



Calculation of Adequate Remodeling Period for The Improvement of Thermal Insulation Performance of External Walls in Deteriorated Apartments

Choi, Doo-Sung* · Lee, Myung-Eun**

* Dept. of Building Equipment & Fire Protection System, Chungwoon Univ., South Korea (trebelle@chungwoon.ac.kr)

** Corresponding author, Dept. of Architectural Engineering, Suwon Univ., South Korea (pigbab@naver.com)

ABSTRACT

Purpose: Under the purpose of presenting the adequate remodeling period for the improvement of thermal insulation performance of external walls in deteriorated buildings, the change in external wall and residential environment problem(dew condensation) due to aged deterioration after the apartments were constructed in Korea were analyzed. **Method:** Temperature Difference Ratio Outside(TDRo) and Heat Flow Meter(HFM) were used as measurement methods to evaluate the thermal insulation performance of deteriorated buildings. For TDR evaluation, thermo-graphic camera was used to measure and analyze the surface temperature of external wall. Also, dew condensation evaluation was analyzed using the Temperature Difference Ratio Inside(TDRi). **Result:** As a result of analyzing thermal performance through TDRo, the first decline point of thermal insulation performance began after 14-16 years have passed since construction was completed, and after 20 years have passed the decline point of thermal insulation performance reappeared. As a result of analyzing U-value with HFM measurement method, the decline rate of external wall's thermal insulation performance is lower than 2% in average at around 5 years after completion, and 8.7% in average at 10-15 years, and over 10.2% in average at 20 years.

KEYWORD

아파트
결로
단열 성능
열관류율
열화상카메라

Apartment
Dew Condensation
Thermal Insulation Performance
U-value
Thermo-graphic camera

ACCEPTANCE INFO

Received Mar 17, 2017
Final revision received Mar 30, 2017
Accepted Apr 4, 2017

© 2017 KIEAE Journal

1. Introduction

1.1. Research Background and Purpose

The insulation of the old apartment house was designed and constructed with remarkably low performance compared with the current insulation design standard, and as thermal insulation performance is further deteriorated due to aged deterioration after completion, the amount of heat that flows through the doors, windows, and walls increases, causing dew condensation, which leads to a problem of deteriorating the residential environment.

Recently, the government has introduced a design guideline 1) for prevention of dew condensation from May 2014 as the interest in the residential environment such as the comfort of the residential space and the health of the resident increases, and recently, a remodeling method is considered for securing the thermal insulation performance of the external walls with the aim of preventing the energy loss of the old buildings and improving the residential environment performance.

In this study, we analyzed the change trend of thermal insulation

performance change of external walls according to aged deterioration after completion for apartments among domestic representative residential buildings. Also, by evaluating the typical residential environment problems (dew condensation) caused by thermal insulation performance change (deterioration) in parallel, it aims to propose a proper remodeling time for improving thermal insulation performance of exterior walls in old buildings

1.2. Research methods and scope

The thermal insulation performance for old buildings was evaluated by using measurement method of TDRo (Temperature Difference Ratio Outside) and Heat Flow Meter (hereinafter referred to as HFM). The TDR evaluation is the method of measuring the surface temperature of external walls through thermo-graphic camera, and comparing the difference with the indoor and outdoor temperature using the surface temperature. The HFM evaluation is the evaluation method that analyzes the amount of heat passing through the wall and can be derived from the quantitative U-Value of the insulation wall.

The condensate dew condensation performance was evaluated by TDRi, Temperature Difference Ratio Inside (hereinafter referred to as TDRi) proposed in the design standard for preventing the dew condensation. TDRi is the evaluation method for

measuring the surface temperature through the thermo-graphic camera in the same way as the TDRo, but the measurement site is not the external walls, but the surface temperature of weak areas (wall junction, windows, doors) where dew condensation occurs in the room.

The subjects to be measured were selected as apartments with the same insulation wall structure, it was limited to the apartments in the central area with the same thermal insulation design standard (U-value) of the internal and external walls in the energy saving design standard,²⁾ And to evaluate the insulation and dew condensation performance due to aged change, the scope of subjects to be measured was set as apartments in the new city where apartment development, planning and demand are most concentrated.

2. Outline of insulation and condensation performance analysis

2.1. Performance evaluation of insulation and dew condensation by thermo-graphic measurement

Performance of insulation and dew condensation by thermo-graphic measurement was evaluated by using the infrared ray method standard proposed in ISO 6781 and the formula of TDRo and TDRi of Equation 1. Thermal insulation performance (TDRo) is evaluated by the emissivity and reflection temperature of the surface finish material of the external walls and the indoor and outdoor temperatures during the measurement.

$$TDR_o = \frac{T_o - T_{os}}{T_i - T_o}, \quad TDR_i = \frac{T_i - T_{is}}{T_i - T_o} \quad (1)$$


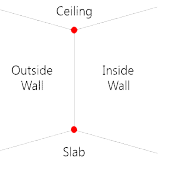
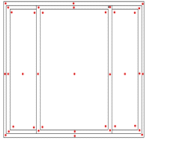
Here,

- T_i : Room temperature (°C)
- T_o : Outside temperature (°C)
- T_{is} : Surface temperature of window and wall junction, internal wall (°C)
- T_{os} : Surface temperature of external walls

The occurrence of indoor dew condensation (TDRi) was assessed for the vulnerable areas presented in the design guidelines for preventing dew condensation in apartment housing. Table 1 below shows the vulnerable areas of dew condensation and the minimum performance standard for the central region presented by the Ministry of Land, Infrastructure, and Transport.

2) Energy saving design standard of building(Ministry of Land, Infrastructure, and Transport Notice No. 2013-587), Ministry of Land, Infrastructure, and Transport, 2013

Table 1. The Performance Standards by Element

Measuring points		TDRi ^{1), 2)}	Location of TDRi
		Central area	
Door	Leaf	0.33	
	Frame	0.24	
Wall Junction		0.25	
Window	Glass Central region	0.18(0.18)	
	Glass corner region	0.24(0.29)	
	leaf / frame	0.28(0.33)	



- 1) Each subject part should all be satisfied
- 2) Inside the parentheses are based on Aluminum(AL) fitting application

2.2. Thermal insulation performance evaluation of external walls through HFM measurement

The HFM evaluation is carried out by installing the device measuring heat flow on the inner surface of the insulation wall facing directly to the open air and evaluating the U-value of the wall by analyzing the heat flowing through the wall. The measurement was performed according to the standard set out in ISO 9869. As U-value was derived from long-term useful data, in this study, U-value of each subjects to be measured was derived by measuring at intervals of 10 minutes for 120 hours.

Table 2 below shows the specifications of the thermo-graphic camera used in this study and the heat flow measuring equipment for indoor and outdoor environment and HFM evaluation.

Table 2. Specification of Measuring Equipment

Measuring Equipment	Specification		
 IR Camera (FLIR T620)	Meas. range	-20°C to +150°C	
	Accuracy	±2°C or ±2%(reading)	
	Wavelength range	7.8µm to 14µm	
	Viewing angle	horizon 25 × vertical 19	
	Emissivity rang	0.01 to 1.0	
	IR Resolution	640 × 480 pixels	
 Multi-Parameter (TSI-8386)	Velocity	Meas. range	0 to 50m/s
		Resolution	0.01m/s
		Accuracy	±3% or ±0.015m/s
	Temperature	Meas. range	-17.8 to 93.3°C
		Resolution	0.1°C
	Humidity	Accuracy	±0.3°C
Meas. range		0.0 to 95.0% RH	
Resolution		0.01% RH	
	Accuracy	±3% RH	

<p>Heat Flow Meter (TESTO 435 Set)</p>	Data Logger (1)	Meas. range	NTC type : -50 to +150°C
		Resolution	0.1°C
	Heat Flow Meter (2)	Oper. temp.	-20 to +50°C
		Meas. range	-20 to +50°C

3. Apartment insulation and dew condensation performance evaluation

3.1. Subjects to be measured and method

Domestic apartments represent the most development and demand centered on new cities. The development and planning of a new city began in the 1980s and is divided into first generation (late 1980s to mid 1990s) and second generation (late 2000s). In this study, apartments were selected as subjects to be measured in the new city constructed according to the planning year of two generations. And, additional 1.5 apartments were selected arbitrarily because the difference of the planning year of the two generations occurred, and the insulation and dew condensation performance of total 55 apartments were analyzed.

The trend of thermal insulation performance by aged year was analyzed by TDRo of external walls, and then, the representative unit home by generation of each new city was selected and the external walls U-Value was analyzed by HFM measurement method. In the representative unit home, accurate measurement was performed to determine whether indoor dew condensation occurred (TDRi). Table 3 shows the outline and classification of analysis objects selected under the above conditions

Table 3. Classification of analysis objects

New Town	17	1.57	27
Completion Year	1985~1996	1997~2006	2007~2015
Building ¹⁾	Case_1~20	Case_21~40	Case_41~55
Unit Home ²⁾	4	3	4

1) Building : TDRo

2) Unit Home : TDRo, TDRi, U-Value

The external wall thermal insulation performance evaluation was performed on the sidewall structure that has the largest heat gain and heat loss and is directly facing the outside air. Through thermo-graphic before the measurement, areas where surface temperature is high or not homogeneous such as heat bridge areas, insulation materials leaks, other construction problems, external walls of non-heating spaces, etc. were excluded. Under the above conditions, the measurement was carried out in the winter when the temperature difference between indoor and outdoor is more than 10 °C.

3.2. Trend analysis of thermal insulation performance of main external walls

Table 4 below shows the TDRo calculation results of external walls (sidewalls) by subject to be measured(55 apartments).

Table 4. Analysis Result of Exterior Wall TDRo

	Case	Year	Outdoor Temp	Surface Temp	TDRo	Case	Year	Outdoor Temp	Surface Temp	TDRo
	1st generation (1985 ~ 1996)	1	1986	0.3	4.7	-0.235	11	1993	3.8	7.7
2		1987	-1.9	4.1	-0.237	12	1993	7.6	10.0	-0.194
3		1987	0.6	5.6	-0.234	13	1994	4.3	8	-0.284
4		1989	-7.3	-3.0	-0.149	14	1994	2.5	7.3	-0.270
5		1991	-7.1	-3.3	-0.135	15	1994	5.6	8.7	-0.212
6		1992	3.4	5.8	-0.145	16	1995	4.0	8.8	-0.300
7		1992	3.0	7.4	-0.259	17	1995	2.5	10.4	-0.367
8		1992	7.5	11.1	-0.288	18	1995	2.7	7.7	-0.291
9		1993	7.6	11.1	-0.282	19	1995	7.2	10.7	-0.274
10		1993	4.0	7.7	-0.231	20	1996	8.2	10.2	-0.169
1.5 generation (1997 ~ 2006)	21	1997	7.2	10.8	-0.281	31	2003	1.2	4.7	-0.186
	22	2000	7.5	9.6	-0.168	32	2004	1.6	4.6	-0.163
	23	2001	2.8	7.8	-0.291	33	2004	6.8	8.8	-0.152
	24	2001	7.7	10.4	-0.220	34	2004	5.0	8.3	-0.220
	25	2001	-6.5	-1.7	-0.163	35	2005	0.9	3.5	-0.136
	26	2001	7.2	8.6	-0.109	36	2005	7.2	8.0	-0.063
	27	2002	-3.3	0.6	-0.164	37	2005	6.7	9.4	-0.203
	28	2002	7.5	8.4	-0.072	38	2005	5.0	7.3	-0.153
	29	2003	2.0	5.4	-0.166	39	2006	-1.5	3.4	-0.218
	30	2003	0.0	5.4	-0.270	40	2006	-7.2	-0.6	-0.219
2nd generation (2007 ~ 2015)	41	2007	2.9	4.9	-0.117	49	2009	3.5	3.5	-0.000
	42	2008	3.7	5.3	-0.098	50	2009	2.9	4.2	-0.076
	43	2008	6.4	6.5	-0.007	51	2011	5.3	6.0	-0.048
	44	2008	5.2	5.3	-0.007	52	2011	3.9	4.7	-0.050
	45	2009	2.4	5.3	-0.167	53	2013	3.6	5.1	-0.091
	46	2009	2.4	5.7	-0.188	54	2014	3.3	4.0	-0.042
	47	2009	3.0	5.1	-0.124	55	2015	2.2	5.6	-0.191
	48	2009	5.2	5.9	-0.047	※ The shaded are subjects for housing unit measurement				

The thermal insulation performance of the wall through TDRo is considered to be poorer as the thermal insulation performance converges to -1, conversely, as converges to 0, the thermal insulation performance is better. In the TDRo analysis of 55 measurement subjects analyzed in this study, TDRo represented the trend pattern of index type converging to -1 in proportion to the increasing number of years. Each measured subject to be measured does not show a proportional thermal insulation performance depending on the year of construction due to the influence of surrounding environment and the firmness of the insulation construction. However, after the completion, it is

evaluated that it is different from initial performance of building as the years go by.

Analysis of distribution of TDRo by new city generation shows that the average TDRo of in the second new city is -0.084. This shows that the TDRo distribution values are 2.2 times (-0.181) and 2.8 times (-0.240) lower than the TDRo measurement results for the apartment building in the 1.5 and 1 generation new town.

The initial thermal insulation performance is different due to the difference of the insulation design value according to the legal insulation design standard of the completion year by analysis subject, but compared with the legal insulation design performance standard, the thermal insulation performance gradually deteriorate after completion in all subjects. Under a pattern in which index form thermal insulation performance deterioration occurs according to aged change, it is analyzed that the time point of deterioration of the primary insulation performance, in which the deterioration rate in thermal insulation performance slightly increases from 14 to 16 years after the completion of the construction (as of 2016), appears, and the deterioration point of the secondary insulation performance, in which the deterioration rate of thermal insulation performance increased again from the point that 20 years have passed after that.

3.3. HFM analysis of external walls of Unit Home

To verify the thermal insulation performance analysis (TDRo) and to quantitatively analyze deterioration rate of the thermal insulation performance in 55 apartments, we selected each typical Unit Home (Table 3) by generation new city of subjects to be measured and derived the U-value of the wall through the HFM measurement method. In order to obtain long - term useful data according to the characteristics of HFM measurement, we measured for 120 hours in this study. However, the measurement data of the first 12 hours after the installation of the measuring equipment was regarded as an unstable period of heat flow through the wall and excluded from the analysis. In this study, effective data for the U-value measurement of the wall heat transfer rate in this study is data measured for a total of 108 hours from 13 hours to 120 hours after the measurement. The following Table 5 and 6 show the analysis result of U-value through HFM measurement by measurement Unit Home, and Fig. 2 shows the result of comparing and analyzing the HFM measurement results compared with the initial thermal insulation performance planned and constructed of measurement unit home.

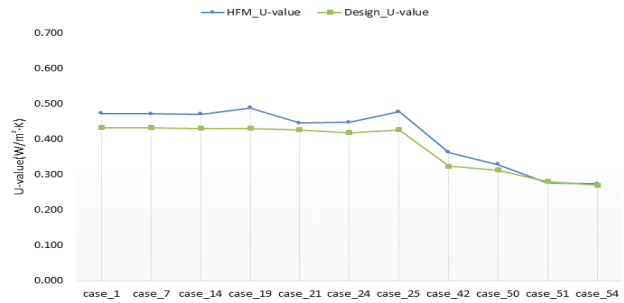


Figure 2. Analysis Result of The Variance Error of U-Value

As a result of the analysis, the average U-value of HFM measured in the new city (Case_2, 7, 14, 19) apartment in the 1 generation new city passed an average of 20 years (as of 2016) was $0.475\text{W/m}^2\cdot\text{K}$, and the performance was found to be deteriorated by about 10.2% when compared with the U-value of the initial thermal insulation performance (average, $0.431\text{W/m}^2\cdot\text{K}$). In case of 1.5 generation new city (Case_21, 24, 25), which passed more than 15 years and less than 20 years after completion, the average U-value of HFM was $0.456\text{W/m}^2\cdot\text{K}$, and the performance was found to be deteriorated by about 7.7% when compared with the initial thermal insulation performance (average, $0.423\text{W/m}^2\cdot\text{K}$). In case of 2 generation new city (Case_42, 50, 51, 54, the average U-value of HFM was $0.310\text{W/m}^2\cdot\text{K}$, and the performance was analyzed to be deteriorated by about 4.6% when compared with the initial thermal insulation performance (average, $0.296\text{W/m}^2\cdot\text{K}$).

In contrast to the initial thermal insulation performance, the average deterioration rate of decrease was 4.6% in apartments passed less than 15 years after completion, and in Case_25 apartment where 15 years passed, a rapid deterioration rate of 11.8% compared with the initial thermal insulation performance appeared, which was evaluated as the deterioration point of the initial thermal insulation performance. Thermal insulation performance of apartments passed more than 16 years and less than 20 years showed average deterioration rate of 5.6% compared with the initial thermal insulation performance. However, in Case_19 apartment where 21 years passed, thermal insulation performance showed average deterioration rate of 13.3% compared with the initial thermal insulation performance, which was evaluated to show the deterioration point of secondary thermal insulation performance

As shown in Fig. 2, U-value analysis result of external walls by HFM measurement method showed a deterioration pattern of thermal insulation performance according to aged change similar to the result presented in the TDRo analysis

Table 5. Result of Calculation & Measurement U-Value by Unit Home(Case_1 ~ 5)

Case	Exterior Wall	Material	Thickness (m)	Thermal Conductivity (W/m·K)	Thermal Resistivity (m ² ·h·°C/W)	Results of HFM U-Value(W/m ² ·K)
2		Outdoor Resistivity	-	-	0.043	
		Concrete	0.180	1.600	0.113	
		Glass Wool	0.070	0.035	2.000	
		Gypsum Board	0.009	0.180	0.050	
		Indoor Resistivity	-	-	0.110	
	Total				2.315	
	Calculation of U-Value(W/m ² ·K)				0.432	
Measurement of U-Value(W/m ² ·K)				0.472		
7		Outdoor Resistivity	-	-	0.043	
		Concrete	0.180	1.600	0.113	
		Glass Wool	0.070	0.035	2.000	
		Gypsum Board	0.009	0.180	0.050	
		Indoor Resistivity	-	-	0.110	
	Total				2.315	
	Calculation of U-Value(W/m ² ·K)				0.432	
Measurement of U-Value(W/m ² ·K)				0.471		
14		Outdoor Resistivity	-	-	0.043	
		Concrete	0.200	1.600	0.125	
		Glass Wool	0.070	0.035	2.000	
		Gypsum Board	0.009	0.18	0.500	
		Indoor Resistivity	-	-	0.110	
	Total				2.328	
	Calculation of U-Value(W/m ² ·K)				0.430	
Measurement of U-Value(W/m ² ·K)				0.470		
19		Outdoor Resistivity	-	-	0.043	
		Concrete	0.200	1.600	0.125	
		Glass Wool	0.070	0.035	2.000	
		Gypsum Board	0.090	0.180	0.050	
		Indoor Resistivity	-	-	0.110	
	Total				2.328	
	Calculation of U-Value(W/m ² ·K)				0.430	
Measurement of U-Value(W/m ² ·K)				0.487		
21		Outdoor Resistivity	-	-	0.043	
		Concrete	0.200	1.600	0.125	
		Glass Wool	0.070	0.035	2.000	
		Gypsum Board	0.012	0.180	0.068	
		Indoor Resistivity	-	-	0.110	
	Total				2.345	
	Calculation of U-Value(W/m ² ·K)				0.426	
Measurement of U-Value(W/m ² ·K)				0.444		
24		Outdoor Resistivity	-	-	0.043	
		Concrete	0.200	1.600	0.125	
		EPS	0.070	0.031	2.059	
		Gypsum Board	0.012	0.180	0.067	
		Indoor Resistivity	-	-	0.110	
	Total				2.390	
	Calculation of U-Value(W/m ² ·K)				0.418	
Measurement of U-Value(W/m ² ·K)				0.446		

Table 6. Result of Calculation & Measurement U-Value by Unit Home(Case_1 ~ 5)

Case	Exterior Wall	Material	Thickness (m)	Thermal Conductivity (W/m·K)	Thermal Resistivity (m ² ·h·°C/W)	Results of HFM U-Value(W/m ² ·K)
25		Outdoor Resistivity	-	-	0.043	
		Concrete	0.200	1.600	0.125	
		Glass Wool	0.070	0.035	2.000	
		Gypsum Board	0.0125	0.180	0.069	
		Indoor Resistivity	-	-	0.110	
	Total				2.347	
	Calculation of U-Value(W/m ² ·K)				0.426	
Measurement of U-Value(W/m ² ·K)				0.476		
42		Outdoor Resistivity	-	-	0.043	
		Concrete	0.200	1.600	0.125	
		Glass Wool	0.105	0.035	2.763	
		Gypsum Board	0.0095	0.180	0.053	
		Indoor Resistivity	-	-	0.110	
	Total				3.094	
	Calculation of U-Value(W/m ² ·K)				0.323	
Measurement of U-Value(W/m ² ·K)				0.361		
50		Outdoor Resistivity	-	-	0.043	
		Concrete	0.200	1.600	0.125	
		Glass Wool	0.100	0.035	2.857	
		Gypsum Board	0.0125	0.180	0.069	
		Indoor Resistivity	-	-	0.110	
	Total				3.205	
	Calculation of U-Value(W/m ² ·K)				0.312	
Measurement of U-Value(W/m ² ·K)				0.328		
51		Outdoor Resistivity	-	-	0.043	
		Concrete	0.200	1.600	0.125	
		EPS	0.100	0.031	3.226	
		Gypsum Board	0.012	0.180	0.067	
		Indoor Resistivity	-	-	0.110	
	Total				3.571	
	Calculation of U-Value(W/m ² ·K)				0.280	
Measurement of U-Value(W/m ² ·K)				0.276		
54		Outdoor Resistivity	-	-	0.043	
		Concrete	0.200	1.600	0.125	
		EPS	0.105	0.031	3.387	
		Gypsum Board	0.090	0.180	0.050	
		Indoor Resistivity	-	-	0.110	
	Total				3.715	
	Calculation of U-Value(W/m ² ·K)				0.269	
Measurement of U-Value(W/m ² ·K)				0.273		

3.4. TDRi analysis by vulnerable site of dew condensation occurrence of Unit Home

In comparison with the TDRi calculation value by internal surface temperature measurement of the measurement unit home (11) and the minimum performance standard for preventing dew

condensation, dew condensation occurrence by thermal insulation performance deterioration was analyzed. However, this study aimed to derive the timing of remodeling according to the change of insulation and dew condensation performance of external walls, so the dew condensation performance evaluation was performed to evaluate the occurrence of dew condensation of window and wall

junction of the room where the side wall was located except the door. In Table 7, the surface temperature and the indoor and outdoor temperatures shown on the vulnerable areas of each dew condensation show the analysis results measured and averaged for 6 hours, and Figure 3 to 5 show the comparison and analysis results compared with the minimum performance standard.

Table 7. Result of Surface Temperature & TDRi

New town	Case N	Temp.		Surface Temperature(°C)			TDRi				
		In	Out	Wall Junction	Window		Wall Junction	Window			
					Glass Central	Glass Corner		Leaf / Frame	Glass Central	Glass Corner	Leaf / Frame
1st	2	22.8	4.7	17.2	21.6	20.4	20.7	0.16	0.21	0.40	0.25
	7	18.7	5.0	10.6	17.2	16.1	16.0	0.28	0.37	0.42	0.36
	14	22.3	0.3	16.3	18.9	17.8	18.2	0.25	0.18	0.22	0.15
	19	18.6	1.0	9.5	16.4	14.1	13.1	0.34	0.11	0.39	0.35
1.5	21	18.3	0.1	9.8	17.8	15.7	14.2	0.16	0.13	0.14	0.12
	24	21.1	-0.4	14.1	18.7	17.7	17.4	0.30	0.13	0.13	0.08
	25	22.3	0.3	17.4	21.7	20.2	20.9	0.29	0.13	0.22	0.15
2nd	42	23.0	1.1	15.7	22.5	20.4	19.9	0.27	0.26	0.34	0.25
	50	20.1	-4.0	15.4	19.1	17.1	18.2	0.18	0.09	0.16	0.08
	51	18.5	0.1	14.0	16.8	16.0	16.9	0.25	0.13	0.23	0.22
	54	22.3	3.1	19.8	19.4	19.1	18.9	0.21	0.12	0.18	0.18

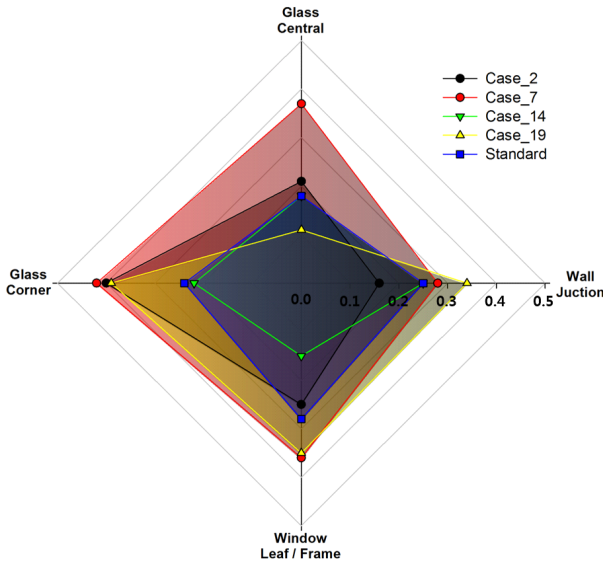


Figure 3. Comparison-analysis of 1st generation new city's TDRi

As shown in Fig. 3, in the 1st generation new city apartment, it was analyzed that dew condensation occurred as most vulnerable areas appeared beyond the minimum performance standard (blue area). In particular, the corner area of window glass was 1.7 times (average 0.41) higher than the standard TDRi (0.22) value. And the apartments in the 1st generation new city, which were old apartments passed an average of 24 years, were evaluated that thermal insulation performance of the external walls was

deteriorated greatly and dew condensation occurred in the wall joint at all households.

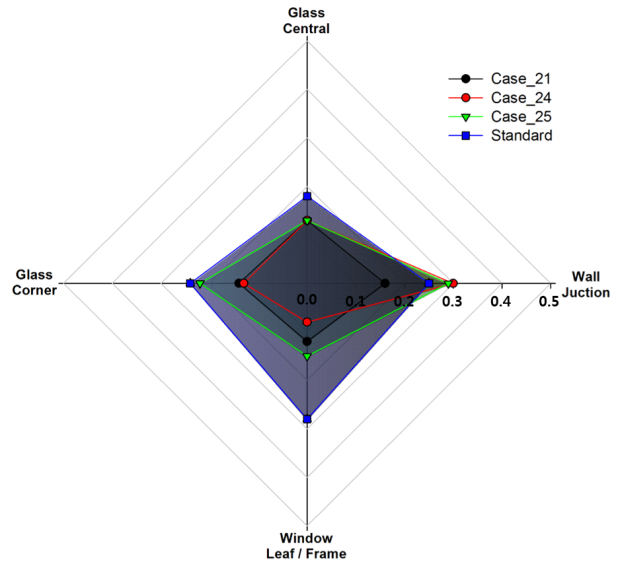


Figure 4. Comparison-analysis of 1.5 generation new city's TDRi

As shown in Fig. 4, the apartments of the 1.5 generation new city was found to satisfy the minimum performance standard in the rest of vulnerable areas except for the wall junction. In case of more than 15 years after completion of construction, similar to TDRo and HFM analysis results with the high risk of dew condensation of more than 10% of performance deterioration compared to the standard (0.25) at wall junction, and average 16 years of age, the thermal insulation performance was evaluated to show characteristics that decrease rapidly

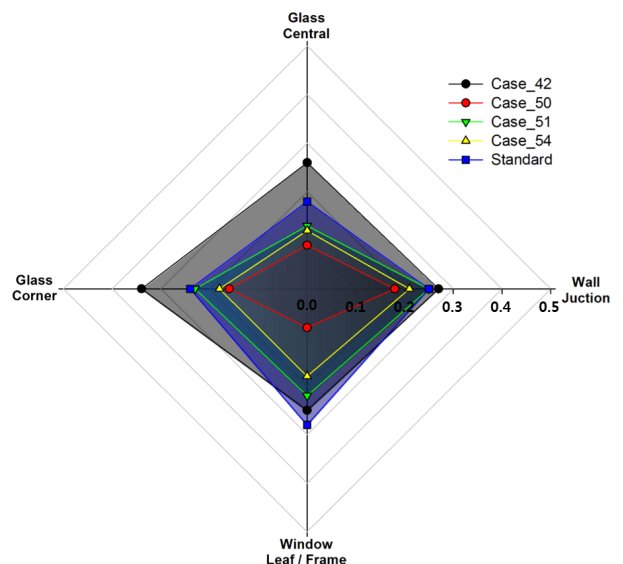


Figure 5. Comparison-analysis of 2nd generation new city's TDRi

As shown in Fig. 5, in the 2nd generation new city apartment, the rest of measurement home except for Case_42, were found to meet the minimum performance standard for preventing dew condensation. In Case_42, there was a high risk of dew condensation in the window, and TDRi of the wall junction which is directly related to the thermal insulation performance of external walls, was 0.2 higher than the minimum performance compared to standard (0.25), and it was evaluated that the risk of dew condensation was not high.

As a result of analyzing the thermal insulation performance deterioration due to aged change of Unit Home by new city and residential environment (dew condensation) performance caused by this, the risk (occurrence frequency) of dew condensation of wall junction and window was also high after 15 years or more after completion and again 20 years later that thermal insulation performance deterioration rate was markedly higher.

4. Conclusion

According to the results of analysis of thermal insulation performance and risk of occurrence of dew condensation in apartment external walls by aged change, the main results of this study suggesting the proper timing of remodeling external walls of old buildings are as follows.

As a result of evaluating the thermal insulation performance change trend of external walls by standard of TDRo analysis result, the thermal insulation performance shows the point at which thermal insulation performance deterioration rises primarily after about 14 to 16 years after completion with the initial (design) thermal insulation performance standard. On the other hand, Case_42, despite the apartment complex completed in 2008 (8 years of elapsed years) showed a deterioration rate similar to Case_25. It is determined that the error range of measurement results is considerably increased due to the solidity of the insulation construction, the wet condition of the wall, the influence of the surrounding environment, and the thermal insulation pattern of the residents. It was analyzed to show the second deterioration point that the thermal insulation performance rapidly deteriorated from the time that 20 years passed after that.

The tendency of deterioration of thermal insulation performance showed the similar characteristics in U-Value analysis result through HFM measurement method for typical unit home. Thermal insulation performance deterioration rate of external walls was less than 2% in 5 years of elapsed years after completion of the building, while thermal insulation performance of the external walls after 10 to 15 years elapsed showed the characteristics deteriorated by average 8.7% compared with the initial performance. And the thermal insulation performance of

deteriorated apartment buildings over 20 years showed thermal insulation performance deteriorated more than average 10.2%.

In addition, in the point at which thermal insulation performance deterioration appears clearly, the point 15 years passed after completion and the point more that 20 years passed, the risk of dew condensation in wall junction and window frames was significantly high.

As the results of analysis of deterioration of thermal insulation performance and the occurrence of residential environment problem by aged change, it is considered that measures and systematic management are required to improve thermal insulation performance from the point at least 15 years passed after completion of the building, and the remodeling action should be performed to improve the thermal insulation performance substantially before the maximum 20 years passed after completion.

Acknowledgements

This study was conducted by support of Korean Research Foundation (NRF-2014R1A1A2059927) funded by government (Ministry of Education, Science and Technology).

Reference

- [1] Choi, Gyeong-Seo, On-site Evaluation for Thermal Performance of Building Envelope using an Infrared Method, Department of Architectural Engineering Graduate School, Hanyang University, 2010
- [2] Choi, Bo-Hye, Kang, Jae-Sik, "The Thermal Performance of Building Insulation Materials According to Long-Term Aging, Korean Journal of Air-Conditioning and Refrigeration Engineering, Vol.25, No. 11, 2013
- [3] Park, Se-Young, A study on the improvement of the condensation prevention standards in residential buildings, Department of Convergence Engineering for Future City Sungkyunkwan University, 2014
- [4] Jeong, Chan-woul, Kim, Hyun-Soo, Jeong Su-Hyeon, kim, Young-Tak, Song, Doo-sam, Comparison and Analysis of Domestic and Foreign Standards for Preventing the Condensation in Multi-residential House, Korean Journal of Air-Conditioning and Refrigeration Engineering, 2013
- [5] PARK, Jung-Hun, An Analysis of Thermal Insulation and a Study of Application of Reinforced Insulation in Apartment Houses, Department of Architectural Material Graduate School of Kong-ju National University, 2014
- [6] Moore, Patrick O, "Nondestructive Testing Handbook : Infrared & Thermal Testing, American Society for Nondestructive Testing", 2001
- [7] Akira Hoyano, Kohichi Asano, Takehisa Kanamaru, "Analysis of the sensible heat flux from the exterior surface of buildings using time sequential thermography", Atmospheric Environment 33, 1999