A \times 0{,}5}{4.92}$$
$$10 = \frac{17{,}046 \times A}{4.92}$$
$$A = \frac{10 \times 4{,}92}{17{,}046} = 2.89m^2$$

- For Bedroom

$$2 = 60\frac{0{,}5682 \times A \times 0{,}5}{41.9}$$
$$2 = \frac{17{,}046 \times A}{41.9}$$
$$A = \frac{2 \times 41{,}9}{17{,}046} = 4.92m^2$$

Redesign process has achieved attempted results of higher ACH value. Unfortunately, all the units only have a single opening plane. Thus, creating an ideal opening area would not be possible. Analysis results and resolution formulation were simulated on Autodesk Flow Design software to acknowledge the impact of redesign in indoor-outdoor airflow exchange. (Fig. 15)



Ground level housing unit

Upper level housing unit

Figure 15. Air flow simulation in housing unit

IV. Conclusion

Dwellings formed in a row configuration have a distinctive characteristic of airflow behavior in the environment context. Moreover, they have a particular treatment for building mass orderings and openings. The final results are stated as the most crucial design elements for rowhouse planning.

- Determine an ideal building width to utilize wind tunnel as it should be distributed evenly to all units.
- Airflow pattern in the built environment context needs to be mapped, which related to make use for wing walls as an airflow catalyst.
- Roof openings are necessary to use for decreasing room temperature, which benefited from cross ventilation effect.
- Recommended opening types consisted of vertical opening that aims the airflow to be distributed towards living zone (0-2 meters above floor).
- Design simulation is indeed necessary using a digital software to obtain a calculated passive design concept on indoor-outdoor airflow movements.

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