Framework for Evaluating the Thermal Insulation Performance of Existing Residential Buildings Using the Infrared Thermal image and Image Processing Method

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ABSTRACT

Various green projects were executed to reduce the energy consumption in building sector. In particular, it is necessary to improve the thermal insulation performance of existing residential buildings. Even though it is critical to evaluate the thermal insulation performance in operation and maintenance phase, most of the policies and previous studies have focused on thermal insulation materials and systems in design phase. To address this limitation, this study aimed to develop the framework for evaluating the thermal insulation performance of existing residential buildings using the infrared thermal image and image processing method. Towards this end, this study was conducted in two steps: (i) establishment of the building information and infrared thermal image; and (ii) estimation of the thermal loss areas in building surface using the image processing. The result of this study could help building users and managers to estimate the thermal insulation performance in operation and maintenance phase.

Keywords –
Thermal Insulation Performance; Infrared Thermal Image; Image Processing Method; ISODATA; Existing Residential Building.

1 Introduction

Various efforts have been exerted worldwide to solve the global warming and lack of fossil fuels [1-3]. Compared to new buildings, existing buildings account for nearly 97% in South Korea [4]. The government has effort to reduce the energy consumption of existing buildings through various sustainable policies (e.g., *Act on the Promotion of Green Buildings*). Also, several green projects (e.g., *Green Remodelling Project, Passive House Projects and 3-Liter House*, etc.) are being executed to improve the thermal insulation performance of existing buildings [5].

Previous studies regarding thermal insulation performance were conducted from the three points of view. First, the thermal insulation performance of building material was evaluated. Mukhopadhyaya et al. (2014) evaluated and verified constructability and long-term thermal performance of the vacuum insulation panels in Canadian subarctic climate [6]. Al-Homoud presented the characteristics of commonly-used insulation materials and evaluated their thermal insulation performance [7].

Second, the thermal insulation performance of the insulation system was evaluated. Song et al. (2009) evaluated the thermal bridges in building surface. Compared to the inside insulation, it was determined that the outside insulation diminished linear thermal transmittance [8]. Ozel et al. (2014) evaluated the effect of wall structures (e.g., inside, outside, and middle of the wall) on the thermal insulation performance and suggested the optimal insulation thickness [9].

Third, the building's thermal defects were evaluated. Huda et al. (2013) developed the thermal defect identification system using the electrical equipment and neural network [10]. Asdrubali et al. (2012) analyze the thermal bridges using the thermographic techniques [11].

However, previous studies have two limitations: (i) most of the previous studies evaluated the thermal insulation performance of building material and insulation system in design phase and (ii) there is a lack of previous studies on the quantitative evaluation of the thermal insulation performance of existing building surface using the image processing method (e.g., classification) in operation and maintenance phase.

To address these limitations, this study aimed to develop the framework for evaluating the thermal insulation performance of existing residential buildings using the infrared thermal image and image processing method, which can be used in operation and maintenance phase.

2 Method

'J' residential building was determined as a case study. To evaluate the thermal insulation performance, the thermal loss areas should be estimated in the building surface. To estimate the thermal loss areas, this study was conducted in follow two steps: (i) establishment of the building information and infrared thermal image and (ii) estimation of the thermal loss areas in building surface using the image processing.

2.1 STEP 1: Establishment of the Building Information and Infrared Thermal Image

This study evaluated the thermal insulation performance of 'J' residential building located in Gyeonggi-do Province, South Korea. Table 1 shows the characteristics of 'J' residential building.

Table 1. The characteristics of 'J' residential building

Class	Detailed description
Location	Gyeonggi-do (South Korea)
Completion year	1996
Floor area by household unit	78 m^2
Floor height	2,600 mm
Heating system	Central heating

To evaluate the thermal insulation performance, two types of data sets were established: (i) the characteristics of 'J' residential building (e.g., location, floor area by household unit, heating system, etc.) and (ii) the infrared thermal image of 'J' residential building.

Table 2. The technical specifications of the infrared thermal camera

Class	Detailed description
Temperature range	-20 ℃ ~ 250 ℃
Thermal image pixels	320 × 240 pixels
Resolution	0.1 ℃
Accuracy	± 2℃ or ± 2% of reading
Spectral range	8 to 12 μm

First, the characteristics of 'J' residential building were established from the property management office (refer to the Table 1). Second, the infrared thermal image of 'J' residential building was established using TH7800 produced by 'NEC Avio Infrared Technologies Co., Ltd.'. Table 2 shows the technical specifications of the infrared thermal camera. TH7800 has the temperature range of -20 ℃ ~ 250 ℃ and the thermal image pixels of 320 × 240.

2.2 STEP 2: Estimation of the Thermal Loss areas in Building Surface Using the Image Processing

Figure 1 shows the infrared thermal image of the 16 households ('A' ~ 'P') in 'J' residential building, which was taken at 2:37 A.M (18 January 2015). It was shown that the building surface temperature was distributed from -15.9 ℃ to 10.9 ℃. Based on this distribution, it was determined that a difference in the thermal insulation performance of existing buildings may occur in operation and maintenance phase, even though the insulation system was designed with the same building material in design phase. Therefore, it is necessary to continually evaluate the thermal insulation performance of existing buildings in operation and maintenance phase.

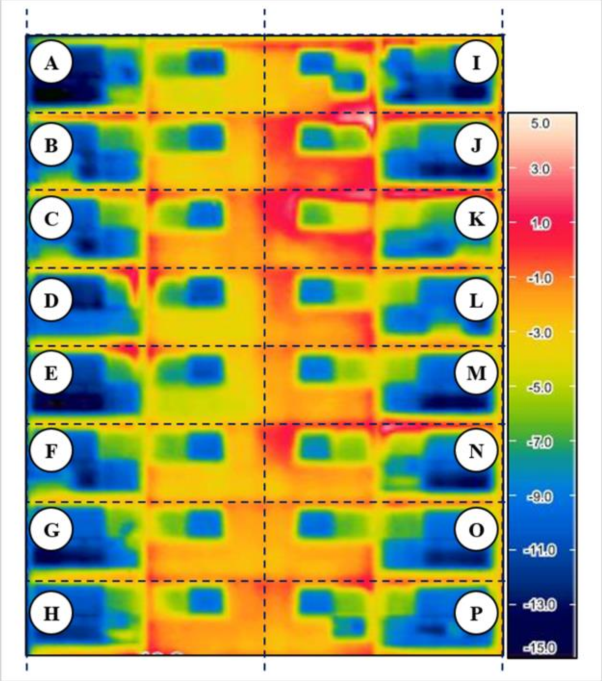

Figure 1. Infrared thermal image of 'J' residential building

The thermal loss areas in building surface can be estimated using the image processing method. The infrared thermal image can measure the building surface temperature of each household unit; however, it cannot quantify the thermal insulation performance of existing buildings. To solve this problem, the image processing method can be used to classify the distribution of surface temperature in each household unit. Namely, the degree of thermal losses in each household unit can be quantified. Consequently, the relative thermal insulation performance of each household unit can be evaluated.

There are two classification methods for the infrared thermal image: (i) supervised classification and (ii) unsupervised classification. First, in the supervised classification, the training data should be established in advance. The pixels with the similar properties in the infrared thermal image are to be classified into the same cluster. The final decision-maker can directly determine the number of classifications in the infrared thermal image; however, more data should be collected to establish the training data. Second, in the unsupervised classification, a statistical method is used to classify the pixels with the similar properties in the infrared thermal image. Compared to the supervised classification, less data is used for the image processing [12-13].

The iterative self-organizing data analysis (ISODATA) was used for clustering the irregular pixels of the building surface temperature, which is an algorithm of the unsupervised classification (refer to Table 3). To do this, this study used ‘ERDAS Imagine’ produced by ‘Hexagon Geospatial’.

Table 3. Detailed descriptions of the ISODATA options

Class		Detailed description
Algorithm		ISODATA
Clustering option	Initialize	Statistics
	Std. deviation	1.00
Processing option	Maximum iteration	6
	Convergence threshold	0.950
	Skip factors	X: 1, Y: 1

Figure 2 shows the result of the image processing using the ISODATA algorithm in ‘J’ residential building. The irregular pixels of the building surface temperature in infrared thermal image were classified into a total of five classes. The five classes were expressed with five colours (i.e., red, yellow, green, sky-blue, and blue). The thermal losses through the building surface become smaller from class 1 (red colour) to class 5 (blue colour). Namely, the higher the building surface temperature is, the greater the thermal losses through the building surface are.

Table 4 shows the thermal loss areas in building surface by each household unit. It was found that there was a difference in the thermal loss areas of each household unit. For example, the thermal loss areas in class 1, class 2, class 3, class 4, and class 5 for household unit ‘A’ were determined to be 0.18 m^2 (0.89 %), 8.60 m^2 (42.23 %), 3.48 m^2 (17.10 %), 3.75 m^2 (18.40 %), and 4.36 m^2 (21.38 %), respectively. Meanwhile, the thermal loss areas in class 1, class 2, class 3, class 4, and class 5 for household unit ‘J’ were determined to be 7.34 m^2 (35.15 %), 4.32 m^2 (20.72 %), 2.93 m^2 (14.02 %), 5.14 m^2 (24.60 %), and 1.15 m^2 (5.51 %), respectively. It can be concluded that the thermal insulation performance of household unit ‘A’ was superior to that of household unit ‘J’. Through this approach, the thermal insulation performance of existing building surface in operation and maintenance phase can be quantitatively evaluated.

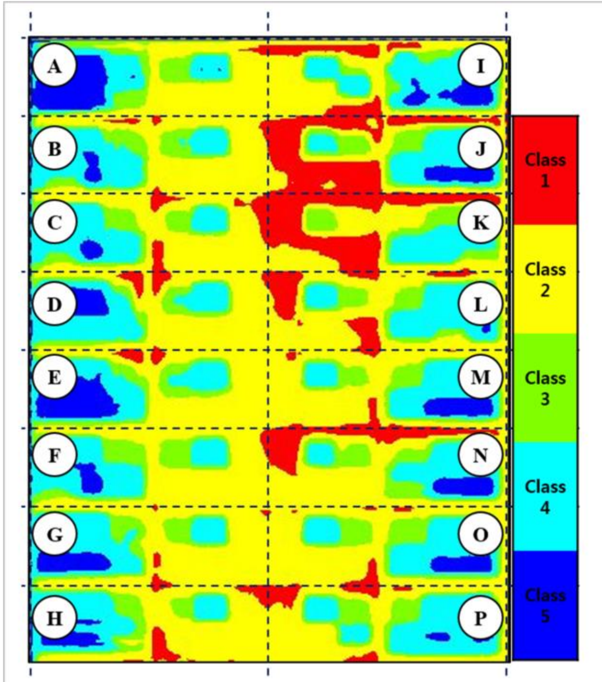

Figure 2. The result of the image processing using the ISODATA algorithm in ‘J’ residential building

3 Conclusions and Discussion

This study aimed to develop the framework for evaluating the thermal insulation performance of existing residential buildings using the infrared thermal image and image processing method. Using the proposed framework, it was determined that the relative thermal insulation performance of each household unit can be quantified.

The proposed framework can be used for the following objectives: (i) estimation of the relative thermal insulation performance of existing buildings in operation and management phase; (ii) continuous management of the thermal insulation performance of existing buildings by establishing a database on the thermal insulation performance of each household unit; and (iii) establishment of the optimal energy retrofit strategy for improving the thermal Insulation performance of existing buildings.

Table 4. The thermal loss areas in building surface by each household unit

Household unit	Class 1 (m^2)	Class 2 (m^2)	Class 3 (m^2)	Class 4 (m^2)	Class 5 (m^2)
A	0.18 (0.89%)	8.60 (42.23%)	3.48 (17.10%)	3.75 (18.40%)	4.36 (21.38%)
B	0.46 (2.22%)	9.88 (47.60%)	3.21 (15.49%)	6.28 (30.28%)	0.92 (4.41%)
C	1.45 (7.00%)	9.67 (46.59%)	2.97 (14.30%)	6.25 (30.13%)	0.41 (1.98%)
D	3.89 (3.89%)	9.36 (45.08%)	2.66 (12.84%)	5.81 (27.98%)	2.12 (10.20%)
E	0.46 (2.22%)	8.85 (42.63%)	2.98 (14.35%)	4.88 (23.50%)	3.59 (17.30%)
F	0.20 (0.98%)	9.76 (47.05%)	3.75 (18.06%)	6.36 (30.66%)	0.68 (3.25%)
G	0.29 (1.39%)	9.90 (47.71%)	2.99 (14.40%)	5.84 (28.15%)	1.73 (8.35%)
H	1.25 (6.02%)	9.84 (47.42%)	2.83 (13.66%)	5.49 (26.46%)	1.34 (6.44%)
I	2.38 (11.62%)	7.93 (38.70%)	2.52 (12.31%)	5.89 (28.72%)	1.77 (8.65%)
J	7.34 (35.15%)	4.32 (20.72%)	2.93 (14.02%)	5.14 (24.60%)	1.15 (5.51%)
K	6.71 (32.14%)	7.67 (35.29%)	3.12 (14.93%)	3.68 (17.65%)	0.00 (0.00%)
L	2.65 (32.14%)	9.11 (35.29%)	3.17 (14.93%)	5.87 (17.65%)	0.09 (0.41%)
M	0.92 (4.43%)	10.15 (48.62%)	3.08 (14.77%)	5.40 (25.86%)	1.32 (6.33%)
N	3.13 (14.99%)	8.54 (40.89%)	3.54 (16.95%)	4.54 (21.75%)	1.13 (5.42%)
O	0.50 (2.40%)	10.02 (47.98%)	3.64 (17.43%)	5.67 (27.16%)	1.05 (5.03%)
P	1.39 (6.65%)	8.49 (40.68%)	3.52 (16.87%)	6.79 (32.54%)	0.68 (3.26%)

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References

[1] Hong, T., Koo, C., Jeong, K. A decision support model for reducing electric energy consumption in elementary school facilities. *Applied Energy*, 95:253-266, 2012.

[2] Koo, C., Kim, H., Hong, T. Framework for the analysis of the low-carbon scenario 2020 to achieve the national carbon Emissions reduction target: Focused on educational facilities. *Energy Policy*, 73:356-367, 2014.

[3] Hong, T., Koo, C., Kwak, T.; Park, H.S. An economic and environmental assessment for selecting the optimum renewable energy system for educational facility. *Renewable & Sustainable Energy Reviews*. 29:286-300, 2014.

[4] KSIS. Korean Statistical Information Service. On-line: http://kosis.kr/statisticsList/statisticsList_01List.jsp?vwcd=MT_ZTITLE&parentId=H#SubCont, Accessed: 9/12/2014.

[5] MLTM. *Support for Development of Green Buildings Act*. In: Ministry of Land, Transport and Maritime Affairs; 2012.

[6] Mukhopadhyaya. P., Maclean, D., Korn, J., Reenen, D.V., Molleti, S. Building application and thermal performance of vacuum insulation panels (VIPs) in Canadian subarctic climate. *Energy and Buildings*, 85:672-680, 2014.

[7] Al-Homoud, M.S. Performance characteristics and practical applications of common building thermal insulation materials. *Building and Environment*, 40:353-366, 2005.

[8] Song, S.Y., Koo, B.K., Lee, B.I. Insulation performance evaluation of thermal bridges in apartment building envelop using the linear thermal transmittance. Korean *Institute of Architectural Sustainable Environment and Building Systems Conference Proceeding*, 117-120, 2009.

[9] Ozel M. Effect of insulation location on dynamic heat-transfer characteristics of building external walls and optimization of insulation thickness. *Energy and Buildings*, 72:288-295, 2014.

[10] Huda, A.S.N and Taib, S. Application of infrared thermography for predictive/preventive maintenance of thermal defect in electrical equipment. *Applied Thermal Engineering*, 61(2):220-227.

[11] Asdrubali F., Baldinelli, G., Bianchi, F. A quantitative methodology to evaluate thermal bridges in buildings. *Applied Energy*, 97:365-373.

[12] Jensen, J.R. *Introductory digital image processing: a remote sensing perspective*, 3rd Ed. Prentice Hall, 2004.

[13] Huang, K., A synergistic automatic clustering technique for multispectral image analysis, *Photogrammetric Engineering & Remote Sensing*, 68(1): 33-40, 2002.