Load management of nZEB - an important element for future energy supply and implementation of renewable energy sources

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This article describes two projects in nZEB housing including heat pumps, where the aim was to create and operate buildings which meet future demands on energy efficiency and living comfort. The guiding principle for the development and operation of these buildings is that an optimal use of solar energy should be implemented. This results in a higher energy gain than the buildings' needs. Both projects use control strategies to increase the use of photovoltaic electric power and reduce grid consumption. In order to reach this target the energy concepts make use of flexible components, i.e., heat pumps in combination with thermal and electrical storages. Thus, a high share of solar electricity usage can be achieved.

Introduction

This article describes two building projects in nZEB housing, where the aim was to create and operate buildings which meet future demands on energy efficiency and living comfort.

The houses described are a single family house "Berghalde" and the terraced houses "Herzo Base". They aim to show the energy potential of EnergyPlus Buildings for reaching a high degree of photovoltaic (PV) self consumption and contributing to stabilize the grid. The houses are characterized by a high PV production and a low energy demand. This results in a positive energy balance, on an annual basis. The energy concepts for both types of buildings are based on the control of heat pumps in combination with PV, as well as the application of thermal and electrical energy storages.

Through a sustainable energy concept and a high share of solar self usage, the presented EnergyPlus-Houses provide part of the solution to the challenge of our future energy supply and the implementation of nZEB.

During the course of the projects, a comprehensive monitoring and optimization program, as well as pre-simulations for load management, were carried out in order to obtain and document verified knowledge about the performance of the buildings and the facilities. The focus was on optimization measures to increase the share of self-consumption of the PV production of electricity.

Architecture and energy concepts

The single family house Berghalde near Stuttgart, Germany, was completed by the end of 2010. See Figure 1. The building's net floor area is approximately 260 m². The northern part of the basement is dug into a slope and the southern part opens up to the valley with a

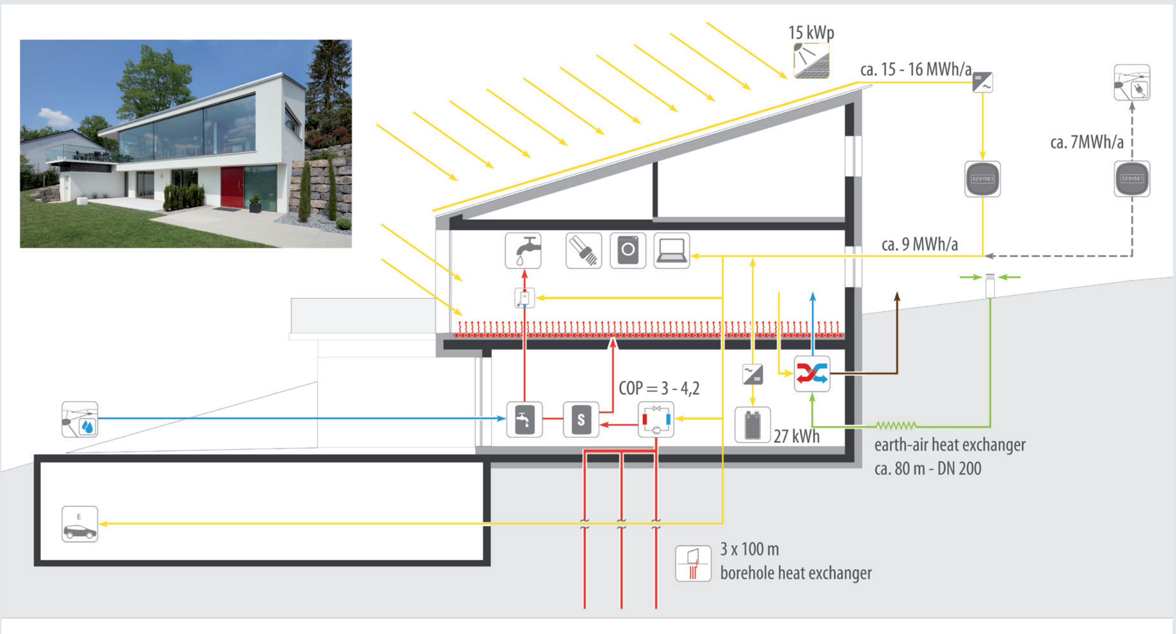

Figure 1. Berghalde - energy concept

large window front. The north, east and west façades are mainly kept opaque. Due to the slope, all living spaces are oriented towards the south (to the left in the figure). The children's and guest rooms are located in the ground floor with a room-high window front. A large adjacent kitchen, dining and living area is located on the first floor. The secondary rooms, such as bathrooms, utility room and building equipment are located on the north side. A structural sun protection for the ground floor is provided by the cantilever of the top floor. Sun protection for the first floor is provided by an external shading system.

The terraced houses Herzo Base (See Figure 2) will be finished by the end of 2017, and consist of eight units. The net floor area is approximately 150 m² per terraced house, distributed on three floors and a basement. The orientation is east-west, which leads to a balanced PV production during the day. The technical equipment is located in a common installation room in the basement.

The basic idea of both energy concepts is to supply the electrical power from the PV system. The self-generated energy primarily covers the demand for electricity in the building during the daytime. Energy surplus is stored in batteries, which provide the energy for instance for the artificial lighting and household appliances in the evening. Only the remaining surplus is then fed into the public grid.

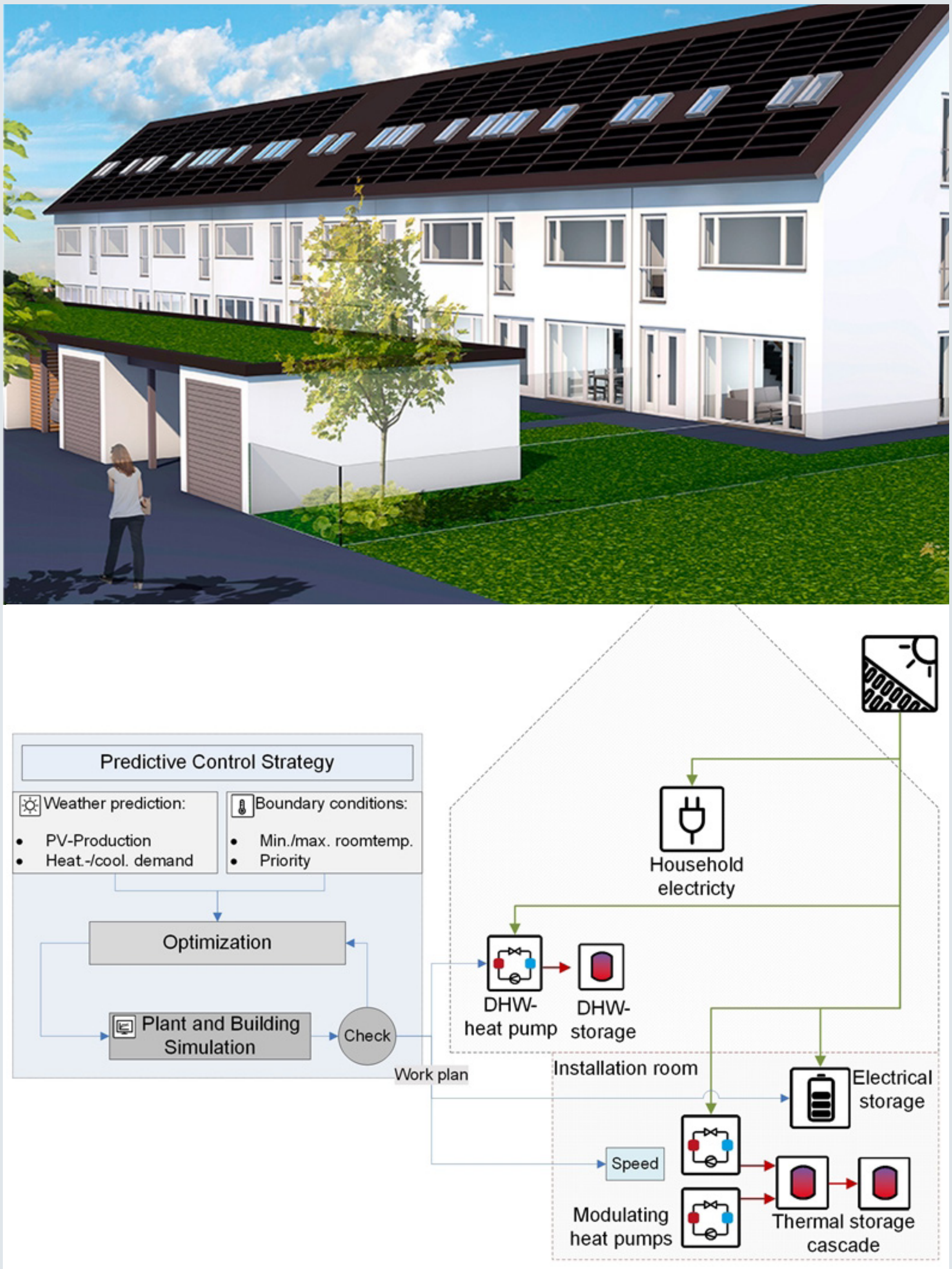

Figure 2. Herzo Base - energy concept

Heating energy is generated by a heat pump, which is coupled to borehole heat exchangers. The Herzo Base houses have two common Modulating (variable speed) Heat Pumps (MHP), that are located in the common installation room. The heat transfer in the building takes place via floor heating and additional radiators in the bathrooms. The hygienic ventilation is ensured by a mechanical ventilation system with heat recovery. In Herzo Base, the domestic hot water is provided by decentralised domestic hot water heat pumps (DHW-HP) that are integrated in each terraced house.

EnergyPlus Standard

The applied definition and calculation method for the EnergyPlus standard is based on the specification and the definition of the German Federal Ministry of Transport, Building and Urban Development (BMVBS) for the "Effizienzhaus Plus", see here (in German). For the calculation of the EnergyPlus standard, either the building or the property boundary is defined as a balance limit. The balance includes all energy needed for conditioning and operating the building as well as the equipment. It includes the demand for heating and cooling, ventilation, lighting, and auxiliary energy sources, as well as household appliances and wireless computer network.

The energy consumption is compared to the renewable energy production based on the annual balance. The difference (consumption minus production) must be less than zero regarding both final energy and primary energy.

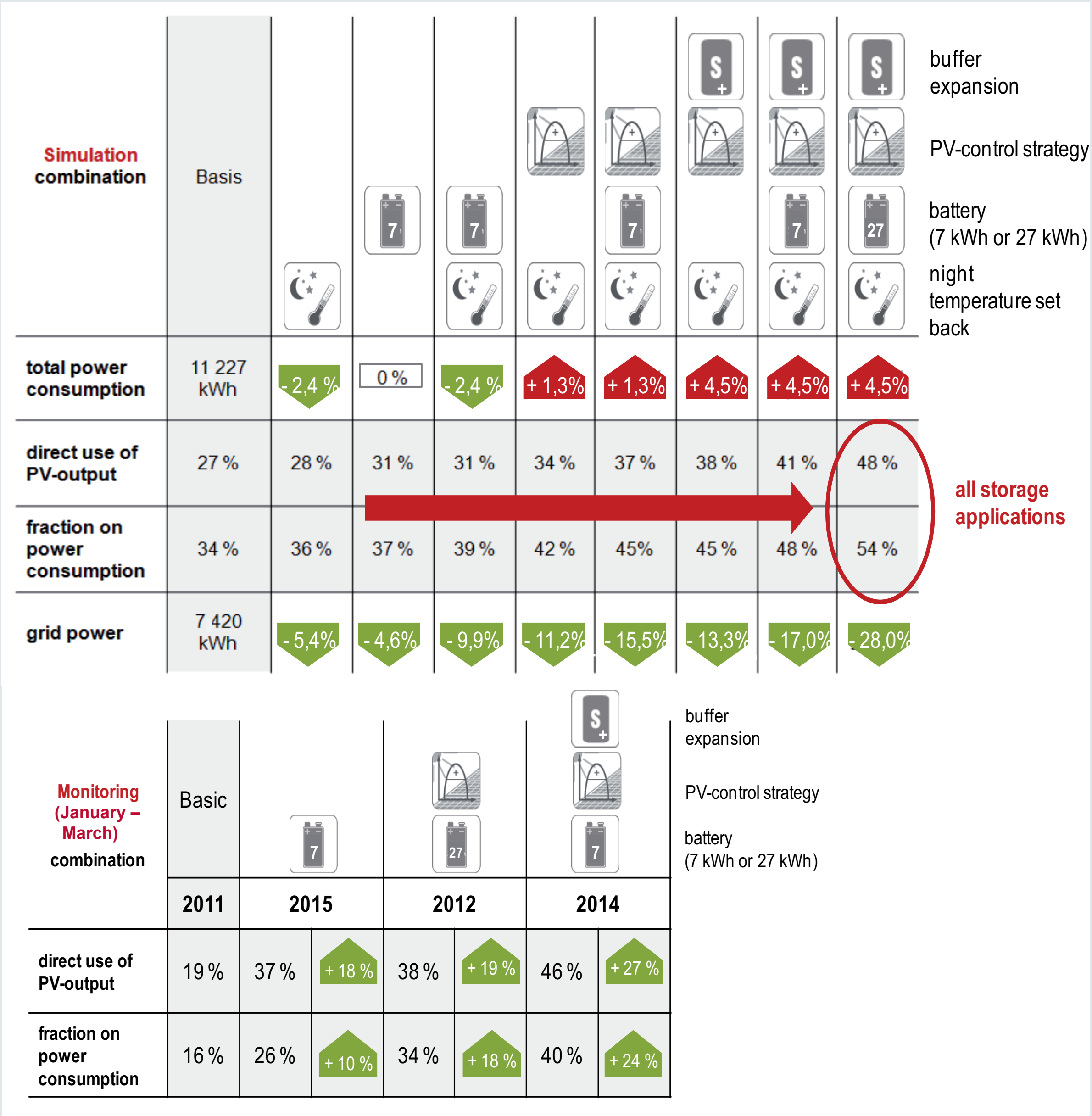

Figure 3. Berghalde - Simulation (top) and monitoring results (bottom)

Berghalde: Increase of self usage share

To increase the direct use of power, different measures were taken in advance by building and system simulations, and afterwards implemented in the building during test phases.

The selected system options (see below) for increasing the share of self usage of power consumption are based on thermal and electrical storage of self-produced electricity. The main focus of the simulation study was to increase self-consumption of PV output and thus reduce the feed-in to, and the extraction from, the public grid.

The following five options build on each other. Each is complemented by a new component, compared to the previous one.

1. Integration of a 7 kWh Battery
2. Battery (7 kWh) + night temperature setback of supply temperature
3. Battery (7 kWh) + night temperature setback + PV-control strategy
4. Battery (7 kWh) + night temperature setback + PV-control strategy + buffer-expansion (add another water storage)
5. Integration of a 27 kWh-battery + night temperature setback + PV-control strategy + (water storage) buffer-expansion

The PV-control strategy is outlined as follows:

- All available thermal storages such as floor heating and the buffer are used for running the heat pump, while enough solar energy is available;
- Raising the temperature in the buffer (up to 60 °C) to increase the storage capacity;
- Increasing the reference value of surface and supply temperature of the floor heating.

Buffer expansion:

- A second buffer (700 l) is connected and coupled to the existing buffer (825 l). Thus, the volume increases from 825 liters to 1 525 liters;
- A restriction of the user comfort is not to be expected at any time by the proposed measures.

The simulation results show that the use of the various components (battery, buffer, etc.) leads to a direct increase of use of PV-power from 27 % (base) to 48 % and the PV solar fraction of power consumption increased from 34 % (base) to 54 %, see Figure 3. In addition, the share of electricity from the grid can be reduced by up to 28 % by implementing all options mentioned above. However, the electricity demand will also increase by up to 4.5 % by the measures, due to lower COPs from the heat pump (higher temperature) and battery losses.

Within the scope of the monitoring, and in order to make a comparison between theory and practice, different combinations of measures were implemented within three test phases. The test phases were evaluated for the period January to March (See Figure 3, lower part). It can be seen that the previously simulated predictions in direct use and fraction on power consumption are well met in the application inside the building.

Herzo Base: A simulation study

The focus of the terraced houses is the development of Demand Side Management (DSM) that controls the MHPs and DHW-HPs in order to reduce the additional grid power and at the same time increase the consumption of electric power generated by PV. Since the MHPs are able to adjust their speed from a fraction of the maximal speed of 0.1 to 1, the DSM can adapt the speed of the MHPs to the PV power. Two thermal storage units are connected to a storage cascade. The second 2 000 litre surplus storage can be switched on in order to increase the storage capacity during PV production. As each DHW storage has a small volume of 200 litres, the water will be renewed daily. This prevents Legionella contamination of the DHW system (in accordance with German legislation). Regarding the advantages of a high temperature source for heat pumps, the water-water HPs use the thermal storage cascade as a heat source. In addition to the thermal storage units, an electrical storage is installed for storing the surplus PV production after filling the electrical demand of the household and heat pumps. Furthermore, the DSM also influences the temperature level of the thermal storage units.

During PV production in the heating period:

1. The temperature level of the DHW storage units increases from 50 °C to 65 °C;
2. The surplus storage is also charged and the temperature level is 35 °C during the heating period.

During battery and grid consumption in the heating period:

1. The temperature level of DHW storage units is 50 °C;
2. The MHPs decrease the speed to 0.4 because the best COP is for a speed between 0.3 and 0.4 of the maximal speed.
3. The first storage is charged to 35 °C.

A minimum storage temperature of 27 °C has to be guaranteed during the heating period.

In the summertime, the heating demand is restricted to DHW. The inlet source temperature for the DHW-HPs is limited to a minimum value of 20 °C. For that reason, only the first storage unit of the storage cascade is charged to a temperature of 30 °C.

The developed control strategy was evaluated as a basic variant with a standard control strategy. The basic control strategy consists exclusively of a heat-controlled operation of heat pumps with an on-off speed and developed control strategy.

Important values for evaluating the DSM are the efficiency of the heat pump systems and the

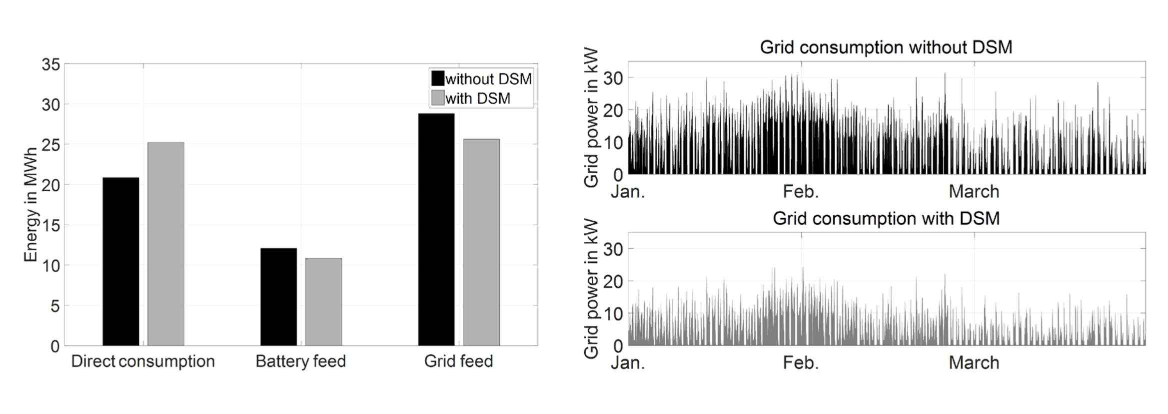

Figure 4. Herzo Base - PV-selfconsumption and load peak reduction

self-consumption of PV electricity. The SCOP of both geothermal heat pumps increased from 4.5 (on-off speed) to 5.3 (modulating speed; not taking the auxiliary energy into account). This higher COP is due to the modulation of the heat pumps with a lower compressor speed. The PV self-consumption increased by 21 % (See Figure 4). As an effect of the increased direct consumtion, the battery feed decreased by 10 % because of the low surplus afterwards. Nevertheless, the grid feed decreased by 11 %. Another result of the DSM is its contribution to the grid integration of nZEBs. The maximum load peak was reduced by 24 % (See Figure 4). The reduction of grid consumption, PV feed and load peaks show the impact of the terraced houses on stabilizing the grid.

Conclusion

The EnergyPlus-Houses, which include heat pumps and have a high PV power self supply, are important elements for our future energy supply and implementation of renewable energy sources.

The results of the optimization and increase of the self consumption show that there is still potential to increase the self-use of solar electricity.

The flexible heat pumps in combination with thermal storage units can adapt to PV power. The adaption and the increase of storage capacity results in an increase of PV power use and a reduction of additional grid power and load peaks.

Both approaches and buildings show that today's load management is indispensable for the implementation of energy-efficient buildings with energy supply from renewable energies.

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