Energy use in multi-family dwellings – measurements and analysis

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Abstract

In 2001, several multi-family dwellings were built in Västra hamnen, Malmö, Sweden. Well known Swedish architects were involved in designing the buildings, hence they reflect modern architecture. Prior to the inauguration, the buildings were displayed at the international housing exhibition 'Bo01'. The housing exhibition had an ecological and sustainability focus. Regarding energy use, all buildings were restricted to use no more than 105 kWh/m² annually including space heating, domestic water heating, common electricity and household electricity. A measurement programme including hourly measurements of district heating, common electricity and household electricity was set up to monitor the energy use of the buildings. Use of district heating, use of domestic water heating, use of common electricity and use of household electricity were all studied in detail. The variations in total energy use between the different properties were large. Although all buildings were designed to meet the same goal concerning energy use, there was a factor of almost three between the lowest and highest use. Key values are presented that can be used to critically examine different designs, systems and results from energy calculations.

Introduction

BACKGROUND

During 2001, the international housing exhibition Bo01 was held in Västra hamnen, in Malmö, in the south of Sweden. This housing exhibition had an ecological and sustainability focus. The area was supposed to be self supporting regarding energy with 100 percent locally produced renewable energy and there was supposed to be an annual balance of energy production and energy use at the area (Lövehed, 2005). Multi-family dwellings were built at 14 properties. Several well known Swedish architects were involved in designing the buildings, hence they reflect modern architecture.

Regarding the energy supply systems, heat was mainly generated by a heat pump, which took heat from an aquifer and from the sea. Solar collectors placed on several of the buildings provided some additional heat. Electricity was primarily generated by a wind turbine with additional electricity provided by solar electric photovoltaic panels. The heat and electricity production systems in the area were connected to the public grids through which the buildings got their heat and electricity. By connecting the heating and electricity production systems to the public supply systems, it was possible to use heating and electricity from these systems during days when the energy use of the buildings was higher than production. For days when production was higher than use, it was possible to deliver heat and electricity to the public supply systems.

To achieve the balance between energy used and produced in the area, all buildings were designed to use a maximum of 105 kWh/m² bought energy annually including space heating, domestic water heating, common electricity, and household electricity (Quality Programme Bo01, 1999). The developers used different techniques to achieve the restrictions regarding energy use. Before receiving a building permit, the developers had to present calculations that proved that their building's energy use fulfilled the demand maximum of 105 kWh/m². The quality program required that the energy used at the properties was measured for two years after inauguration. A measurement program was set up to monitor the energy use of the buildings. Since the buildings were taken into operation, use of district heating, common electricity and household electricity have been measured and stored every hour.

OBJECTIVES

The objective of this research was to study the measured energy use in the multi-family dwellings built for the housing exhibition Bo01. This shows whether or not the different properties fulfilled the requirement regarding energy use in the quality program after the first years of use. The key values concerning energy use can be used to critically examine different designs and systems, and results from calculations. Energy use for space heating, domestic hot water, common electricity and household electricity is presented to give input that helps designers of buildings to fulfil demands concerning low energy use.

METHODS

When energy use is to be analysed, the only method with reasonable accuracy is measurements of the physical parameters in a positivistic research approach. It would be interesting to combine these measurements with a hermeneutic approach with for example interviews and questionnaires for the building users, but in this research project, the focus has been limited to measurements.

Before this research project was formed, the energy use measurements were outlined. The energy use data have been collected hourly by the energy supplier. The resolution has been 1 kWh. Outdoor climate data have been collected hourly from a weather station located four kilometres away.

To be able to analyze the energy use, a number of models and assumptions based on other studies and theories were used (Bagge, 2007). Data about the buildings, their construction and technical systems, have been collected from the developers.

LIMITATIONS

From the 14 properties of residential units built, due to different circumstances, only nine properties were included in this study. The energy use at two other properties in the area was studied by Haryd (2006).

The energy use after 2005 was not included because the energy meters were replaced and a new measurement system was installed. Hence, this study includes the energy use during 2002, 2003, 2004 and 2005.

Energy use was measured at the property level. If there was more than one building on a property, it was not possible to separate the energy used in the different buildings.

THE EXAMINED PROPERTIES

The building techniques and the characteristics of the buildings at the examined properties have been described by Nilsson (2003) and Nilsson (2006). At seven of the properties, there were both high rise buildings and terraced houses. At two of the properties there were only high rise buildings. Table 1 presents key data of the buildings at the examined properties regarding number of apartments and area. Table 2 presents key data regarding heating, ventilation and heat recovery systems.

Properties 1, 5 and 8 included commercial space. At property 1 there were two clothiers, at property 5 a coffee house and at property 8 two restaurants and a clothier.

At properties 2 and 6, each apartment had its own air handling unit consisting of supply- and exhaust air fans and a heat pump. The heat pump system was setup to primarily heat the domestic hot water and secondarily heat the supply air. At properties 4 and 9, the supply air to the garage was the extract air from the apartments.

Result

TOTAL ENERGY USE

Figure 1 presents the total energy use during 2005 divided into use of space heating, use of domestic water heating, use of common electricity and use of household electricity. In this study, use of household electricity includes all electricity that was used in the apartments. The household electricity bill is paid by the occupants. Use of common electricity includes electricity for operating the building's technical systems such as fans and pumps, exterior and staircase lightning, equipment in community laundry rooms, elevators and heat recovery. Common electricity bills are paid by the property owner. Common electricity is the difference between the total electricity use and household electricity use. Table 3 presents the average, lowest and highest use of; district heating, domestic water heating, common electricity and household electricity.

The measured total energy use varied by a factor of three between the highest and the lowest use during operation. Only one out of nine properties fulfilled the requirement in the Quality program (1999), of total annual energy use below 105 kWh/m². Three properties used more than 190 kWh/m² annually, five properties used between 110 kWh/m² and 140 kWh/m² and one used 100 kWh/m². The total average annual energy use of all properties was 157 kWh/m² during 2005.

According to the Swedish building regulations, valid from 2007 (The National Board of Housing, Building and Planning, 2008), residential buildings must not use more than 110 kWh/m² and 130 kWh/m², in the south and north regions of Sweden respectively, for bought energy including space heating, domestic water heating and electricity for operating the building. Household electricity use is not included in the restrictions and as a result, the limit in the Bo01 Quality pogram (1999) of 105 kWh/m² was stricter. All the studied buildings except three meet the requirement regarding energy in the present Swedish building regulations.

According to Elmroth (2002) it is too common that measured energy use exceeds predicted use. Elmroth refers to a number of residential buildings in Stockholm, Sweden, built during the 1990s that have measured energy use exceeding the prediction by 50 to 100%. Lindén (2006) studied the energy use at a housing area built in 2001 in Stockholm, Sweden. The buildings were designed to use no more than 60 kWh/m² annually, including all electricity. During operation, none of the buildings met that goal. Lindén concludes that the energy restriction set to 60 kWh/m² was impulsive and not based on what could be

Table 1. Data regarding the number of apartments in the buildings, different floor area of interest and window percentage is presented for each property respectively.

	Apartments in the high-rise building	Apartments in the terraced house	Total area /m²	Heated floor area excluding garage /m²	Apartment area /m²	Window area per heated floor area /%
Prop. 1	37	4	7550	5463	4001	21
Prop. 2	9	2	1570	1445	1242	26
Prop. 3	16	7	4749	3546	2002	23
Prop. 4	15	5	4075	2623	1657	30
Prop. 5	23	-	6251	3115	2656	36
Prop. 6	8	3	1750	1739	1309	23
Prop. 7	27	-	4322	3467	2667	37
Prop. 8	21	1	3772	2437	2686	34
Prop. 9	13	5	3366	2390	1621	27

Table 2. Characteristics regarding heat distribution system, ventilation system and ventilation heat recovery is presented for each property respectively. Electrical heaters in bathrooms can be towel dryers and under floor heating or both.

	Heat distribution system			Ventilation system		Ventilation heat recovery	
	Hydronic radiators	Hydronic underfloor heating	Electrical heaters in bathrooms	Mechanical exhaust air	Mechanical supply and exhaust air	Exhaust air heat pump, space heating	Exhaust air heat pump, domestic hot water
Prop. 1	x		x	x		x	
Prop. 2	x		x		x	x	x
Prop. 3	x		x	x		x	
Prop. 4	x		x	x			
Prop. 5		x	x	x		x	
Prop. 6	x		x		x	x	x
Prop. 7	x	x		x			
Prop. 8		x		x			
Prop. 9	x		x	x			

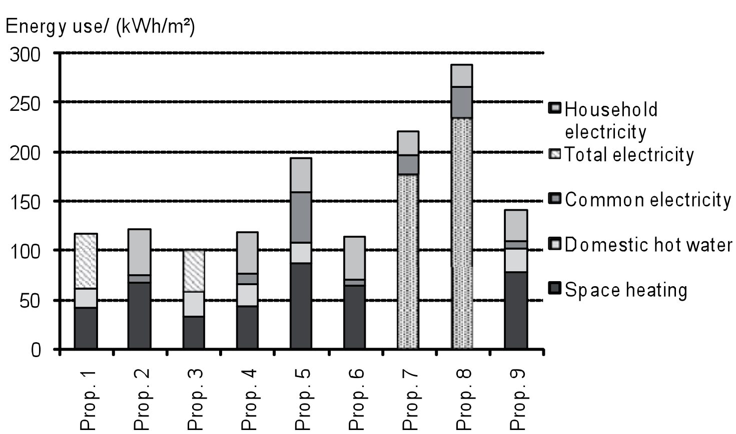

Figure 1. Energy use during 2005 at the different properties. At properties 1 and 3, total use of electricity is presented since household electricity and common electricity were not measured separately.

Table 3. Average, lowest and highest measured annual use.

Energy use/ (kWh/m²)	Average	Lowest	Highest
District heating	104	58	234
Domestic water heating*	23	19	25
Common electricity	20	6	52
Household electricity	35	22	47

**Domestic water heating is a part of District heating*

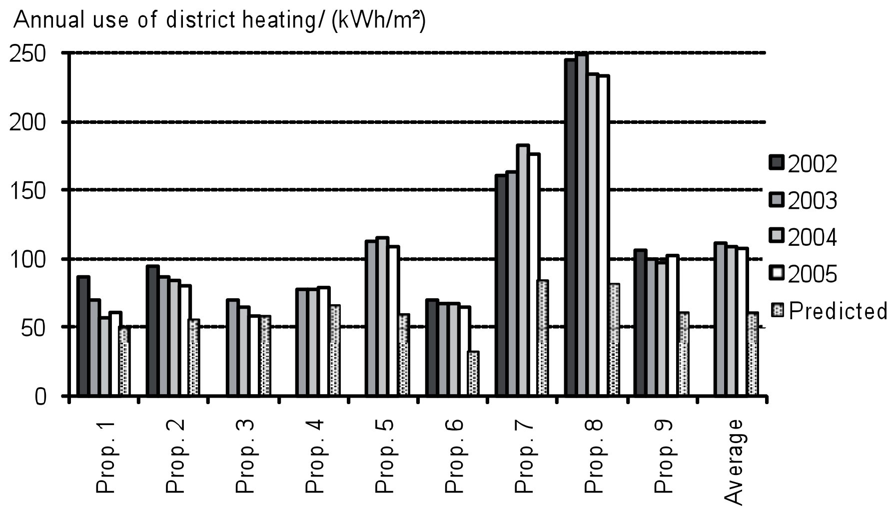

Figure 2. Measured annual use of district heating from 2002 to 2005, corrected for differences in outdoor temperature, including the developers' predicted annual use. The use is presented as use per heated floor area, garage excluded.

achieved in reality. Karlsson et al (2007) studied energy use in passive houses built in Lindås, Sweden. The measured energy use during operation was 50% higher than the use predicted during the design phase. According to Karlsson et al this is partly due to higher indoor temperatures and less efficient heat exchangers than predicted. Obviously, it is not uncommon that measured energy use exceeds predicted and calculated energy use. The difference between predicted and measured energy use in the studied buildings has the same order of magnitude as that found in the literature.

DISTRICT HEATING

Figure 2 presents the measured annual use of district heating, corrected for differences in outdoor temperature, and set alongside the developers' predicted annual use. District heating was used for space heating and domestic water heating at all properties except properties 2 and 6.

The mean annual energy use across all properties has decreased from 111 kWh/m² during 2003, to 104 kWh/m² during 2005. The energy use during 2005 was lowest at property 3, at 58 kWh/m², and highest at property 8, at 234 kWh/m². The mean predicted annual energy use across all properties was 60 kWh/m². The measured and outdoor temperature-corrected use was on average 73% higher than the predictions. If the energy use during 2005 is compared to the energy use during 2002, the energy use decreased at seven out of nine properties. At most properties, the use of district heating decreases from year to year. At individual properties, the energy use might first have increased where it decreased afterwards. The energy use has decreased the most, 30%, at property 1 and increased the most, 10%, at property 7. The results show a wide span in the use of district heating between the different properties. There is a factor four between the highest and the lowest use of district heating during 2005. Properties 7 and 8 used significantly more district heating than the other properties.

The properties that have low use of district heating typically have some kind of ventilation heat recovery. At properties with ventilation heat recovery the average use of district heating during 2005 was 72 kWh/m². Note that at two of these properties domestic hot water was not heated by district heating. At properties without ventilation heat recovery the use of district heating was 145 kWh/m². The use of district heating was higher at properties with under floor heating as the primary heat distribution system compared to the use of district heating at properties with radiators as the primary heat distribution system. The average use of district heating at properties with under floor heating was 173 kWh/m² compared to 70 kWh/m² at properties with radiators. Note that two of these properties did not use district heating for domestic water heating.

According to Statistics Sweden (2006) the average use of district heating in residential buildings was 153 kWh/m² during 2005, in temperature zone 4 which includes Malmö. This was 50% higher than the average use of district heating at the Bo01 properties. A report from SABO (2006) presents the use of

Table 4. The measured annual use* of domestic water heating and the developers' predicted use. At properties that do not have commercial space, the measured annual use* of domestic water heating is presented as use per apartment. It was not possible to measure this at properties 2, 6, 7 and 8.

	Measured* annual use			Predicted annual use	
	/kWh	/(kWh/m²)	/(kWh/ap.)	/(kWh/m²)	/(kWh/apt.)
Prop. 1	105270	19.3		28.2	4056
Prop. 3	78408	25.5	3564	31.5	4396
Prop. 4	60984	23.3	3049	29.3	3838
Prop. 5	67017	21.5		31.3	4238
Prop. 9	56472	23.6	3322	29.6	4164

* *Measured annual use of domestic water heating was calculated based on the measured use during July.*

space heating and domestic water heating in newly built multi-family dwellings with different types of ventilation systems. The use refers to data from 75 properties and reported use from the property owners. The use is presented per area to let which should give slightly higher values compared to if the heated floor area excluding the garage area was used. The average use of heat at properties with mechanical exhaust air was 146 kWh/m². At properties with mechanical supply and exhaust air and heat exchangers, the average use was 134 kWh/m², and at properties with mechanical exhaust air and exhaust air heat pumps, the use was 53 kWh/m². The average use at Bo01 properties with mechanical exhaust ventilation was 140 kWh/m², which is slightly lower than the reported average. The average use at Bo01 properties that includes exhaust air heat pumps was 72 kWh/m², which is higher than the reported average.

In buildings with exterior walls made from lightweight concrete, initial moisture will increase the heat transfer. Bagge et al (2004) studied the energy use in an energy efficient lightweight concrete house and found that the energy use was higher than predicted since the moisture content in the lightweight concrete caused higher transmission losses. The buildings at properties 2 and 5 have lightweight concrete exterior walls and the decrease in use over the years might be due to the concrete drying out.

DOMESTIC WATER HEATING

Annual use of energy for heating the domestic hot water was calculated based on the use of district heating during July 2005 and the variation in use during the year presented by Aronsson (1996) (Bagge, 2007). The use of district heating was measured at the property level, which means that the measured values are the sum of the use in all the apartments at the property. The individual inhabitants' behaviour will have a greater effect on the total use at properties with fewer apartments. At properties that include premises and restaurants, their use has been included and it has not been possible to separate this from residential consumption. In addition, it was not possible to separate the use for domestic hot water where there was a demand for space heating. It was not possible to calculate the use at properties 7 and 8 because these used district heating to heat towel dryers, also during summer. Table 4 presents the calculated annual use of domestic water heating and the developers' predicted use.

The average measured annual use of domestic water heating was 23 kWh/m². At properties that do not have any commercial space the average annual use per apartment was 3310 kWh. The average developers' predicted annual use including all properties was 33 kWh/m² or 4320 kWh per apartment. The average assumed use per apartment was 30% higher than the measured use at properties that did not have commercial space, the assumed use per m² was 35% higher. At properties that used district heating to heat the domestic hot water, it was on average 31% of the total use of district heating, and at properties that do not include commercial space, 34%.

Elmroth et al (2005) studied energy use in an energy efficient single family house in Malmö, Sweden. The annual use of domestic water heating was 2000 kWh. This was thought to be low. The low use was explained by the occupants' habits and that circulation was not used. The use was much lower compared to the average use at the Bo01 properties that did not include commercial space. Bøhm and Danig (2004) monitored the energy use in a district heated apartment building in Copenhagen and found that the gross domestic water heating was 3600 kWh per apartment, while the useful, net domestic water heating was 1275 kWh per apartment which shows that the heat loss from the boiler and the pipes were major. The measurements showed higher energy use for domestic water heating during the winter compared to the summer. The gross domestic water heating was almost the same as the average use at the Bo01 properties.

COMMON ELECTRICITY

In this study, use of common electricity includes electricity for operating the building's technical systems such as fans and pumps, exterior and staircase lighting, equipment in community laundry rooms, elevators and heat recovery. Common electricity bills are paid by the property owner. Common electricity is the difference between the total electricity use and household electricity use. The annual common electricity use has been measured at seven properties. At properties 1 and 3, only the total electricity use, including both household and common electricity, was measured. The measured annual use of common electricity over the first four years after inauguration is presented in Figure 3.

The use at the different properties varied to different extents over the years. There is no general trend for all properties. The use during 2005 was, on average, 19.5 kWh/m². The highest use of common electricity was 52 kWh/m². and the lowest 6 kWh/

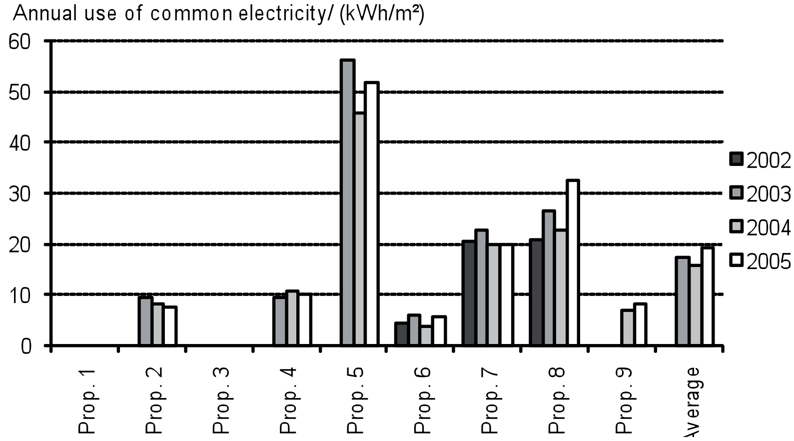

Figure 3. Annual use of common electricity per heated floor area, garage area excluded. Use of common electricity was not measured separately at properties 1 and 3.

m². Data presented below refer to 2005. The differences in use of common electricity between the properties were large. There was almost a factor of nine between the highest and the lowest use. The average use at properties with mechanical exhaust air was 18 kWh/m². At the properties where each apartment had its own air handling unit and a heat pump supported by household electricity, the average use of common electricity was 6.5 kWh/m². Property 5 has mechanical exhaust ventilation with central fans and a heat pump. The garage has a separate ventilation system consisting of mechanical supply and exhaust air and a heat exchanger. The high use of common electricity might be partly due to the two separate ventilation and heat recovery systems and a large garage. The use of common electricity is divided by the heated floor area excluding garage area which means that all electricity used in the garage is allocated to the heated floor area excluding garage area.

According to Dalenbäck (2006), property owners estimate the use of common electricity to be about 20 kWh/m². Dalenbäck presents results from the database E-nyckeln which gives an average use of common electricity of 37 kWh/m². The average use estimated by the property owners corresponds, almost exactly, with the average use at Bo01 while the average from E-nyckeln is much higher. Sandberg (2006) presents an overview of measured use of common electricity. The MEBY-project studied the use of common electricity in buildings built during the 1990s. The use was, on average, 16 kWh/m². In a further study of 22 properties built between 1997 and 2002, the use of common electricity was, on average, 15 kWh/m². None of the studied properties used any kind of exhaust air heat recovery. The use of common electricity at the studied properties varied between 4 and 37 kWh/m². These values are lower than at Bo01, which is to be expected since the properties studied in the MEBY-project did not use any kind of exhaust air heat recovery. The use of common electricity at the properties of four big property owners in Sweden varied between 17 and 27 kWh/m² (Sandberg, 2006). There is no information to what extent different ventilation systems were used. However, the average use at Bo01 falls within these reported averages.

A report from SABO (2006) presents use of common electricity at properties with different types of ventilation systems. The energy use refers to data from 75 properties and reported energy use from the property owners. The energy use is presented per area to let, which should give slightly higher values compared to if heated floor area excluding garage area was used. The use of common electricity at properties with mechanical exhaust air was 17 kWh/m². At properties with mechanical supply and exhaust air with a heat exchanger, the use was 36 kWh/m² and at properties with mechanical exhaust air and exhaust air heat pump, the use was 50 kWh/m². The use at the Bo01 properties with mechanical exhaust ventilation was slightly higher. The use at property 5 was 52 kWh/m², which is quite similar to the reported average use at the properties with exhaust air heat pumps. However, property 5 also includes a large garage that uses mechanical supply and exhaust air and heat exchangers.

The use of common electricity at the Bo01 properties was in the range of what is normally found in Swedish buildings. The use of common electricity might vary to a great extent between different properties. In order to rate whether the use is high or low, a qualitative judgment is necessary. It might not be appropriate to compare the use of common electricity at different properties without, at the same time, studying the use of heat and household electricity.

HOUSEHOLD ELECTRICITY

In this study, use of household electricity includes all electricity that was used in the apartments. The household electricity bill is paid by the occupants. Figure 4 presents the annual use of household electricity per heated floor area over the first four years after inauguration. At properties 1 and 3, the presented use is total use of electricity since only total electricity use was monitored at these properties.

The use at the different properties has varied to different extents over the years. At property 8, the use was very high during 2003 compared to the use during 2004 and 2005. This was due to heaters in some apartments where construction work was going on.

The use of household electricity during 2005 was on average 35 kWh/m². The highest use was 47 kWh/m² and the lowest was 22 kWh/m². Figure 5 presents the annual use per apartment during 2003 through 2005.

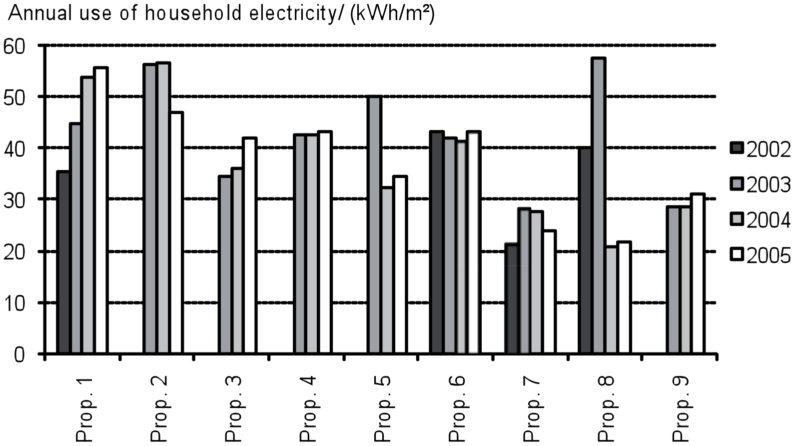

Figure 4. Annual use of household electricity per heated floor area, garage area excluded. The use at properties 1 and 3 is the total (common plus household) use of electricity.

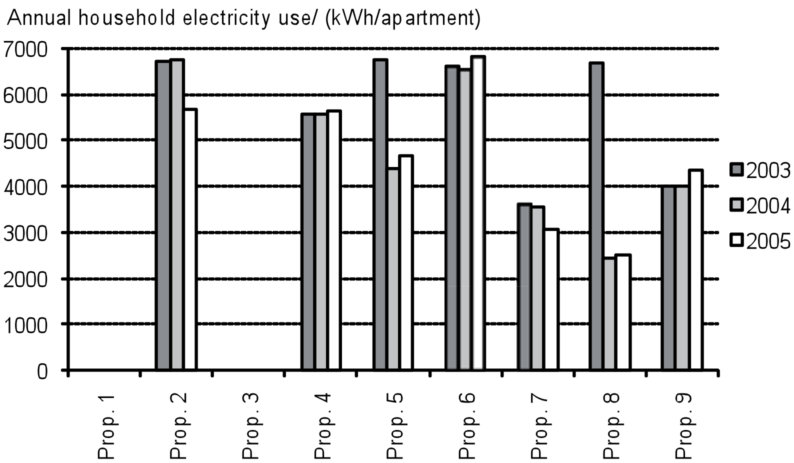

Figure 5. Annual use of household electricity per apartment.

The average annual use per apartment during 2005 was 4680 kWh/apartment. The highest use was 6815 kWh/apartment and the lowest was 2520 kWh/apartment.

Properties 5, 7 and 8 consist of rentable flats. In Figure 6 the use per apartment at these properties has been corrected with respect to the number of vacant apartments. It is assumed that there was no use of household electricity in the vacant apartments. The exclusion gives higher use per apartment. The exclusion of vacant apartments should provide a better value for household electricity use per apartment. At the other properties, the apartments were owned (co-operative flats) and vacant apartments were not filed. Figure 7 presents the annual use of household electricity per apartment area. This means that the use is divided by the area where the household electricity was actually used.

The average annual use per apartment area during 2005 was 47 kWh/m². The highest use was 68 kWh/m² and the lowest 28 kWh/m².

The use of household electricity will have different values depending on how it is distributed. If the use was divided by heated floor area excluding garage area, the average annual use was 35 kWh/m². The use per heated floor area was highest at property 2 and lowest at property 8. If the use was divided by the number of apartments at the properties, the average use per apartment was 4680 kWh. The use was highest at property 6 and lowest at property 8. If the use per apartment is corrected for vacant apartments, the use was lowest at property 7. If the use is divided by apartment area, the average annual use was 48 kWh/m². The use was highest at property 4 and lowest at property 8. These examples illustrate the importance of a carefully chosen distribution when energy use at different properties or buildings is compared in order to give a fair rating.

At properties that had electric heaters, towel dryers and under floor heating in bathrooms, the use during 2005 was on average 36 kWh/m² or 4900 kWh per apartment. At properties that had heaters in bathrooms, powered by district heating, i.e. properties 7 and 8, the use was on average 23 kWh/m² or 2800 kWh per apartment. At properties that had air handling units and heat pumps run by household electricity, and also used electrical heaters in bathrooms, the use was on average 45 kWh/m² or, 6200 kWh per apartment. Persson (2005) reported that electrical heaters in bathrooms could increase the

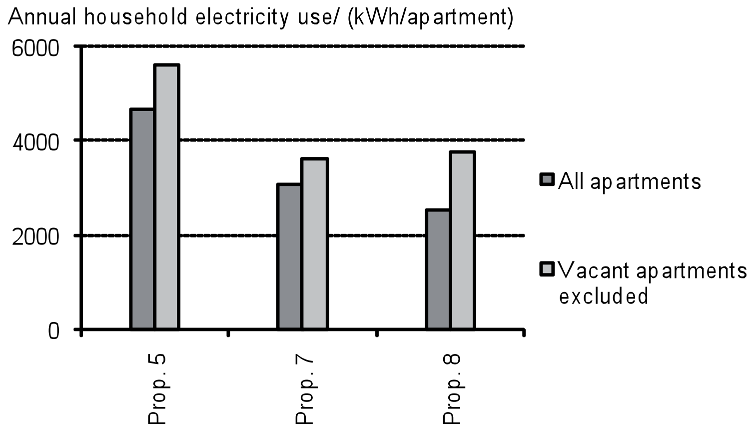

Figure 6. Annual use of household electricity during 2005 with and without respect to the number of vacant apartments.

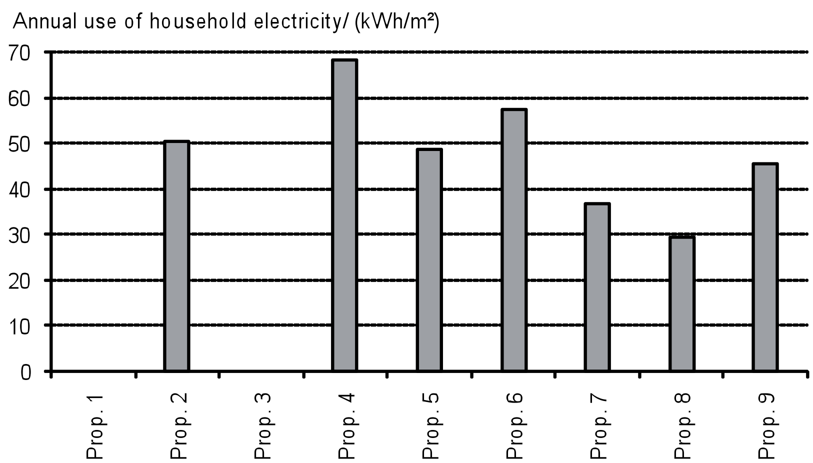

Figure 7. Annual use of household electricity per apartment area during 2005.

use of household electricity by 2000 kWh annually per apartment.

Bagge et al (2005) studied energy use in an energy efficient house in Sweden. The measured use of household electricity was 4150 kWh or 30 kWh/m². During the planning phase, the use was assumed to be 22 kWh/m² or 28% less than the measured use. Wall (2006) studied energy use in energy-efficient terraced houses. The measured use of household electricity was 31.8 kWh/m². During the planning phase of these houses, the use was assumed to be 23.8 kWh/m² or 25% less compared to the measured use. Lindén (2006) studied the energy use at a housing area built in 2001 in Stockholm, Sweden. The buildings had a restriction to use no more than 20 kWh/m² electricity annually, including all electricity. The average use of household electricity during 2005 was 27 kWh/m². Compared to the result from these three studies, the average use per heated floor area at Bo01, 35 kWh/m², was higher.

Discussion

Although all buildings were designed to use less than 105 kWh/m², only one property fulfilled this requirement. The three properties that had the highest total energy use had three particular characteristics. They were the three properties with the highest window area in relation to heated floor area, they all had under floor heating as primary heat distribution system and they had the highest use of district heating. The two properties that had the highest use of heat did not have any kind of exhaust air heat recovery. These properties had the highest and the third highest window area in relation to the heated floor area and under floor heating as the primary heat distribution system. This indicates that a combination of the three characteristics; under floor heating, large window area and no heat recovery might be unfavourable from an energy use perspective.

District heating was not the only heating source at all properties. If electric towel dryers and under floor heating is used in bathrooms, some of the household electricity is also used for heating. If heat pumps are used to generate heat, the compressor is run by electricity. If it is a central heat pump, it is probably run by common electricity and if the heat pumps are located in individual apartments, they might be run by household electricity. Furthermore, the heat pumps might deliver heat to space heating as well as domestic hot water, or both. To enable an accurate analysis of a buildings' heat use, electricity used for heating purposes or for generating heat should be measured separately to avoid the assumptions that otherwise have to be made. These measurements are also necessary to enable an accurate analysis of household and common electricity use. A higher use of common electricity due to heat recovery should lead to lower use of heating. Furthermore, higher use of common electricity due to use of laundry rooms should lead to lower use of household electricity. This demonstrates that it is of greatest concern to study the building as a system and only studying single parameters might give results that are hard to interpret or are even misleading. To be able to analyze the energy use of a building, the entire picture of the different types of energy is needed. When it comes to money and environmental impact, different types of energy are also usually valued differently. It is apparent that it is not possible to rate a building with only one parameter regarding energy use.

The Swedish building regulations of 2007 require that predicted energy use shall be verified by measurements in the actual building. It is recommended that safety factors are used to assure that the energy use during operation aligns with the predicted use. No guidelines regarding the safety factors are given in the building regulations. The energy predictions for the examined properties were executed by consultants that made energy predictions on a regular basis. Yet, the actual use of district heating was much higher than predicted. Several other studies have found equal differences between measured and predicted energy use. If these results are representative, a safety factor of at least two should be appropriate to ensure that the actual energy use does not exceed the predicted energy use. However, a safety factor that high is unrealistic and pinpoints the necessity of better knowledge for the designers and the construction workers. It is of greatest concern to have energy simulations carried out carefully and with suitable input data and critical examination of the results to get realistic predictions. The construction work needs to be best practice for the buildings' different elements and technical systems to match the design data.

Conclusions

To enable a detailed analysis of a building's energy use and to find reasons for differences between calculated and measured energy use, the measurements need to have a high time resolution and they need to be divided into suitable end uses of energy. This was partly done at the examined properties but was not enough. It was, for example, not possible to split domestic water heating from space heating, and in many cases, common electricity or household electricity was apparently a part of the heating system without separate meters.

The results stress the importance of a detailed analysis of energy use in order to rate a building or a property. Studying just a few parameters, for example use of heating and common electricity, might result in an inappropriate rating of the energy use.

A specific goal concerning total energy use in the newly built multi-family dwellings resulted in a difference with a factor of three between the highest and the lowest total energy use during operation and only one property out of nine that fulfilled the goal. This result stresses the importance of higher quality energy predictions to enable design of buildings that fulfil demands for low energy use, regardless of whether the deviation is due to insufficient usage of energy simulation tools, unqualified consultants or imperfect construction work.

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