HRV-systems using the Energy Signature Method

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ABSTRACT
The energy use for the residential sector in Sweden is about 40% of Sweden’s total energy use. The European Union (EU) has specified that all new buildings by the year 2020 shall be close to zero energy buildings. This poses a challenge for the measurement methods available when household electricity, sun heating and heat recovery ventilation (HRV) systems become more important for the energy balance. All these sources are becoming more important in standard houses and especially in low energy houses of today and in the future. This paper deals with a data-driven technique based on the Energy Signature method to investigate how single family houses with HRV systems installed performs by comparing the effective U-value based on the total heat loss factor and envelope area for each house. The results show that no distinct difference between the HRV and non-HRV houses can be seen in this study, but a larger spread in data is observed for the HRV houses.

KEYWORDS: Energy Signature, Energy performance, Effective U-value, Heat recovery ventilation

1. INTRODUCTION

The energy use for the residential sector in Sweden is about 40% (Energimyndigheten 2012) of Sweden’s total energy use. The European Union (EU) has in the EU directive for building performance (EU directive 2010), stated that the energy use in the building sector by the year 2020 shall be reduced with 20% compared to 1990 for the EU as a whole. It is further specified that all new buildings by the year 2020 shall be close to zero energy buildings. It also contains the framework for how member states shall build up there building regulations and what should be considered. A numerical indicator for primary energy use expressed in kWh/m² per year is also needed.

Sweden implements these guidelines in the Swedish building code (Boverket 2011). This newer form of the Swedish building code is from 2006 and has been updated 2008 and 2011. In the building code Sweden is divided into three climate zones, north, centre and south. These zones have different permitted levels for bought energy (kWh per m² heated floor area and year). For houses with an electrical source for main heating the regulations range from 95 [kWh/m² and year] in the north to 55 [kWh/m² and year] in the south, with a maximum allowed average U-value of 0.4 [W/m²K]. There is no demand on air tightness other than that the building has to be airtight enough to accommodate the bought energy demand, but there are limits on ventilation rates. The building has to be ventilated with 0.35 [l/s and m² floor area] when it is occupied and 0.1[l/s and m² floor area] when not occupied. To accommodate these rules house builders today often install a Heat Recovery Ventilation (HRV) system in single family houses to fulfil the ventilation demands as well as the bought energy demand.

Different techniques or models are used to estimate energy use in buildings, these techniques can be put into two main categories; Forward or Prediction models and Data-driven models (Rabl 1988). The Forward technique is used in the design stage of a building to estimate the energy need while the Data-driven models are used after the building is built and it is possible to collect energy use data from the building (Olofsson, Mahlia 2012).
This paper deals with a Data-driven technique based on the Energy Signature model (Fels 1986, Hammarsten 1987, Sjögren 2007). The Energy-Signature depends on the possibility to measure the energy input for heating or cooling. It is unclear what happens when the input comes from non-measurable sources such as heat from household electricity, people, sun or HRV-systems. All these sources are becoming more and more important in standard houses of today and especially in low energy houses.

Hence, the aim in this paper is to investigate how single family houses with HRV systems installed perform versus houses without HRV-systems when applying the Energy signature method. The case study comprises four buildings and the analysis is done by comparing the effective U-value based on the total heat loss factor and envelope area for each house.

2. Methods

2.1 Description of houses

Four houses situated in Luleå in Northern Sweden are examined. They are heated with district heating. Two houses have HRV-systems installed and two houses have natural ventilation (only kitchen fan installed). Table 1 summarizes the house characteristics.

Table 1. Characteristics of the studied houses.

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Frame/facade</td>
<td>Timber/Brick</td>
<td>Timber/Wood</td>
<td>Timber/Wood</td>
<td>Timber/Wood</td>
</tr>
<tr>
<td>Footprint [m²]</td>
<td>100</td>
<td>155*</td>
<td>142*</td>
<td>253*</td>
</tr>
<tr>
<td>Stories</td>
<td>1 1.5**</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Envelope Area [m²]</td>
<td>298</td>
<td>596*</td>
<td>477*</td>
<td>759*</td>
</tr>
<tr>
<td>Theoretical U-value [W/m²K]</td>
<td>0.53</td>
<td>0.34</td>
<td>0.35</td>
<td>0.33</td>
</tr>
<tr>
<td>HRV-System</td>
<td>None</td>
<td>none</td>
<td>Systemair VM2</td>
<td>HERU 90 T EC</td>
</tr>
<tr>
<td>Inhabitants</td>
<td>4 (2 adults, 2 children)</td>
<td>4 (2 adults, 2 children)</td>
<td>6 (2 adults, 4 children)</td>
<td>4 (2 adults, 2 children)</td>
</tr>
</tbody>
</table>

*Including heated garage

**1.5 stories means one ground floor and one top floor where not the entire top floor has full ceiling height

2.2 Theory and measurements

Energy calculations in buildings are based on an energy balance meaning that energy in (Q_in) is equal to energy out (Q_out).

\[ Q_{\text{in}} = Q_{\text{out}} \]  \hspace{1cm} (1)

The basic Energy-Signature equation from (Hammarsten 1987) is expressed in Eqn. 2 where \( Q_0 \) is the energy need for technical systems and appliances such as fans, refrigerators, pumps etc., \( K \) is the heat loss coefficient in [W/K], \( T_i \) and \( T_e \) are the indoor and outdoor temperatures.
\[ Q_{IN} = Q_0 + K(T_i - T_e) \]  

(K (Eqn. 3) is the interesting term to determine and it can be described as the sum of the power supplied from district heating \((P_H)\), free gained power \((P_G)\), dynamically stored/released power \((P_{DYN})\) and power gains from the HRV-system \((P_{HRV})\).)

\[ K(T_i - T_e) = P_H + P_G + P_{DYN} + P_{HRV} \]  

Since the houses are connected to a district heating network \(P_H\) can be described as the power for heating \((P_{DH})\), power for tap warm water \((P_{DHW})\) and the losses in the system \((P_L)\).

\[ P_H = P_{DH} + P_{DHW} + P_L \]  

The free gained power \((P_G)\) can be described as the combination of power gained from the sun \((P_{SUN})\), household electricity \((P_{HE})\), household operating electricity \((P_{OE})\) and people \((P_P)\).

\[ P_G = P_{SUN} + P_{HE} + P_{OE} + P_P \]  

(K can then be described as in Eqn. 6.)

\[ K(T_i - T_e) = P_{DH} + P_{DHW} + P_L + P_{HRV} + P_{SUN} + P_{HE} + P_{OE} + P_P - P_{DYN} \]  

The choice of November to February as measurement period was made with a few main points in mind. First the temperature difference between \(T_i\) and \(T_e\) during this time varies between 15°C to 45°C yielding a large temperature span for the measurements. At the same time the darkest period of the year in northern Sweden occurs, with very few sun hours (SMHI 2012) thus the effect of \(P_{SUN}\) can be neglected without introducing any large errors (Sjögren, Andersson et al. 2009).

Since this study is focused on single family houses that have a light timber frame construction the effects of \(P_{DYN}\) are assumed to be negligible without introducing large errors when using daily averages, which is supported by (Hammarsten 1984).

When the house is a single family house most of the electricity usage is household electricity, thus \(P_{HE}\) and \(P_{OE}\) are measured as one \(P_E\) and no separation is made for specific installations.

Since no occupancy level has been investigated \(P_P\) can only be assumed for example the inhabitants can be assumed to spend a certain amount of time as idle, active and not at home with a specific power production for each state. For example persons can be assumed to produce 41 W when sleeping and 128 W when performing an activity such as assembling (Hens 2011) but this assumption will only affect \(Q_0\) since it is not dependent on temperature thus it lacks importance to \(K\) and can be neglected.

Total power for the district heating \((P_H)\) is measured and then separated into \(P_{DH}\) and \(P_{DHW}\) by the measurement system (Yliniemi, Delsing et al. 2009).

The district heating measurement is done at the district heating substation inside the house. This substation is placed where the pipes enter the house so all losses in the system actually contributes to the heating of the house and are covered by the measurements, thus \(P_L\) is zero.

\(P_{HRV}\) is difficult to determine since the measurement system is not able to separate the electricity used by the HRV nor is it able to record the data from the HRV such as percentage of heat recovery temperatures in the in- and outlets, air change rate etc. Thus a different approach is used to identify the effect of \(P_{HRV}\). From the linear regression of the power versus temperature difference \(K\), i.e. the slope of the curve, can be determined. This slope has the unit of \([W/°C]\) and by dividing this with the envelope area a number with the unit \([W/m²°C]\) is achieved. This number is the effective \(U\) value since it is a total heat loss factor that shows the zero sum of all energy exchanges over the building envelope. By comparing this to the theoretical \(U\)-value of the building envelope a distinct
difference should be seen between the houses with and without HRV. Houses with HRV are expected to have effective U-values closer or below the theoretical U-values while the buildings without HRV should have higher effective U-values compared to the theoretical ones. This leaves $K$ described as in Eqn. 7.

$$K(T_i - T_e) = P_{DH} + P_{DHW} + P_E$$  \hspace{1cm} (7)

To check if all parameters in Eqn. 7 are actually contributing to $K$ (rather than $Q_0$), linear regressions were made for each of $P_{DH}$, $P_{DHW}$ and $P_E$ versus outdoor temperature. If the parameter is not dependant on the outdoor temperature it will only give a static power contribution which does not influence $K$.

3. Result and Discussion

Linear regression analyses of the measured data during the period November 2012 to February 2013 are shown below for each of the four studied houses.

The linear regression models for the house built in 1967 are shown in Figure 1. Electricity, 1a, shows very low dependency on outdoor temperature, the small dependency that can be seen might be due to the few cold days. Heating, 1b, shows a clear dependency on outdoor temperature with a high $R^2$ value indicating a good correlation to a linear model. Hot water, 1c, shows no dependency on outdoor temperature. Total district heating use, 1d, also shows a good model fit ($R^2 0.94$) and a $K$ of 165 [W/°C] is used to determine the effective U-value. This house is a standard building, electricity is only used for household equipment and not heating. Hot water and electricity are linked to user behaviour and the users do not behave different depending on the outdoor temperature. Only district heating is used to heat the house, which shows a clear and stable correlation to the outdoor temperature.
Figure 2 shows the regression models for the house built in 2006. The energy signature and correlations between user behaviour and outdoor temperature are the same as for the house built in 1967. K of 182 [W/°C] is used to determine the effective U-value.

Figure 3 shows regression models for the house built in 2007. Electricity, 3a, shows no dependency on outdoor temperature. Heating, 3b, shows a clear dependency on outdoor temperature with a high $R^2$ value indicating a good correlation to a linear model. Hot water, 3c, shows no dependency on outdoor temperature. Total district heating use, 3d, shows an acceptable model fit ($R^2 = 0.83$) and a K of 229 [W/°C] is used for determine the effective U-value. Electricity is only used for household equipment and for the HRV thus it was expected to see a difference in electricity use compared to the naturally ventilated houses. Instead, the standard deviation is larger. Hot water 3c and heating 3b show more variation than the naturally ventilated houses, which likely is inherited from the total district heating 3d that also has a larger spread in data.

Figure 4 shows regression models for the house built in 2012. Electricity (4a) shows very low dependency on outdoor temperature, but with a slightly higher usage probably linked to the HRV. The separation between heating (4b) and hot water (4c) from total district heating use (4d) does not work in this case although the total district heating values are correct. There is a very large spread in data which results in a low linear correlation ($R^2 = 0.35$). The most likely reason for this is that the residents use their installed fireplace. When asked how often it was used the answer was “a lot”. It can be argued that the distinct top edge of the data cloud in Figure 4d (circled with dashed line) represent the days where the fire place is not used and the days below this “edge” is days when it is used. Figure 4e shows the linear regression for selected observations that are assumed to represent the days when the occupants have not used their fireplace. The model has a slope of 208 [W/°C] (4e) which is used as K to calculate the effective U-value.

Table 2 shows the house envelope area and K used to calculate the effective U-value, for comparison the theoretical U-value is also shown. No distinct difference between the HRV and non-
HRV houses can be seen when examining the U-value however, when studying the correlation between the linear model and the data, it is clear that houses with HRV have a larger standard deviation.

Figure 3. House built in 2007
Table 2. Theoretical U-values and effective U-values

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<tbody>
<tr>
<td>Effective U-Value</td>
<td></td>
<td>0.55</td>
<td>0.31</td>
<td>0.48</td>
<td>0.27</td>
</tr>
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</table>

*According to the model shown in Figure 4e.

4. Concluding remarks

From the case study presented, there is no clear difference between houses with and without HRV systems when examining the U-values. However, the houses with HRV systems show a larger standard deviation in the data and thus produce a lower correlation coefficient to the linear power model suggested by the energy signature method. This fact needs further investigation using a larger data set. The two non-HRV houses in this study were also included in (Nordström, Lidelöw et al. 2012) where a very good correlation with the linear power model was found. The question should be raised if the HRV-systems are responsible for the less stable performance and if this can be linked to the lack of communication between installed systems, difference in amount of ventilated air or a combination of both.

Another noteworthy point is the use of a fire place in the house from 2012 that seems to be a real performance boost, in this case it might even be enforced by the HRV-system being able to spread the heat to the entire house.
5. Acknowledgment

Financial support from the European regional development fund via the Interreg IVA North program is gratefully acknowledged.

6. References


