Effect of technical building system types on load matching indicators for net zero energy residential buildings

László Zsolt Gergely, Tamás Csoknyai, Miklós Horváth
Budapest University of Technology and Economics, Budapest, Hungary

Abstract

To decarbonize residential building stocks, on-site photovoltaic generation is a widespread solution. A consequent issue is the simultaneity of the generation and the load of the households. With the help of dynamic building energy performance simulation in TRNSYS this work focused on the load matching indicators of net zero energy buildings with different technical building systems and three building types. Results revealed that higher shares of domestic hot water production in the electricity demand as well as higher amounts of cooling need can improve the indicators. Nevertheless, it must be noted that the mutual presence of these increased loads can also worsen the results. Yet, air-to-air heat pump systems with electric water heater consistently outperformed air-to-water heat pump systems.

Highlights

- PV systems shall be sized to serve around 20-50% of annual electricity consumption to reduce grid interactions.
- Air-to-air heat pumps with electric boilers outperform air-to-water heat pumps for load-matching indicators.
- Annual yield of photovoltaics suggests an easier estimation of load-matching indicators than their orientation
- Net zero energy PV sizing increases grid interaction by 45% compared to no PV.
- Net zero buildings only produce 16% of their energy streams directly to themselves.

Introduction

Transition of the residential building stock to nearly zero energy buildings (nZEB) is a core topic for the European legislation in achieving goals regarding reducing energy consumption, carbon emission and dependence on imported energy (D'Agostino et al. 2021). Requirements of the nZEB level vary by nation, but it is a common practice that these buildings involve photovoltaics (PV) for generating electricity and the installation of heat pumps for tempering the building or even for domestic hot water (DHW) generation. This is also especially valid for Net Zero Energy Buildings (NZEBs), when on an annual base, renewable energy production is equal to the consumption of a specific building.

Electrification and prosumerism bring up new difficulties – estimating the loads are challenging for the grid operators. To ease the case, an upcoming trend is to enhance the use of generated PV power locally. This can be tracked through the change of feed in system (yearly net metering is transforming to monthly or higher resolution metering systems). Scientific research aims to investigate the problem via the so-called load-matching indicators (LMIs), which quantify the synchrony of power generation and consumption using different metrics.

Scientific research predominantly uses, self-consumption (SC) and self-sufficiency (SC) for the evaluation of this intermittence problem, when approaching from energy point of view. Numerous authors aim to investigate the effect of building insulation or thermal inertia level (Pinamonti, Prada, and Baggio 2020; Franzoi et al. 2021), heating, ventilation and air conditioning system type and layout (Cillari, Franco, and Fantozzi 2021; Pinamonti and Baggio 2020; Heinz and Rieberer 2021) on these metrics. Others focus on the effect of different climates (Franzoi et al. 2021; Pinamonti, Prada, and Baggio 2020) or reveal the issue of sizing the PV with its influence on the SC and SS metrics (Gjorgievski et al. 2020; Cillari, Franco, and Fantozzi 2021).

Based on literature research, investigating the effect of PV orientation, different kinds of air-source heat pump systems and the effect of building geometry is less common. This research aims to investigate the effect of such parameters on SC and SS indicators as well as to extend the observations to self-production (SP) and grid-liability (GL) metrics, introduced in our previous research. GL and SP have an additional benefit that they can suggest the optimal PV capacities to maximize on-site energy utilization and minimize grid necessity (Gergely, Csoknyai, and Horváth 2022).

Abbreviation	**Meaning**
ASHP	air-source (air-to-air) heat pump
AWHP	air-to-water heat pump
COP	Coefficient of performance
DHW	domestic hot water
GL	grid-liability
GTDR	generation to demand ratio
LMI	load-matching indicator
nZEB	nearly zero energy building
NZEB	net zero energy building

PV	photovoltaic
SC	self-consumption
SP	self-production
SS	self-sufficiency

Methods to assess the effect of the different parameters on the load matching indicators, dynamic building energy performance simulation case studies have been elaborated using theTRNSYSv18 software (Klein and S.A 2018).

Building types

In the current research three types of buildings were modeled, two selected from the Hungarian residential building typology (referenced as Type 2 and Type4) developed in a previous project using the synthetical average building method, which was also used for the National Building Energy Strategy (ÉMI 2015; KEOP 2015). These two types are very widely built all over the country and in the neighboring countries as well. The third one was proposed with the geometry of a possible reconstruction of the common “Kádár-cubes”(Type 38) (Csoknyai et al. 2022). As the scope of the study is to reveal the energy consumption patterns and utilization of NZEBs, the first step is the retrofit of the building envelope. The thermal transmittance characteristics were set to meet the national standard for retrofits, namely, 0.17 W/m^{2}K for the attic slab, 0.24 W/m^{2}K for the external walls, 1.12 W/m^{2}K for the glazed surfaces. Envelope size characteristics are detailed in Table 1.

Table 1: Modelled buildings’ geometry characteristics.

Building type	Type 2	Type 4	Type 38
Heated floor area [m^2]	77.2	100.3	98.2
Heated volume [m^3]	208.5	320.5	283.0
External wall surface [m^2]	93.0	102.8	141.1
Glazed opening area [m^2]	10.7	13.8	36.0
Floorplan shape	Rectangular	Rectangular	“L” shape

Technical building system description

All three models have been simulated with two different HVAC systems. Firstly, an air-to-water heat pump system (AWHP) has been simulated for heating, with floor heating, cooling with slab cooling, and DHW generation with an immersed coiled-tube heat exchanger. The sizing of the heat pump system provides that the AWHP can cover the heating needs in a monovalent manner. The floor heating system is designed for forward end return temperatures of 35/30°C, the chilled ceiling is with 17/22°C. For DHW production, the storage tank capacity of 200 l is with a desired temperature of 50°C, provided by the heat pump. For leaving water temperatures of 35°C and 55°C, the heat pump has a coefficient of performance (COP) of 3.46 and 2.27 respectively, at 2°C ambient temperature and part load ratio of 100%.

The second system builds up from an air-to-air heat pump (ASHP) for heating and cooling, and an electric water heater for domestic hot water generation. With a normalized air flow rate of 1, outdoor air dry bulb temperature of 0 °C, internal air temperature of 20 °C, the COP is 2.80 of the simulated models. Heat pumps have been sized to cover the loads of the buildings at the highest demands of the used Typical Meteorological Year weather profile (TRNSYS database from Meteonorm) for Budapest-Lorinc. Performance maps for both TRNSYS components (Table 2) have been used by the sample catalog data (Klein and S.A 2018).

Regarding DHW consumption, a European Standard profile was taken into account matched with a national average 126 l/household consumption (European Committee for Standardization-CEN 2012; Vámos and Horváth, n.d.).

For PV generation, three orientations – west, south and east facing – and three inclination angle – 15, 35 and 60° were simulated for 1 kWp capacity. Capacities until 9 kWp with a step of 1 kWp were obtained from the simulations of 1 kWp modules.

Table 2 sums up the components and the specifications used in the simulations.

Table 2: TRNSYSv18 components used in the simulation.

Element	TRNSYS component	Description
House model	Type 56	Surfaces accordingly to the house type.
AWHP	Type 525b_v2	Variable speed compressor heat pumps. Parameters sized to the heat demand of the house.
ASHP	Type 786_v2a	
Domestic hot water buffer	Type 156	Storage tank with immersed coiled-tube heat exchanger. Heated with either AWHP through the coil (200 l) or electric resistance of 1.8 kW (120 l).
Photovoltaics	Type 103	Polycrystalline PV panel. 1 kW peak modelled; other sizes scaled up accordingly.

Electricity consumption was assumed by the statistical load profile of a distribution system operator and the national average of 2,500 kWh annual consumption (E.on 2022).This was applied as an alternative of simulating various load profiles for the appliances used, that can also affect on the results (Gjorgievski et al. 2020). Electrical battery has not been involved in the simulations.

In total, 54 simulations were run,

- 3 building types,
- 2 HVAC layouts,
- 9 PV orientations,

and scaling for PV capacities from 1 kW to 9 kW, 486 scenarios were analyzed in the study.

Results are aggregated for the whole year period in a resolution of 5 minutes (Povolato et al. 2023; Jiménez-Castillo et al. 2021). Self-consumption, self-sufficiency, self-production, and grid-liability metrics were investigated in the study. Using the notations of Figure 1, 'A' for load covered from the electricity grid, 'B' surplus power fed back to the grid and 'C' power utilized directly on-site, the indicators can be calculated as the following:

self-consumption:

$$SC = C\,/\,(B{+}C) \tag{1}$$

self-sufficiency:

$$SS = C\,/\,(A{+}C) \tag{2}$$

self-production:

$$SP = C\,/\,(A{+}B{+}C) \tag{3}$$

grid-liability:

$$GL = (A{+}B)\,/\,(A{+}C) - 1 \tag{4}$$

SC, SS and SP have their range in the range of [0,1] and, and the higher value is the more appealing. However, while SC and SS are monotonous as the function of the installed PV capacity, SP has an optimum for it. Similarly, GL has an optimum as of the installed PV capacity, but in this case the optimum is a minimum. GL has a range of [-1, ∞). -1 means that the site is operating fully independently from the grid, 0 means it has just as much interaction with the grid as without a PV system and positive values mean that there is an increase in grid interaction compared to no PV case.

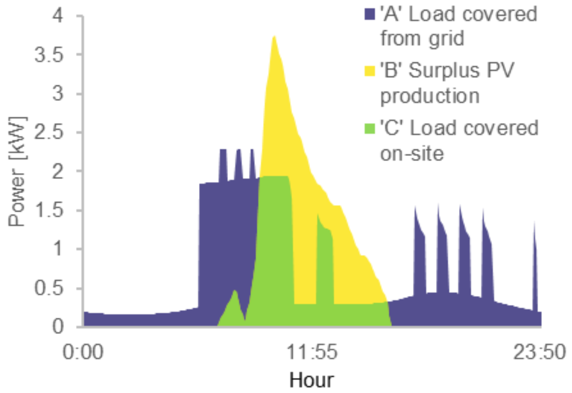

Figure 1: Scheme of power streams for load-matching indicator characterization.

Results and discussion

Energy demand for the different scenarios

To analyze the behavior of the load matching indicators for the different scenarios, it is necessary to meet the results of the simulations. Table 3 represents the annual energy consumption of the simulated cases, while Table 4 the kWh/kW peak production ratio for the different PV orientations.

Table 3: Annual and seasonal energy consumption [kWh/year]

Type	2	4	38	2	4	38
HVAC	**AWHP**			**ASHP**		
Energy cons. [kWh/yr]	5575	5746	6367	6955	7185	7670
HVAC energy during Apr-Oct. [kWh/yr]	355	334	679	1173	1202	1429
HVAC energy during Oct-March [kWh/yr]	2720	2912	3188	3282	3483	3741

Table 4: Annual yield [kWh/year] per kW peak capacity by PV orientation.

[kWh_{yr}/ 1 kWp]	W	S	E
15	1061	1180	1056
30	1024	1223	1007
60	883	1138	862

Load matching indicators for NZEB PV capacity

At first, load matching indicators in general are investigated by the results of the simulations. NZEB-sized PV systems are defined as buildings with a generation to demand ratio (GTDR) of [0.9,1.1], which means that the annual PV yield is +/-10% of the gross electricity consumption. This provides the following statistical results for the indicators seen in Table 5, which correspond to 66 cases out of the 486 (minimum 10, maximum of 13 PV orientations for each of the building types and HVAC system combination).

Table 5: Statistical values for load-matching indicators with NZEB-sized PV systems.

	SC	SS	SP	GL
Mean	0.2768	0.2752	0.1601	0.4456
Minimum	0.2274	0.2337	0.1336	0.3166
Maximum	0.3263	0.3137	0.1842	0.5889
Standard deviation	0.0228	0.0209	0.0137	0.0623

SC and SS come with approximately the same mean value, 0.276 and vary in a very similar range. Consequently, this means that a NZEB building can produce approximately 27.6% of its energy consumption by direct on-site utilization. Further demand is provided from the grid and consequently, this same amount is fed back to the electricity network in other periods. Self-production and grid-liability metrics highlight exactly the controversiality of these buildings. The represented NZEBs result a significantly lower mean for SP, 0.1601, meaning that only 16% of the energy streams (import + load + export) is generated for direct on-site utilization.

The other 84% of the energy streams of the house is participating in grid transfer. Either surplus PV production that is fed back to grid or consumption, covered from grid.

In addition, NZEB sizing strategy leads to increased grid interaction, as GL reveals. A mean of 45% suggests, that, these “net zero” buildings exchange 45% more energy with the grid, than the same buildings without photovoltaics. It is to highlight that even the minimum is 32%.

Effect of building type and HVAC system

To reveal the influence of building type and the HVAC system in case of the NZEB types defined by the previous paragraph, it is necessary to look at the consumption in details. Table 3 revealed that there is practically no difference of the final energy consumptions of building types 2 and 4. Figure 2 highlights, that this is due to the relatively large ratio of the consumption of the appliances and domestic hot water generation. In both aspects, difference emerging from heating energy consumption is reduced as of the high efficiency of the heat pump system. Furthermore, there is no cooling energy need for these two types. In case of Type 38 cooling appears as well, accounting for approximately 5% of energy consumption in both cases.

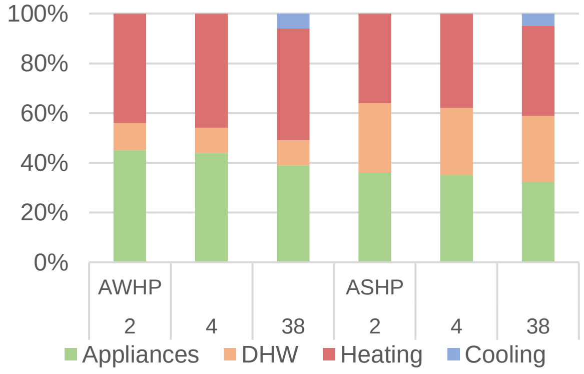

Figure 2: Share of consumptions for building types

Contrast of AWHP and ASHP systems comes as expected. For the latter, usage of electric water heater requires much larger energy, increasing the share of DHW generation (Table 3).

These are determinant on the SC and SS of the different building types and HVAC systems, as the energy matching chart (Figure 3) shows.

The simulation results show similar trends for building types 2 and 4. Apart from the few outliers, these types have lower SC and SS in case of the AWHP systems and higher in case of ASHP systems than type 38. A probable explanation is that in case of the AWHP system, as the heat pump either cools or generates hot water, peaks of HP have a limit. While in case of ASHP with electric boiler, the operation of the two appliances can come at the same time, providing higher peak demands, which are uncertain to be served by the PV system (Gergely, Csoknyai, and Horváth 2022).

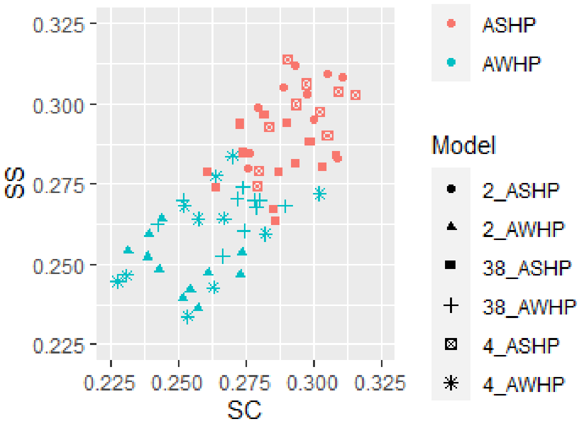

Figure 3: Energy matching chart for net zero energy photovoltaic sizing strategy

Similarly, impact of DHW usage during summer periods is traced on the GL and SP metrics as the functions of the energy consumptions (and consequently, building types). Higher PV production is harvested with the increased electricity need in case of electric water heaters, thus increasing GL and SP in case of the ASHP system.

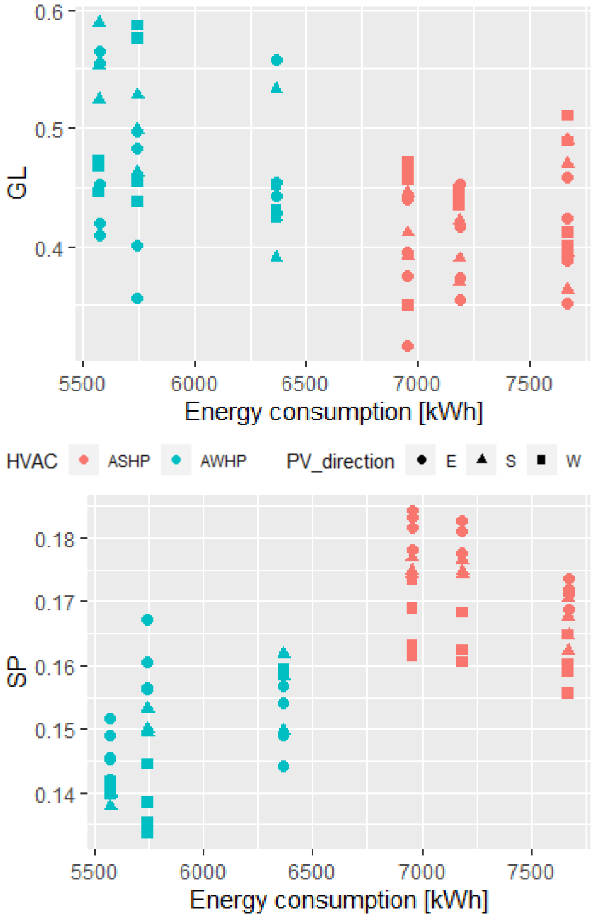

Figure 4: Grid-liability and self-production as the function of annual energy consumption of the net zero energy buildings

This idea is supported with Figure 5, load analysis of a spring day. It is certain, that with both PV systems sketched, on-site utilization of photovoltaics is higher in case of ASHP systems. Covering approximately the same ratio of DHW demand on the shown example, exactly means an increased simultaneity, as in case of ASHP systems, the DHW share is more significant as shown earlier.

Figure 5 also suggests that when sizing PV for NZEB yield, if winter loads are dominant – such in case of AWHP systems, lower fraction of high-yield periods can be exploited. On the contrary, if DHW need is dominant in PV sizing, high amount of summer yields can be utilized for DHW production (Gergely, Csoknyai, and Horváth 2022). This could be enhanced with a cooling-dominant example (Bee et al. 2019).

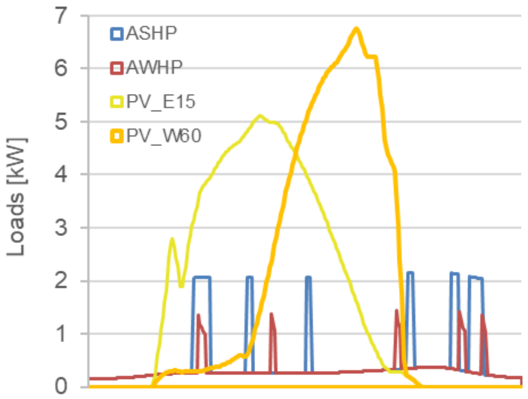

Figure 5: Loads of air-source heat pump system (ASHP), air-to-water heat pump system (AWHP) and photovoltaic production for net zero sizing with east facing 15°inclination and west facing 60°inclination for a spring day

Impact of PV orientation, capacity and yield

The other core question of the study is to reveal the circumstances which suggest the optimum of the indicators (maximum in case of SC, SS, SP and minimum for GL) along the parameters of the PV system. Plotting the simulation results for the range of 1-9 kW PV peak capacity and smoothing a curve on the datapoints by orientation helps to examine the effect of both the direction the panels facing at, and the angle of incidence. Figure 6 reveals that the best orientation of all the indicators are east facing with high incidence angle. West facing PVs are favorable for SC though not performing well for SS.

While in case of self-sufficiency, the higher the yield, the better the indicator, it is the opposite for self-consumption. Noting this leads to the idea that the different yield per peak capacity of the various orientations have a disfiguring effect.

Consequently, LMIs are indicated by the annual yield of the different systems in Figure 7. The comparison of the figures justifies this preconception – which is quite logical, though may not be obvious. Based on this it is also unambiguous why trends of the different orientations spread by the indicators for the observation over the peak capacity, and why it is moderated over the annual yield case. This implicitly also suggests, that LMIs are easier to estimate by the annual yield of the PV system rather than the capacities.

An indicator-by-indicator analysis also brings changes to the LMIs by PV orientation. While by capacity, west facing panels achieved good results, for annual yield they become the worst for SC and GL. Thus, applying the capacity of the panels mislead the results for those indicators.

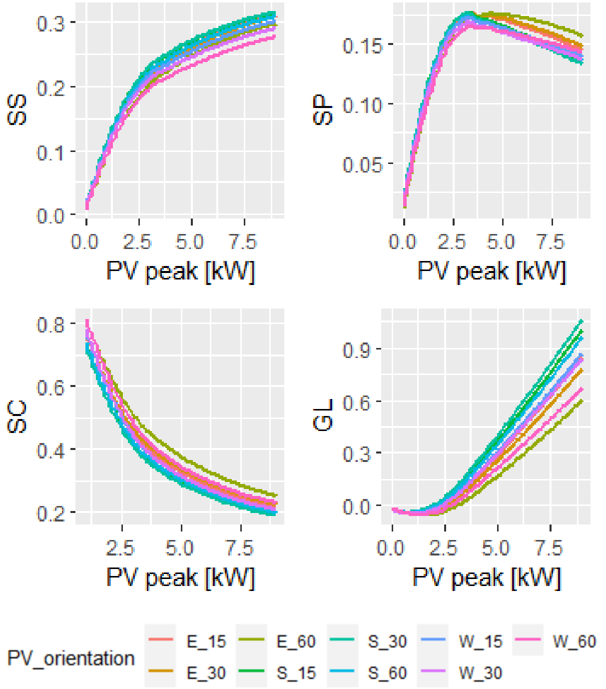

Figure 6: Load-matching indicators for different PV peak capacities[kW] and orientations (by color).

In the meantime, the effect of production periods is more remarkable for the eastern orientation, as with even lower annual yield per peak capacity ratio, eastern orientations still provide optimum for all the LMIs.

Table 6: Orientations of minimum and maximum values of load-matching indicators, sizing for annual electricity consumption (+/-10%).

	SC	SS	SP	GL
Minimum at	W_60	W_60	W_60	E_15
Maximum at	E_15	E_60	E_15	S_30

Poor results of south facing panels are consolidated by changing from capacity to annual yield, providing values consistently between the eastern and western alternatives.

It is also notable, while SC, SS and GL has changed notably, SP is less effected by altering to annual yield from capacity, which is due to the construction of the indicator. Self-production merges all the energy streams (from grid, on-site directly utilized and to grid) at once to its denominator.

Figure 8 sums the notices of the previous paragraphs. SP and GL of the different HVAC systems as the function of generation to demand ratio reveals, that from the perspective of PV sizing, NZEBs result in buildings with heavily increased interaction with the grid.

The optimum of SP suggests approximately the half of the system that is applied in case of NZEBs (so systems that approximately generate the half of the household's overall electricity consumption). This would enhance the utilization of generated PV directly on-site yet would not increase grid-liability heavily. The optima of GL values appear at around 0.2 GTDR.

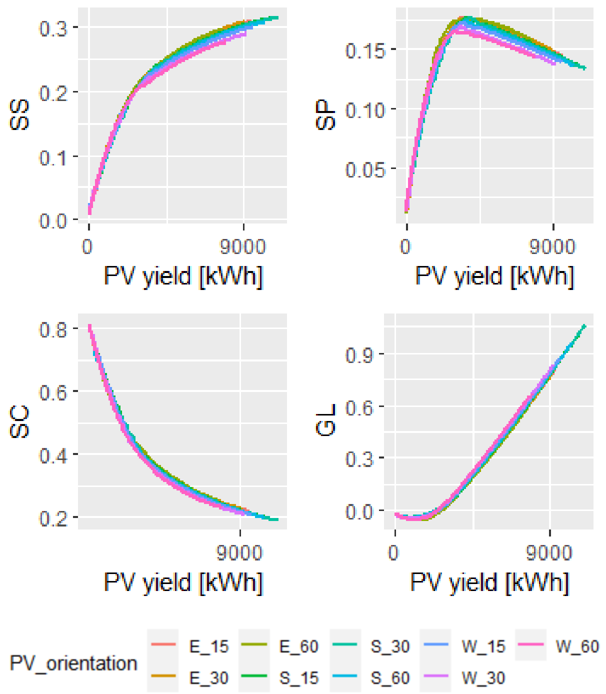

Figure 7: Load-matching indicators for different PV annual yields [kWh] and orientations (by color).

Figure 8: Self-production and grid-liability as the functions of the generation to load ratio, by the specific heating system type.

Conclusions

Net zero energy building design is a core element of the European legislation. This includes on one hand, a low energy consumption building and on the other, a technical building system based on renewable energy. Predominantly this is achieved with solar panels and heat pumps in case of residential buildings. Intermittence of these systems, nonetheless, is a key issue in the transformation of the building stock to carbon neutral. Load matching indicators aim to describe the synchrony of the loads and the generation. In the present study we aimed to reveal the aspects of applying different system layouts, namely air-to-water heat pump system for heating, cooling and domestic hot water generation once and twice, air-to-air heat pump for maintaining the preferred temperatures with electric water heater for providing hot water. Simulation results of three houses with the same DHW need and electric load profile of appliances revealed, the system type is determinant for the load matching metrics. Higher share of summertime consumption leads to better indicators with NZEB PV sizing. Consequently, systems with higher DHW energy consumption (in the context, electric boiler compared to HP water heating) can improve the load matching indicators. Similarly, increased share of cooling loads can be accounted for improved simultaneity.

From the perspective of the applied PV system annual yield seems to be a better choice when drawing conclusions for the indicators, as they show a moderated variance compared to the plot over the PV capacity. With the loads observed, east facing panels with higher angle of incidence (60°).

Eventually, it is to be highlighted that the observed net zero energy buildings could achieve self-consumption and self-sufficiency at around 27%, yet this resulted a heavily (by 45%) increased grid interaction (grid-liability) to a case without photovoltaics. In the meantime, self-production has also revealed that only 16% on the energy streams of these NZEBS are provided for on-site utilization, 42% is the load covered from the grid and another 2% of the total energy balance is the PV production fed back. Self-production and grid-liability metrics suggest that an optimal sizing strategy to residential PV systems would be a coverage of 20-50% of the annual loads.

In continuing research, the amount of DHW and the profile and the cross effect of it with the increase of cooling load will be observed more detailed. As well as the load emerging from the appliances will be varied and effect of applying household size batteries will be investigated.

Acknowledgement

The work has been carried out within the research project entitled "Integrated development of the residential building stock and the electricity mix models for decarbonised building stock scenarios". The project (no. K 142992) has been implemented with the support provided from the National Research, Development and Innovation Fund of Hungary, financed under the K_22 funding scheme.

This paper was supported by the Janos Bolyai Research Scholarship of the Hungarian Academy of Sciences.

The research reported in this paper is part of project no. TKP-9-8/PALY-2021 has been implemented with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the TKP2021-EGA funding scheme.

References

Bee, Elena, Alessandro Prada, Paolo Baggio, and Emmanouil Psimopoulos. 2019. “Air-Source Heat Pump and Photovoltaic Systems for Residential Heating and Cooling: Potential of Self-Consumption in Different European Climates.” *Building Simulation* 12 (3): 453–63. https://doi.org/10.1007/s12273-018-0501-5.

Cillari, Giacomo, Alessandro Franco, and Fabio Fantozzi. 2021. “Sizing Strategies of Photovoltaic Systems in NZEB Schemes to Maximize the Self-Consumption Share.” *Energy Reports* 7: 6769–85. https://doi.org/10.1016/j.egyr.2021.09.117.

Csoknyai, Tamás, Zsuzsa Szalay, László Zsolt Gergely, Dóra Szagri, Miklós Hotváth, Borbála Takácsné Tóth, and Péter Kotek. 2022. “A Rezsicsökkentés Szabályváltozásának Hatása a Magyar Lakóépületszektor Gázfogyasztására.” Vol. 2022.

D’Agostino, Delia, Sofia Tsemekidi Tzeiranaki, Paolo Zangheri, and Paolo Bertoldi. 2021. “Assessing Nearly Zero Energy Buildings (NZEBs) Development in Europe.” *Energy Strategy Reviews* 36 (July): 100680. https://doi.org/10.1016/j.esr.2021.100680.

E.on. 2022. “Statistical Load Profiles of Residential Consumers - 2021.” 2022.

ÉMI. 2015. “National Building Energy Strategy (in HU).”

European Committee for Standardization-CEN. 2012. *EN 12381 - Energy Performance of Buildings - Method for Calculation of Design Heat Load - Part 3: Domestic Hot Water Systems Heat Load and Characterisation of Needs*.

Franzoi, Nicola, Alessandro Prada, Sara Verones, and Paolo Baggio. 2021. “Enhancing PV Self-Consumption through Energy Communities in Heating-Dominated Climates.” *Energies* 14 (14): 1–17. https://doi.org/10.3390/en14144165.

Gergely, László Zsolt, Tamás Csoknyai, and Miklós Horváth. 2022. “Novel Load Matching Indicators for Photovoltaic System Sizing and Evaluation” 327 (September): 0–9. https://doi.org/10.1016/j.apenergy.2022.120123.

Gjorgievski, Vladimir Z., Nikolas G. Chatzigeorgiou, Venizelos Venizelou, Georgios C. Christoforidis, George E. Georghiou, and Grigoris K. Papagiannis. 2020. “Evaluation of Load Matching Indicators in Residential PV Systems-the Case of Cyprus.” *Energies* 13 (8): 1–18. https://doi.org/10.3390/en13081934.

Heinz, Andreas, and René Rieberer. 2021. “Energetic and Economic Analysis of a PV-Assisted Air-to-Water Heat Pump System for Renovated Residential Buildings with High-Temperature Heat Emission System.” *Applied Energy* 293 (April). https://doi.org/10.1016/j.apenergy.2021.116953.

Jiménez-Castillo, G., C. Rus-Casas, G. M. Tina, and F. J. Muñoz-Rodriguez. 2021. “Effects of Smart Meter Time Resolution When Analyzing Photovoltaic Self-Consumption System on a Daily and Annual Basis.” *Renewable Energy* 164: 889–96. https://doi.org/10.1016/j.renene.2020.09.096.

KEOP. 2015. “Költségvetési Szervek Kezelésében Álló Épületek Energiahatékonysági Felújítását Szolgáló 2014-2020. Évi Fejlesztési Program És Akcióterv Kidolgozása És a Lakossági Épület Energiahatékonysági Potenciál Felmérése.” https://doi.org/10.1016/j.jnc.2020.125798%0Ahttps://doi.org/10.1016/j.smr.2020.02.002%0Ahttp://www.ncbi.nlm.nih.gov/pubmed/810049%0Ahttp://doi.wiley.com/10.1002/anie.197505391%0Ahttp://www.sciencedirect.com/science/article/pii/B9780857090409500205%0Ahttp:

Klein, and S.A. 2018. “TRNSYS 18 - A Transient System Simulation Program.” 2018. http://sel.me.wisc.edu/trnsys/.

Pinamonti, Maria, and Paolo Baggio. 2020. “Energy and Economic Optimization of Solar-Assisted Heat Pump Systems with Storage Technologies for Heating and Cooling in Residential Buildings.” *Renewable Energy* 157: 90–99. https://doi.org/10.1016/j.renene.2020.04.121.

Pinamonti, Maria, Alessandro Prada, and Paolo Baggio. 2020. “Rule-Based Control Strategy to Increase Photovoltaic Self-Consumption of a Modulating Heat Pump Using Water Storages and Building Mass Activation.” *Energies* 13 (23). https://doi.org/10.3390/en13236282.

Povolato, Margherita, Alessandro Prada, Sara Verones, and Paolo Baggio. 2023. “On the Effect of the Time Interval Base and Home Appliance on the Renewable Quota of a Building in an Alpine Location.” *Energies* 16 (1). https://doi.org/10.3390/en16010384.

Vámos, Viktória, and Miklós Horváth. n.d. “RESIDENTIAL DHW CONSUMPTION ANALYSIS FOR MULTIFAMILY BUILDINGS SUPPLIED BY DISTRICT HEATING,” 265–68.