Energy and Buildings 130 (2016) 107–112

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Non-parametric method for separating domestic hot water heating spikes and space heating

Peder Bacher*, Philip Anton de Saint-Aubain, Lasse Engbo Christiansen, Henrik Madsen

DTU Compute, Technical University of Denmark, Matematiktorvet, Building 303B, 2800 Kgs. Lyngby, Denmark

ARTICLE INFO

Article history:
Received 31 May 2016
Received in revised form 9 August 2016
Accepted 10 August 2016
Available online 17 August 2016

Keywords:
Separation of total heat load
Kernel smoother
Robust estimation
Statistical modeling
Time series analyses
Smart grid
Smart metering
Heat metering

ABSTRACT

In this paper a method for separating spikes from a noisy data series, where the data change and evolve over time, is presented. The method is applied on measurements of the total heat load for a single family house. It relies on the fact that the domestic hot water heating is a process generating short-lived spikes in the time series, while the space heating changes in slower patterns during the day dependent on the climate and user behavior. The challenge is to separate the domestic hot water heating spikes from the space heating without affecting the natural noise in the space heating measurements. The assumption behind the developed method is that the space heating can be estimated by a non-parametric kernel smoother, such that every value significantly above this kernel smoother estimate is identified as a domestic hot water heating spike. First, it is showed how a basic kernel smoothing approach is too simple to deliver reliable results. Therefore the problem is generalized to a local least squares problem, which makes it possible to design a robust kernel smoother, which estimate is not affected by the spikes. Furthermore, the generalized model makes it possible to estimate higher order local polynomials. Finally, the results are evaluated and it is found that the method is capable of calculating a reliable separation of the total heat load into the two components.

1. Introduction

The energy performance of buildings can be assessed in many ways. As more and more data is collected on the actual energy consumption data driven assessment becomes feasible. When analyzing the total energy consumption of a building it is important to acknowledge that it is composed of several components. In many cases the two most important components are related to the building envelope and the occupancy behavior, and for labeling the energy performance of a building it is important to consider which components to include – often the interest is in the envelope.

In this paper a method for separating the total heat load into domestic hot water (DHW) heating and space heating is presented. Data from an individual residential building located in Denmark is used. It consists of a time series of 10 min values of total heat load, which is the sum of DHW and space heating. DHW is used by the inhabitants for showering, dish washing, etc., and the space heating is used to heat the house. The DHW heating generates spikes added to the (or on top of) the space heating. This is due to the fact that showering and dish washing use intense amount of energy in a short period. A commercial opportunity for this study is that the number of sensors needed can be reduced, since the DHW and space heating do not need to be measured separately, i.e. the same information can be retrieved with a single heat flow meter instead of two. Thus system costs can be decreased and often only the total heat load is available, thus the method can be useful in such cases for data analysis purposes.

The described method for separating the total heat load is quite generic and can therefore easily be used for other applications, where spikes must be separated from other signals. The separation can be useful for building energy performance estimation based on data [1,2] and for load forecasting where the presented method was actually used [3]. The separated DHW load can be used for example for constructing load profiles for DHW [4,5], the latter using inhomogeneous Markov chain models providing a fully data-driven stochastic modeling approach. Another important application is in control for heating systems enabling demand response for integration of renewables, for example by using a hot water tank [6] or the building structures [7] for energy storage.

Separating consumption signals into sub-components has been studied quite intensively the last decades, mainly for electrical appliance load monitoring [8,9], where the electrical load is dis-aggregated into event categories. Also residential water consumption dis-aggregation into end-use categories has been studied

* Corresponding author.
E-mail address: pbac@dtu.dk (P. Bacher).

http://dx.doi.org/10.1016/j.enbuild.2016.08.037
0378-7788/

[10], where high resolution readings (5 s) were used. Such methods are event based, where patterns are matched and related to the properties of appliances or events. Methods for spike detection have been studied in-depth in for example medical applications such as electroencephalography (EEG). Several approaches for determining amplitude thresholds are used. For example different statistical approaches [11], as well as filtering and wavelet approaches [12]. A comprehensive review of different techniques is given by [13].

In the present study a statistical time series approach [14] based on kernel smoothing techniques for time series [15,16] is used and combined with robust estimation (see [17,18]). The proposed method enables separation of very high spikes to be carried out without interfering with the remaining signal. The method is based on the idea of using a non-parametric model (i.e. the kernel smoother) to estimate the space heating. The space heating changes over time as it is a low-pass filtered response of mainly the outdoor temperature and the solar radiation. Consequently, the space heating changes at frequencies related to those variables, thus in a slow moving and rather smooth pattern. The DHW generates spikes (a noisy and high frequency component) added to the slower changing space heating signal. The method is therefore designed such that the non-parametric estimate follows the slower changes only, without being influenced by the spikes – which is possible by using a robust estimation scheme. Since the estimate is not affected by the spikes they can be identified and separated from the space heating signal.

1.1. Outline

In Section 2 the data used for the study is presented and in Section 3.1 a simple kernel smoother model applied to separate the DHW spikes from the data is described. In Section 3.2 a robust estimation scheme is presented, and in Section 3.3 it is described how the method is extended further by using a second order polynomial model. Finally, in Section 4 the results are analyzed and in Section 5 the conclusions are drawn.

2. Data

The data used in the study consists of the total heat load of a single-family free standing residential building with two occupants. The total heat load is the sum of DHW heating used for heating water for showering, dish washing, etc., and space heating used for heating the building. Sønderborg Fjernvarme (consumer owned district heating company) located in the southern part of Denmark delivered the data. The period used is covering one month from 1st of March to 2nd of April 2010. The data was logged every 10th minute. The total heat load is represented with the time series

$$\{Q_t, \quad t = 1, \ldots, N\} \tag{1}$$

where Q_t is the value at time t and $N = 4607$ is the number of observations in the times series, i.e. equidistant sample points. Per convention $\dot{Q}$ is used for denoting the rate of heat, however the dot is left out to simplify the notation, such that Q_t is the heat transferred in the time interval from $t-1$ to t and the unit of the heat series is kept in megajoule per hour [MJ/h]. The upper plot of Fig. 1 shows the raw data from this period. Some of the spikes are as high as 160 MJ/h and have been cut off by the frame of the plot in order to make the lower variations visible. It can be seen that in a two week period from Friday 12th until Friday 26th there are no spikes and the total heat load has very little variation. It is assumed that the inhabitants were on holiday and left the house with the usual space heating during these two weeks. The inclusion of this holiday

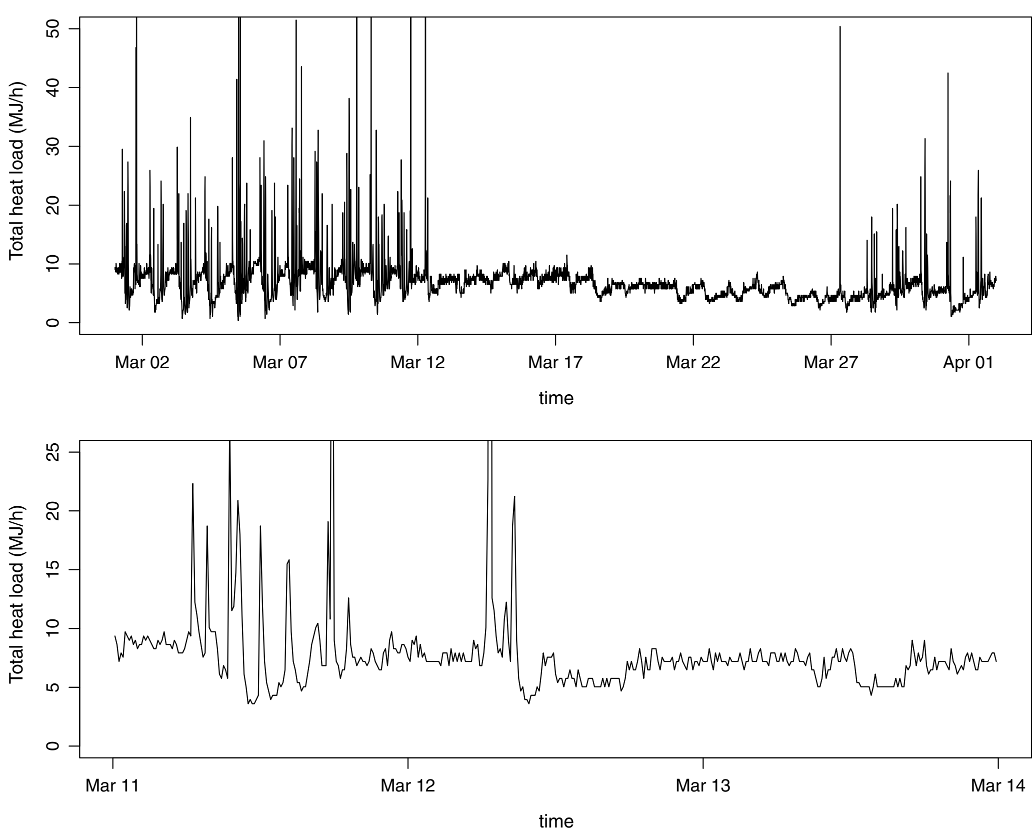

Fig. 1. The upper plot is of the total heat for March 2010 and the lower plot is for the four days period, where the spikes end and it is assumed that the inhabitants leave the house.