Electricity use in two low energy office buildings in Norway

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Introduction

In order to perform a proper building energy labeling, it is important to document and measure building energy use. Documentation, measurements, and quality control of building energy performance would increase in importance as new concepts are implemented and further step towards zero emission building are taken. Lifetime commissioning (LTC) has been recognized as a quality control tool for building energy performance through the entire system lifetime [1-3]. The relationship between the standards developed under the European *Energy Performance of Buildings Directive* (EPBD) umbrella and LTC is explained in [4].

Measurement and monitoring of the building energy performance can be challenging and expensive depending on the monitoring platform, the monitoring platform ownership, the age of the building, when the building monitoring platform was installed, etc. Due to the above mentioned importance of the energy measurement, the research work on building performance energy monitoring has initiated different activities, Annex 47, Cost-effective Commissioning for Existing and Low Energy Buildings [5] and Annex 53, Total Energy Use in Buildings: Analysis and Evaluation Methods [6].

The aim of this article is to show the total electricity use in two low energy office buildings in Norway. A few years of energy monitoring data are presented. The research work on these low energy buildings has been reported to Annex 53.

Building descriptions

Detailed data have been collected for two low energy office buildings in Norway through the research project Lifetime commissioning for energy efficient operation of buildings [7]. The detailed building data were collected by using LTC procedures, which are explained in [4]. These two analyzed buildings are located in Trondheim and Stavanger. Both buildings are role model buildings for the Norwegian Energy Efficiency Agency [8].

The first building is a low energy office building in Trondheim, Norway, with a heated area of 16 200 m². The design outdoor temperature is -19°C, while the average annual outdoor temperature is 6°C. The building has been in use since September 2009. Since then the number of occupants has been increasing. Eight variable air volume (VAV) systems were installed in the building with a maximum air volume from 12 500 m³/h to 22 000 m³/h. Specific air flow rate was 8.9 m³/h/m². A brief overview of the installed VAV systems is given in **Table 1**. The overview gives the performance of the installed ventilation systems, which includes air flow rate, fan power, and specific fan power of the entire ventilation system (SPF_e).

All the ventilation systems in **Table 1** were VAV systems with modern Static Pressure Reset Demand Control Ventilation (SPR-DCV) that is frequently called *optimized* VAV [9]. In the low energy office building in Trondheim heating was provided by radiators, while cooling of the IT rooms was provided by fan-coils. The heating energy for ventilation, space heating, and domestic hot water was supplied by district heating and heat pumps. There were two heat pumps installed. The first heat pump was a reversible heat pump providing part of the heating energy for ventilation in the winter period, while in the summer period the evaporator of the heat pump provided cooling for ventilation.

Table 1. VAV systems in the office building in Trondheim.

System ID	Air flow rate		Fan power		SFP_e (kW/(m³/s))
	Supply fan (m³/h)	Exhaust fan (m³/h)	Supply fan (kW)	Exhaust fan (kW)	
36.01	22 000	22 000	7.47	6.89	2.17
36.02	22 000	22 000	7.47	6.89	2.17
36.03	20 000	20 000	6.30	5.83	2.01
36.04	20 000	20 000	6.30	5.83	2.01
36.05	15 000	15 000	4.68	4.28	1.97
36.06	18 000	18 000	6.50	5.88	2.30
36.07	14 500	14 500	5.07	4.53	2.21
36.08	12 500	12 500	3.97	3.52	1.99

Table 2. Ventilation systems in the office building in Stavanger.

Ventilation system	Air flow rate		Fan power		SFP_e (kW/(m³/s))
	Supply fan (m³/h)	Exhaust fan (m³/h)	Supply fan (kW)	Exhaust fan (kW)	
360.010	90 000	90 000	38.8	41.6	4.64
360.011	75 000	75 000	32.6	32.7	4.69
360.012	90 000	90 000	38.8	41.6	4.64

This heat pump is a water/air heat pump and it supplies eight heating/cooling coils in the air handling units given in **Table 1**. Depending on the evaporation and condensation temperatures, maximum heating capacity of the condenser can be 550 kW, and maximum compressor power 150 kW. This heat pump has three compressors, which are step-wise controlled. The second heat pump was a cooling plant which provided cooling for IT rooms, while the condenser heat was utilized to support heating. This cooling plant has a maximum heating capacity of the condenser of 260 kW, maximum compressor power of 60 kW, and maximum evaporator load of approximately 200 kW depending on the evaporation and condensation temperatures. Detailed information of the first case building can be found in [10].

The second case building is located in Stavanger, Norway, where the design outdoor temperature is -9°C, while the average annual outdoor temperature is 7.5°C. This building has been in use since June 2008 and is rented as an office building. The heated area of the building is 19 623 m² and it was designed for 1 200 occupants. Currently, there are about 1 000 occupants. The ventilation system consists of three variable air ventilation systems, where the maximum air volume is 90 000 m³/h for two ventilation systems and 75 000 m³/h for the third system. A brief overview of the installed ventilation system is given in **Table 2**. Specific air flow rate was 12.9 m³/h/m².

The three VAV systems operate with constant air pressure. The higher SFP_e in **Table 2** could be explained by an additional pressure drop in double façade. In the second case building, the fresh air was supplied to offices and then extracted via a central atrium. The extracted air was used for heat recovery in ventilation and finally extracted through double façade. Heating is provided by radiators and ceiling panels, while cooling is provided by fan-coils. Heating energy for ventilation, space heating, and domestic hot water is supplied by district heating and supported by condenser heat. Cooling energy is supplied by two cooling plants. Heat realized from the cooling plant condensers is used as additional energy for heating. This way, the cooling devices are at the same time heat pumps. The installed heat pumps are frequency controlled. The installed cooling capacity of one heat pump is 200 – 600 kW and the compressor power 50 – 130 kW, while the cooling capacity of the second heat pump is 420 – 1200 kW and the compressor power 120 – 300 kW. Detailed information of the second case building can be found in [11].

Hourly electricity use

The first case building is equipped with a high number of energy meters, which include measurement of electricity for light, appliances, ventilation, etc. The second case building has a lower number of energy meters, but a higher data quality of the energy measurements. Before the hourly profiles of electricity use are presented, the issues in measurements and data logging are explained.

Issues in energy measurement

The first case building located in Trondheim is equipped with 74 energy meters, where 66 meters are for electricity and eight meters are for heating and cooling measurements. The technical platform for the energy measurement was separated from the building energy management system (BEMS). Therefore, there is no history of the energy measurements in the BEMS of the first case building. These energy measurements were transferred to an energy savings company database. The use of two different technical platforms for building management and energy monitoring, where energy consumption had not been logged in the BEMS, could be an issue. This issue can be explained with poor functional integration, because the labeling of the system and components in the energy service company was slightly different than in BEMS and it might be that what was shown as the compressor electricity use was that of another equipment. Specifically, it can be difficult to estimate energy use of equipment that has its own control unit. Such equipment can be heat pumps, cooling plants, and air handling units. Even thought equipment manufacturers guarantee good data transfer from the equipment control unit to the BEMS, there can be many problems in the data transfer. Challenges in heat pump performance estimation are reported in [12], while other issues and data reliability are explained in [13].

Electricity use

The hourly profile of the electricity use in the office building in Stavanger for one week in September 2009 is shown in **Figure 1**. In Figure 1, electricity use profiles are summed up. The electricity use was independent of the outdoor temperature, but instead determined by the building users. In average over the year, hourly electricity profiles were varying from 180 kW during non-occupied periods to 550 kW during occupied periods. By comparing hourly electricity use profiles over several years, it was found that the hourly electricity profiles were quite similar as in **Figure 1**.

In **Figure 1** it is possible to notice that both fans and cooling plant contribution to the total electricity use was low. Actually, electricity use was dominated by the use of appliances such as PCs. The reason for the low energy use of the cooling plant was that the heat pumps were oversized (for the current purpose) as explained in [14]. Most of the year, one heat pump was working and the second heat was shut down. For example, in 2009 both heat pumps were in use only 116 hours. In August 2011, most of the PCs in the building were replaced by laptops and the operation time of the ventilation system was decreased by one hour. These measures resulted in decreasing the hourly electricity profiles to approximately 160 kW during non-occupied periods and to 460 kW during occupied periods. Results of these measures on the total electricity use will be shown in the next Section.

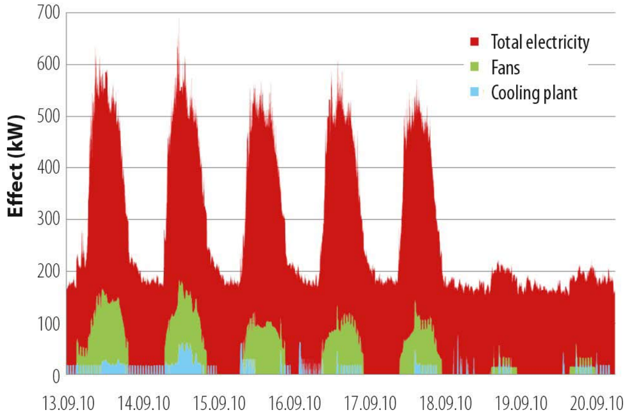

Figure 1. Hourly profiles of electricity use in the office building in Stavanger.

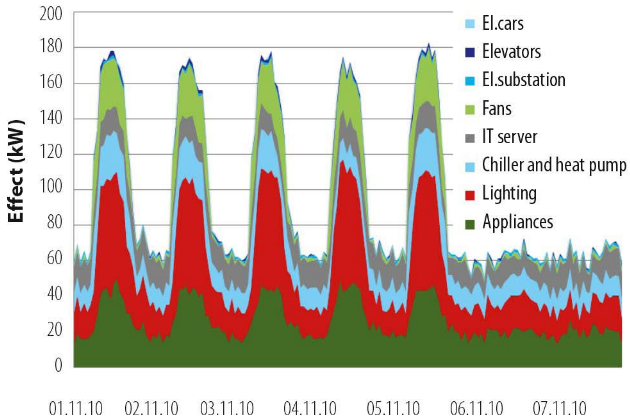

Figure 2. Hourly profiles of electricity use in the office building in Trondheim.

The hourly profile of the electricity use in the office building in Trondheim for one week in November 2010 is shown in **Figure 2**. The electricity use in **Figure 2** was summed up by the purpose of the electricity use.

In **Figure 2** *El. substation* implied electricity for circulation pumps and additional devices necessary for the substation operation. In the case of the office building in Trondheim, electricity use was also independent of the outdoor temperature, but instead determined by the building users. In average over the year, hourly electricity profiles were varying from 70 kW during non-occupied periods to 200 kW during occupied periods. The electricity consumption of the fans was determined by the building users as it is possible to notice in **Figure 2**. The VAV systems were controlled by presence sensors, meaning the fans were operating only when there were users in the building. The electricity consumption of the heat pump and chiller was quite constant as shown in **Figure 2**. The reason for this was that the heat pump

Table 3. Specific electricity use in the office building in Trondheim.

Purpose	Appliances	Light	Cooling plants	IT server	Fans	Substation	Elevators	El.cars
Specific use (kWh/year/m^2)	15.1	14.3	8.4	6.4	6.0	1.0	0.3	0.1

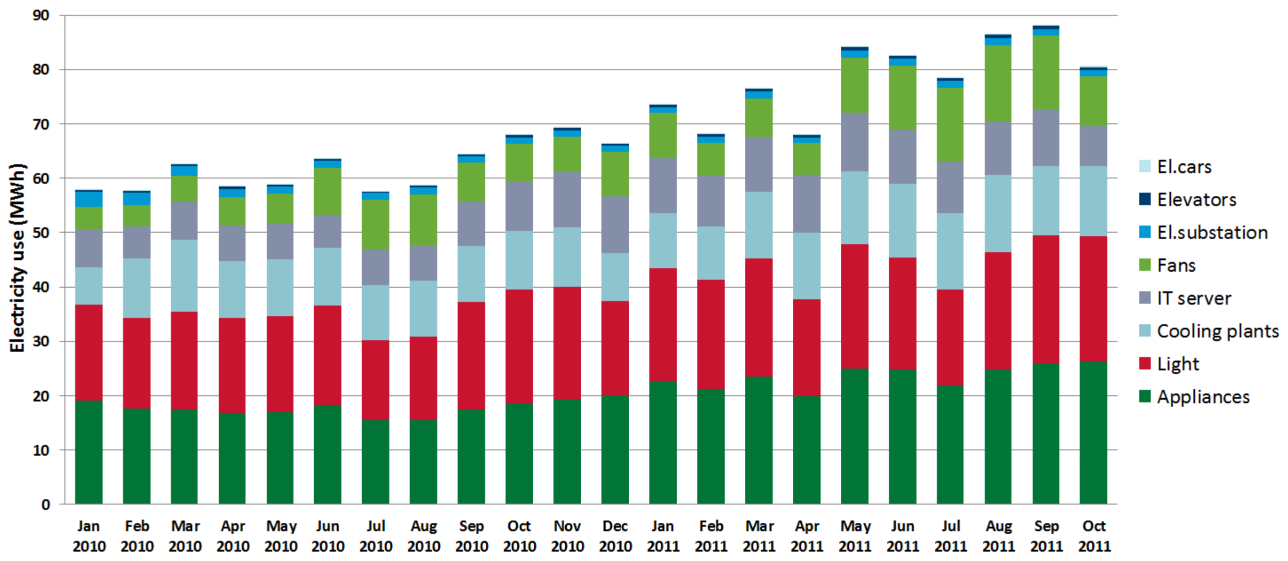

Figure 3. Total electricity use for the office building in Trondheim.

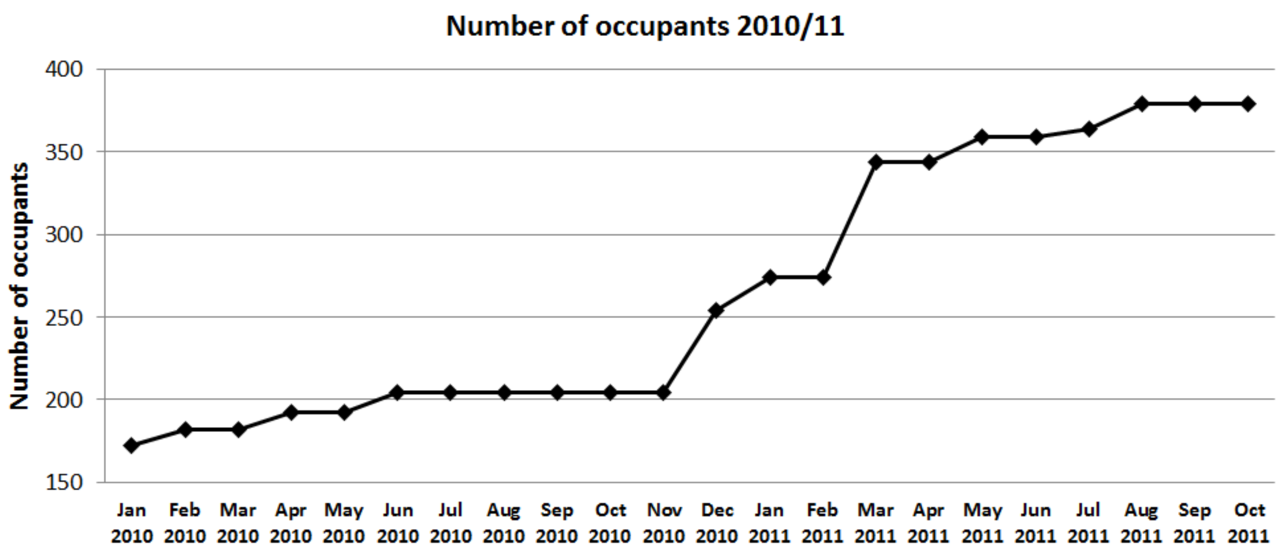

Figure 4. Number of occupants in the office building in Trondheim.

and chiller were oversized and the compressors were in operation all the time at the lowest step and thereby using constant power. In **Figure 2**, it is possible to notice that appliances, lighting, chiller, heat pump, and IT server contributed mostly to the hourly profiles during non-occupied periods as well as during occupied periods.

Total electricity use

The total electricity use for the office buildings in Trondheim and Stavanger are shown in **Figure 3** and **Figure 5**, respectively. Recall that the number of occupants increased in the office building in Trondheim, as shown in **Figure 4**.

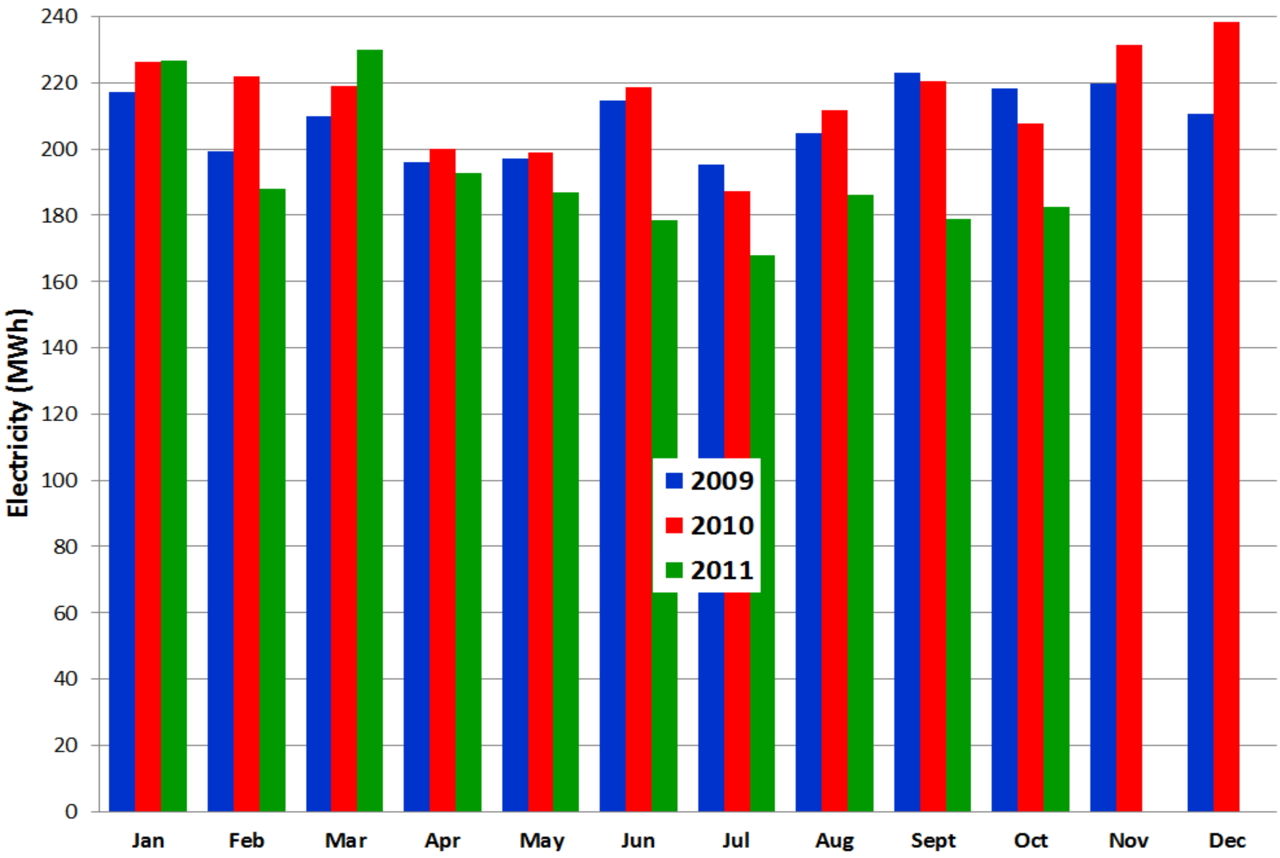

Figure 5. Total electricity use for the office building in Stavanger.

By comparing the results in **Figure 3** and **Figure 4** it is possible to notice that the total electricity use increased with an increase in the number of occupants. Further, in **Figure 3**, it is noticeable that appliances, light, cooling plants, and electricity for the IT server contributed the most to the total electricity use. This could also be assumed based on the hourly profiles in **Figure 2**, because appliances, light, cooling plants, and IT server were dominating in the hourly profiles. Finally, specific electricity use for the office building in Trondheim per m^2 is given in **Table 3**. The results in Table 3 are sorted based on the highest specific use.

The total electricity use over three years for the office building in Stavanger is shown in **Figure 5**. Two energy saving measures were implemented in this building since August 2011, as mentioned before. These measures decreased the hourly electricity profiles and resulted in a 30 MWh decrease in the total monthly electricity use.

Conclusions

The article presented electricity use in two low energy office buildings in Norway. Appliances, light, cooling plants, and IT server seemed to dominate to the total electricity use of the low energy buildings. The reasons for the relatively high electricity use of the cooling plant were oversizing plant and the choice of plant unsuitable for its current purpose. Results for the office building in Trondheim showed that the *optimized* VAV system resulted in an electricity use for the fans of 6 kWh/year/m^2. Results on the electricity use in the office building in Stavanger showed that simple energy efficiency measures gave a definite decrease in the total electricity use. The results of our research on LTC showed the importance of proper energy measurements to enable proper decision making, energy labeling, and proof of concepts.

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References

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