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Energy efficiency of residential buildings in the U.S.: Improvement potential beyond IECC

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ABSTRACT

The International Energy Conservation Code (IECC) is commonly used to improve building energy efficiency, and its multiple iterations have been adopted by numerous countries, as well as most states in the U.S. The study assesses the effects and energy saving potentials of multiple passive and active building design features for new residential construction by using a baseline model designed to mimic existing characteristics of residential buildings in the Northeast region of the U.S. The developed model was verified for the two commonly adopted iterations of IECC codes to attain realistic results, and to quantify potential energy savings calculated beyond those that are provided by the Code. CFD analysis was used to assess indoor temperature variation and air velocity, together with an assessment for occupant comfort. Results indicate annual overall energy savings of 114 kWh/m^2 in a detached single family home, which represents a 39% reduction in building total energy consumption in addition to and beyond the energy efficiency gains required by the 2012 IECC. CFD analysis results also indicate that occupant comfort is not compromised by techniques analyzed. For an individual residential building in the studied region, the energy savings over its lifetime would total 500 MWh. At the regional scale, should all new residential construction in the next 6 years in the cold climate region of the U.S. adopt the studied techniques, their cumulative savings would exceed energy generated in the U.S. from solar power in 2016.

1. Introduction

Energy, and methods for producing, distributing, and consuming energy has received global attention in recent years. As a result, various fields of engineering have focused more on energy consumption of their projects and designs. However, buildings and the energy they consume far exceed energy consumption by a single consumable product and thus may be considered as one of the most significant areas for potential improvement.

Buildings are responsible for approximately 40% of global energy consumption [1]. Therefore, they are also capable of saving significant amount of energy and environmental emissions if they are managed well. Despite the fact that there are available techniques and technologies for reducing energy consumption and environmental impacts, their implementation on residential buildings has been lacking. It is possible to provide more efficient living spaces by choosing from currently available alternative designs during the early phases of design. Better use of natural resources available at a particular site are capable of producing energy-efficient and comfortable conditions for indoor environments.

There are international efforts in the building sector to provide regulations and guidelines for energy efficiency of buildings. The International Energy Conservation Code (IECC) is the most widely adopted code in the U.S., where it is currently in use by 49 states in the country [2]. IECC provides a model for states and local jurisdictions who may use the Code as part of their building regulations and standards. States are free to adopt and even to further modify the model regulations according to their specific needs, climatic conditions, and demands [3]. Energy standards for buildings and construction are typically not made mandatory, but are recommended for implementation. On the other hand, energy codes are regulatory and are mandatory for buildings and construction to apply. This study has utilized both energy codes and standards in building modeling and simulations.

There are existing studies on building energy consumption and potential techniques that could help reduce energy consumption in residential buildings. One of the main research tracks focuses efforts towards predicting and modeling energy demand in buildings from the consumption point of view [4–10]. The other research track focuses

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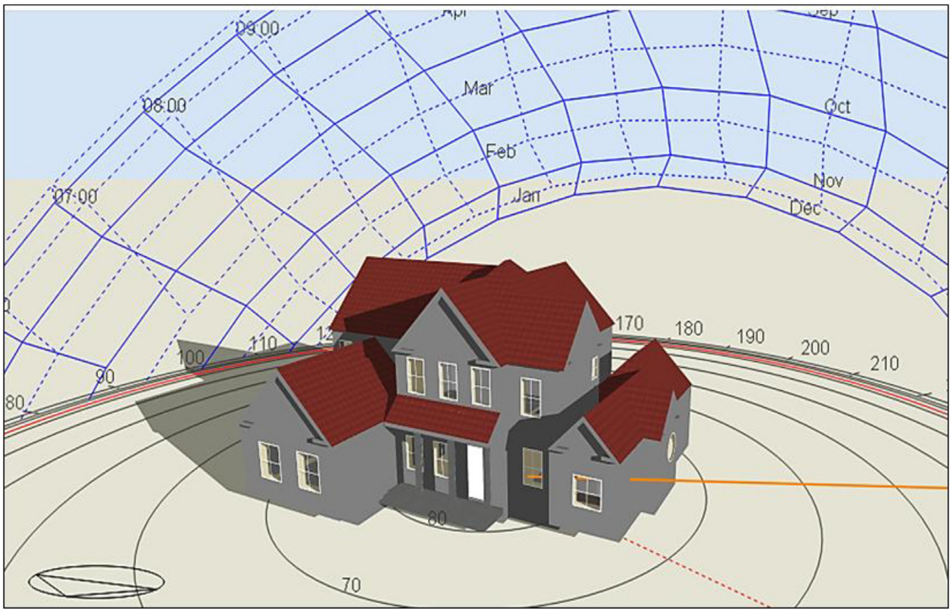

Fig. 1. Building model utilized in the study based on existing average homes in the Northeast U.S., and adhering to the IECC requirements.

more on individual technique towards energy efficiency. A study by Pérez-Lombard et al. has specifically focused on the Heating, Ventilation, and Air Conditioning (HVAC) systems and their energy consumption in the buildings, and have concluded that HVAC systems are responsible for approximately 50% of the buildings total energy consumption [11]. Another study by Goia aimed to obtain the optimal window-to-wall ratio for different climates in the European context. The study concluded that although there are different optimal values for various climates, a window-to-wall ratio between 30 and 45% provide the best results, although values out of the given range may be suitable for south-faced facades in the buildings located in the very cold climates [12]. It is interesting to note the differences between proposed optimal ratios in the study with those found here. Research by Saffari et al. evaluates the effects of passive cooling methods on building energy consumption, where the focus is on numerical simulation of building envelopes [13]. A study by Wang et al. investigate the impacts of climate change on heating and cooling demands in 5 climatic conditions, and conclude that climate change has more impact for poorly performing buildings [14].

This study surveyed possible and currently applicable technologies on residential buildings and have simulated them on a model building to understand possible energy savings by existing technologies, as well as quantify their impacts and interaction with one another. The aim was to quantify and recommend what engineers can do today when constructing new buildings to minimize future impacts that would occur throughout the lifetime of a building. Average residential building lifetime was taken as 60 years [15]. Techniques analyzed were integrated with the 2012 IECC Code, which is currently in effect in the studied region. The interaction of various elements was also investigated through the use of CFD analysis to quantify indoor temperature variation and air velocity, together with an assessment for occupant comfort.

There have been some studies analyzing each technique individually. However, their interactions and impacts on each other and the energy consumption when working together has not been analyzed. A difficulty with comparing results of various studies is the differences in the baseline or the reference point studies use. It is not possible to add efficiency gains results of various studies when their baseline parameters are all very different. Existing studies indicate the differences and discrepancies among established building simulation tools together with the need for further verification in the field [16–18]. The model developed in this study uses statistical building characteristics for the region provided by the U.S. Census Bureau, and uses a two-step verification method to ensure reliability and repeatability of results. Among the studies reviewed, there is also insufficient integration of the IECC Code, whereas the Code forms the basis for building energy efficiency standards in many states in the U.S. Meanwhile, this research work has also taken into account indoor comfort conditions after technique implementations through the CFD analysis, more specifically to quantify temperature variation and air velocities after implementing the proposed techniques and technologies. The presented study expands existing knowledge in the field in terms of its standardization of a baseline, its extent of scope, and its focus on the occupant comfort aspects.

2. Methods

There are approximately 126 million existing dwellings in the U.S. 56% of these units are detached single family houses [19]. As for new construction, approximately 750,000 detached single family houses are being built annually across the country [19].

Both for baseline analysis and verification, as well as to quantify the benefits of implemented techniques, a model home was developed based on average characteristics of residential buildings in the Northeast U.S. region. A comparison between existing buildings and the model building was required in order to verify the reliability of the model building for further steps of the analysis. The final step was to realize how much energy buildings would consume should they incorporate the studied techniques. Designbuilder V5.0 software program was used for modeling, as well as to quantify energy consumption under different conditions. Simulation results present a breakdown of the amount of energy savings, heating loads, cooling loads, and energy consumption. Designbuilder provides results based on the integrated Energy plus version 8.5.0 simulation system.

A preliminary step was to collect required information on housing characteristics from reliable databases. The U.S. CENSUS database, which contains a detailed record of housing characteristics was exclusively used in this study [20]. To simulate an average home representative of buildings in the region, the following data on building characteristics were found from the database for 2015 and used in the study: the median area of a single family house of 232 m^2; 4 bedrooms; 3 bathrooms; 2 stories; 2 parking spaces; and a full or a partial