Verified net Zero Energy Building with air source heat pumps for SME

Field measurements were conducted on a net zero energy building designed for small to medium enterprises (SMEs). Energy flow and comfort parameters were monitored. The net zero energy concept, built around air source heat pump technology, achieved a positive energy balance of 977 kWh after one year of measurements. The study was conducted in cooperation with five European research institutes.


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Introduction

Since the publication of the EPBD recast (2010), much attention has been paid to nearly zero energy buildings (nZEB). As a building equipment manufacture, Daikin too has been closely following and contributing to this development. High efficiency solutions after all play an important role in the total energy picture. To this end, field measurements at a Net Zero Energy Building were


Figure 1. Interior views of the meeting room and an office.

started in March 2010 as part of an nZEB project in cooperation with major research institutions. The aim of the project is to develop an economically feasible Net Zero Energy Building concept using heat pump technology. In a first phase, current technology is being evaluated in a newly constructed building in the German Ruhr region. On the one hand, the building and its measurements are being used to study whether a net zero energy building is feasible today using an open and flexible architectural approach with high efficiency equipment. On the other hand, it is being used to demonstrate a net zero energy building in real use to customers, policy makes and consultants.

nZEB concept

Building description

The project concerns a newly constructed office building (2009) for a small to medium enterprise that is home to 15 fulltime employees. An 800-m² warehouse is connected to the north side of the 2-story office. Interior views can be seen in **Figure 1**. The entire construction is steel frame. The general building characteristics, including the climate data, are shown in **Table 1**.

Since the idea was to start with an open and flexible architectural approach, the building envelope did not target extreme insulation values, but rather a slight im-

Table 1. General building characteristics.

Location	Herten. Germany
Owner	Athoka Gmbh. Zeller Gmbh
Typology	Office and showroom + warehouse and workplace
Climate data	Heating: T_{design}: -8.6°C Cooling: T_{design}: 30.3°C
Number of floors	2
Net floor area	545 m^2
Conditioned floor area	515 m^2
Conditioned volume	1424 m^3
Lighting level	>500 lux
Indoor temperature	Winter: 20-23°C, zone depending Summer: 24°C, with individual user control
Ventilation rate	According to EN15251, method B1.3
Envelope to volume ratio	0.66

provement in the German EnEV standard (**Table 2**), in combination with measures to reduce the loads such as controllable solar shading on the facades and windows, cool roof covering, and a free cooling option in the heat recovery ventilation system.

Table 2. Envelope technical data.

	Material	U value (W/m^2K)	EnEV reference Construction
External walls	Brickwork (insulation 14cm) + sandwich panels (insulation 10cm)	0.23 -0.25	0.28
Roof	Steel deck (insulation 20cm)	0.19	0.2
Windows	Double glazing + insulated aluminum frames	1.3	1.3
Office envelope (average)		**0.41**	

Figure 2. Daikin Altherma outdoor unit (right) and VRVIII outdoor unit (left).

Equipment description

As a next step, high efficiency systems are used to reduce energy consumption. The primary system for heating the building is an air source heat pump, with a water circuit connected to underfloor heating. Each room has one or more piping zones for which the water volume flow is individually controlled by valves, managed by PID-controlled temperature sensors per zone. This ensures a balance between optimal comfort and energy savings. Since heat pump performance very much depends on the provided water temperature, the leaving water temperature is intelligently controlled in function of the weather. The project revealed that good knowledge of the building and its users can facilitate a perfect match between solutions used. Trying to avoid inefficient back-up heater operation in extreme winter conditions can lead to an overdimensioned design, which results in lower efficiency at low partial load operation (e.g. warmer temperatures). Therefore for this project, the choice was made to optimise the heating system for partial load efficiency, and use *combined operation* in extreme winter conditions, i.e. augmenting heating capacity using the – already present – air-to-air heat pump (designed for cooling the building, but able to run in heating mode). The building's control system was designed so the that underfloor heating remains the dominant heating system, and use of the electrical backup heater is minimised. This combined operation resulted in high seasonal efficiency. Both outdoor units of the Daikin Altherma and VRV system can be seen in **Figure 2**.

As noted above, comfort cooling during the summer period is handled by an air-to-air heat pump in reversed cycle mode (VRV III). Each room has individual control of its indoor unit.

Ventilation is provided by two heat-recovery ventilation systems with a temperature exchange efficiency of 75% and an enthalpy exchange efficiency of 60-65%. The control system uses free cooling whenever possible in the summer period.

The lighting design makes use of LED and other efficient lighting technology where possible. The desks have personalised lighting to guarantee light comfort and the highest possible energy efficiency.

A Net Zero Energy Building concept may be defined as a building that is energy neutral over a period of one year: i.e., it must deliver as much energy to the supply grid as it takes from this grid. The energy saving component was handled with the previous actions; the remaining component is the addition of renewable energy sources. In this project, 27.3 kWp thin-film photovoltaic panels were installed on the roof. This system was chosen for its combination of easy installation and good response to the infrared light of the CIGS solar cells (copper indium gallium selenide). The latter is important since the research included an evaluation of the effect of Daikin's durable sun reflective coating Zeffle on the photovoltaic energy production (the results and a comparison with standard white coating can be found in paragraph "Increased PV performance"). A picture of the roof can be seen in **Figure 3**.

Figure 3. View on the roof with photovoltaic panels and standard white roof coating.

All equipment and sensors are connected to online measurement and visualisation systems that allow Daikin engineers to remotely monitor performance and comfort at the field test site.

Measurement results

Energy flows

The building and its equipment were closely monitored for a 12-month measurement period. An analysis of the energy flows shows an energy surplus for measurement year 2011-2012. The positive outcome of 977 kWh (1.8 kWh/m²) is displayed in **Table 3** and **Figure 4**. This is result includes the aspects mentioned in the European Energy Performance of Buildings Directive: heating, cooling, domestic hot water, ventilation and lighting. These measurements were conducted in cooperation with five research institutes.

Table 3. Measured energy performance of the building. All specific values are per net floor area.

	Delivered and exported energy, kWh/(m²a)	Primary energy factor, -	Primary energy use, kWh/(m²a)
Heating	14.5	2.6	37.7
DHW	1.7	2.6	4.4
Cooling (incl. server room)	5.1	2.6	13.3
Ventilation	4.3	2.6	11.2
Lighting	11.1	2.6	28.9
PV power generation	-38.5	2.6	-100.0
Total	**-1.8**		**-4.6**

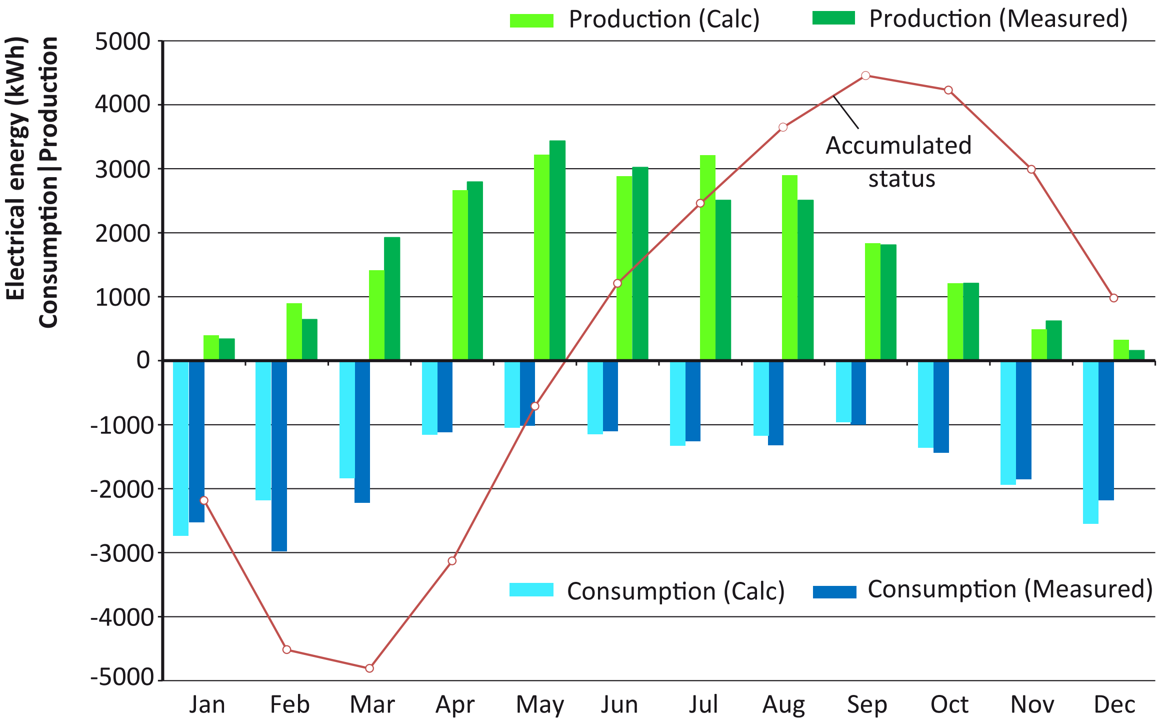

Figure 4. Yearly comparison of simulated and measured energy consumption and generation.

As can be seen in **Figure 4**, energy consumption was in line with the calculation made according to the German DIN18599 energy standard. The months of February and March deviate the most from the calculation. In March 2011, measurement had just started and the lighting control was not yet fully operational. February 2012 was a month with extreme winter conditions: –15°C as a daily minimum, compared to -8.6°C in the reference year.

Heat pumps appear to be an excellent solution for zero energy buildings. The results of the project show that the success of a zero energy project is already highly influenced in the first stage of the project: the design phase. The aim was to allow an open and flexible architectural approach in which the goal of achieving zero energy building performance would not create obstacles for the architect in the design and form of the building. This was made possible by the early integration of the technical concept into the architectural, allowing both to converge, resulting in a technically and architecturally superior building.

Increased PV performance

Daikin's durable sun reflective coating Zeffle is designed to reduce the roof temperature and be a passive measure for reducing the building's cooling demand. In this field test, a part of the roof was coated with Zeffle in order to compare it with standard white roof coating. The effect on the photovoltaic energy yield was expected to be twofold: (1) increase the solar reflection on the photovoltaic cells and thus increase the energy produced, and (2) lower the working temperature of the cells and thus increase the potential difference across the field (top in the **Figure 5**). These two aspects resulted in a measured yield increase of 11% in comparison with the standard white roof coating (graph in the **Figure 5**) [1].

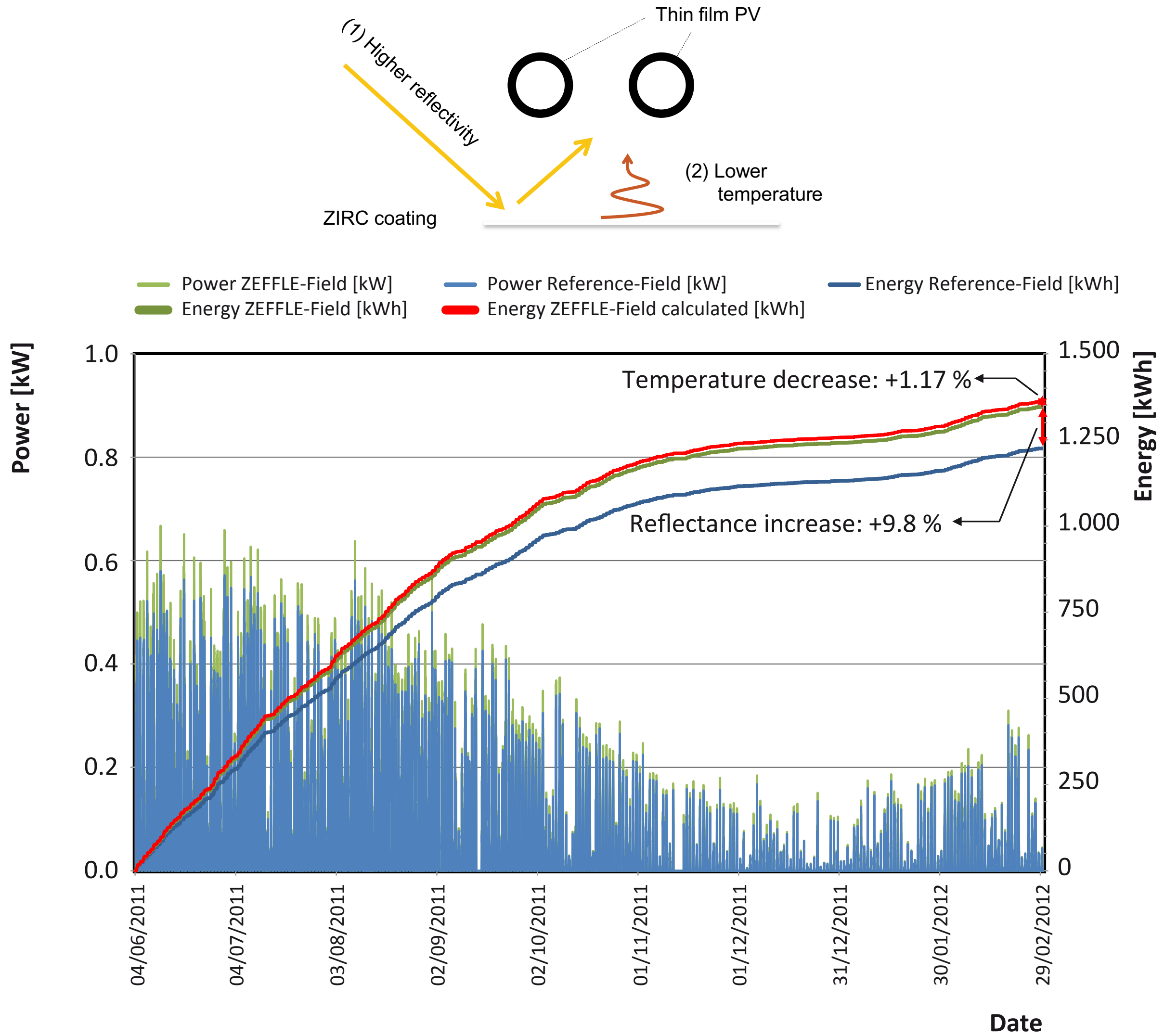

Figure 5. Principle (top) and results of measurement on yield increase of the photovoltaic system.

[1] The difference between the blue continuous line and the red continuous line gives the increased PV yield due to the Zeffle coating.

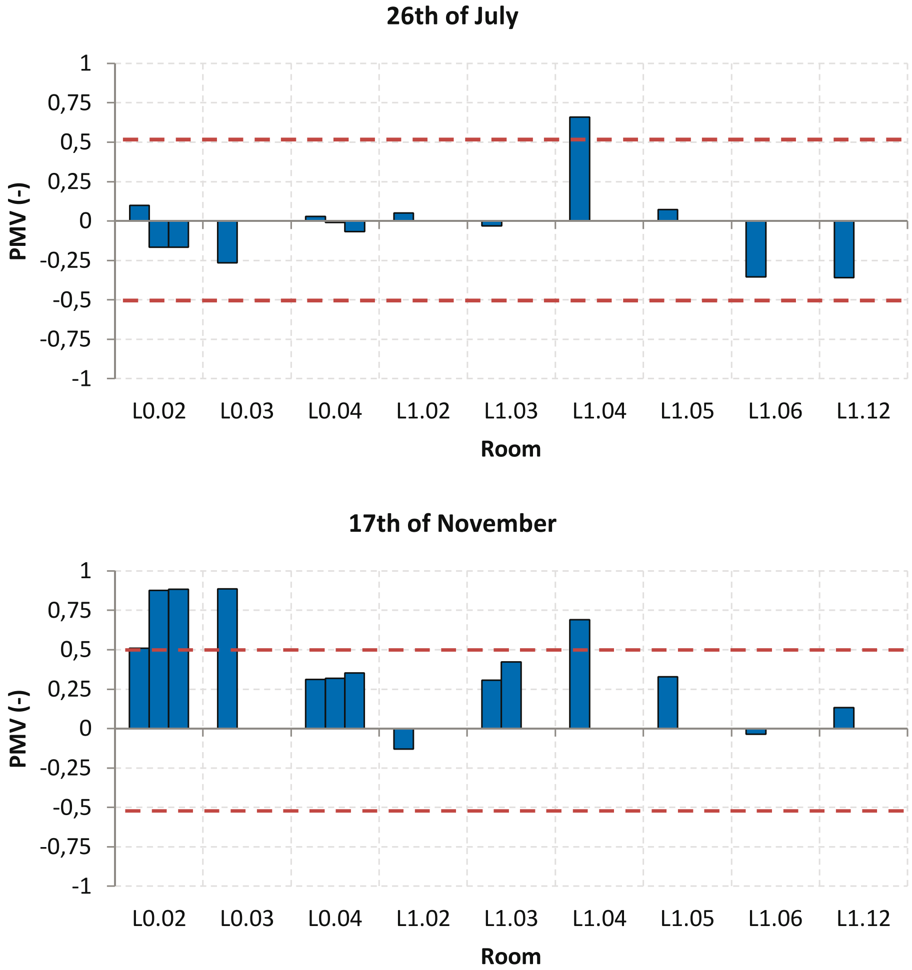

Figure 6. Results of two thermal comfort spot measurements (measured as PMV) in the summer and winter period [2].

Comfort

The project's priorities included not only energy savings but also ensuring the highest comfort levels for building users. Thermal comfort was measured as PMV (predicted mean vote). PMV is a function of room temperature (°C), partial water vapour pressure (Pa), air movement (m/s), mean radiant temperature (°C), metabolic rate per unit human surface (W/m²), human external mechanical work per human surface (W/m²) and clothing thermal insulation (m²K/W). **Figure 6** shows the results of two spot measurements in the summer and winter period [2]. The outcome falls mainly within the comfort boundaries, i.e. between -0.5 and 0.5. Room L0.02 can be seen as an exception in the winter period due to the preferred settings of the end-user.

Experience gained

After more than one year of monitoring building operation, two aspects deserve attention.

- In low energy buildings, proper product dimensioning and selection is a crucial step. Good interaction with the building owner and users prevented oversizing of equipment.
- Manual monitoring makes it possible to discover upcoming problems before these would be noticeable to the building user and result in a wasting of energy. This process could be automated.

Conclusion

The projects project shows that a net zero energy building can be achieved today with an open and flexible architectural approach, in combination with high efficiency equipment. Measurements over the one-year period show a net gain of 977 kWh, while guaranteeing comfort throughout the year.

We are presently improving the HVAC system in order to further reduce energy consumption in a next phase.

References

[1] ef.Ruhr GmbH – Technische Universität Dortmund, Effectiveness of Building Enerergy Management Systems of Daikin Test nZEB and Integration into an Intelligent Grid, 2012.

[2] Fraunhofer IBP, Validation of Net Zero Energy Building Concepts – Study executed for Daikin Europe NV, 2012.