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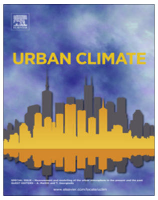

Temperature response functions for residential energy demand – A review of models

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ABSTRACT

Climate is a major influence on residential energy demand and energy demand patterns. A better understanding of the link between climate and energy demand responses is crucial to improve energy forecasting outcomes and to evaluate the potential of climate change adaptation strategies. This paper reviews models of residential energy demand to temperature. We classify the models used in papers published in peer-reviewed journals and observe that the credibility of energy demand projections hinges in part on the assumption that the shape and type of the temperature response function is stationary. The evidence of acclimatization to warmer conditions may oppose this assumption. While the studies reviewed here only tested the impact of changes in the temperature thresholds and the shape of temperature response functions, a comprehensive understanding of changes in energy demand patterns and climate adaptation potentials requires knowledge of building stock turnover rates and associated changes in technology and behavioral responses of building occupants. These are not yet part of the standard repertoire of temperature-based demand models.

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1. Introduction

The impact of changes in energy use on greenhouse gas emissions has long occupied the climate change research community (Hillman and Ramaswami, 2010; Lenzen, 1998; Schipper et al., 1997). Similarly, climate impacts on energy use and electricity load are well researched, showing that temperatures outside desirable ranges call for changes in heating and cooling demand. What that relationship between temperature on the one hand, and heating and cooling demand on the other hand looks like, and how it unfolds as climate changes, however, is significantly less understood. Yet, temperature-energy demand relations are used to project, seasonally and over the long term, the capacity requirements of the energy sector, fuel use in electricity generation, space heating and cooling needs by final consumers, and associated emissions (e.g. De Cian et al., 2007; Kirshen et al., 2008; Mansur et al., 2005; Moral-Carcedo and Vicéns-Otero, 2005).

Energy demand is typically more responsive in the residential sector to weather changes than in the commercial sectors, in part because the latter are dominated by process needs and the smaller ratio of building envelope surface area to interior space (Brown et al., 2015). Besides, space conditioning in commercial settings is less adjusted over the course of any given day. The relative importance of temperature for energy demand in the residential sector therefore makes an understanding of temperature-energy demand relationships of particular importance for energy sector management in urban areas. The higher the impact of temperature on demand, for example, the more critical it will be to plan for capacity changes and deploy demand side management measures as climate change accentuates demand profiles. Additionally, the more geographically concentrated are the demand change, the more affected can be the transmission and distribution networks on which energy demand depends.

While researchers have studied the influence of other potential factors such as population, household size, income, price of fuel and building characteristic on residential energy demand, this paper focuses on various temperature response functions (TRF) that have been used in previous studies to quantify and model how residential energy demand varies with temperature. A central concept in these studies is the use of degree day calculations (Madlener and Alt, 1996; Parti and Parti, 1980), where a degree-day is defined as the difference between a day's average temperature and some temperature threshold, often referred to as the balance point temperature (T_b):

$$\mathrm{HDD}_T = \sum_{days}(T - T_{b,h}) \quad \text{when } T \geqslant T_{b,h} \tag{1}$$

$$\mathrm{CDD}_T = \sum_{days}(T_{b,c} - T) \quad \text{when } T \leqslant T_{b,c} \tag{2}$$

In the above equations, T is the daily average temperature of a region and $T_{b,h}$ and $T_{b,c}$ are the balance point temperatures for heating and cooling, respectively.

Where there is insufficient daily data or where research interests are on broader aggregate trends, average monthly temperatures are used (Asadoorian et al., 2008; De Cian et al., 2012; Fung et al., 2006; Mansur et al., 2008; Mendelsohn, 2003; Moral-Carcedo and Vicéns-Otero, 2005). Whether for short or long-term assessments, there are methodological and data challenges surrounding the choice of balance point temperature(s), assumptions about the speed at which households switch between heating and cooling, and assumptions about changes over time in thresholds and demand behaviors that may come from changes in technology and preferences.

In this paper, we primarily review the best-fitting short-run response functions relating HDD and CDD to residential energy demand. In the subsequent section, we review the application of TRFs in energy demand modeling and forecasting. We begin with assumptions of a single balance point temperature and linear, symmetric responses around it, and eventually attend to studies dealing with multiple thresholds and with non-linear and asymmetric responses. We close our review with a discussion of the potential for the respective specifications to help evaluate the capacity of adaptation to climate change for residential energy demand. As the evaluation of adaptation strategies depends directly on how the climate sensitivity of residential cooling and heating energy use is modeled, we recognized gaps in the literature that, if closed, could help strengthen the scientific basis for such strategies.

2. Temperature response functions

This study expands a recent review by Auffhammer and Mansur (2014), which focused on cross-sectional climatic evidence and panel (or time series) evidence of weather shocks, and Brown et al. (2015) which classified studies on the basis of models used in analysis. Here, we group the literature by types of TRF used to model relationships between climate and energy demand in the residential sector, and compare the abilities of these functions to predict energy use and to assess impacts of climate adaptation measures.

2.1. Linear symmetric models

Linear symmetric models are based on the assumption that there is a single balance point temperature for heating and cooling (Fig. 1). Additionally, some studies assume symmetric sensitivity to a marginal change in temperatures around the