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Development and validation of a simple estimating tool to predict heating and cooling energy demand for attics of residential buildings

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ABSTRACT

The application of attic radiant barriers as a residential building energy conservation tool has received considerable attention in recent years. Quantifying the benefits of radiant barrier is complicated because the energy savings provided by this system depend on various factors including local climate, geometry, and other building parameters. Therefore, the objective of this study is to develop a simple estimating tool that may be used by homeowners and designers to assess the effectiveness and economic benefits of radiant barrier under different climatic conditions in the US. The developed tool is based on transient three-dimensional finite element models that were validated based on the results of an experimental field study. The results of the finite element models were used to develop a set of regression equations to predict the thermal performances of radiant barriers under a wide range of operating conditions. Although the theoretical basis behind this tool is robust and accurate, the developed tool is simple, flexible, and user-friendly to encourage its use among practitioners and homeowners with minimal background about this system and heat transfer mechanisms. It is anticipated that the developed tool will facilitate the integration of energy efficiency in residential design and construction.

1. Introduction

The US Green Building Council reported that buildings are responsible for 36% of total energy use, 65% of electricity consumption, and 30% of greenhouse gas emissions [1]. With the high amount of energy used by buildings, there is an increasing need for non-renewable energy sources such as coal. By 2030, an estimated 80% more coal will be needed, shifting the US to import coal from other countries [1]. Since buildings represent the largest energy consumption sector, efforts to reduce energy use and negative environmental impacts are important issues.

Several experimental and numerical studies have been carried out to identify the energy savings of radiant barriers in attics during summer and winter seasons [2–19]. A transient heat and mass transfer model was developed by Medina et al. [4,5] to predict hourly ceiling heat/gain in residential construction, with the aim of estimating heating–cooling load reduction produced by radiant barriers. Using this model, Medina and Young [10] evaluated the influence of the climate and local environmental variables on the performance of attic radiant barrier system (RBS) in the US. Later, Miranville et al. [12] studied the thermal performance of radiant barriers based on dynamic simulations and field measurements. A test cell equipped with a standard roof was used for field measurements. Results demonstrated that the overall thermal performance of the roof was controlled by convective heat transfer in the lower air layer and that thermal bridges had little effect on roof thermal performance. The efficiency of different types of radiant barriers available in civil construction market was studied by Michaels et al. [13]. More recently, the thermal resistance of a roof-mounted multi-reflective radiant barrier was evaluated experimentally for tropical and humid conditions. The thermal performance of multi-reflective radiant barrier was determined based on the mean energy method. Results showed that this method is able to predict the thermal performance of multi-reflective radiant barrier given the prevailing climatic conditions [16]. Asadi et al. [19] developed a three-dimensional (3D) transient finite element (FE) model to assess the thermal performance of an attic radiant barrier system. Finite element analysis was validated using experimental data form a house complex in Zachary, LA. The authors also examined different design variables and their influence on the performance of the radiant barrier insulation system. It was concluded that the presence of an air gap on both sides of the radiant barrier had a considerable effect – compared to other variables – on the performance of the radiant barrier insulation system.

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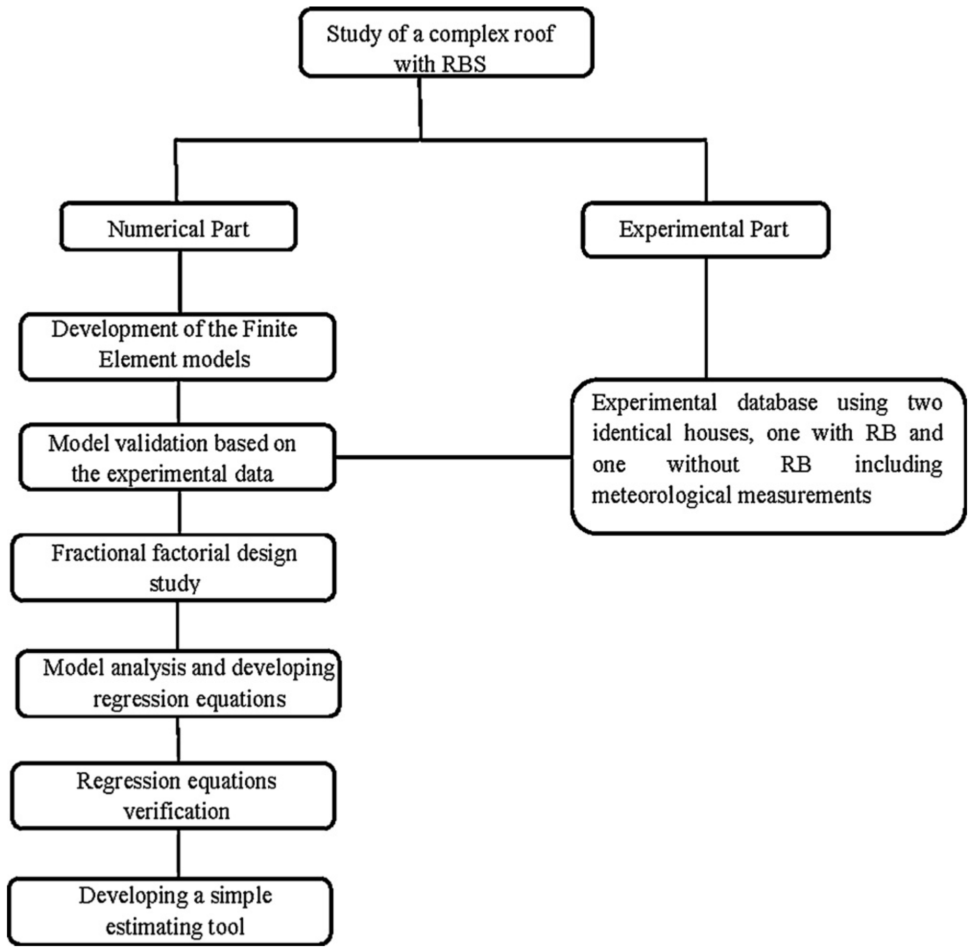

Fig. 1. Methodology used for the present study.

Energy-conscious consumers deal with the decision of whether or not to install a radiant barrier in their home, and if so, what type of radiant barrier to install. Therefore, the objective of this study is to develop a simple estimating tool that may be used by homeowners, stage agencies, and contractors to assess the effectiveness and economic benefits of radiant barrier insulation systems under different climatic conditions in the US. This tool can help demonstrate how important design decisions can impact building energy performance. To achieve this objective, a series of FE simulations based on a partial factorial design were conducted to investigate the influence of different design and operational parameters on the performance of radiant barrier. Results of the FE models were then implemented into a set of regression equations to predict the thermal and economic performances of radiant barriers under a wide range of operating conditions. The tool calculates annual heating–cooling loads for any type of building inputs provided by the user. It is anticipated that the developed tool will facilitate the integration of energy efficiency in residential design and construction. This tool was designed based on the following principles: ease of use, minimum number of inputs, and simplicity and practicality of outputs.

2. Methodology

The flowchart of the methodology adopted in the development of the estimating tool is illustrated in Fig. 1. Estimating tool development consisted of two steps: an experimental study and a numerical study. The experimental part of this study was carried out in Louisiana. Two identical houses were selected for this study. One of the houses had radiant barrier insulation system in its attic while the second one had conventional insulation. The experimental study lasted for 8 months in order to collect data in the winter and summer seasons.

In the numerical study, 3D transient FE models were employed to simulate the heat transfer mechanism in the attic. The developed models were validated based on experimental measurements. After validation, a fractional factorial design study was carried out to evaluate the effect of different design and operational parameters on the performance of radiant barrier system. Based on the results of the fractional factorial design, regression equations were developed and verified for different cases. These equations were used to build the simple estimating tool to predict annual heating–cooling load and total cost savings for different climatic conditions in the US.

2.1. Descriptions of the finite element model

Three dimensional transient finite element heat transfer models for an attic with and without radiant barrier system were developed to evaluate the thermal performance of radiant barrier under different design and environmental conditions in the US. Fig. 2 demonstrates the various heat transfer mechanisms that take place in the attic. A five-sided attic, which is geometrically symmetric with respect to *XY* and *YZ* planes, was simulated. The attic had two pitched roof sections, two vertical gable-end sections, and one horizontal ceiling frame. The model considered all the heat transfer mechanisms that may occur within the space. It is worth mentioning that many factors affect the calculated temperature