STUDY ON THE EVALUATION OF CROSS VENTILATION PERFORMANCE OF DETACHED HOUSES

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ABSTRACT

The distribution of indoor airflow velocity by cross ventilation is influenced by the regional climate conditions, and the location as well as the shape of the building. In this study, CVDHI of 25 cases to change the number and position of openings at 842 cities in Japan are calculated for the simple house model. The results indicate that CVDHI increases relatively in every case from the south to the north of Japan. The magnitude of the increases is larger along the coastal areas, and smaller in inland areas. CVDHI increases when an opening is placed on an opposite wall in a straight line, and placed at the corner of the room.

KEYWORDS

Cross Ventilation, Opening Layout, Indoor SET*, Cross Ventilation Degree Hour of Indoor

INTRODUCTION

The distribution of indoor airflow velocity by cross ventilation is influenced by the regional climate condition, as well as the location and shape of the building. One of the effects of cross ventilation is to decrease the sensible temperature level due to increased airflow velocity. Thus, the effectiveness of cross ventilation cannot be evaluated simply by analysis of the air change rate. It is very important to evaluate indoor airflow characteristics precisely in planning the layout of windows, as well as the regional climate of each city. In this study, CVDHI_B, CVDHI_P and CVDHI_T of Cross Ventilation Degree Hour of Indoor values (CVDHI) are proposed. These values are calculated from the Cross Ventilation Degree Hour of Outdoor values (CVDHO)[Refer 1.]. The CVDHI values of 25 cases to change the number and layout of open windows in 842 cities in Japan are calculated for the simple house model.

METHOD OF SIMULATION

Evaluation Index of Indoor Cross Ventilation Performance

Figure 1 shows the factors relating to climate conditions that influence the human body in a room. It is assumed that the human "weather sense" can be evaluated by the thermal comfort index. Table 1 shows the analysis of the condition of CVDHI. The climate data are "Expanded AMeDAS Weather Data

Table1. Analysis of the conditions of CVDHI

Weather Data	Expanded AMeDAS Weather Data in Japan （Wind Velocity, Wind direction, Temperature, Humidity, Radiation every hour）
Indoor Airflow Velocity when SET* calculation	Min 0.3m/s、Max 3.0m/s
Clothing	0.5clo（July ～ September）
	1.0clo（December～February）
	0.75clo（March ～ June、October、November）
Metabolic Rate	1Met
Non-Heating Period	Average Temperature of a day：More than 18℃
Non-Sleeping Time	6:00 ～ 23:00

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in Japan" by AIJ (Architectural Institute of Japan). Figure 2 shows a flowchart analysis of CVDHI. SET* is used as the evaluation index for indoor thermal comfort. The airflow velocity (16 wind directions) that is necessary to calculate SET* is given by isothermal CFD analysis using a standard k-e turbulence model. Room air temperature, room air humidity and wall surface temperature are given by TRNSYS-COMIS. Figure 3 illustrates the concept of CVDHI. CVDHI is the multiplication of the difference between SET* at an airflow velocity of 0.3m/s and SET* at an actual indoor airflow velocity that is lower than 3.0m/s when SET* is beyond 26 degrees centigrade in the non-heating period and the non-sleeping time. The indoor airflow velocity used to calculate SET* ranges from the lowest value of 0.3m/s to a maximum value of 3.0m/s.

CVDHI is defined as follows:

If SET*①≧23℃,
  and SET*①＜26℃
$\mathrm{CVDHI_P}$ = (SET*②－SET*①)×T
If SET*③≧26℃
  $\mathrm{CVDHI_B}$ = (SET*③－SET*②)×T
And, $\mathrm{CVDHI_T} = \mathrm{CVDHI_P} + \mathrm{CVDHI_B}$

Where the following definitions apply :

$\mathrm{CVDHI_P}$: The effect that decreases sensible temperature by the airflow velocity due to cross ventilation.

$\mathrm{CVDHI_B}$: The exhaust heat effect that drains indoor heat to outdoors by cross ventilation in the room affected by sunlight.

SET*①: SET* calculated by the actual airflow velocity of each city and the actual air change rate of each city. [℃]

SET*②: SET* calculated by the minimum airflow velocity (0.3 m/s) and the actual air change rate of each city. [℃]

SET*③: SET* calculated by the minimum airflow velocity (0.3 m/s) and the standard air change rate (0.5 1/h).[℃]

T: Accumulated hours for which SET* is in the optimum temperature range in the non-heating period and the non-sleeping time.[h]

Case of Simulation

Figure 4 shows the perspective, plan and vertical cross section of the analyzed model. Table 2

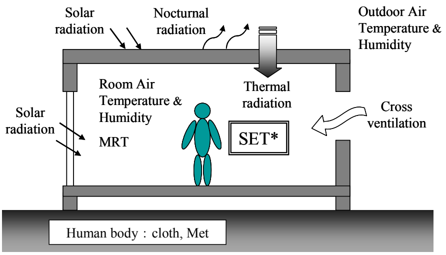


Figure 1. Factors relating to climate conditions that influence the human body in a room

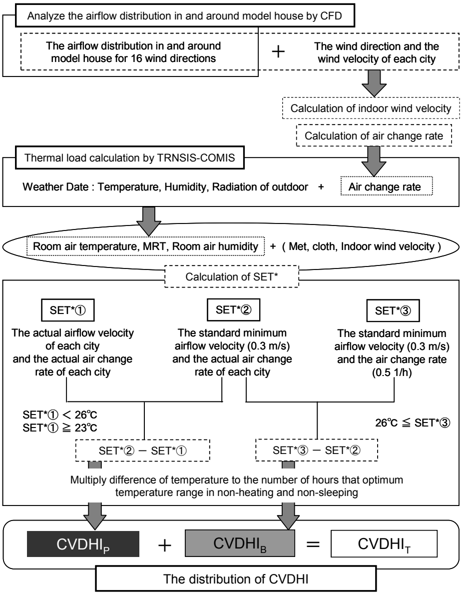


Figure 2. Flowchart analysis of CVDHI

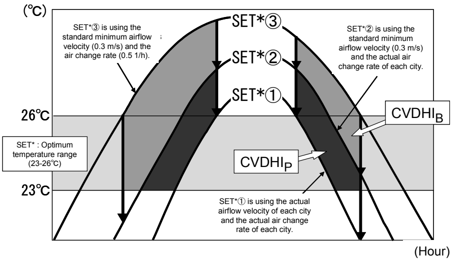
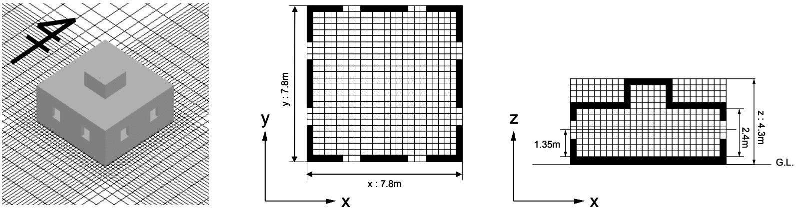


Figure 3. Concept of CVDHI

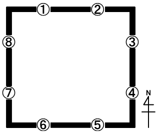
shows the case of the opening layout. The area of the windows is 0.81 ㎡(0.9m×0.9m). 25 cases are analyzed to change the number and layout of the openings. In all cases, window No.⑤ is open. The CVDHI values of 842 cities in Japan are calculated for the simple house model.



(1) Perspective (2) Plan (3) Vertical cross section

Figure 4. Perspective, plan and vertical cross section of the analyzed model

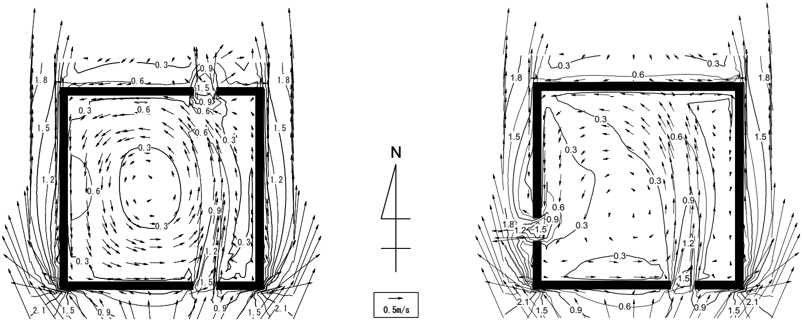
Table 2. Case of the opening layout

<table>
<tr><td rowspan="9"> </td><td colspan="9">One Window Area is 0.81㎡(0.9m×0.9m). In all cases, Window No.⑤ is opening</td></tr>
<tr><td rowspan="8">25 cases to change number and position of open windows</td><td rowspan="2">Two openings</td><td>case1</td><td>case2</td><td>case3</td><td>case4</td><td>case5</td><td rowspan="2" colspan="2"></td></tr>
<tr><td>②</td><td>①</td><td>⑦</td><td>⑧</td><td>④</td></tr>
<tr><td rowspan="2">Three opening</td><td>case6</td><td>case7</td><td>case8</td><td>case9</td><td>case10</td><td>case11</td><td>case12</td></tr>
<tr><td>①, ②</td><td>②, ⑦</td><td>②, ④</td><td>①, ⑦</td><td>①, ⑧</td><td>⑦, ⑧</td><td>③, ④</td></tr>
<tr><td rowspan="4">Four opening</td><td>case13</td><td>case14</td><td>case15</td><td>case16</td><td>case17</td><td>case18</td><td>case19</td></tr>
<tr><td>①, ②, ⑦</td><td>①, ②, ⑧</td><td>①, ②, ③</td><td>①, ⑦, ⑧</td><td>①, ③, ⑧</td><td>④, ⑦, ⑧</td><td>①, ②, ⑥</td></tr>
<tr><td>case20</td><td>case21</td><td>case22</td><td>case23</td><td>case24</td><td>case25</td><td rowspan="2"></td></tr>
<tr><td>⑥, ⑦, ⑧</td><td>②, ⑦, ⑧</td><td>②, ④, ⑦</td><td>②, ③, ④</td><td>①, ③, ⑦</td><td>①, ④, ⑧</td></tr>
</table>

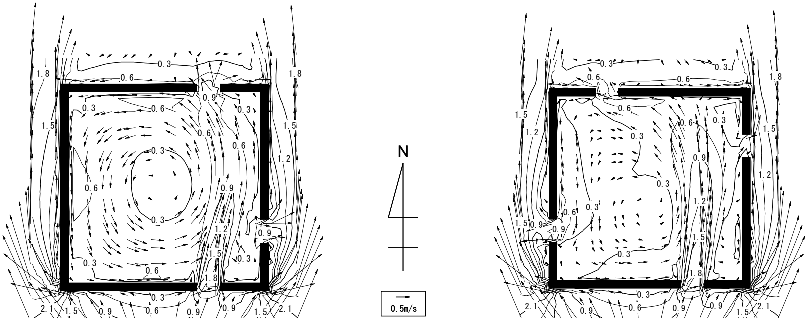
RESULTS OF SIMULATION AND DISCUSSION

CFD Simulation

Figure 5 shows the distribution of airflow velocity when the wind direction is S (case 1, 3, 8 and 24). In the case of two openings, in case1, a straight airflow passage is formed from the windward opening to the leeward opening, inducing the circulation of airflow in the whole room, and airflow velocity in the whole room is fast. In case 3, the airflow is spread through the room from a windward opening, and there is no airflow passage through two openings; thus, there is no circulating airflow, and room airflow velocity becomes slower than case 1. In case 8, in which one opening is added compared to case 1, circulating airflow is induced and airflow velocity is fast in the whole room, in the same way as in case 1. Airflow velocity of the windward side is faster, and that of the leeward side is slower. Airflow velocity of the leeward opening becomes slow; there is one windward opening and two leeward openings so that the airflow is divided into two directions. In case 24, in which has four openings, the airflow velocity of windward side is faster, and the leeward side is slower, the same as in case 8. Comparing case 1 (two openings) with case 24 (four openings), case 1 has a larger area in which the airflow velocity is faster than case 24. When the airflow passage from the windward opening to the leeward opening is formed, like in case 1 and case 8, the airflow velocity becomes fast in the whole room, because circulating flow is induced. Even when the numbers of openings are few, it is possible to make indoor airflow velocity faster than in cases with a large number of openings. Therefore, it is important to consider the outdoor wind direction and wind velocity, and to plan a suitable layout of open windows for each city.



(1) case 1 (2) case 3



(3) case 8 (4) case 24

Figure 5. The distribution of in and around airflow velocity (wind direction S, height about a floor 1.35m)

Horizontal average (height from a floor 1.35m) of CVDHI values（CVDHI$_P$、CVDHI$_B$、CVDHI$_T$）

Figure 6 shows horizontal average value of CVDHI in Tokyo and Niigata. The ratio of average CVDHI$_P$ and CVDHI$_B$ is about 1: 20 in all cases in both Tokyo and Niigata. Niigata have higher average CVDHI$_T$ than Tokyo. In the case of two openings, the average CVDHI$_T$ of case 1 is the largest value of 5,061℃h in Tokyo, and case 2 is the largest value, amounting to 5,629℃h, in Niigata. In the case of three openings, the average CVDHI$_T$ of case 8 is the largest value of 5,740℃h in Tokyo and case 10 is 6,233℃h in Niigata. In the case of four openings, the average CVDHI$_T$ of case 22 is the largest value of 6,093℃h in Tokyo and case 22 is 6,501℃h in Niigata. CVDHI$_T$ is less than 5,000℃h in Tokyo and Niigata for cases 3,4,5 and 11.

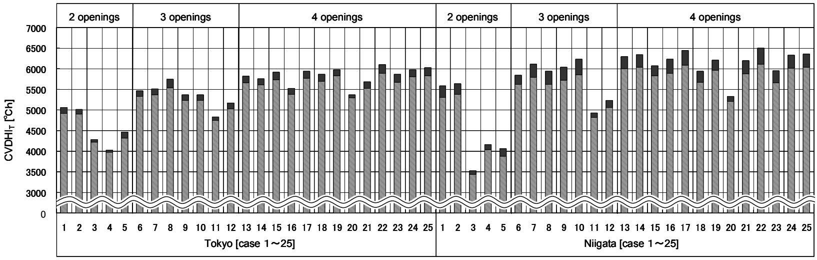
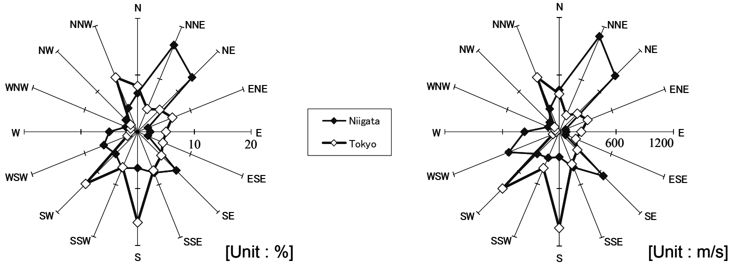


Figure 6. Horizontal average value of CVDHI in Tokyo and Niigata

Horizontal Distribution of CVDHI$_T$

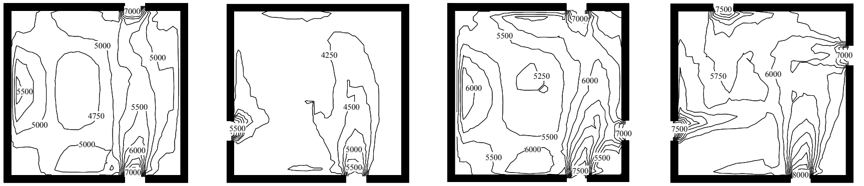
Figure 7 shows the wind rose and the accumulation wind velocity rose according to the wind direction in the non-heating period and the non-sleeping time in Tokyo and Niigata. In Tokyo, the ratio of the wind directions S, SW and NNW is high, and the wind velocity of these wind directions is fast. In Niigata, the ratio of the NNE, NE, SE～SSW is high and the wind velocity of these wind directions is fast. In particular, the wind velocity of the NNE, SE is fast in Niigata.



(1) Wind rose (2) Accumulation wind velocity rose

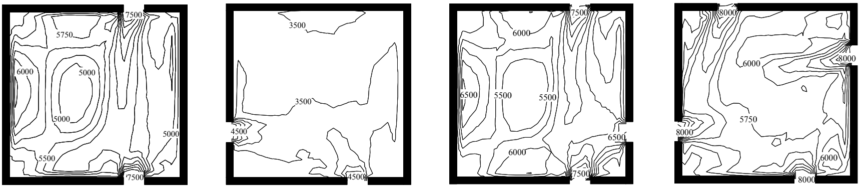
Figure 7. Wind rose and accumulation wind velocity rose according to the wind direction in the non-heating period and the non-sleeping time in Tokyo and Niigata

Figure 8 shows the horizontal distribution of CVDHI$_T$ in Tokyo and Niigata (case 1, 3, 8 and 24). In the case of two openings, the values of CVDHI$_T$ around the openings are about 7,000℃h in case 1 and about 5,000℃h in case 3. In both cities, the CVDHI$_T$ values of case 3 are large around the openings, but the values of CVDHI$_T$ not around the opening are less than 4,000℃h in Niigata. Otherwise, all areas of the room in case 1 have large CVDHI$_T$ values, because airflow induces a circulating flow in the whole room. The average CVDHI$_T$ is 5,061℃h in Tokyo and 5,581℃h in Niigata in case 1, and 4,280℃h in Tokyo and 3,524℃h in Niigata in case 3. In the case of three openings, the average CVDHI$_T$ is 5,274℃h in Tokyo and 5,934℃h in Niigata for case 8 and these values are larger than for case 1. In the



Case 1 Ave. 5,061℃h Case 3 Ave. 4,280℃h Case 8 Ave. 5,274℃h Case 24 Ave. 5,978℃h

(1) Tokyo



Case 1 Ave. 5,581℃h Case 3 Ave. 3,524℃h Case 8 Ave. 5,934℃h Case 24 Ave. 6,324℃h

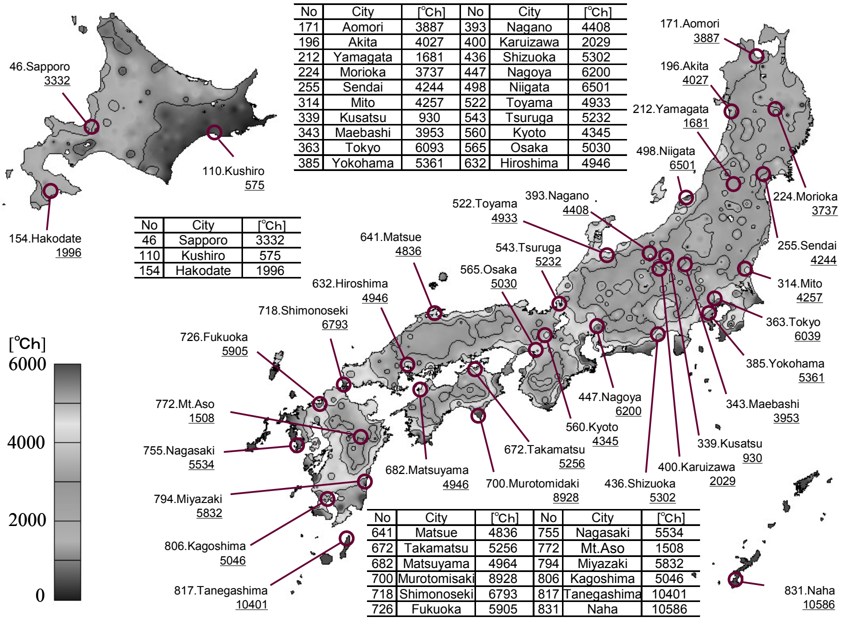
(2) Niigata

Figure 8. The horizontal distribution of CVDHI$_T$ in Tokyo and Niigata (Height from a floor :1.35m)

case of four openings, the average CVDHI$_T$ is 5,978℃h in Tokyo and 6,324℃h in Niigata in case 24, and this is nearly equal for case 8 with three openings. Case 8 and 24 has a wide area where values of CVDHI$_T$ are large in the room. But compared with case 10 and case 20 (Figure 6), the average CVDHI$_T$ is not always larger when the number of openings is increased. When the cross ventilation of a building is planned, it is important to consider the opening layout of the building and the regional climate conditions, such as the wind direction of each city. This is more important than increasing the number of the openings which does not always lead to effective cross ventilation. If the number of openings is very restricted, it can be possible to obtain effective cross ventilation by establishing an opening at the most suitable and appropriate position.

Horizontal Average CVDHI$_T$ in 842 Cities in Japan

Figure 9 shows the horizontal average CVDHI$_T$ Map in Japan for case 22. Average CVDHI$_T$ relatively increases in every case from the south to the north of Japan, and is larger along the coast compared to inland areas. Average CVDHI$_T$ is small in cities where the height above sea level is high, because the average temperature is low in the summer so that the non-heating period is short. Kusatsu and Karuizawa (famous summer resorts) have short non-heating periods, and the average CVDHI$_T$ is smaller than Maebashi and Nagano in the same prefecture. Average CVDHI$_T$ is 930℃h in Kusatsu and 2,029℃h in Karuizawa. Average levels of CVDHI$_T$ are relatively small on the mountains. Average CVDHI$_T$ is 1,508℃h in Mt. Aso in the Kyushu region. Along the sea coast, average CVDHI$_T$ is larger on the Pacific side than the Japan Sea side. For the Southward Plains of the Kanto region along the seashore, the value of average CVDHI$_T$ becomes about 4,000℃h. Average CVDHI$_T$ values in the island part are large, because the non-heating period is long, and cross ventilation effects can last for a long time. Average CVDHI$_T$ values are 10,401℃h in Tanegashima and 10,586℃h in Naha.



No	City	[℃h]	No	City	[℃h]
171	Aomori	3887	393	Nagano	4408
196	Akita	4027	400	Karuizawa	2029
212	Yamagata	1681	436	Shizuoka	5302
224	Morioka	3737	447	Nagoya	6200
255	Sendai	4244	498	Niigata	6501
314	Mito	4257	522	Toyama	4933
339	Kusatsu	930	543	Tsuruga	5232
343	Maebashi	3953	560	Kyoto	4345
363	Tokyo	6093	565	Osaka	5030
385	Yokohama	5361	632	Hiroshima	4946

No	City	[℃h]
46	Sapporo	3332
110	Kushiro	575
154	Hakodate	1996

No	City	[℃h]	No	City	[℃h]
641	Matsue	4836	755	Nagasaki	5534
672	Takamatsu	5256	772	Mt.Aso	1508
682	Matsuyama	4964	794	Miyazaki	5832
700	Murotomisaki	8928	806	Kagoshima	5046
718	Shimonoseki	6793	817	Tanegashima	10401
726	Fukuoka	5905	831	Naha	10586

Figure 9. Horizontal average CVDHI$_T$ Map in Japan for case 22

The Best of Case

Figure 10 shows the number of cities with the largest average $CVDHI_T$ values in each case, according to the number of openings. For two openings, case 1 and case 2 had a lot of cities where average $CVDHI_T$ values were largest; for three openings, case 8 and case 10 had a lot of cities; in four openings, case 22 had a lot of cities. Both case 8 and case 22 are similar to case 1. In these cases, the opening is placed in a straight line in the room, and an opening is placed on the next wall. Average $CVDHI_T$ values increase when an opening is placed on the opposite wall in a straight line, and also when placed in the corner of the room.

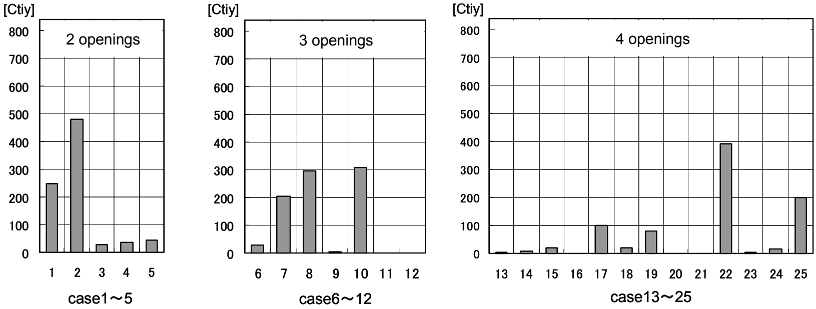


Figure 10. Number of cities with the largest average $CVDHI_T$ values in each case, according to the number of openings

CONCLUSION

In this paper, the CVDHI values of 25 cases to change number and position of the openings in 842 cities in Japan are calculated for the simple house model, and cross ventilation performance are analyzed quantitatively.

1. In case 1 and case 8, airflow velocity is fast in the whole room, because a straight airflow passage is formed from the windward opening to leeward opening, inducing circulating airflow in the whole room.
2. The ratio of average $CVDHI_P$ and $CVDHI_B$ values is about 1: 20 in all cases in Tokyo and Niigata.
3. The average $CVDHI_T$ of case 22 is the largest value of 6,093℃h in Tokyo; case 22 is 6,501℃h in Niigata. $CVDHI_T$ is less than 5,000℃h in Tokyo and Niigata for cases 3,4,5 and 11.
4. When the cross ventilation of a building is planned, it is important to consider the opening layout of a building and the regional climate conditions, such as the prevailing wind directions for each city. And, it should be noted that increasing the number of the openings does not always lead to effective cross ventilation. If the number of openings is very restricted, it is possible to obtain effective cross ventilation by establishing an opening at the most suitable position.
5. Average $CVDHI_T$ values relatively increase in every case from the south to the north of Japan, and values are larger along the coast, and become smaller in inland areas.
6. For two openings, case 1 and case 2 have a lot of cities where average $CVDHI_T$ values are largest. For four openings, case 22 has a lot of cities where average $CVDHI_T$ values are largest. Average $CVDHI_T$ increases when an opening is placed on the opposite wall in a straight line, or placed in the corner of the room.

ACKNOWLEDGEMENTS

This document is a summary of various documents from past domestic and international conferences.

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