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Field measurement of U-value using multiple sensors at test chamber and EIFS building

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ABSTRACT

The purpose of this study is to analyse the heat flux difference and examine applicability of the heat flux sensor along with various sensor attachment methods. Using multiple sensors and various tapes, a KS F 2278 thermal test was performed in hot/cold chamber conditions with standard panel specimen. The measured heat flux values of sensors were stable. But values of sensors were smaller than the heat flux result of KS F 2278. Thus, thermal resistance of attachment tape on a sensor should be considered during on site U-value measuring process. This study also examined the differences between measured U-value and design U-value by attaching the different sensors in the same area using multiple heat flux sensors. All cases are shown to the same patterns on each heat flux and U-value graph, but U-values with regard to various sensors have shown some differences to the designed values. Using in-situ measurement, the EIFS wall was found to be difficult to measure accurately due to the small level of heat flux.

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KEYWORDS

Heat flux sensor; U-value;
Chamber test; EIFS

Introduction

Carbon dioxide emission, a major cause of serious global warming problems, has become a big threat to sustainable human life. According to IEA (2015) data, 68% of global warming emission is generated from energy division, and the energy production has an inevitable relation with human life (Dongwoon 2016). In particularly, 90.9% of carbon dioxide emissions in Seoul is generated from energy consumption used in building and transportation, among them, 68.5% is generated from building cooling-heating energy consumption (Lee 2016; Dongwoon 2016).

Currently, in respect of the field test measuring thermal performance of buildings, a U-value measuring method using heat flux sensor is the most representative test. However, while laboratory conditions are standard, a field measuring test encounters different environmental conditions; in particular, there are various factors such as wall surface smoothness, material quality, position of the sensor, attachment state of the sensor, variation according to the season, etc. Accordingly, reliance on the measured data depends on how precisely the test was performed. Therefore, in order to expand the supply of eco-friendly buildings, a method of accurately measuring and verifying the insulation performance of the building envelope should be firmly established.

This research aimed at conducting comparison analysis by utilising multiple heat flux sensor, concentrating on the thermal contact of the sensor and

target wall surface among the variable factors that influence reliability on heat flux measuring value while measuring thermal performance of the external building on site by heat flux sensor.

Research method and procedure

In respect of measuring building insulation performance, the method currently used in general is site measurement of U-value utilising heat flux sensor. The characteristic of Heat flux Plate is the sensor utilising ceramic-plastic material, maintaining heat resistance as the most popular sensor in measuring the soil and building wall available for in-situ measurement, also available for measuring insulation value and heat transmission rate (Hukseflux 2017).

When measuring heat performance of wall on site, generally 1~2 heat flux sensors are used, however more precise wall U-value can be calculated when measuring by using multiple heat flux sensors.

In this study, the heat flux measured by using the heat chamber according to KS F 2278 and the heat flux measured by the multiple heat flux sensors were compared and analysed in order to determine the accuracy according to the attachment method of the multiple heat flux sensors. In addition, field measurements were performed on EIFS(External Insulation Finish System) walls to evaluate the applicability of the multiple heat flux sensors.

The existing literature and related standard consideration

Jeong, Jaewon and four researchers determined overall heat transfer coefficient (U-value) of exterior wall, floor, and roof of Nakseonjae, a Korean traditional residence via field measurement of transient heat flow and temperature difference across each envelope component using heat flux sensors and T-type thermocouples (Jae-Weon et al. 2008).

Heo, Eunji and two researchers suggested a method of measuring insulation function regardless of outdoor seasonal condition, in respect of the method to easily measure the laboratory insulation function on site (Eun-Ji et al. 2012).

Yun, Heewon and one researcher considered and analysed the standard and the existing research result as the system development to exactly evaluate building insulation function on site in order to reinforce energy performance of the existing building (Heewon and Doosam 2013).

Choi, Changsik and three researchers differentiated the point along with a measuring method to select proper measuring points when measuring U-value utilising a heat-blow meter, which were then analysed and evaluated (Chang-Sik et al. 2016).

Kim, Sung-Im and three researchers evaluated the actual insulation performance of opaque outer walls of old commercial buildings by field measurements using various standard methods. The actual insulation performance was found to be approximately two-thirds of the required level prescribed in the insulation regulation (Sung-Im et al. 2014).

International standard ISO 9869 defined the onsite measurement of building wall thermal transmittance. The heat flux sensor is attached to the side wall of the room, and the indoor and outdoor temperatures are measured. In this process, a heat flux meter should be installed in a stable position and the sensor area should be in direct thermal contact with the element surface. Simultaneously, through the computer connected to the data logger, the heat flux is measured for 72 hours at 1 minute intervals through the electrical data of the thermal and temperature sensors. The value of R (heat resistance) obtained at the end of the test shall not deviate by more than $\pm 5\%$ from the value obtained 24 hours before, and the thermal resistance value is calculated by the averaging method or the dynamic method (ISO 9896 2014).

KSF 2278 (2017) specifies the insulation test method for windows. A heating box is installed inside the hot chamber where the standard panel specimen is installed, and a cold air take-out device is installed in the cold chamber. A standard panel with a fixed U-value can be used to measure the heat loss of the chamber and calculate the surface heat transfer rate. The opening of the hot chamber is blocked with

a standard panel used for setting the surface heat transfer and for calculating the calibration energy for the peripheral wall of the heating box and the mounting frame of the specimen. The temperature sensor is installed in a hot chamber and a cold chamber, and the amount of power is measured while maintaining a temperature difference of 20°C . The temperature and the heat flux are measured three times at intervals of 30 minutes to calculate the heat resistance and the U-value.

The US ASTM C 1155 standard also specifies a method for calculating thermal resistance using data collected from field measurements in a manner similar to ISO 9869 (ASTM C1155 2013).

In this study, we investigate the characteristics of the heat flux sensor according to the attachment method under the laboratory conditions, which were not covered in the previous studies, and to examine the applicability of the multiple heat flux sensor in field measurement.



Related equipment and device overview

ISO 9869 and KS L ISO 9869 regulate that the correction of already known type of heat flux sensor should be verified with equal material and equal temperature measurement when necessary every two years. It specifies that change of the correction factor should be within $\pm 2\%$.

For this, the research measured 2 KS standard tests by performing U-value measuring test attaching eight multiple heat flux sensors on the surface of constant temperature side standard panel specimen of a thermal chamber according to KS F 2278, to measure the accuracy of the heat flux sensor, then compared and analysed. Table 1 treats the content of data logger and heat flux sensor as the major measuring device in the test based on ISO 9869.

Measuring preparation should be completed according to KS L ISO 9869, and each device and all equipment should be connected. Figure 1 shows a diagram of the heat flux sensor, data logger attached to the standard panel specimen (EPS board) between the hot and cold chamber, and computer connection. Figure 2

Table 1. Heat flux sensor and data logger.

Photo	Device	Use
	CR 1000	Data logger
	·Analog input: 16 SE, 8 Diff channels	
	·Input voltage scope: ± 5000 mV	
	·Voltage measurement accuracy: 1 μV	
	HFP01 sensor (8EA)	Heat flux measure
	·Sensitivity: $50 \mu\text{V}/\text{Wm}^2$	
	·Temp. range: $-30^{\circ}\text{C} \sim 70^{\circ}\text{C}$	
	·Measuring scope: $2000 \sim -2000\text{W}/\text{m}^2$	
	·Error range: $\pm 5\%$	

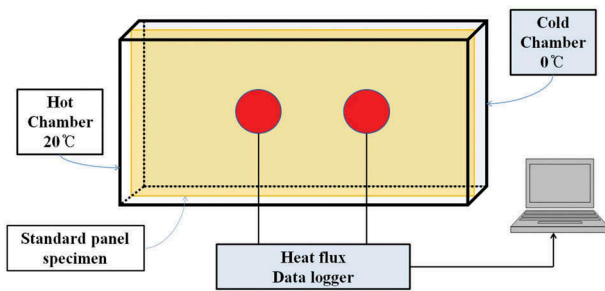


Figure 1. Overview of heat flux measurement device composition using KS F 2278.

(a) illustrates the hot and cold thermal chambers as the major devices based on KS F 2278.

Measurement and data collection method

Eight heat flux sensors are attached onto the center of the standard panel, where is less influenced by corner thermal effect, on the constant temperature side within the thermal chamber. Sensors attached with different attachment methods, are connected with data logger, data collecting device in Table 1. The data logger is connected with the computer, enabling real-time monitoring of data, and the data transmitted to computer until termination of test can be saved in Excel sheet.

After checking data collection through a computer in the completed state of test preparation, a connect temperature sensor for the thermocouple test is placed

according to KS F 2278. Figure 2(b), (c), and (d) indicates the temperature sensors attached to the standard panel within the thermal chamber and the attached state.

Test along with attachment method difference(1st test)

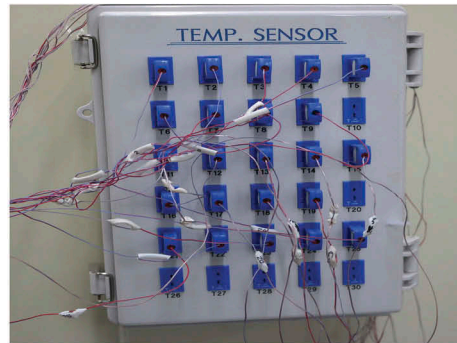
As a test to vary the method of fixing the heat flux sensor to the standard panel in attachment method, a total of eight sensors were attached to the standard panel in four methods using the equivalent two sensors. When investigating each method, Method A sensor was attached with a general transparent cellophane tape, Method B sensor with thick black paper tape, Method C sensor with insulation tape, and Method D sensor with very thin green transparent cellophane tape. Figure 3 indicates the initial state of the heat flux sensor attached to the standard panel along with the attachment method and the attachment state of the sensor after completion of the test.

Test along with the difference in heat contact area(2nd test)

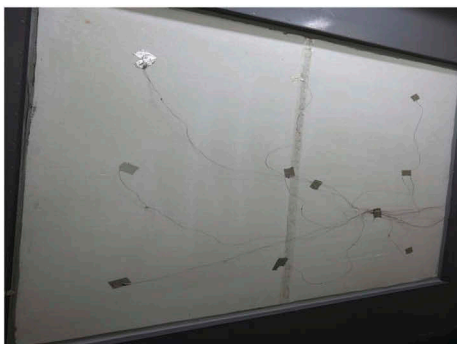
Using a different standard panel from the first test, the attachment was made in three ways, i.e. a general attachment method between the standard panel specimen performed with heat contact with the sensor, thermal pad, and thermal compound.



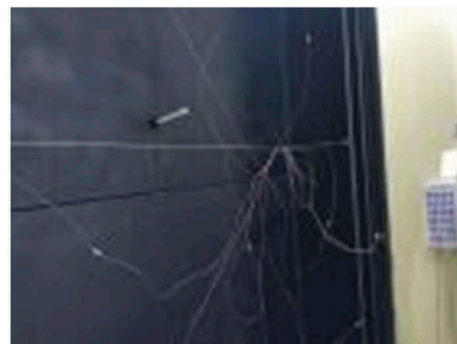
(a) Hot-cold chamber exterior



(b) Temp. sensors



(c) Sensor attachment points



(d) Heating box interior

Figure 2. KS F 2278 chamber and equipments.

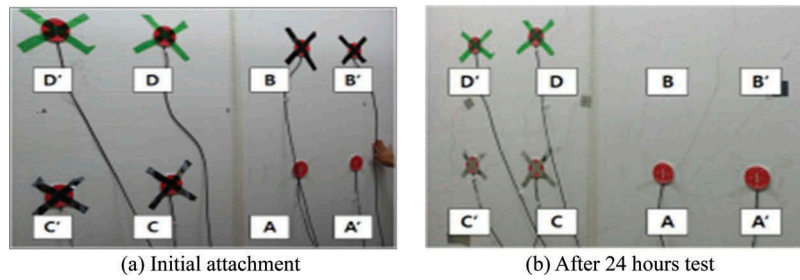


Figure 3. Difference in heat flux sensor attachment method and attachment state (1st test).

A1 and A2 are the general tape attachment method, equally attached as the preliminary stage test. B1, B2, B3 are the pad method, attached with thermal pads of three types with different heat conduction and thicknesses, respectively. C1, C2, C3 represent a compound method; three types of compounds were utilised, the same as in the pad method. Figure 4 indicates the material of the contact section for each method.

Table 2 indicates heat conductivity and thickness per material in the contact section classified in the three methods.

Figure 5 indicates the initial state of the heat flux sensor attached in different heat contact method, respectively, to the standard panel and the sensor attachment state after completion of the the ty test.

Results of measuring U-value along with attachment method and the difference in heat contact section

(b) of Figure 3 indicates heat flux sensor attachment state after completing measurement for 24 hours. In the case of the heat flux sensor used with paper tape

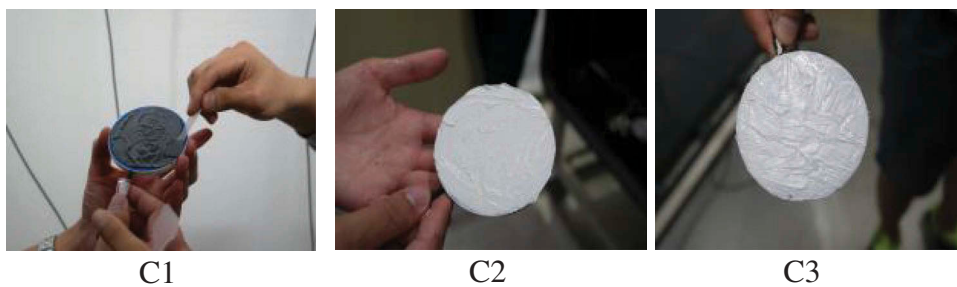
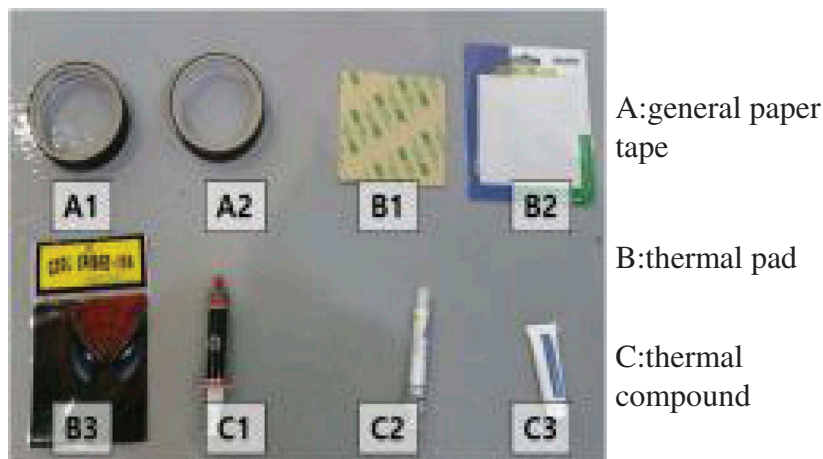


Figure 4. Materials in the heat contact section.

Table 2. Heat conductivity and thickness of contact material according to the method.

Type	Cellophane tape		Thermal pad			Thermal compound		
	A1	A2	B1	B2	B3	C1	C2	C3
Conductivity (W/m-K)	-	-	1.20	6.00	0.85	3.80	0.84	1.01
Thickness (mm)	-	-	1.0	1.5	0.1	-	-	-

(B and B'), the hat sensor failed to attach to the test sample due to internal air flow on the constant temperature side (hot chamber). It was found that the heat flux sensor had dropped due to the decrease of adhesion between the standard panel (bead insulation) and the paper tape.

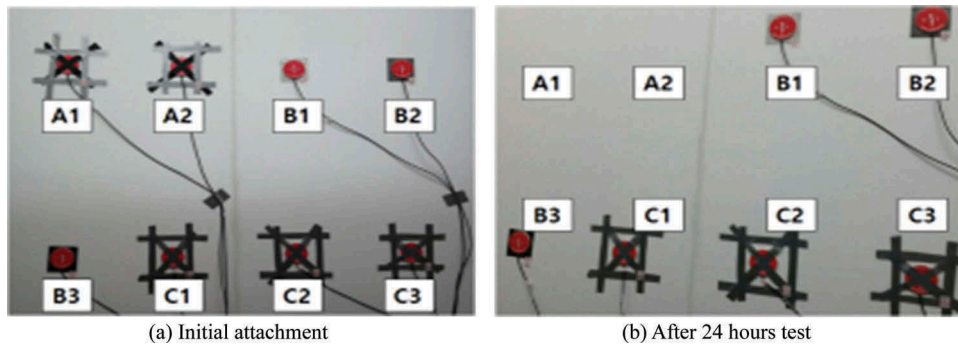


Figure 5. Difference in heat contact section of heat flux sensor and attachment state (2nd test).

Figure 6 indicates the entire results of the test period, the overall scope of heat flux value measuring result per each sensor. Figure 7 is a graph that extracts the 90-minute portion representing the stabilized heat flux value in Figure 6. Figure 7 shows the result that heat flux between the same attachment methods, A-A', C-C', and D-D' appeared very similar to each other. Also, similarity among A-C-D attachment types differentiated with fixing method while attaching also was confirmed, however C' and D' sensor heat flux showed relative error in 6.4% in a specific point. And the heat flux of C and C' sensors using thick insulation tape with low thermal conductivity is somewhat lower than other sensors.

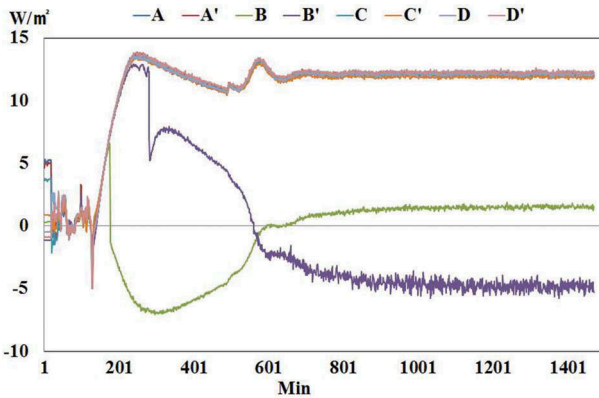


Figure 6. Overall heat flux measured by sensors (1st test).

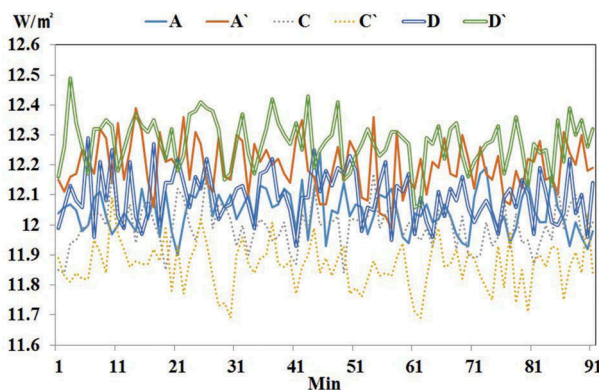


Figure 7. Heat flux measured in stable period (1st test).

Table 3 indicated comparison between the KS F 2278 test heat flux and thermal transmittance value (U-value) of standard panel specimen and ISO 9869 test heat flux sensor. Heat transmittance value of KS F 2278 test was calculated through the formula according to KS F 2278, and the heat transmittance value of the heat flux sensor was calculated through the sum of the heat flux divided by the sum of indoor and outdoor temperature difference, the average method according to ISO 9869.

Thermal transmittance value of standard panel specimen was $0.684 \text{ W/m}^2 \cdot \text{K}$. Thermal transmittance value through heat flux sensor was measured $0.604 \text{ W/m}^2 \cdot \text{K}$. The reason why the difference appears in measured thermal transmittance value is because, as described in ISO 9869, it is presumed that the value of the heat flux rate can be changed according to the change of the surface heat resistance value of the heat flux sensor on the hot chamber side. However, the measured value per sensor shows very similar data: accordingly, the value seems stable.

Figure 5(b) also indicates heat flux sensor attachment state at 24 hours after terminating measurement

After starting measuring. As the 1st test, in case of the heat flux sensor used with the paper tape (A1, A2 in Figures 5 and 8 9) showed the result of failing in heat flux sensor by the internal air flow generated while measuring, however total 7 data could be collected wince the failing period of A2 sensor among A samples of the equal condition was performed in the stable period (Figure 9).

Figure 8 indicates 24 hours' sample results, the overall scope of heat flux measuring result per each sensor. Ninety minutes' sample results in the stable period of heat flux per each sensor, as indicated in Figure 9.

Figure 9 indicates the result that shows very similar values in heat flux in B, pad type, and C, compound

Table 3. Average heat flux and U-value per attachment sensor (1st test).

Sensor	A	A'	C	C'	D	D'
Heat flux [W/m^2]	12.05	12.20	12.00	11.87	12.09	12.28
U-value [$\text{W/m}^2 \cdot \text{K}$]	0.602	0.610	0.600	0.593	0.605	0.614

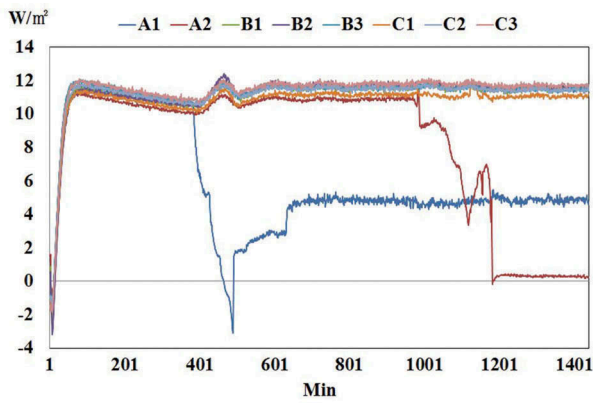


Figure 8. Overall heat flux measured by sensors (2nd test).

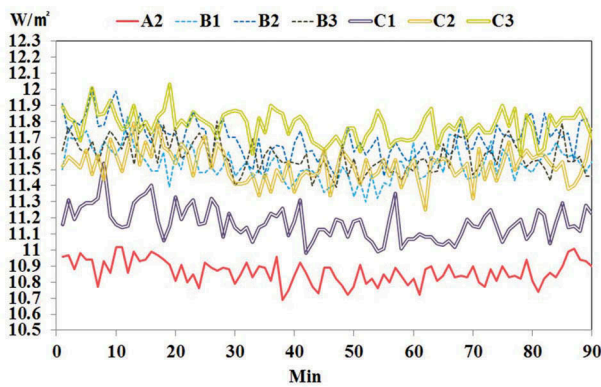


Figure 9. Heat flux measured in stable period (2nd test).

type, except type A. A2 and C3 sensor heat flux, which showed the biggest error, showed relative error of 10.8% at a specific point. This seems to be because method A formed a low value due to the possibility of influence of standard panel surface porosity and air flow between the contact sides. Type B showed relatively stable heat flux according to thermal conductivity due to regular pad thickness; however, as in Figure 4 C1, C2, C3, type C showed difference in U-value measuring value per product without establishing a proportional relation with heat conduction function, since its spread thickness was nor regular due to hand-spread of the compound.

Table 4 indicates average heat flux and thermal transmittance value among the data collected in data logger in a stable period in 24 hours' test by arranging per sensor. Thermal transmittance of a standard panel specimen was measured 0.628 W/□·K. Thermal transmittance value through heat flux sensor was measured 0.573 W/m²·K. As in the first test, the U-value measured by the heat flux sensor was lower than the chamber test.

Table 4. Average heat flux and U-value per attachment method (2nd test).

Sensor	A2	B1	B2	B3	C1	C2	C3
Heat flux [W/m²]	10.86	11.53	11.69	11.59	11.17	11.53	11.78
U-value [W/m²·K]	0.543	0.577	0.585	0.579	0.559	0.576	0.589

Table 5 shows a comprehensive comparison between KS F 2278 test U-value and thermal transmittance value of a standard panel test and the measured value through heat flux sensor of ISO 9869 test. Table 5 also shows the detailed conditions of the KS F 2278 test, and the heat flux sensor result is the mean value measured by multiple sensors.

Field measurement at actual EIFS building

In this study, field measurements were carried out to determine the U-value of heat flux sensors using thermal contact paste. Figure 10 shows the target building to be measured and the measurement location. The outer wall of the building under measurement is composed of adhesive EIFS (exterior insulation finishing system), and the cross-sectional details are shown in Figure 11. Also Table 6 shows the design values of the thermal performance of the building walls to be measured.

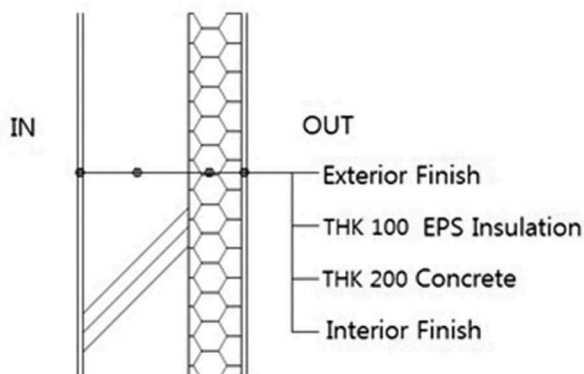
Figure 12 is a schematic representation of the attachment location according to the heat flux sensor number. The heat flux measurement was carried out twice in the winter, seven days for each case, and the room heating set temperature was 18°C. In order to investigate the tendency of the heat flux value when different sensors are applied to the same location, measurements were conducted for cases 1 and 2. Figures 12 and 13 show the location of the heat flux sensor. In accordance with ISO 9869, each heat flux sensor is attached to the wall surface using a thermal contact pad, and a data logger and a T-type thermocouple are installed for measuring the temperature inside and outside of the room. Figures 14 and 15 show the measured value of the heat flux by each sensor and the temperature difference between indoor and outdoor during a stable period of one day. In Case 1 of Figure 14, the values of HF1, HF2 and HF8 tend to be larger than those of the other six sensors. Case 2 in Figure 15, which means only the arrangement of sensors at the same measurement position as case 1, shows a tendency to be larger than that of HF5, HF6, and HF4 sensors. Since the four different sensors show similar values at the same position, the reason why the left and right side wall heat flux values in Case 1 and 2 are large is not the error of the sensor. It can be considered as a difference according to the change of the cross-sectional state of the wall adjacent to the window.

Table 7 shows the calculated U-values according to the same measurement positions with regard to cases and sensors by the averaging method presented in ISO 9869.

The measured values of the heat transfer rate were different for each sensor and position. Case 1 showed a higher U-value than the design value of 0.327 W/m²·K at all measurement positions. In case

Table 5. Comparison between KS F 2278 measured value and heat flux sensor value.

KSF 2278 result	Measured item	Measured type	1st test			2nd test		
			Session			Session		
			1 st	2nd	3rd	1st	2nd	3rd
Heat flux sensor result	Air temperature [°C]	Constant temp. room	19.88	19.92	19.91	20.08	20.09	20.10
		Heating box	20.06	20.07	20.06	19.85	19.80	19.76
	Energy[W]	Cold room	-0.01	0.02	0.03	0.13	0.12	0.11
		Temperature differ.	20.07	20.05	20.03	19.72	19.68	19.65
		Total supply energy	74.20	73.56	73.49	64.75	64.01	64.00
		Corrected energy	19.39	19.01	19.18	15.19	14.93	14.66
	Test sample surface heat transmission resistance [m ² ·K/W]	Test sample pass energy	54.81	54.54	54.31	49.55	49.09	49.34
		Inner surface resistance	0.11	0.11	0.11	0.12	0.12	0.12
		Outer surface resistance	0.06	0.06	0.06	0.04	0.04	0.04
	U-value [W/m ² ·K]	Correction value	-0.01	-0.01	-0.01	0.00	0.00	0.00
Thermal transmittance resistance [m ² ·K/W]		0.687	0.684	0.682	0.629	0.625	0.629	
Heat flux sensor result	Measured value	1.46	1.46	1.47	1.587	1.599	1.588	
	Average Heat flux [W/m ²]	12.09	12.08	12.06	11.51	11.39	11.44	
	U-value [W/m ² ·K]	0.605	0.604	0.603	0.576	0.570	0.572	
	Thermal transmittance resistance [m ² ·K/W]	1.653	1.656	1.658	1.737	1.755	1.748	

**Figure 10.** Target building and measurement location.

2, the U-value was lower than that of the design value at the centre of the wall. In cases 1 and 2, the patterns of the U-value values of the sensors are similar, but the values of case 1 and case 2 are different. Also the reliability of the heat flux measurement is insufficient because the measured value is lower than the design value.

Conclusion

In this study, a thermal chamber test and building site measurement were performed to evaluate the wall U-value measurement performance of multiple heat flux sensors.

As the test result, it was determined that adhesive strength was different along with attachment method of the heat flux sensor. Also, U-value per heat flux sensor with the equivalent attachment method showed very similar results.

The U-values through the KS F 2278 test were greater than the U-values measured through the heat flux sensor. Therefore, it is necessary to understand the

Table 6. Designed U-value of target building exterior wall.

Materials	Depth (mm)	Conductivity (W/m·K)	Resistance (m ² ·K/W)
Exterior Convective Thermal Resistance	-	-	0.043
THK100 EPS Insulation	100	0.036	2.778
THK200 Concrete	200	1.600	0.125
Interior Convective Thermal Resistance	-	-	0.110
Total Resistance		3.056 m ² ·K/W	
U-value		0.327 W/m ² ·K	

**Figure 11.** Detail of exterior wall.

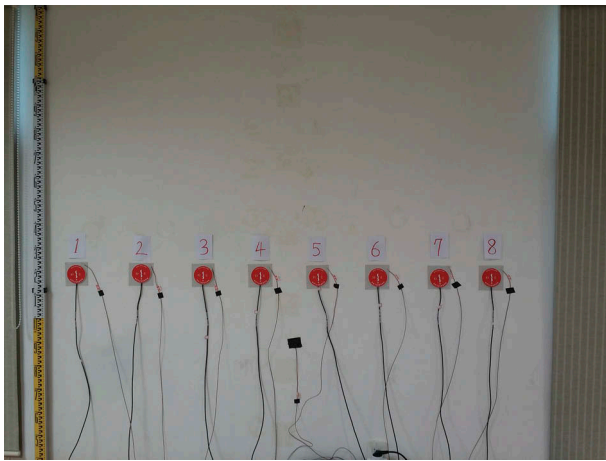


Figure 12. Attachment of sensors and its number (case 1).

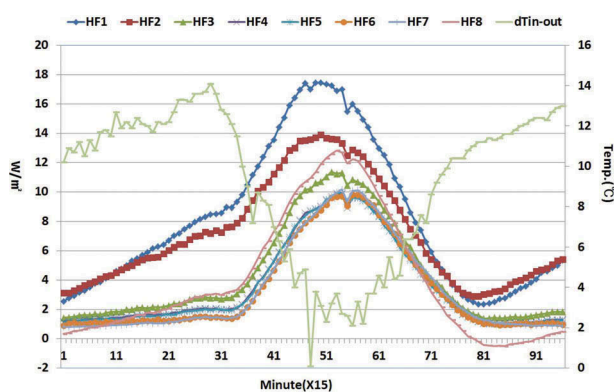


Figure 13. Attachment of sensors and its number (case 2).

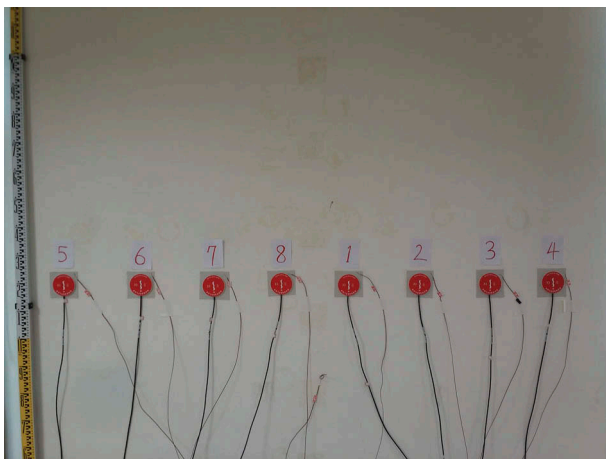


Figure 14. Measured heat flux and in-out temp.(case 1).

influence of the surface heat resistance of the adhesive tape on U-value measurement using a heat flux sensor.

In the test to determine the difference along with heat contact section between sensor and standard panel specimen test, the general attachment method using tape has a high anxiety factor with no reliability on measurement value, since the possibility of failure

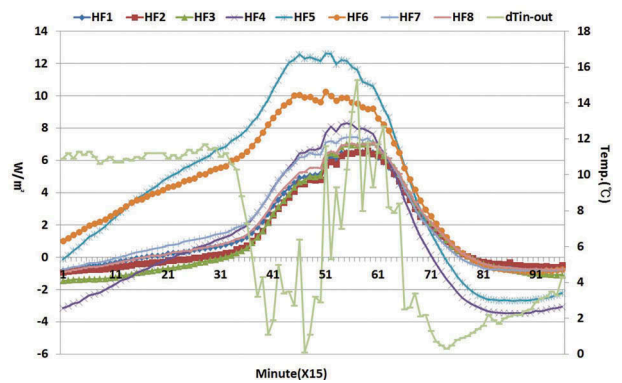


Figure 15. Measured heat flux and in-out temp. (case 2).

Table 7. Measured U-values by sensor.

U-values (designed U-value: 0.327 W/m ² · K)			
Case 1		Case 2	
U-value	Sensor no.	U-value	Sensor no.
1.137	①(HF1)	0.951	⑤
0.958	②(HF2)	0.814	⑥
0.551	③(HF3)	0.405	⑦
0.42	④(HF4)	0.319	⑧
0.394	⑤(HF5)	0.289	①
0.356	⑥(HF6)	0.257	②
0.381	⑦(HF7)	0.287	③
0.514	⑧(HF8)	0.388	④

is high due to the influence of air flow that can be generated on the contact side.

In the case of a thermal compound, the adhesive surface is not uniform because it is stretched by the tester's hand and there is a risk that the measured value may change. In respect to attachment state, thermal pad is available for stable test due to low possibility of failure, and regular thickness can be secured between sensor and contact side; also, thermal transmittance value was measured in proportion to heat conduction function, which shows the highest reliability within a relative error rate of 5% between pads.

In actual building field measurement using thermal pad and multiple sensors, since different values of the U-value are measured according to the position of the target EIFS, it is considered that a plurality of heat flux measurement sites should be selected in order to measure the accurate average U-value of the wall.

The field measurement method applied in this study is considered to make difficulties for calculating the representative average U-value. It is considered that the absolute value of the passing heat flux itself is small due to the characteristics of the EIFS wall.

The results of this study indicate that there is no problem in the measurement performance of the heat flux sensor applied in this study. If the indoor and outdoor temperature difference is small or the insulation performance of the wall is excellent, the passing

heat flux may be small and the heat flux measurement may not be accurate.

It is necessary to further understand the effect of measurement condition variables such as indoor/outdoor temperature conditions, passing heat flux, and sensor surface heat transfer rate on the measurement results.

Disclosure statement

No potential conflict of interest was reported by the authors.

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