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A study of energy efficiency in residential buildings in Knoxville, Tennessee

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ABSTRACT

Energy efficiency is an essential aspect in the design and operation of residential buildings. Residential energy consumption is shown to account for approximately 8% of the electricity and 3.5% of the natural gas consumption in the U.S. The heating, ventilation, and air conditioning (HVAC) system and lighting system are two major factors influencing energy consumption in residential buildings. About 52–72% of the average energy consumed by residential buildings is used to keep buildings at comfortable temperatures, provide hot water, and circulate fresh air indoors. In the service region of the Tennessee Valley Authority (TVA), 92% of the electricity is non-renewable electricity, and approximately 41% is generated by coal. Therefore, energy consumption in residential buildings directly relates to the proportion of pollutants and greenhouse gas emissions from the power plants. With the development of advanced technology and strict energy policies, however, the energy consumption in the residential sector and the corresponding emission of pollutants can be significantly reduced.

This study presents an approach for analyzing the energy efficiency metrics in residential buildings based on three dimensions: sustainable physical infrastructure, energy efficient equipment, and energy efficient behavior. The results of this analysis subsequently provide a residential building system with a strategy for conversion to cleaner energy sources by identifying opportunities in each of the three primary dimensions. For this study, energy consumption data for each of the metrics are collected by a survey of 102 participating residential buildings in Knoxville, Tennessee in the United States.

1. Introduction

The continuous increase in fossil fuel prices and the deterioration of the overall quality of the environment worldwide have prompted policy makers in the energy sectors to develop strategies to reduce energy consumption and dependence on fossil fuels (Ji et al. 2012; Upreti et al., 2012). However, energy consumption in the residential sector is predicted to increase at the rate of 1.1% per year from 2008 to 2035 (U.S. EIA, 2011). The importance of energy efficiency in this sector can be inferred based on statistical data released by the U.S. government, where energy consumption in the residential sector, primarily for heating, cooling, and lighting systems, accounts for 22% of the total national energy consumption (U.S. EIA, 2012a). In 2010, energy consumption in the residential sector correlates to approximate 313.4 million metric tons of carbon dioxide (CO_2) emissions annually (Brajer et al., 2010). Survey conducted by the U.S. Energy Information Administration (EIA) indicates that about 48% (U.S. EIA, 2012b) of the total energy consumption for residential buildings in the U.S. comes from heating and cooling needs and varies by region. For example, in milder climatic regions, such as the southern states and Pacific coast, the energy requirements for heating in winter are less than of cities in the north for the same season. Conversely, the need for air conditioning (cooling system) during summer months is much higher in the southern states than in the northern states. Heating and cooling systems and their usage in particular, have been considered as potential areas that can be targeted for energy savings (Mardookhy, 2013). The use of high energy efficiency equipment and separate HVAC units can help achieve this goal. In addition, using double-paned windows, repairing windows or doors to avoid air leakage, and keeping houses well insulated can reduce the HVAC system load, thus also reducing energy expenditure. Moreover, any energy consumption improvement in the residential sector can contribute to environmental pollution control (Reijnders and van Roekel, 1999).

As shown in Fig. 1, the State of Tennessee ranks twentieth in the U.S. for per capita total energy consumption and fourth in per capita

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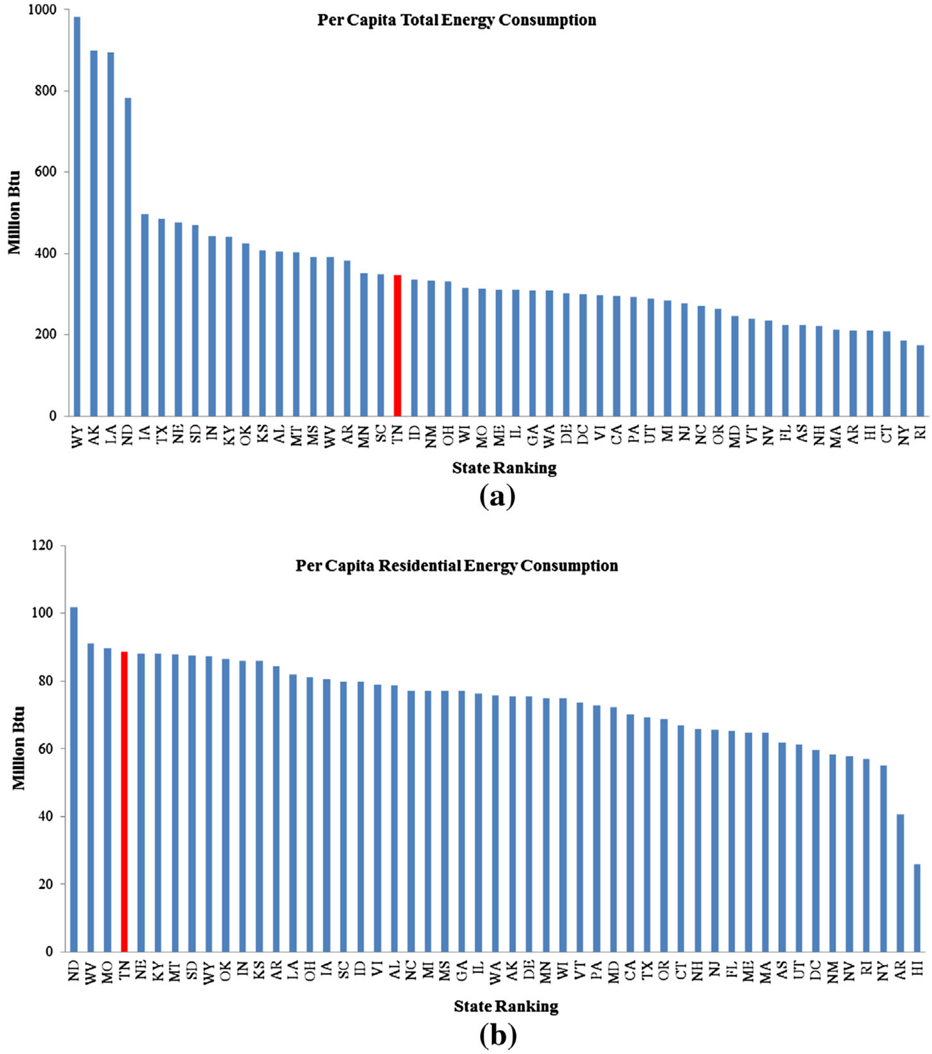

Fig. 1. (a) State ranking of total energy consumption per capita in 2011; (b) State ranking of residential energy consumption per capita in 2011 (U.S. Census Bureau, 2010; U.S. EIA, 2011).

residential energy consumption (U.S. Census Bureau, 2010; U.S. EIA, 2011). The Knoxville metropolitan area, which is the third most populated city in Tennessee, has not been an exception to national energy and environmental challenges. Although improved energy efficiency technologies for residential buildings have developed since the 1970s, seldom are these improved technologies implemented. The most critical barriers to improve energy efficiency in residential buildings are the long lifetimes of residential buildings and equipment and the lack of sufficient public and private support (Painuly et al., 2003; Mardookhy, 2013).

Some research has been conducted regarding energy efficiency assessment for residential buildings. For example, an assessment of residential buildings was conducted based on indicators of energy efficiency considering climate diversity and building types in China. For this purpose, 17 weighted indicators of energy efficiency were used for the assessment in a particular climate zone of China. In this research, a survey consisting of questions in five categories (building design, performance of envelope, energy efficiency in building facilities, building operation and management, and comfort and health) was designed based on group analytic hierarchy process (AHP) (Yang et al., 2010). In another example, a regression model was created to analyze consumption of energy in the Dutch residential sector. A sample of households in Holland was selected to investigate the relation between the physical characteristics of residential units and their energy usage. The authors also analyzed the relation between households' demographic configuration and households' consumption of gas and electricity (Brounen et al., 2012).

An analysis of the underlying economic and organizational causes for stagnating energy efficiency and slow adoption of energy efficient technologies in the Swedish building sector was conducted for the time period of 1970–2002. The outcome of this study implies that a change in specific energy use may require relatively large increases in energy price (Nässén, Sprei et al., 2008). The regression model and path analysis were used to determine interactions and relation roles of aspects such as building system, climates, and the interaction between occupants for the residential energy consumption in the 50 states of the U.S. (Steemers and Yun, 2009).

Based on a Domestic Energy and Carbon Model (DECM) to forecast emissions of CO_2 and energy usage for the residential buildings in England, building type and socio-economic class of the household have significant impact on energy consumption and CO_2 emissions (Cheng and Steemers, 2011). A financial method for