SIMULATING ENERGY USE IN MULTI-FAMILY DWELLINGS WITH MEASURED, NON CONSTANT HEAT GAINS FROM HOUSEHOLD ELECTRICITY

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ABSTRACT

It is crucial to perform energy simulations during the building process in order to design a building that meets demands regarding low energy use. In a low energy building, internal heat gains such as excess heat from household electricity, are a large part of the heat balance of the building. The internal heat gains are depending on the occupants and not constant. Result from energy simulations with household electricity that varied during the day and the year according to a model based on measured data are presented. To make accurate energy calculations of low energy buildings, the daily and annual variations in use of household electricity should be taken into account.

INTRODUCTION

As a part of decreasing the energy use, and thus carbon dioxide emissions within the European Union, focus has increased on both low energy buildings and the ability to simulate the energy use of buildings properly. To design a building that fulfils demands on low energy use, it is crucial to perform energy simulations of the building in question during the building process and the simulations must represent the building during operation (Bagge, 2009). Karlsson et al (2007) stresses the importance of accurate input data for energy simulations. The building users' behaviour is very important in low energy buildings and also the hardest to model according to Karlsson et al (2007). When optimising the design of a low energy building, it is of great importance to know what amount of household electricity is likely to be used and how it varies over the year and during the day in order to understand the internal load pattern, since excess heat from household electricity is a major heating source.

Bagge (2008) studied the energy use of 145 apartments located in buildings at seven properties in Malmö, Sweden. The household electricity use during 2005 was on average 35 kWh/m² with the highest use being 47 kWh/m² and the lowest 22 kWh/m². Elmroth et al (2005) studied energy use in an energy efficient house in Sweden. The measured annual use of household electricity was 4150 kWh or 30 kWh/m². Wall (2006) studied energy use in energy efficient terrace houses. The measured annual use of household electricity was 32 kWh/m². Lindén (2006) studied the energy use at a housing area built in 2001 in Stockholm, Sweden. The annual use of household electricity during 2005 was 27 kWh/m².

At places where the outdoor climate varies during the year, the use of space heating will also vary since it depends on the outdoor temperature. The use of space heating will be largest during the winter and lowest during the summer. Other types of energy use such as use of household electricity and use of domestic hot water are also different at different times of the year. Tso and Yau (2003) studied the daily consumption patterns of household electricity in about 1500 households in Hong Kong. The use was about the same during a 24 hour period except for a large peak in the evening. No noticeable difference was found between the patterns for weekdays and weekends. The use was higher during summer compared to winter due to the use of air-conditioning to cool the apartments. Riddell and Manson (1995) studied power usage patterns of domestic consumers in New Zealand. It was found that mid morning and early evening peaks displayed the same trends. Capasso et al (1994) monitored the electricity use in 95 households in Milan. The daily average load profile showed a small peak at eight o'clock in the morning and a big peak at eight o'clock in the evening. The use was least around five o'clock in the morning. After the morning peak, the use stayed at a higher level compared to the use during the night. Paatero and Lund (2005) monitored use of household electricity in 702 households in Finland. The variations during the day have a large peak around eight o'clock in the evening during both weekdays and weekends. The use increased during the morning but there was no peak. Between mornings and evenings, the use was higher during weekends compared to weekdays. Bagge (2008) studied the variations during the day and the year in use of household electricity of 145 apartments located in buildings at seven properties in Malmö, Sweden. The use during the winter was higher compared to the use during the summer. The use during the year varied between 75% and 130% of the annual mean power. Norén (1998) and Sandberg (2006) have found similar variations. The variations during the day had common characteristics at the seven properties. The use

- was least during the night
- increased during the morning where there was a small peak
- was almost constant during the day and afternoon
- increased during late afternoon
- reached a maximum at eight or nine

During weekends, the use increased later during the morning compared to weekdays. The use was higher during the afternoon during weekends compared to weekdays. Due to the variation in use during the year, the daily use will be different at different times of the year. Bagge (2007) found that the relative variation during the day, hourly power for each hour of the day compared to that day's average power, was equal during the year despite the variations during the year.

Bagge et al (2006) interviewed consultants who ran energy simulations of buildings. The consultants seldom simulated the variations in use of household electricity during the day and the year although they were aware that there were variations. This was because no data regarding the variations were available and most energy simulation programs for buildings used by the consultants, were not adapted for input data that varied during the day and the year.

Objectives

A typical residential apartment building was simulated with constant household electricity and varying household electricity over time respectively to analyse the difference between these simulations based on measured household electricity variations. Some energy use related parameters were varied to show the influence from the design of the house.

Limitations

Internal heat gains from persons were set constant. Window airing was not considered in the simulation model as was not varying indoor temperatures in different apartments. The building was simulated as one zone. Space cooling was calculated for one parameter, but not generally analysed.

METHOD

The variation in use of household electricity during the year and the day were described. Simulations of space heating demand with and without respect to the variations were performed with different parametric variations.

Variations during the year and the day

Bagge (2008) presented measured variations during the day and during the year. To be able to use the measurements effectively in simulation code, the variation during the year was described by a sinus function based on the twelve monthly mean powers as part of the yearly mean power according to Equation 1, where P_{mom} is the actual power at the time t and P_{av} is the annual average power.

$$P_{mom} = P_{av} + P_{av} \cdot 0.238 \cdot \sin(0.000717 \cdot t + 1.42) \quad [t] = h \tag{1}$$

The variation during the day was described by the 24 discrete hourly ratios between the actual power and that day's mean power, which means that the daily profile was a step function. Figure 1 and 2 show the modeled variations in use of household electricity based on the measurements.

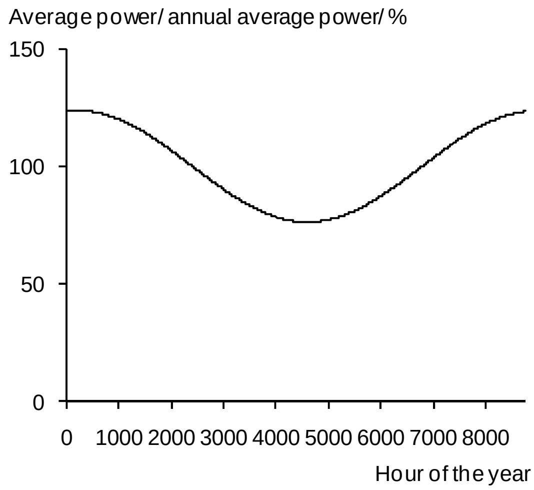

Figure 1 The modelled variation in use of household electricity during the year.

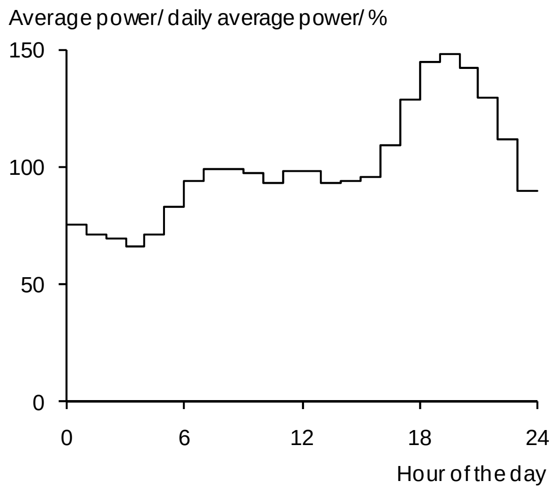

Figure 2 The modelled variation in use of household electricity during the day.

Test building

The test building used in the simulation was a theoretical building, which default configuration was supposed to be representative for buildings in Sweden built according to the Swedish building regulations (The National Board of Housing Building and Planning, 2008). The theoretical building was a four storey two stair case multi-family building containing four two bed room apartments of 75 m^2 each on each storey. The building was 16 m by 12 m and each storeys height was 2.4 m. The total heated floor area was 1264 m^2. The long sides were facing north and south with an equal amount of window area. The total window area was 13% of the heated floor area. Table 1 presents the thermal transmittance and area of the different building elements. The thermal bridges were set to 72 W/K.

Table 1
The area and thermal transmittance of the different building elements

Building element	Thermal transmittance /(W/(m²·K))	Area /m²
Foundation	0.10	316
Roof	0.10	316
Walls	0.18	572
Windows	1.2	164

The average thermal transmittance of the building envelope including thermal bridges was 0.32 W/(m^2·K). The windows solar heat gain coefficient was 0.4 including possible shading effects. The total ventilation airflow rate was 480 l/s and the ventilation heat exchanger temperature efficiency was 75% and constant. The supply air temperature was 18˚C and constant. The building was heated to an indoor temperature of 21˚C. No cooling system was used. Air leakage at 50 Pa pressure difference between indoors and outdoors was 0.8 l/(s·m^2) building envelope. The thermal storage capacity was 15000 J/(m²·K) for an area of 1896 m². Internal heat gains were household electricity, 30 kWh/(m^2·year), and one occupant per apartment on average with 100 W per person. The default theoretical building was located in Malmö, southern Sweden, lat N55.6º.

Simulation tool

Since there seems to be a lack of commonly used commercial tools that simulate varying input data both over the day and year, code was developed to simulate the energy use by the help of the power balance shown in Figure 3 (Johansson, 2005).

ROOM is the simulated zone. P_{trans} is the transmitted heat, P_{cap} is the heat from the first order heat capacitor with the temperature t_{cap}, P_{solar} is incoming shortwave solar radiation that heats the room and P_{vent} is the power needed to change the temperature of the supply air, t_{sa}, to the temperature of the exhaust air, t_{ex}. It is assumed that the room temperature, t_{room}, is the same as the exhaust temperature.

The air handling unit was assumed to use a heat recovery with a constant temperature efficiency of 75%, but never lower outgoing air temperature than 0°C. Leakage air was assumed to have a constant airflow rate, $q_{leak,}$ of 5% of the airflow rate at 50 Pa pressure difference, which is reasonable for a supply and exhaust ventilation system with under balance to prevent over pressure (Johansson, 2008; Torssell, 2005). P_{int} refers to the load from people that was assumed to be constant, and for household electricity that was assumed to heat the indoors and vary over the day and year.

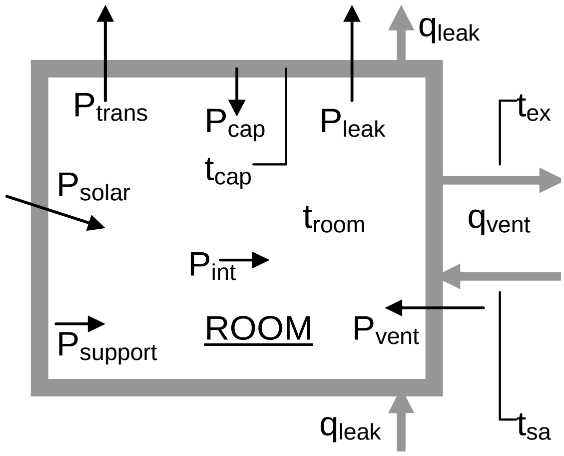

Figure 3 Power balance used in the simulation tool for the building. The air handling unit is not shown. Quantities are given in the text.

$P_{support}$ is the energy needed to keep the room in balance at the desired t_{room}. Since it was assumed that there was no cooling system, $P_{support}$ could not be negative. In that case, the code solved for the t_{room} at balance. Outdoor climate data was obtained from the computer program Meteonorm (Meteotest, 2003) which simulates outdoor climate data for the entire world.

Simulations

Simulations of space heating demand were performed with household electricity that

- was constant (Constant)
- varied during the day (Daily)
- varied during the year (Annual)
- varied during the year and the day (Both)

A multiplication of the daily and annual corrections were used for the variations over both year and day. The space heating demand for the different cases were compared. Other types of bought energy, included in the demand of the Swedish building regulations (The National Board of Housing Building and Planning, 2008), not analysed in the study, are common electricity used for example for air handling units and outdoor lighting and domestic hot water heating.

Studied parameters included are

- average thermal transmittance
- window's solar heat gain coefficient
- building's thermal storage capacity
- average use of household electricity
- outdoor annual average temperature

Table 2 gives the outdoor climates tested.

Table 2
Simulated outdoor climates and their annual average temperature in Figure 9. Malmö was default.

Building element	Annual average outdoor temperature/°C	Lat/°
Karasjok, Norway	-2.52	N69.4
Kiruna, Sweden	-1.23	N67.8
Frösön, Sweden	2.53	N63.2
Umeå, Sweden	3.67	N63.8
Stockholm, Sweden	6.66	N59.3
Malmö, Sweden	8.01	N55.6
Glasgow, UK	9.41	N55.8
London, UK	10.6	N51.5
Milano, Italy	11.7	N45.4
Madrid, Spain	14.8	N40.4
Los Angeles, US	18.1	N34.1

Furthermore, the cooling need at different use of household electricity was studied.

RESULT

Table 3 gives the result of the simulated heating demand for the default theoretical building for the different cases of variations of the use of household electricity.

Table 3
Simulated space heating demand with constant, daily, annual and both daily and annual variation in use of household electricity.

Building element	Annual Space heating /(kWh/m^2)	Relative to constant/ %
Constant	18.1	100
Daily	18.6	102.8
Annual	16.7	92.4
Both	17.2	95.1

Beside the space heating demand, the buildings total energy demand includes domestic hot water heating, common electricity, electricity for operating the building's technical systems and household electricity.

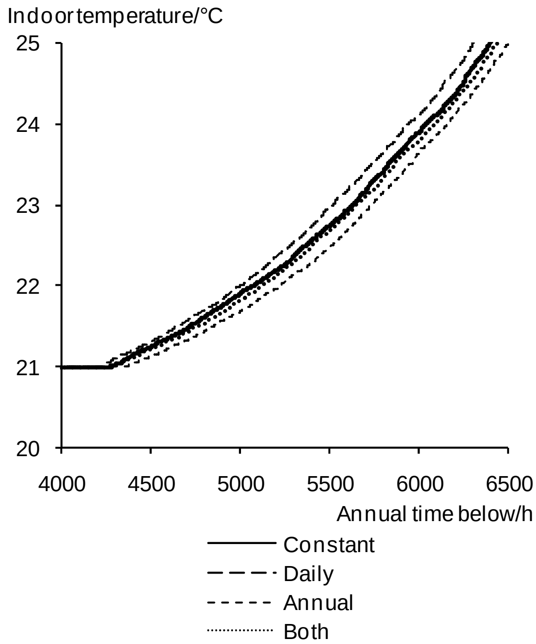

Figure 4 Permanence of indoor temperatures simulated with constant, daily, annually and both daily and annually varied use of household electricity respectively.

Figure 4 gives the accumulated indoor temperature for the different cases of the default theoretical building. Figure 5 through Figure 10 presents the annual space heating demand simulated with a constant household electricity use and the relative difference to the space heating demand simulated with daily, annual and booth daily and annual variations in use of household electricity for different parameters. The relative difference shown is the value with a certain type of varying use of household electricity minus the value with constant use of household electricity. This difference is then divided by the value with constant use of household electricity.

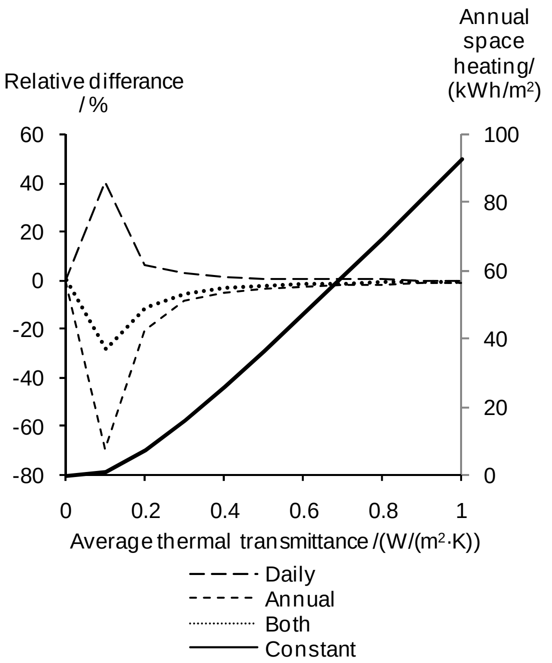

Figure 5 The annual space heating demand with constant load and the relative difference with daily, annual and both daily and annual variations respectively for varying average thermal transmittance.

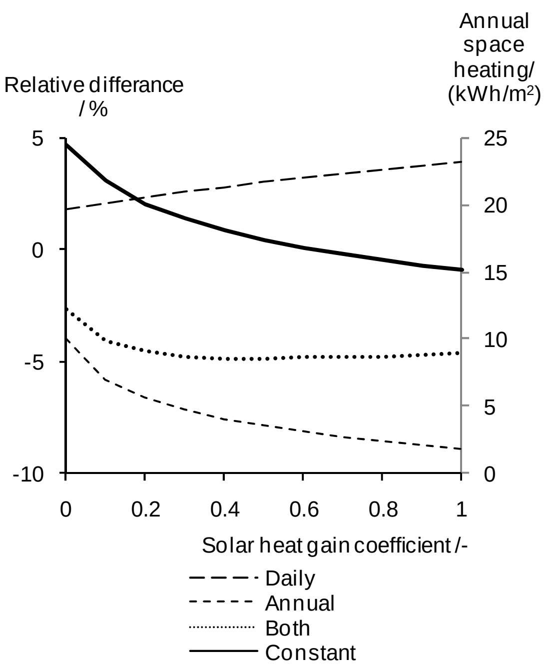

Figure 6 The annual space heating demand with constant load and the relative difference with daily, annual and both daily and annual variations respectively for different solar heat gain coefficients.

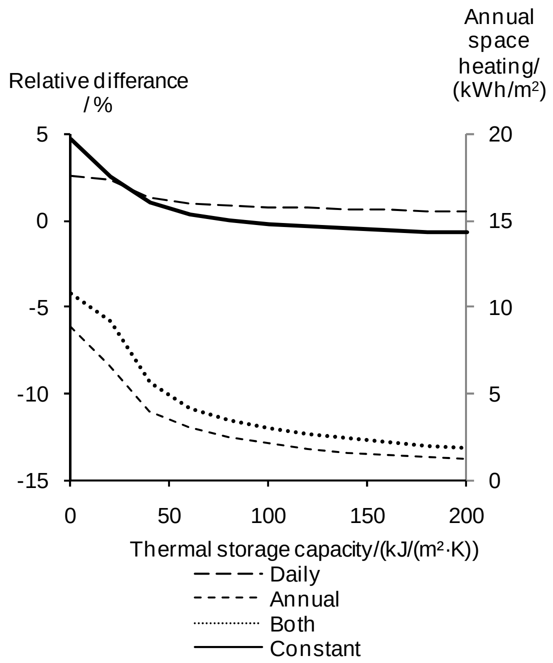

Figure 7 The annual space heating demand with constant load and the relative difference with daily, annual and both daily and annual variations respectively for varying thermal storage capacity.

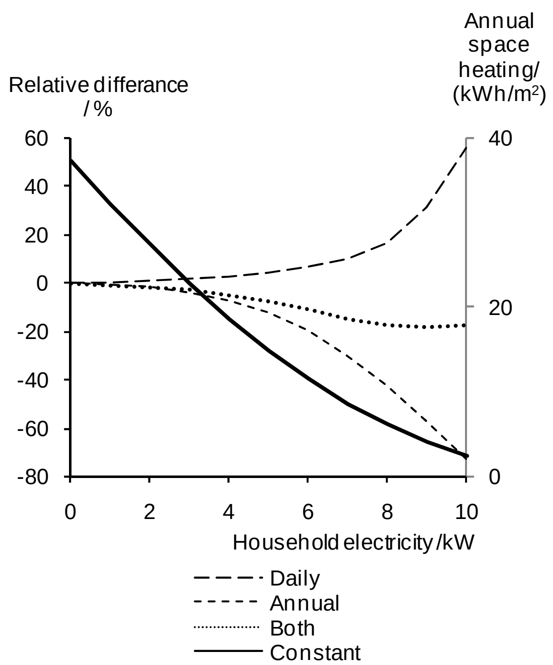

Figure 8 The annual space heating demand with constant load and the relative difference with daily, annual and both daily and annual variations respectively for varying average household electricity power. The default case was 4110 W.

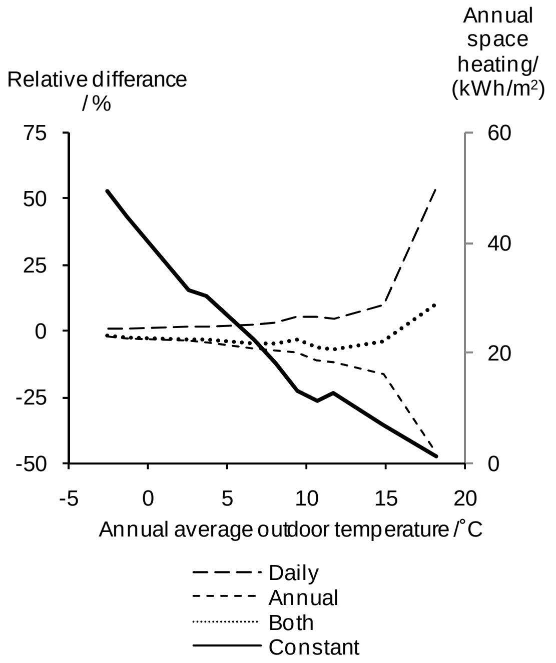

Figure 9 The annual space heating demand with constant load and the relative difference with daily, annual and both daily and annual variations respectively for some outdoor climates with varying annual average outdoor temperatures.

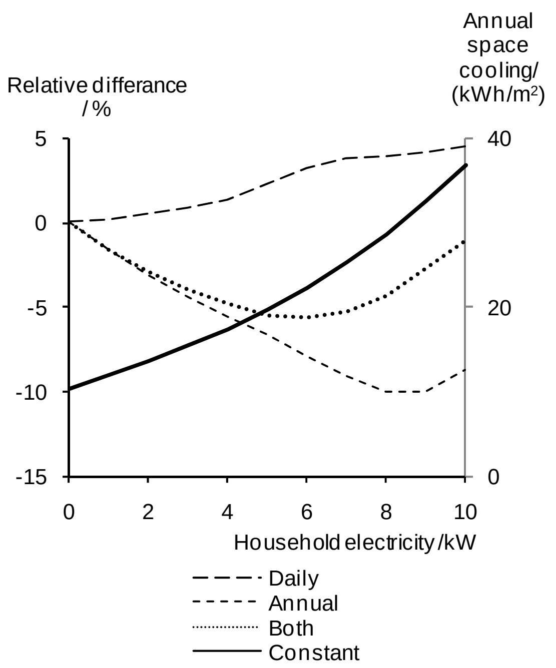

Figure 10 The annual space cooling demand with constant load and the relative difference with daily, annual and both daily and annual variations respectively for varying average household electricity power.

DISCUSSION AND CONCLUSIONS

For all tested parameters, the simulated space heating demand increased with variations during the day in use of household electricity compared to constant use. A reason for this is that the household electricity power is lower during nights than days when the temperature typically is lower and there is no solar radiation. With household electricity powers varying during the year, the space heating demand was lower in all cases. This can be explained by the fact that the use of household electricity is higher when the temperatures are lower and the solar radiation is lower, which means that the benefit from the internal load is more frequent.

If the use of household electricity was assumed to vary during both the day and the year, the space heating decreased in all cases compared to the case with constant use of household electricity. The difference between the decrease for annual variations only and combined variations is close to the difference between the value of the space heating in the case with use of household electricity varying over the day and constant use. The number of hours with high indoor temperature for the different cases of variations reflects the same effect. For example, the lower use of household electricity during summer than during winter, decreases the number of hours with a certain high indoor temperature. It should be pointed out that no airing was modeled, which resulted in some unreasonably high indoor temperatures.

Regarding the parametric study, the thermal transmittance has high impact on the absolute space heating demand. At low thermal transmittance, the relative difference for varying load patterns is high, but the absolute difference between the space heating demand for the case with variations both over the day and year is highest at a thermal transmittance of 0.3 W/(m²·K).

When the solar heat gain coefficient is increased, the space heating demand with daily variation depends more on the solar heat gain coefficient than the annual variation does. Varying the thermal storage capacity shows that the heat storage is effective over a day and not over a year. Regarding the outdoor climate, the absolute influence from daily variations in Los Angeles is smaller than for any other location, due to the fact that the difference between winter and summer outdoor climate is smaller and that there is many hours close to the outdoor temperature where there is power balance without space heating power.

The influence on the space cooling demand from varying load patterns over both day and year compared to constant load increases with increasing use of household electricity at low use of household electricity. On the other hand it decreases with increasing use of household electricity at high use of household electricity due to the fact that there will be a cooling need a large part of the year.

The variation in use of household electricity, during the day and the year, are not negligible, and to make accurate energy calculations, the variations should be taken into account. This is particularly important when modern low energy buildings are designed since excess heat from household electricity is a major heating source. The presented yearly and daily load patterns can be used to simulate internal heat gains from household electricity when energy calculations for low energy buildings are made, but there is need for more measurements regarding occupancy patterns which reflects one of the remaining parts of the power balance of a building.

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