CLIMA 2022
Eye on 2030 | Towards digitalized, healthy, circular and energy efficient HVAC

REHVA 14th HVAC World Congress
22nd – 25th May, Rotterdam, The Netherlands

Monitoring a deep energy renovated building

Matthias Haase [a]

[a] Institute of Facility Management, Zurich University of Applied Sciences, Waedenswil, Switzerland, Matthias.haase@zhaw.ch.

Abstract. A typical residential building from 1937 located near Wurzburg in Germany, was deep retrofitted in 2013. The energy use and costs could be drastically reduced compared to the old building. However, increase in energy costs can thread economic success. Therefore, it is important to monitor also the performance of the different technical systems. A measurement campaign of a real building with energy consumption and production ("prosumer model") proves the concept of prosumer over time. The total energy costs were 387 € in 2018 and have increased to 839 € in 2021. This is an increase of 217%., changes in energy prices and tariff structures might influence the lifetime energy costs as well as the savings. Electricity use of the compact unit was measured, share of ventilation and heat (heating and DHW) was calculated based on standard models. Electricity use is illustrated and contrasted with electricity production from a 7.95 kW solar PV system.

Keywords. performance monitoring, electricity use and production, economic evaluation **DOI**: https://doi.org/10.34641/clima.2022.248

1. Introduction

Residential use of energy is responsible for 28% of EU energy consumption [1]. The barriers to consumer energy saving have been known for more than 30 years but are still present. in particular split incentives (e.g. tenants vs. landlords). lack of information. high initial investment in energy-efficient equipment and habits of energy users [2].

Likewise. while awareness of the existence of renewable energies has improved considerably in the last years. there is still a lack of understanding of how to use and optimize them in practice.

The EPBD requires nearly zero energy buildings (nZEB) from 2021. There are many approaches to this goal and several pilot buildings have been built and extensively measured [3]. The theoretical approach is normally based on three pillars; first, energy saving measures have to be applied that ensure a massive reduction of heating energy. The second pillar is energy efficient equipment and third the production of renewable energy on-site [4]. All measures have been applied in this case.

2. Energy renovation (motivation)

A residential building from 1937 located near Wurzburg in Germany was deep retrofitted in 2013. The project received funding from the German Bank for Rebuilding (KfW) in the class kfW55 which uses 55% of the energy budget defined in the existing German building code (EneV) [5]. More ambitious levels (e.g. KfW40 or any type of zero energy buildings) do not exist for refurbishments (only new constructions). There were, however, additional funding schemes for heating systems and Feed-in tariff (FIT) for photovoltaics (PV) [6]. Today, the funding schemes as well as FIT are under revision [7].

The old building was equipped with an oil boiler connected to central heating system with radiators in each room. In the energy renovation strategy towards nZEB, the following steps were followed:

1. Reduction of heat losses through the building envelope).
2. Supply heat with efficient equipment; supply heat with efficient heat pump, underfloor heating, and ventilation air.
3. Installation of 7.95 kW_p PV to produce electricity.

The new energy concept is based on a heat pump with balanced ventilation which provides heating through the central heating system as well as through an underfloor heating in the kitchen and living room 1. The successful renovation was reported in 2016 [8]. In addition, a greywater system was installed which reduces water consumption.

2.1 Building envelope

Roof. façade and ceiling in the basement were highly insulated and thermal bridges were minimized. Windows were replaced with three-layered glazed windows with wood-aluminium windows [8]. The roof was additionally equipped with a 7.95 kW PV system which produces electricity. This is used in the building for covering the household electricity, the remaining electricity is fed into the grid (FIT).

2.2 Balanced ventilation system

The compact unit also comprises a balanced ventilation system as illustrated in Fig. 2. The fresh air rates are adjustable in three levels (140, 185 and 220 m3/h, i.e. 0.36, 0.48, 0.57 ACH) and flow rates required for indoor air quality are used. In 2018 and 2019 night-time flow rates of 140 m3/h (0.36 ACH) were used. But in 2020 it was switched to 185 m3/h (0.48 ACH). This was done because the building is fully occupied during night-time and less occupied during daytime. However, it was decided not to reduce daytime airflow rates further (but remain on level 2).

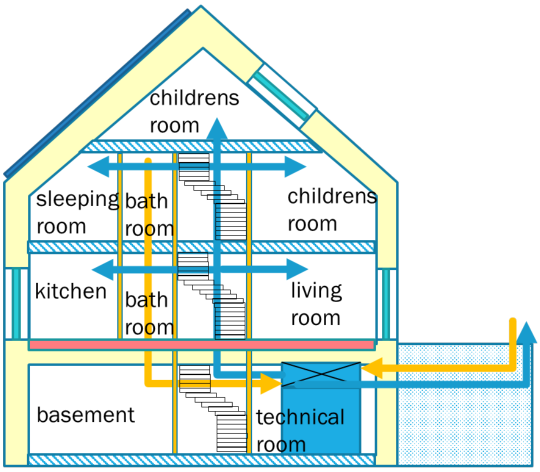

Fig. 2 – Ventilation concept.

This delivers 185m3/h to all the rooms (except storage room in 2. floor; 35m^2) as shown in Figure 2 with a supply and extract fan (with dampers). A cross-plate heat exchanger with 85% thermal efficiency was included in the compact unit. The ventilation ducts were integrated into the existing chimneys. Fan power is kW/(m3/s).

2.3 Compact unit

A compact unit (balanced ventilation system with integrated air-to-water heat pump) was installed. Exhaust air is used as heat source as shown in Figure 1. An underfloor heating system was installed in the kitchen. The electricity used for the compact unit is monitored in a separate meter. This is the know "classical" compact unit: all building services are realized in one appliance: heating, ventilation and domestic hot water. In this case, the hot water is connected to the central heating system and with a mixture valve also to the underfloor heating system. Supply water temperatures for domestic hot water (DHW) are 55°C and then cascade to 30 – 38 °C for the central heating and 25 – 30 °C for the underfloor heating system.

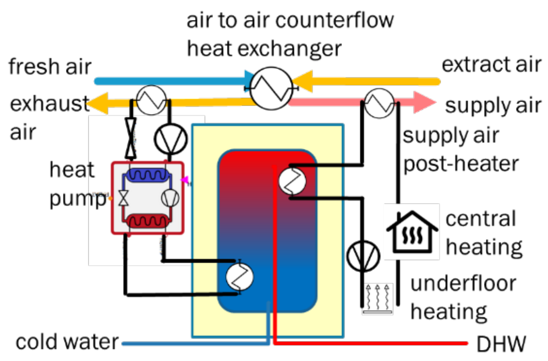

Fig. 1 – Compact unit.

The temperatures are controlled by the outdoor temperature, so that low outdoor temperatures result in higher supply temperatures (heating curve) and pump power is 600 W/(l/s) (with a water flow rate of 0.05 l/s.

2.4 PV system

A 7.95 kW solar PV system was installed on the south-west facing roof. It consists of 30 modules and covers 42m². An inverter was placed in the technical room and connected to the household grid and equipped with a two-lane meter.

3. Objectives

This paper reports the long-term measurement results of a comprehensive energy renovation (towards nZEB). The energy use and costs could be drastically reduced compared to the old building. However, increase in energy costs can thread economic success. Therefore, it is important to monitor also the performance of the different technical systems. Therefore, the energy use (and savings) of a residential building located in Wurzburg, Germany was monitored over a period of four years. Consumption pattern can be used to evaluate standard key performance indicators, like energy use, electricity use, production and costs.

4. Method

A measurement campaign of a real building with energy consumption and production ("prosumer model") proves the concept. Electricity use of the compact unit was measured, share of ventilation and heat (heating and DHW) was calculated based on standard models. Electricity use was illustrated and contrasted with electricity production from a 7.95 kW solar PV system.

Electricity use of the compact unit was measured. This is used for heating, fans and pumps.

Specific fan power is given to SFP = 2.5 kW/(m³/s). Specific pump power is given to SSP = 0.6 kW/(m³/s) so that total energy use of ventilation can be determined.

Thus, the energy demand for heat could be calculated:

$Q_H = Q_h + Q_{DHW}$ (1)

$SPF = Q_H / E_H$ (2)

$E_{HP} = E_H + E_V$ (3)

$E_V = E_{vent} + E_{pump}$ (4)

Q_h is the heating demand of the building

Q_{DHW} is the heat demand for DHW

SPF is the seasonal performance factor. Here, the boundaries for SPF used includes fan and pump power.

E_{vent} is the electricity demand of the fans and can be calculated by

$E_{vent} = V_{vent} * SFP * t$ (5)

E_{pump} is the electricity demand of the pumps

SPF is the specific fan power of the fans

$E_{pump} = V_w * SPP * t$ (6)

SPP is the specific pump power

with

- SPF (specific fan power) = 2.5 kW/(m³/s)
- V_{vent} = 185 m3/s (level 2) (140 m³/s (level 1: night level in 2018 and 2019))
- SPP = 0.6 kW/(l/s)
- t = time of use

The SPF was derived from COP tables of HP provider, with following formula.

$SPF = 2.4 + (0.1*T_{out})$ (7)

With
Tout = outdoor temperature (°C)

There are several energy tariffs for different electricity streams. At least four different tariffs have been considered:

- Electricity purchased for household
- Electricity purchased for heat pump (divided into HT and LT for day and night-time)
- PV electricity self-consumed
- PV electricity sold to grid

The energy price is including working tariff, fixed fees (transfer pricing and fixed performance price) and all taxes which are included in the bill. For the electricity of the self-consumed electricity from PV production only the working tariff plus taxes (electricity tax and value added tax) have been considered. For the electricity supply a special 'heat-pump' tariff was chosen (HT: during daytime; LT: during nighttime).

5. Results

Electricity measurements were monitored:

- Electricity purchased from the grid
- Electricity sold to the grid
- Electricity produced by PV
- Electricity costs

Fig. 3 shows electricity purchased and sold from and to the local provider. It can be seen that the energy purchased is slightly higher than energy sold. Therefore, the building does not reach NZEB

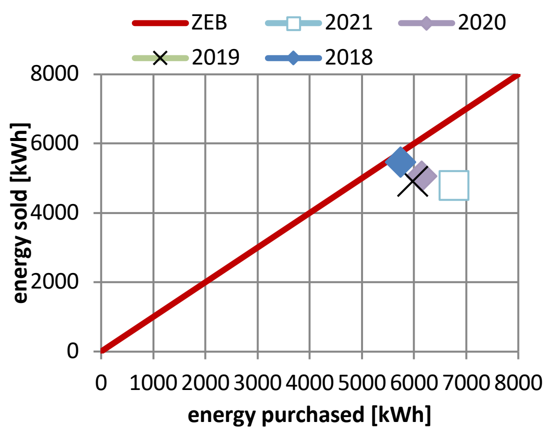

Fig. 3 – Annual electricity purchased and sold (2018-2021).

5.1 Domestic hot water (DHW)

DHW is produced by the compact unit. The amount of water consumption was measured and calculated to hot water and energy need for this was calculated. In 2020 the greywater system was not in operation.

Tab. 1 – Domestic hot water use in 2020.

month	days/month	litres/month	kWh/month
1	31	4617,52	269,4
2	24	3574,86	208,5
3	31	4617,52	269,4
4	25	3723,81	217,2
5	28	4170,67	243,3
6	27	4021,71	234,6
7	31	4617,52	269,4
8	14	2085,33	121,6
9	21	3128	182,5
10	31	4617,52	269,4
11	24	3574,86	208,5
12	28	4170,67	243,3
sum	315	46920	2737

Thus, the freshwater consumption could be measured without recovery which amounted to 138 m³. According to a water consumption survey (IWU) 34% is used for DHW. This amounts to 128 l/d. The DHW use was calculated to liters per month and energy demand for DHW was derived. Table 1 gives the values for 2020. The calculations were done for the other years accordingly, as shown in Table 1.

5.2 Ventilation

The balanced ventilation system consists of two main distribution ducts from the basement up to ground floor and first and second floor. It provides fresh air in living room 1 and 2, the office rom (in ground floor) and the sleeping/children rooms in second and third floor. Extract openings are located in the two bathrooms in ground floor and first floor. The total energy use of ventilation is Event = (1125 + 526) kWh = 1751 kWh.

5.3 Heating (heat pump)

The heat pump is a compact unit (Stiebel Eltron) with 420 l storage tank.

The temperature dependent SPF was then calculated as shown in Fig. 4 and Fig. 5.

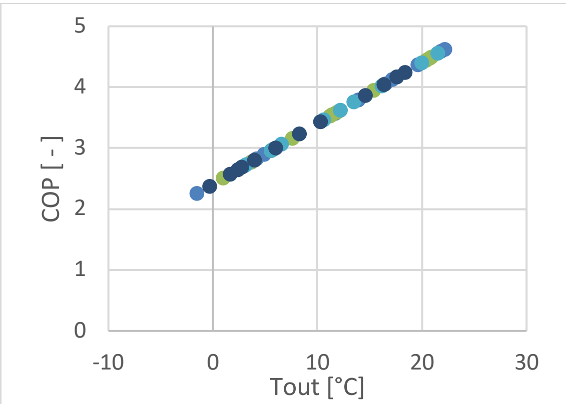

Fig. 4 – COP for air/water HP depending on outdoor air temperature.

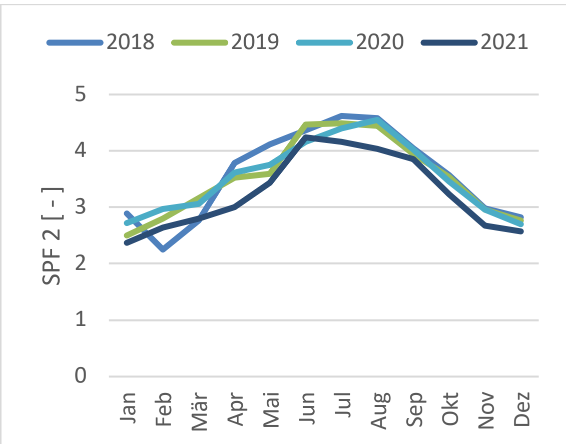

Fig. 5 – SPF for heat pump (2018 – 2021).

5.4 Electricity costs / tariffs

The energy tariffs for different electricity streams as summarized in Table 2. It can be seen that electricity tariff for household electricity ranges between 0.34 and 0.39 ct/kWh.

Tab. 2 – Electricity tariffs (2018 – 2021)

year	house-hold	heat pump HT	heat pump LT	PV (OC)	PV (FIT)
2018	0.3411	0.2281	0,.073	0,3411	0.454
2019	0.3700	0.2390	0.2182	0,3700	0.1454
2020	0.3863	0.2610	0.2401	0,3863	0.1454
2021	0.3863	0.2610	0.2401	0,3863	0.1454

(FIT: Feed-in tariff); HT: high tariff; LT: Low tariff)

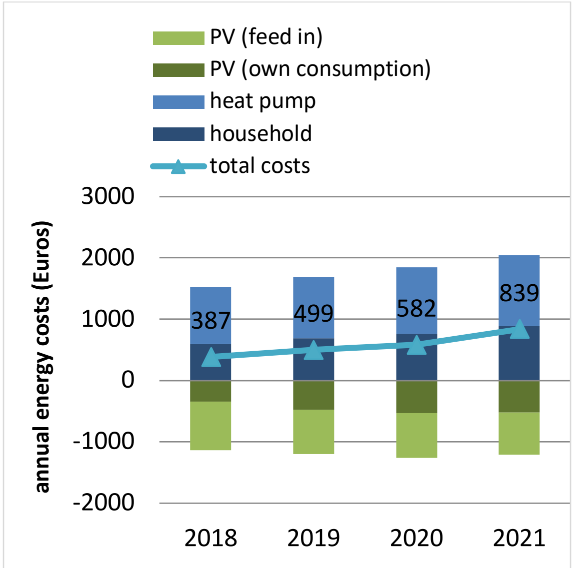

Fig. 6 – Economic figures for 2018 - 2021.

Fig. 6 summarizes annual electricity costs for heat pump, household, self-consumption and electricity use (for household). For comparison reasons, the figure also includes energy costs revenues for PV sold. It can be seen that total energy costs (blue line) as well as household energy costs (dark blue) have increased since 2018.

The revenue from PV electricity production (counted as negative) consists of revenue from selling electricity to the energy provider plus the revenue from saved electricity costs from self-consumption (dark green).

The total energy costs were 387 € in 2018 and have increased to 839 € in 2021. This is an increase of 217%. It should be noted that energy costs amounted to 4897 € (1415 € for electricity; 3482 € for heating (oil)) before renovation. This could have decreased to 4358 € in 2018 and increased to 4679 € in 2021. There are still energy cost savings due to the renovation measures, but the increase of energy costs influences the payback calculations of the renovation measures considerably.

6. Discussion

The deep energy renovation was very successful and energy use and costs could be drastically reduced. However, several technical systems were installed which need to be monitored in more detail. The compact unit was measured separately but still some performance indicators are good to check, e.g. the SPF.

This measurement campaign was done in a building in operation. Not all boundary conditions could be monitored. For example, the building operation was paused in short periods for maintenance. Also, the opening and closing of windows and doors was not monitored. But the household is a rather typical one, with six persons sharing 158.5 m^2 it is rather densely occupied. But water consumption is rather low compared with figures from other surveys.

The performance of the PV system was not in focus of this report.

7. Conclusions

7.1 Energy renovation

The energy use and costs could be drastically reduced compared to the old building. However, increase in energy costs can thread economic success. Therefore, it is important to monitor also the performance of the different technical systems. The PV system is also an important system, but it was not in focus of this report.

7.2 Heat pump

There is an optimization potential for the operation of the compact unit, but it is rather difficult to make improvements and to monitor the improvements in performance. A digital twin could be useful to run in the shadow, not only to quantify improvements in the planning phase but also in order to be able to quantify improvements in operation

7.3 Economic appraisal

Combined energy consumption and production profiles represent a new type needs further recognition. An optimization of the energy costs can be achieved by improving the operation of the building and of the PV system. However, changes in energy prices and tariff structures might influence the lifetime energy costs as well as the savings.

7.4 Proposal for future work

We suggest setting up a Digital twin. This will help to analyse further performance influencing factors.

An analysis tariff structures and their changes over time (decades) will be helpful.

An analysis of PV system (not only parameters orientations, shading, size, costs) by also considering different tariff structures will become even more important when considering additional energy storage options.

It is advised to apply sensitivity analysis of PV system over a longer period (several years) and analysis with weather data to get a better understanding of the influencing parameters.

8 Acknowledgement

This work was written within the project “PEB”. Financial assistance from ZHAW is greatly acknowledged.

9 References

[1] Energy strategy for Europe (2012) Energy market country report 2011 – Belgium. European Commission.

[2] BPIE 2013. Data Hub for the energy performance of buildings. Source: http://www.buildingsdata.eu/

[3] EPBD. 2010. Energy Performance in Buildings Directive 2008/0223. European Commission. Brussels. revised 2010. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF. access date: April 2015

[4] Lysen E.H (1996) 'The Trias Energetica - Solar Energy Strategies for Developing Countries', in: Proceedings of the Euro sun Conference; Freiburg

[5] Energieeinsparverordnung 2014. (EneV). http://enev-2014.info/. access date Jan 2016

[6] Act on the Development of Renewable Energy Sources ((Renewable Energy Sources Act RES Act 2014). (in German: Erneuerbare Energien Gesetz EEG 2014). http://www.erneuerbare-energien.de/EE/Redaktion/DE/Gesetze-Verordnungen/eeg_2014_engl.pdf?__blob=publicationFile&v=4. access date: jan 2016

[7] Bergner, J. And Quaschning, V., Sinnvolle Dimensionierung von Photovoltaikanlagen für Prosumer, in German: Meaningful sizing of PV systems for prosumers, Verbraucherzentrale NRW e.V, https://pvspeicher.htw-berlin.de/, access date: 21.12.2021

[8] Haase, M., Case study of deep retrofitting of a residential building towards plus energy level, proceedings IEECB&SD conference (IEECB&SD2016), 16-18 March 2016, Frankfurt, Germany