Spread in energy use in buildings dependent on choice of heating and ventilation system

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Pär Johansson*[1] and Paula Wahlgren[1]

1 Chalmers University of Technology
Sven Hultins gata 8
412 96 Gothenburg, Sweden
**Corresponding author: par.johansson@chalmers.se*

ABSTRACT

The energy use in buildings is dependent on the choices made during the design, construction and renovation. The causes for these differences are, among others, caused by the behavior of the occupant of the building and the choice of heating and ventilation system. The European scheme of Energy Performance Certificates (EPCs) aims at reducing the energy use in the built environment. It is most common to calculate (i.e. not measure) the energy use for the buildings which are affected by the scheme. In Sweden, on the other hand, the EPCs are normally based on measurements of the actual energy use in the building. This makes comparisons between calculated energy use for building permit and measured energy for EPCs possible. In this paper a study of the differences between the calculated and measured energy use and its correlation with the choice of heating and ventilation system is presented. This is done by detailed investigations of the calculated and measured energy use in 44 buildings. For further analysis, a database of 1 753 buildings with measured energy use (EPCs) is used to study the dispersion in energy use for buildings with different heating and ventilation systems. Analysis using numerical simulations tools on human behavior has also been performed. The results of the investigation can be used to further improve the measured EPCs.

KEYWORDS

Energy use in buildings, Energy performance certificate, Occupancy behavior

1 INTRODUCTION

The energy use in buildings should be decreased within the European Union to reach the goal of a 20% overall reduction in greenhouse gases until 2020 (European Parliament, 2010). The required energy performance of buildings is specified in the national building codes. In Sweden, the first code was implemented in 1946 (IEA, 2013) and the first energy use requirements were introduced in 1975 after the oil crisis in 1973-1974. The requirements were specified with maximum U-values and demands on the airtightness for different building parts. The codes were developed during the following years, tightening the demands on the energy use. The codes have the same requirements for new developments and retrofitted buildings, and since 2006 the code is based on performance criteria (Boverket, 2015).

The European scheme of Energy Performance Certificates (EPCs) aims at reducing the energy use in the built environment. It is most common to calculate (i.e. not measure) the energy use for the buildings which are affected by the scheme. In Sweden, on the other hand, the EPCs are normally based on measurements of the actual energy use in the building. The measured energy use is corrected for the climate variability by using a reference year. The energy use should also be corrected for 'normal' usage. This makes comparisons between calculated energy use for building permit and measured energy for EPCs possible. This paper presents an investigation on the difference between the calculated and measured energy and its correlation with the choice of heating and ventilation system. The aim of the study is to investigate parameters that cause deviations between the calculated and measured energy use. This is done by investigations of the calculated and measured energy use in 44 buildings in Lerum municipality (in south west Sweden). For further analysis, a larger database of EPCs for single and multi-family houses has been analyzed. This database represents Västra Götaland (south west region) and includes 1 753 EPCs. Analysis using numerical simulations tools on human behavior has also been performed, using one of the buildings in Lerum municipality.

2 ENERGY USE IN BUILDINGS IN SWEDEN

The energy use in buildings varies depending on, for example, the choices made during the design, construction and renovation of the building. The final energy use for space heating and domestic hot water is on average 171 kWh/m^2/year in Swedish multi-family buildings from before 1980 heated with district heating, which should be compared to 144 kWh/m^2/year for buildings built after 1980 (Statistics Sweden, 2012). For single family houses the average energy use for space heating and domestic hot water has reduced from 165 kWh/m^2/year in 1995 to 126 kWh/m^2/year in 2011. This is a 24% energy use reduction. However, at the same time the domestic electricity use has increased by 6%, from 38 kWh/m^2/year to 41 kWh/m^2/year. A part of this increase can be explained by more use of electricity to power circulations pumps, ventilation and floor heating (Swedish Energy Agency, 2014). Other causes for the differences are the behavior of the occupants in the building and the choice of heating and ventilation system. In the following section statistics of the heating and ventilation systems of the Swedish single family houses are presented.

2.1 Heating system

The technologies available, cost and legal demands changes the settings when a building is designed. Figure 1 presents how the percentage of different heating system in single family houses in Sweden has changed between 1990, 1999 and 2010.

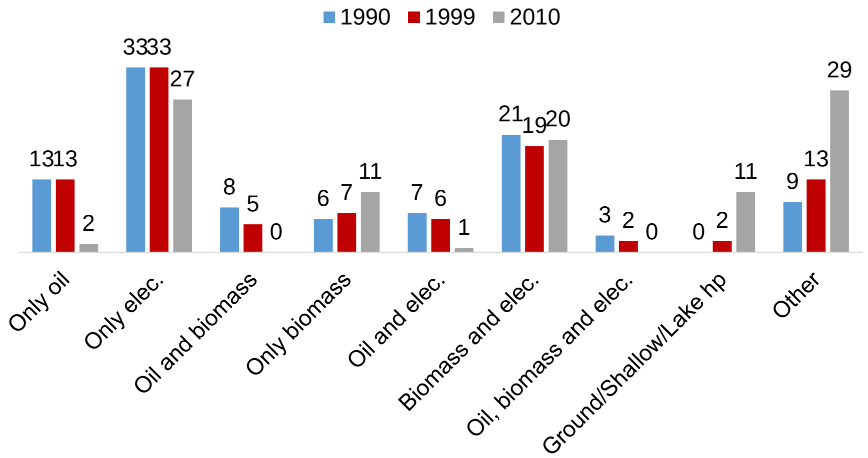

Figure 1: Percentage of different heating systems in Swedish single family houses in 1990, 1999 and 2010. The category 'Only electricity' also contains the houses with an air to air and air to water heat pump. The category 'Other'means combinations of heating systems that are not listed (Statistics Sweden, 2012).

It is clear that the number of houses with heating systems using only oil and electricity is declining and that it is more common in 2010 than in 1990 to use a variety of energy sources. In single family houses especially heat pumps have become very popular. In 2013 half of all single family houses had a heat pump. Air heat pumps are the most common heating system which accounts for 50% of the heat pumps. Ground, shallow and lake heat pumps were the second most common heat pump with 40% of the heat pump market (Swedish Energy Agency, 2014).

The space heating to the room can be supplied either by direct electricity, heating by air or hydronic heating. Hydronic heating is by far the most common supply system used in 70% of the single family houses. Direct electricity is used in around 25% of the houses and the remaining 5% are heated by air. The average indoor temperature is 21°C in the single family houses. Older houses have a 1°C lower average indoor temperature than newer houses (Boverket, 2010).

2.2 Ventilation system

Similarly to the heating systems, the ventilation systems in single family houses have changed during the years. In houses from before 1960, natural ventilation is used in 97% of the houses compared to 11% in the houses built in 1996-2005. Figure 2 shows the percentage of all single family houses that have natural ventilation, exhaust air, supply and exhaust air, supply and exhaust air with heat recovery and exhaust air with heat pump compared to the houses built in 1996-2005.

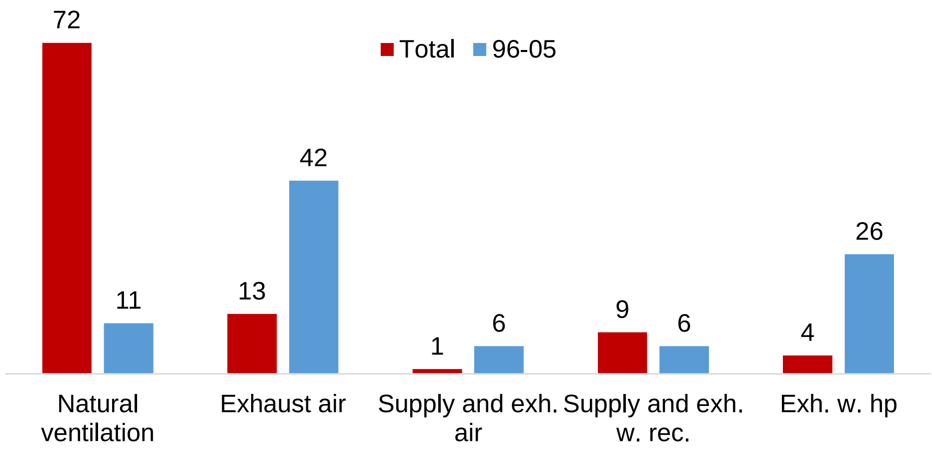

Figure 2: Percentage of different ventilation systems in all Swedish single family houses compared to the houses built 1996-2005 (Boverket, 2010).

The newer buildings has a larger percentage of exhaust air and exhaust air with heat pump compared to the total housing stock. This explains partly the increased electricity use in the buildings.

3 CALCULATED VS. MEASURED ENERGY USE IN LERUM MUNICIPALITY

Lerum municipality is located in south of Sweden close to Gothenburg on the west coast. The vision of Lerum municipality is to become Sweden's best performing municipality concerning the environment in 2025. One of the main parts of this vision is to stimulate buildings with less energy use. The energy advisors give advices to house owners on energy efficiency measures which leads to less energy use in existing buildings. To encourage construction of new buildings with low energy use, the politicians in 2010 decided to introduce a reduction in the fees for urban planning and building permits for low energy buildings in 2011. The municipality also has a lower maximum bought energy demand than what is defined in the national building code (BBR). The difference between the calculated and measured bought energy use for 44 single family houses in Lerum municipality is presented in Figure 3.

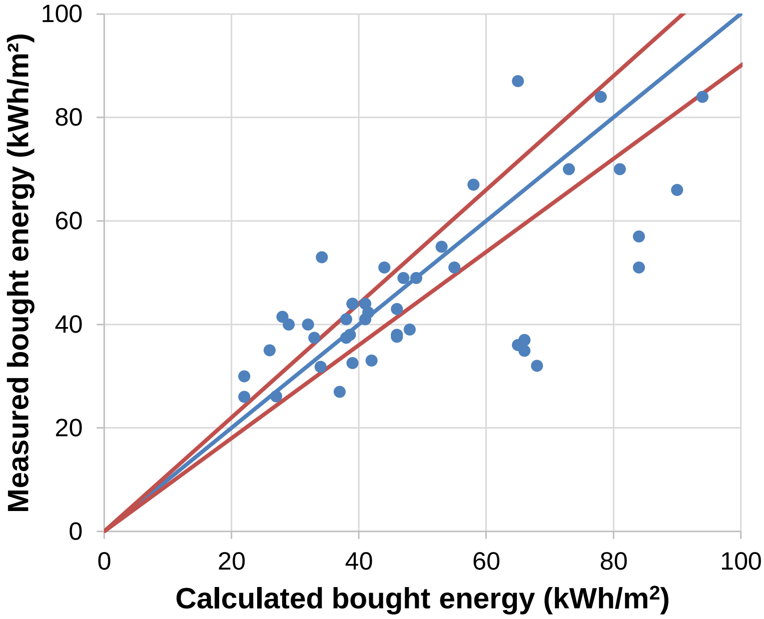

Figure 3: Calculated and measured bought energy use for 44 single family houses in Lerum municipality. The blue line indicates a perfect match between the calculated and measured energy use. The red lines indicate a deviation of 10% from the perfect match.

There are 29 houses of the 44 which have a larger difference between the calculation and measurement than 10%. Smaller than 10% is considered acceptable according to Sveby (2012). The average difference is 25% while the house with the largest difference has a 113% larger measured energy use than calculated. The sample is too small to make conclusions on the difference based on the choice of heating and ventilations system. Therefore a larger database of EPCs is used to study these influences.

4 VARIATIONS IN MEASURED ENERGY USE

The energy use is further studied with the EPC database containing 1 028 multi-family buildings and 725 single family houses from 2006 and onward. The reported categories with respect to ventilation systems are the same as shown in Figure 2. However, the types of ventilation systems that represented less than 5% of the database of buildings have been omitted from the analysis. This leaves exhaust air, supply and exhaust with heat recovery and exhaust with heat pump. As for heating systems, the categories are electricity (direct, hydronic and air borne), heat pump (exhaust air, air/air and air/water), ground source heat pump and district heating. Out of these, the categories with sufficient number of buildings are ground source heat pump, district heating and exhaust air heat pump. The hypothesis is that the type of ventilation system and type of heating system is affecting the accuracy of the measurement. This is studied by investigating the dispersion in the energy use of the different types of heating and ventilation systems for each building. The dispersion for each ventilation system is quite large. In all cases, the spread is at least ± 10% for half of the buildings (in one case corresponding spread exceeds ±25%). For the heating systems the dispersion is smaller. Maximum spread is ±17% for single family houses (ground source heat pump) and ±14% for multi-family buildings, see Figure 4. This can be interpreted as the energy use being more influenced by the heating system than by the ventilation system.

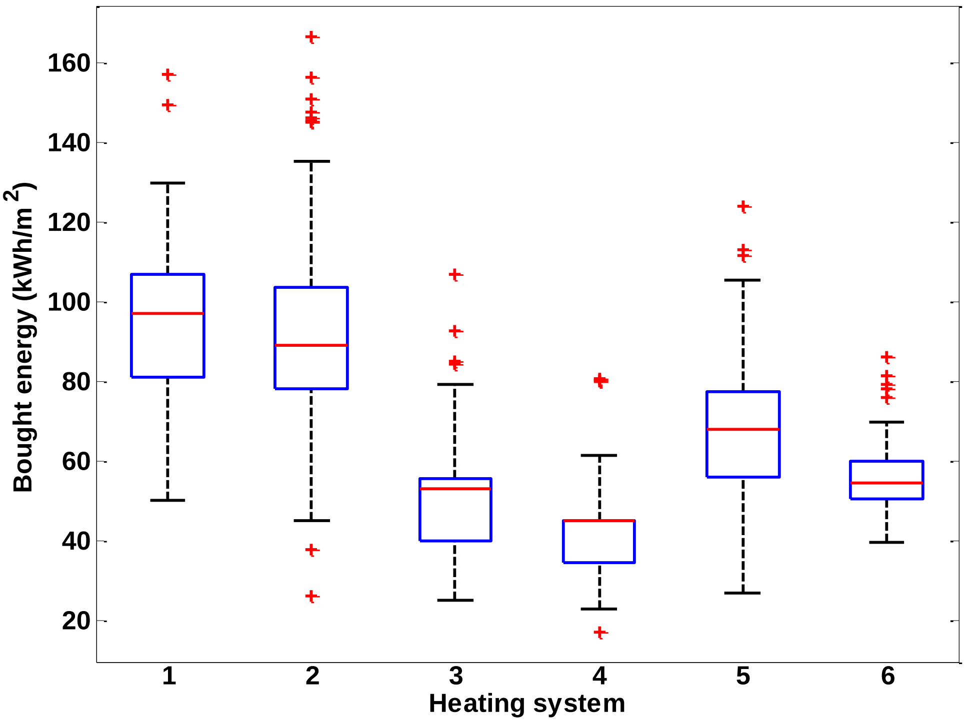

Figure 4: Measured bought energy use with respect to heating system in single family and multi-family buildings (from 2006 until now). Odd numbers are single family houses and even numbers are multi-family buildings. System 1-2 is district heating, 3-4 is ground heat pump and 5-6 is exhaust air heat pump.

Another important aspect that influence the energy use is human behavior. The occupants' behavior give rise to large variations in energy use. Fremling (2013) describes that 50 % of the energy use can be attributed to the occupant behavior. Hot water consumption, airing and indoor air temperature are three aspects that have major impact on the energy use. In single family houses, the measured EPCs is very much affected by the behavior of the group/family living in the house. In multi-family buildings, the dispersion will be smaller since some apartments have lower energy use (e.g. use less hot water) and some have higher. This will decrease the variation. As seen in Figure 4, the dispersion in energy use is slightly smaller in multi-family buildings (bar 4 and 6) and larger in single family houses (bar 3 and 5). An exception is district heating (bar 1 and 2). The reason is probably that there is an error in the measured energy use in multi-family buildings due to culvert heat losses, which is explained in section 6. This larger dispersion in multi-family buildings evens up the single family house dispersion due to behavior.

5 SIMULATIONS OF ENERGY USE AND OCCUPANT BEHAVIOR

Occupants affect the energy use by varying behavior and preferences when it comes to indoor temperature, hot water consumption, electricity use, airing habits, etc. The first three factors have been investigated using the numerical program IDA Indoor Climate and Energy 4.5.1 (IDA ICE) to simulate a single family house in Lerum. In total 54 cases have been simulated. The average indoor temperature is 21°C in single family houses and 22°C in multi-family buildings while 20°C is the temperature used when calculating energy use in passive houses (Sveby, 2012). Therefore these three levels (20°C, 21°C and 22°C) of indoor air temperature were used in the simulations. The number of people in the dwelling varies depending on the size on the house. The most common number of people in single family houses is 2 adults, followed by 1 adult, and 2 adults with 2 children (Statistics Sweden, 2010). The household electricity in dwellings has increased during the last years by the use of more household appliances which has not been counteracted by the more energy efficient equipment. During 2005-2008 measurements in 200 single family houses showed that the household electricity was 5 100 kWh per year on average. The recommended value for household electricity in single family houses is 2 500 kWh per household and year plus 800 kWh per person and year (Sveby, 2012). The hot water consumption varies depending on if the dwelling is located in a single family house or in a multi-family building. Measurements have shown that the hot water consumption is generally lower in single family houses than in multi-family buildings. In 1994 an area with mostly single family houses had a hot water consumption of 53 m^3 per person. In a study from 2007, the hot water consumption was found to be 12 m^3 per person in single family houses. Sveby (2012) recommends that a hot water consumption of 14 m^3 per person is used in energy use calculations for single family houses. Table 1 presents the input data used in the simulation study.

Table 1: Input data on behavior analysis in IDA ICE. The values are based on the recommendations given by Sveby (2012) and variations found in the literature (Sveby 2012).

Number of persons	**Household electricity**	**Hot water consumption**	
1	3.3W/m^2 = 5 100 kWh/year	145 l/pers/d = 53 m^3/year/pers	High (blue/left)
2	1.6 W/m^2 + 0.52 W/m^2/pers = 2 500 kWh/year + 800 kWh/year/pers	38.4 l/pers/d = 14 m^3/year/pers	Medium (red/middle)
4		32.9 l/pers/d = 12 m^3/year/pers	Low (green/right)

When all 54 combinations of these cases are simulated, on the same house, there are large differences in the results, and the energy use vary from 73 kWh/m^2 to 39 kWh/m^2 due to behavior. This corresponds to the results in Fremling (2012). The variation in hot water causes the largest difference, which is shown in Figure 5.

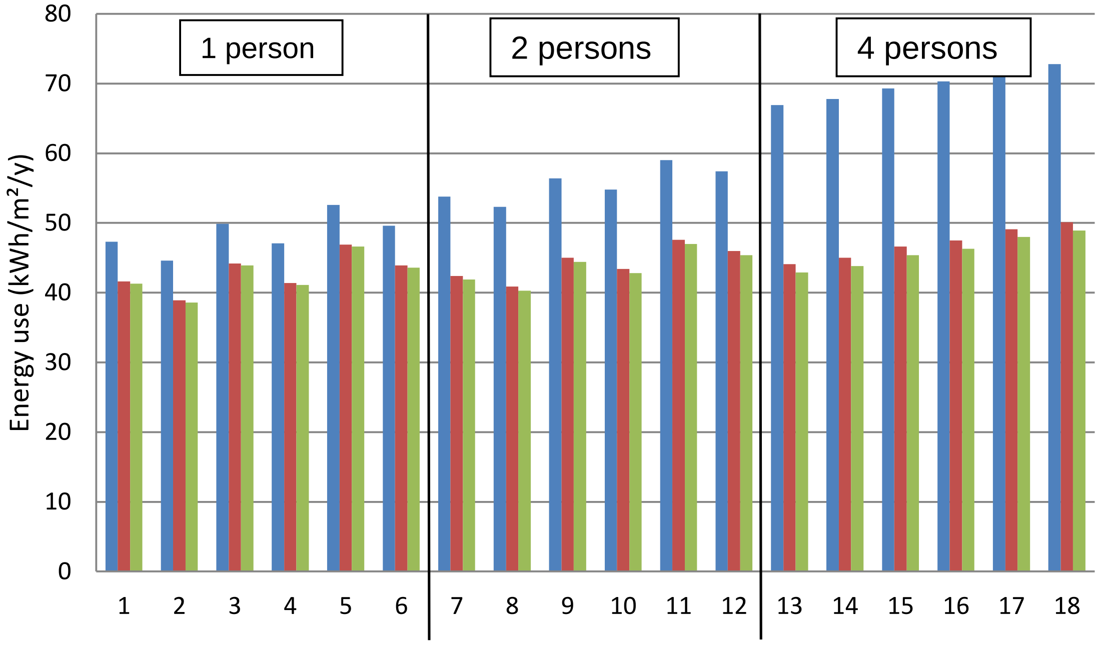

Figure 5: Energy use for space heating and hot water in a simulated single family house with 1, 2 and 4 people in the building. The different cases have different indoor air temperature (20°C, 21° and 22°C) and different household equipment use, as presented in Table 1. (Blue/left bar- high usage, red/middle bar-medium usage, green/right bar- low usage.)

The highest consumption compared to the lowest consumption give differences as large as 36% when it comes to hot water (four persons in the house). Corresponding number for indoor air temperature is 11.5% (20°C compared to 22°C) and for household equipment it is 6.5% (four persons compared to 1 person in the house). In the Swedish EPC, the measured energy use should be corrected to represent a normal year in terms of climate. The measurements should also be corrected with respect to ‘normal’ usage. However, this is very rarely done. A ‘normal’ usage is not defined in the EPC and the behavior in the house (for example indoor air temperature) is not followed up.

6 MEASURED ENERGY USE IN DISTRICT HEATING SYSTEMS

In addition to occupant behavior, the measured EPC is also affected by the location of the energy meter. Losses in the distribution of heat in a property with several buildings can be substantial if the culvert is placed outside of the building envelope, after the energy meter. In energy use calculations this heat loss is often omitted which could explain parts of the difference between measured and calculated energy use for buildings heated with district heating. Figure 6 presents a building with 117 rental apartments divided on 10 staircases.

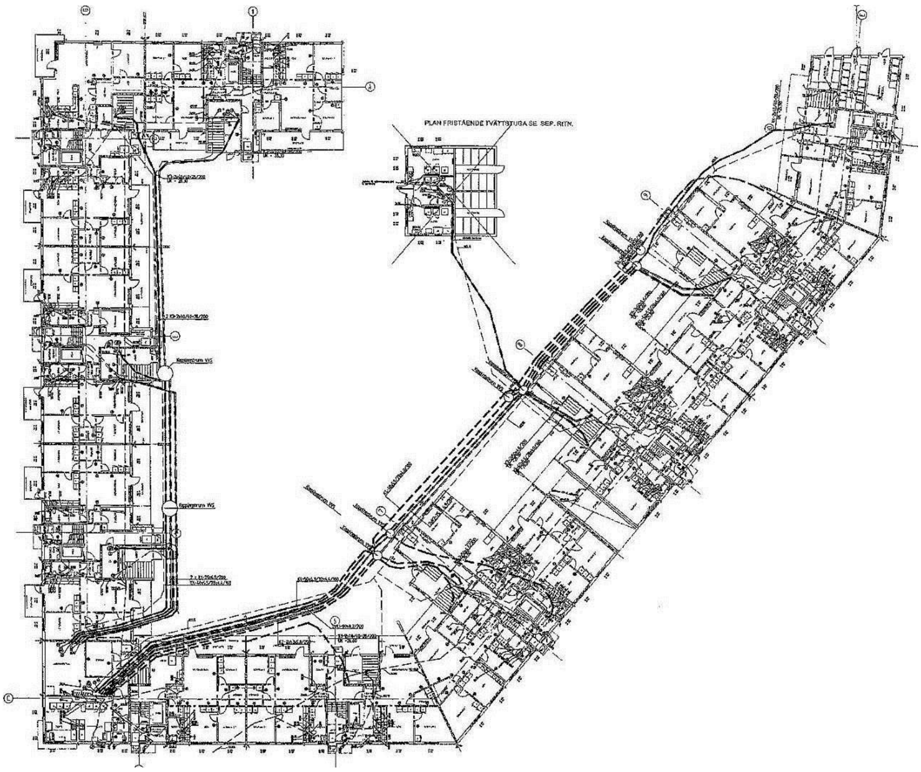

Figure 6: Buildings with an 800 meter long heating culvert placed outside of the building envelope (Bergqvist, 2011).

The building was constructed in 2008 and is located in Huddinge, south of Stockholm. It is heated by district heating and a supply and exhaust air handling unit with heat recovery is installed. In the EPC the reported energy use is 118 kWh/m^2. A detailed investigation (Bergqvist, 2011) of the building showed that this energy use is higher than expected by normal use. Three reasons were identified. A lower efficiency (50%) of the heat exchanger in the air handling unit and 50% higher hot water consumption than expected. Furthermore, there were also large heat losses from a heating culvert outside of the building envelope with a total length of approximately 800 meter. The measured energy use of the building is 82 kWh/m^2 when these abnormalities were accounted for. Of the additional heat losses the culvert accounted for 10.3 kWh/m^2, which increases the energy use with 12.6% if it is not corrected (Bergqvist, 2011).

7 DISCUSSION AND CONCLUSIONS

This study investigated the measured energy use of buildings reported in the EPCs in Sweden. The correlation between choice of ventilation system and heating system with the energy use was studied by using a database with 1 028 multi-family buildings and 725 single family houses constructed after 2006 in Västra Götaland (south west region). The dispersion in energy use is more influenced by the choice of heating system than by the choice of ventilation system. The occupant’s behavior has large influence on the energy use which could partly explain the higher dispersion for single family houses than for multi-family buildings. It is difficult to evaluate the energy performance of a building with measurement since human behavior is included. There is supposed to be an adjustment in the EPC for usage that is not normal. However, the term normal is not defined and it is also difficult to follow up. The simulation study revealed that the energy use in a single family house can vary with more than 30%. The most important parameter is the variation in hot water use. In the database of EPCs only 1.5% of the single family houses and 5.4% of the multi-family buildings had this information. For further evaluation more information is needed on the measured hot water use in each of the buildings to be able to rate the buildings' performance independent of the occupant's behavior.

8 ACKNOWLEDGEMENTS

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