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Estimation of potential impact of climate change on the heating energy use of existing houses

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Abstract

This paper presents a method for the estimation of potential impact of climate change on the heating energy use of existing houses. The proposed method is based on the house energy signature that is developed from historical energy use data. The method can be applied to any individual house, by using the utility bills from the owner, or can be used by utility companies, which have databases of recorded energy use for large number of houses. The second case can lead to accurate estimates of potential impact of climate change within a city, a province or a country. A case study of a house in Montreal (Canada) is presented, and the results obtained with different sampling rates of data are discussed. The method is also applied to a sample of 11 existing houses, and the results show the reduction of heating energy use between 7.9% and 16.9% due to climate change between the present period (1961–1990) and the future period (2040–2069).

Keywords: Climate change; House energy signature; Heating energy use

1. Introduction

The Intergovernmental Panel for Climate Change (IPCC, 2001) predicted that the average surface temperature would increase by 1.4–5.8 °C by the end of the 21st century. This climatic change could have a significant impact on the built environment, on thermal comfort of occupants, and the energy use for heating and cooling of residential buildings. Over the past decade, a few researchers published predictions of the potential impact of climate change on the energy use in buildings. For instance, Belzer et al. (1995) used the degree-days method to estimate the changes of energy use in commercial buildings due to climate change. Levermore and Chow (2004) presented the plan for evaluating the climate change impact on the thermal comfort using the Dry Resultant Temperature, an indicator used in the UK. Gaterell and McEvoy (2005) used the TAS software along with a few scenarios about climate change and five insulation strategies, and predicted the reduction of heating energy use between 17% and 72% in the residential sector in the UK by 2050. Ouranos (2004) used the degree-days method and estimated the reduction of heating demand in Quebec by 7.7% in 2050 compared with 2001. Thatcher (2006) used a linear regression model, and predicted the change in peak regional electric demand in Australia between −2.1% and +4.6% for a simple climate change scenario of 1 °C increase in the average outdoor temperature. Mirasgedis et al. (2007) used a multi-regression model, developed from historical data of 11 years, to estimate the influence of several climatic and socio-economic factors on the future electricity demand in Greece. They estimated the increase of 3.6–5.5% in annual electricity demand due only to climate change.

The method presented in this paper for the prediction of the impact of climate change on the annual heating energy use of existing houses is an extension of the previous work by Zmeureanu (1990, 1992). The method proposed in this paper relies on the use of historical energy use data. It can be applied to any individual house, by using the utility bills from the owner, or can be used by utility companies, which

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have databases of recorded energy use for large number of houses. The second case can lead to accurate estimates of potential impact of climate change within a city, a province or a country. In this case, the proposed method can become a useful tool for energy policy makers.

2. Proposed method

The proposed method uses the house energy signature, which is usually defined as the linear relationship between the heating energy use and the heating degree-days (Fels, 1986)

$$E = aH + b, \quad (1)$$

where E is the daily average energy use, in kWh/day; a is the heating slope or the weather-dependent energy use, in kWh/(day °C); H is the heating degree-days; and b is the intercept or the non-weather-dependent energy use, in kWh/day.

Early approaches used a fixed value of H, calculated for a constant reference outdoor air temperature for which the internal plus solar gains offset heat losses of the building. Princeton scorekeeping method (PRISM) (Fels, 1986) assumes a linear relationship between the daily average energy use (obtained from each billing period) and the heating degree-days calculated with respect to a variable reference outdoor air temperature

$$E = aH(T_{\mathrm{ref}}) + b. \quad (2)$$

The coefficients a and b are calculated by using the least squares method. The reference temperature T_{ref} is then calculated in such a way that the linear relationship between E and $H(T_{\mathrm{ref}})$ has the highest coefficient of determination R^2. The Normalized Annual Consumption (NAC) is estimated by using the coefficients a and b together with the long-term annual average of heating degree-days $H_0(T_{\mathrm{ref}})$

$$\mathrm{NAC} = aH_0(T_{\mathrm{ref}}) + b. \quad (3)$$

Other researchers developed the energy signature as the linear relationship between the energy use of given period and the corresponding average outdoor air temperature (Deeble and Probert, 1986; Jacobsen, 1985; Lyberg, 1987; Zmeureanu, 1990). Zmeureanu (1992) used the energy signature of a commercial building along with the number of hours of occurrence of each temperature bin to calculate the Normalized Annual Consumption. The results of weather-normalization method were compared with predictions by the DOE-2 program.

The proposed method is composed of the following steps.

2.1. Development of the heating energy signature

The heating energy signature of a house is obtained from historical data of energy use and weather:

$$E_i = aT_{0,i} + b, \quad (4)$$

where E_i is the measured heating energy use during the period i, in kWh; $T_{0,i}$ is the measured average outdoor air temperature of the same period, in °C.

The values of (E_i, $T_{0,i}$) must be available for at least one heating system. The coefficients a and b are estimated by applying the least-squares method to the number of available pairs (E_i, $T_{0,i}$). The heating energy signature of the house, which is developed from measured data, does not change from one heating season to another, provided that no major renovations of the building envelope and heating system took place, and that the energy behavior of occupants did not change (e.g., change of the heating set point temperature).

2.2. Estimation of annual energy use for heating

If the energy signature is developed from hourly or daily total values of (E_i, $T_{0,i}$), the annual energy use for heating E_{h}, in kWh, is calculated by using the energy signature and the frequency of occurrence of each temperature bin throughout the heating season (Table 5 for hourly values or Table 6 for daily values)

$$E_{\mathrm{h}} = \sum_j (aT_{0,j} + b)\mathrm{BIN}(T_{0,j}), \quad (5)$$

where BIN ($T_{0,i}$) is the number of occurrences of each temperature bin (j) of a typical year.

If the energy signature is developed from daily average values (monthly or bimonthly values of energy use divided by the number of days), the annual energy use for heating E_{h}, in kWh, is calculated as follows:

$$E_{\mathrm{h}} = \sum_j n_{\mathrm{month},j}(aT_{0,\mathrm{avge},j} + b), \quad (6)$$

where $n_{\mathrm{month},j}$ is the number of days of month j and $T_{0,\mathrm{avge},j}$ is the monthly average outdoor temperature (Table 1).

The annual energy use $E_{\mathrm{h,present}}$ for heating the house during a reference year, which is representative of present climate, is estimated using the weather data of 1961–1990 and formula (5) or (6). The annual energy use $E_{\mathrm{h,future}}$ for heating the house during a typical year of future climate is estimated using the weather data of 2040–2069, and formula (5) or (6).

2.3. Estimation of impact of climate change

The potential reduction/increase of the annual heating energy use of the house due to climate change is calculated as $(E_{\mathrm{h,present}} - E_{\mathrm{h,future}})/E_{\mathrm{h,present}} \times 100$ [%]. The potential impact of social, technological and economic factors, beyond those changes considered by the climate changes scenarios, is not included.

The method presented in this paper is first used to estimate the potential change on the heating energy use of a case study house in a cold climate (Montreal, Canada). The first application uses synthetic energy use data, obtained from detailed computer simulation by using the TRNSYS