A Design Criteria of Ventilation Holes to Reduce a Vapor Condensation on the Balcony Walls in Apartment Housings

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ABSTRACT

LH has installed sashes to the balcony to save energy and increase residential space. Then, it is very difficult to protect a condensation of vapor on the walls in the winter time, because the space is closed and the wall surface temperature becomes very low in a balcony. We have tried to get the optimal thermal design methods to reduce the condensation on the walls. The one of the chosen method is to make holes on the walls, and then the condensation shall be reduce because the dew point temperature will be lower due to the effect of dehumidify. In this case, it is just necessary to find as like that how many holes should be perforated through the wall, what's their size, and where is their positions. In this study, a computational fluid dynamics was applied to analyze the temperature, the pressure and the velocity distribution for an incompressible flow in the balcony spaces. And field tests were also carried out to get the data to compare to the simulation results. Finally the design criteria of the ventilation holes in the balconies was suggested by analysis of the computer simulation models.

Keywords: Apartment housings, Balcony, Ventilation hole, Vapor condensation, CFD

1. Introduction

The Rental Housing Act was amended to be able to install a sash to apartment balconies. Since the Act has took effect on, LH has installed sashes to the balcony to save energy and increase residential space. Then, it is very difficult to protect the condensation of vapors on the walls in there because the space is closed and the wall surface temperature becomes very low. If the condensation occurs on the wall, it is clear that residents are displeased with the situation.

So, we have tried to get the optimal design criteria to reduce the condensation on the wall, and the chosen method is to make holes on it. In this case, it is natural that the condensation shall be reduce because the dew point temperature is lower than the space without holes. In this case, it is just necessary to find as like that how many holes should be perforated into the wall, what is their size, and where is their positions.

In this study, a computer simulation for three dimensional incompressible flows shall be considered to analyze temperature, pressure and velocity distribution in balconies. Also the field tests

shall be carried out to get the date comparing to the simulation results. Finally, the design criteria for the holes shall be suggested by a computer simulation after demonstration of the simulation modeling.

2. Field test

2.1 Purpose

The interested houses for a field test are two houses which have same area of 46m². One is located in Chun-cheon and the other is in Dong-hae. Figure 1 shows their planes. The measuring values are temperature of air and wall surface, fluid velocity in the balconies, wind velocity, and humidity in the balconies, rooms, outdoor air. The purposes of a field test are to get the boundary condition data to be applied a CFD simulation program, and to get the data comparing with a simulation data.

2.2 Measurement system

Figure 2 shows the schematic diagram of the measurement system which can measure and record temperature, fluid flow,

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and humidity. Table 1 shows a specifications of the measuring instruments. The 60 thermocouples were set up to measure the temperature of living room and walls, and 72 thermocouples were set up to measure the fluid temperature in balcony: the 3 zones with 4 points in the direction of width and 6 points in it of heigh. Also 3 hygrometers were set up to room, balcony and the outdoor air.

3. Computer Simulation of Heat and Fluid Flow in the Balcony

In this chapter, the fluid flow and temperature distributions in balcony shall be calculated by computer simulation. It is reasonable that the fluid is inviscid, incompressible, turbulent, and natural convection. The SC/Tetra; a code which has been applied generally to engineering field for an analysis of a fluid flow and heat transfer, was used to calculate the fluid velocity and temperature. It has been well known as good converging code for a turbulent flow and natural convection models.

3.1 Governing Equations

As previously stated, the fluid in balcony is turbulent because the Rayleigh number is about 4.67×10^9; this value was measured by the field test. It also is incompressible because density is constant due to a time variation. And it is natural convection because the velocity is very low, about $3 \sim 20 cm/s$. So, the governing equations of the fluid in the balcony are as follows.

1) The equation of continuity

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

2) The equation of motion

$$\frac{\partial u_i}{\partial t} + \frac{\partial u_j \rho u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \mu \frac{\partial u_i}{\partial x_j} - g_i \rho \beta (T - T_0) \tag{2}$$

3) The equation of energy

$$\frac{\partial \rho C_p T}{\partial t} + \frac{\partial u_i \rho C_p T}{\partial x_j} = \frac{\partial}{\partial x_j} K \frac{\partial T}{\partial x_j} + q \tag{3}$$
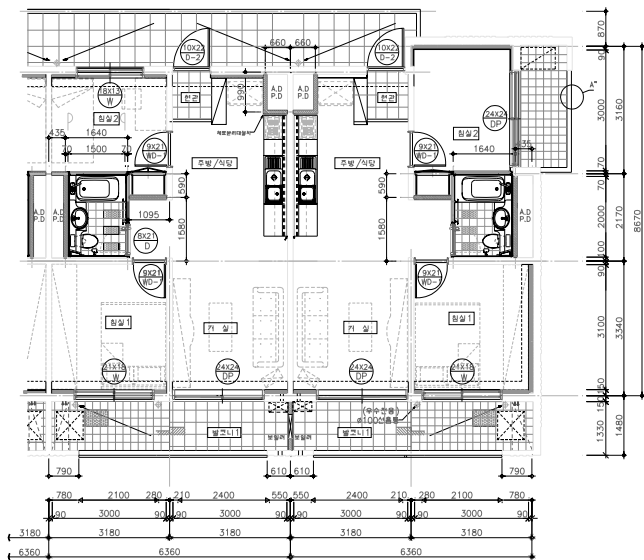

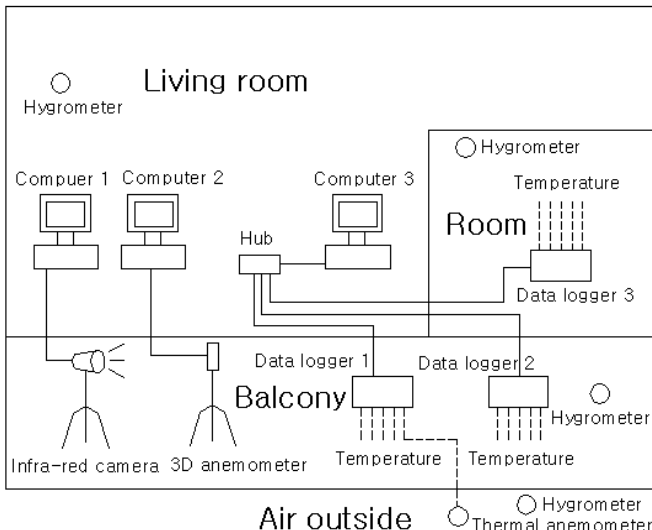Fig. 1. Plane view of the field test house

Fig. 2. Schematic diagram of the measurement system

Table 1. Specification of the measuring instruments

Measurement items		Instruments	a note
Temperature	Air (balcony, room, outside) and surface temperature	T-type thermocouple (C-C sensor)	Error range : ±0.5℃
	Surface	Infrared camera (IRE S-400)	USA IRE
Humidity	Relative humidity of room, balcony, outside	Packaged hygrometer	Japan
Aerofoil	Flow direction and velocity	3 dimensional supersonic anemometer (WA-590)	Japan KAIJO
	Wind velocity	Thermal anemometer (TSI 8465)	USA TSI
write/ storage	Data write	Data logger (NetDAQ 2640)	USA Fluke
	Data storage	Notebook computer	Korea

4) The equations of turbulent energy and dissipation rate (k-ε equation)

$$\frac{\partial \rho k}{\partial t} + \frac{\partial}{\partial x_i} = \frac{\partial}{\partial x_i}(\frac{\mu_t}{\sigma_k}\frac{\partial_k}{\partial x_i}) + G_\delta + G_\tau + \rho_\epsilon \qquad (4)$$

$$\frac{\partial \rho_\epsilon}{\partial t} + \frac{\partial u_i \rho\epsilon}{\partial x_i} = \frac{\partial}{\partial x_i}(\frac{\mu_i}{\sigma_\epsilon}\frac{\partial \epsilon}{\partial x_i}) + C_1\frac{\epsilon}{k}(G_s + G_\tau)(1 + C_3'R_f) - C_2'\frac{\rho\epsilon^2}{k}$$

$$(5)$$

3.2 Modeling

3.2.1 Geometry

Figure 3 shows a geometry for a computer simulation. This geometry is same with the field test houses except cutting the symmetry regions to reduce a computer calculation memory.
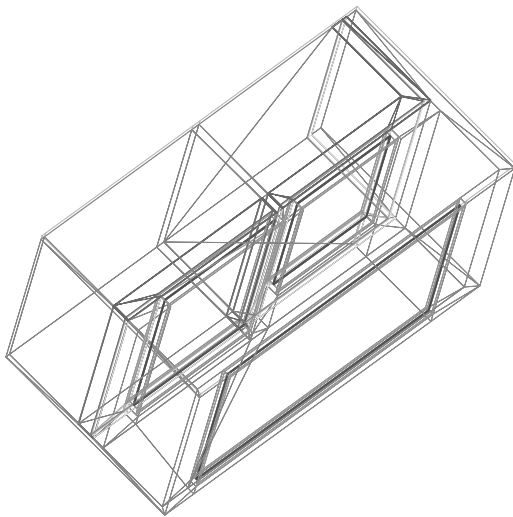
Fig. 3. Geometry for a computer simulation

3.2.2 Properties and Bboundary Conditions

(1) Properties

Many properties are required to calculate the fluid flow and temperature characteristics of indoor air, i.e., density, specific heat, conductivity, viscosity, and expansion coefficient for a reference temperature. Table 2 shows the properties of materials.

Table 2. Properties of materials

Items Materials	Conductivity (W/mK)	Specific heat (J/kgK)	Density (kg/m³)	Viscosity (kg/ms)	Expansion coefficient (K⁻¹)
Concrete	1.6	880	2,100	-	-
Insulation	0.037	1,210	50	-	-
Dew protector	0.065	840	300	-	-
Gypsum board	0.18	1,134	910	-	-
Glass(5-6-5)	0.147	745	1,500	-	-
Flame	0.175	1,930	1,250	-	-
Air	0.0256	1,007	1.177	1.83e-05	1/T

(2) Boundary Conditions

Table 3 shows the boundary conditions to be applied to the simulation model.

Table 3. boundary conditions

Items	Boundary conditions
Inlet air	air temperature, Velocity, k-ε values
outlet air	Static pressure = Constant
Cutting surface	Adiabatic, Free-slip
Overlapped walls	Free-slip, No thermal resistance
Surface of walls	Non-slip, Log law condition
Floor	floor temperature, overall heat transfer coefficient

3.2.3 Comparison with the Simulation Results and the Measuring Data

(1) Air Temperature in Balcony

The period of comparison was about a.m. 4:00 when the outdoor air was low enough and became steady state. Then the outside air temperature was about -5℃, wind velocity was 0.7m/s, and floor surface temperature was about 30℃. Figure 4 and Figure 5 show the measuring data and simulation data each
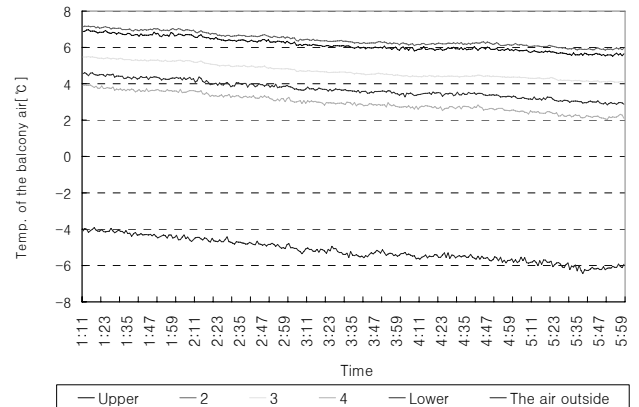

Fig. 4. Air temperature distribution in balcony from lower part to upper part at the middle region (Field test)
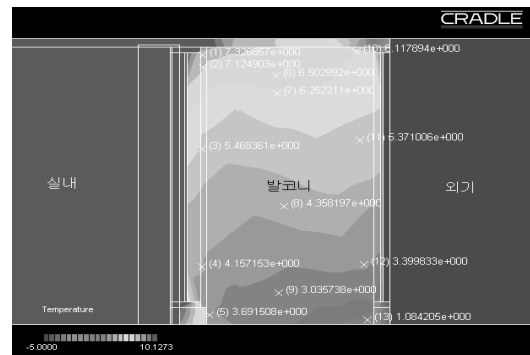

Fig. 5. Air temperature distribution in balcony by a computer simulation

other. The measuring data are the values from lower part to upper part at the middle point with the width direction of balcony. The temperature distribution from the lower to upper parts is $3℃ \sim 6℃$, and it is almost equal to the simulation data of the figure 5.

(2) Surface Temperature

Figure 6 shows the simulation result for the surface temperature of wall, glass, and window frame. Figure 7 shows the surface temperature difference with the simulation results and measuring data. It looks like that two results are about the same.
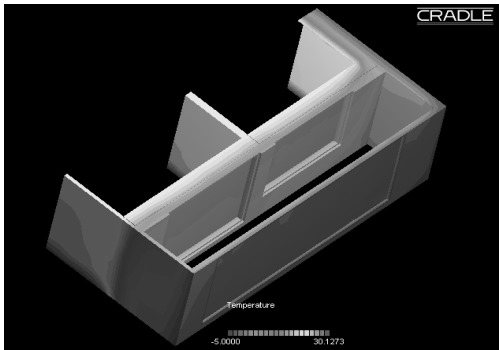
Fig. 6. Temperature distribution of the surface by a computer simulation
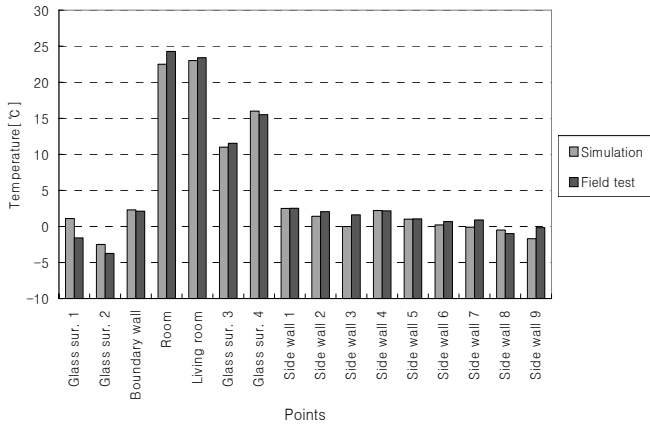
Fig. 7. Comparison with simulation result and measuring data

(3) Fluid Flow Distribution in the Balcony

Figure 8 is the results when the outdoor air temperature was -$2℃$, the room temperature was about $26℃$. Figure 8 (a) shows the measured fluid velocity vector in balcony, and the (b) and the (c) show the flow direction and velocity by a computer simulation. The (a) shows that the velocity is $3 \sim 13cm/s$, and the flow direction is equal to the sum of the direction of gravity and heat transfer. As shown to the (b) and the (c), the velocity is about $2 \sim 14cm/s$, and the fluid direction is the about same with (a).
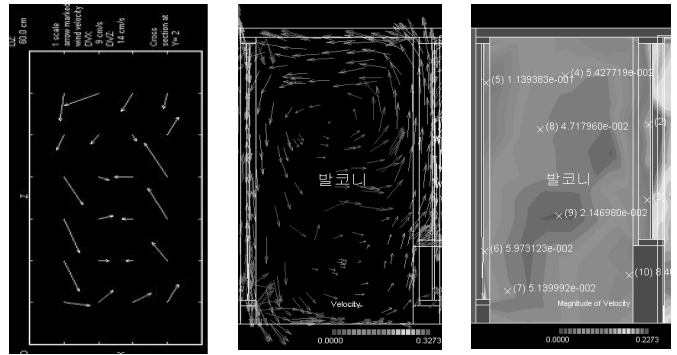
(a) Measurement　(b) Simulation(vector)　(c) Simulation(velocity)

Fig. 8. Comparison of the fluid flow with simulation and measured data

4. Ventilation Plan to Reduce a Vapor Condensation on the Balcony Walls

4.1 84m² Apartment Housing

4.1.1 Closed Balcony Space (No Ventilation Holes)

Figure 9 shows the air temperature distribution by simulation to the middle height of the 84m² apartment housings' balcony. It is almost constant to the internal zone of balcony, but it is very irregular along the perimeter zone. Also the temperature is high along the inside perimeter zone, and it is low along the outside. That is because the heat transfer resistance is high near the wall surface due to the thick boundary layer. Figure 10 shows the velocity at the same position. It is clear that the air is stagnated at corners and wall surface, so the boundary layer is thick along the
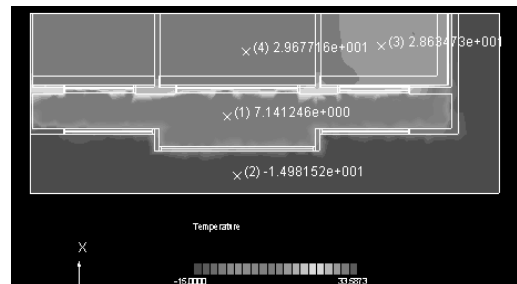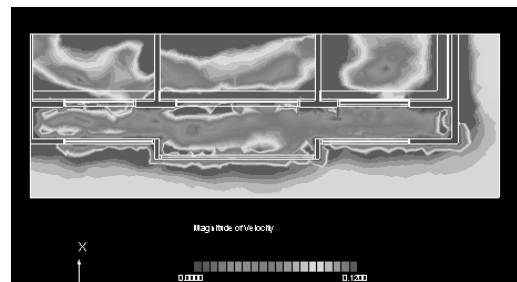

Fig. 9. Air temperature distribution for 84m²

Fig. 10. Velocity distribution for the 84m²

regions. Figure 11 shows the surface temperature. Figure 12 shows the possibility of a vapor condensation on the wall. The condensation may be happened to the most part of a wall.
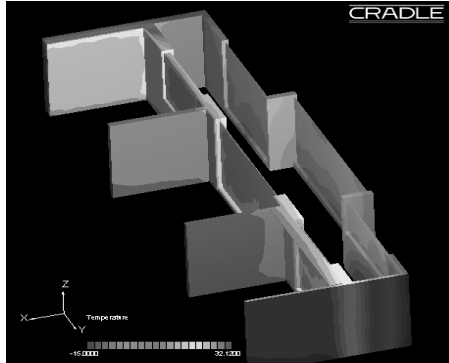

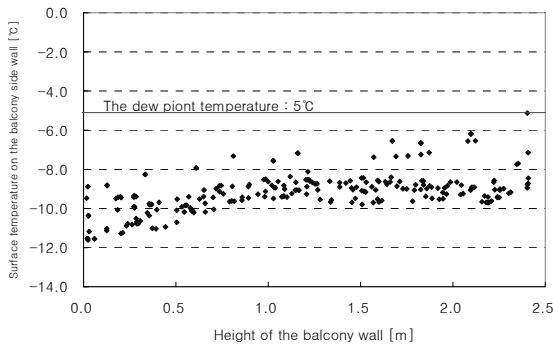Fig. 11. Temperature distribution on the wall surface for the 84m²

Fig. 12. Possibility of the vapor condensation on the balcony wall of the 84m²

4.1.2 Open Space (Perforated Holes for Ventilation)

(a) Model

Fig. 13 shows the drawing of which 4 holes are perforated into the concrete wall. Then it is clear that natural convection will be more active than the closed space. Figure 14 shows the geometry made by SC/Tetra Code.

(b) Results

Figure 15 shows the vapor condensation area ratio on the wall. It is 79.1% if the diameter of holes is 0mm: it is the same with a closed space. It is about 79% when the 4 holes with 30mm diameter are perforated through the wall. If 4 holes with 70mm diameter will be perforated, the possibility may be about 3.5%. In the case of two holes with 100mm diameter, which one is up of the left and the other is down of the right, then the possibility is 0%. But if the both holes are to the same height, for example, upper or middle or lower, it is not good design method to protect the vapor condensation. Figure 16 shows an average air temperature in the balcony. The area of holes is more larger and larger, it is getting lower and lower. (the sign of hole designs type refer to the conclusion)
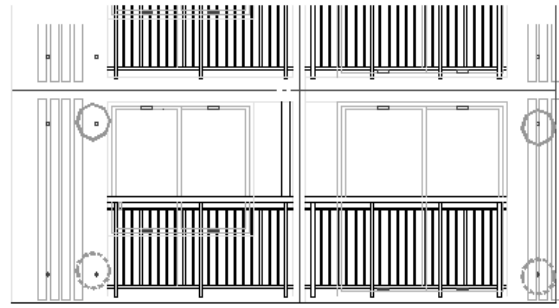

Fig. 13. Perforated holes for natural convection
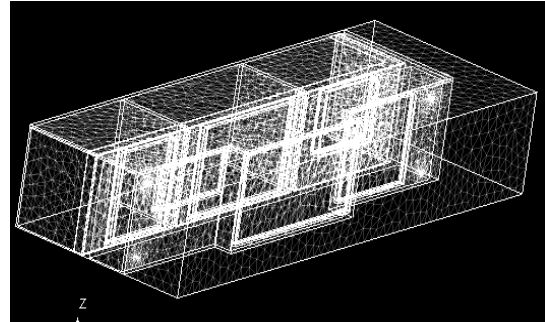

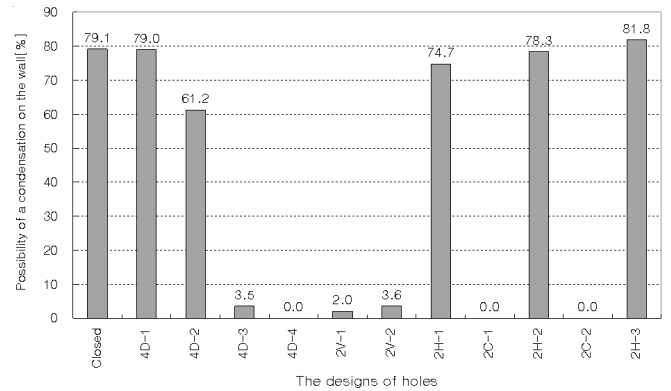Fig. 14. Geometry made by the SC/Tetra Code

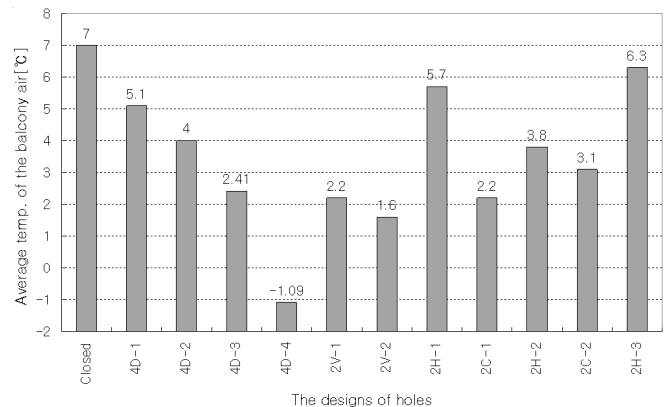Fig. 15. Vapor condensation area ratio on the balcony wall for the 84m²

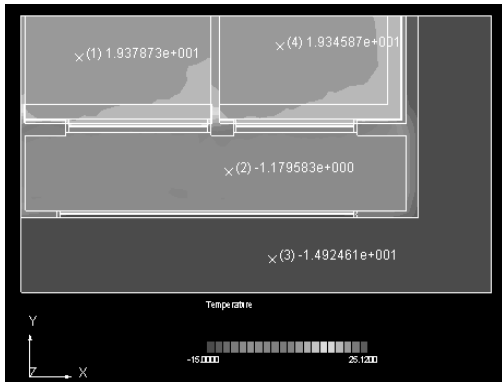Fig. 16. Air temperature in balcony per the hole designs for the 84m²
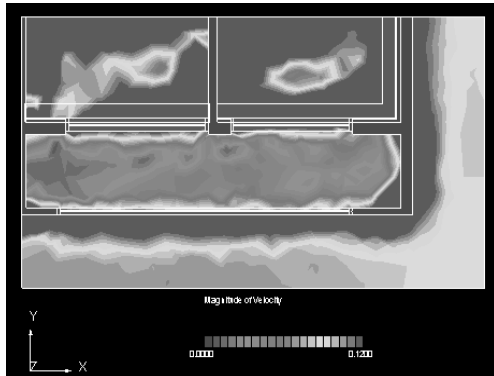
Fig. 17. Air temperature distribution for the 46m^2
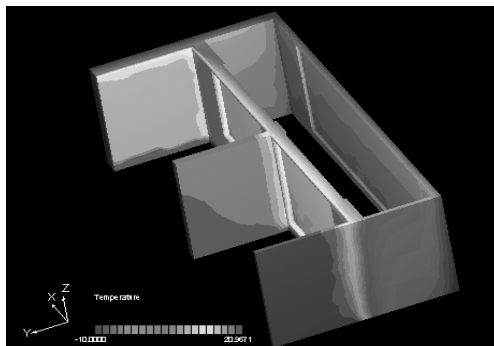

Fig. 18. Velocity distribution for the 46m^2
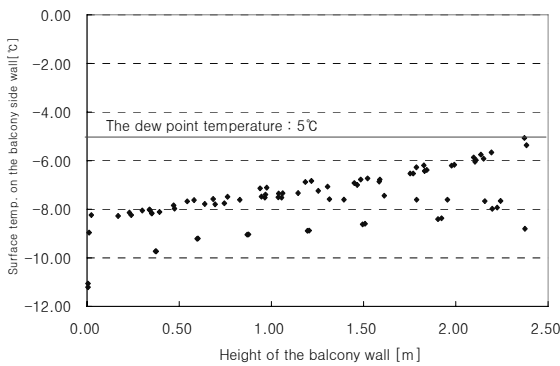

Fig. 19. Surface temperature for the 46m^2

Fig. 20. Possibility of the condensation on the balcony wall for the 46m^2

4.2 46m^2 Apartment Housing

4.2.1 Closed Balcony Space (No Ventilation Holes)

Figure 17 shows the air temperature distribution by simulation for the 46m^2 apartment housing. The balcony air temperature is almost constant to the internal zone and the perimeter zone. This result is different from that of the 84m^2 apartment housing. Moreover, the room temperature of this plane is more lower than that of the 84m^2. It is guessed that the flow and temperature characteristics are dissimilar to each other because the shape of the balcony planes are different from each other.

Figure 18 shows the velocity distribution in the balcony plane. As shown in this figure, the velocity is very fast at the corners and nearby the surface. So the convective heat transfer coefficient is very high at the region, and then heat is get out very well from the room to outdoor air. So the air temperature in the balcony and rooms of 46m^2 is more lower than that of the 84m^2.

Figure 19 shows the surface temperature, and figure 20 shows the possibility of a vapor condensation on the walls. A vapor condensation will be happened almost balcony wall surface as same as the 84m^2.

2) Open Space (Perforated Holes for Ventilation)

The holes for ventilation are also perforated through the concrete wall in the same method with 84m^2 apartment housing. Then, figure 21 shows the vapor condensation area ratio on the balcony wall. It is about 77% when the balcony space is closed, i.e. the diameter of holes is 0mm. And it is about 47% for four holes with diameter 30mm, and it is 0% for four holes with diameter 50mm. If there are two holes with 70mm diameter which one is down of the left and the other is up of the right, it is also 0%.

Figure 22 shows the average air temperature in the balcony. It is about -1℃ in case of closed space, however, it is more higher if the holes are perforated. It is because the temperature is calculated for the only middle section of balcony space. If the average temperature would be calculated for all of the region in balcony it will be more lower than that of the closed space.
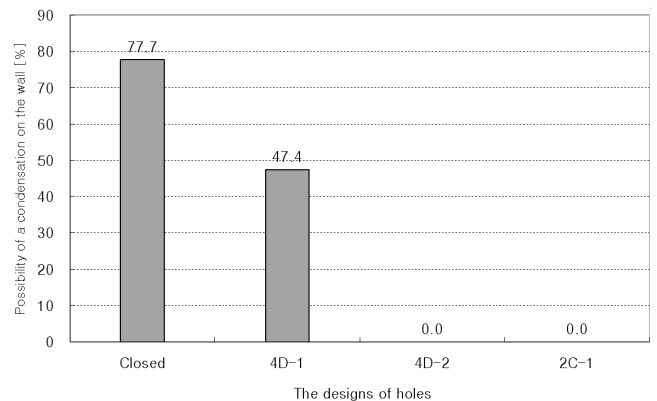

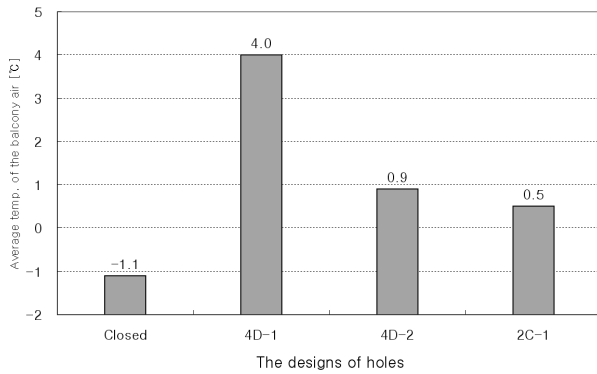Fig. 21. Vapor condensation area ratio on the balcony wall for the 46m^2

Fig. 22. Air temperature in balcony per the hole designs for the 46m²

5. Conclusion

In this study, a field test and a computer simulation were performed to find the optimal design criteria of ventilation holes reducing the vapor condensation on the balconies wall. The results of a simulation modeling using the SC/Tetra Code was about similar with the results of the field test data. So, the optimal design criteria was proposed by the computer simulation analysis. Table 4 shows the proposed design criteria.

Table 4. Design criteria of ventilation holes to reduce the vapor condensation on the balcony wall

Designs		Diameter (m)	Area ratio of condensation (%)	Air temp. in balcony (℃)	Choice	Note (The position of holes)
84m²	Type 1	0	79	7	×	Closed space (present)
	4D-1	0.03	79	5.1	×	4 holes (R/L: up and down)
	4D-2	0.05	61	4	×	4 holes (R/L: up and down)
	4D-3	0.07	4	2.4	△	4 holes (R/L: up and down)
	4D-4	0.1	0	-1.1	○	4 holes (R/L: up and down)
	2V-1	0.1	2	2.2	△	2 holes (R: up and down)
	2V-2	0.1	4	1.6	△	2 holes (L: up and down)
	2H-1	0.1	75	5.7	×	2 holes (R: up, L: up)
	2H-2	0.1	79	3.8	×	2 holes (R: middle, L: middle)
	2H-3	0.1	82	6.3	×	2 holes (R: down, L: down)
	2C-1	0.1	0	2.5	○	2 holes (R: down L: up)
	2C-2	0.1	0	3.1	◎	2 holes (R: up L: down)
46m²	Type 1	0mm	78	-1.1	×	Closed space (present)
	4D-1	0.03	47	4	×	4 holes (R/L: up and down)
	4D-2	0.05	0	0.9	○	4 holes (R/L: up and down)
	2C-1	0.07	0	0.5	◎	2 holes (R: up L: down)

Note: 1. R : Right, L : Left, R/L : Right and left
2. Right is side wall, and Left is symmetry wall to meet next door house

As these results, it is the optimal design criteria for the 84m² that two holes with 100mm diameter are perforated through the balcony outside wall, where one is a lower part of the symmetry wall and the other is an upper part of the side wall. The 2 holes with 70mm diameter is optimal for the 46m², as same as position with 84m².

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