Comfort cooling and solar power – a perfect match?

ELSA FAHLÉN
PhD. Energy systems
NCC Construction Sweden AB
elsa.fahlen@ncc.se

HENRIK OLSSON
M.Sc. Eng.
NCC Construction Sweden AB
henrik.t.olsson@ncc.se

NIKLAS CHRISTENSSON
Energy Controller
Eksta Bostads AB
niklas@eksta.se

In buildings where there is a demand for comfort cooling, electricity-driven compression chillers combined with photovoltaics may be an interesting solution to achieve net zero in energy use for cooling thanks to the potential simultaneity in demand and generation of electricity during summer. Using the first passive house-certified retirement home in Sweden as a case, this paper presents and evaluates how well the load demand and the solar power generation coincide hour by hour.

Keywords: solar power, photovoltaic, comfort cooling, load matching, passive house, net zero energy building, low energy building, retirement home.

The EU Directive 2010/31/EU on the energy performance of buildings implies that in the next few years all new buildings or existing buildings that are subject to major renovation have to be so called net zero energy buildings (December 31 2018 for public buildings and December 31 2020 for other buildings) [1]. Apart from having a very low energy use, a high share of the energy used in these buildings should come from renewable energy sources, including renewable energy sources on site or nearby.

A lot of effort has been made to reduce the use of energy in Swedish buildings, especially the energy used for heating. However, when the heat demand is lowered due to improved insulation, the need for cooling increases. Apart from the cooling demand due to climatic conditions, growing population and higher living standards, increased numbers of technical appliances such as lighting, printers and computers also increase the need for cooling. In warmer countries, the peeks in the power demand are partly due to the use of electricity-driven cooling facilities [2]. Within the European countries, the growing number of cooling facilities increases the already strong daily variations in electricity demand and thereby also the need for peak load power generation [3] which is associated with high operating costs and CO_2 emissions.

During summer, power demand for comfort cooling and solar power generation coincide well since both are related to the solar radiation. Therefore, electricity-driven compression chillers coupled with photovoltaics (PVs) may be an interesting solution to achieve net zero in energy use for comfort cooling. However, even if the electricity used for cooling may easily be covered by solar power from a PV plant on a monthly basis, is there a perfect match also on an hourly basis?

Objective

This paper presents and evaluates how well the load demand and the solar power generation coincide hour by hour and how this affects the annual coverage rate and the amount of surplus power generated. The study is a case study of electricity-driven compression chillers and PVs located at the retirement home in the passive house area Vallda Heberg, see the upper left corner in **Figure 1**.

Vallda Heberg passive house residential area

In the residential area Vallda Heberg, in the municipality of Kungsbacka in Sweden, all buildings are designed, built and certified according to the Swedish passive house standard Feby [5]. The municipal housing company, Eksta Bostads AB, and the construction company, NCC Construction Sweden AB, have built the passive house area which consists of single family houses, apartment blocks, terrace houses, a retirement home and commercial buildings, see **Figure 1**.

These highly insulated buildings with heat recovery have a very small energy demand for space heating. The small amount of energy needed for space heating and domestic hot water is supplied by 100% renewable energy generated on site and which is distributed in a local district-heating network. The goal is that as much as 40% of the annual energy use for domestic hot water and for space heating will come from solar thermal collectors. The rest of the heat needed is supplied by a local wood pellet boiler.

The first retirement home certified as passive house in Sweden

The retirement home in Vallda Heberg is the first passive house certified retirement home in Sweden. It has a net floor area (Atemp) of 7,280 m² and consists of 64 small apartments divided into six departments on three floors. The retirement home also has social areas and activity rooms for the residents, a kitchen and a restaurant and office for the employees.

Residents in retirement homes are more sensitive to higher temperatures during the summer season. In order to reduce problems with over-temperatures during summer in the retirement home in Vallda Heberg, solar shading has been mounted above the windows. Still there is a small demand for comfort cooling during the summer and, therefore, a cooling system has been installed.

In order to cover a part of the electricity used in the retirement home, 545 m² of photovoltaics have been installed on the roof, see **Figure 2**. The goal is that at least 40% of the total building service electricity and 100% of the electricity used for comfort cooling, will be met by solar power on an annual basis.

Figure 1. Passive house residential area Vallda Heberg during construction [4].

Figure 2. Photovoltaics installed on the roof of the retirement home in the passive house area Vallda Heberg [6].

Technical description of the heating, cooling and power system

The calculated annual specific energy use is 50 kWh/m² A_{temp}. This includes energy use for space heating and domestic hot water, electricity use for lighting, pumps, fans and elevators and solar power generated (as a negative energy use). In the simulation of the building energy performance, the temperature is allowed to vary between 22°C and 25°C.

The performance of the PVs and the compression chillers installed are described in **Table 1**.

Measurements and limitations

The solar power generation has been measured since August 2013. Measurements of electricity in the retirement home building started in the summer of 2013. The first tenants moved in October 2013 and the retirement home was not fully occupied before the beginning of 2014. Therefore, it is problematic to get a full year of representative data concerning the electricity use in the building. Detailed hourly measurements [kWh] for the building are listed below.

- Solar power generation from the PVs.
- Electricity use for comfort cooling.
- Electricity use for buildings services, including electricity use for comfort cooling and kitchen cooling and electricity for lighting (of common spaces), pumps, fans and elevators.
- Other activity-related electricity use in the building, including electricity to the retirement home activities such as the industrial kitchen, social areas, office areas.

Monthly surplus electricity delivered to the grid has been provided by the electricity retailer.

Note that no measured values have been statistically adjusted due to the outdoor temperature and solar radiation and their duration for a normal year. The summer of 2014 was warmer than a normal summer in Sweden, and can, in that sense, not be considered as representative for a normal year. This means that it is not straightforward to compare these values with design values.

Results and analysis

Coverage rates on an annual and monthly basis

The first year of measurements (Sep 2013 to Aug 2014) show that 72.8 MWh (10.0 kWh/m^2,year) solar power was generated in the PV plant, that 5.3 MWh (0.7 kWh/m^2,year) electricity was used for cooling and that 130.9 MWh (18.0 kWh/m^2,year) electricity was used for all building services (including comfort cooling). Thus, there is no doubt that the solar power generation at the retirement home reaches its targets of 100% coverage rate of the power used for cooling and 40% coverage rate of the power used for all buildings services on an annual basis. In fact, as much as 56% of the power used for all building services was met by solar power using measurements for the first year. The solar power generation from the PV plant over the year was higher than estimated (134 instead of 113 kWh/m^2 PV).

Table 1. Technical performance of cooling and PV system.

Photovoltaics	
Photovoltaics installed	Hanwha SolarOne HSL 60 Poly
Installed capacity	330 modules, 245 W/module, total PV area 545 m^2 mounted at 6°
Estimated power generation	61 500 kWh, year 112.8 kWh/ m^2, year
Compression chillers	
Chillers installed	Two Mitsubishi PUHZ-P200YHA3 chillers and one Mitsubishi PUHZ-P250YHA3 chiller
Installed cooling capacity	60 kW (19×2 kW × 2 and 22 kW)
Energy efficiency ratio according to the manufacturer	2.6 for both chiller models
Energy efficiency ratio according to Eurovent (35°C outdoor temperature)	3 for both chillers (3.04 for PUHZ-P200YHA3 and 3.01 for PUHZ-P250YHA3) [7]

Using monthly instead of annual measurements, still as much as 97% of the solar power generated can be used for building services. In other words, the remaining power generated is very small compared to the use of building service electricity on a monthly basis. Calculated coverage rates based on total solar power generated and total electricity use for comfort cooling and building services each month are presented in **Table 2**. The coverage rates for comfort cooling are 100% over the entire year, whereas the share of solar power used for building services varies from a few percentages up to a full coverage.

Coverage rates on an hourly basis

According to national energy requirements in Sweden, only the power generated that can be used within the building for building services can reduce the specific energy use of the building [8]. The measurements of the electricity used for building services and the solar power generated each month during the first year of operation are presented in **Figure 3**. In order to see how much electricity was used for comfort cooling each month, the electricity used for building services (the left column in **Figure 3**) is split into electricity used for cooling and electricity used for other building services. The measurement results show that electricity used for building services seems to be quite constant during the year, except for the summer months when the need for cooling increases.

The measurements of the power generated in the PV plant are presented in the right column in **Figure 3**. In order to see how much of this electricity that "instantly" (on an hourly basis) can be used within the building, the column is split into electricity delivered to different appliances and services. They are prioritised as follows: electricity to the comfort cooling plant, to other building services as well as to other services and appliances in the retirement home. The remaining power generated is delivered to the grid.

The monthly values of surplus electricity delivered to the grid show that only a very small percentage of the electricity generated (6%) cannot be used within the building on an hourly basis. Evidently, the combination of building service electricity – for cooling and other purposes – and activity-related electricity seem to provide a very good match to the solar power generation in this particular case. However, a substantially smaller percentage of the total solar power generation can be used when only building services are accounted for (63% compared to 94%).

The coverage rate, the share of electricity for building services that comes from the PV plant, varies between 3% and 60% over the months when considering the hourly use of electricity, as shown in **Table 2**. When hourly load match of generation and use is taken into account, the coverage rate on an annual basis will be considerably lower than if basing the coverage rate on annual or monthly measurements. The annual coverage rate for building services based on hourly measurements is 35%, which is still close to the 40% target set on an annual basis.

Table 2. Coverage rates of solar power used for comfort cooling (CC) and building services (BS incl. CC) based on monthly and hourly measurements. Note that there is a lack of measurements for June 2014, which has been assumed to have coverage rates equal to the ones found in May.

	Coverage rates on a monthly basis		*Coverage rates on an hourly basis*	
Month	CC	BS (incl. CC)	CC	BS (incl. CC)
Sep-13	100%	73%	49%	37%
Oct-13	100%	28%	51%	23%
Nov-13	100%	11%	49%	11%
Dec-13	100%	3%	31%	3%
Jan-14	100%	6%	28%	6%
Feb-14	100%	16%	34%	14%
Mar-14	100%	52%	26%	36%
Apr-14	100%	82%	58%	47%
May-14	100%	100%	85%	60%
Jun-14	*100%*	*100%*	*85%*	*60%*
Jul-14	100%	84%	88%	58%
Aug-14	100%	74%	87%	51%

Using hourly measurements, instead of monthly or annual measurements, when calculating the annual coverage rate of the power used for all comfort cooling,

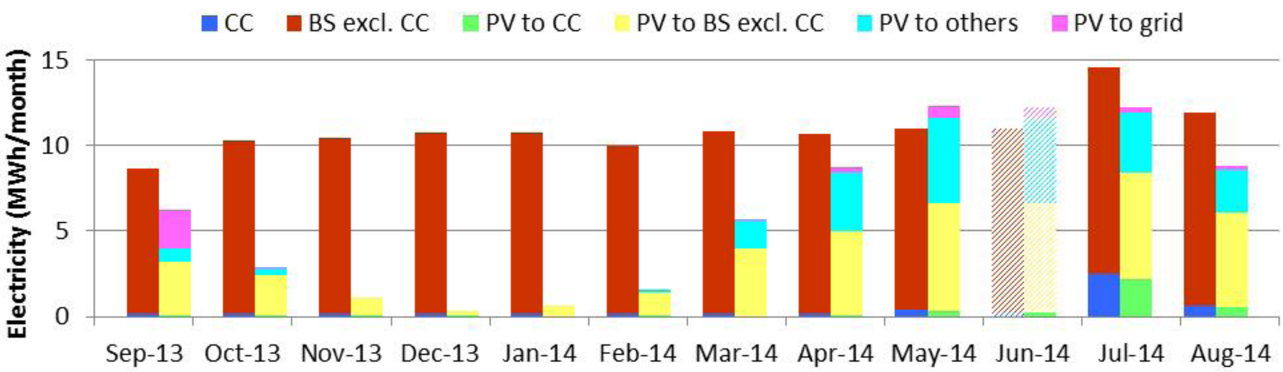

Figure 3. Monthly use of electricity (left columns) for comfort cooling (CC) and for other building services (BS excl. CC) as well as monthly generation of solar power in the PVs (right columns). The power generation is divided into four different destinations based on the hourly load match and the following prioritisation of usage categories: PV to comfort cooling (PV to CC), PV to other building services (PV to BS excl. CC), PV to others and PV to grid. Note that there is a lack of measurements for June 2014, which has been assumed to have PV generation and coverage equal to the ones found in May.

results in a coverage rate of 75% instead of 100%. Nevertheless, due to the intermittent nature of the solar power generation, it would be practically almost impossible to supply 100% of any load over a short time without the possibility of storage. Only a short moment of mismatch means that the goal cannot be reached. Solar power coverage rates for the comfort cooling electricity based on hourly load match are presented in **Table 2**. Highest coverage rates during the summer reach almost 90%, while they are much lower during the winter months.

It should be noted here that the winter coverage might not be representative, since the cooling need is so small. The measurements registered for the comfort cooling are only in full kWh. During the winter it can take many hours for the electricity meter to count one full kWh. If the meter changes to next kWh during the night when no solar power is generated, the last kWh will be counted as not covered even though most of it could actually have been supplied by solar power earlier in the day. This may lead to a probable underestimation of the yearly coverage on an hourly basis.

Detailed comparison of power demand and power generation

Figure 4 presents the measurements of solar power generation, electricity used for comfort cooling and all building services for a week in July 2014. **Figure 5** presents the calculated net electricity when comparing solar power generated and total building service electricity for the same week. At first glance, it is clear that the maximum power generated at midday by the solar PV is more than enough to cover the peak load of the cooling and other building services for all days of this week. There is also a correlation between the need for cooling and generation of solar power. There is a tendency for the comfort cooling to linger on late in the evenings when the solar power generation has decreased, which is one important reason for mismatch in this system.

Even though there is a correlation between them, the solar power generation and the need for cooling are not always present simultaneously. Different types of weather are sources of mismatches, e.g. warm, cloudy summer days when need for cooling might be present but solar power generation is low.

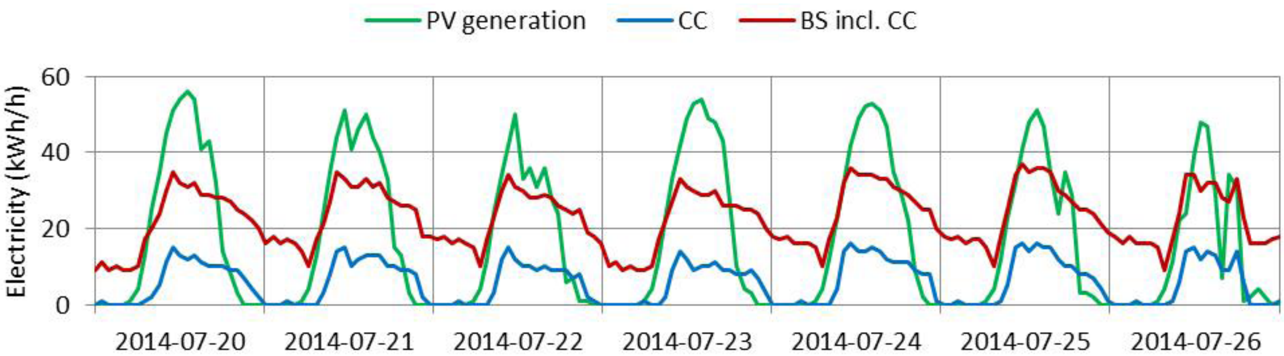

Figure 4. Hourly production of solar power and hourly use of electricity for cooling and of total building service electricity (including power used for cooling) one week in July 2014.

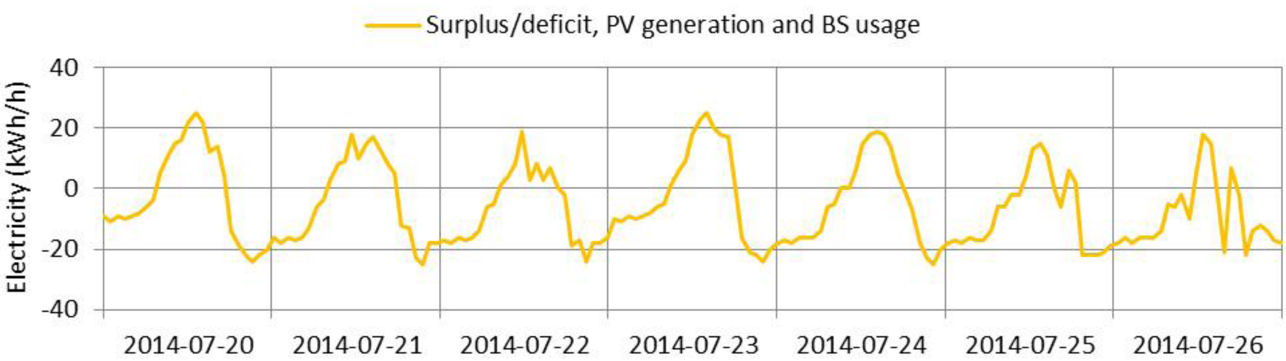

Figure 5. Hourly net production of solar power, defined as solar power production minus total building service electricity (including electricity for cooling) one week in July 2014. A positive result means overproduction and a negative result means there is need for additional electricity from the grid.

Conclusions

Solar power and comfort cooling – a perfect match?

This paper presents and evaluates how well the load demand and the solar power generation coincide hour by hour and how this affects the fulfilment of the coverage rate targets as well as how it affects the amount of surplus power generated in the PV plant at the retirement home in the passive house area Vallda Heberg, in Sweden.

According to the results presented in this paper, there is no doubt that the solar power generation at the retirement home reaches its targets the first year – 100% of the power used for cooling and 56% of the power used for all business services were met by solar power on an annual basis. If hourly measurements are instead used when calculating the coverage rates, they are considerably lower but are still as high as 35% and 75%, respectively. Since a large share of the rest of the electricity generated each hour can be used for other appliances and services in the retirement home, only 6% of the solar power generated was delivered to the grid, according to measurements for the first year.

In this particular case, the presence of electricity-driven chillers does not have a large influence on the share of solar power in electricity used for building services on an annual basis. This is explained by the relatively small need for electricity for comfort cooling compared to the total building service electricity.

Is solar cooling in net zero energy buildings a good idea?

Of course, measures to reduce the need for comfort cooling are the first actions to be taken when designing a building. In cases where there is still a limited comfort cooling demand, there is a good potential of meeting this demand by solar power. Using the first passive house-certified retirement home in Sweden as a case, this paper illustrates that a comfort cooling plant combined with photovoltaics could be an interesting solution to achieve net zero or near zero in energy use for comfort cooling thanks to the high correlation in power generation and use of electricity.

As shown in this study, the answer if solar power used for comfort cooling could be a good solution for achieving net zero energy use for cooling depends on the definition – if it refers to net zero energy use on an annual basis or an hourly basis. ■

Acknowledgements

This study is part of a demonstration project of the entire passive house area in Vallda Heberg which is focused on the evaluation of energy performance, indoor climate and energy system solution. The authors want to acknowledge the financers of this project: LÅGAN – a collaborative project between the Swedish Construction Federation, the Swedish Energy Agency, Region Västra Götaland, Formas and others; SBUF – the Swedish construction industry's organisation for research and development; NCC Construction Research and Development. Thanks to Stephen Burke, NCC Construction Sweden AB, for reviewing the paper.

References

[1] DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings (recast).

[2] District cooling, balancing the production and demand in CHP, IEA District Heating and Cooling Annex V, Report 1999:T2, published by November <http://www.iea-dhc.org/scanned_brochures/8DHCT99-02LR.pdf> (25.01.12).

[3] Ecoheatcool, Work packages, Brussels: Euroheat and Power, 2006, <http://www.euroheat.org> (16.10.14).

[4] Photograph by Bergslagsbild AB.

[5] FEBY - Forum för energieffektiva byggnader, Specification of requirements for passive houses (in Swedish), <http://www.nollhus.se/rapporter> (16.10.14).

[6] Photograph by Anders Ljungberg.

[7] Eurovent certified performance, <http://www.eurovent-certification.com> (16.10.14).

[8] Swedish Building Regulations (Boverkets Byggregler Avsnitt 9 BFS 2011:6 ändrad t.o.m. BFS 2014:3, in Swedish), Boverket – the Swedish National Board of Housing, Building and Planning, <http://www.boverket.se> (21.10.14)..