Applied Energy 144 (2015) 19–30

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

The impact of weather variation on energy consumption in residential houses

Mahelet G. Fikru [a], Luis Gautier [b,*]

[a] Missouri University of Science and Technology, Department of Economics, 500 W 13th Street, Rolla, MO 65409, USA
[b] University of Texas at Tyler, Department of Social Sciences, 3900 University Blvd., Tyler, TX 75799, USA

HIGHLIGHTS

- There is evidence for significant intraday variation of energy use.
- The sensitivity of energy use to weather variation falls via efficiency features.
- The sensitivity of energy use to weather depends on the specific time of day/night.
- High frequency data helps to accurately model the energy use-weather relationship.

ARTICLE INFO

Article history:
Received 29 May 2014
Received in revised form 21 October 2014
Accepted 9 January 2015
Available online 5 February 2015

Keywords:
Energy consumption
Solar radiation
Solar energy
Case study
Intraday-variation
Texas climate

ABSTRACT

This paper studies the impact of weather variation on energy use by using 5-minutes interval weather–energy data obtained from two residential houses: house 1 is a conventional house with advanced efficiency features and house 2 is a net-zero solar house with relatively more advanced efficiency features. Our result suggests that energy consumption in house 2 is not as sensitive to changes in weather variables as the conventional house. On average, we find that a one unit increase in heating and cooling degree minutes increases energy use by about 9% and 5% respectively for house 1 and 5% and 4% respectively for house 2. In addition, our findings suggest that non-temperature variables such as solar radiation and humidity affect energy use where the sensitivity rates for house 2 are consistently lower than that of house 1. Furthermore our result suggests that the sensitivity of energy use to weather depends on the season and specific time of the day/night.

1. Introduction

Following the 1970s global oil crisis, the United States (US) put together several energy policies aimed at reducing the country's reliance on fossil fuels and increasing energy efficiency. The Department of Energy (DoE) was created in 1977 with the aim of creating a balanced national energy plan. The Energy Policy and Conservation Act of 1975, which is one of the earliest energy policies targeting energy efficiency, was crafted with the aim of energy efficiency for federal buildings. A few years later, a more comprehensive policy, the National Energy Conservation Policy Act of 1978, set the country's energy policy with the purpose of increasing energy efficiency for the whole country, limiting growth in energy demand, reducing reliance on imported oil, and reducing demand for non-renewables.

Recent policies such as the Energy Policy Act of 2005 emphasized reducing energy consumption and greenhouse gases as well as increasing alternative energy sources. The Energy Policy Act of 2005 also provides tax incentives and subsidies for technologies that reduce greenhouse gases and agents that use alternative energy sources. More recently, the Obama administration has focused on 'building a clean energy economy, tackling climate change and protecting the environment' (www.whitehouse.gov/energy). The proposed plan (Clean Energy Standard Act of 2012) is aimed at doubling the share of electricity generated from clean sources by the year 2035.

According to the US Energy Information Administration (EIA) the residential sector consumes about 21% of total energy delivered to all sectors in the country. The sector is expected to maintain its share of energy consumption until 2040. Even though the sector's share of electricity from renewable sources stood at only 7% in 2011, it has exhibited a fast growth rate (www.eia.gov). For instance, as Fig. 1 illustrates the residential sector's solar energy consumption has more than doubled from 2000 to 2011. This is

* Corresponding author.
E-mail addresses: fikruma@mst.edu (M.G. Fikru), lgautier@uttyler.edu (L. Gautier).

http://dx.doi.org/10.1016/j.apenergy.2015.01.040
0306-2619/

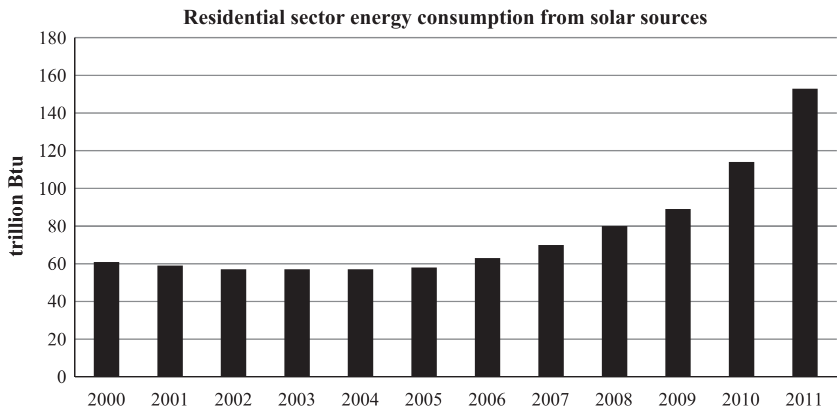

Fig. 1. Role of solar energy in residential sector. *Source:* authors' calculation based on EIA data.

driven by homeowners' preference towards energy efficient and green homes, but also policies which induce energy consumption from solar sources. For instance, a recent study conducted by Shelton Group [1] shows that 63% of consumers are interested in owning or renting energy efficient homes, whereas 43% are interested in green homes. According to the study, about 37% of consumers responded that a green home must have a renewable electric power generation such as from solar, geothermal, or wind.

Thus, if the residential sector continues to consider clean energy sources to light up houses as well as prioritize energy efficiency at their homes, it is important and timely to extensively study how these features perform when the weather fluctuates in the short-run. Furthermore, given the recent incentives and policy focus towards alternative energy sources, it is important to study the impact of weather variation on energy consumption at a residential house which uses an alternative energy source as well as incorporates some efficiency design features. As Hong et al. [2] points out with a 'better understanding of which technology and energy sources are more sensitive to weather variation, building designers, owners, operators and policy makers can make more informed decisions on energy efficiency implementations'.

This study makes use of a unique detailed dataset obtained from two residential houses. House 1 is a conventional house with advanced efficiency features and house 2 is a net-zero solar house with more advanced efficiency features. We address the following specific research questions: What is the nature of the relationship between weather variables and energy use in residential houses with efficiency designs? How do more advanced energy-efficiency designs improve energy use when the weather changes in the short-run? How sensitive is the energy–temperature relationship to the time of the day/night?

The two houses are located in Tyler, Texas. They are similar in size and location but differ significantly in energy-efficiency design features. We believe Tyler, Texas's experience should be an interesting one for several reasons. First, Texas is one of the leading states in alternative energy sources such as wind power. In addition, the state has recently experienced the fastest growth in renewable electricity production.[1] Furthermore, the state ranks 13th in installing the highest solar electric capacity. The state has installed enough solar energy to light up to 13,000 homes.[2] In 2011, the residential sector in Texas used about 1.4 trillion Btu of solar energy which is about 15.74 kW h per capita.[3]

Second, Texas has several financial incentives for residential renewable energy use as well as efficiency improvements. For instance, there are rebate programs for homeowners who install photovoltaic systems, loan programs to finance residential energy efficiency improvements, exemption of state property tax on the appraised property value that arises from the installation of a solar or wind powered device, etc. Even though the state does not have net metering law, individual cities like Austin and Brenham and retail electricity providers apply net metering procedure for residential photovoltaic systems.[4] Third, results from the analysis may be extended to areas with similar weather conditions such as the hot-humid regions of the country or even other countries with similar weather conditions.

In the following section, we present an overview of findings from previous studies regarding energy–weather relationships; we also establish the contribution of our study relative to past studies. In Section 3 we discuss the data source and present the basic empirical methodology employed. In Section 4 we present results and discuss findings. Finally, we conclude in Section 5 by forwarding some policy recommendations and questions for future study.

2. Literature review

Although the subject of energy–weather relationship (and long term climate change) is not more than three decades old,[5] there is a growing literature that examines the effect of weather change on energy consumption. The residential sector in the US has one of the highest climate and weather related fluctuations in energy use. Temperature, humidity, wind and precipitation affect how much energy the sector consumes [4]. The effect of weather change on energy use is usually measured in terms of energy demand for cooling and heating [5]. This is because about 58% of residential energy demand in the US is for heating and cooling (space conditioning) excluding domestic hot water consumption [4].

The literature on residential energy demand uses the concept of cooling and heating degree days to estimate the effect of weather on energy use. A 'degree day' is typically defined as the difference between a day's average temperature and a given threshold temperature, where the threshold is considered to be a normal temperature which does not require heating nor cooling [4,5]. Heating

[1] Source: retrieved from http://www.eia.gov/todayinenergy/detail.cfm?id=13991&src=Renewable-b1.

[2] Source: retrieved from http://www.seia.org/state-solar-policy/texas.

[3] Source: authors' calculation based on EIA data.

[4] Source: retrieved from http://dsireusa.org/incentives/homeowner.cfm?state=TX&re=0&ee=0.

[5] US Climate Change Science Program [3] reports 20 studies relating climate change to energy consumption in the residential and commercial sector in the USA since 1990.