# Equalization of wind pressure on the inner wall of double-skin of tall buildings for the natural ventilation

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ABSTRACT

This research concerns natural ventilation of the building with double-skin. It aims to get high performance cross ventilation by the control of opening and closing windows on outside exterior wall and to make the wind pressures on the inner wall to be equal, small, positive value. That is called pressure equalization.

As the result, the building can easily intake outdoor air from windows of every walls and exhaust used air through the chimney or air void located at the interior part of the building.

From such a viewpoint, the author made the wind tunnel tests to decrease and equalize inner wall wind pressure using a simple building model, and could attain the purpose under some conditions

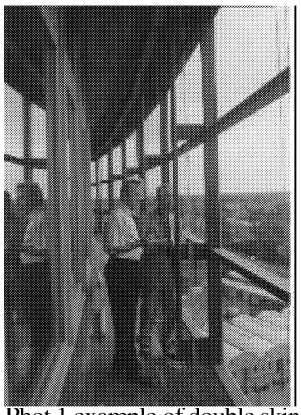
## 1. INTRODUCTION

Natural ventilation is being introduced for the purpose of improving energy conservation and the thermal and air environment quality of high rise buildings. The more serious problem that arises when doing so, however, is the existence of excessive positive and negative wind pressure that is generated in the strong wind, making it difficult to obtain stable ventilation.

As one of the solution, the double-skin buildings have appeared in recent years. Double-skin consists of double glass walls, and the 0.3-1.0m wide space between them works not only as the thermal buffering zone, but also as ventilation space.

Many of this kind of buildings have atrium or void having openings for vent, in order to exhaust used air, which is taken from double-skin.

The purpose of this research is to equalize the pressure of the inner double-skin walls as much as possible and obtain a small positive value by controlling the area of the ventilation ports on the exterior wall to make it possible to obtain relatively moderate cross ventilation. Of course, this means to clarify conditions of the double skin to enable it to function as a pressure chamber



Phot.1 example of double skin by prof. J. Stoll

## 2. WIND TUNNEL TEST METHOD

### *2.1 Wind tunnel*

As the wind tunnel, we used the horizontal closed circuit wind tunnel (Gottingen type) of the Wind Tunnel Laboratory, Science and Technology Laboratory, College of Science and Technology, Nihon University. The size of the cross-section of the measurement site is 2m (horizontal) x 2m (vertical) with a length of 5.3m. The wind speed can be set within a range of 2.5m/s – 50m/s (maximum) and the strength of disturbance is less than 0.1% at a wind speed of 40m/s with a uniform flow.

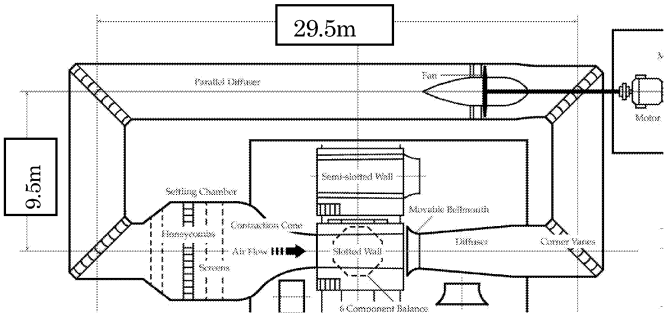



Fig.1 wind tunnel of Nihon-University

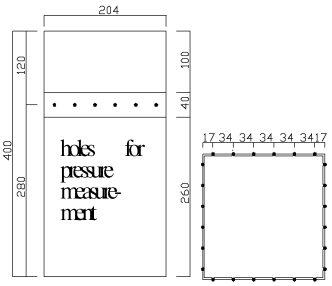



Figure 2: Model- 1 popular bldg.

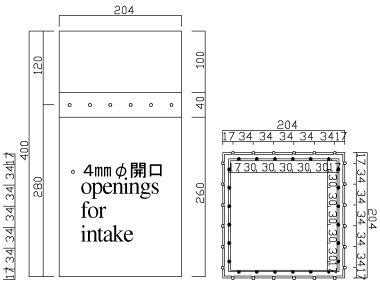
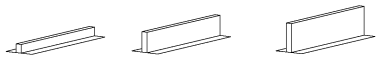



Figure .3 :Model- 2 bldg. with full double skin wall, Model- 3 bldg. with double-skin with partition plates in it



A(l=d/3) B(l=2d/3) C(l=6 d /7)

d ; width of double skin (=7mm)

Figure 4 ; Partition plates; flow resistance

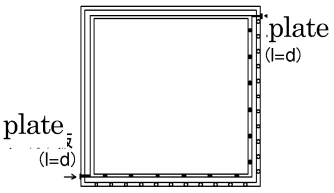



Fig 5 Model-3&4 1 or 2 side double skin wall

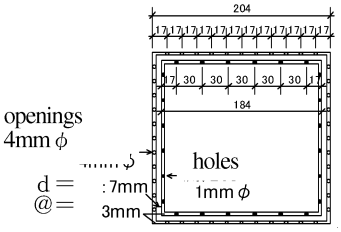



Fig 6 Model-5 twice Numbers of openings

## 2.2 *Building model*

As the model, a square column with a square cross-section with a height of 400mm and width of 204mm with a scale of 1/100 is assumed.

Ventilation ports (4mm dia.) were opened in the exterior wall equally at 6 or 11 locations on each surface at a height of 280mm.

In addition, the double skin was installed at a height of 260-300mm, considered to be most susceptible to the effects of wind pressure. The inner wall was a square column with a height of 400mm and width of 184mm with 6 wind pressure measurement holes (1mm dia.) opened in each surface at the same height as the ventilation ports.

It was furthermore possible to provide the model with 4 different types of double skin, namely, full circumference open type, resistance plate insertion type, 1-surface type and 2-surface type, using partition panels. The model is shown in detail in Table 1 and Fig.2-Fig. 6.

Table 1: Kinds of Building Model and their features

| | |
|---|---|
| Model 1<br>Popular bldg. | Fig.2 Popular building without double-skin, a square colum with a height of 400mm and width of 204mm. 6 pressure measuring holes (1mm dia. ) are on each surface at a height of 280mm. |
| Model 2<br>Full circumference double-skin type | Fig.3 Basic double skin building model with same size as Model 1. Double skin is installed at a height of 260-300mm. Ventilation ports( 4mm dia. )were opened in the exterior wall equally at 6 locations. The inner wall is also a square column with width of 184mm with 6 pressure measurement holes. |
| Model 3<br>Resistance plate insertion type | Fig.3 Its as same as Model 2. But this has flow resistant plate in the space of double skin, which are shown in Fig.4 and fully separated to two zones. To examine how the flow resistance has the influence on pressure distribution in the spce of double skin. Flow resistant plates were inserted at both center of East & West side walls. |
| Model 4<br>1-surface double-skin type | Fig.5 Most popular double-skin type building. This model is easily made from Model 5 by inserting the partition plate. To examine even if the building has double skin only in one side, is the pressure equalization possible? |
| Model 5<br>2-surfaces double-skin type | Fig 5 Two sides of wall have the double skin. Its popular buldg. next to Model 4. To examine even if the building has double skin only in two side, is the pressure equalization possible? |
| Model 6<br>Full circumference double-skin type | Fig 6 Ventilation ports are opened in the exterior wall eqully at 11 locations. To examin the function of pressure chamber of doubleskin by comparing with Model 2 |

## 2.3 *Data processing*

Measurements of the wind pressure on the inner wall of the double skin were conducted at 100Hz for 10 sec. The wind speed of uniform flow in every test was set at 10m/s on the upward flow side, which was the least susceptible to the effects of the model in all cases.

Since wind pressure Pw and wind pressure coefficient C have a proportional relationship, the wind pressure coefficient C is used in the discussion of the tests.

## 2.4 *Cases examined*

The test cases are shown in Table 2.

At case 1, validity of the wind tunnel experiment was confirmed by comparing the result about

popular building which is a traditional square shape column.

There is actually resistance to the air flow within the double skin with full circumference type double skin. Thus, case 6-13 were conducted by insertion of a resistance plate of I = d/3, 2d/3, 6d/7 and fully closed type,

Table 2All cases of wind tunnel experiment

| Type of D.Skin | Case | Model | Resistance plate | Wind direction | Conditions of openings*1 |
|---|---|---|---|---|---|
| Popular bldg. | 1 | 1 | — | 0° | Reference model |
| Full circumference double skin type | 2 | 2 | — | 0° | Full open |
| | 3 | 2 | — | 45° | Full open |
| | 4 | 2 | — | 0° | W④～E④closed |
| | 5 | 2 | — | 45° | S③、W③～N④closed |
| | 6 | 2 | B | 0° | Full open |
| | 7 | 2 | B | 45° | Full open |
| | 8 | 2 | B | 0° | W③～E③closed |
| | 9 | 2 | B | 45° | W④～N④、E③、S③closed |
| Resistance plate insertion type | 10 | 3 | C | 0° | Full open |
| | 11 | 3 | C | 45° | Full open |
| | 12 | 3 | Closed | 0° | W,E sides closed |
| | 13 | 3 | Closed | 0° | W sides,N③～S④closed |
| 1-surface double skin type | 14 | 4 | — | 30° | Full open |
| | 15 | 4 | — | 30° | S-11open |
| | 16 | 4 | — | 45° | Full open |
| | 17 | 4 | — | 45° | S-7,11open |
| | 18 | 4 | — | 60° | Full open |
| | 19 | 4 | — | 60° | S-5 open |
| 2-surfaces double skin type | 20 | 4 | — | 30° | Full open |
| | 21 | 4 | — | 30° | S-11 E-1open |
| | 22 | 4 | — | 45° | Full open |
| | 23 | 4 | — | 45° | S-11 E-1open |
| | 24 | 4 | — | 120° | Full open |
| | 25 | 4 | — | 120° | S-5 E-7,9 open |
| | 26 | 4 | — | 135° | Full open |
| | 27 | 4 | — | 135° | S-5 E-4,7 open |
| | 28 | 4 | — | 150° | Full open |
| | 29 | 4 | — | 150° | E-7,9 open |
| Full circumference double skin | 30 | 5 | — | 0° | Full open (44 openings) |
| | 31 | 5 | — | 30° | Full open (44 openings) |
| | 32 | 5 | — | 45° | Full open (44 openings) |
| | 33 | 5 | — | 60° | Full open (44 openings) |

*1 examp E-7 means No.7 opening in the East side wall

## 3. Test results

### *3.1 Validity of wind tunnel test*

Test result in case of 0 degree is shown at Fig.7and it is very similar to the old references[1)]
It shows the validity of this wind tunnel experiment.

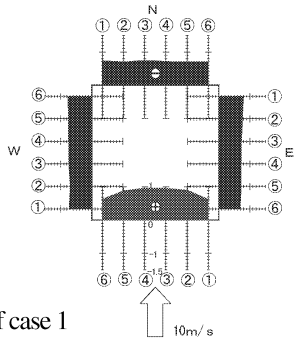



Figure .7; the result of case 1

### *3.2 Results of case 2 – 5*

Next, the wind pressure on the inner wall side of double-skin was measured with Model 2.
The state of case2 (Fig 8-1) and 3 (Fig.9-1) were obtained while openings opened completely.

Afterwards, case4 (Fig.8-2) and 5 (Fig.9-2) were able to be obtained by substituting the pattern that closed the opening with the trial and error to obtain the value that the wind pressure on the inner wall side was even, positive, and small.

The figure under the left in the wind pressure distribution chart shows the state of openings of the outside wall in 24 places, ○ means opening, and ●means the close.

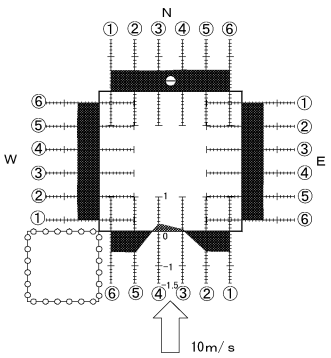



Figure 8-1; case 2

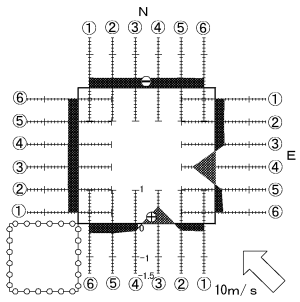



Figure 9-1; case 3

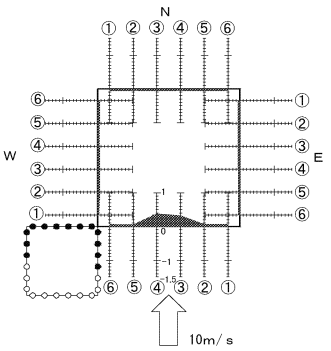



Figure 8-2 ; case 4

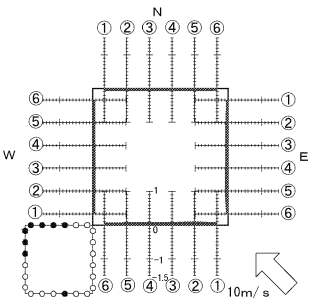



Fig 9-2 ; case 5

By the experiment result of case2 and 3 both in Figure 8-1, 9-1 in 0 and 45 degrees of the wind direction, the wind pressure coefficient of all surroundings are equal and uniform

The pressure measurement hole S3 and S4 in Fig.8-1 and E4 in Fig 9-1 show differential positive pressure, because the wind flow through near openings attached directly on them.

So as not to hit the measurement hole directly, S3 and the leeward side openings were closed

In case5, a uniform, small, positive pressure was able to be obtained.

Pressures equalization was achieved in both cases, and it is thought that the selection of the area of

opening was appropriate for the purpose to form the air chamber.

*3.3 Resistance plate insertion type double-skin*

The partition plates (Fig.4) were set in the middle of E and W wall of Model2 and Model 3 in the case6-13. The wind pressure distribution in both wind direction 0 and 45 degree are indicated inFig.10 -Fig. 15.

Since Model 2 with both partition A and partition B are not different from those without partitions, only results about partition B are shown in Fig 10-Fig 11.

Even partitions B are installed, pressure equalization is achieved as like as shown in Fig.10-2 and 11-2.

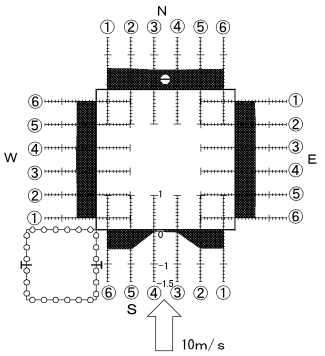



Figure 10-1; case 6

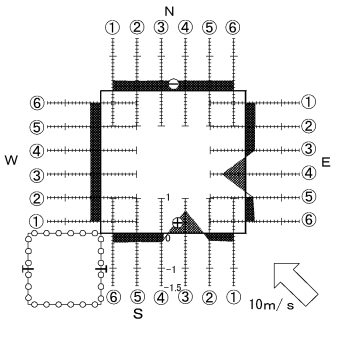



Figure 11-1; case 7

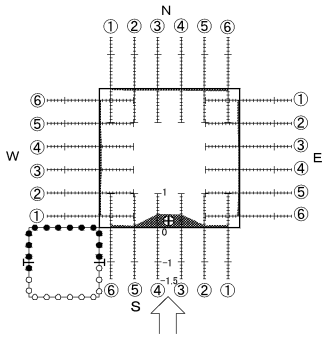



Figure 10-2; case 8

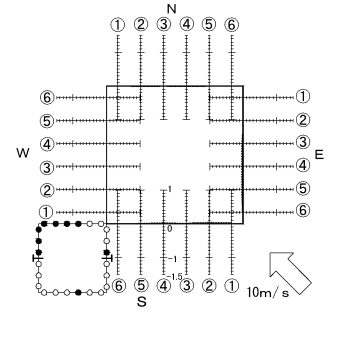



Figure 11-2; case 9

In case of l=6d/7, there are big pressure difference between zones separated by partitions (Fig.12, Fig13),
and moreover, in case of perfectly separated like Fig.14-15, pressure distributions are completely different.
In those 4 cases (12-15), pressure equalization can not be achieved despite many trials.

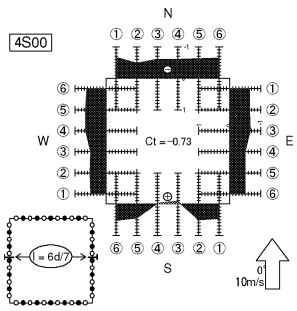



Figure 12; case10

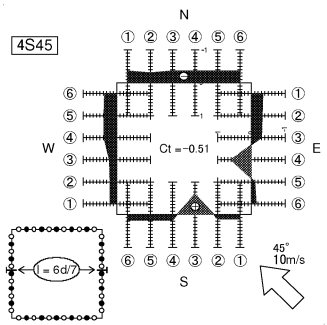



Figure 13; case11

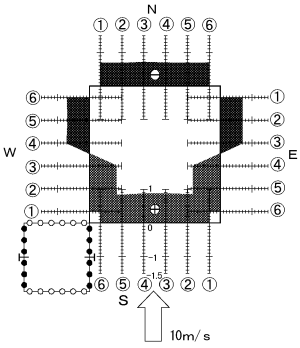



Figure 14; case 12

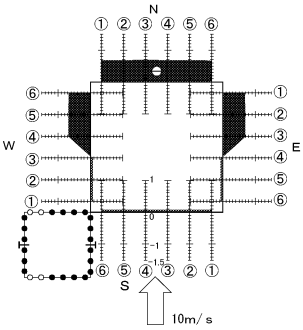
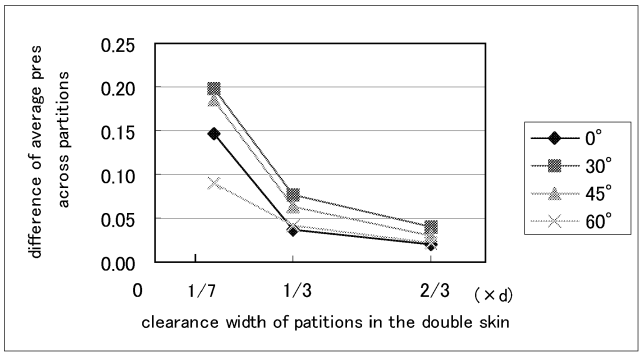



Figure 15; case 13

Based on Fig. 16, which shows the differences of average pressure between windward and leeward at each resistance plate by wind direction, it can be seen that pressure differentials are comparatively large at all angles when the clearance is d/7 and that it has no function as a pressure chamber. Therefore, in order to realize the function of pressure chamber, it is probably necessary for the clearance to be d/3 or more.




Figure; 16 Relation between area of clearance in double skin and the difference of average pressure across partition

*3.4 1-surface double skin*

The wind pressure distributions without any arrangement in each wind direction are indicated in Fig.17.1-Fig.20.1. Those of Fig.17.2 - Fig.20.2

show results of pressure equalization.
They mean if a slight positive pressure is added on even one part of inner wall, it was possible to secure a slight and uniformly positive pressure in the double-skin by closing the ports that had strong negative wind pressures.

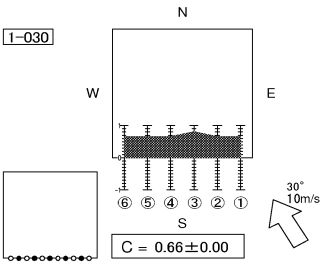


Figure17-1; case14

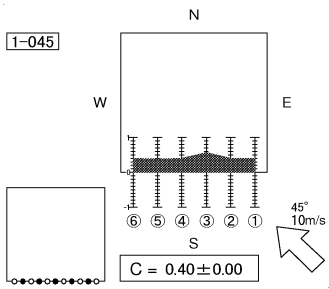


Figure18-1; case16

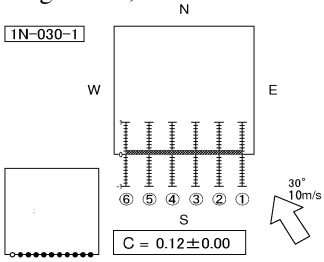


Figure17-2; case10

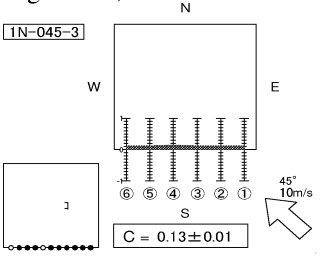


Figure18-2; case12

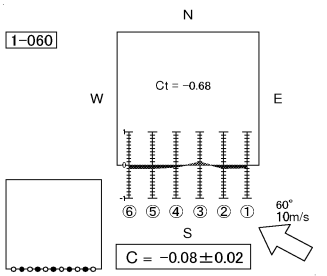


Fig.19-1 case18

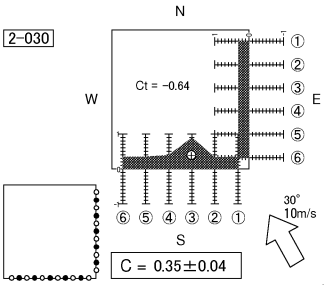


Fig.20-1 case20

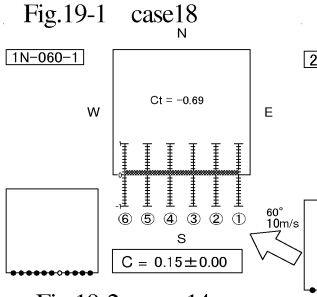


Fig.19-2 case14

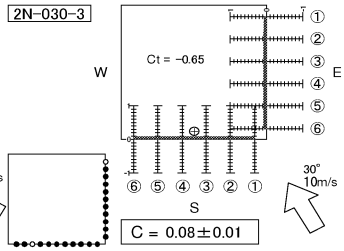


Fig20-2 case16

### *3.5 2-surface double skin*

The wind pressure distributions without any arrangement in each wind direction are indicated in Fig.21.1-Fig.24.1. Those of Fig.21.2 - Fig.24.2 show results of pressure equalization.
Favorable results were obtained when the ventilation ports were open primarily on the S and

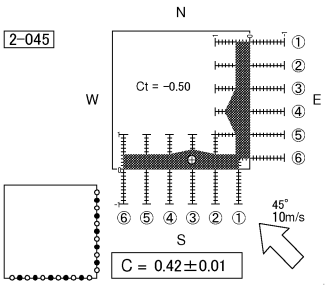


Fig.21-1 case22

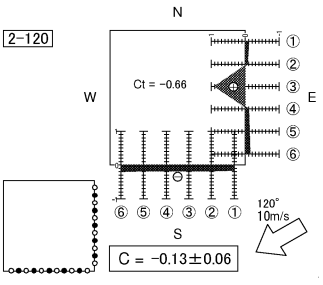


Fig.22-1 case24

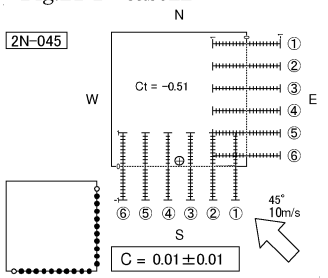


Fig21-2 case23

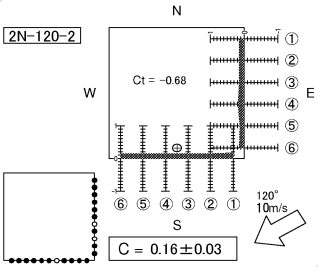


Fig.22-2 case25

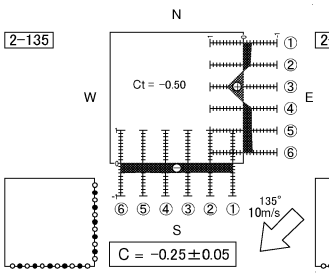


Fig.23-1 case26

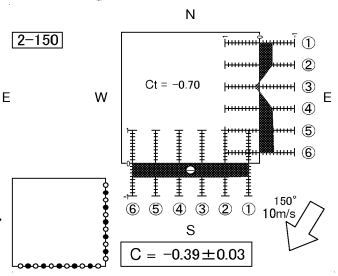


Fig24-1 case28

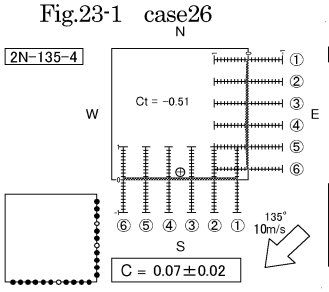


Fig23-2 case27

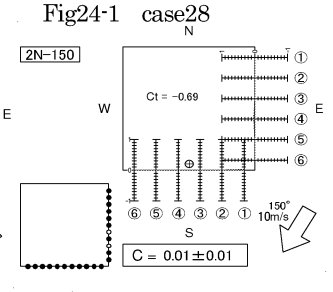


Fig24-2 case29

E surfaces. Compared to the 1-surface type double skin, we succeeded in controlling wind pressure within a further +90° range of wind directions. As a result, it can be said that it is possible to readily control wind pressure as long as there are clearly-defined windward and leeward sides.

This means even if 1-surface type double skin has openings at the corner side of the end, pressure equalization will be easily achieved.

### *3.6 Function as a pressure chamber*

Wind pressure distribution was caused in Model 6, in the case 25-28 (Figure 30-33) where the area of openings increased by about twice of Model 2.

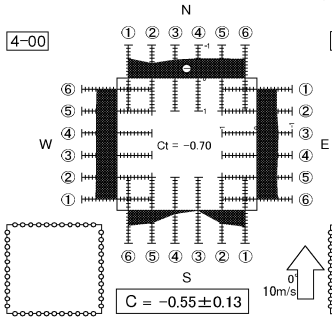



Fig.25 case30

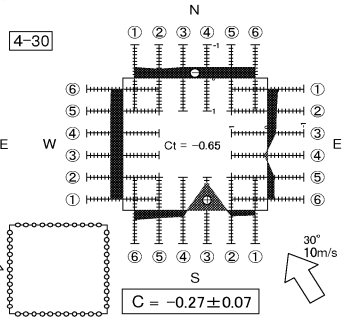



Fig.26 case31

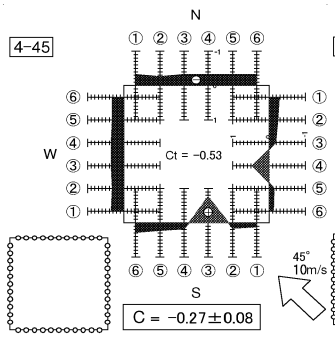



Fig.27 case32

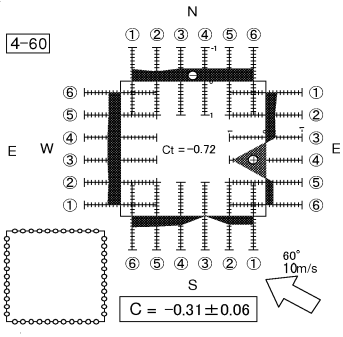



Fig.28 case33

Wind pressure distribution for case of model 2(number of openings; 24) and model 6(number of openings; 44) is compared and the results are shown in Table 3. If about 5 % or less in uniformity of pressure (turbulent intensity) is judged to be excellent, It can be said that the function as the pressure chamber is roughly satisfied up to the 24 openings.

Table 3 Average of C and their Turbulent Intensity

| wind direction | 0° | | 30° | | 45° | | 60° | |
|---|---|---|---|---|---|---|---|---|
| number of openings for ventilation | 24 *1 | 44 *2 | 24 | 44 | 24 | 44 | 24 | 44 |
| average of C | −0.61 | −0.55 | −0.29 | −0.27 | −0.27 | −0.27 | −0.33 | −0.31 |
| standard deviation σ | 0.02 | 0.13 | 0.04 | 0.07 | 0.04 | 0.08 | 0.03 | 0.06 |
| turbulent intensity σ/\|C\| | 2.5% | 23.3% | 13.8% | 24.8% | 13.1% | 28.8% | 8.7% | 18.0% |

*1 model 2 ; 6 openings/1 side
*2 model 5 ; 11 openings/1 side
total area of openings model 2 = 3.01cm$^2$ , model 5 = 5.53cm$^2$
volume of double skin V = 217.28cm$^3$

## 4. CONCLUSION

1) The inside of full circumference double-skin tends to become negative pressure,
even if the resistance to flow exists in it.
2) Consequently, It succeeded in making the wind pressure on the entire inner wall
uniform and small positive value by principally closing openings on the leeward side.
3) If the opening and shutting of openings is controlled while detecting the wall
wind pressure and the wind direction, calm ventilation can be obtained.
4) When double-skin (width d) is divided in the windward and leeward, the inner wall pressure on the leeward side can be controlled to be positive, If clearance of d/3 or more is secured.
5) As long as there is a point that indicates positive pressure for 1 or 2 side double-skin,
uniform and small positive pressure can be obtained by getting the area balance of windward and leeward openings.
6) It is not possible to control wind pressure by opening and closing ventilation ports in a state in which the wind pressure on double skin surfaces is totally negative.
7) Condition of double skin consisting as pressure chamber and possible cases of pressure equalization in partial double-skin are examined.

## ACKNOWLEGEMENT

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## REFERENCE

-- Martin J, Franck N, Model-Scale Tests in Turbulent Wind Part Ⅱ Phenomena Dependent on the Velocity Pressure Wind Loads on Buildings, The Danish Technical Press, 1965

-- Togari S, Hayakawa S, Experimental Study on supply air distribution through plenum air chamber, Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan, 1977 p.245, in Japanese