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Improvement of Condensation Performance in Corridor Type Apartment Door

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Abstract

Condensation has mainly occurred in corridor type apartment door which is exposed to the outside air and is made of steel, which has high thermal conductivity. As a result, the total costs of repair have increased with the number of disputes with residents. In this study, therefore, we investigate materials and construction methods used in apartment door, perform a computer simulation to find out possible improvements, and then suggest the dew point to prevent the occurrence of condensation throughout simulation. The results indicate that the temperature that condensation does not occur is 15.4 ℃, and the optimum method of achieving this dew point is shown to be a door frame system including a large vertical slot to decrease the area of thermal conduction between the outer and inner portions of the door frame. Mock-up tests show that the surface temperature of the door frame was higher than the dew point, and the system can withstand severe cold conditions of -20℃. In application test, the surface temperature of door frame with vertical slots is 5.9 ℃ in average, which is higher than the existing door frame. Furthermore, in the temperature distribution of the surrounding door measured with infrared ray camera, the existing door shows the high temperature distribution indicating lack of insulation, but the improved door shows the low temperature distribution indicating higher insulation.

Keywords : Condensation Performance, Corridor Type Apartment Door Unit, Dew Point, Insulation, Mock-up Tests

1. INTRODUCTION

Condensation in corridor type apartment generally occurs inside surfaces of the doors which are in direct contact with the outside air, and particularly those doors in which insulation is insufficient. The door is mainly made of steel, which has higher thermal conductivity. Due to condensation in door surface, the total cost of repair is expected to be raised along with the number of disputes with residents. These troubles will increase with further construction of 1.5 million units of national rental housing for low-income people planned by government in next 10 years. Despite that most of these apartments will be of the corridor type, a few studies for the prevention of condensation have been carried out (Lee and Hwang, 2001). Accordingly, this study has investigated the materials and construction methods for the existing apartment doors and suggested the dew point temperature to prevent condensation. The computer simulations are performed to analyze the effects of different materials used and construction methods and to find the optimum systems for achieving the dew point. In addition, the optimum systems suggested by computer simulation are verified by mock-up and application tests based on the experiments. This study aims at providing more comfortable living conditions for residents and reducing the number of defects in insulation units and the life cycle costs for the repairs.

2. CRITERIA FOR DEW POINT

2.1 Survey for temperature and humidity of surrounding door

The general insulation design criteria of temperature and relative humidity to prevent condensation are 25℃ and 55%, respectively. However, these criteria correspond to the case of living room and bedroom only. Therefore, new criteria for the temperature and humidity are needed for the surrounding of the door.

1) Survey area
The temperature of the living room and surrounding of the doors inside, and the outer temperature of sixty corridor type apartments are surveyed. Temperature and humidity are recorded automatically at intervals of 2 hours for a total of 48 hours.

2) Survey results
As shown in Table 1, the temperature surrounding of the doors inside is 1.3℃, which is lower than that in the living room while relative humidity is higher than that in the living room.

Table 1. Temperature and humidity

Location	Measurement	Average value	Standard variation
Living room	Temperature	24.4 ℃	1.4
	Relative humidity	45.6 %	10.2
Surrounding of the door (inside)	Temperature	23.1 ℃	1.3
	Relative humidity	50.0 %	10.9

2.2 Establishment of the dew point

The temperature and humidity of door areas in corridor type apartment have a constant ratio, regardless of changes in air temperature. This observation is known as the theory of difference ratio of temperature and humidity (Yamada, 1979), and it has generally been applied to prevent condensation. Applying this theory to the survey data indicates that the dew point at which condensation does not occur in occupied housing is 15.4℃.

$$\frac{(\text{Temp. of main enterance surrounding - Outer Temp.})}{(\text{Inner Temp. - Outer Temp.})} \tag{1}$$
$$= \text{Difference ratio of Temp.}$$

$$\frac{(\text{A.H. of main enterance surrounding})}{(\text{Inner A.H. - Outer A.H.})} = \text{Difference ratio of humidity} \tag{2}$$

where temp indicates temperature, A.H indicates absolute humidity.

Table 2. Average of temperature and humidity

Difference ratio	Average	Standard variation
Temperature	0.93	0.04
Humidity	1.01	0.16

Table 3. Criteria for preventing condensation

Temperature	Relative humidity	Dew point
22℃	66 %	15.4℃

3. IMPROVEMENT BY COMPUTER SIMULATION

3.1 Simulation method and condition

The computer program "PHYSIBEL" is used to analyze thermal conduction. The temperature distribution is analyzed by using the "TRISCO" program with analytic module of three dimensions.

Figure 1 shows the geometrical model for the analyses drawn up by the PHYSIBEL, and it is used to analyze the temperature distribution of each inner part of the door. Boundary conditions for the analyses, which are the surface temperature of the door are shown in Table 4.

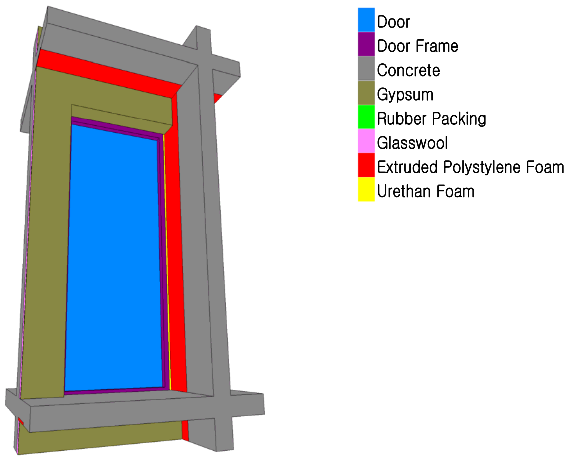

Figure 1. Geometrical model for the analyses

Table 4. Boundary conditions

Items each condition		Design criteria
Inner condition	Temperature (℃)	22
	Relative humidity (%)	66
	Dew point temperature	15.4
	Ratio of thermal conduction (W/m^2℃)	7.7
Outer condition	Temperature (℃)	-15
	Ratio of thermal conduction (W/m^2℃)	25

3.2 Condensation analyses by computer simulation

1) Surface temperatures of door and door frame

Tamping materials used to insulate the inside of the door frame are glass wool, urethane foam, and polyethylene foam. Computer simulation indicates that the surface temperatures of the urethane foam(0.050W/m℃) and glass wool(0.035W/m℃) for door frame are not significantly different even though the ratios of thermal conductivity are different for two materials. However, it can be estimated that urethane foam is to be filled effectively in the inside of door frame rather than glass wool on condition that ratio of thermal conduction is about the same.

2) Insulation performance of various methods of door frame

We use a variety of methods to insulate the door frame and investigate the surface temperature of the surroundings of the door in each method. To standardize results, the inner part of the door is fixed to the condition of an air layer and the inner part of door frame is filled up to urethane foam for all methods. Figure 2 shows the existing main door has a door frame temperature of 6-7℃, which is not satisfied with a dew point requirement of 15.4℃. Figure 3 shows a design connecting the inner and outer frames using rivets in order to reduce thermal conduction. The surface temperature of the door frame which uses this rivet connection design is 3-4℃, which is higher than the conventional door frame, but did not reach the dew point of insulation design. Figure 4 shows a design which connects the inner and outer frame by welding, and the surface temperature of the door frame is about 6-7℃, which is higher than the conventional door frame. The design shown in Figure 5 is a large vertical slot system, 6mm in width which decreases the area of thermal conduction. The surface temperature of door frame with slot is 13℃, which is close to the dew point. Furthermore, it is estimated that the system has several advantages including pre-fabrication and increased insulation performance.

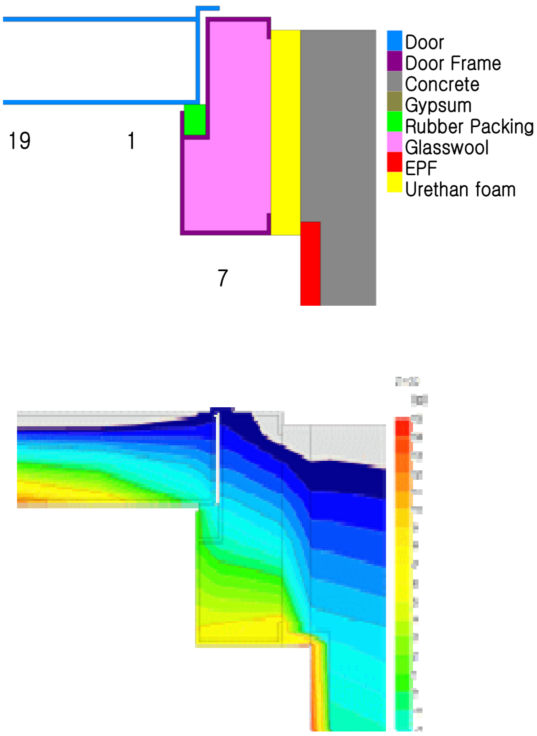

Figure 2. Existing main entrance

3) Insulation performance of door

As shown in Figure 6, the door is made with inner and outer steel sheets which are connected by strong adhesive tape without bending in order to decrease the area of thermal conduction. The result indicates that the surface temperature of this system is similar to the existing door, and has not reached to the dew point because the adhesive tapes are not thick enough. Figure 7 shows that the door and door frame are bended to increase an airtight performance and PVC insulation material is inserted into the gap between the inner and outer steel sheets. The computer simulation shows that the bending system would be more effective than the adhesive tape system. However, the bending system door design has the disadvantage that needs more detailed and precise construction on site. None of the door designs is satisfied with the dew point requirement due to lack of thickness of the door itself. The use of polyethylene foam as a tamping material in the door frame is shown to be more effective than the existing honeycomb type.

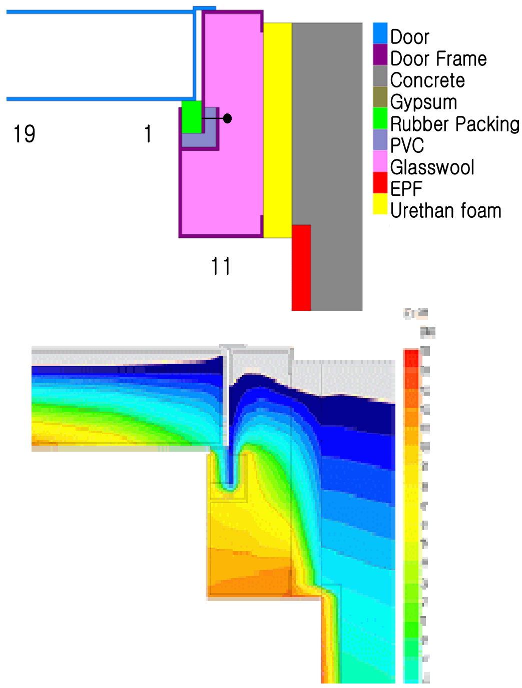

Figure 3. Rivet system

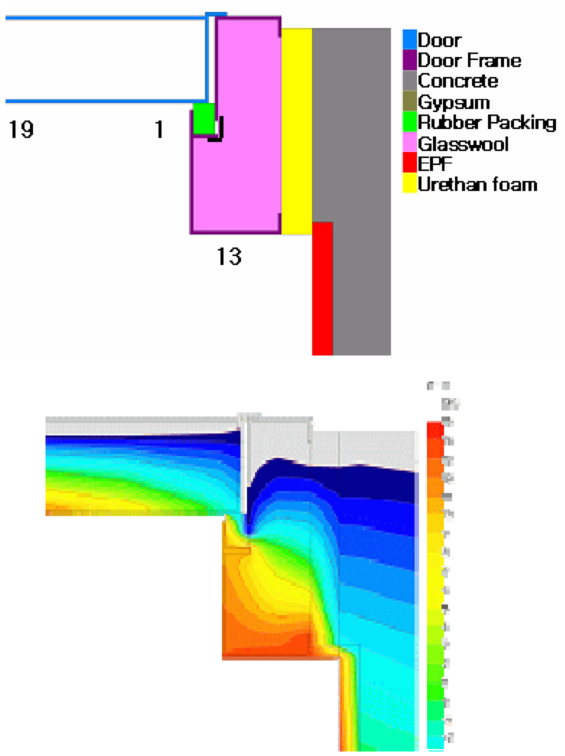

Figure 4. Welding system

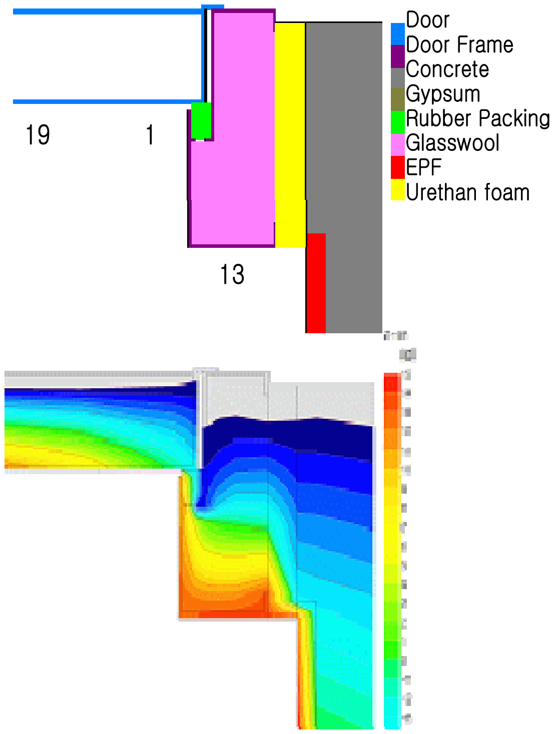

Figure 5. Slot system

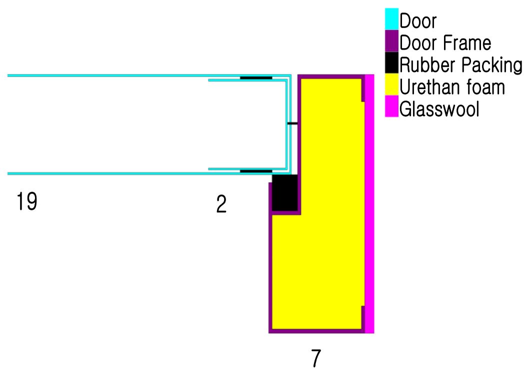

Figure 6. Adhesive tape design of door

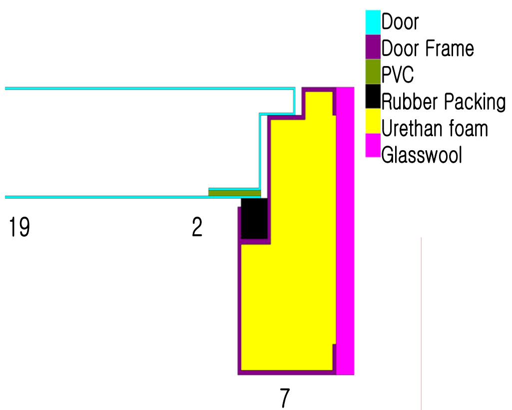

Figure 7. Bent frame design of door

3.3 Suggestion for improved door frame design

From the above tests, it is found that any system of door and door frame are not satisfied with the dew point of 15.4℃. In turn, the optimum two systems, exceeding the dew point of 15.4℃ and providing constant insulation performance and construction simplicity on the site are suggested on this chapter based on the above results. As shown in Figure 8, the door frame has two large vertical slots and surface of the door frame is reinforced by MDF (Middle Density Fiberboard) and the inner part of door is filled with foamy polyethylene. The computer simulation indicates that this system is satisfied with the dew point to an outer temperature of -15℃, but could not satisfy the dew point requirement at an outer temperature of -20℃. The MDF has several advantages for manufacturing and cost, but has the disadvantage of being structurally weak in moist conditions. Figure 9 shows that the door frame has two large vertical slots and the surface of the door frame is insulated with foamy PVC which can be easily prefabricated. It is found that this system is sufficiently satisfied with the dew point requirement of 15.4℃ even in severe temperature conditions of -20℃.

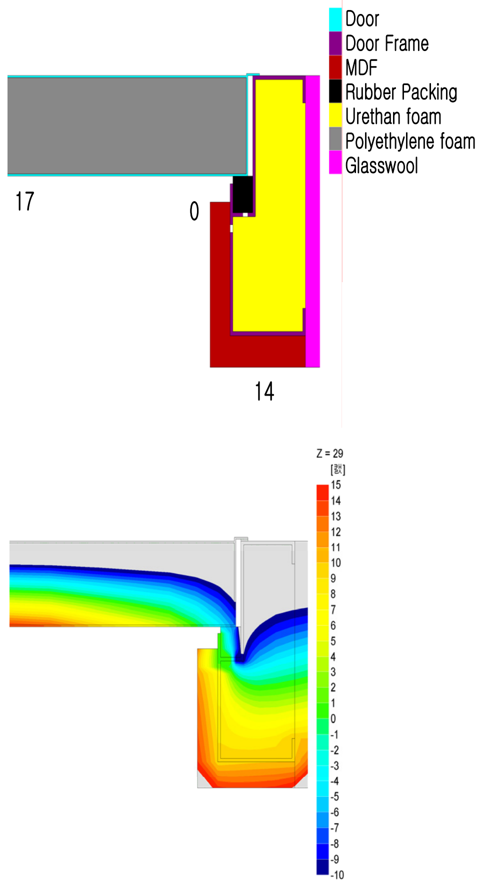

Figure 8. Improved system I

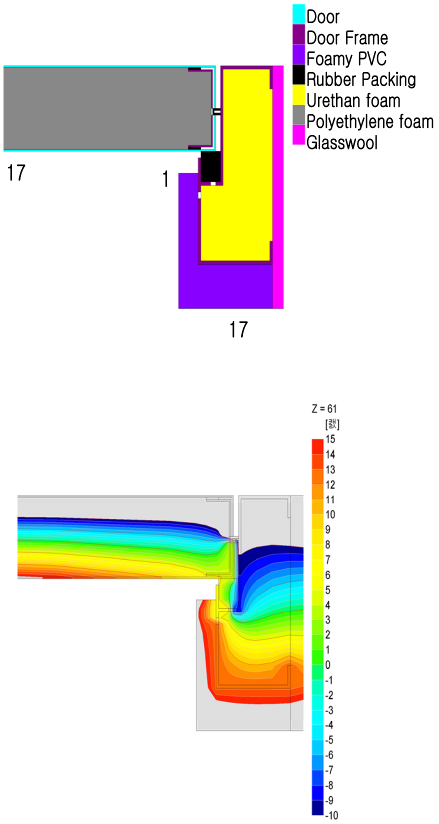

Figure 9. Improved system II

Table 5 below summarizes the temperature simulation at each system.

Table 5. Surface temperature of each system

Classification	Door(℃)		Frame (℃)
	Center	Edge	
Existing main entrance	19	1	7
Rivet system	19	1	11
Welding system	19	1	13
Slot system	19	1	13
Adhesive tape design of door	19	2	7
. Bent frame design of door	19	2	7
Improvement system 1	17	0	14
Improvement system 2	17	0	14

4. MOCK-UP TEST AND PERFORMANCE QUALITY

The condensation performances of the optimum two systems suggested by the computer simulation are experimentally tested as mock-up test.

4.1 Performance test for condensation by mock-up

The conditions of constant temperature and humidity for mock-up tests are shown in Table 6. The chamber under low temperature changes from 5℃ to -10℃ in accordance with KS F 2295. However, systems suggested by computer simulation are applied up to -20℃ in order to simulate regional conditions in the northern area of South Korea.

Table 6. Conditions of mock-up test

Classification	Existing main entrance	System I	System II
Constant temperature and humidity chamber	22 ℃, 66%	22 ℃, 66%	
Low temperature chamber	5 ℃	-5 ℃	
	0 ℃	-10 ℃	
	-5 ℃	-15 ℃	
	-10 ℃	-20 ℃	

Figure 10. Specimens for condensation test

4.2 Test results

As shown in Figure 11, the existing door frame is not satisfied with the dew point requirement even in an air temperature of 0℃. However, it is shown that both suggested designs are satisfied with the dew point requirement in an air temperature of -20℃ as a result from computer simulation. Furthermore, only a very small amount of condensation is found only on the inner surface of the door frames at an outside air temperature of -20℃ equivalent to severe conditions in the northern regions of South Korea. Figure 12 indicates that the two systems using foamy polyethylene and hairs as windbreaks are more effective in maintaining indoor temperature than the existing door system, but a small amount of condensation is found on the inner surface of the door at an external air temperature of -5℃.

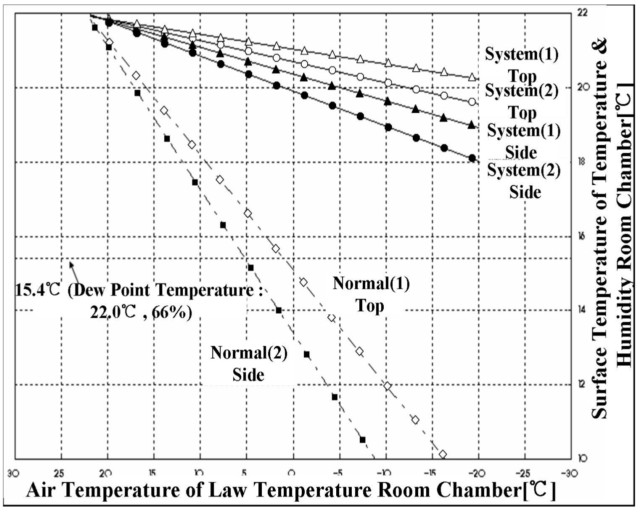

Figure 11. Surface temperature of door frame by mock-up test

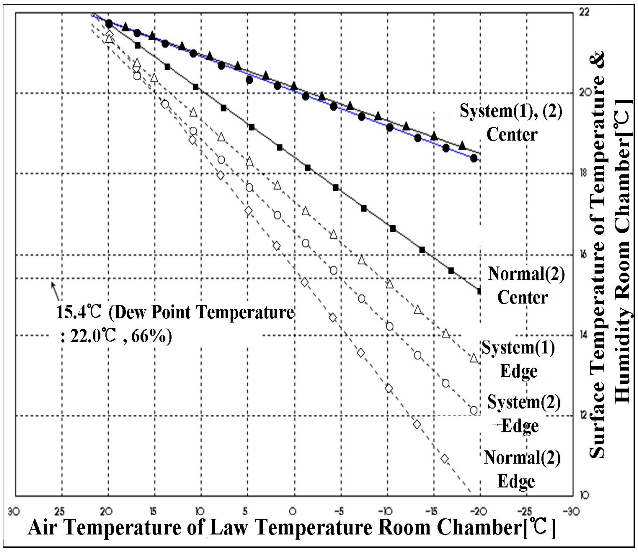

Figure 12. Surface temperature of door by mock-up test

4.3 Performance quality of door and door frame

Tests also demonstrate that performance quality such as flexible strength, impact stress, and opening and shutting capability of door and door frame generally is complied to the building standard, KS F 3109 (Door set).

5. APPLICATION TEST

5.1 Summary of the test

Application test is to evaluate an application property of slot system which is effective to prevent condensation of door frame according to the computer program simulation and mock-up test.

Table 7. Measurement method

Test method	No of Units		Test item	Test equipment	Test Period
	Old	New			
Prelimi-nary test	2	4	Temperature Moisture (In-ner & outer)	Automatic thermal equipment	1time per a day for 8 days
Detailed test	1	1	Surface tem-perature of door, Temperature Moisture (In-ner & outer)	Data log-ger, Thermal conduction stand	1 time per 10 minutes for 4days

Figure 13. Measurement point of surface temperature

5.2 Test result

Outer temperature condition for test period ranges between -15℃ and 4.5℃, and the average temperature is -4.8℃. Any condensation situation in units which the improved slot system is applied is not observed in preliminary test. However, the existing door system has small water drops flowing on the surface of door frame.

On the other hand, outer temperature in detailed test to measure the surface temperature ranges between -15.3℃ and 5℃, and the average temperature is -6.2℃. Inner temperature shows 22℃ on the average, and the both existing door and improvement door have similar temperature distribution.

Figure 14 shows the surface temperature of the existing door frame and improved door frame with large vertical slots. Condensation of the existing door frame has been shown on all parts of door frame from outside air temperature of -5℃ while improved door frame has been shown on only the lower part from -10℃. As a result, it can be estimated that the surface temperature of door frame with vertical slots is 5.9℃ in average, which is higher than the existing door.

As shown in Figure 15, condensation of both existing door and improved door has occurred in the lower part of the door from outside air temperature of -5℃. Figure 16 shows the temperature distribution of the surrounding of the door units measured with infrared ray camera. As shown in the photo, it can be estimated that the existing door system shows red color indicating high temperature distribution due to lack of insulation, but the improved door system shows yellow color indicating low temperature distribution.

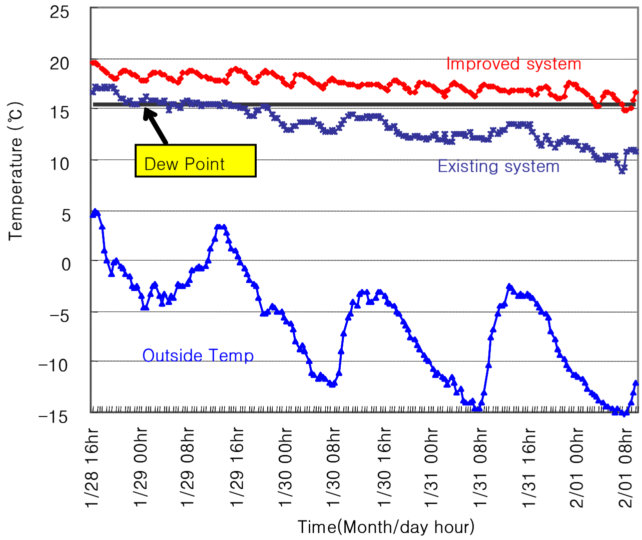

Figure 14. Surface temperature distribution of door frame

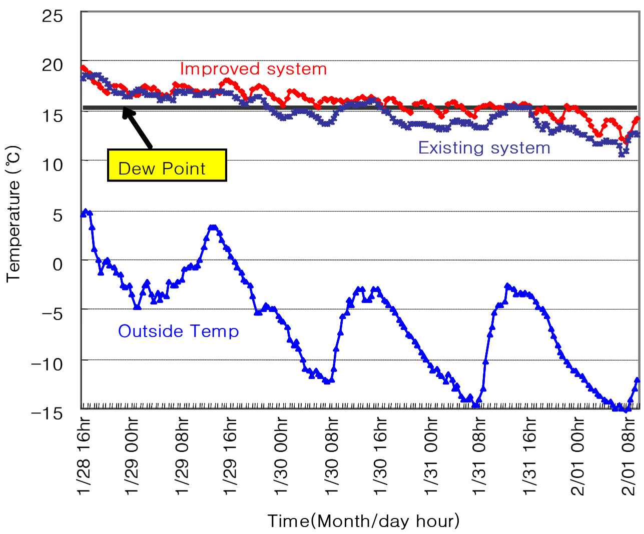

Figure 15. Surface temperature distribution of door

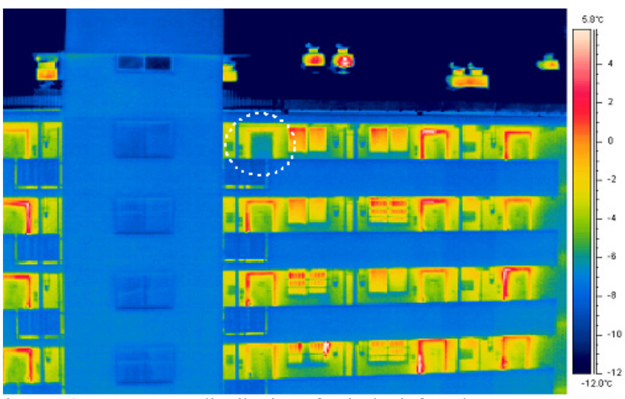

Figure 16. Temperature distribution of units by infrared ray camera

6. CONCLUSIONS

The average temperature and relative humidity inside the main entrance of occupied housing is 22℃ and 66% respectively, and the dew point temperature at which condensation does not occur is 15.4℃.

The computer simulation indicates that the optimum method of exceeding the dew point temperature is the door frame system including a large vertical slot to decrease the area of thermal conduction between the outer and inner portions of the door frame. Furthermore, MDF (Middle Density Fiberboard) and foaming PVC materials should be used on the surface of the door frame in order to withstand in severe temperature conditions.

The result of the Mock-up experiment used to test the performances of the system suggested by the computer simulation indicates that the surface temperature of the door frame is higher than the dew point temperature, and dew condensation does not occur in severe temperature conditions of -20℃.

In application test, the surface temperature of door frame with vertical slots was the average 5.9 ℃ higher than the existing door frame. Furthermore, in the temperature distribution of the surrounding of door taken pictures with infrared ray camera, the existing door showed the high temperature distribution with red color because of lack of insulation, but the improvement door showed the low temperature distribution with yellow color.

The quality performances such as flexible strength, impact stress, and opening and shutting ability of the door systems generally comply with the building standard.

This system will provide more comfortable living conditions for residents and reducing the number of repair costs in insulation of units and the life cycle costs for the repairs of apartment.

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