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Methods for a smart thermostat to estimate the characteristics of a house based on sensor data

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Abstract

Smart thermostats can play an important role in achieving more economic energy usage in domestic situations. This paper focuses on the energy used for natural gas-based heating, and monitoring of gas usages versus indoor and outdoor temperatures over time. Two methods are presented that enable the smart thermostat to learn, over time, characteristics of the house such as heat loss rate and heat capacity. Through this, the thermostat can make some homeowners aware, for example, that there is room for improvement in insulation of the house. The presented methods are able to deal with sensor data with varying extents of imperfection concerning their completeness.

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Keywords: heat loss rate; heat capacity; cooling down rate; heating degree days; smart thermostat

1. Introduction

In northern parts of Europe much energy is used for domestic heating. Smart thermostats are devices used more and more to get insight in domestic energy usage; e.g., [1–3]. They can contribute to more economic energy use in two ways. On the one hand, they can control the heating system in an economic manner, for example by not heating the house if they detect that nobody is at home. But, on the other hand, they play an important role in making the

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persons in the house aware of their energy usage; so, that they are encouraged to change their behaviour or their house into a more sustainable situation.

A challenge here is to give the smart thermostat the intelligence needed to analyze what are the energetic characteristics of the house. This could provide the basis for comparisons with other users and tailored advices about measures to reduce energy usage. To achieve this, both monitoring devices and analysis methods for interpreting the data are used. The work described in this paper uses the data of gas consumption used for heating and the indoor and outdoor temperatures over time to derive the energetic characteristics of the house. A particular additional challenge is that often sensor data do not provide complete time series. From time to time data may be missing. To analyse the heating characteristics of a house, often so called heating degree day methods are used; e.g., [4–9]. These methods allow to estimate how the heating demand of a house relate to differences between indoor and outdoor temperatures.

Taking such heating degree day and other information, in this paper two methods are discussed that enable the smart thermostat to estimate characteristics of the house such as heat loss rate and heat capacity; so, that home owners can possibly be made aware that there is room for improvement in insulation of the house. The proposed methods are also able to handle sensor data with certain extents of imperfection concerning their completeness.

In the paper, in Section 2 some background theory about gas-based heating is discussed. In Section 3, the available dataset is described. Section 4 describes how the adaptive methods have been applied to the dataset and which outcomes were achieved. Finally, Section 5 is a discussion.

2. Theoretical basis

This section discusses the theoretical background concerning gas-based heating and the relation to outdoor temperature, and central concepts characterizing a house such as heat loss rate ε (depending on insulation level of the house) and heat capacity C of the house (depending on volume of the house).

2.1. Central concepts

The energy loss of a house per time unit with indoor temperature T_{id} and lower outdoor temperature T_{od} is proportional to the temperature difference between indoor and outdoor temperatures. The proportion factor ε is the loss rate:

$$energy\ loss\ per\ time\ unit = \varepsilon(T_{id} - T_{od}) \tag{1}$$

This loss rate depends on insulation level of the area of the house in contact with the outside: the walls, windows, floor and roof.

Another central concept is the heat capacity of a house. The amount of energy needed to increase the indoor temperature is proportional with the difference ΔTid in indoor temperature. The proportion factor C is the heat capacity:

$$energy\ needed\ for\ increase = C\Delta T_{id} \tag{2}$$

The heating capacity of a house, C, depends on the volume (content) of the house. Note that, during a time interval of temperature increase, still energy loss takes place as well. More specifically, there are three types of situations:

- Indoor temperature increase: in periods of increase of indoor temperature both types of energy described by (1) and (2) have to be added to each other to get the total amount of energy spent;
- Maintaining constant indoor temperature: when heating takes place just to maintain a given indoor temperature, only the energy loss is compensated by the heating. The amount of energy needed for this is described by (1);
- Natural cooling down without heating: when no heating takes place the house follows a natural cooling down process. During such a time interval the energy loss (per time unit) described by (1) leads to a temperature decrease (per time unit) described by (2):