EVALUATION ON THERMAL PERFORMANCE COMBINED WITH MEASUREMENT AND SIMULATION FOR DEVELOPMENT OF ON-SITE EVALUATION METHOD

Gyoung Soek Choi[1], Kyoung Woo Kim[1], Jae Sik Kang[1], Seung Eon Lee[1]

[1]Building & Urban Research Department, Korea Institute of Construction Technology, Gyeonggi-Do, 411-712, Republic of Korea

ABSTRACT

The last object of this study is to develop standard method for building insulation performance on-site evaluation using Infra-red camera. The goals of this study are 1) to propose the Temperature Difference Ratio (TDR) which is an on-site evaluation index for building thermal performance, 2) to measure thermal condition of the mock-up structure as actual building structure by T-type thermocouple sensor and infra-red camera, 3) to perform heat transfer simulation on the mock-up structure by PHYSIBEL simulation program, 4) to analyze measurement and simulation results.

The insulation performance evaluation method obtained on the basis of the study will be utilized for evaluation of insulation defects after the completion of the construction of a new building and quantitative evaluation of insulation performance before and after repairs, therein contributing to the improvement of the environment and thermal performance of the building.

KEYWORDS

Thermal performance, On-site evaluation method, Infra-red thermograph, Temperature Difference Ratio (TDR), Heat transfer simulation

INTRODUCTION

Background and aims of the study

There are many instances where the actual thermal performance of a building has different thermal characteristics to what was intended in the design stages due to many reasons including the level of soundness in site construction, deterioration from changes in heat insulation material from ageing, moisture content changes in the wall interior based on the regional characteristics (Lee et al. 2003), occurrence of cracks due to structural defects etc. Apart from the increase in energy loss, these changes in heat insulation performance are revealing occurrences of structural defects and shortening the life of the building (KICT 2003). Although there is a need for quantitative evaluation of insulation performance in building walls regarding the reduction in thermal performance of building walls, the present reality is that a standard evaluation method has not been developed. Also, infra-red thermal measurement devices are at a standard where they are utilized as study reference equipment and diagnosis of thermal performance in buildings (KICT 1997).

Accordingly, this study is a plan for improving the environment & thermal performance of buildings and increasing building life, and it aims at proposing a quantitative on-site evaluation method for the insulation performance in buildings using infra-red thermal imaging analysis techniques.

Study methods

The greatest feature of the infra-red diagnosis method is that large areas can be diagnosed without contact, and the results can be recorded and kept in images. The high reliability of the data leads to frequent use in building insulation diagnosis (Moore 2001).

The aim of this study is to produce a quantitative measurement of insulation performance in buildings using an infra-red camera. Although there needs to be a system and heat flow measurement to maintain constant temperature conditions on the measurement area for a quantitative analysis of insulation performance, this application is not possible with the actual on-site conditions, so this study proposes an index called Temperature Difference Ratio (TDR) on the defective parts. By using this, an insulation performance evaluation method for buildings is produced and proposed (Choi et al. 2004).

In addition, in this study, we measured and simulated laboratory mock-up samples to compare and evaluate insulation performance as a step prior to the implementation of a construction site insulation performance evaluation method using the infrared thermal imaging system.

1) Analysis of temperature and heat flow patterns for each section of the building using PHYSIBEL simulation program

2) Proposal of TDR, an evaluation index of building insulation performance

3) Comparative evaluation of the insulation performance of the mock-up structure by means of

measurements using the infrared camera and surface temperature sensor and the PHYSIBEL simulation

ANALYSIS OF TEMPERATURE AND HEAT FLOW PATTERNS FOR EACH PART OF THE BUILDING

Simulation overview and interpretation process

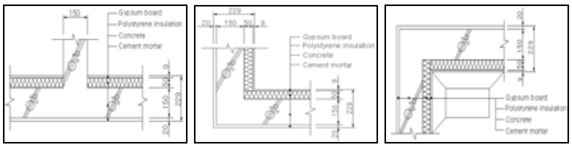
As each part of a building has a multi-layered composite structure, and columns and beams create 3-dimensional heat flow, it is difficult to accurately interpret infrared camera thermal images without prior knowledge of the building envelope structure. Up until now, evaluating the insulation performance of a building has been limited to the detection of parts with relatively low surface temperature using the IR camera, but the relatively high or low temperature shown in thermal images does not simply translate into the presence of thermal defect. (KICT 2003).

Accordingly, in this study, for analysis of the anticipated envelope temperature distribution and heat flow pattern of the building envelope as a step prior to using the infrared thermal imaging system to evaluate insulation performance, the PHYSIBEL program which can interpret heat transfer in a steady-state conditions is used in this study. PHYSIBEL program is a computer silumation program capable of evaluating the thermal environment of the building by graphically visualizing the analysis results that can be used for analyzing the heat flow of the entire building and part of the building, heat conductivity, and thermal bridge.

The shape of the building walls for each angled section and the property of the material matter constituting the wall are set, and using the heat transfer interpretation program, interior & exterior temperatures, surface temperature distribution and patterns from the reflex angle section (heat transfer section) to the normal wall sections in accordance with insulation performance conditions are produced.

The reflex angle sections of the wall selected as the subject of the interpretation consists of the following parts which are representations of general buildings, ① walls between floors & partition walls and the horizontally joined exterior wall sections (flat reflex angle sections), ② 2 adjacent exterior wall sections joined horizontally (reflex angle sections of 2 wall surfaces), ③ corner sections where 3 exterior walls are joined (reflex angle sections of 3 wall surfaces).

With the wall surface temperatures produced ① the surface temperature difference ratio (C) of the reflex angle section in accordance with the insulation conditions (heat transfer section, T_c) and the normal section (T_p) are calculated, and the functional relation (f'(x)) with each insulation condition and the calculated ratio is constructed, and ② the rate of change in surface temperature (E) in accordance with the distance from the reflex angle section is calculated and regression analysis is conducted for the rate of change using the model formula in a function form. This mathematical model, a function formula made using the variations of the reflex angle section shapes and insulation conditions together with the surface temperature difference ratio results gained from a limited simulation, can predict surface temperatures of reflex angle sections of the wall and the surface temperature distribution in accordance with the distance from the reflex angle section using the shape of the reflex angle section and insulation condition (rate of overall heat transmission (K) in normal sections of the wall). A summary of the formula model construction process is shown in the following figure 2.



a) Dimension of modeling wall

b) Thermal conductivity of modeling wall

Figure 1 Simulation subject wall for pattern analysis

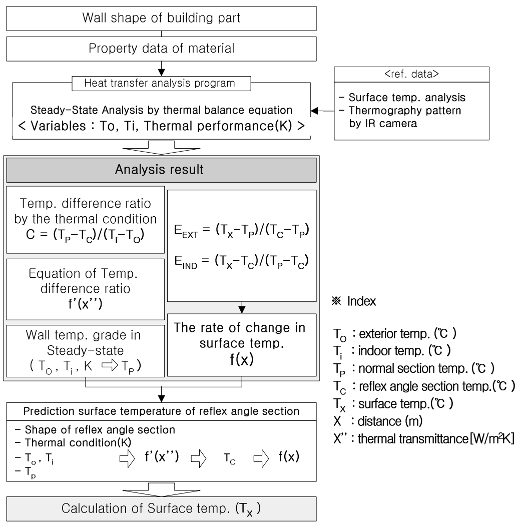


Figure 2 Process for predicting model surface temperature of reflex angle wall sections

Results of surface temperature & heat transfer pattern analysis for each wall section

The results of temperature change rate of the wall surface in accordance with the changes in outside air temperatures made dimensionless according to the rate of change formula (E) of the interior & exterior surface temperatures based on the the distance from the heat bridge section as proposed in figure 2 are shown in figure 3. Depending on the outside air temperature, the temperature difference between the interior/exterior heat transfer section and normal sections is high, but the ratio was found to be similar indicating that the dimensionless surface temperature is constant regardless of seasonal changes (changes in the outside air temperature) (Jeong et al. 2003).

In accordance with insulation conditions of each wall section, the model formula of the rate of change in surface temperature (E) and the surface temperature difference ratio (C) between the defective and normal sections is arranged in table 1.

$$E_o = \frac{T_x - T_{nt}}{T_{dt} - T_{nt}}, \quad E_i = \frac{T_x - T_{dt}}{T_{nt} - T_{dt}} \quad (1)$$

$$C_o = \frac{T_{nto} - T_{dto}}{T_i - T_o}, \quad C_i = \frac{T_{nti} - T_{dti}}{T_i - T_o} \quad (2)$$

E_o, E_i ; The rate of change in surface temperature

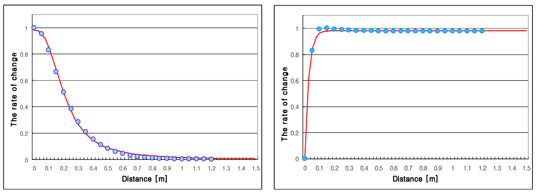
C_o, C_i ; The surface temperature difference ratio

T_x ; Surface temp. in the measuring point

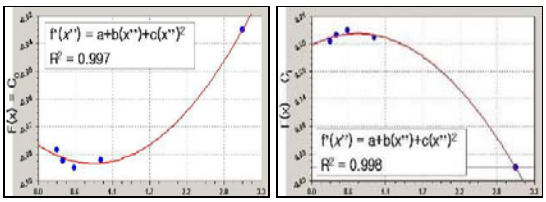
T_{nt} ; Surface temp. in the normal section

T_{dt} ; Surface temp. in the defective section

T_i ; Interior air temp. , T_o ; Exterior air temp.



a) Rate of change in exterior/interior surface temperature



b) Exterior/interior surface temperature difference ratio

Figure 3 The rate of change in surface temp. (E) & surface temperature difference ratio (C) in accordance with thermal performance of the flat section

IR THERMAL IMAGE ANALYSIS METHOD FOR THE EVALUATION OF BUILDING THERMAL PERFORMANCE

Thermal performance of the building exterior cover is fundamentally measured in a steady state. A steady- state is where the boundary conditions (interior/ exterior air temperature & surface heat transmission rate etc.) of thermal performance analysis do not change over time and remains fixed. Because actual buildings have wide areas with diverse exterior sections, heat transfer measurements of all the exterior sections using the direct contact method has many limitations in terms of cost and time. That is why an on-site insulation performance evaluation using an infra-red camera which can capture the temperature distribution of the building exterior at the one time is being proposed as an alternative. This study is conducted to construct a building thermal evaluation method using an infra-red camera, and with this evaluation method, an evaluation method using TDR (KICT 1997, 2003) is to be proposed.

Outline of the TDR, an evaluation index of building thermal performance

To explain the TDR concept based on the thermal equilibrium equation, a one dimensional steady state of the wall is assumed and the thermal equilibrium equation constructed in accordance with this assumption is as follows.

$$Q_1 = U \times A_1 \times (T_i - T_o), \quad Q_2 = \alpha i \times A_2 \times (T_i - T_{is})$$
$$Q_3 = \alpha o \times A_3 \times (T_i - T_{os})$$

In a steady state wall the heat transfer per unit time is identical for any section of the wall, so if $Q_1 = Q_2$, $Q_1 = Q_3$, the following formula is produced.

$$\frac{U \times A_1}{\alpha i \times A_2} = \frac{r \times A_1}{R \times A_2} = \frac{T_i - T_{is}}{T_i - T_o} = TDR_i \quad (3)$$

$$\frac{U \times A_1}{\alpha o \times A_3} = \frac{r \times A_1}{R \times A_3} = \frac{T_o - T_{os}}{T_i - T_o} = TDR_o \quad (4)$$

T_i =interior temp., T_o =exterior air temp.

T_{is} =interior surface temp., T_{os} =exterior surface temp.

Q_1, Q_2, Q_3 = heat transmission in the exterior wall surface (W/m^2)

U = heat transmission rate of the wall ($W/m^2 \cdot K$)

$\alpha i / \alpha o$ =heat transfer rate in wall surface ($W/m^2 \cdot K$)

A_1, A_2, A_3 = exterior surface section area (m^2)

R = heat transmission resistance in the wall

r = interior surface heat transfer resistance ($m^2 \cdot K/W$)

TDR_i is used as a method for deciding condensation in relation to the interior surface section of the wall (KICT 1997), and indicates the rate of difference between the indoor air and surface temperature in relation to the indoor and outdoor temperature difference. TDR_o is for the evaluation of insulation performance of the exterior surface of the building, and is an index produced by applying the TDR_i concept to the exterior surface.

If the thermal resistance of the wall is 0 in the TDR_i equation, the indoor surface temperature will be the same as the temperature of the outdoor air. So TDR_i becomes 1. The greater the thermal resistance of the wall, the greater the indoor surface temperature. So TDR_i approaches 0.

COMBINED EVALUATION ON THERMAL PERFORMANCE OF A MOCK-UP STRUCTURE

As a prior stage of the evaluation on the on-site building thermal performance, to reduce the error difference occurring from solar radiation and wind (KSA 2005), a thermal performance evaluation of a MOCK-UP structure with a insulation non-defect & defect section was conducted through a lab experiment where the indoor & outdoor temperature and humidity could be kept constant with the application of an identical rate of radiation.

The experimental structure for thermal performance measurement, a MOCK-UP structure, consisting of 2 floors in the interior with a scale of 6,000(W) × 1,000(L) × 3,500(H) mm including reflex angle and flat sections was constructed. The mock-up structure, made for the purpose of verifying the building insulation performance evaluation technique, is 150mm-thick concrete structure insulated with 50mm Expanded Polystyrene on the inside, and is finished with 9.5 mm gypsum board, and consists of defective parts and non-defective parts assuming that heat insulating materials are missing and damaged.

Figure 4 illustrates the indoor and outdoor façade of the mock-up structure, and Figures 5 displays the parts of the mock-up that have insulation defects. The theoretical thermal transmission rate based on the thermal resistance of each layer of the mock-up structure is 0.58 $W/m^2 \cdot K$.

Figure 6 shows the shape of the mock-up structure and the physical properties of materials for the PHYSIBEL simulation program, which verifies the reliability of the surface temperature data measured with the T-type thermocouple sensor and infrared thermal imaging system.

The indoor temperature was set at 20℃, 50% and the outdoor temperature at 10, 0, -10℃ and using 1) IR camera, 2) T-Type thermocouple sensor, and 3) PHYSIBEL simulation program the evaluation of insulation performance was conducted.

First, the indoor and outdoor surface temperature measured with the infrared thermal imaging system is compared with the surface temperature measured with the T-type thermocouple sensor in each condition, and adjusting emissivity for correction, and then the surface temperature, TDR_i and TDR_o of each measurement point of the T-type thermocouple sensor and simulation are compared, and the infrared thermal imaging system is used to obtain the mean temperature of each part and mean TDR_i and TDR_o.

Figure 4 Indoor/ outdoor façade of Mock-up structure

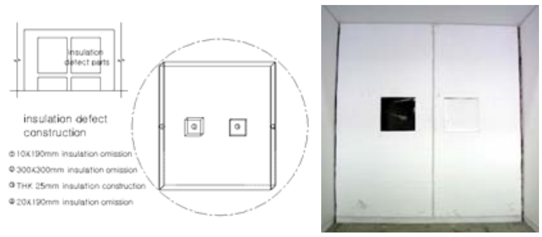


Figure 5 Insulation defects in mock-up structure

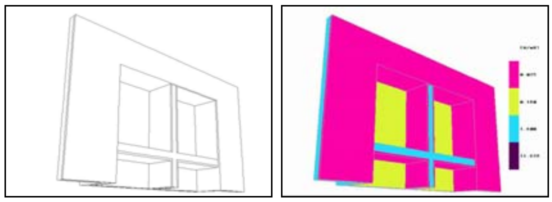


Figure 6 Mock-up shape & property for simulation

Outdoor setting temperature -10 ℃

As a result of the experiement with the outdoor setting temperature set at -10℃, figure 7 shows infrared thermal imaging data of the upper part of the specimen before emissivity adjustment. The corners located at the parts with artificial defects and the structural joints showed low temperature distribution, and figure 8 shows the thermal imaging data of the indoor and outdoor surface temperature data measured with the PHYSIBEL simulation program. The indoor surface temperature is similar to the infrared thermal imaging data, but the thermal bridge phenomenon at the corner is lower than the measurement result obtained from real specimens, and the structural joints and the parts without heat insulating materials show high outdoor surface temperature.

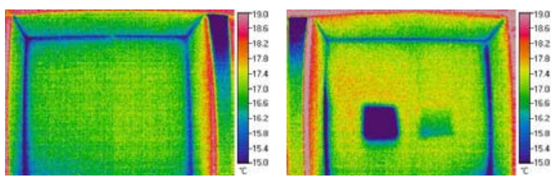


Figure 7 Infra-red thermal imaging data before emissivity adjustment

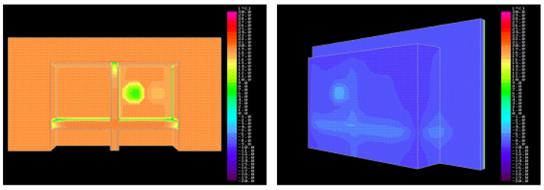


Figure 8 Indoor and outdoor simulation data

Figure 9 shows the surface temperature distribution measured with the thermocouple sensor and the TDR_i and TDR_o, the insulation index of each measurement point. During the measurement perid the mean indoor temperature was 19.7℃, and the mean outdoor temperature was -5.5℃, and the indoor surface temperature and TDR_i of the part finished with the gypsum board were 17.0 ~ 18.7℃ and 0.040 ~ 0.107 for the non-defective parts, and 16.4 ~ 18.2 ℃ and 0.060 ~ 0.131 for the defective parts. The surface temperature and TDR_o of the outdoor curved corner surface temperature were -5.0 ~ 0.0℃ and -0.020 ~ -0.218.

Figure 10 shows the surface temperature, TDR_i and TDR_o measured through simulation. The indoor surface temperature and TDR_i were 18.0 ~ 18.3℃ and 0.057 ~ 0.066 for the non-defective parts, and 17.4 ~ 18.3℃ and 0.058 ~ 0.089 for the defective parts, whereas the surface temperature and TDR_o of the outdoor corner were -9.7 ~ -5.9℃ and -0.011 ~ -0.136.

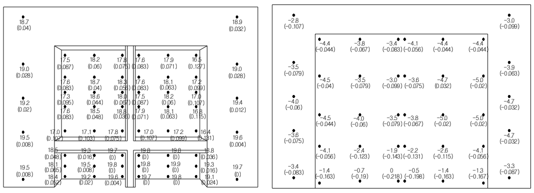


Figure 9 Surface temp. and TDRi, TDRo (T-type sensor)

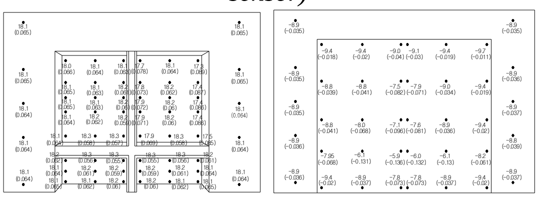
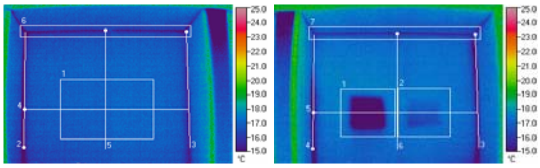


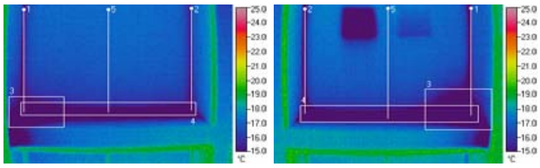
Figure 10 Surface temp. and TDRi, TDRo (Simulation)

Figure 11 shows the infra-red thermal imaging data of the upper and lower part of the non-defect and defect part, and Table 2 shows the mean indoor surface temperature and TDR_i of the flat part and corner.

As for the mean temperature (mean TDR_i) of the flat part, the Rect 1 of the non-defect part was 18.3℃ (0.056), and that of the defect part was 14.6℃(0.020) and Rect 2 of the defect part was 17.5℃(0.087). The insulation performance of the defective part without any heat insulating material insulation performance was about 2.6 times lower, while the heat insulation performance of the part with 25mm heat insulation materials was 55% lower than that of the non-defect part. In addition, Line 4 and 5 of the non-defect part (upper) were 18.1 ℃ (0.063) and 18.0 ℃ (0.067) respectively, showing relative good insulation performance in general. Line 5 of the defect part (upper) was 16.7℃(0.119), and Line 6 was 17.7℃ (0.079). The heat loss due to the lack of heat insulating materials worsened insulation performance.



(a) non-defect section(upper) *(b) defect section(upper)*



(c) non-defect section(lower) *(d) defect section(lower)*

Figure 11 Infra-red thermal imaging data

Table 2 Mean surface temperature & TDRi

Fig. 11(a)	Rect. 1	Line 2	Line 3	Line 4	Line 5	Rect. 6
ST*	18.3	15.9	16.7	18.1	18.0	17.1
TDR*i*	0.056	0.151	0.119	0.063	0.067	0.103

Fig. 11(b)	Rect. 1	Rect. 2	Line 3	Line 4	Line 5	Line 6	Line 7
ST*	14.6	17.6	15.3	15.5	16.7	17.7	17.0
TDR*i*	0.202	0.087	0.175	0.167	0.119	0.079	0.107

Fig. 11(c)	Line 1	Line 2	Rect. 3	Rect. 4	Line. 5
ST*	15.6	16.4	14.7	14.5	17.9
TDR*i*	0.163	0.131	0.198	0.206	0.071

Fig. 11(d)	Line 1	Line 2	Rect. 3	Rect. 4	Line. 5
ST*	15.1	15.3	14.5	14.2	17.8
TDR*i*	0.183	0.175	0.206	0.218	0.075

ST*: Surface Temperature

Outdoor setting temperature 0°

As a result of the experiement with the outdoor setting temperature set at 0℃, Figure 12 shows the surface temperature distribution measured with the T-type sensor, and the TDR_i and TDR_o, the insulation performance indexes of each measurement point. During the measurement period, the mean indoor temperature was 20.0℃, and mean outdoor temperature was 1.7 ℃ . The indoor surface temperature and TDR_i of the part finisihed with the gypsum board were 18.0 ~ 19.3℃ and 0.038 ~ 0.109 for the non-defective part, and 17.6 ~ 18.9℃ and 0.060 ~ 0.131 for the defective part. The surface temperature and TDR$_o$ of the outdoor corner were 2.1 ~ 5.7℃ and -0.022 ~ -0.219.

Figure 13 shows the surface temperature, TDR$_i$ and TDR$_o$ measured through simulation. The indoor surface temperature and TDR$_i$ were 18.7 ~ 18.9℃ and 0.057 ~ 0.066 for the non-defect parts, and 18.3 ~ 18.8℃ and 0.058 ~ 0.087 for the defect parts. The surface temperature and TDR$_o$ of the outdoor curved corner were 0.4 ~ 2.7℃ and -0.011 ~ -0.136.

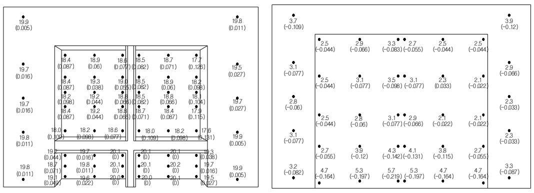


Figure 12 Surface temp. and TDRi, TDRo(T-type sensor)

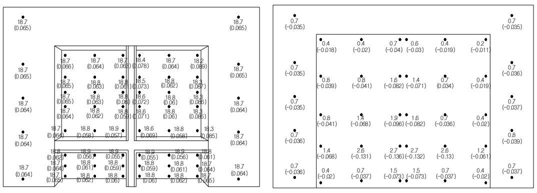


Figure 13 Surface temp. and TDRi, TDRo(Simulation)

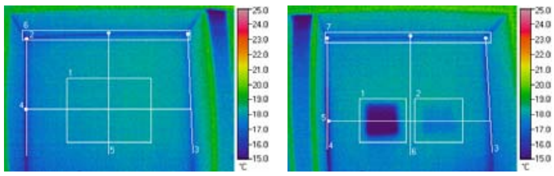
Figure 14 shows the infra-red thermal imaging data, and Table 3 shows the indoor mean surface temperature and TDR$_i$ of each part. As for the mean temperature (mean TDR$_i$), Rect 1 for the non-defect part was 18.9℃(0.060), and Rect 1 of the defect part was 16.2℃(0.208) and Rect 2 was 18.3℃(0.093). The insulation performance of the defect part with the insulating materials completely missing was about 2.5 times lower, whereas the part with 25mm heat insulating material was about 55% lower than thar of the non-defect parts. In addition, Line 4 and 5 of the non-defect part (upper) were 18.9℃(0.060) and 18.8 ℃ (0.066) respectively, showing good insulation performance in general. Line 5 of the defect part (upper) was 17.7℃(0.126), and Line 6 was 18.6℃(0.077). The heat loss caused by the heat insulating material defect lowered insulation performance.

The corners, equivalent to the joints of each part of the structure generally showed higher TDR$_i$ than the flat parts, thereby lowering insulation performance. The insuation performance of Line 2 of the non-defect part (upper) was lower than that of Line 3, about 17% in terms of TDR$_i$. In addition, the insulation performance of the defect part (upper) was about 20% lower at Line 3 and about 40% lower at Line 4 due to the heat insulating material defect than the same coners of the non-defect part (upper).

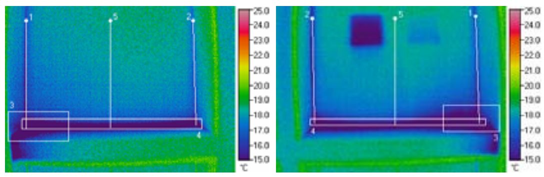
The lower part of the mock-up shower lower surface temperature distribution(high TDR$_i$ distribution) than the upper part. As the joints of the vertical and horizontal structure were poorly insulated at Rect 3 and Rect 4, there is a severe thermal bridge phenomenon likely to create thermal defects on the indoor surface, such as condensation.

Outdoor setting temperature 10 ˚

As a result of the experiment with the outdoor setting temperature set at 10℃, figure 15 shows the surface temperature distribution measured with the T-type ensor, and TDR$_i$ and TDR$_o$, the insulation performance indexes of each point.



(a) non-defect section(upper) *(b) defect section(upper)*



(c) non-defect section(lower) *(d) defect section(lower)*

Figure 14 Infra-red thermal imaging data

Table 3 Mean surface temperature & TDRi

Fig. 14(a)	Rect. 1	Line 2	Line 3	Line 4	Line 5	Rect. 6
ST*	18.9	17.3	17.8	18.9	18.8	18.1
TDR*i*	0.06	0.148	0.120	0.06	0.066	0.104

Fig. 14(b)	Rect. 1	Rect. 2	Line 3	Line 4	Line 5	Line 6	Line 7
ST*	16.2	18.3	16.8	16.9	17.7	18.6	18.0
TDR*i*	0.208	0.093	0.175	0.169	0.0126	0.077	0.109

Fig. 14(c)	Line 1	Line 2	Rect. 3	Rect. 4	Line. 5
ST*	17.0	17.6	16.4	16.2	18.7
TDR*i*	0.164	0.131	0.197	0.208	0.071

Fig. 14(d)	Line 1	Line 2	Rect. 3	Rect. 4	Line. 5
ST*	16.7	16.8	16.3	16.0	18.6
TDR*i*	0.180	0.175	0.202	0.219	0.077

ST*: Surface Temperature

During the measurement the mean indoor temperature was 20.2 ℃, and the mean outdoor temperature was 10.9 ℃. The indoor surface temperature and TDR$_i$ of the part finished with the gypsum board were 19.2 ~ 19.8℃ and 0.043 ~ 0.108 for the non-defect parts, and 19.0 ~ 19.6℃ and 0.065 ~ 0.129 for the defect parts. The surface temperature and TDR$_o$ of the outdoor corner were 11.1 ~ 12.9℃ and -0.022 ~ -0.215. Figure 16 shows the surface temperature, TDR$_i$ and TDR$_o$ measured through simulation. The indoor surface temperature and TDR$_i$ were 19.3 ~ 19.4℃ and 0.057 ~ 0.066 for the non-defective parts, and 19.1 ~ 19.4℃ and 0.058 ~ 0.087 for the defect parts. The surface temperature and TDR$_o$ of the outdoor curved corner were 10.1 ~ 11.4℃ and -0.011 ~ -0.136.

Figure 17 shows the infra-red thermal imaging data, and Table 4 shows the mean indoor surface temperature and mean TDR$_i$ of each part. The mean temperature (mean TDR$_i$) of the flat part was 19.7℃ (0.054) for the non-defect parts, and 18.3℃(0.204) and 19.4℃(0.087) for the defect parts. The defect part without any heat insulating materials showed clearly lower insulation performance. In addition, Line 4 and 5 of the non-defect part(upper) were 19.7 ℃ (0.054) and 19.6 ℃ (0.065), good insulation performance in general. Line 5 of the defect part (upper) was 19.0℃(0.129), and Line 6 was 19.5℃ (0.075). it is obvious that the heat insulation material defect worsened insulation performance.

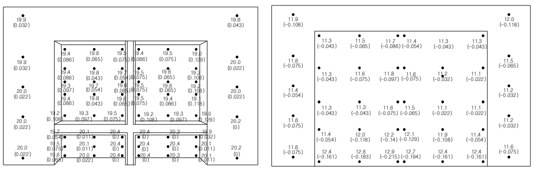


Figure 15 Surface temp. and TDRi, TDRo (T-type sensor)

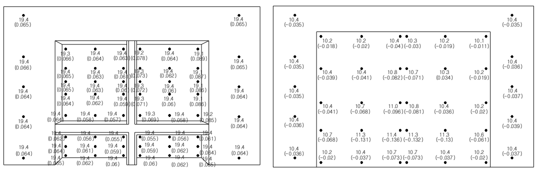
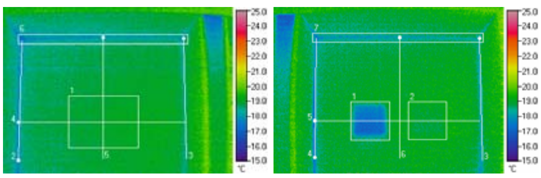
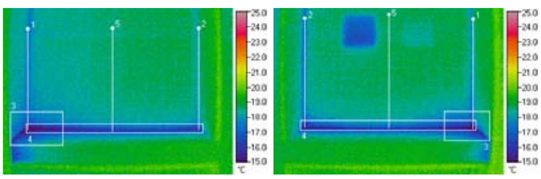


Figure 16 Surface temp. and TDRi, TDRo (Simulation)



(a) non-defect section(upper) *(b) defect section(upper)*



(c) non-defect section(lower) *(d) defect section(lower)*

Figure 17 Infra-red thermal imaging data

Table 4 Mean surface temperature & TDRi

Fig. 17(a)	Rect. 1	Line 2	Line 3	Line 4	Line 5	Rect. 6
ST*	19.7	18.9	19.1	19.7	19.6	19.3
TDR*i*	0.054	0.140	0.118	0.054	0.065	0.097

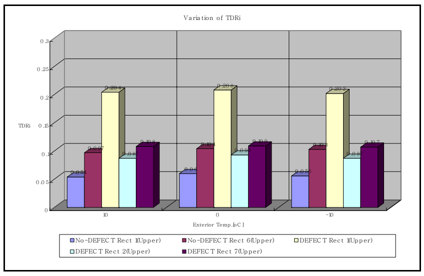
Fig. 17(b)	Rect. 1	Rect. 2	Line 3	Line 4	Line 5	Line 6	Line 7
ST*	18.3	19.4	18.6	18.7	19.0	19.5	19.2
TDR*i*	0.204	0.087	0.172	0.161	0.129	0.075	0.108

Fig. 17(c)	Line 1	Line 2	Rect. 3	Rect. 4	Line. 5
ST*	18.7	19.1	18.4	18.3	19.5
TDR*i*	0.161	0.118	0.194	0.204	0.075

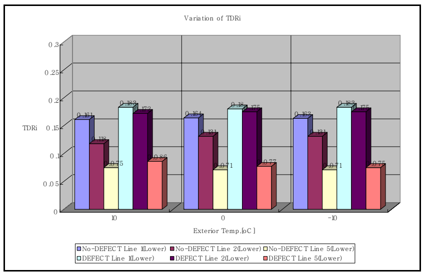
Fig. 17(d)	Line 1	Line 2	Rect. 3	Rect. 4	Line. 5
ST*	18.5	18.6	18.3	18.1	19.5
TDR*i*	0.183	0.172	0.204	0.226	0.086

ST*: Surface Temperature

Figure 18 shows that with the changes in TDR$_i$ in accordance with the changes in the outdoor temperature (10℃, 0℃, -10℃), the average index of insulation performance of each section, TDR$_i$ have constant values regardless of the changes in exterior temperature.



(a) The upper section of mock-up structure



(b) The lower section of mock-up structure

Figure 18 Changes in TDRi in accordance with the changes in the outdoor temperature

CONCLUSION

This study is a plan for improving the environment & thermal performance of buildings and increasing building life, and it aims to propose a quantitative on-site evaluation method for the insulation performance in buildings using infra-red thermal imaging analysis techniques.

As a step prior to evaluation, we analyzed the actual temperature distribution of the measured part, the temperature and heat flow pattern of each building part with the PHYSIBEL simuation program to predict temperature distribution in the normal state. On this basis we derived an equation for predicting the surface temperatue and the surface temperature change rate by building part. We used the measured indoor and outdoor surface temperature to present the Temperature Difference Ratio, which quantitatively evaluates the insulation performance of a building, and evaluated.

As a step prior to on-site evaluation, the insulation performance of the laboratory mock-up structure was compared and evaluated through experiments and simulation. TDR have constant values regardless of the changes in outdoor temperature.

On the basis of the results of this study, we are planning to quantitatively evaluate on-site insulation performance of actual buildings by means of simulation and the infra-red thermal imaging system.

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Table 1 The rate of change in surface temperature(E) and Surface temperature difference ratio(C)

		RATE OF CHANGE IN SURFACE TEMPERATURE (E)				**SURFACE TEMP. DIFFERENCE RATIO (C)**		
		RATE OF CHANGE IN SURFACE TEMP. IN ACCORDANCE WITH DISTANCE	**RELATION BETWEEN INSULATION CONDITION (K) AND THE COEFFICIENT FOR THE RATE OF CHANGE IN SURFACE TEMP. (A)**	**REGRESSION COEFFICIENT**		**MODEL FORMULA**	**REGRESSION COEFFICIENT**	
Flat section	Exterior	$y = 1 \times e^{ax}$	$a = f(x') = \alpha + \beta(x')$	α	-4.2504	$y = a + bx + cx^2$	a	-0.0788
				β	-0.2603		b	-0.0204
							c	-0.0120
	Interior	$y = 1 - e^{-ax}$	$a = f(x') = \alpha + \beta(x')$	α	21.3909	$y = a + bx + cx^2$	a	0.2466
				β	31.5718		b	0.0723
							c	-0.0504
2 surface reflex angle section	Exterior	$y = 1 - e^{-ax}$	$a = f(x') = \alpha \times (x')^{\beta}$	α	4.6901	$y = a + bx$	a	0.0030
				β	0.3790		b	0.0414
	Interior	$y = 1 - e^{-ax}$	$a = f(x') = \alpha \times (x')^{\beta}$	α	7.9211	$y = a \times e^{bx}$	a	0.0048
				β	-0.2748		b	0.6944
3 surface reflex angle section	Exterior	$y = 1 - e^{-ax}$	$a = f(x') = \alpha \times (x')^{\beta}$	α	2.7770	$y = a + bx$	a	0.0008
				β	0.3070		b	0.0562
	Interior	$y = 1 - e^{-ax}$	$a = f(x') = \alpha + \dfrac{\beta}{(x')}$	α	31.6910	$y = a \times (b - e^{-cx})$	a	0.1359
				β	-1.3442		b	1.7571
							c	0.8753
Particulars		x = distance from the heat transfer section (m) x' = overall heat transmission rate of the wall ($W/m^2 \cdot K$)				x = overall heat transmission rate of the wall ($W/m^2 \cdot K$)		