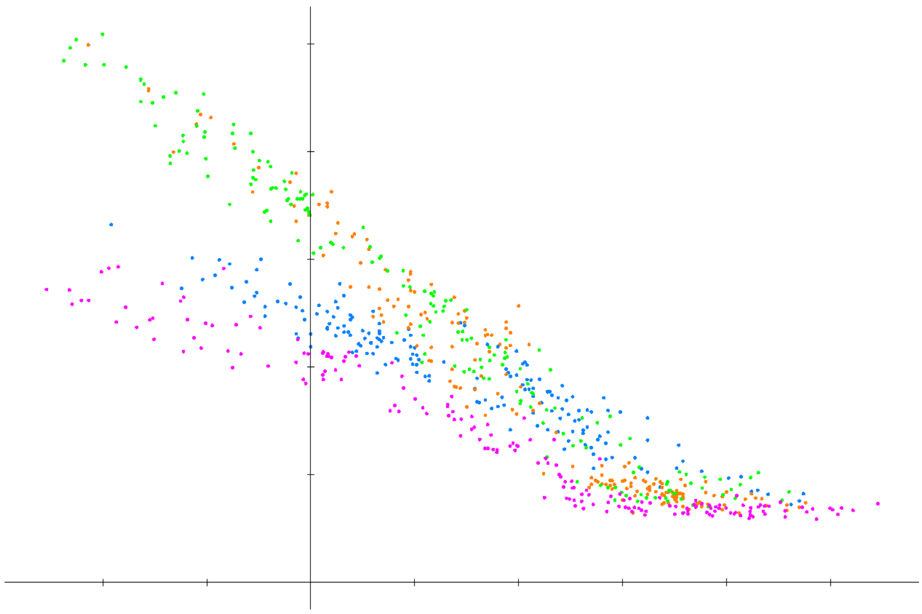

Identifying apartment buildings with potential heating issues

Master of Science Thesis in Complex Adaptive Systems

JORIS VAN ROOIJ

Department of Energy and Environment
Division of Physical Resource Theory

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden, 2011

Report No. FRT 2011:10

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Cover:
The energy used for heating a specific building plotted against the outside temperature for every day in 2009 and 2010. See also figure 7 on page 14.

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Abstract

The residential sector in Sweden uses a large amount of energy for heating and hot water. Sweden as well as all other European countries need to reduce its energy consumption with 9% by 2016. It is important to make sure that this heating is done in an optimal way in order to meet this demand.

A method to identify buildings with possible heating problems is described in this thesis. The method uses analysis on the energy signature of buildings in order to construct parameters that point out buildings with possible problems. The method is applied to a set of 352 apartment buildings located in Gothenburg. The results show that a very large part of the set shows signs of possible heating problems.

Keywords: Energy signature, building, heating

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1 Introduction

The European Union has decided that every member state should aim to reduce its energy consumption with 9% by 2016. It has also decided that the measures to reach this goal should be "cost-effective, practicable and reasonable" [1].

Sweden used 374,4 TWh energy in 2009 [2], of which 25,6 TWh went to heating and warm water for the residential apartment buildings [3]. Small improvements on large amounts of energy can make a substantial difference, so reducing the amount of energy used for heating and warm water could be a good way to help reach the reduction goals.

Remote reporting of energy consumption using so-called smart meters is becoming increasingly common due to new rules from the Swedish government [4]. These new meters make it possible to get detailed consumption data for residential buildings. This data could be used by building owners to find buildings that use more energy than they should, and then fix the problem that is causing the increased energy consumption.

1.1 Objective and method

The objective of this thesis is to find a method that can be used to identify buildings with possible heating problems from a large set of buildings. This will be done by analyzing the energy signatures of the buildings. The available data consists of the daily outside temperature and the amount of energy delivered from the district heating system.

Only possible heating problems will be identified since the available data is not enough to accurately identify heating problems.

1.2 Outline

Chapter 2 gives background information on heating for apartment buildings. Information on the energy signature and how to calculate it can be found in chapter 3. The different parameters that are constructed for identification of buildings with possible heating issues are described in chapter 4, while the results from these parameters are presented in chapter 5. Finally the conclusions and some suggestions for further research are located in chapter 6.

2 Background

A building with an indoor temperature that is higher than the outdoor temperature will lose heat to the environment. This heat will have to be replaced in order to keep the indoor temperature at a constant level. When the indoor temperature is constant, the ingoing and outgoing energy is in balance. This balance is affected by several variables.

2.1 Variables that influence the energy balance

The outdoor temperature is one such variable that has a lot of influence on the energy balance. Newton's cooling law says that the amount of heat that an object loses is proportional to the temperature difference between the object and the temperature of the environment it is in. For a building this translates to:

$$\dot{Q}_c = -h \cdot A(T_i - T_o),$$

where $\dot{Q}_c$ is the flow of thermal energy due to cooling, T_i is the indoor temperature, T_o the outdoor temperature, A the surface area of the building and h is the heat transfer coefficient.

A second variable that can have large impact is ventilation. Swedish building regulations demand an airflow of at least 0,35 l/s per m^2 floor area [5]. The flow of thermal energy due to ventilation, $\dot{Q}_v$ can then be written as:

$$\dot{Q}_v = -c \cdot (1 - \eta) \cdot (T_i - T_o),$$

where c is a constant that depends on the amount of air ventilated and the heat capacity of the air and η is the efficiency of a possible heat exchanger.

The weather also influences the energy balance. On a sunny day, the sun will warm the building up, thus reducing the need for extra heating. Cold windy days can need extra heating if the building isn't airtight. Air with high humidity can contain more thermal energy than air with low humidity. This means that on days with a high air humidity, more energy can leak through the ventilation, which in turn means that extra heating is necessary to maintain a stable indoor temperature.

A fourth variable in the energy balance are the inhabitants. If the building houses many residents who have their windows open for large amounts of time, then this building will need more heating than a building where the residents don't open their windows as much. Electrical equipment that the inhabitants own and use also generates heat and influences the energy balance.

Finally their is the heating system itself. A malfunctioning heating system can have a large impact on the amount of heat needed to maintain a stable temperature. Examples of malfunctions in a heating system are leaks, sensor errors, heat exchangers that don't work optimally or ventilation issues.

2.2 Balance temperature

It is convenient to bundle the energy gains and losses due to the weather and the inhabitants in one variable: Q_a. The energy added by the heating system can be called Q_b, and Newton's cooling law and the ventilation stands for the rest of the losses. With these variables, the energy balance can be written as:

$$Q_a + Q_b = h \cdot A(T_i - T_o) + c \cdot (1 - \eta)(T_i - T_o).$$

All terms on the right hand side depend on the difference between the indoor and outdoor temperature, which means that this equation can be rewritten to:

$$Q_a + Q_b = C \cdot (T_i - T_o), \tag{1}$$

where C is just the product of the constants.

If no energy is added to a building by the heating system and the energy from the inhabitants and the weather is assumed to be constant, then there exists a positive temperature difference between the inside and outside temperatures. This means that Q_a can be represented as a temperature difference. Because of this temperature difference, a building where the inside temperature is kept at a constant 21 °C does not have to be heated until the outside temperature drops below 21 minus the temperature difference.

Q_a and T_i can be assumed constant in which case every building has its own lowest temperature at which no energy from the heating system is necessary to maintain the indoor temperature. This lowest temperature is the buildings balance temperature.

2.3 Heating an apartment building

Apartment buildings can be heated in many different ways, a common way is to generate the required heat at a central site in the building and then use a liquid medium, like water, to transport it to radiators in all the areas that need to be warmed up. The central heat generator can be a burner that runs on for example oil or wood, a heat pump extracting heat from the environment or district heating. The most common way to heat residential buildings in Sweden is to use district heating [6].

A schematic view of the heating and water control system in a typical residential building is shown in figure 1 on the next page. In the figure, the incoming hot water from the district heating central is connected to two heat exchangers. One for the hot water used by the tenants while the other heat exchanger heats the water for the radiators.

2.3.1 Controlling the indoor temperature

The indoor temperature in an apartment building should remain stable at a level specified by the tenants. This can be accomplished by using radiator valves, these can be thermostatic valves that control the flow through the radiator in order to reach a specific temperature in the room. Non-thermostatic radiator valves have to be controlled by the tenants, the indoor temperature then depends on the flow through the radiator and the temperature of the water.

The temperature of the water also influences the time it takes to heat a room that is below the desired temperature. Warmer water will heat the room faster and while this is desirable, warmer water also has disadvantages. Losses in the pipes and heat exchanger will be higher.

For these reasons a water temperature is chosen that heats the room at an acceptable rate, but is as low as possible to minimize the losses. This temperature is dependent on the outside temperature since the rate at which a building loses energy, and in turn requires energy, depends on the outside temperature as explained earlier. The building with the control system illustrated by figure 1 has

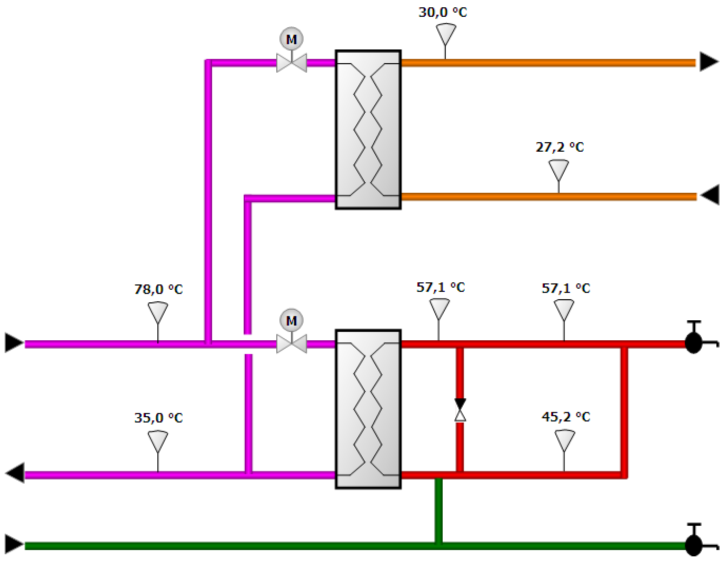


Figure 1: A typical control system for heating and hot water for the studied buildings. The upper two lines on the left are connected to the district heating. The supplied energy is used both for heating the building and for the hot water used by the tenants. The upper two lines on the right side are connected to the radiators. The lowest tap represents cold water used by tenants, while the upper tap represents hot water.

incoming water to the radiators at a temperature of 30 °C. This is only about 10 degrees above the desired indoor temperature, which indicates that this building didn't need much extra energy at the time the figure was created.

More advanced control systems can use extra information, such as the indoor temperature or a weather forecast, to control the water temperature.

2.3.2 Increased energy use

There are many reasons for why a heating system might increase its energy use. A malfunctioning sensor for example could cause a water temperature that is higher than necessary, which in turn causes a higher energy use. Higher energy use can also be caused by the residents of a building, a window that has been left opened in a heated room for example. A third cause can be that the indoor temperature has been too low and therefore has been raised.

The first example is a problem that the building owner should solve as soon as possible to minimize the losses, while the second problem is both harder to localize and harder to solve for the owner. The third case is not a problem but rather the solution for a low indoor temperature. It is not possible to differentiate between these three cases by only analyzing the outside temperature and the energy consumption. Unfortunately this is the only data available for this thesis, so therefore this thesis will focus on identifying all potential problems without regard to the cause.

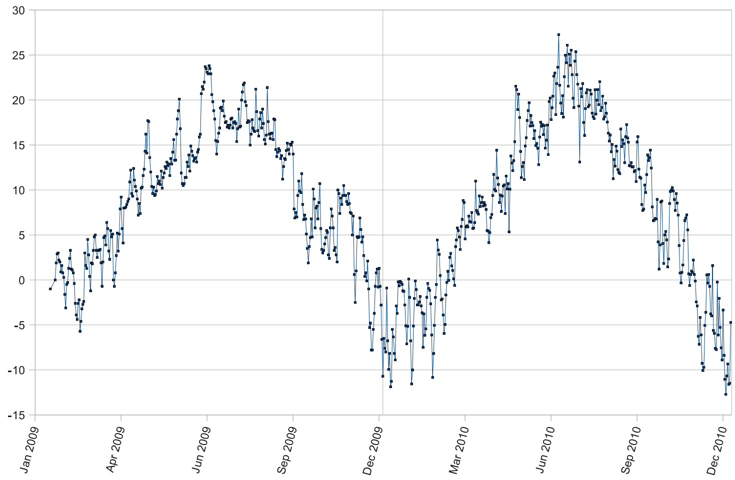


Figure 2: The daily temperature in central Gothenburg in 2009 and 2010.

2.4 About the data

The data used in this work consists of the district heat consumption of 352 buildings as well as the daily temperature in Gothenburg, Sweden. The buildings are mainly residential, some have shops or other services on the ground floor. All buildings in the set have the same owner.

The buildings use district heating as their primary source of warm water and heating. This means that the data will not only contain the energy used to heat the building but also the energy used to produce the hot water. 36 buildings in the dataset only have data for 2010, the 326 remaining buildings have data for both 2009 and 2010. In this report, the buildings will only be identified by a number.

The temperature data used is collected at a central spot in Gothenburg and is shown in figure 2.

2.4.1 Filtration

Section 2.3.2 described several causes for a measured energy use that deviates from the expected amount. A cause that was not mentioned there is errors in the measurements. A malfunctioning meter can give values both higher and lower than what they should be.

Filtration of the measurements could be used to remove such errors in the data, but the problem is that a deviating value could also be caused by a real problem. Therefore the measurements in the dataset have not been filtered, in order to be able to identify all buildings with possible heating issues.

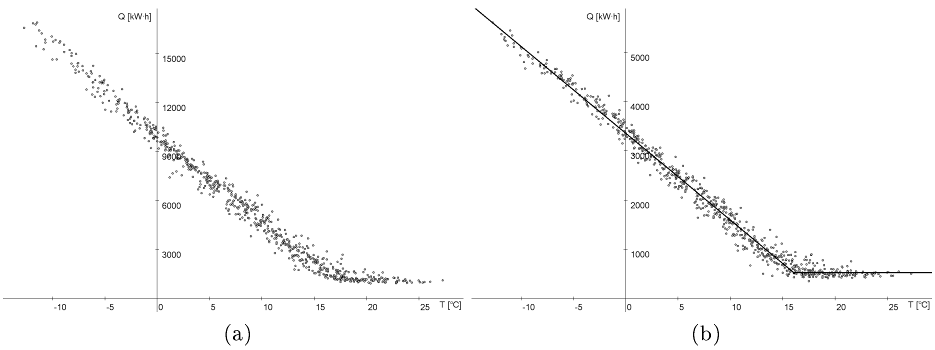


Figure 3: The left figure shows a plot where the daily energy for building 869 is plotted against the outside temperature. The figure on the right shows a similar plot for building 1973 and also shows the energy signature for the building marked with two black line segments.

3 Energy signature

Since equation 1 suggest that the energy use of a building has a temperature dependency, it makes sense to plot the consumed amount of district heating per day against the average outside temperature for that day. The available data is the total amount of district heating used, this includes energy used for heating the building, but also the energy required for the hot water used by the tenants. The equation also predicts that the amount of energy used only depends on the outside temperature for all temperatures below the balance temperature of the building. For temperatures above the balance temperature, no heating is necessary but the amount of energy used for hot water is still measured. This means that a plot of the outside temperature versus the amount of district heating used, will consist of two parts. A more or less constant part for all temperatures above the balance temperature and a part with a slope for temperatures below.

Figure 3 shows two such plots. The plots clearly show that there indeed is a temperature dependent and a more independent part. The balance temperature for the building in the left plot is approximately 16 °C while the building in the right plot is in balance at a little over 15 °C. The plot on the right side also shows two connected straight lines. These lines are the lines that best fit the data and are called the energy signature of the building [7].

3.1 Finding the energy signature

The energy signature consists of two line segments that are connected at the balance temperature. Finding a single straight line that fits data is commonly accomplished with simple linear regression.

3.1.1 Simple linear regression

In the simplest form of linear regression, one just takes a line, $y = b_0 + b_1 x$ and determines the parameters b_0 and b_1 by minimizing the residual sums of squares,

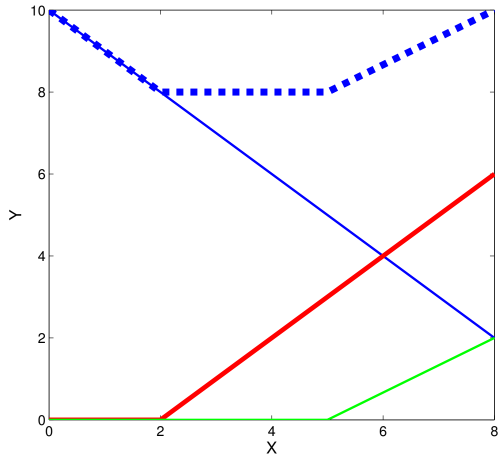


Figure 4: The dashed line is a linear spline constructed by taking the sum of the three other plotted functions.

RSS, of the data points. This residual is defined by

$$RSS = \sum_{i=1}^{n} \left(y_i - (b_0 + b_1 x_i)\right)^2 , \tag{2}$$

where the n data points are given by x_i and y_i. The values of b_0 and b_1 that minimize the residual can be obtained by taking the derivative of equation 2 with respect to both parameters, setting these derivatives to zero and solve the resulting equations for b_0 and b_1.

3.1.2 Linear spline regression

Finding a single line that fits the data is not good enough to find the energy signature for a building, since two line pieces are necessary. This problem can be solved by using a linear spline [8].

A linear spline is a function that consists of multiple line segments. An example of a linear spline can be seen in figure 4. The spline in this figure is constructed by taking the sum of several dummy functions. The dummy functions used are of the form $D(x - T)$ where the function is zero if $x - T$ is smaller than zero and $x - T$ otherwise. The points in the spline where the line segments connect are called knots.

With these dummy functions, a new function can be fitted to the data:

$$y_i = b_0 + b_1 x_i + b_2 D(x_i - T_1) + \ldots + b_{m+1} D(x_i - T_m).$$

This can be rewritten in a more convenient form using vector notation:

$$\mathbf{b} = \begin{bmatrix} b_0 & b_1 & \ldots & b_m & b_{m+1} \end{bmatrix}^T$$

and

$$\mathbf{X}_i = \begin{bmatrix} 1 & x_i & D(x_i - T_1) & \ldots & D(x_i - T_m) \end{bmatrix},$$

to give the much shorter expression

$$y_i = \mathbf{X}_i \cdot \mathbf{b}$$

The function that needs to be minimized can then be written as:

$$RSS = \sum_{i=1}^{n} (y_i - \mathbf{X}_i \cdot \mathbf{b})^2 \tag{3}$$

This equation has $m + 1$ derivatives that all can be written as:

$$\frac{\partial RSS}{\partial b_j} = -2 \sum_{i=1}^{n} (y_i - \mathbf{X}_i \cdot \mathbf{b}) \cdot \mathbf{X}_j = 0.$$

Setting the derivatives to zero gives $m + 1$ equations,

$$\mathbf{X}_j^T y = b_0 \mathbf{X}_j^T \mathbf{X}_0 + b_1 \mathbf{X}_j^T \mathbf{X}_1 + \ldots + b_{m+1} \mathbf{X}_j^T \mathbf{X}_{m+1},$$

these can also be written as

$$\mathbf{X}^T \mathbf{X} \cdot \mathbf{b} = \mathbf{X}^T y.$$

This equation can be solved for **b** which gives the linear spline that fits the data best.

For a buildings energy signature, only two line segments are needed. This means that one dummy function is enough. The only problem is that $T_1$for this dummy function, the balance temperature of the building, is unknown.

3.2 Finding the balance temperature

Since the energy signature should minimize the residual sums of squares of the data points, the balance temperature should be chosen so that it minimizes this sum. For some buildings this doesn't work however. The right panel of figure 5 shows a plot with the outside temperature against the district heat consumption of building 1574. The left panel of the figure shows the average deviation from the energy signature per data point in kWh plotted against different candidates for the balance temperature. This plot shows that the temperature that minimizes the deviation from the energy signature is 2,5 °C. But is this temperature really the balance temperature?

The balance temperature should not only be the point that minimizes the residual sum of squares, it should also be the point where no additional heating is required in order to maintain a stable indoor temperature. The right panel of the plot shows that the balance temperature should be something near 18 °C. Building 1574 seems to have a non-linear temperature dependency which is causing the minimum at 2,5 °C.

It is important to have a reasonable estimation of the balance temperature in order to be able to identify buildings with heating problems. Building 1547 shows that defining the balance temperature as the temperature that minimizes the residual sum of squares is not good enough. It is possible to demand that the balance temperature lies above some threshold value, but it is problematic to define a threshold value with good results for all buildings. Windproof and well

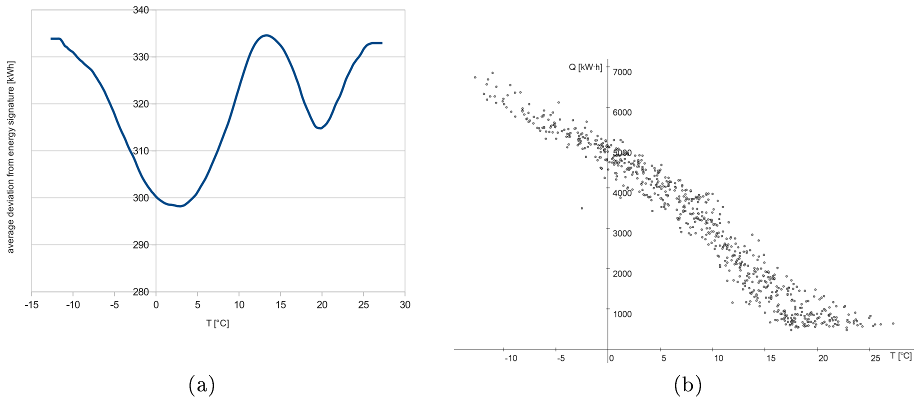


Figure 5: The figure on the left shows the average deviation from the fitted spline plotted against the position of the knot for building 1574. The figure on the right shows the T-Q plot for this building.

insulated buildings can have a very low balance temperature, while buildings that are not adequately insulated can have a balance temperature very close to the indoor temperature.

Another solution to this problem is to require that the energy signature for temperatures above the balance temperature should be constant. This will introduce an error in the estimated balance temperature, since the energy signature for these temperatures isn't necessarily constant. Hot days might require less district heating for the warm water used by the residents, because the water that needs to be heated has a higher temperature to begin with. Hot days also usually happen in the summer when residents might be away on vacation, but on the other hand, residents that are at home on hot days might shower more often...

The assumption that the energy signature is constant for days with temperatures above the balance temperature is most likely wrong, but at least it will give a reasonable estimation of the balance temperature for all buildings. Figure 6 on the facing page shows the average deviation from the energy signature per data point when the energy signature is constant for temperatures above the balance temperature. The global minimum at 2,5 °C has disappeared and the new global minimum gives a much better estimation of the balance temperature.

A constant signature for temperatures above the balance temperature can be accomplished by setting the slope of the dummy function, b_2 to $-b_1$. The function fitted to the data can now be written as:

$$y_i = b_0 + b_1 x_i - b_1 D(x_i - T_1).$$

This equation can be simplified to

$$y_i = b_0 + b_1 \left(x_i - D(x_i - T_1)\right),$$

which can be fitted to the data using simple linear regression. The unknown balance temperature can be found by minimizing the residual sum of squares using an appropriate algorithm.

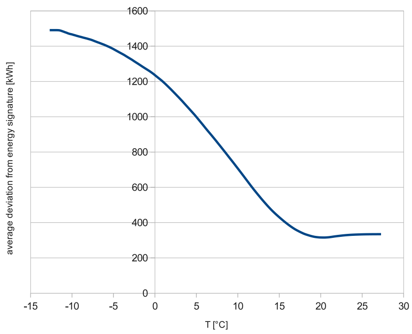


Figure 6: The average deviation from the fitted spline for building 1574. The spline consists of two segments, the segment at the right has zero slope.

4 Indicator parameters

Just looking at the energy signature of a building is not enough to determine if a building has problems with heating. Some parameters that shed more light on the issue have to be defined.

4.1 Deviation from signature

A first indication that the control system of a building isn't working optimally is a high amount of scattering in the consumption data, see also section 4.2. An easy way to quantify the amount of scattering is to sum the deviation of all data points from the energy signature. The total amount of scattering can then be defined as:

$$S_{total} = \sum_{j=1}^{n} \left| Q_j - (b_0 + b_1 (T_j - D(T_j - T_b))) \right|,$$

where T_b is the balance temperature.

Some normalization of this parameter is required to be able to compare different buildings. Different buildings can have different amounts of data points and the total amount of scattering will also depend on the average consumption. The first problem is easily fixed by dividing the total amount of scattering with the number of data points to give the average scattering per data point. Dividing with the average consumption of the building will finally give an indicator parameter that can be used to compare the amount of scattering for different buildings. The relative amount of scattering per data point, S can then be defined as:

$$S = \frac{1}{n \cdot \overline{Q}} \sum_{j=1}^{n} \left| Q_j - (b_0 + b_1 (T_j - D(T_j - T_b))) \right|$$

where $\overline{Q}$ indicates the average consumption.

4.2 Difference in slope

Many possible reasons exist that can explain a large amount of scattering. Scattering can be weather related, but a large amount of scattering can also be an indication that something is wrong with the control system.

Building 1961 is an example of a building where the consumption data is very scattered. Figure 7 shows the outside temperature plotted against the heat consumption for every day in 2009 and 2010. The two years have been divided in four periods of six months and every period has a different color in the plot. With these different colors, it becomes obvious that the large amount of scattering doesn't depend on anything weather related but instead is time dependent.

A way to find buildings with such a time dependency can be to analyze the slope of the temperature dependent part of the energy signature for different periods.

One way to do this is to look at the difference between the slope for the n-th time period and the $n+1$-th. To be able to compare this value with other buildings, it should again be normalized. This can be done by dividing with the average consumption and with the number of slopes compared minus one. The difference in slope Δs can then be defined as:

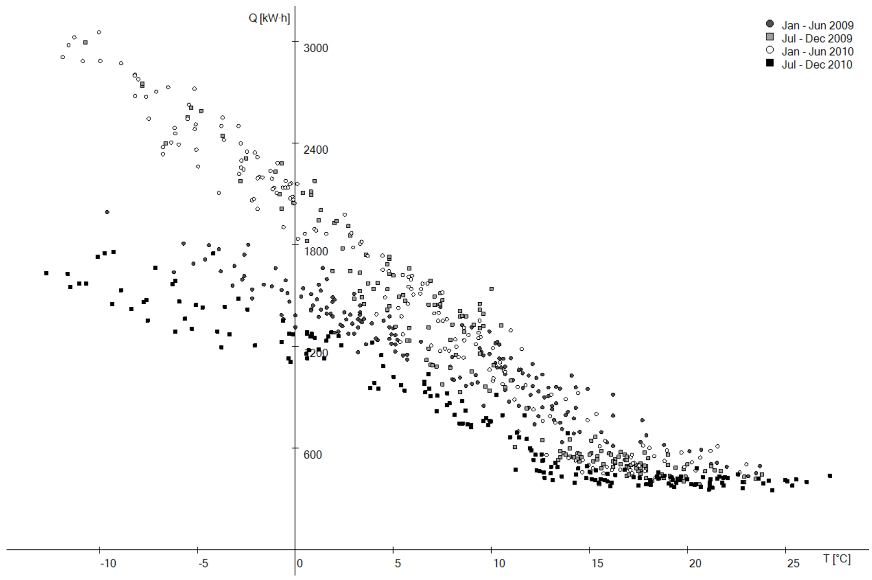


Figure 7: T-Q plot for building 1961 with different colors for different periods.

$$\Delta s = \frac{1}{\overline{Q} \cdot (N-1)} \sum_{n=0}^{N-1} |s_{n+1} - s_n|$$

where N is the number of slopes, s_n is the slope for period n, and $\overline{Q}$ is the average value of the consumption as before.

It is important to keep in mind that the value of this parameter can indicate different types of building behavior depending on the number of slopes compared. When comparing only two slopes, a large value of this parameter will mean that there has been a significant change in the slope of the signature in those periods. But when more slopes are compared, a large value could indicate either one large change or multiple large changes in more than one time period.

4.3 Increasing trend

Analyzing the slopes of the energy signature for different periods can be a good way to identify buildings that have multiple energy signatures. However a building can have an energy signature with large differences but where the difference between the slopes is very small. The energy signature of such a building, building 2477, is plotted in figure 8. The figure shows two slopes, one for the first half of 2010 and one for the second half. The difference between these slopes is only $1,47$ kWh per degree, even though there are some substantial differences in the energy signature.

Another problem that could occur in the control system of a building is that the building consumes more heat than usual at specific temperatures. This could happen because the control system is usually temperature dependent as described earlier.

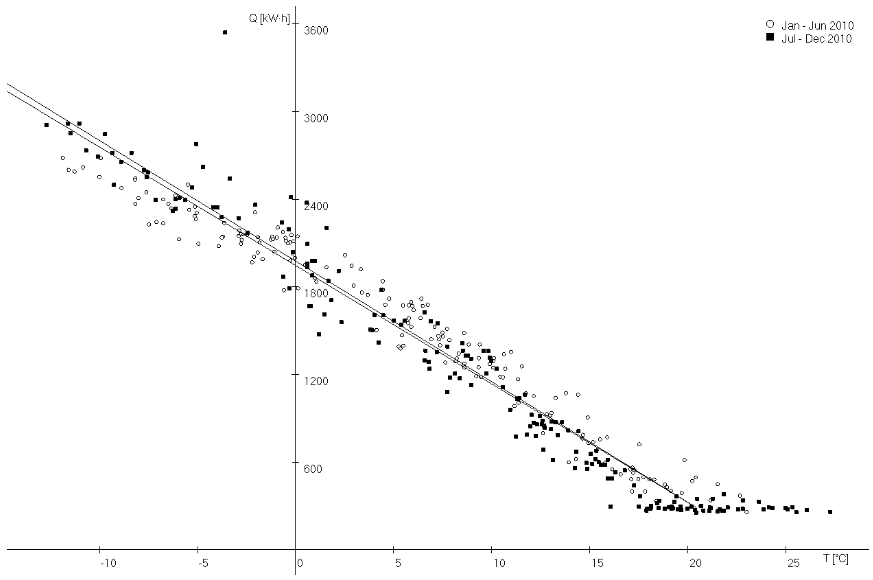


Figure 8: The energy signature for building 2477 has very little difference between the slopes for the different periods plotted. The difference between these periods is substantial nonetheless. The lower slope belongs to the first half of 2010, the upper to the second half.

Both of these problems can be identified by fitting a function to the consumption data that is more flexible than the energy signature. The energy signature is a linear spline with only two pieces, using more pieces will give a better fit to the data. A spline with as many pieces as there are data points will give a perfect fit, but won't give any additional information. A spline with a segment for every five degrees has plenty of data points for most segments and gives a better fit to the data points than a spline with only two segments.

Placing knots at every multiple of 5 degrees gives several new points that fit the data and can be compared for different periods. However, segments with very few data points don't give reliable new points because random variations in the energy consumption of a building can have a large influence on these new data points. Using a minimum number of five data points per segment gives more reliable results. Segments that don't have enough data points are discarded.

These new data points have been used to identify buildings where the energy consumption at a specific temperature has increased. If the temperature dependent data points are labeled $D_{T,n}$, where n stands for the period and T for the temperature of the data point, then the increase at this temperature I_T can be defined as:

$$I_T = \frac{1}{\overline{Q} \cdot (N-1)} \sum_{n=1}^{N-1} \max(D_{T,n+1} - D_{T,n}, 0)$$

Here the parameter has been normalized using the average consumption and the number of periods that are summed over. A high value for this parameter will give a strong indication that something has happened with the heating system.

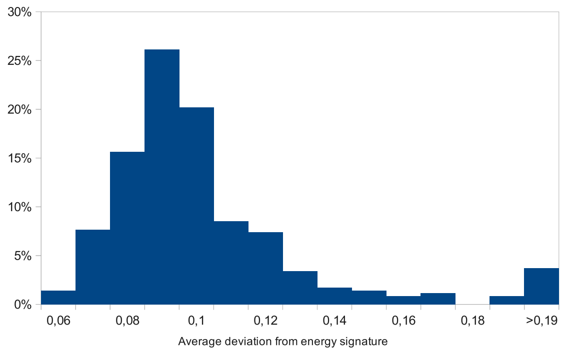


Figure 9: Distribution of the average deviation from the energy signature. A low value means that the data closely matches the energy signature. The mean value is 0,10 while the median is 0,089.

5 Results

The values of the indicator parameters have been tested on the data from the buildings in the dataset.

5.1 Deviation from energy signature

The average deviation from the energy signature have been calculated for all buildings in the dataset, the results are represented as a histogram in figure 9. The figure shows that approximately 45% of the buildings has an average deviation that lies between 0,080 and 0,10. This matches nicely with the median value for the set, which is approximately 0,089.

Is this median value of 0,089 good or bad? The amount of used district heating is plotted against the outside temperature for a building with a deviation value close to the median, building 585, in figure 10 on the following page. In this figure, only the values for the second half of 2009 and the first half of 2010 are plotted, different colors are used for the different halves. These two 6 month periods are the two periods in 2009 and 2010 that differ most, the other data points lie generally in between these the data points of the plotted periods. The figure clearly shows that there is a substantial difference between the consumption in the plotted periods. The difference is the largest for temperatures below 10 °C.

This shows that a deviation value of 0,089 can mean that there are large differences in the energy signature. This is especially the case for buildings where the deviation is concentrated in one or more periods, like building 585. Large differences in the energy signature can in turn indicate that there is a issue with the heating system of the building. In the case of building 585, the energy consumption for the first six months of 2010 is higher than the energy consumption for 2009 at similar outside temperatures. It is impossible to say if this unusual consumption pattern depends on a problem with the heating system of the building without more information, but it is at the very least a strong indication that something could be wrong.

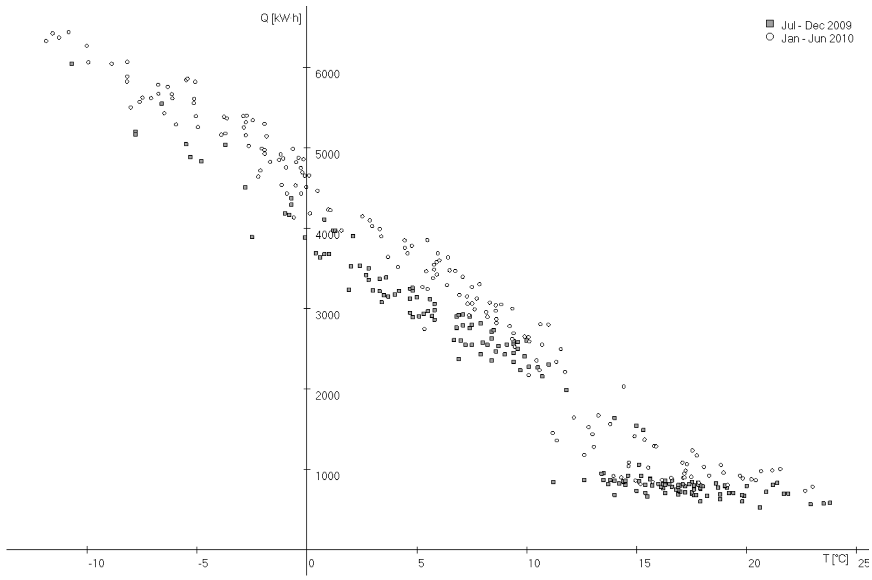


Figure 10: The T-Q plot of building 585, the building with the median value of deviation from the energy signature in the total set of buildings. Large differences between the two plotted periods exist in the amount of energy used at temperatures below 10 °C.

5.2 Difference in slope

The results from the difference in slope for the buildings in the set can be analyzed in a similar way, the results are presented in a histogram in figure 11 on the next page. The median value for the slope difference is 0,0044 and the difference for building 1058 has approximately this value. The values for this building as well as the different slopes are plotted in figure 12 on the facing page.

The figure shows that the energy use was significantly lower between January and June 2009 compared to the rest of 2009 and 2010. The slope for this period is smaller than the other slopes, which contributes to the high value for the slope difference parameter.

A closer look at the figure reveals that something happened with the heating system of this building during the fall of 2009, when the average outside temperature was between 14 and 15 °C. An approximate date for this event can be obtained from the data, this date can be helpful in identifying the cause of the increased consumption.

5.3 Increasing trend

The results from the increasing trend parameter of the buildings in the dataset are shown as histograms in figure 13. The figure shows clearly that there is a large difference between the results at -10 °C and all other temperatures. At -10 °C almost 55% of the buildings had no increase in the energy use, while all other temperatures have between 5 and 17% buildings without increase.

This remarkable result can be explained by looking at the outside temperatures

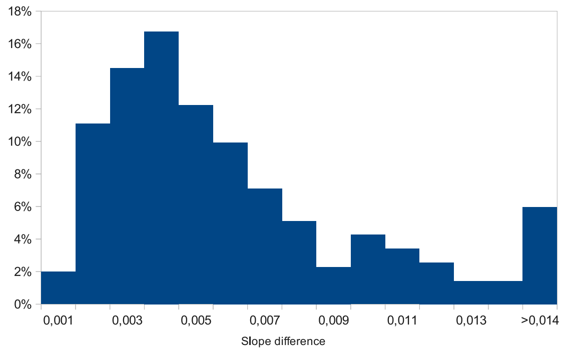


Figure 11: Distribution of the slope difference parameter for the buildings in the dataset. The median value is 0,0044.

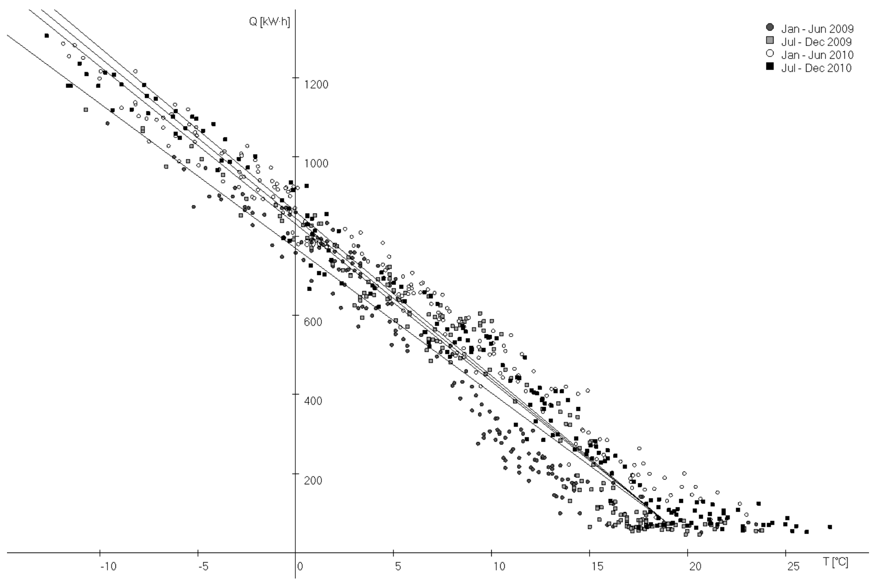
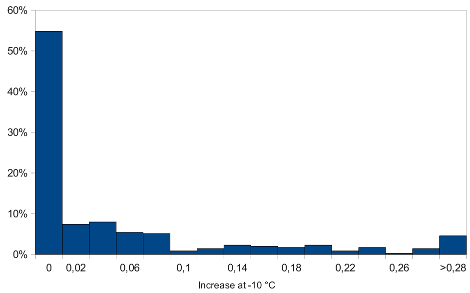


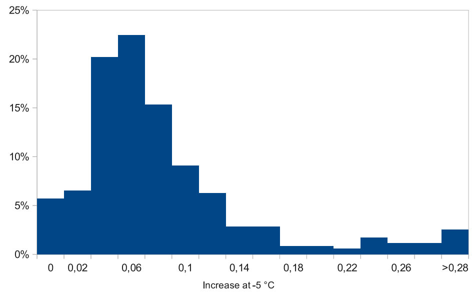
Figure 12: The T-Q plot for building 1058, different colors are used for the different periods. The slopes for the data from the different periods is marked with black lines. From top to bottom: Jan-Jun 2010, Jul-Dec 2010, Jul-Dec 2009 and Jan-Jun 2009.

in figure 2. The figure shows that 2009 hasn't been as cold as 2010 with the consequence that only two six month periods can be compared for -10 °C. All other analyzed temperatures have four compared periods. If assumed that the probability for an increase in the consumption from period n to period $n + 1$ is $0,5$, then the expected amount of buildings without an increase is 50% if only two periods are compared. If four periods are being compared then the expected amount of buildings without increase is $0,5^3$ or 12,5% which explains the results in figure 13.

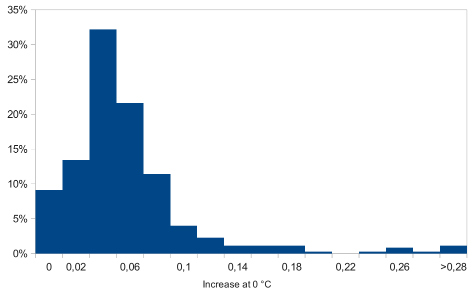
The purpose of the increasing trend parameter is to find buildings with large variations in their energy signature but that don't have large variations in the slopes for the different periods. Building 2477, plotted in figure 8, has a value of 0,0014 for the slope difference which is among the 25 lowest values for the buildings in this dataset. The value for the increasing trend at -5 °C on the other hand is 0,23, which is among the 25 highest values for this temperature.



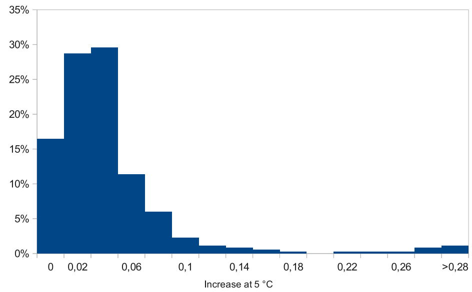
(a) -10 °C



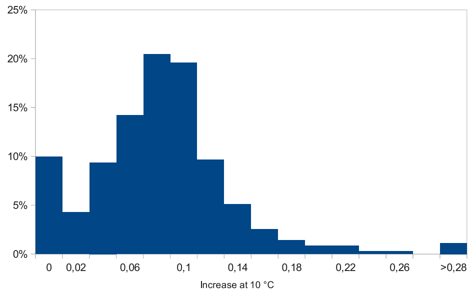
(b) -5 °C



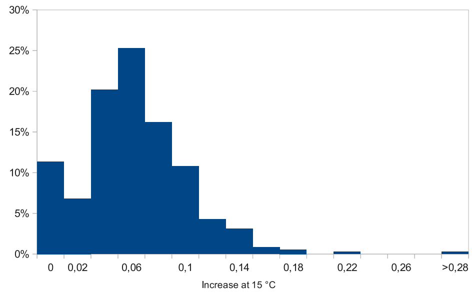
(c) 0 °C



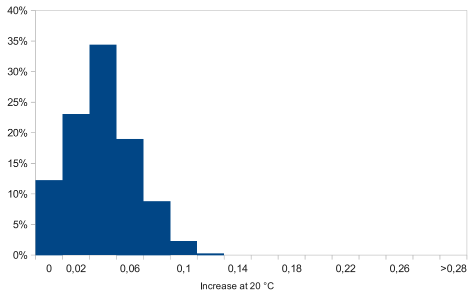
(d) 5 °C



(e) 10 °C



(f) 15 °C



(g) 20 °C

Figure 13: Distributions of the increase in the energy signature at different temperatures.

6 Conclusion

The introduced parameters adequately identify buildings with suboptimal heating. An important note although is that they will only find buildings where the problem occurred during the analyzed period, a building that consistently uses too much energy during the measurements will not be identified.

It is also worth noting that there are no specific values of the parameters that guarantee that there is a problem with the heating of a building. Buildings with unacceptable high values will need extra investigation to identify the problem. The building owner will have to decide what is acceptable and what not.

Another way to be more sure if a deviation is due to a problem or not, is too use more data in the analysis. The indoor temperature for example could give strong indications if a deviation depends on a malfunction or not.

A very surprising result is the amount of buildings with possible heating issues. Buildings close to the median of the parameters already show clear signs of possible problems, half of the buildings in the set have values that are higher and thus larger possible problems.

Further research could focus on identifying relations between the type or age of a building and the the amount or size of the heating issues. Another research direction could be to find the causes of the heating problems, automatic identification of a problem and its cause. Swift identification of these problems and their causes could possibly save large amounts of money and energy.

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