A Discourse of Micro Wind Environment and Indoor Temperature and Humidity adapted on the Building Openings of Taiwan in Subtropical Zone

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Summary
This research is to improve, Taiwan’s high temperature and high humidity climate environment located at the subtropics area. This study proposes an appropriate opening design and implementation method for buildings in Taiwan, with the aim to improve such environment. The subject of this study was a three-floor atrium-style building, and 8 residential units were investigated. The two-sided openings were formed by shutters and glass, and could be categorized into 4 models. The research method was numerical simulation and field measurement. The numerical simulation divides into three criteria field ranges of three scales, in order to understand the wind flow situation surrounding the buildings. The simulation results and measurements were approximate. Also, the measuring results on temperatures and relative humidity inside the units showed that two-sided shutters are more effective to dissipate heat at night in summer than two-sided glass windows are. In winter, full-closed openings with small gaps could make the indoor temperature 2°C higher than the outdoor temperature, and the relative humidity could reduce by 10%. If there are furniture and heat source inside, the indoor temperature can be 1~2°C higher, and relative humidity can be 3~8% lower. Based on the results, this study proposed the window-opening ways are suitable for summer and winter, and discussed the wind guide effect after installing vertical deflector outside of the opening to improve the natural ventilation effect. In accordance with simulated results, after installing the vertical deflector, its average ACH can increase approximately 260% when the wind direction is parallel to the external windows. Also when the wind direction with the building stand the surface becomes 45°, and the angle of vertical wind deflectors (P=0° ~ 22.5°) is advantageous to the indoor airflow field evenly, however, with the vertical wind deflectors at 67.5°, there is a reduction in DR (draft rating).

1. Introduction
Many studies in the past pointed out that the indoor temperature and humidity significantly affects people's health and their working efficiency. The outer layers of a building, like the cells on the surfaces of foliages, have the functions of adjusting the air flows, temperature and humidity. The Opening Design of a building greatly impacts the indoor environment conditions in this high temperature and high humidity weather climate of Taiwan. Based on the premise of energy conservation, many studies investigating on the ways to improve the efficiency of natural ventilation are very popular in Taiwan. The objective of these studies is to maintain a healthy and comfortable indoor environment.

Based on the theory of ventilation, Cross ventilation has very good ventilation performance. Some studies (Chiang, 1999, Chiang et al, 2005) pointed out that one-sided opening space is very effective in ventilation by changing window opening patterns and by utilizing the thermal buoyancy principle. However, the use of natural ventilation is still not easy because factors such as the outside winds, building distribution and height in the practical environment. Therefore, in order to understand the effects of natural ventilation on indoor environment, we must understand the external environment conditions such as wind direction, wind speed, wind temperature, etc. However, data such as these are difficult to obtain. The majority of data are obtained from the weather station of the Central Weather Bureau located in the vicinity of the base building. But these data do not represent the actual wind situations around the base building.
In this study, a three-floor atrium-style building (Symbiosphere No.1) located at Fulong, a city in the northeast corner of Taiwan, was used as the research target. A long-term climate monitoring stations was set up at this base building. From data obtained from 1999 to 2001, it is shown that the general weather around the base is as follows: It is hot in summer and cold in winter, and it has distinct different temperatures for the four seasons. The highest temperature in summer is on the “Solar Term” called "DaShu- Great Heat ", the lowest temperature is on the “Solar Term” called "LiChun- Beginning Spring". The temperature difference between these two is 17.3 °C. There are 25% of the 24 Solar Terms in a year with high temperature over 28 °C (from late June to early September). There are 37.5% of the 24 Solar Terms in a year with low temperature lower than 20 °C (from early December to early April next year). Since Taiwan is an island, its climate is generally humid. Fulong has high humidity (relative humidity is above 70%) all year long, especially in spring and winter. Its relative humidity is over 80% for 2/3 of a year (early October to early May next year). Mainly influenced by the monsoon wind, terrain and the sea-land wind, the local wind roughly is Northwest, North or Northeast in winter and mainly Southeast wind in summer as shown in Figure 1.

In summary, the main objective of this study is to propose the building opening designs to maintain a healthy and comfortable living environment according to the wind characteristics around the base.

2. Steps and Method

This study is divided into the following three stages:

2.1 Study of the wind environment around the base

Numerical simulations and field measurements of the wind environments around the base were used to explore the difficulties in using natural ventilation. In order to thoroughly understand the airflow changes around the base building, simulations of three field ranges of different scales were performed in the study, as shown in Table 1. These three are: simulation of wide range valley terrain (large range), simulation of field range around the base building (medium range), and simulation of air flows inside the building (small range).

<table>
<thead>
<tr>
<th>Field Range</th>
<th>Large Range</th>
<th>Medium Range</th>
<th>Small Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition</td>
<td>The whole valley terrain in Fulong area</td>
<td>Terrains and buildings around the base building</td>
<td>The base building (Symbiosphere No.1)</td>
</tr>
<tr>
<td>Model Picture</td>
<td><img src="https://example.com/photo1.png" alt="Photo" /></td>
<td><img src="https://example.com/photo2.png" alt="Photo" /></td>
<td><img src="https://example.com/photo3.png" alt="Photo" /></td>
</tr>
</tbody>
</table>

Table 1: The descriptions of the numerical simulations of the three field ranges of different scales.
2.2 Study of the temperature and humidity conditions in the resident units

The field measurement method was used to measure temperature and relative humidity in eight resident units in the base building. Based on daylight utilization and ventilation, four two-sided opening models were created by mixing the shutters and openable windows, as shown in Figure 2 and 3, in order to understand the indoor temperature and relative humidity conditions under the extreme weather (extreme cold or extreme hot).

![Figure 2](image1)

Figure 2  The positions of the eight resident units and the four two-sided opening models in Symbiosphere No.1.

![Figure 3](image2)

Figure 3  The types of shutters and glass at the openings.

2.3 The improved design of the opening model

The numerical simulation methods were used to further analyze the situation of the base and resident units to identify the solutions of increasing the efficiency of natural ventilation. The numerical simulation used in this study is the Reynolds-Averaged Navier-Stokes (RANS) simulation method. It analyzed the flow fields inside and outside of the building, and established basic assumptions for the computational domain, as shown in table 2.

<table>
<thead>
<tr>
<th>Basic Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Steady State flow (wind speed, pressure)</td>
</tr>
<tr>
<td>2. Turbulence Flow</td>
</tr>
<tr>
<td>3. Do not consider the influence of Gravity</td>
</tr>
<tr>
<td>4. The speed field on the wall is assumed to be zero</td>
</tr>
<tr>
<td>5. Do not consider the roughness of the wall</td>
</tr>
<tr>
<td>6. Use Wall Function</td>
</tr>
<tr>
<td>7. 3D Cartesian Coordinate</td>
</tr>
<tr>
<td>8. Incompressible Flow</td>
</tr>
</tbody>
</table>

The turbulent transfer model selected is the widely used standard k-ε model. This model has good predictability for the mean velocity of the natural convection, and the required calculation time is also shorter (Chen, 1995). The average governing equation about the continuous, momentum and turbulence scale k and ε is shown in equation (1).

\[
\frac{\partial (\rho \phi)}{\partial t} + \nabla \cdot (\rho \vec{V} \phi) = \nabla \cdot (\Gamma_\phi \nabla \phi) + S_\phi
\]  

(1)

In equation (1), \( \phi \) represents 1, u, v, w, k, \( \varepsilon \), and source, \( S_\phi \) has different descriptions for different equations. Convection and diffusion are the same in all motion equations. \( \Gamma_\phi \) represents diffusion coefficient for quantity variables and the effective viscous coefficient for velocity variables.
In order to understand the ventilation effects, this study evaluates the ventilation rate (air changes per hour). The air changes per hour (ACH) is defined as the number of times a volume equivalent to the room volume are replaced per hour as shown in equation (2), where $Q$ is the ventilation volume ($m^3$); $V$ is the room volume ($m^3$); $T$ is the ventilation time (hr).

$$ACH = \frac{Q}{V \times T}$$  \hspace{1cm} (2)

Since under natural ventilations, the ventilation rates are influenced by external environmental factors such as the outdoor wind speed and wind directions, therefore by merely looking at the magnitudes of the measurements provides no common basis for evaluation. Hence, in this study, the ACH was converted under different conditions to dimensionless air change increase rates and compared them. The calculation equation is shown in equation (3) where $Q_{\text{normalize}}$ is the air change increase rate (%); $Q_c$ is for ACH with vertical deflectors; $Q_e$ is ACH without vertical deflector.

$$Q_{\text{normalize}} = \frac{Q_c - Q_e}{Q_e}$$  \hspace{1cm} (3)

3. Results

3.1 Analysis of the simulation results of the wind environment around the base

Figure 4, 5 depict the numerical simulation results for the summer and winter wind fields of large range. From the flow structure it can be found that in summer, wind mostly comes from the Southeast, and in winter, it comes from the North as predicted. However, the simulation results also show very detailed changes in the flow field. The wind speed is significantly lower on the Eastern side of the building in summer (Figure 4), on the contrary, its wind speed is higher in winter. The wind speed on the North side is also high because of the air compression (Figure 5). The South side is the main static area both in summer and winter.

To examine the accuracy of the simulation results, the simulated values of wind speeds were compared with the field measurements of those. From the simulation results of the wind field around Symbiosphere No.1, five (A–E) places that have dramatic changes of wind speed, and some places surrounding the Symbiosphere No.1 were selected to measure wind speeds. Those places surrounding the Symbiosphere No.1 include five measurement points E1–E5, on the East side because the wind on that side is stronger affecting by the terrain, and three measuring points individually on the remaining three sides W, S, N.

The results of the comparisons on the A–E points are shown in Figure 6. On places A and B, there are larger differences where measured wind speeds are lower than the simulated values. But on the others (C, D, E), the simulation results and the field measurements are consistent. The results of the comparisons of the wind speeds on the places around the Symbiosphere No.1 are shown in Figure 7. The results from the large-scale simulation have larger differences than those from the medium-scale simulation, especially shown on the points (E1–E4) on the East side. The correlation coefficient between the medium-scale simulations and measurements can reach to 0.89. It demonstrates that the medium-scale simulation can more approach the real situations.

In addition, the accuracies of the simulation results are different on locations with different heights. The comparison of large-scale simulation results from the height of 5m and 13m show that the latter has higher correlation as shown in Figure 8.
The medium-scale simulation can also model the very small air flow changes surrounding the base building. Figure 9 and 10 are the simulation results for the air flows in summer and winter respectively. It shows that in both summer and winter, the air flows are closely in parallel to the window surface. With respect to the ventilation needs for different seasons, we extremely need indoor natural ventilation to dissipate the heat for summer. However, Figure 9 shows that, in summer, there are some small air flows getting indoor in resident units on the West side and the air flows are not noticeable in the resident units on the East side. Hence the effects of heat dissipation are limited. In order to let air get indoor more effectively, installing the some deflector at opening is necessary to change wind direction. For the analysis of the impacts of installing vertical wind deflectors to natural ventilation using small-scale simulation, please see 3.3.

3.2. Measurement results of the temperature and relative humidity in resident units

3.2.1 Measurements of the temperature and relative humidity in summer

The temperature and relative humidity were measured in summer at the Solar Term: Great Heat and in winter at the Solar Term: Beginning Spring - the extreme climates of these two seasons (extreme cold or extreme hot). Whether the windows are open or closed depends on the need of the season, it is open for summer, closed for winter.

In the area of temperature, due to the fact that sometimes the ventilation during the higher temperatures in the day time not only has no benefit to reduce the indoor temperature, but also cause a great deal of heat to get into the interior of a building, hence ventilation cooling is mainly performed at night time. Figure 11 is the changes of the indoor temperatures in the resident unit, Type-A, during Great Heat. It shows that when the outdoor temperature plunged at night, the indoor temperature of the Type-A will also droop sharply. The indoor temperature is only higher than the outdoor temperature by an average of 0.81 °C. However, the effects of other types of night time ventilation for heat dissipation are less significant. The temperatures of Type-B, Type-C, and Type-D are higher than the outdoor temperature by 0.87, 0.98, 1.08 °C respectively.

In the area of relative humidity, the relative humidity decreases because of the higher temperature for the day, so to prevent high humidity at night is our main goal. Figure 12 shows that the difference is larger between indoor and outdoor relative humidity for Type-A. The indoor relative humidity is lower than that of the outdoor by an average of 6.53%. The differences between indoor and outdoor humidity for Type-D also can reach an average of 5.53%. Type-B and Type-C are less effective in lowering the humidity than Type-A and Type-D. The differences between indoor and outdoor humidity for Type-B and Type-C are only 3.38% and 4.02% respectively.
The test results during Beginning Spring show that every opening model is somehow effective for thermal and humidity insulation, with the indoor temperature higher than that of the outdoor by about 2 to 3°C and the indoor relative humidity less than that of the outdoor by about 10%. Take Type-C for example, the impacts of the indoor furniture and heat source are shown in Figure 13 and 14. The indoor temperature for the unit with furniture and heat sources is higher for about 1 to 2°C. In other words, it is maintained at 17 to 18°C, about 4°C higher than the outdoor temperature (13 ~ 14°C). The relative humidity of the unit with furniture and heat sources is maintained at 65 ~ 70%, about 3 to 8% lower, or approximately 15% lower than that of the outdoor humidity of 80 ~ 85%.

3.3 Simulation results for the improved opening model

3.3.1 Numerical simulation results

From the small-scale simulation (as shown in Table 3), we can see that when the wind direction S is 45 ~ 90 degrees, the outside air entering the room would cause the higher speed air flow concentrate on the edge of the walls. This will make the wind speed lower in the middle of the room because the airs can not be distributed uniformly in the room. As a result, large areas of “Dead Zones” tend to develop in the room.

Table 3 also shows that if the angel P of the vertical wind deflectors is set to 0 or 22.5 degrees, air flow can spread more evenly to the living space through the wind deflectors to improve the problem of uneven distribution of flow velocity. The improvement is the most significant when the wind direction S is 45 degrees. The improvement is less effective when the angel P of the vertical wind deflectors is larger than 45 degrees. But at these angles, the wind deflectors have the ability to reduce the wind speed. Especially the wind speed was reduced significantly when the angle P of the vertical wind deflectors is 67.5 degrees, the indoor draft rating DR is thus lower.

3.3.2 The analysis of the Air Changes per Hour (ACH)

In addition, installing vertical wind deflectors improve indoor ventilation when the wind direction is parallel to the external windows. It can be seen from Table 4 that when the outdoor wind speed is 0.5 m/s, after installing the vertical wind deflectors of 0 degrees, ACH increased from 2.9 to 9.2. The greater the wind speed, the more increase in the ACH. When the wind speed is 2.0 m/s, the ACH increased from 10 to 38. The difference in ACH is not significant with different wind deflecter angles, especially when the wind speeds are low.
Table 4 The comparison of the ACHs with and without the vertical wind deflectors.

<table>
<thead>
<tr>
<th>V</th>
<th>0.5 m/s</th>
<th>1.0 m/s</th>
<th>1.5 m/s</th>
<th>2.0 m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>P(°)</td>
<td>Non</td>
<td>Non</td>
<td>Non</td>
<td>Non</td>
</tr>
<tr>
<td>S = 90°</td>
<td>2.9</td>
<td>9.2</td>
<td>10</td>
<td>9.0</td>
</tr>
<tr>
<td>ACH</td>
<td>0.5</td>
<td>9.2</td>
<td>10</td>
<td>9.0</td>
</tr>
</tbody>
</table>

Annotation: V: Wind speed, P: Wind deflector angle, S: Wind direction, Non: Without vertical deflector, ACH (Unit: h⁻¹)

Following the discussion above, the equation (3) was used to calculate the air change increase rate ($Q_{\text{normalize}}$) at various wind deflector angles under different wind speeds as shown in Figure 15. The ACHs of the rooms with installed different wind deflector angles has an average increase of about 260 percent than those without the deflector.

4. Discussions

4.1 The necessity and the difficulties of the numerical simulation of different scales

Large-scale simulations help us understand the wind environment change in the area. However, since this model is rough so it affects the accuracy of the simulation. Like some objects including trees, bushes on the ground were not built in the model could cause the simulation values higher than the real values. Furthermore, as shown in Figure 8, that the errors are larger at heights closer to the ground maybe is impacted by the terrain because the complete landscape could not be modeled. These problem can solved either by setting more roughness on the ground in the model, but the values of the settings may vary for difference cases, or by narrowing the domain of simulation, and increasing the details in the model. In the second case of medium-scale simulations, the model gradually approaches the true situation and can show micro-environment wind changes in the base to achieve a more accurate simulation results. However, the impact could be significant if the transformations of the boundary conditions of simulations of different scales in the numerical simulation are not performed correctly.

4.2 Comparison of four opening models

4.2.1 Reductions of the temperature and humidity in summer

With respect to indoor cooling, Type-A has the advantages. The main reason is that inside and outside openings of Type-A are all shutters. Cross-ventilation can be formed to reduce the temperature rapidly. Especially when the temperature rises in the afternoon, a lot of ventilation makes people feel more comfortable. Other types of cooling effect are less significant because the open area is not large enough so the ventilation is not adequate.

With respect to indoor humidity reduction, Type-A can remove moisture by ventilation because of the larger open areas. The indoor relative humidity of Type-D is lower because its glass outside prevents external moisture from getting into the room. On the other hand, Type-B and Type-C are less effective than Type-A and Type-D for removing moisture because their ventilations are inadequate and they allow more external moistures to enter inside.

4.2.2 Maintain temperature and reduce humidity in winter

In winter, even the resident units with shutters on both sides are effective in maintaining temperature and reducing humidity mainly because the window frames are hermetically treated which block the majority of heat loss and moistures entering. The ventilation relies on the gaps on the floor alone. In addition, rooms with furniture and heat sources are more effective in maintaining temperature and reducing humidity. The heat sources (such as computers, people, lights, etc.) provide heat to raise the indoor temperature and lower relative humidity. Other factors of influence are the ability of the furniture to absorb moisture and the shutters...
to block the transfer of heats to outside. The proper and simple window-opening ways for summer and winter is suggested as shown in Table 5 based on the above analysis.

Table 5 Suggestions on the window-opening ways in summer and winter for Symbiosphere No.1.

<table>
<thead>
<tr>
<th>Season</th>
<th>Time</th>
<th>East Side</th>
<th></th>
<th>West Side</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Outside</td>
<td>Inside</td>
<td>Outside</td>
<td>Inside</td>
</tr>
<tr>
<td>Summer</td>
<td>Day</td>
<td>All Open or Half Open, All Open in the afternoon</td>
<td>All Open</td>
<td>All Open or Half Open, All Open in the afternoon</td>
<td>All Open</td>
</tr>
<tr>
<td></td>
<td>Night</td>
<td>All Open</td>
<td>All Open</td>
<td>All Open</td>
<td>All Open</td>
</tr>
<tr>
<td>Winter</td>
<td>Day</td>
<td>All Closed</td>
<td>All Closed</td>
<td>All Closed</td>
<td>All Closed</td>
</tr>
<tr>
<td></td>
<td>Night</td>
<td>All Closed</td>
<td>All Closed</td>
<td>All Closed</td>
<td>All Closed</td>
</tr>
</tbody>
</table>

4.3 Discussion on the angles of the vertical wind deflectors

We can see from the cross-section of the flow field shown in Table 3 that although the vertical wind deflectors can deflect the air indoor, but air flows accelerated when it passed through the shrunk openings and may cause greater wind draft to the staff indoors. Hence, the adjustable vertical wind deflectors are more suitable both for indoor ventilation and comfort. It can be adjusted according to the wind changes in the external environment.

Because feeling of the wind draft for humans is inversely proportional to the temperature, proportional to the wind speed, so improving ventilation should be more considered when the temperature is high or wind speed is low. The angle $P$ of the vertical wind deflectors should be smaller in these situations. When the temperature is low or the wind speed is high, the impact of the wind draft needs to be more considered, so the angle $P$ of the vertical wind deflectors should be larger.

Furthermore, when this study investigate the impacts of the vertical wind deflectors on natural ventilations, it sets limits on the five kinds of designated wind directions, four kinds of wind speeds (0 to 2 m/s) and four kinds of wind deflector angles (separated by 22.5 degrees). We will conduct more in-depth researches in the future with other conditions.

5. Conclusions

In this study, micro-environment wind field and indoor temperature of the real room are used to investigate which opening models benefit natural ventilation. By using numerical simulations of different scales, the monitored data obtained from the weather stations are converted to more detailed wind flow situations around the base buildings. Assisted by the investigation on the indoor temperature and humidity, the conclusion is that, the two-side shutters is more effective than the two-side glass windows in using night time ventilation to dissipate heat in summer. When they are all closed except some small gaps, the indoor temperature is higher than the outdoor temperature by about 2 °C, the relative humidity is reduced by 10%. With furniture and heat sources, indoor temperature can be further raised by 1 to 2 °C and relative humidity dropped by another 3 to 8%. This study also proposed the window-opening way suitable for summer and winter. When the wind direction is parallel to the external windows, the average $ACH$ increases about 260% with the installation of vertical wind deflectors. When the wind direction with the building becomes 45 degrees, the wind deflector angel set between 0° to 22.5° ($P = 0°$ to 22.5°) is advantageous to the indoor airflow field evenly. When wind deflector angle is 67.5° ($P = 67.5°$), it can reduce wind speed and help lower the draft rate DR. Therefore, respect to the Taiwan's subtropical climate, installing vertical wind deflectors with the appropriate angles at openings of the building has noticeable improvement in natural ventilation.

Acknowledgement

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