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Thermal performance evaluation of low-income buildings based on indoor temperature performance

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HIGHLIGHTS

- Indoor temperature pattern can be similar even building conditions are different.
- If similar indoor temperature patterns occur, energy demand is also similar.
- Changes in energy demand are similar when window thermal performance is changed.
- Overall thermal performance of low-income buildings can be diagnosed.
- Databases can store remodeling plans using indoor temperature for future use.

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ABSTRACT

In South Korea, about 40,000 buildings of low-income households have been diagnosed and remodeled annually by the Energy Welfare Program, using the normative method. The normative method is based on the heat gain elements of a building. In contrast, the performance-based method is based on the output derived from the thermal performance of each building part. In the normative method, there is no other building in which the input conditions of a building are perfectly matched. Further, cost-effective energy remodeling strategies vary according to the capacity of the diagnosis engineer. In this paper, we analyze the thermal performance of buildings by the performance-based method using indoor temperature, and examine the possibility of a database for the optimal remodeling method. For this, we analyzed more than 2500 simulation cases by combining thermal performance of each building part. The indoor temperature pattern can be similar even when the thermal performance of each building part is different. In buildings with similar indoor temperature patterns, the coefficient of variation of the root mean squared error of energy demand falls within the acceptable error range. Furthermore, changes in energy demand and predicted mean vote are similar when window thermal performance is changed.

1. Introduction

The Energy Welfare Program for low-income households is being implemented domestically and abroad. Since 2007 in South Korea, the government has been implementing a “Low-income Energy Efficiency Improvement Program (LEEIP)” for households receiving public assistance, by remodeling walls and windows to reduce energy poverty levels. From 2007 to 2014, 330,000 households were supported and a total of 205 million dollars invested. More than 200 diagnosis engineers are dispatched to diagnose 40,000 low-income households annually: one diagnosis engineer diagnoses about 200 households per year. The diagnosis engineer diagnoses building wall, window, and infiltration performance and remodels the house [1,2]. The measured data are entered into Eco-House Software [3], developed by the Korea Institute of Energy Research, to calculate the load and energy consumption of the building and remodel aging areas within the specified construction budget. After remodeling, the building is measured and simulated again to check the improved thermal performance of the building and whether low-income conditions are alleviated.

There are normative and performance-based methods to evaluate the thermal performance of a building, as shown in Fig. 1 [4]. LEEIP performs simulations using the normative method, which evaluates the “means” and “cause” of the formation of the building thermal environment and is based on the thermal performance of each element of

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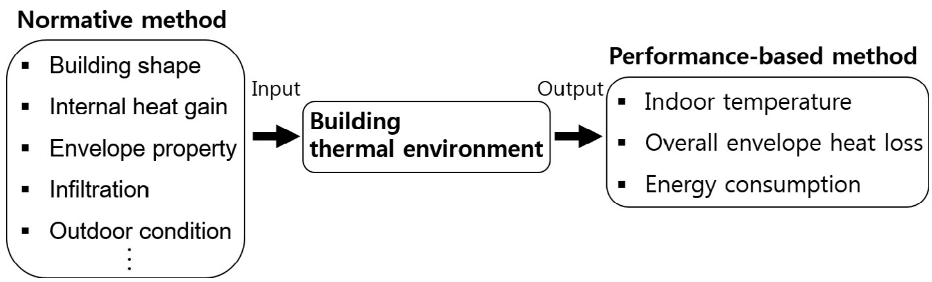

Fig. 1. Schematic diagram of normative and performance-based methods of assessing thermal performance of a building.

the building [5,6]. Hong et al. [7] calculate the energy use of a building, and identify and evaluate retrofit measures in terms of energy savings, energy cost savings, and payback using the normative method. Furthermore, use of the normative method in building codes is often considered easy to follow because it clearly outlines what is acceptable [8]. However, it is difficult to secure reliability because of the uncertainty of each element. Uncertainties arise from numerous factors such as occupant behavior, changes in internal heating schedules and densities, changes in indoor thermal capacity and solar radiation inflow from indoor furniture, and changes in wall and window performance due to building aging and construction [9–11]. In addition, it is difficult for a diagnosis engineer to measure the thermal performance of the floor and ceiling, meaning that often building codes from the year of construction are used as simulation input conditions. When remodeling a building without proper diagnosis of thermal performance, beneficial effects can be reduced or energy consumption may increase compared to the situation before remodeling [12].

Above all, the normative method cannot use previously analyzed data or populate a database. This is because there is no second building that matches all input conditions including building type, building orientation, floor area, ceiling height, internal heat gain, envelope properties, and weather conditions. Therefore, energy-related data and the optimal envelope design methods analyzed for 300,000 households cannot be applied to other buildings and must instead be simulated individually, which requires considerable time and money. In addition, there is a difference in energy saving, Predicted Mean Vote (PMV) improvement, and construction cost by remodeling depending on the capability of the diagnosis engineer. If data derived from previous studies could be used, considerable time and costs would be saved, and the optimum remodeling effect could be obtained regardless of the capability of the diagnosis engineers. Therefore, although most building codes and standards have used prescriptive criteria in the past, there has been strong interest globally in recent years in developing codes and standards that are more performance-based [13].

In contrast to the normative method, the performance-based method is based on the "output" derived by the building thermal environment, so it focuses on the overall thermal performance of a building rather than the performance of parts of a building [8,13]. Therefore, even if the performance of some building parts is low, other parts can offset this. There are examples of the use of performance-based methods in building codes, such as the Envelope Thermal Transfer Value (ETTV) of Singapore and the Perimeter Annual Load (PAL) of Japan. ETTV specifies the heat transfer that is ultimately emitted through the total building envelope rather than the thermal performance of building parts, by specifying a maximum heat transfer of 50 W/m^2 [14,15]. PAL regulates envelope performance by dividing the annual energy demand of the perimeter by the floor area of the perimeter [16,17]. However, since these criteria are designed to regulate envelope performance, comprehensive thermal performance of a building cannot be assessed.

In addition, the performance-based method has limitations in that it cannot determine the performance of each building part. To remodel a building under a mechanism such as LEEIP, there is a need to reflect both the thermal performance of walls and windows, as well as the overall thermal performance of the building. Therefore, a combination of normative and performance-based methods should be used.

This enables energy-related data such as energy demand and optimal remodeling strategy derived from previous research to be stored, and the thermal performance of large-scale building groups can be quickly and accurately diagnosed, requiring only simple simulation. Since no expert knowledge or equipment is required, a simple simulation analysis can lead to an optimal remodeling strategy, which can save considerable time and cost. Moreover, because all diagnoses can derive the same outcome, the same benefits can be given to all low-income households.

2. Material and methods

2.1. Analyzing building thermal performance using indoor temperature

To investigate the feasibility of analyzing the thermal performance of a building using indoor temperature, research was conducted as shown in Fig. 2. First, the applicable input variables were set for each building part, and various building cases were derived by combining the respective items. Input variables are discussed in more depth in

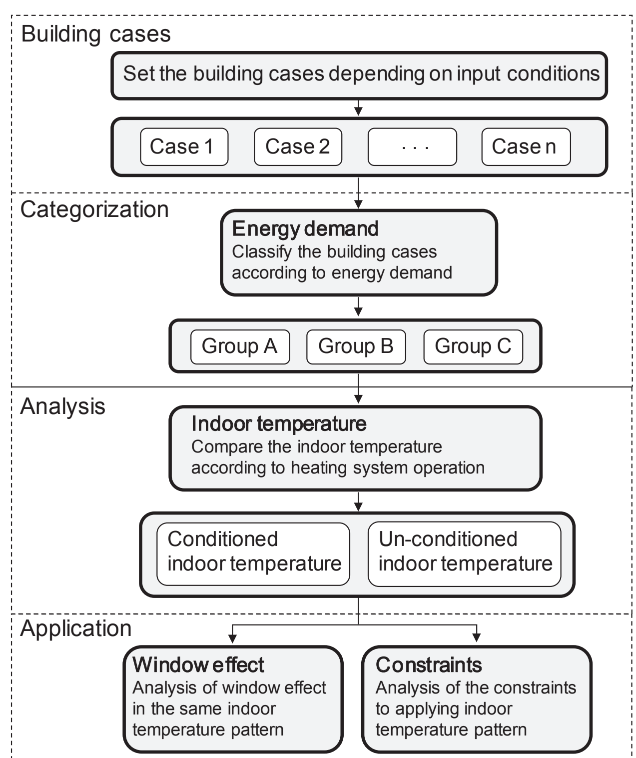

Fig. 2. Research process for diagnosis and remodeling of buildings using indoor temperature.