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Evaluation of Efficiency and Renewable Energy Measures Considering the Future Energy Mix

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ABSTRACT

Sustainable and responsible use of resources is required in order to mitigate climate change. Micro-economic goals usually consider the capitalized investment costs and/or the purchased energy but disregard environmental impacts. However, on macro-economic scale, the aim must be the reduction of the (non-renewable) primary energy (PE) use and of CO₂-emissions. There is need for an appropriate evaluation method for comparing and ranking different passive and active building technologies, e.g. according to their impact on the PE consumption. National conversion factors for PE/CO₂ differ significantly between different countries and are subject to change. Seasonal variations are not considered at all.

The electricity mix is and will be influenced to a higher extend in future by the available renewable energy sources, which are hydropower, wind energy and PV with strong differences in daily and seasonal availability. Without presence of seasonal storage, fossil fuels will predominantly cover the winter load. The electricity mix is also influenced by the load: buildings, have a high demand in winter, and lower in summer. The share of electricity for heating is still relatively low, but will increase with the more widely use of heat pumps and electric heating. Hence, savings in winter will have higher value.

This paper discusses - using a realized NZE multi-family building as an example - a PE evaluation method, that allows to include future development of the load (i.e. building stock) and electricity mix (share of REs) with seasonal variations and shows the impact on the ranking of different passive and active technologies.

KEYWORDS

Renewable Energy and Efficiency in Buildings, Primary Energetic Evaluation, Monthly Primary Energy Factors

INTRODUCTION

Sustainable and responsible use of resources is required in order to mitigate climate change. Micro-economic goals usually consider the capitalized investment costs and/or the purchased energy but the disregard environmental impact. However, on macro-economic scale, the (non-RE) primary energy (PE) use and CO₂-emissions must be reduced. The potential of the energetic use of biomass for buildings is limited. A significant further increased use of biomass for buildings will not be possible as high density energy will be also required for processes and mobility in a future sustainable energy system (see also Feist 2014).

The electricity mix is influenced by both, the (seasonal and daily) availability of renewable energy (RE) sources such as hydropower, wind and PV and by the load (i.e. the building stock).

Available energy sources: hydro power availability is relative homogeneous (slightly lower in winter), wind energy is volatile and slightly higher in winter and PV features very strong differences in daily and seasonal availability.

Load: buildings have a high demand in winter and lower in summer. The share of electricity for heating is still relatively low (e.g. in the range of below 5 % in Germany (D) acc. to BEDW 2016 and also in Austria (At) acc. to Statistik Austria 2016). It will increase with the

more widely use of heat pumps and electric heating in nZEBs/NZEBs (see below for a definition). This will result in a stronger seasonal variation of the electricity load. Without presence of seasonal storage, the winter load will be covered predominantly by fossil resources. Hence, savings in winter have higher value.

PREDICTING MONTHLY PRIMARY ENERGY CONVERSION FACTORS

There is a need for an appropriate evaluation method for comparing and ranking different passive and active technologies on micro- and macro- economic scale. National conversion factors for PE/CO₂ differ significantly between different countries and also between the EU member states and are subject to change. For example, the PE factor for electricity is 1.8 in Germany (ENeV) since 2016 (2.4 before), in Austria 1.91 since 2015 (2.62 before) (OIB-6, 2015, OIB-6, 2011). Seasonal variations are not considered at all.

For the electricity mix, the share of renewables within the time frame of consideration (e.g. 20 years) should be included and not as usually done the current (or past) status. A significantly increased share of RE electricity can be expected in the near future in particular in summer (PV), while in winter only a moderate increase is likely, unless there is a significant further extension of wind power or seasonal storage capacities are strongly build up.

If a large number of buildings use heat pumps (HP) for space heating and DHW preparation and produce electricity with on-site PV, both, the purchased electric energy and the share of renewables in the electricity mix depend on each other. Electricity that is used on site is not available in the grid and an increased share of fossil fuels in the energy mix have to be considered. PV electricity sold to the grid will replace fossil fuels more likely in winter, spring and autumn than in summer. Thus, a model for the PE/CO₂ conversion factor of the electricity mix needs to consider RE availability and the load curve. A possible approach of balancing PE demand (and CO₂ emissions) of a building with onsite RE generation is shown schematically in Fig. 1. Solar thermal (ST) energy is used to reduce the energy demand (heating, DHW + storage and distribution losses) that has to be covered by e.g. a heat pump (HP). Onsite PV can be used directly for appliances and auxiliary energies or to drive the HP. For higher own consumption, a (battery) storage is required, which is subject to losses.

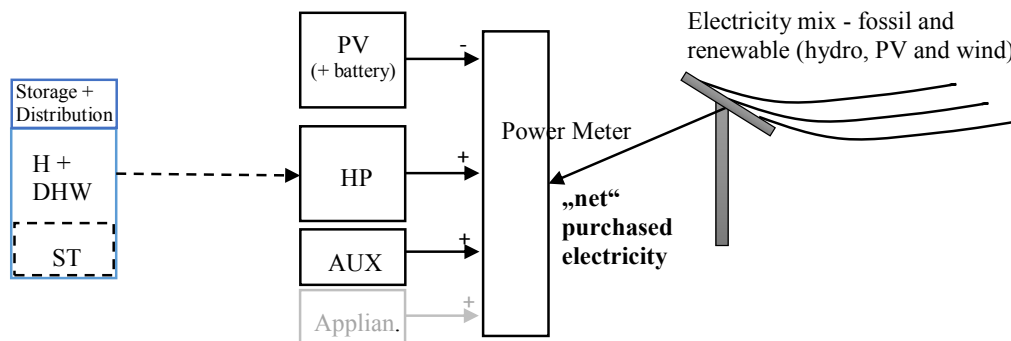


Figure 1 Possible approach for the calculation of the monthly net energy balance with heating (H) and domestic hot water (DHW) demand covered partly by ST; the remaining demand is covered by a heat pump (HP), which is partly powered by onsite PV, the remaining electricity demand for the HP, auxiliary energies (and appliances) is covered by the grid with volatile shares of renewable electricity

A monthly evaluation based on monthly primary energy factors is proposed, which can be used to calculate a more representative environmental impact of different efficiency and RE measures. The specific primary energy e_{PE} is calculated for each month (i)

$$e_{PE} = \sum f_{PE,i} \cdot w_{el,i} \quad (\text{eq. 1})$$

where $f_{PE,i}$ is the primary energy conversion factor for each month (i) considering the energy mix in each month and $w_{el,i}$ is the specific electric energy purchased in each month, see Fig. 2.

In two scenarios (A and B) with different shares of hydro, wind, PV and fossil energy, the PE conversion factor were calculated on monthly basis using e.g. the PE conversion factors shown in Fig. 2 and Table 1.

$$f_{PE} = f_{PE,hyd} \cdot W_{el,hyd} / W_{el} + f_{PE,wind} \cdot W_{el,wind} / W_{el} + f_{PE,PV} \cdot W_{el,PV} / W_{el} + f_{PE,fos} \cdot W_{el,fos} / W_{el} \quad (\text{eq. 2})$$

Table 1. CO₂-emissions and primary energy (PE) conversion factors of fossil and renewable electric energy sources, acc. to DVGW 2016

Source	CO ₂ / [g/kWh]	f _{PE} / [kWh _{PE} /kWh _{el}]
Electricity Mix Germany	520	
Electricity from Gas	432	2.4
Hydro		0.01*
Wind	9	0.05
PV (off-site)	56	0.1

*assumptions

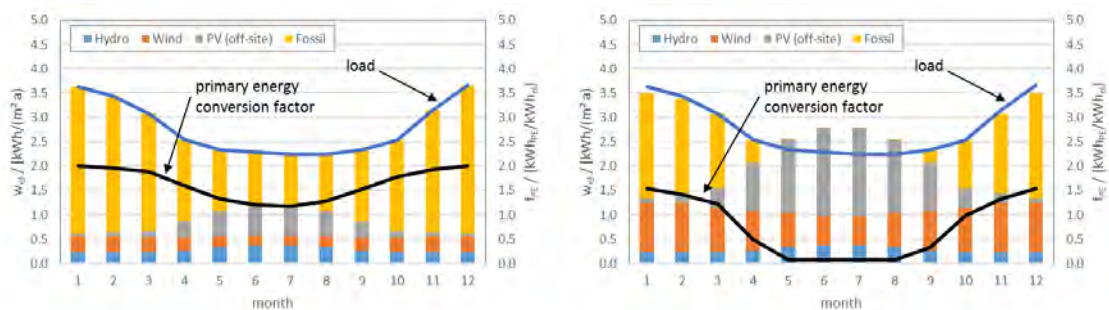


Figure 2 Monthly share of renewables (hydro, wind, PV, fossil) and corresponding PE conversion factor, example of a PH with a HP for heating and DHW supply with (A) a share of 10 % hydro, 10 % wind, 10 % PV and 70 % fossil, and (B) a share of 10 % hydro, 30 % wind, 30 % PV and 30 % fossil in the electricity mix

Table 2: Monthly PE conversion factors see Fig. 5 and PE conversion factors acc. to Tab. 1

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	av.
A: 10-10-10	2.01	1.96	1.89	1.60	1.33	1.20	1.18	1.28	1.53	1.78	1.92	2.01	1.6
B: 10-30-30	1.53	1.42	1.23	0.50	0.08	0.08	0.08	0.08	0.33	0.98	1.33	1.54	0.8

CASE STUDY: NZEB Innsbruck Vögelebichl

The Passive House (PH) project Vögelebichl in Innsbruck, two multi-family houses (MFH) with together 26 flats of the social housing company NHT (see Fig. 3) was designed such that the optimum share of PV and Solar Thermal (ST) should enable a NZE balance for heating, DHW preparation and aux. energies. One roof of the MFH is covered by PV (99.8 m²), the other is partly used for PV (52.5 m²) and partly for ST (73.6 m²). Fig. 4 shows a simplified hydraulic scheme including the GW heat pump (two stage), solar thermal collector (SC) field as well as the low temperature heat distribution and the separate decentral fresh water preparation (DHW plate HX). The double stage heat pump is equipped with hot gas (HG) de-superheating. Depending on the operation mode (heating or DHW preparation), the flow of the heat pump enters the buffer store (BS) at the top or at 1/3 of the height from the top. The combined return of the heating and DHW loop enters the large 6 m³ buffer store depending on the temperature level either at the bottom or at about 1/3 of the height of the store in order to enhance stratification. The electric backup heater (BH) is currently not used.

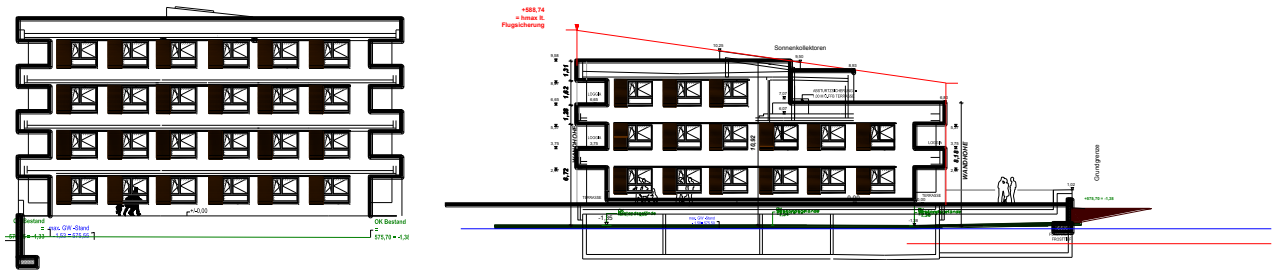


Figure 3 West view of the two MFHs in Innsbruck Vögelebichl, NHT Tirol; PHs with 4-pipe low temperature distribution system and fresh water modules in each flat

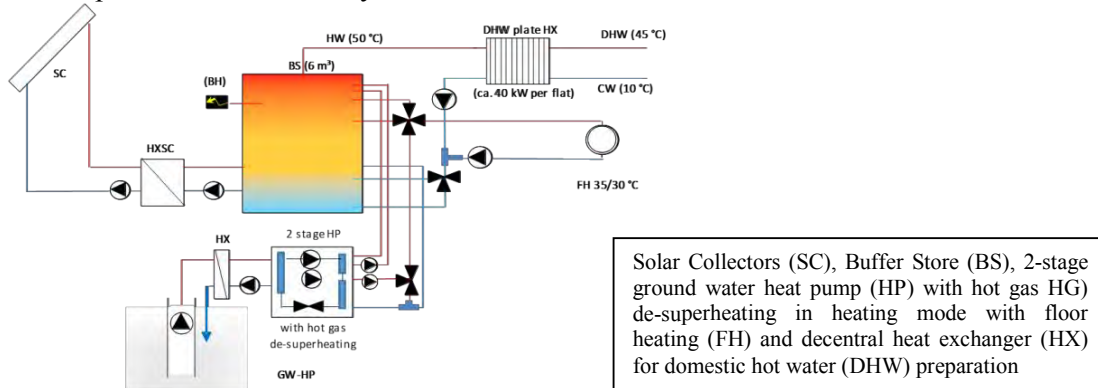


Figure 4 Simplified hydraulic scheme of the two NZEBs, project NHT Vögelebichl

nZEB vs. NZEB

nZEBs and NZEBs are comparable in the sense that both aim at minimizing CO₂-emissions and non-RE primary energy, nevertheless, their definitions differ quite much in detail and thus, their performance might eventually be quite different.

nZEB: nearly zero Energy Building according to EPBD, 2010. Each member state has a national definition with significant differences with respect to the energy use considered (heating, cooling, DHW, auxiliary, appliances), the maximum limits, the conversion factors etc. (see BPIE, 2016).

NZEB: Net Zero Energy Building. Generally an NZEB is a "grid-connected building which produces the same amount of energy on-site by renewable energy sources as it consumes on annual basis." (IEA SHC T40/HPT A40). There is a fuzziness in this definition regarding the interpretation of the system boundary, the energy flows, the weighting/conversion factors etc. Usually, Net Zero includes heating (and cooling), DHW supply and aux. energies (HRV, pumps, control, etc.) but excludes appliances. Even though, appliances have a large contribution to the overall electricity consumption (1500 kWh/a to 4500 kWh/a depending on the number of persons per household for a typical central European household, Statistik Austria 2016, BEDW 2013). According to this definition, a NZEB can consume relative high amount of (electric) energy in winter, when correspondingly a large PV area produces this amount as excess electricity in summer. This means, that according to the NZEB concept, the electric grid is considered as a loss-free seasonal storage, which is obviously not the case. In order to account for this weakness in this concept, additional performance indicators such as the load match factor or fraction of PV own consumption were suggested (see IEA SHC T40/HPT A40).

Remark: „net-zero“ as a goal can be a misleading concept, since optimization for net-zero may lead to one storey buildings, because reaching the net zero balance is more difficult compared to a multi-storey building (with smaller roof and façade area related to treated area). However, MFHs, which are more compact, are favorable from the overall energetic and macro-economic point of view (compare also Feist et al. 2014).

SIMULATION AND MONITORING RESULTS

In Ochs et al. 2017, detailed monitoring results of the buildings (heating and DHW demand) and of the system (distribution losses, performance factors, solar thermal and PV yield) are reported and improvements after the first year of operation were discussed and design recommendations based on monitoring data and simulation results were given. It has to be noticed that the first year of operation is not representative (construction moisture, partial occupation, adjustment of control/set points, etc.) and should not be used for the analysis. After the initial phase and after implementing some first optimization measures (adapted set points, etc.), an operation of the buildings and the HVAC system with net zero energy balance can be expected. Fig. 5 (a) gives the simulated monthly energy balance with the introduction of the improvements. Fig. 5 (b) gives the resulting electric energy balance that is used for further analysis of the data. Net energy balance for heating, DHW and auxiliary energy is achieved with PV on the roof. PV on the façade is required, if appliances are considered, too.

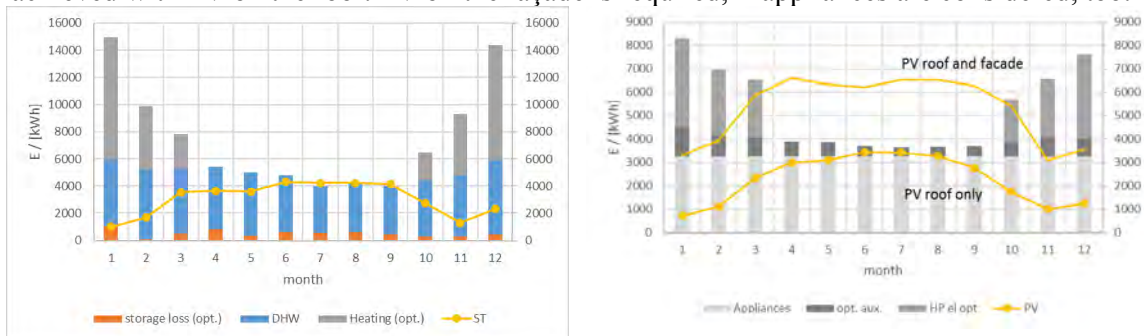


Figure 5 (a) simulated monthly thermal energy balance and (b) simulated monthly electric energy balance with PV on roof (as realized) and PV on roof and south façade (not realized)

RESULTS and DISCUSSIONS

The specific PE (e_{PE}) for heating and DHW production including the HP (after introduction of improvements, i.e. NZEB is achieved), appliances and with or without 300 m² of PV in south façade is calculated for the two scenarios (Fig. 2). It can be seen in Fig. 6 that in scenario B with higher share of renewables in the grid (all together 70 %), the additional PV in the façade yields less PE savings than in the scenario A (all renewables 30 %).

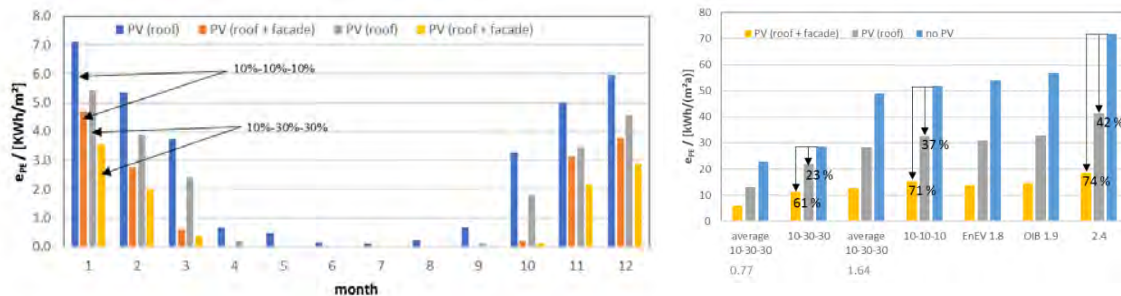


Figure 6 Specific PE (e_{PE}) for heating and DHW supply including the improved HP, appliances and with or without 300 m² of PV in south façades for scenario A (10 % hydro, 10 % wind and 10 % PV) and scenario B (10 % hydro, 30 % wind and 30 % PV); monthly balance.

In scenario A, the additional PV in the façade reduces the annual specific PE demand from 32.7 kWh_{PE}/(m² a) to 15.2 kWh_{PE}/(m² a), or by 53.5 % while in scenario B, it reduces from 21.9 kWh_{PE}/(m² a) to 11.2 kWh_{PE}/(m² a) or by 49.2 %.

State of the art is to use a constant PE conversion factor, e.g. 1.8 in Germany and 1.9 in At. PE savings with a constant PE conversion factor are 42 % without and 74 % with PV in the façade compared to the case without any onsite PV). In scenario A, savings reduce to 37 % without and 71 % with PV in the façade and to 23 % (without) and 61 % (with) in scenario B. With constant (i.e. average) PE conversion factor, savings are accounted for with the same weighting independent of the season. Thus, savings in summer are overrated. Measures such as (even) better insulation level, reduced storage and distribution losses or (even) better HPs would further reduce the winter load and are favourable compared to more PV.

CONCLUSIONS

Two MFHs in PH Standard with ST and HP system and onsite PV to achieve maximum PE savings were realized in Innsbruck and monitored for a period of more than two years. Net zero energy balance (for heating and DHW and auxiliary energies) could not be achieved during the first year of monitoring (2016), but predictions based on results after introduction of improvements show that Net Zero can be achieved. PH standard is key for achieving NZEB level for heating, DHW and aux. energies. If electricity consumption of appliances is included in the energy balance, additional PV on the south façade would be required.

NZEB do not significantly reduce winter grid load. The mismatch between (electricity) demand and PV yield has to be considered, e.g. by means of different electricity prices for purchase and sell or by seasonal/monthly PE conversion factors. A method is discussed allowing to compare different nZEB/NZEB concepts considering the time (season) of the electricity purchase from the grid in order to be able to optimize concepts towards reduced non-RE PE demand or CO₂-emissions in winter when renewable electricity is rare. The future development of the electricity mix and the load (building stock) can be considered and possible scenarios can be evaluated.

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REFERENCES

- BPIE, *Nearly Zero Energy Buildings Definitions Across Europe*, EPISCOPE project (IEE/12/695/SI2.644739), 2016
- BEDW (2016), *Wie heizt Deutschland*, BEDW-Studie zum Heizungsmarkt, Juli, 2016.
- BEDW (2013), *Energie-Info*, Stromverbrauch im Haushalt, Berlin, 2013.
- DVGW 2016, Weiterentwicklung der Primärenergiefaktoren im neuen Energiesparrecht für Gebäude, Endbericht 7.4.2016
- Feist, Wolfgang (2014), Passivhaus – das nächste Jahrzehnt. In: Tagungsband zur 18. Internationalen Passivhaustagung, Aachen, April 2014.
- OIB-6 Richtlinie 6, *Energieeinsparung und Wärmeschutz*, Österreichisches Institut für Bautechnik, 2011, update 2015
- Ochs Fabian, Dermentzis Georgios, Feist Wolfgang (2014), Minimization of the Residual Energy Demand of Multi-storey Passive Houses – Energetic and Economic Analysis of Solar Thermal and PV in Combination with a Heat Pump, Energy Procedia Volume 48
- Ochs Fabian, Dermentzis Georgios, Aleksandra Ksiezyk (2018), Simulation and Monitoring Results of two MFHs in PH Standard with Heat Pump, Solar Thermal and PV, Solar Works Congress, 2018, Abu Dhabi, UAE, 2018
- Statistik Austria, Bundesanstalt Statistik Österreich, 2016