Study on Utility Cross-Ventilation in Guangzhou and Shenzhen, China

Masashi Imano*, Yunchan Zheng, Yoshihiko Akamine, Narongwit Areemit, Motoyasu Kamata and Yuzo Sakamoto

1 Assistant Professor, Department of Architecture, Graduate School of Engineering, The University of Tokyo, Japan
2 Mechanical & Electrical Engineering Department, Nikken Act Design, Japan
3 Project Assistant Professor, Department of Architecture, Graduate School of Engineering, The University of Tokyo, Japan
4 Architect/Energy Specialist, A49, Thailand
5 Professor, Department of Architecture, Kanagawa University, Japan
6 Professor, Department of Architecture, Graduate School of Engineering, The University of Tokyo, Japan

Abstract

As rapid increase in energy consumption has raised concerns among researchers regarding the use of conventional air-conditioning systems, substantial effort has been devoted to the exploration of alternative solutions. One possible solution is a natural ventilation approach. In the present study, the authors have focused on the feasibility of cross-ventilation due to natural ventilation potential. The study centered on cases located in the Guangzhou and Shenzhen areas on the Pacific coast of China, well known for their dense population and high-energy consumption. In the current research, the analysis of weather data to investigate the feasibility of cross-ventilation in Guangzhou and Shenzhen was initially performed. A questionnaire survey was then carried out in order to grasp the residences' actual configurations and conditions. Sequentially, based on the results obtained from the prior investigations, the existing problems were raised and solutions for cross-ventilation enhancement were tested by means of a wind tunnel experiment. It can be concluded that the presence of VOID (vertical opening common space) without an opening on the lower part of the buildings significantly improves the cross-ventilation flow rate by 1.3-2 times over the cases without VOID.

Keywords: cross-ventilation; China; Guangzhou; Shenzhen; void; multiple dwelling house

1. Introduction

As the use of conventional air-conditioning systems has become a necessity in hot and humid climates, the consequential rapid increase in energy consumption has raised concerns among researchers. Therefore, in order to lessen the severity of the situation, substantial effort has been devoted to exploring alternative solutions to air-conditioning systems. Among the possibilities, natural ventilation has been firmly established as one of the alternatives to air-conditioning systems. In the present study, the authors have focused on the feasibility of cross-ventilation due to natural ventilation potential, specifically in the regions of Guangzhou and Shenzhen on the Pacific coast of China, which are well known for their dense population and high-energy consumption.

2. Weather Conditions in Guangzhou and Shenzhen

2.1 Temperature and humidity

The Guangzhou and Shenzhen areas are considered to have hot and humid climates. Annual mean temperature is approximately 22.2°C, while relative humidity is about 70%. In Fig.1., the climograph illustrates monthly mean temperature and relative humidity in Guangzhou, Tokyo and Taipei. It can be concluded that the presence of VOID (vertical opening common space) without an opening on the lower part of the buildings significantly improves the cross-ventilation flow rate by 1.3-2 times over the cases without VOID.

*Contact Author: Masashi Imano, Assistant Professor, Department of Architecture, Graduate School of Engineering, The University of Tokyo 7-3-1, Hongo, Bunkyo-ku, Tokyo, Japan, 113-8656 Tel: +81-3-5841-6164 Fax: +81-3-5841-8511 E-mail: imano@arch.t.u-tokyo.ac.jp (Received October 8, 2007; accepted January 11, 2008)

Fig. 1. Climograph for Guangzhou, Tokyo and Taipei
seen that even the annual lowest dry bulb temperature and relative humidity in January are approximately 14°C and 70% respectively. In addition, Guangzhou experiences higher annual mean temperature and humidity compared to Tokyo as well as a higher annual change in humidity level than Taipei.

2.2 Wind velocity and direction

In Fig.2., monthly average wind velocities are illustrated. In April, wind velocity is found to reach the lowest annual level because it is in the middle of the raining season. Additionally, it reaches the highest level in July during the monsoon season. Annual mean wind velocity in Guangzhou is found to be around 1.5m/s. The wind roses during summertime and wintertime in Guangzhou are shown in Fig.3. During summertime, the prevailing wind direction approaches from the southeast while during wintertime, it approaches from the northwest direction.

2.3 Feasibility of cross-ventilation according to the weather conditions

The calculation of feasibility of cross-ventilation according to weather conditions was based on the standard weather data during the years 1988 to 1997 (Zhang and Asano, 2001). In addition, the conditions for calculating SET* are briefly summarized in Table 1. Besides temperature and humidity obtained from the standard weather data, air velocity with stagnant flow was maintained at 0.13m/s. Clothing level altered between 0.4 and 0.9 during summertime and wintertime respectively. Reports indicate that it is feasible to utilize natural ventilation for cross-ventilation while SET* is in the 22.2 – 25.6°C range (Gagge, 1971). The frequency of time when SET* falls in the ranges was calculated and illustrated in Fig.4. As can be seen, during wintertime, it can be analyzed that cross-ventilation seems to be feasible during daytime. On the other hand, it is difficult to utilize natural ventilation during summertime. In addition, there is a high feasibility of implementing natural ventilation during the periods in between. In total, there are approximately 1,850 hours throughout the year where feasible cross ventilation could potentially achieve comfort. Since the distance between Shenzhen and Guangzhou is about 165 kilometers and the climate in these cities are almost the same, the calculation result can be generally applied to Shenzhen.

| Temperature | Standard weather data in Guangzhou |
| Humidity | Standard weather data in Guangzhou |
| MRT | Identical to temperature |
| Air velocity | Constant at 0.13m/s |
| Clothing level | 0.4 clo (May-Oct), 0.9 clo (Nov to April) |
| Metabolic rate | 1.17met |

2.3 Feasibility of cross-ventilation according to the weather conditions

The calculation of feasibility of cross-ventilation according to weather conditions was based on the standard weather data during the years 1988 to 1997 (Zhang and Asano, 2001). In addition, the conditions for calculating SET* are briefly summarized in Table 1. Besides temperature and humidity obtained from the standard weather data, air velocity with stagnant flow was maintained at 0.13m/s. Clothing level altered between 0.4 and 0.9 during summertime and wintertime respectively. Reports indicate that it is feasible to utilize natural ventilation for cross-ventilation while SET* is in the 22.2 – 25.6°C range (Gagge, 1971). The frequency of time when SET* falls in the ranges was calculated and illustrated in Fig.4. As can be seen, during wintertime, it can be analyzed that cross-ventilation seems to be feasible during daytime. On the other hand, it is difficult to utilize natural ventilation during summertime. In addition, there is a high feasibility of implementing natural ventilation during the periods in between. In total, there are approximately 1,850 hours throughout the year where feasible cross ventilation could potentially achieve comfort. Since the distance between Shenzhen and Guangzhou is about 165 kilometers and the climate in these cities are almost the same, the calculation result can be generally applied to Shenzhen.

Table 1. Conditions for Calculating SET*

| Temperature | Standard weather data in Guangzhou |
| Humidity | Standard weather data in Guangzhou |
| MRT | Identical to temperature |
| Air velocity | Constant at 0.13m/s |
| Clothing level | 0.4 clo (May-Oct), 0.9 clo (Nov to April) |
| Metabolic rate | 1.17met |

3. Characteristics of Residential Houses in China and Questionnaire Survey on the Residents' Awareness Regarding Cross-ventilation

3.1 Characteristics of residential houses in China

Multiple dwelling houses in China can be categorized into the Tower, Corridor and Unit types, which are described in detail as follows:

- Tower type (Fig.5.) – Similar to center-core mid-to-high-rise buildings in Japan.
- Corridor type (Fig.6.) – Equivalent to side and central corridor types in Japan.
- Unit type (Fig.7.) – Close to walk up type. However it is different from those in Japan where one staircase connects up to 3 – 6 units.

Fig.5. Tower Type
3.2 Questionnaire survey on residents' consciousness regarding cross-ventilation
3.2.1 Questionnaire survey methodology

The survey was conducted from the beginning of October to December 2005 in Guangzhou and Shenzhen. The main data collected was residence type, opening configurations and conditions, use patterns of air-conditioning systems and subjects' awareness regarding natural ventilation. Field sampling took place with 300 questionnaires distributed in a random manner and 281 responses were obtained. The response rate was as high as 94%.

3.2.2 Results of questionnaire survey

a) Residences

As illustrated in Fig.8., there were a high percentage of subjects in multiple dwelling houses. Within these the Tower, Corridor and Unit types had percentages of 38, 24 and 38 respectively. In addition, as summarized in Fig.9., the majority of subject residences in the Corridor and Unit types were below the 9th floor.

b) Opening configurations

As shown in Fig.12., the percentages of either leaving windows open for the whole day or opening the windows in the presence of occupants were as high as 65% in living rooms and 56% in bedrooms. It can be seen that utilizing natural ventilation in these areas is a common practice.

c) Opening conditions

As shown in Fig.10., the percentage of openings with security grilles was found to be 70% in living rooms and bedrooms, while kitchens and bathrooms possessed 55%. In addition, as shown in Fig.11., residences on the upper floors tend to have a lower percentage of installed security grilles. Since the percentage of net window usage was about 83% in the survey in Taiwan (Tu et al., 2004), our survey at 15% was found to be comparatively low. The results led us to infer that the concern about security and pest infestation matters differs between China and Taiwan.

d) Use patterns of air-conditioning systems

In Fig.13., the sole use of air-conditioning systems and use together with fan was 47% in living rooms and fairly high at 72% in bedrooms. Furthermore, in Fig.14., it is found that there was a high percentage of subjects who felt uncomfortable with long periods of air-conditioning system use.

e) Awareness of feasibility of cross-ventilation due to natural ventilation potential

In Fig.15., the percentage distribution of responses to overall comfort according to the utilization of natural ventilation is shown. From the figure, it is found that during the periods January to June and October to
December, 50% of respondents felt no discomfort, while approximately 20% felt comfortable during mid-summer. Of note is the relatively high percentage of responses in the semi-comfortable to comfortable categories. This confirms the feasibility of cross-ventilation due to natural ventilation in Guangzhou.

f) Indoor airflow driven by natural ventilation during summertime

As illustrated in Fig.16., to the question regarding the preference between natural ventilation and air-conditioning systems, 80% of responses showed an intention to utilize natural ventilation, which implies a preference for cross-ventilation. Additionally, in Fig.17., the percentage distribution of responses to indoor air movement according to the height of the subject unit is illustrated. "Insufficient" and "Insufficient - Comfortable" responses were found in 63% and 52% in subjects living on the 1st – 2nd floors and 3rd – 4th floors of buildings, respectively. In addition, more than half of the subjects on the lower floors of buildings felt the insufficiency of air movement. These findings are similar to the results reported in the survey in Taiwan (Tu et al., 2004).

g) Conclusions Regarding the Questionnaire Survey

While expectation regarding the cross-ventilation approach is seen to be high, actual cross-ventilation detected in the lower floors of buildings is in reality considered to be insufficient. Therefore, a solution for cross-ventilation enhancement is necessary in such cases.

4. Selection of the Type of Residences for Further Investigation

The questionnaire results collected from subjects in Guangzhou and Shenzhen in section 3.2 show that the percentage of residences in either Tower or Unit type residences was above 30%. Between these two, Tower type residences with a relatively high percentage of high-rise buildings in particular of over 10 stories are considered to possess high feasibility regarding cross-ventilation. However, in the Unit type, in which a majority of residences are mid-high-rise buildings below nine stories, the percentage of residential units below the 6th floor was even higher than 70%, which makes it difficult for cross-ventilation to be realized.

Therefore, the current research opts for Unit type residences for further investigations concerning cross-ventilation enhancement.

5. Wind Pressure Coefficient of Unit Type Buildings Measured in the Wind Tunnel Experiment

A model of a typical Unit type building was used in the wind tunnel experiment facility together with its neighborhood environment. The distribution of wind pressure coefficient was initially measured according to the ordinary configuration and later compared with that of improved configurations for cross-ventilation enhancement.

5.1. Description of experiment

The wind tunnel experiment was conducted in the facility buildings at the University of Tokyo. A view of the building model and wind tunnel facility is illustrated in Fig.18. A model of a subject Unit type building was made to a scale of 1:100. The array of neighborhood buildings with two rows of buildings on the south and north sides, as well as another row of buildings on the east and west sides were also set up. As shown in Fig.19., for the purpose of reproducing the wind characteristics to which the group of mid-high-rise buildings was subjected, the power index representing turbulent boundary layer inlet flow was set at 0.27. Wind velocity at the identical height to the

![Fig.14. Percentage of Responses after Long Period of the Use of Air Conditioning Systems](image)

![Fig.15. Percentage of Responses Corresponding with Comfort while Utilizing Natural Ventilation](image)

![Fig.16. Percentage of Preferences between Cooler and Natural Ventilation](image)

![Fig.17. Percentage of Responses to Interior Airflow According to Opening Conditions](image)

![Fig.18. Model for Experiment](image)

(Left: Targeted Residential Unit, Right: Model Set up)
The top level of the targeted building (198mm) was set at 7m/s as a reference wind velocity $U_o$. The interval of wind direction angle was set at 22.5 degrees with 16 possible patterns.

Regarding the typical building, as illustrated in Fig. 20, one building consists of four residential units with two identical units; one on the west and the others on the east. Two units share a staircase acting as a core forming a left-right symmetrical plan. The wind pressure coefficients were measured on two units on the east. It was assumed that openings exist at positions S1-4, N1-4 and W1-4.

The experimental cases with different configurations are briefly summarized in Table 2. As can be seen, case 0 represented the case without any adjacent buildings, while cases 1, 2 and 3 differed in the interval distance between adjacent buildings on the south and north at 1/4L, 1/2L and 3/4L respectively and a fixed distance at 1/2L to adjacent buildings on the east and west. Furthermore, as shown in Fig. 21, in order to achieve the enhancement of cross-ventilation, the space between the east and west units was enclosed and transformed into a vertical open space from the bottom of the 1st floor to the building's roof. Later in this paper, this element is called VOID. The effect of parameters, for instance, the depth of void, total height of void, opening at 1st floor level etc. are further investigated, which brings the total number of experiment cases to 15.

5.2 Interval distance between adjacent buildings

In Fig. 22, the distribution of the differential wind pressure coefficients between positions S1 and N1, comparing different interval distances with adjacent buildings in case 0-3 is shown. Here, the differential wind pressure coefficient was achieved by averaging the values obtained from the tests with 16 different wind directions. By comparing the results obtained from each floor, the coefficients were highest at the 6th floor and gradually reduced as it approached the lower floors. As low differential wind pressure coefficient implies low cross-ventilation, it can be considered that there is a lack of cross-ventilation in the low height part of buildings, which matches with the results stated in the questionnaire survey. Furthermore, the effect of adjacent buildings on the differential wind pressure efficiency is obviously highlighted in cases 1-3, which was relatively low at only 1/4 of case 0. This leads us to state that the effect of adjacent buildings is considerably significant. With previous findings in mind, a further investigation concerning void configurations to enhance cross-ventilation was performed in the following sections.
5.3 Basic void configurations

In Fig.23., the distribution of differential wind pressure coefficient between positions S1 on the exterior side and W1-4 in the void on the 4th floor comparing the different interval distances with adjacent buildings from cases 0-1 to 3-1 is illustrated. The extremely low level of the differential wind pressure coefficient can be seen in every case, including the results on other floors besides the 4th. Thus, further investigations will only focus on the differential wind pressure coefficient between S1 and W1. Furthermore, it can be further seen in the figure that as the interval distance with adjacent buildings reduced, the wind pressure coefficient accordingly decreased and resulted in difficulty in utilization of cross-ventilation. Thus, further investigations will pay attention to cases with the lowest interval distance with adjacent buildings at 1/4 L.

Regarding void depth, the distributions of differential wind pressure coefficient between S1 and W1 in cases 1-1/4 and 1-3/4 are shown in Fig.24. No particular difference in the differential wind pressure coefficient is found. Thus, void depth D can be inferred as a standard depth in further investigations.

As shown in Fig.25., existence of the void has almost no impact on the differential wind pressure coefficient between S1 and N1. So it can be considered that the void has no negative influence on the differential wind pressure coefficient in the south and north directions.

6. Enhancement of Cross-ventilation Due To The Presence of Voids

In Fig.26., the distribution of differential wind pressure coefficient comparing cases 0, 0-1, 1 and 1-1 is shown. From the figure, in cases 0 and 0-1 without neighboring buildings, the presence of voids considerably increased the differential wind pressure coefficient and resulted in obvious enhancement of cross-ventilation. However, in cases 1 and 1-1, which take into account adjacent buildings, no particular influence on the differential wind pressure was found. In addition, in an attempt to improve cross-ventilation, the extension of void height over the roof by one and two floors height in cases 1-1-1Fa and 1-1-2Fa, as well as the presence of an opening on the 1st floor in cases 1-1-1Fb and 1-1-2Fb were analyzed. The results in the differential wind pressure coefficient between positions S1 and W1 of the mentioned cases, together with ordinary case 1 are shown in Fig.27. As can be seen, by extending the void over the roof, a significant increase in differential wind pressure coefficient was found, which consequently enhanced the cross-ventilation potential. This could be due to the fact that wind velocity generally increases as height level increases, which creates higher negative pressure over the interior side of voids. Despite this, the placement of an opening on the 1st floor greatly reduced the differential wind pressure coefficient. In conclusion, the effects of vertical void extension are confirmed and it is suggested to take this into consideration regarding the enhancement of cross-ventilation. Furthermore, although extension of the void over the roof by two floor heights is considered impractical, extension by one floor height is practically possible.

7. Prediction of Cross-ventilation Flow Rate in the Targeted Buildings

The cross-ventilation flow rate was estimated by using a ventilation network calculation based on the wind pressure coefficients obtained from the
wind tunnel experiment. The enhancement of cross-ventilation due to void configurations was therefore quantitatively evaluated.

7.1 Calculation conditions

The targeted residential unit for calculation is illustrated as the shaded area previously shown in Fig.20. Additionally, flow rate calculation conditions are summarized in Table 3. The main doors were assumed to be constantly closed. As constantly opened doors can be considered unrealistic in terms of practical occupant behavior, a small opening over the partition door was assumed for the calculation. The openings at positions S1 – 2, N1 – 2 and W1 were also assumed. Flow rate coefficient was set at a constant rate of 0.67 regardless of the conditions involved. Reference wind velocity over the top of the building at 19.8m above ground level was referred to the constant value of 1.84 m/s obtained by averaging the values of Guangzhou's standard weather data during the interim periods. In addition, 16-wind directions were involved in the calculations as previously mentioned. With respect to wind pressure coefficients, the values obtained from the measurement illustrated in Table 3, were used as input. Additionally, regarding the ventilation network calculation, only ventilation generated by outdoor wind was involved, while ventilation caused by temperature difference was totally ignored.

Table 3. Conditions for Cross-ventilation Calculation

| Opening Session | Scale of opening (m, m²) | Window type | Flow rate coefficient |
|------------------|--------------------------|-------------|-----------------------|
| S 1              | 0.75 × 2.4 = 1.8         | Sliding Windows | 0.67                 |
| S 2              | 0.75 × 1.0 = 0.75        |              |                      |
| N 1              | 0.5 × 2.4 = 1.2          |              |                      |
| N 2              | 0.75 × 1.0 = 0.75        |              |                      |
| W 1              | 0.5 × 1.0 = 0.5          |              |                      |
| Between units    | 0.3 × 0.9 = 0.27         |              |                      |

7.2 Calculation results

In Fig.28., the distribution of mean air change rate obtained by averaging the results from all 16-wind directions in cases with the distance to adjacent buildings of 1/4 L is illustrated. The air change rate of 12 ach was found in case 1, without voids. In addition, as expected, the maximum air change rate of 21 ach was obtained in case 1-1-2Fa with voids extended over the roof by two floor heights and without openings in the first floor. This is considered to be as much as two times the air change rate obtained in case 1. In addition, in case 1-1-1Fa with voids extending over the roof by one floor height, an air change rate of 16 ach was obtained, which is considered to be 1.3 times that of ordinary case 1.

8. Conclusions

In the present study, an investigation on the utilization of cross-ventilation in Guangzhou and Shenzhen was conducted. The findings are listed as follows:

(1) Based on the results of SET* calculated by using the standard weather of Guangzhou, 1,850 hours per year is considered to be feasible for natural ventilation utilization. Therefore, cross-ventilation can be considered possible as a promising approach in this area.

(2) Regarding the results of the questionnaire survey obtained from subjects in Guangzhou and Shenzhen, a high awareness of natural ventilation was found. Additionally, the lack of ability to apply cross-ventilation on the lower parts of buildings led the authors to further investigate solutions to enhancing cross-ventilation potential.

(3) Wind tunnel experiments were performed on Unit type multiple dwelling houses. The effects due to the distance between adjacent buildings and voids on wind pressure coefficient were found.

(4) Based on the wind pressure coefficients obtained from the wind tunnel experiment, it can be considered that the presence of voids plays an important role in enhancing cross-ventilation flow rate. In addition, by using ventilation network calculation, it is possible to predict the cross-ventilation flow rate.

In summary, it can be concluded that the presence of voids without openings on the first floor of buildings significantly improves the cross-ventilation flow rate by 1.3 – 2 times over cases without voids. As this study is restricted to Unit type multiple dwelling houses, it can be recommended for further study to investigate...
the effect on other types of residence. Furthermore, it is worth mentioning that the modifications concerning various aspects, for instance, staircases, placement of voids in each room, scheduled operation of openings etc., may possibly further improve cross-ventilation due to natural ventilation.

Acknowledgement
This study was supported by the 21st Century COE Program on "Sustainable Urban Regeneration" of the Ministry of Education, Culture, Sports and Technology, Japan.

References
1) Akamine, Y. et al. (2004) A Study on Evaluation of Cross-Ventilation Performance of Openings Part 13: Experimental Study on Openings with Projections. Proceedings of Annual Meeting of The Architectural Institute of Japan. D-2, pp.805-806. (in Japanese)
2) Cai, J. et al. (2001) Measurement of the Components of Reynolds Stress and Comparison of the Wind Pressure Coefficient of High-rise Residential Buildings with or without a Balcony with Wind Tunnel Experiment. Proceedings of Annual Meeting of The Architectural Institute of Japan. D-2, pp.681-682. (in Japanese)
3) Gagge, A.P. et al. (1971) An Effective Temperature Scale Based on A Simple Model of Human Physiological Regulatory Response. ASHRAE Transactions, Vol. 77, pp.247-262.
4) Ishida, Y. et al. (2005) Study on Wind Environment in Urban Block by CFD (Part 2): Wind Velocity in Void Spaces in 3-D Densely Built-up Area. Proceedings of Annual Meeting of The Architectural Institute of Japan. D-2, pp.825-826. (in Japanese)
5) Kato, S. et al. (2005) Study on Wind Environment in Urban Block by CFD (Part 1): Concept of Void Spaces in Built-up Areas and Analysis of Wind Velocity over 2-D Urban Street Block Model. Proceedings of Annual Meeting of The Architectural Institute of Japan. D-2, pp.823-824. (in Japanese)
6) Shiraishi, Y. et al. (2002) ENHANCEMENT EFFECT OF NATURAL CROSS VENTILATION AND REDUCTION EFFECT OF COOLING LOAD FOR POROUS RESIDENTIAL BUILDING: Study on Reduction of Environmental load by Residences in Urban Areas in Hot and Humid Regions. Journal of Architecture, Planning and Environmental Engineering. No. 558, Aug, pp.15-22. (in Japanese)
7) Tu, Y. et al. (2003) A Preliminary Study in the Utility of Cross-Ventilation in Taiwan Part 1: About Cumulative Distribution Frequency of Wind Speed Based on Climatological Datum. Proceedings of Annual Meeting of The Architectural Institute of Japan. D-2, pp.607-608. (in Japanese)
8) Tu, Y. et al. (2004) A Preliminary Study on the Utility of Ventilation in Taiwan Dwellings Part 2: The Study on Behavior of Using Ventilation and Air-conditioner Based on Questionnaire Survey. Proceedings of Annual Meeting of The Architectural Institute of Japan. D-2, pp.603-604. (in Japanese)
9) Tu, Y. et al. (2005) A Preliminary Study on the Utility of Ventilation in Taiwan Dwellings: Part 3 Techniques of Ventilation Improvement in Houses of Congested Urban Area Based on the Wind Tunnel Experiment. Proceedings of Annual Meeting of The Architectural Institute of Japan, D-2, pp.615-616. (in Japanese)
10) Zhang, Q. and Asano, K. (2001) DEVELOPMENT OF THE TYPICAL WEATHER DATA FOR THE MAIN CHINESE CITIES. Journal of Architecture, Planning and Environmental Engineering, No. 543, May, pp.65-69. (in Japanese)
11) Zhang, Q. (2005) DEVELOPMENT OF HOURLY WEATHER DATABASE AND CHARACTERISTICS OF CLIMATIC CHANGE FOR MAIN CHINESE CITIES. Journal of Architecture, Planning and Environmental Engineering, No. 591, May, pp.97-104. (in Japanese)
12) Zheng, Y. et al. (2006) A Preliminary Study on the Utility of Cross-Ventilation in Southeast Asia: Part 1 The Question Survey in Guangzhou and Shenzhen. Proceedings of Annual Meeting of The Architectural Institute of Japan, D-2, pp.595-596. (in Japanese)
13) Zheng, Y. et al. (2007) A Preliminary Study on the Utility of Cross-Ventilation in Southeast Asia: Part 2 Improving Cross-Ventilation with a Void in a TANGEN-type Residential Building. Proceedings of Annual Meeting of The Architectural Institute of Japan, D-2, pp.797-798. (in Japanese)