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The flame dilemma: A data analytics study of fireplace influence on winter energy consumption at the residential household level

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HIGHLIGHTS

- A big data model is proposed by layering energy and infrastructure information.
- Winter energy use of fireplaces is compared in size, vintage, and fuel type categories.
- Homes with fireplaces consume more winter energy disregarding size and vintage.
- San Antonio homes with fireplaces used 31% more winter energy than homes without.
- Big data analysis provides a "measure to manage" tool for utilities.

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ABSTRACT

This study investigates the effect of the presence of fireplaces at the household level independent of the function of ambiance and indoor air quality. The focus of this study is on the winter heating energy use of homes with and without fireplaces to promote energy conservation. Three years of winter energy usage (2011–2013) of 365,190 single-family homes are analyzed and compared. The data is further segmented by fuel type, all-electric versus dual-fuel homes as well as by size and vintage. On average, homes with fireplaces used 23,650 kBtu, source energy, for heating purposes during the winter months versus 18,055 kBtu ($p \leq 0.0001$) during the same time period, January, February, and December. There is a significant 31% increase in energy use in homes with fireplaces. In conclusion, policy prescriptions and retrofits are recommended during new home construction permits, renovations, and utility rebate outreach programs to encourage more efficient and cleaner fireplace technology applications.

1. Introduction

The objective of this study is to quantitatively answer the question: are homes with fireplaces more or less energy efficient in the winter, and if so, by how much? A dataset of 365,190 single-family detached homes in San Antonio, Texas is used for this study.

Common knowledge since 1745 has indicated that fireplaces are not efficient, dating back to Benjamin Franklin's writing describing how heat "flies directly up the Chimny. Thus five sixth at least of the heat (and consequently of the fewel) is wasted, and contributes nothing towards warming the room" (Streever, 2013). The Department of Energy (DOE) estimates that "traditional fireplaces draw in as much as 300 cubic feet per minute of heated room air for combustion, then send it straight up the chimney" (2013). Yet most of the recent literature and technology have focused on the indoor pollutant load of fireplaces, and there is a lack of literature on their true effectiveness as heating devices in the winter. More so, there is continuous interest in purchasing homes with fireplaces. According to the United States (US) Census Bureau data approximately half of the country's new single-family homes are built with a fireplace(s) in 2011. Similarly, in this case study, 46% of San Antonio, Texas single-family detached homes built as of December of 2013 and included in this study have fireplaces (Fig. 1).

Targeting the residential sector for energy savings opportunities remains a national priority, not only for energy security, but also for reduced impact on natural resources. The residential sector is not only considered more homogeneous than other areas of industry, manufacturing, and services but is also seen as more consistent in demand structures due to similarities in equipment and infrastructure (Haas, 1997; Pimentel et al., 2004; Hirst and Brown, 1990).

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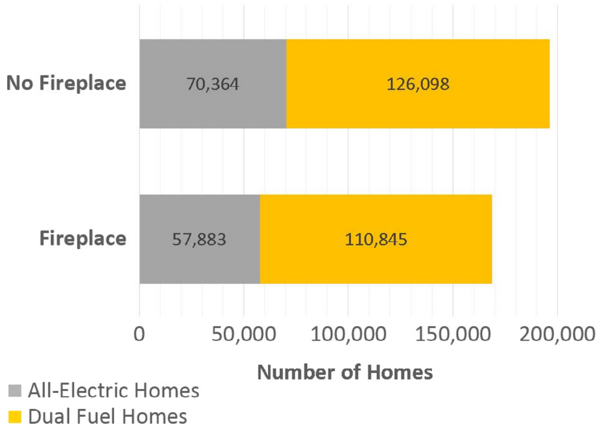

Fig. 1. Total number of homes in case study with and without a fireplace by fuel type.

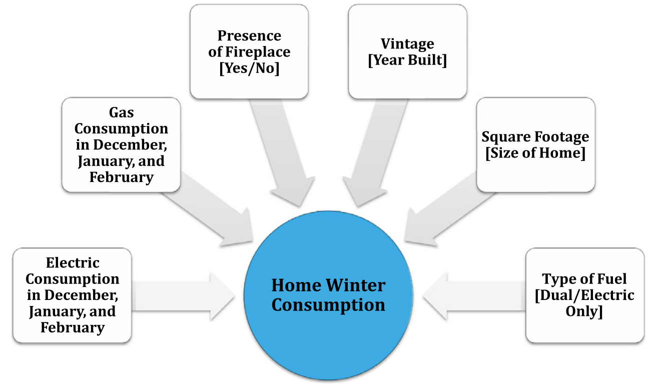

Fig. 2. Data analytics parameters set for each of the 365,190 homes in the dataset.

Similar to retail and business industries (Manyika et al., 2011; Brynjolfsson et al., 2011), with the new age of data analytics, segmenting the various types of homes and appliances will provide a better approach to conservation. Data analytics can highlight individual impacts of building archetypes (Gomez et al., 2014), swimming pool presence (Elnakat et al., 2015), appliances and equipment, and why not fireplaces? Yet in the literature, there is a lack of comparative and segmented energy informatics on many energy-consuming systems, devices, and appliances such as swimming pool pumps (Elnakat et al., 2015), water heaters, fireplaces and many others. The lack of actionable information makes it challenging for homeowners to make informed decisions (Hirst and Brown, 1990) regarding home operation and performance.

Generally, and inaccurately, consumers correlate energy use to the magnitude of size and function of the appliance (Steg, 2008). Examining the 365,190 homes in this case study provides an unprecedented scaled look into the significance of variations in energy consumption patterns due to the fireplace effect.

2. Description of dataset and methodology

Utility billing data for the years 2011, 2012, and 2013 are obtained and merged with the residential building characteristics obtained from the county property tax assessor's office. Relevant building characteristics included vintage (year the home was built), size (living area or area of conditioned space), type of fuel used for space heating and cooling, the presence of swimming pools, and the presence of a fireplace. Swimming pools are also considered high energy consumers at the residential level as recently published in Elnakat et al. (2015); therefore, multivariate analysis coupled with a disciplined segmentation approach is performed to better assess the fireplace impact since in San Antonio, the swimming pool pumps usually operate year round. Data available to identify the presence of fireplaces did not include whether the fireplace was vented or unvented or the fuel consumed (e.g., electricity, natural gas, propane, or biomass).

Monthly billing records contained bill start and end dates, number of days on bill, and consumption information for electricity and natural gas in kilowatt hours (kWh) and one hundred cubic foot (ccf), respectively. Energy use for this study is converted to British thermal units (Btu), were both the electricity consumption and gas consumption are combined.

Historical weather data is obtained from Weather Data Depot (0000) and Weather Underground (0000). Parameters of interest are daily average temperature, cooling degree-days, heating degree-days, and total degree-days. The weather station chosen is located at the San Antonio International Airport. While microclimates will vary slightly across the study area due to local effects such as wind, urban heat island, and other factors, for the purpose of this comparative analysis, a constant temperature across the city is assumed. Based on historical weather data, winter months, when space heating is required, are defined as the months exhibiting the highest number of heating degree-days, which for the San Antonio area are January, February, and December.

In addition, for each of the 365,190 homes the following parameters are identified to enable more accurate comparative data analytics (Fig. 2):

- Electric Consumption in January, February, and December
- Gas Consumption in January, February, and December
- Type of Fuel [Dual/Electric Only]
- Presence of Fireplace [Yes/No]
- Vintage [Year Built]
- Home Size [Living Area]
- Presence of Swimming Pools and spas [Yes/No].

The segmentation approach utilized for this study apportions single-family detached homes into one of 64 subcategories based on the vintage and size of each house ranging from old (built before 1950) to new (built on 2010 or later) and small (<1000 sf) to large (>4000 sf). Furthermore, homes are categorized based on the fuel utilized as all-electric or dual fuel homes. All-electric homes have access to only electricity for all end uses while dual fuel homes have access to natural gas. Natural gas may be used for space heating, water heating, cooking, and even drying clothes.

The final count of this large database reached over 30 million records of compiled and enriched data to be used for energy informatics, the database architecture included a validation process that removed null results, private records, duplicate records, homes with change of ownership and homes with interruptions of service during the time of the study. Structured query language software and python programming is used in a relational database management system. Data is encrypted and analyzed per security protocols administered to protect the privacy of the homeowners. Geolocation of each residential dwelling is the common attribute that is used to center the database and the data enrichment.

2.1. Energy estimates and end use disaggregation

To disaggregate energy consumption between the various end uses, energy utilized throughout the year is divided into two main groups: weather sensitive (cooling and/or heating) versus non-weather sensitive (baseload, minimum amount of energy necessary to operate the home year round). Each home's baseload consumption is estimated based on minimum monthly electricity and natural gas consumption, which may not occur during the same month or season. Lowest electricity consumption is generally