THE HEAT TRANSFER SIMULATION FOR THERMAL BRIDGE EFFECT OF THE CORNER WALLS OF BUILDING ACCORDING TO THERMAL CONDITION

YoungSun Jeong[1], GyoungSeok Choi[1], KyoungWoo Kim[1], SeungEon Lee[1]

[1] Building and Urban Research Department, Korea Institute of Construction Technology, Goyang-Si, Gyeonggi-Do, Republic of Korea

ABSTRACT

In this article, we would like to estimate the surface temperature and heat flow pattern of the four corner walls of building envelope with thermal bridge.

In doing so, this study made use of infra-red camera and the heat transfer simulation. The field measurement using infra-red thermography shows thermal bridge and thermal insulation performance of each part of actual existing building envelope. The heat transfer simulation program calculated 3-D steady state heat transfer properties in the corner walls of building envelope as boundary condition (structure shape, thermal insulation, ambient temperature).

Through this study, we provide the mathematical models for estimating thermal bridge effect of the corner walls per boundary condition and we expect to contribute to the effecitve evaluation of thermal performance of the building envelope.

KEYWORDS

Thermal bridge, Heat transfer, Insulation, Infra-red thermography, Corner wall

INTRODUCTION

The most thermally vulnerable parts of a building are the joints of the concave corners of the building envelope that is directly exposed to outdoor air. Even when the walls have outstanding thermal insulation performance and good thermal designs, these joints, compared to other parts, have greater heat transfer loss caused by the thermal bridge, and it is difficult to interpret heat transfer phenomena, such as the heat flow pattern and surface temperature distribution.

In Korea, the thermal insulation performance of the building envelope simply involves the thickness of the insulation material and the thermal transmission properties of the flat wall and floor by region (KICT, 1997). Accordingly, evaluation of the thermal insulation performance of the concave corners joining the walls and local insulation defects and deterioration hasn't been accmplished yet (Kim et al., 1996).

In this study, we analyzed the thermography patterns of actual buildings by infra-red thermographic measurements. Also, we conducted thermal analysis simulation of the concave corners of building walls in the normal state through the heat transfer analysis program that uses the finite difference method. And then, based on such results, we examined the surface temperature distribution of the concave corners of building walls depending on each insulation condition.

This study will produce basic data for the evaluation of the thermal insulation performance of the concave corners of the wall joints, and the determination of the adequacy of the occurrence of dew condensation. Also, the infra-red thermography measurements will serve as the basic data for evaluating the thermal insulation performance of the building envelope and defective parts of a building.

THERMOGRAPHY PATTERN OF BUILDING ENVELOPE

Infra-Red Thermography

Infrared light refers to the wave that has the average wave band of 0.8 ~ 1,000 ㎛, which is longer than the wavelength of the visible wave but shorter than that of the micro wave. One of the strengths of the infrared light is that there is no heat loss in the process of energy transmission since it does not need any medium when transmitting energy in the form of electromagnetic wave (MCIE, 2003). The following figure shows the basic configuration of the infrared camera .

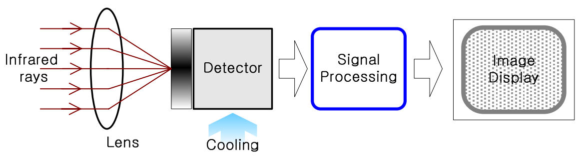


Figure 1. Basic Components of Infrared Camera

Surface Temperature and Thermography of Outside Wall with Insulation

The first picture in Figure 2 shows the uniform temperature and thermography pattern of wall photographed in indoors when the standard outer wall of apartment houses in Korea was well insulated. The image displays an uniformed surface temperature with the temperature difference of approximately ± 0.1℃ in each areas on the image of surface temperature. This translates into satisfactory insulation.

The second picture shows the thermography image of the outer wall and around the windows taken from outdoors. As for the windows, the window frames and lintels show thermal bridge effects caused, not by defective insulation, but by structural reasons.

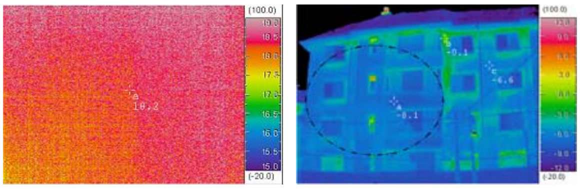


Figure 2. Thermography of Insulated Wall

Surface Temperature and Thermography of Thermal Bridge by Corner Walls

In the concave corners of a building, such as the joints between walls, curvatures and edges show unique thermography peculiar to concave corners even with satisfactory insulation (Kim et al., 2000).

The following figure shows the thermography of thermal bridge by jointed walls. Pictures of apartment and multi-family housings in Korea is shown in Figure 3. Figure 4(Jeong et al., 2003) illustrates the thermography pattern of the concave corner caused by the vertical joining of the building envelope and the wall separating floors or panels, and the thermography pattern of the corner between the two adjacent building envelopes that are vertically joined.

Figure 3. Pictures of Real Buildings in Korea

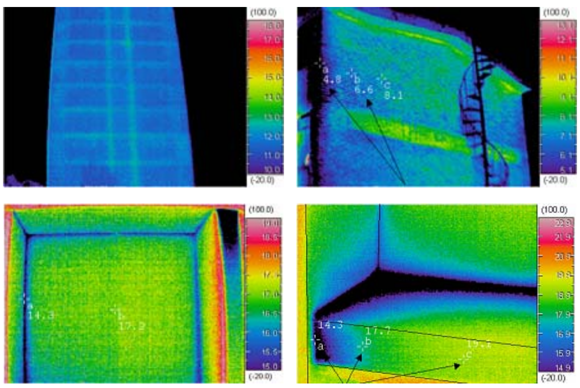


Figure 4. Thermography of Corner Wall with Vertical Joint

It is the thermography pattern of the concave corner caused by the joining of the vertical walls and the horizontal slab. The joints show severe thermal bridge effects from the insufficient insulation for the walls of 3 sided jointed corner.

Surface Temperature and Thermography of Wall with Window

If the outer wall of a building has a window and an opening, the thermal bridge in the window, window frame and lintel results in the relatively low thermal performance. As Figure 5 indicates, heat loss occurs through the wall adjacent to the window from the surface temperature distribution.

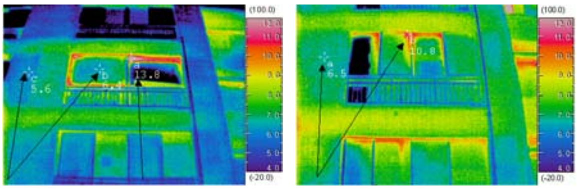


Figure 5. Thermography of Building Envelope with Window

THE HEAT TRANSFER SIMULATION FOR THEMAL BRIDGE

Simulation Program and Analysis Condition

To analyze the temperature and heat flow pattern in buildings, we used the PHYSIBEL program capable of steady-state heat transfer analysis.

The PHYSIBEL software is program for heat transfer simulation focussing on building physics. This program allows calculating 3D steady-state heat transfer in objects described in a rectangular grid. And this program allows simulations fully in line with the standard EN ISO 10211-1 (ISO, 1995).

The three major types of corners walls subject to analysis and generally found in buildings are as follow: ① building envelope with walls that are vertically joined with a floor slab or a partition wall(T Type), ②building envelope vertically joined two adjacent walls(L Type), ③ vertically joined corners with three vertically joined outer walls(S Type). These can be generally found in buildings.

The thermal performance of wall component materials is shown in Table 1 and the configuration of the concave corner was modeled on the basis of the standard building envelope applicable to apartments in Korea (KICT, 1997). Table 2 summarizes simulation conditions for the analysis.

Table 1. Thickness and Thermal Properties of Component Materials

MATERIAL	THICKN-ESS [mm]	THERMAL CONDUCTIVITY [W/(mK)]	THERMAL RESISTANCE [(m²K)/ W]
Plaster Board	9	0.18	0.05
Insulation Material	50	0.0348	1.44
Concrete (1:2:4)	150	1.6	0.094
Mortar (1:3)	20	1.4	0.014
Indoor Surface Thermal Transfer Resistance			0.11
Outdoor Surface Thermal Transfer Resistance			0.06
Total Thermal Resistance of Wall (Total Thermal Transmittance, [W/(m²K)])			1.768 (0.566)

Table 2. Simulation Conditions

	CASE 1	CASE 2	CASE 3	CASE 4
Outdoor Temp.	-20℃	-10℃	0℃	10℃
Indoor Temp.	20 ℃			
Insulation thickness	50 mm			

Simulation Results for T Type Corner Wall

Flat walls that are vertically joined with the uninsulated partition walls, such as the flat vertical outer wall with floor or party wall, have been tested.

The surface temperature and heat flow pattern illustrated in Figure 6 is the simulation result of the flat parts (T Type). The differences in surface temperature between the thermal bridge part (concave corner) and the normal wall are shown in Table 3.

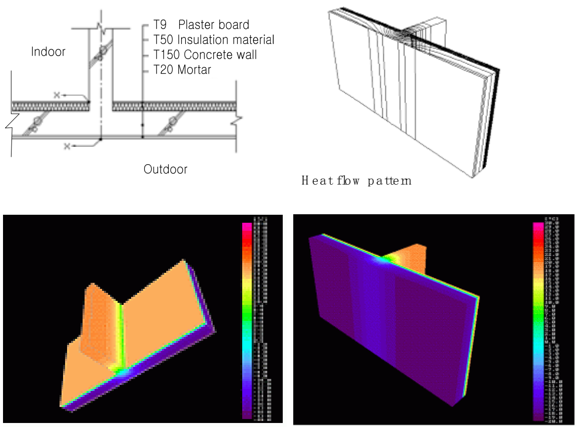
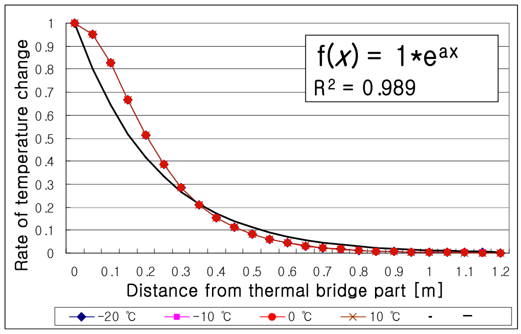


Figure 6. Heat Flux Pattern and Surface Temperature of T Type Corner Wall

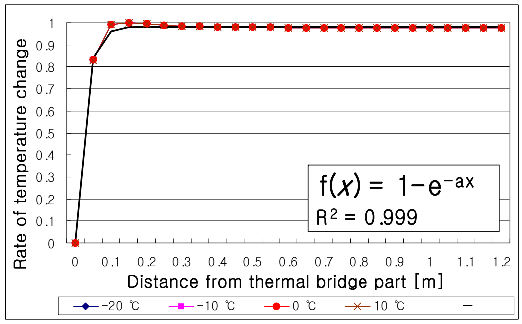
The simulation results showed that the temperature difference between the thermal bridge part and the normal part was the greatest(3.57 ℃) when the outside temperature was -20 ℃, and the lowest (0.89 ℃) when the outside temperature was 10 ℃. The greater the difference between the indoor temperature and the outdoor temperature, the greater the difference between the thermal bridge part and the normal wall.

Table 3. Surface Temperature Difference Between Thermal Bridge Part and Normal Condition Part for T Type Corner Wall

TYPE T	CASE 1	CASE 2	CASE 3	CASE 4
Difference in Outside Surface Temp. [℃]	3.57	2.68	1.79	0.89
Difference in Indoor Surface Temp. [℃]	11.46	8.59	5.73	2.86



a) Outdoor Surface



b) Indoor Surface

Figure 7. Surface Temperature Change Rate of T Type Corner Wall According to Outdoor Temperature

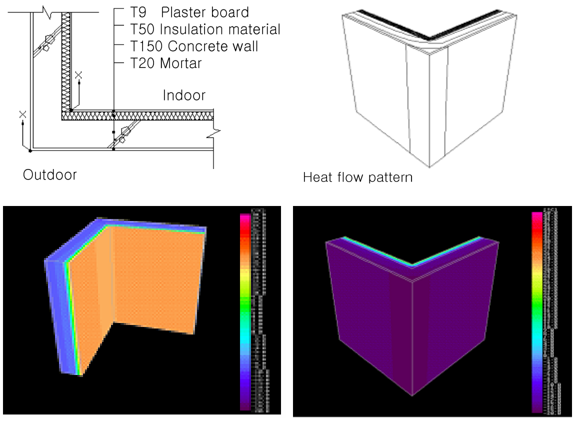
Figure 7 shows the result of the dimensionless calculation of the temperature change rate of the wall surface from the change in outdoor temperature on the basis of the rate(E) of the indoor and outdoor surface temperature change according to the distance(x) from the thermal bridge presented in Figure 6. There seems to be a great difference in temperature between thermal bridge part and the normal part depending on the temperature of the outdoor air, but the proportion was almost the same. This indicates that the dimensionless surface temperature is uniform regardless of the changes in the outdoor temperature.

Simulation Results for L Type Corner Wall

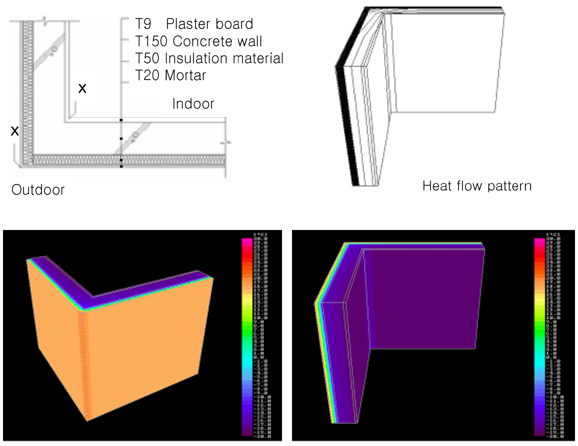
The 2-sided concave corner(L Type) of the wall is the vertical joint between one building wall and another adjacent building wall. The modeling conditions were divided into the concave corner protruding outside(L-1 Type) and the concave corner protruding inside(L-2 Type).

Figure 8 illustrates the surface temperature and heat flow patterns as the result of analyzing 2-sided concave corner. The difference between the surface temperature of the outdoor and indoor concave corner(thermal bridge part) and that of the normal wall according to the condition of the outdoor air are shown in Table 4.

In case of L-1 type, the surface temperature of the outdoor 2-sided concave corner was lower than that of the vertically joined normal part, and in case of L-2 type, it was higher. This phenomenon occurs not because of the outstanding insulation of the wall, but because of the physical joint causing 2-directional heat flux pattern and indoor thermal bridge.



a) L-1 Type Corner Wall



b) L-2 Type Corner Wall

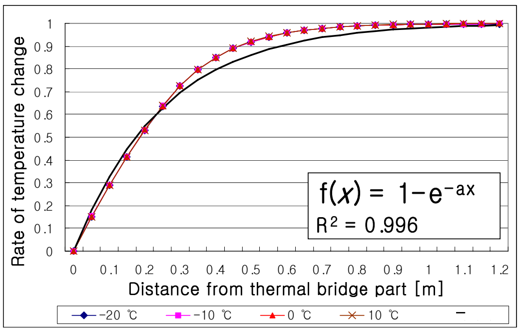
Figure 8. Heat Flux Pattern and Surface Temperature of L Type Corner Wall

Table 4. Surface Temperature Difference between Thermal Bridge Part and Normal Condition Part for L Type Corner Wall

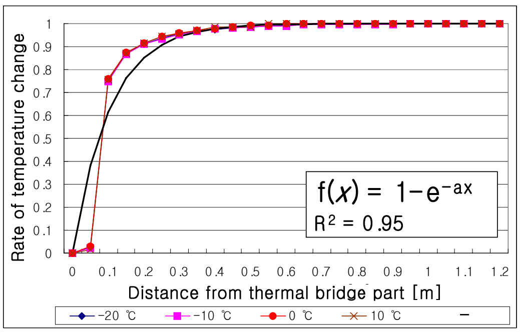
L-1 TYPE	CASE 1	CASE 2	CASE 3	CASE 4
Difference of Outside Surface Temp. [℃]	1.07	0.80	0.53	0.27
Difference of Indoor Surface Temp. [℃]	0.28	0.21	0.14	0.07
L-2 TYPE	**CASE 1**	**CASE 2**	**CASE 3**	**CASE 4**
Difference of Outside Surface Temp. [℃]	0.91	0.68	0.45	0.23
Difference of Indoor Surface Temp. [℃]	2.24	1.68	1.12	0.56

Since such a joint shows lower temperature than the normal wall due to the thermal bridge phenomenon, it is an important phenomenon for analysis.

As Figure 9 and Figure 10, the rate of change in surface temeprature from the outdoor air conditions of 2-sided concave corner for each case is showing the same result that it can be concluded that the proportion of each temperature difference is the same regardless of the change in outdoor air. The outdoor temperature change rate is less steep than the indoor counterpart, and the indoor surface temperature change takes place at the wall joint.

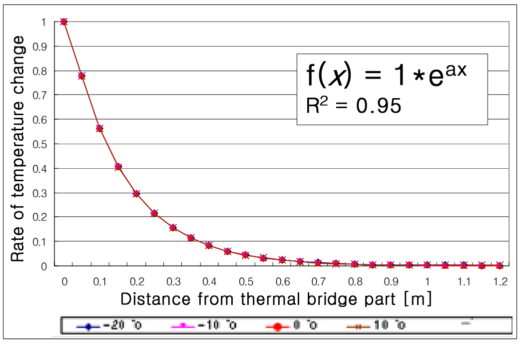


a) Outdoor Surface

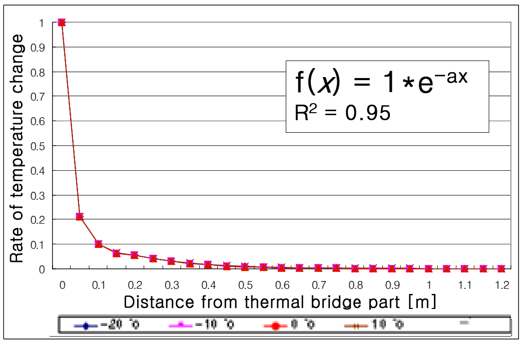


b) Indoor Surface

Figure 9. Surface Temperature Change Rate of L-1 Type Corner Wall according to Outdoor Temperature



a) Outdoor Surface



b) Indoor Surface

Figure 10. Surface Temperature Change Rate of L-2 Type Corner Wall according to Outdoor Temperature

Simulation Results for S Type Corner Wall

Figure 11 illustrates the surface temperature and heat flux patterns as the simulation result of the 2-sided concave coner that is joined vertically with an adjacent wall or floor.

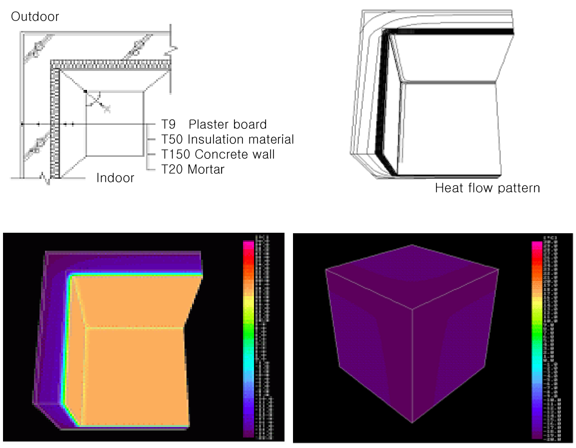


Figure 11. Heat Flux Pattern and Surface Temperature of S Type Corner Wall

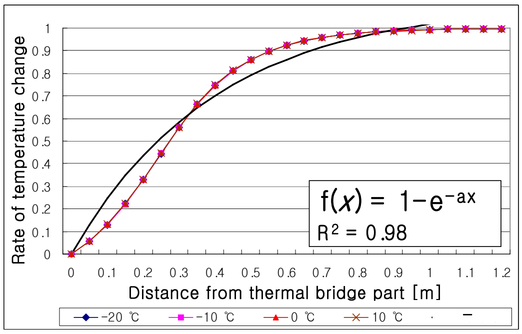
We analyzed the surface temperature distribution according to the distance(x) from the peak of the 3-sided concave corner along the center line of the side of a wall to the normal wall. The differences in the outdoor and indoor surface temperature between the concave corner(thermal bridge part) and the normal wall according to the outdoor air are shown in Table 5.

The indoor surface temperature located at the peak of the 3-sided concave corner showed the lowest temperature due to the thermal bridge taking place in 3 directions. In addition, in case of the indoor surface temperature, the temperature change was most abrupt within 0.15m from the peak of the 3-sided concave corner, and then the surface temperature was remained almost the same.

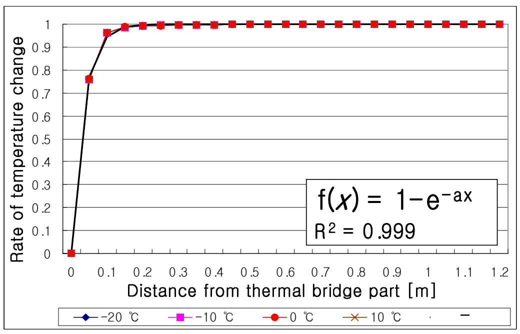
According to the outdoor temperature changes, differences were noted in the surface temperature distribution as shown in Figure 12. The same way as in case of T type and L type, regardless of outdoor air changes, the proportion of each temperature difference was uniform.

Table 5. Surface Temperature Difference Between Thermal Bridge Part and Normal Condition Part for S Type Corner Wall

S TYPE	CASE 1	CASE 2	CASE 3	CASE 4
Difference of Outside Surface Temp. [℃]	1.31	0.98	0.66	0.33
Difference of Indoor Surface Temp. [℃]	6.02	4.51	3.01	1.50



a) Outdoor Surface



b) Indoor Surface

Figure 12. Surface Temperature Change Rate of S Type Corner Wall according to Outdoor Temperature

Simulation Results for Window Wall

As for the out walls with windowns, thermal bridge caused by the windows in the joints between the windows and the wall has been analyzed.

Figure 13 shows the temperature distribution of the wall section, and the surface temperature distribution of the wall. The presence of the thermal bridge is confirmed at the joint between the wall and the window. The outdoor surface temperature distribution was affected by the thermal bridge within 0.5m from the window and the indoor surface temperature was affected by the thermal bridge within 0.15m from the window.

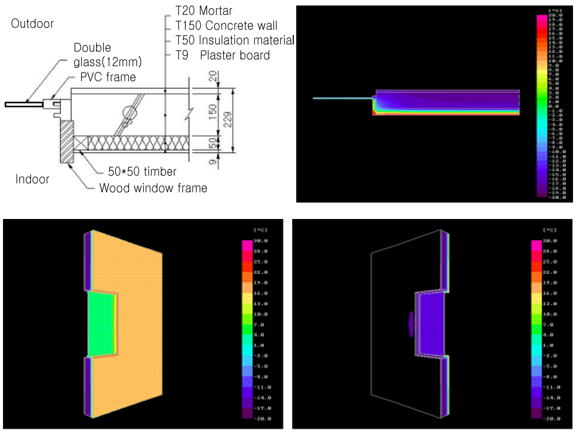


Figure 13. Surface Temperature of Window Wall

CONCLUSION

In this study, Infra-red thermography measurment and the heat transfer simulation were performed to analyze the thermography pattern of corner walls in an actual building.

The results of infra-red thermography confirmed that the concave corner walls had the peculiar thermography caused by the thermal bridge effect. In particular, the 3-sided concave corner showed a severe thermal bridge effect at the joint.

The on-site infra-red thermography images of the concave corners of a building and the heat transfer simulation showed similar results.

According to the simulation result, both the outdoor surface and the indoor surface of the concave corner walls showed a great difference in temperature between the thermal bridge part and the normal wall according to the temperature of the outdoor air. However, the proportion of the temperature difference was almost the same, indicating that the dimensionless surface temperature was uniform regardless of the change in outdoor air.

In the future we need to extend the study to include the insulation conditions of wall and various corner shape including the joints of the building roof. The result of the study would be utilzied as the foundataion data for estimating the adequacy of the thermal insulation performance and dew condensation prevention performance of the wall joints and as the supplementary data for evaluating the insulation performance of the building envelope and the development of the method of investigating defective parts by means of infra-red thermography.

REFERENCES

KICT. 1997. Development of Thermal Insulation Design and Construction System of Building, Korea Institute of Construction Technology.

Kim S.S., Song S.Y., Lee J.W., and Kim K.W. 1996, “A Study on the Thermal Performance Evaluation Method for the Insulation Details of the Joints in a Apartment Building Envelope”, Journal of the Architectural Institute of Korea, Vol 13(3), pp 93-103.

MCIE. 2003. Development of On-site Evaluation Method for Building Insulation Performance Using Infra-red Camera, Final ReportKorea: Ministry of Commerce, Industry and Energy.

Kim K.S., Lee D.B., Lee J.H. and Park H. S. 2000. “A Study on Evaluation of Insulation & Condensation Performance in Corners of Building Envelops”, Journal of the Architectural Institute of Korea, Vol 16(9), pp 163-169.

Jeong Y.S., Choi G.S., Kang J.S. and Lee S.E. 2003. “A Study on Estimate of Surface Temperature in Corners of Building Envelope”, Proceedings of Architectural Institute of Korea, Seoul: Vol 23(2), pp 841-844.

ISO. 1995. ISO Standard, ISO 10211-1: Thermal Bridges in Building Construction-Heat Flows and Surface Temperatures Part 1:General caluction methods, International Standardization Organization.

Choi G.S., Kang J.S., Jeong Y.S. and Lee S.E. 2006. “Development of On-site Evaluation Method for Building Insulation Performance Using an Infra-red Camera”, The World’s Best Infrared Camera Conference, InfraMation 2006, Vol 7, pp 305-316.

Chen Y., Zhou J. and Spitler J. D. 2005, “A Method to Verift Calcuation of Transient Heat Conduction Through Multilayer Building Constructions”, the 9th International IBPSA Conference-Building Simulation 2005, Montreal, Canada, pp 159-165.

http://www.physibel.be/