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Residential energy consumption and conservation

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ABSTRACT

The Swedish energy performance certificates for single-family housing provide rich information on energy consumption and various physical attributes. They also include estimates of the energy conservation potentials resulting from implementing cost-efficient energy saving measures. By matching the certificates issued for single-family houses in 2009 and 2010, with socio-economic data about the residents, local climate data and information about recent improvements of the building we have created a unique database, which can be used to explore a wide variety of questions related to energy consumption and conservation.

One aim of this paper is to assess the role for energy consumption played by socio-economic characteristics of the residents as compared to physical attributes of the house. Another is to estimate the influence of housing attributes and climate on the "engineering estimates" of the conservation potentials.

Our results show that while the quantitative impact of physical attributes dominate the energy use for heating and cooling, the opposite holds for household electricity. The assessed conservation potential, amounting to 15% of the energy consumption, is significantly related to both the housing attributes and the use of energy. The results also indicate a need to improve the information provided by the performance certificates.

1. Introduction

As one of several steps taken to reduce the use of energy and the emission of climate gases, Sweden adopted a law on energy performance certification of buildings in 2006. The law, which is based upon European Union directives, prescribes that rental buildings, cooperative buildings and some non-residential buildings must have energy performance certificates issued by approved experts from 2009. Single-family housing owners are obliged to have the prescribed certificate no later than at the time of selling the house. If the seller does not present such a certificate before the contract of sale is signed the buyer has the right to carry out a certification at the seller's expense.

The idea behind the performance certificates is of course that the information about energy usage, energy-related physical attributes and expert advice on energy conservation should make the households more aware of their energy consumption and, hopefully, take measures to reduce it. Since the residential sector accounts for such a large fraction of the overall final energy use – 21% in Sweden and 26% for 27 EU-countries [18] – it seems clear that even small reductions would be useful.

Several studies support the idea that consumers should benefit from better information [1,4,17]. The information provided by the energy performance certificates for single-family houses issued in Sweden 2009 and 2010 constitute the main source of data for this paper. By complementing this information with socio-economic data about the residents, local climate data and information about recent improvements of the building, the certificates can be used to deepen the current knowledge about the quantitative impact of housing attributes, household characteristics and climate on the energy consumption as well as the assessed conservation potential. The data can also be used to explore to what extent the expert estimates of the conservation potential and the observed energy usage are related to the same explanatory variables. These are the basic aims of our paper and we will use regression analysis to address and analyze the following questions.

- How do the energy conservation potentials suggested by the experts depend upon the housing attributes, the energy consumption and the local climate?
- What role do different household characteristics play for the energy consumption as compared with housing attributes and the climate?

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- To what extent are the experts' energy conservation assessments consistent with the estimated relationship between energy consumption and different explanatory factors?

The third question relates to a much wider one about the quality of expert assessments. Though not a main aim of this paper, the indicated regressions will shed light on some quality-related aspects and we will touch upon others when presenting our data.

Our paper provides new knowledge on the conservation estimates provided by the experts responsible for the energy performance certificates and also on the consistency between these estimates and the observed energy consumption. The large and in many respects unique database is also a new contribution to the earlier literature in this field of research. Another reason making this study interesting outside Sweden is that most EU-countries have similar energy performance certificates for housing. Since Sweden has a relatively long tradition of an ambitious environmental policy one would expect a fairly high degree of environmental awareness among Swedish consumers. It might hence be especially interesting to use Sweden as a benchmark when analyzing certificates from other countries.

The rest of our paper is organized as follows. The next section provides an overview of previous research and a presentation of hypotheses related to our research questions. Section three describes the data and section four the estimations. A short summary and some conclusions for policy and future research are presented in the final section.

2. Literature overview

As described by Swan and Ugursal [20], the frameworks commonly used to analyze residential energy consumption can be grouped into top-down and bottom-up approaches. The top-down approaches, which will not be dealt with further here, are based on an aggregated view and usually relate the energy consumption of the residential sector to factors such as for example gross domestic product, fuel prices, new construction and demolition of housing and to climate conditions. The bottom-up methods treat housing in a disaggregated way and make it possible to analyze the energy consumption impact of different housing attributes as well as of household characteristics and occupant behavior. Using disaggregated approaches a further division can be made by distinguishing studies based on building physics or engineering methods and those based on statistical techniques.

2.1. Engineering methods

According to Kavgic et al. [14], the characteristic feature of engineering models is the use of heat balance equations to calculate the energy consumption of different types of dwellings representing the entire stock of housing. The dwelling types are classified in terms of attributes such as type of housing (i.e. detached single family house), period of construction, attributes characterizing the heating system, the area of different housing elements (i.e. the floor and the windows) along with their thermal characteristics. Several studies provide examples of models focused on the energy use for space heating and cooling [2,5,12]. By including survey data on the average use of appliances, lightening, water heaters and indoor air temperature, engineering models can also be used to estimate the end-use of energy for different purposes. Mata et al. [18] makes use of such a model to assess the potential for improving the energy performance of the Swedish residential sector, and concludes that the final energy demand of the Swedish housing stock can be reduced by over 50%. Larsen and Nesbakken [16] suggests that engineering models using survey information on the average use of e.g. lightening and appliances can be improved if the surveys are designed for applying econometric models.

As pointed out by e.g. Swan and Ugursal [20] a main advantage of the engineering models is their detailed treatment of dwelling and building attributes and the possibility to evaluate the impact of new technology. The most important drawback is the simplified treatment of the residents.

2.2. Statistical methods

Guerra Santin et al. [9] uses data from a sample of 15,000 dwellings in the Netherlands to quantify the impact of housing attributes, household characteristics and occupant behavior on the use of energy for space heating and concludes that household size, income and age has a significant and positive impact on the use of energy but that building characteristics "explain" ten times more of the energy use for heating as compared to occupant characteristics and behavior As expected, more energy is needed the larger the useful living area and the older the dwelling. Type of building, insulation of different parts of the building envelope and presence of bath are examples of other factors shown to have significant impact.

Brounen et al. [3] is another study of residential energy use in the Netherlands. They use data for more than 300,000 households and analyze, to what extent the consumption of gas and electricity can be related to different building and dwelling attributes as compared to characteristics of the households. Unlike Guerra Santin et al. [9], they control for climate differences across the Dutch provinces. Their results indicate that residential gas consumption, which is used for heating, is determined principally by structural dwelling attributes such as e.g. type and vintage of the building, while electricity consumption varies more directly with household characteristics, in particular income and family composition.

Using Census data providing data on the electricity consumption of California homes of different vintages, Costa and Kahn [7] analyzes how the electricity price, at the time when a home was built, influences its later observed electricity consumption. They conclude that low electricity prices at the time of construction are an important determinant of a home's electricity consumption, even several years later on and that the opposite also holds. Their study confirms the strong impact of housing vintage on energy consumption.

Kelly [15] explores factors influencing the energy expenditure among a sample of around 2500 British households and finds that family size and income as well as floor area all have a significant and positive impact. The energy expenditure is also positively related to the difference between outdoor and indoor temperature and to the time different rooms are heated during weekends and daytime.

A number of studies also indicate the importance of considering environmental attitudes, see for example Mansouri et al. [17], Zoric and Hrovvatin [21] and Ek and Söderholm [8]. Environmental concerns do influence the stated reasons for energy-thrift and e.g. for buying green electricity. However, needs for improving comfort and reducing energy bills are more often than not considered as more important.

Another study, Sexton and Sexton [19], adds that some individuals may seek status through display of environmental concern and commitment while the behavior of others are more related to sincere or intrinsic intentions regardless of the outcome.

2.3. Hypotheses

Based on the reviewed studies, we will use our data on single family housing in Sweden to test the following hypotheses relating the energy use to housing attributes and household characteristics. We will use the total energy consumption, the energy consumption