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A Study on the Operational Status of the Chamber for Testing the Thermal Performance of Curtain Walls

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Abstract

The purposes of this study were to analyze criteria for measurement chamber design dedicated curtain wall, and how to measure of performance configuration and status of the chamber that is currently being used. Main dealing criteria is AAMA 1503-09. Measurement of data is made in curtain wall Mock-up experiment station with thermal imaging camera. Measurement data using thermal imaging cameras at Mock-up curtain was made at the test site. The results of this study were as follows; There is no U-value test method for actual size of curtain wall. The thermal test outdoor chamber showed heat loss in the connection part of indoor and outdoor chamber. And the indoor chamber showed unstable temperature distribution by height.

Keywords: Curtain wall, U-value, Thermal chamber, Thermal test, Thermal performance standards

1. Introduction

1.1. Objectives

Energy consumption is rapidly growing around the world, and the reckless energy development and production has increased the greenhouse gases in the atmosphere, leading to the occurrence of abnormal weather phenomena. Since the Kyoto Protocol, which officially came into force in 2005, the government policies, such as the current building energy efficiency rating system and the implementation of the energy-usage-based charging system have been carried out. In South Korea, more than 1/5 of the total energy consumption is consumed by the building sector, and this trend is spreading from year to year. Accordingly, the total energy consumption can be significantly reduced through building energy consumption reduction. A curtain wall, which is the outer skin of a building, boasts excellent constructability and a beautiful appearance, and it can provide the effect of lightweightness. As it is mostly composed of a steel frame and glass, however, compared to the existing wall configuration, and has a high window area ratio due to the characteristics of the system, the problem of dew condensation resulting from large heat losses through the connections of the inside and outside is likely to occur. Thus, it is important to identify and verify the exact thermal performance of the members for the curtain wall to perform its normal function as an external wall. As there are no thermal performance metrics solely for the curtain wall in South Korea, however, curtain wall tests are being implemented using the window thermal transmittance measurement criteria KS F (Korean Industrial Standards in construction sector) 2278 or the overseas curtain wall standards AAMA 1503-09 in most cases. As for windows, the thermal transmittance values of up to 2,000×2,000 mm can be measured in the indoor chamber. In the case of the curtain wall, however, as the specimen is large, it is difficult to measure the thermal transmittance values in the indoor chamber. In this regard, this study attempted to present basic materials for the design and fabrication of the chamber for the measurement of the thermal transmittance performance in preparation for thermal transmittance standards only for large-scale curtain walls and their implementation.

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1.2. Previous studies

The previous studies related to the subject of this study include “Evaluation and Simulation of Condensation in the Curtain Wall Envelop Utilizing a Full Scale Mock-up” by No Sang-tae, where the mock-up test methods and standards used in the design considering insulation and condensation were organized by case (USA, Europe, Australia, Hong Kong, South Korea) with respect to the evaluation of the thermal performance of the curtain wall envelop, and a comparative analysis of the domestic window performance test and overseas curtain wall performance test criteria was conducted.

In “Design Criteria for Preventing Inside Surface Condensation on the Curtain Wall Systems of Office Buildings” conducted by Song Seung-yeong et al., design criteria to prevent surface condensation at home and abroad were investigated and analyzed based on materials like regulations, standards, and specifications, and standard condi-

tions for outdoor/indoor temperature and humidity as well as design criteria for preventing surface condensation of office buildings were proposed using the related materials and data obtained from measurements.

In "A Study on the Airtightness Performance Qualifications for Domestic Curtain Wall Systems," Cho Min-ji investigated a general overview of the curtain wall systems and airtightness performance tests methods related to curtain wall systems applied at home and abroad, and conducted a comparative analysis of airtightness performance criteria related to curtain wall systems in South Korea, USA, Canada, Germany, United Kingdom, and Singapore by categorizing the airtightness criteria into regulations, standards, specifications, and others depending on the natural conditions. In addition, she proposed airtightness performance requirements for domestic curtain wall systems by comparing and analyzing the domestic situations and overseas standards based on the materials. She also conducted a study on the status of the chamber for testing the thermal performance of curtain walls at home and abroad as well as its configuration and performance measurement by collecting, analyzing, and using the past research contents and other materials.

2. Methods

The previous research data and various domestic and overseas reference materials were used to collect data on the domestic and international standards as well as on the test methods used to evaluate the thermal performance of curtain walls. Based on the collected data, the chamber for testing the thermal performance of curtain walls actually used at home and abroad was investigated, and related information was gathered. The curtain wall thermal performance and airtightness performance test criteria were analyzed, and a comparative analysis of the performance requirements of the test chamber was conducted by analyzing the contents of AAMA 501, 1503, which are currently being used in South Korea in the thermal performance test of curtain walls.

In the curtain wall mock-up test at a curtain wall testing site in South Korea, the insulation performance and temperature/humidity inside and outside the test chamber are measured using performance-measuring equipment such as temperature and humidity loggers, infrared thermometers, and thermal imaging cameras.

3. Standards and Tests

3.1. Review of South Korea and international standards thermal performance of curtain wall

The domestic and international standards related to curtain walls include the standard specifications for construction in South Korea, the European EN 12152, SS381 in Singapore, AAMA 501, 1503 in USA, and the British CWCT. The curtain wall airtightness performance criteria affecting the thermal performance of curtain walls for each country are summarized in Table1.

3.1.1. AAMA 1503

According to AAMA 1503, the curtain wall test standards of the United Standards, the essential performance of the thermal-performance-measuring equipment is as follows. The outdoor environment chamber (hereafter referred to as "outdoor chamber") should be able to withstand the pressure applied from inside and outside during the hot/cold chamber test, and all the connections, corners, and other holes in the laboratory should be completely sealed. The cold chamber requires a means for generating a vertical air flow that is uniform enough to apply external factors, and the control and cooling equipment should maintain the temperature at within -18±0.3°C automatically. The temperature control of the indoor environment chamber (hereafter referred to as "indoor chamber") should maintain the temperature at within 21.1±0.3°C automatically. The constant humidity controller of the indoor chamber should be designed not to allow the relative humidity to exceed 25% during the thermal performance

Survey on standards	Collect data related to the domestic and international standards used to evaluate the thermal performance of curtain walls.
▼	
Information collection	Collect information on the chamber for testing the thermal performance of curtain walls used at home and abroad.
▼	
Comparative analysis	Analyze the airtightness performance requirements and thermal performance of the chambers for testing curtain walls based on the collected data.
▼	
Field measurements	Visit the curtain wall mock-up test site through a field trip Measure the insulation and performance of the curtain wall test chamber using infrared thermometers, thermal imaging cameras, and temperature & humidity loggers.

Figure 1. Process of study.

Table 1. The curtain wall airtightness performance criteria for each country

	Data Division	Document name	Country	Object		airtightness performance (Allowed leakage rate)						
						$m^2/h \cdot m^2$	$L/s \cdot m^2$	cfm/ft^2	$m^2/h \cdot m$	$L/s \cdot m$	cfm/ft	Pa
Curtain Wall	Standard	DIN EN 12152	Europe	Fixed part	ClassA1~A4, AE	1.50	0.42	0.08	0.5	0.14	0.09	150~600
		Singapore Standard SS381	Singapore	Fixed part	Air Conditioning	0.94	0.26	0.05	-	-	-	300
					Non-cooperation	1.5	0.42	0.08	-	-	-	
				Moving part	Air Conditioning	-	-	-	1.54	0.43	0.28	300
					Non-cooperation	-	-	-	2.00	0.55	0.36	
	Specification	AAMA 501-05	U.S.A.	Fixed part	General Building	1.08	0.3	0.06	-	-	-	75
					Air, humidity control important building							
		Architectural Standard Specification	S. Korea	Fixed window		1.10	0.30	0.06	-	-	-	75
				Opening and closing windows		-	-	-	2.79	0.77	0.5	75
	Ect.	CWCT Standard and Guide	U.K.	Fixed part	General Building	1.5	0.42	0.08	-	-	-	300
					Low energy, HVAC building	1.5	0.42	0.08	-	-	-	600
				Moving part	General Building	-	-	-	2.0	0.56	0.36	300
					Low energy, HVAC building	-	-	-	2.0	0.56	0.36	600
	Mock-up test baseline	S. Korea	S. Korea	Fixed part		1.08	0.3	0.06	-	-	-	75 300
				Moving part		-	-	-	1.39	0.39	0.25	75 300

test. Equipment for measuring and recording the relative humidity is needed, and the measurement error of the equipment should be within ±5%. All the connections should be tightly connected, and the thermocouple should be manufactured in the same lot with premium-grade 24 gauges or bright-copper Constantine-type T thermocouple wires. In the case of temperature measurement, the indoor air temperature should be measured on the vertical line 75 mm away from the surface of the surrounding panels, and a system of reading the heat flow data every 5 minutes in temperature and humidity data collection should be established. The data needs to be measured at 5-minute intervals, and it is recorded after averaging. The differential pressure of the humidity should also be measured and recorded. Through the test for resistance to condensation and thermal transmittance of doors, windows, and glass sections, the thermal characteristics of windows, doors, and glass curtain walls are measured under standard state conditions, and these are in turn used to determine the thermal transmittance of the product, U-factor, infiltration rate, and condensation resistance coefficients.

The basic principle of this test method is to maintain the temperature difference across the wall of the test chamber at 0. To do this, proper temperature control and monitoring features are essential. The wall of the measurement box should be insulated by using materials with high heat resistance, low thermal capacity, and high airtightness, through which the heat flow can be calculated, and measurement should be made so that it is included in the calculation of the extra flow rate.

3.1.2. AAMA 501

In Korean Industrial Standards, there is no standard for thermal performance test methods solely dedicated to curtain walls, so tests are performed mainly by using the AAMA 501 or AAMA1503 standard. AAMA 501 is a test method for checking the abnormalities of the various members inside and outside, and for measuring the inside and outside surface temperatures of curtain walls. The test method and procedures are as follows.

① Maintain for 2 hours after increasing the temperature of the outdoor chamber up to the maximum temperature.

② Maintain for 1 hour after reducing the temperature of the outdoor chamber to 24°C.

③ Maintain for 2 hours after reducing the temperature of the outdoor chamber to -18°C.

④ Maintain for 1 hour after increasing the temperature of the outdoor chamber up to 24°C.

The above process (①-④) constitutes one cycle, and it takes place for over 30 hours from three cycles to one condensation test.

3.1.3. Other standards

The thermal performance test of curtain walls in Europe mainly complies with the general design methods of insulation and condensation defined in BS 8200 prescribed by BSI (British Standards Institute). In prEN13947 of EAA (European Aluminum Association), the test on the thermal



Figure 2. U.S. Chamber for testing thermal performance.



Figure 3. Canadian chamber for testing thermal performance.

transmittance of curtain walls and calculation methods are prescribed. In Hong Kong, PNAP 106 provides practical guidelines for curtain wall system technicians.

3.1.4. Case of thermal performance test system

Figs. 2 and 3 show the curtain wall thermal performance test systems in Canada and USA. As in the domestic case, the chamber that can conduct air-tightness, water-tightness, and thermal performance (condensation) tests to which the AAMA standard is applied is being operated.

3.2. Measurement of thermal performance of chamber for testing curtain wall

3.2.1. Measurement methods and equipments

Table 2 shows the measuring equipment specifications used to measure the performance of the curtain wall thermal performance chamber in a mock-up test site. The performance measurement was done on the third cycle during the mock-up thermal performance testing period.

A total of four temperature and humidity loggers were installed at the 1,700, 3,250, and 4,950 mm points, respectively, inside the indoor chamber and outside to measure the temperature and humidity at 1-minute intervals. The surface temperatures of 18 areas of the outer surface of the outdoor chamber and of three areas of the connections of the indoor/outdoor chamber were measured using an infrared thermometer. Each measurement point is shown in Fig. 4. A thermal imaging camera was used to photograph the outdoor chamber surfaces, with focus on the areas vulnerable to insulation, such as the connections,

Table 2. The equipments for measurement

Name of equipment	Equipment Description	Figure
Temperature and humidity logger (DT-172)	Humidity measuring range: 0~100%RH Temperature measurement range: -40~70°C Resolving power: 0.1%RH, 0.1°C Size: 94×48×33	
Infrared Thermometer (Ray Temp 38)	Temperature measurement range: -60~1000°C Resolving power: 0.1°C or °F Size: 47×197×203	
Thermal Imaging Camera (FLIR i60)	Temperature measurement range: -20~120°C / 0~350°C Accuracy: ±2°C (±3.6°F) Size: 235×90×17	



Figure 4. Curtain Wall Experiment facility.

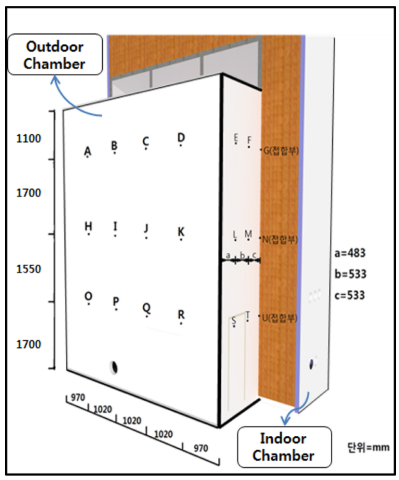


Figure 5. Curtain wall sample and outdoor / indoor combination of chamber.

Table 3. Temperature measurements for each part of outdoor chamber external surface

Location	Temperature (°C)	Location	Temperature (°C)	Location	Temperature (°C)
A	36.6	H	36.7	O	33.7
B	36.6	I	34.4	P	33.1
C	34.4	J	31	Q	29.5
D	33.6	K	31.5	R	29.5
E	32.8	L	32.8	S	29.8
F	32.6	M	33.1	T	28.6
G	21.9	N	21.9	U	15.2

doors, and electric wiring parts, by cycle so that the heat loss during the mock-up test can be visually identified.

3.2.2. Chamber overview

Fig. 4 shows the shape of the specimen located between the outdoor and indoor chambers during the thermal performance test of the curtain wall specimens. Temperature and humidity loggers were installed at the points indicated in Fig. 5 (1,700, 3,250, and 4,950 mm in height), and the temperature and humidity were measured for 24 hours, respectively, for a total of two times during the curtain wall thermal performance testing period. In the inside of the outdoor chamber, two sirocco fans were placed upwards and sideways to make it possible for the device to cause forced convention.

3.2.3. Infrared thermometer measurement of the external surface temperature of the chamber

The data values in Table 3 represent the infrared thermometer measurement results of the external surface of the cold chamber, and each location is shown in Fig. 5. With respect to the surface temperature of the chamber, the temperature of the connections (G, N, U) between the outdoor and indoor chambers was lower by up to 17°C than that of other surfaces, indicating that heat loss is taking place intensively.

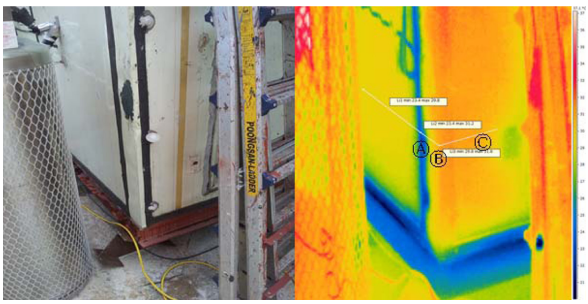


Figure 6. Corner of the chamber, thermal imaging camera photo (Cold cycle).



Figure 7. Corner of the chamber, thermal imaging camera photo (Hot cycle).

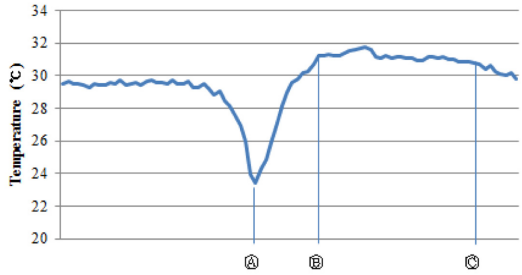


Figure 8. Temperature distribution of Fig. 6.

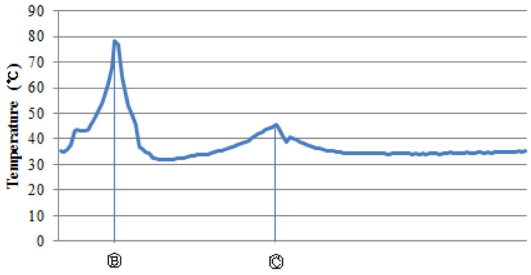


Figure 9. Temperature distribution of Fig. 7.

3.2.4. Detecting chamber surface heat loss using a thermal imaging camera

In the case of the outdoor chamber, each wall is composed of 100-mm-thick sandwich panels, and the about 50 mm gap between the specimen and each chamber is tightly attached by thermal insulating and filling materials. In addition, thin black shades were drawn outside the chamber to minimize the impact of solar radiation during the test.

Figs. 6 and 7 show actual photos of the surface of the outdoor chamber combined with the specimen for the curtain wall mock-up thermal performance test, which was taken by cycle (cold and hot cycle) with a thermal imaging camera.

The analysis results of the thermal imaging photos showed that in both the cold and hot chambers, the connections between the indoor and outdoor chambers or the corners of each chamber suffer greater heat loss than the other surface areas. In addition, the heat loss occurs between the doors and doorframes of the entrance located at both sides of the outdoor chamber.

Figs. 8 and 9 show graphs representing the temperature of each point from the images measured by a thermal-imaging camera, through which the lines drawn from left to right pass to make it easier to check the degree of heat loss. At the cold cycle, the temperature of the connections and openings of the entrance door was about 30°C lower, and the temperature between the connections of the indoor/outdoor chamber was more than 30°C higher at the hot cycle, indicating high heat losses in these areas.

3.2.5. Temperature and results of the indoor chamber

The AAMA 501 thermal performance test method defines an about-3-hour stabilization period, a 2-hour hot cycle, and a 3-hour stabilization period and 2-hour cold cycle as one cycle, and it derives the thermal performance measurement values of the specimens through a total of three cycles of tests and measurements. The measurement of the temperature and humidity inside and outside the indoor chamber in this study was conducted in the third cycle, and the temperature and humidity data were stored at 1-minute intervals. Fig. 10 shows the temperature graphs of the measurement, condensation test, and stabilization periods of the indoor chamber, and Fig. 11 shows the humidity graphs of the same sections. The outside air temperature and humidity showed a very rapid change in sections B and C. Until section C, a reduction in temperature and a rise in humidity due to the slight rainfall occurred, but this had no significant effect on the indoor chamber environment.

Sections A and C represent stabilization periods, and they are the test sections required for the indoor and outdoor chambers to maintain the constant temperature suitable for the data measurement in the conversion from hot to cold cycle, or from cold to hot cycle. Sections B and D represent hot and cold cycle data measurement periods. Section E is the constant humidity section, and it can be said to be a kind of stabilization period for the condensa-

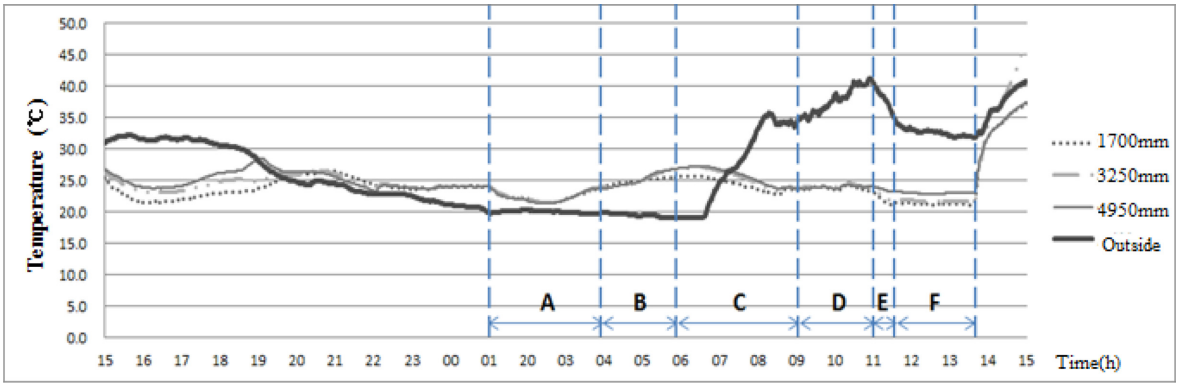


Figure 10. Temperature result of the indoor chamber.

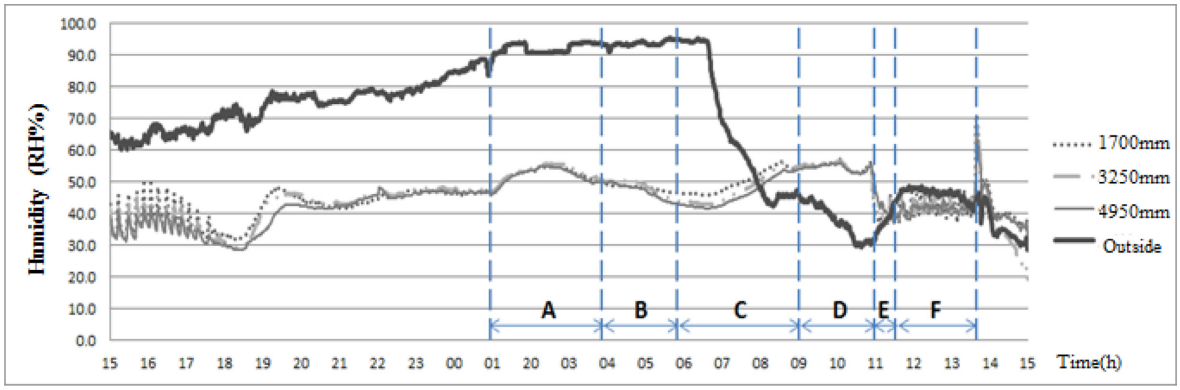


Figure 11. Humidity result of the indoor chamber.

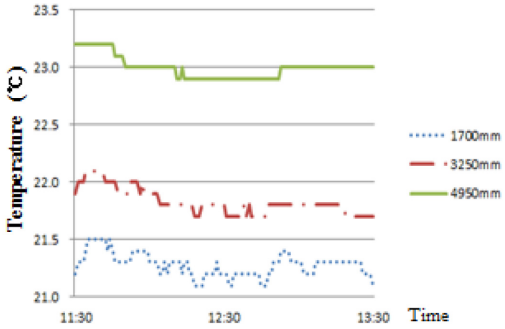


Figure 12. Temperature result of section F.

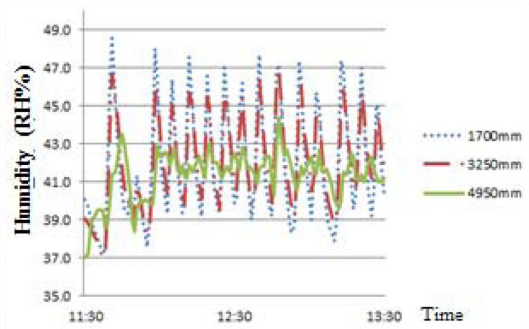


Figure 13. Humidity result of section F.

tion test of section F.

As shown in the graphs in Figs. 10 and 11, the temperature inside the chamber is constantly adjusted in the test, but the humidity is adjusted only in the "condensation test" section. In the graphs in Figs. 10 and 11, the temperature and humidity values seem to show no significant difference according to the height. A look at Fig. 12, in which section F, the condensation test section, is enlarged, revealed the temperature distribution ranges of 21.1~21.5°C at the 1,700 mm point, 21.7~22.1°C at the 3,250 mm point, and 22.9~23.2°C at the 4,950mm point, showing a slight difference. As the case of the indoor chamber is a large space more than 5 m high, it seems that it is rather difficult to maintain uniform indoor temperature environment conditions. In addition, in Fig. 13, the humidity graph of section F, the humidity shows a distribution ranging from 37 to 48.6%. The humidity by height also shows a difference in height, as in the case of the temperature.

4. Conclusion

This study investigated the status and domestic and international standards of the curtain wall thermal performance test chamber and examined the characteristics through on-site measurement on the thermal performance test chamber, in accordance with AAMA 501, which is currently being applied in South Korea.

The measurement results found that considerable heat losses occurred in the connections of the indoor/outdoor chamber, the corners of the outdoor chamber consisting of sandwich panels and openings for the entry into the chamber, and the heat loss could not be identified in a cross-section of the chamber.

During the condensation test, the temperature and humidity inside the indoor chamber were measured, and the results showed that there was a slight difference in temperature distribution by height. At present, the maximum size of the windows where the thermal transmittance values can be measured in the indoor constant temperature and humidity device is 2,000×2,000 mm. Therefore, it was determined that to measure the thermal transmittance values on 4,000×4,000 mm, the actual size of the curtain wall on one floor in the outside with the precision of trust level, it is necessary to maintain the heat loss of the connections between the chambers, and the temperature and humidity environment inside the indoor chamber.

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