COMPARISON OF BUILDING TECHNOLOGIES FOR NEARLY ZERO ENERGY BUILDINGS

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ABSTRACT

Political targets in Europe focus on nearly zero energy buildings (nZEB) to be introduced by 2020. In Switzerland, cantonal energy strategies define a similar target for 2020. While much experience with high performance building envelopes according to MINERGIE-P® exist, a large variety of concepts and standards for nearly zero energy buildings have been defined, making it difficult to compare realized nZEB. In Switzerland an nZEB definition is given by the MINERGIE-A® label. Annex 40 in the IEA Heat Pump Programme (HPP) entitled “Heat pump concepts for nearly zero energy buildings” is investigating heat pump system solutions for nZEB. Task 2 is dedicated to simulation work in order to evaluate performance and cost of different system concepts and to improve design, control and system integration.

As starting point an analysis of system concepts for different demand structures (single-family house (SFH), multi-family house (MFH) and office buildings) is accomplished. Residential buildings are modified from the reference building used in IEA HPP Annex 38/SHC Task 44, while for the office building typical layouts of a three and five storey building are used. For each reference building, building technology and specific consumption of energy were varied by simulations in the software Polysun®. The analyzed criteria are annual costs, energy balance and load match. For the evaluation variable insulation standards are used to enquire the limitation of nZEB balance. Different technology options and combinations are used: air-to-water (A/W) and ground-source brine-to-water (B/W) heat pumps, district heating, solar thermal collectors, boilers and cogeneration (CHP) with heating oil, biomass, biogas or natural gas. For meeting the nearly zero energy balance, photovoltaic panels are used on the roof and façade area.

Simulation results under the chosen boundary conditions confirm that heat pump concepts with photovoltaic panels to balance the energy consumption have the lowest costs to reach a zero energy balance in buildings with moderate energy consumption up to 50 kWh/(m^{2}a). In SFH on MINERGIE-P® level, A/W-heat pumps are more cost-effective as B/W. Solar collectors tend to increase the cost while not necessarily increasing the performance due to competition with the heat pump and PV surface. In MFH heat pumps and district heating as well as biogas CHP can reach an nZEB balance by just using the roof area. However, biogas CHP has higher costs. The other concepts need an extended area by using the façade for PV generation. B/W heat pumps get more cost-effective with increase of specific heat demand. Regarding load match, though, heat pumps increase the deficit of winter electricity. With solar thermal collectors or cogeneration systems, the load match can be improved. For the office buildings possible concepts with the sole use of PV on the roof area are ground-source heat pumps, district heating and cogeneration with biogas. A limit for the nZEB balance is in the range of 4 storeys. For low building energy demands, district heating is most cost-effective, while ground-source heat pumps get cheaper with increasing energy demands. CHP, on the other hand, has the best load match characteristic. Currently, higher integrated concepts as well as retrofit considerations are investigated.

Keywords: nearly zero energy building, building technology, heat pump, system simulation

INTRODUCTION

To reduce energy costs and to achieve greenhouse gas emissions reduction targets, the development of highly energy-efficient buildings is essential. Low-energy buildings are encompassing a high level of insulation and air tightness as well as ventilation with very efficient heat recovery to reduce space heating needs. This leads to the creation of nearly or Net Zero Energy Buildings (nZEB or NZEB, respectively). The main concept of an nZEB is that weighted renewable energy yields generated at the building site have to compensate the amount of the weighted energy use on an annual basis. There are different possibilities to realize an nZEB by using renewable energy sources, such as biomass, heat pumps, solar thermal or solar photovoltaics.

In Europe there is a large variety of concepts and voluntary standards for highly energy efficient buildings or climate neutral buildings. Therefore, it is often difficult to compare realized nZEB. In Switzerland an nZEB definition is given for instance by the MINERGIE-A® standard. The MINERGIE-A® standard considers only the building technologies (e.g. space heating, DHW, ventilation and air conditioning) and uses so-called national Swiss weighting factors for the energy balance.

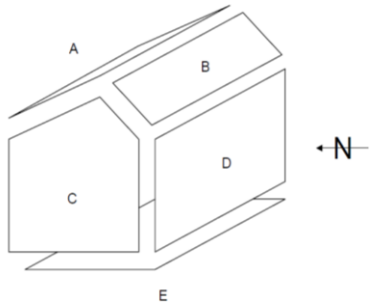
IEA HPP Annex 40 gives an international research framework for research projects on heat pump systems for nZEB. In Task 2 the focus is developed to the simulation work:

- Simulation of promising system concepts for different applications
- Improvement of concepts regarding performance and cost
- Evaluation of the design and control of the systems
- Assessment of options of building and system integration

METHODS

Reference Buildings

The single family house (SFH) is modified from the reference building used in IEA HPP Annex/SHC Task 44 [1]. For the multi-family house (MFH) a typical layout of realised MFH in Switzerland is used. As a model for an office building the company head office of “Marché Restaurants Switzerland” is used as example [2]. The building is certified according to the MINERGIE-P-ECO®- standard.



	building	A =d*a	B =d*b	C =c*(e+r/2)	D =d*e	E =d*c
net (inside) area (m^2)	all	54.6	26.4	45.7	56.0	70.0

Figure 1: SFH reference building IEA HPP Annex 38/SHC Task 44

Figure 2: Head office of Marché Restaurants Switzerland

General characteristics

For the energy balance the weighting factors of MINERGIE-A® are used, corresponding to 0.0 for solar and geothermal energy, 0.7 for biomass, 0.6 for district heating with minimum 50% of renewable share, 1 for fossil fuels and 2 for electricity. The balance for all concepts is evaluated for a whole calendar year to equalise the seasonal differences. For the evaluations different balance boundaries are used for residential (SFH, MFH) and office buildings. The balance for SFH and MFH includes only the building technology according to MINERGIE-A®, for the office buildings the energy use of devices is included, as well. Table 1 shows the general characteristics of the different building types which were used for the simulation.

	SFH	**MFH**	**Office A**	**Office B**
Energy reference area (ERA)	164 m^2	1500 m^2	960 m^2	1680 m^2
DHW	50 l/(pers.*d)	50 l/(pers.*d)	5 l/(pers.*d)	5 l/(pers.*d)
Roof area	54.6 m^2	196 m^2	400 m^2	420 m^2
Slope of roof	40°	40°	35°	35°
South façade for PV	-	312 m^2	101 m^2	168 m^2
Orientation	south	south	south	south
Number of storey	2	5	3	5
Number of person	4	30	78	137

Table 1: General characteristics of SFH and MFH and the two types of office buildings

The energy data for the office buildings are calculated with the default values of SIA 2024 [3]. The electrical expense for the cooling demand is determined by typical EER values of SIA 382/2 [4]. In Table 2 the specific and annual energy demand is given.

	per ERA	**Office A**	**Office B**
Air conditioning	4.7 kWh/(m^2a)	4’512 kWh/a	7’896 kWh/a
Electricity for Cooling	1.1 kWh/(m^2a)	1’067 kWh/a	1’800 kWh/a
Electricity for lighting	16.3 kWh/(m^2a)	15’677 kWh/a	27’434 kWh/a
Devices	12.9 kWh/(m^2a)	12’384 kWh/a	21’672 kWh/a

Table 2: Energy requirements of the office buildings (ERA – energy reference area)

System simulations

The different concepts are simulated with the software Polysun® and are analysed regarding the criteria uniform annual cost [1000 CHF/a], energy balance [kWh/a] and load match [-]. For the evaluation different insulation standards denoted as space heating energy needs of 15 kWh/(m^2a) for MINERGIE-P®, 35 kWh/(m^2a) for MINERGIE® and 55 kWh/(m^2a) for a standard new building are used to find limitations of nZEB balance. Different technology options and combinations of them for providing the space heating and domestic hot water (DHW) energy are used: air-to-water (A/W) heat pump, ground-source brine-to-water (B/W) heat pump, district heating, solar thermal collectors, cogeneration of heat and power with heating oil, biogas or natural gas and boilers with fuel oil, biomass (wood pellets), biogas or natural gas. In this study no integrated system solutions are considered, but all systems are installed side-by-side. For meeting the energy balance, photovoltaic panels are used on the roof area or in the building façade. The cost balance includes the investment cost, the running cost and the interest rate for a uniform time period of 25 years.

RESULTS

Single-family-house

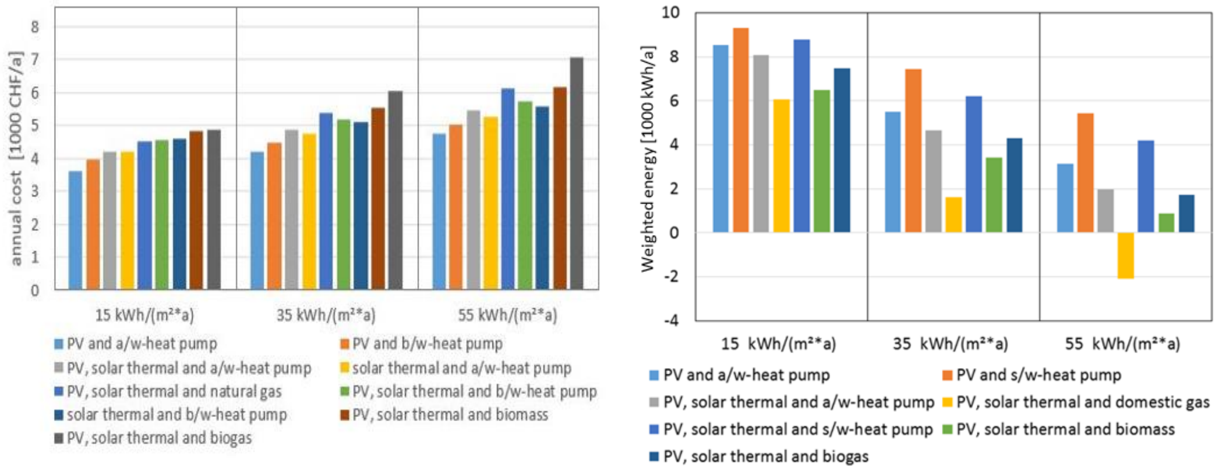


Figure 3: Cost balance (annual cost) and energy balance for SFH

The SFH concepts are simulated with a solar thermal collector area of 8 m^2 corresponding to a DHW design with higher solar fraction. The PV area is designed to use the remaining roof area. The concepts without using PV panels achieve the zero energy balance with electricity purchase from renewable sources. Figure 3 shows the annual cost and energy balance for SFH for different insulation standards expressed as space heating needs 15/35/55 kWh/(m^2a) as described above. In SFH buildings heat pump systems combined with PV have the lowest annual costs. In small buildings with low heating demand A/W are cheaper than B/W heat pumps. Systems with biomass or biogas generate higher annual costs due to higher investment and the high energy costs especially for biogas, which is at current prices about double the price of natural gas. Solar collectors tend to increase the cost while not necessarily improving the performance substantially, which is due to higher cost for storage and piping, decrease of the seasonal performance factor (SPF) of the heat pump, since the heat pump increasingly runs at worse operation conditions, and competition with the PV area. The energy balance in Figure 3 right depict the surplus after energy weighting and confirms that the MINERGIE-A® balance can be reached by most of the concepts up to an insulation standard of a space heating energy need of 55 kWh/(m^2a).

Multi-family-house

In MFH for most concepts a solar thermal collector area of 50 m^2 is chosen corresponding to a system for DHW support. Only for the “PV-solar thermal-A/W heat pump” concept the whole roof area is used for solar thermal collectors and a seasonal storage of 50 m^3 is installed (self-sufficiency for space heating and DHW). The PV area is sized to meet the MINERGIE-A® balance. The results for the cost balance in MFH in Figure 4 left are similar to the results of the SFH. A difference, though, is that the B/W-heat pump gets more cost-effective compared to A/W-heat pumps with the increase of the specific heat demand. Besides the heat pump concepts, district heating and combined heat and power (CHP) on the basis of natural gas offer low-cost solutions with nearly the same cost as the heat pump systems for higher insulation standards (space heating needs of 15-35 kWh/(m^2a)). For low space heating needs the seasonal storage concept has the highest cost, while with increasing space heating needs, the combinations with biogas get the highest cost. Fig. 4 right depicts the percentage of roof area needed to meet the balance. In buildings on passive house level (15 kWh/(m^2a)) the MINERGIE-A® nZEB balance is reached by only using the roof area with all concepts.

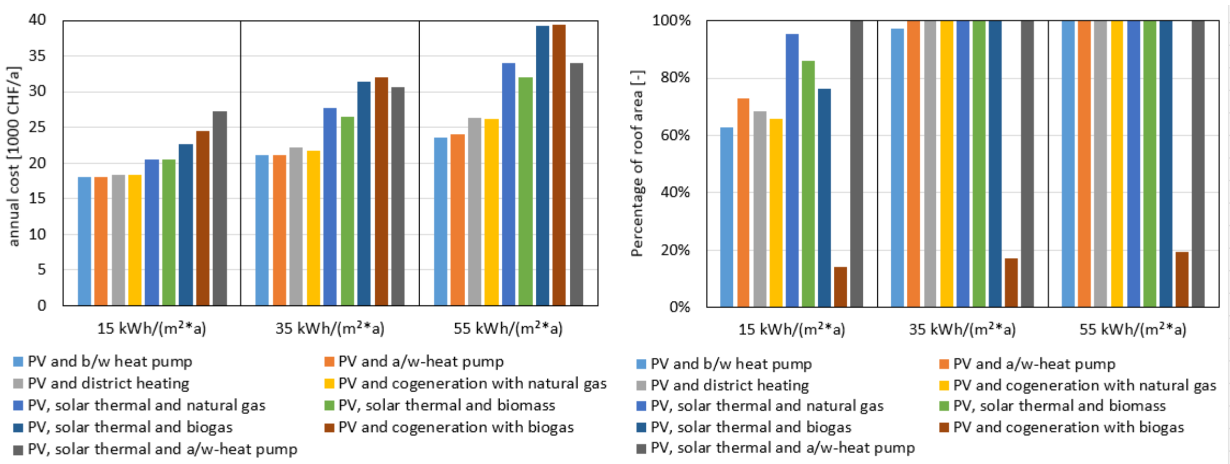


Figure 4: Cost balance (annual costs) and fraction of PV roof area for MFH

With higher specific space heating needs (35-55 kWh/(m^{2}a)) it is necessary to use the façade for additional PV panels. Only CHP with biogas can achieve an nZEB without using the façade area, but biogas has the highest energy cost. An advantage of solar collectors or CHP, though, is to improve the load match, since heat pumps increase the electricity demand in winter, when the PV yield is lower. Therefore, the combination of PV and CHP has a good load match characteristic with winter electricity by CHP and summer electricity with PV.

Office buildings

For the office buildings two buildings with 3 (Building A) or 5 (Building B) storeys were considered to find the limitations of nZEB concepts in office buildings. Besides the roof, also the façades (south, east and west) are used for the PV installations. Different to MINERGIE-A®, the building technologies and also the energy demand for lighting and devices are included in the balance. The cost balance of building A and B are similar, and the number of storeys has only a small impact on the system order regarding annual costs. With low space heating needs, district heating is most cost-effective. B/W and A/W heat pumps get cheaper with increasing needs. CHP with biogas has the highest cost as in the residential buildings.

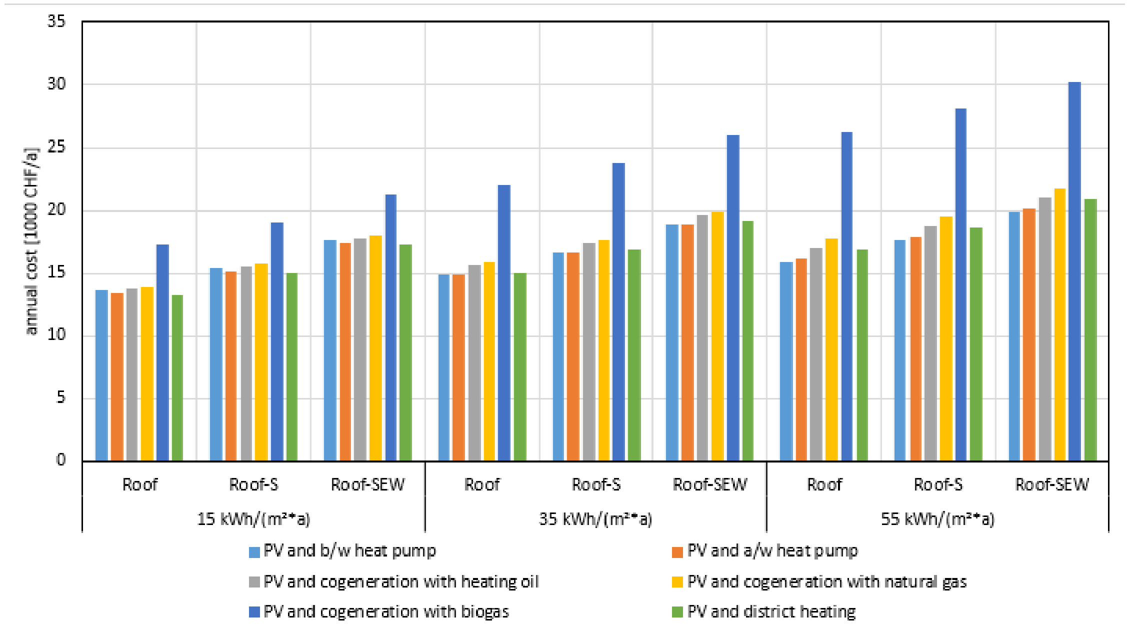


Figure 5: Cost balance (annual costs) office building A

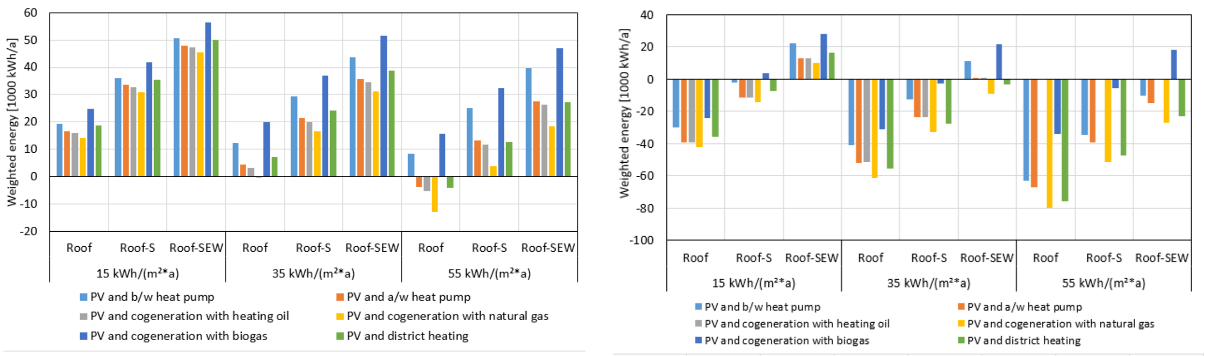


Figure 6: Energy balance of office building A (left) and office building B (right)

CONCLUSION

The heat pump solution is for all building types cost-effective with regard to the annual cost and energy efficient, even though SPF of the heat pump is rather conservative with 2.7 for A/W-heat pump and 3.3 for the B/W-heat pump. Only district heating can compete with the similar annual cost for low space heating needs. With increasing heating needs, ground-coupled heat pumps get more cost-effective due to the better performance and less necessary PV area to meet the nZEB balance. With decreasing heating needs, though, higher investment cost cannot be compensated by the better SPF, so A/W-heat pumps are the cheapest solution. Side by side combinations with solar thermal tend to increase the cost without substantial increase of energy performance due to competition with PV area on restricted overall roof area. Moreover, PV has a weighting factor of 2, while solar thermal energy simply reduces the needs. The only drawback of heat pumps is the limited load match due to the increase of winter electricity. In that sense, CHP has the best load match characteristic, since PV deficits in wintertime are compensated due to CHP operation for winter heating needs resulting in a good load match.

ACKNOWLEDGEMENTS

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REFERENCES

1. Dott, R., Haller, M.Y., Ochs, F., Reuschenburg, J., Bony, J.: The Reference Framework for System Simulations of the IEA SHC Task 44 / HPP Annex 38, Technical report of subtask C, Report C1 part B, Muttenz, 6.9.2013
2. Naef, R., Stemmler, S.: Marché international support office, Kemptthal, Zürich, Final report SFOE research project, Zurich, 2010.
3. Swiss Society of Engineers and Architects : SIA 2024 Standardnutzungsbedingungen für die Energie und Gebäudetechnik, Zurich, 2006
4. Swiss Society of Engineers and Architects : SIA 382/2 Klimatisierte Gebäude – Leistungs- und Energiebedarf, Zurich, 2011