Parametric Analysis of Greenhouse Gas Emissions of the Technical Building System Alternatives in Detached Houses Retrofitted to nZEB Level

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Abstract: Buildings account for a significant part of greenhouse gas emissions. A reasonable way of mitigation is the retrofit of the building stock, both from the perspective of the building envelope and the technical building system. However, to maximize carbon emission savings, effects of these two measures shall be observed hand in hand. This paper approaches the issue through the possible renovation of the detached houses of the Hungarian residential building stock to a nearly zero energy building (NZEB) level. Three system layouts, namely air-to-water heat pumps, air-to-air heat pumps with electric boilers and gas condensing boilers are compared in terms of greenhouse gas emissions while covering heating and domestic hot water demands. Results reflect that heat pumps offer the possibility of a remarkable reduction of carbon-dioxide emissions compared to condensing gas boilers in case of the present electricity mix of Hungary. Furthermore, it appears that after the NZEB renovation, air-to-water heat pumps represent the best solution for detached houses. In the meanwhile, air-to-air heat pumps with electric boilers could remain eco-friendly for applications with relatively low hot water needs.

1 INTRODUCTION

Buildings account for a significant part of both primary energy consumption and carbon emissions worldwide (Mayer, Szilágyi, and Gróf 2020). As a result, building sector is often prioritised in policies aiming the reduction of energy consumption and greenhouse gas emissions. Performance requirements of building structures and technical building systems are getting more and more strict, which in Europe can be traced trough Nearly Zero Energy Building (NZEB) requirements, targeting both minimizing the energy consumption and enhancing the use of renewable energy sources (Balint & Kazmi, 2019). For the latter, heat pumps are often considered as a widely available and effective solution of renewable based technical building system (Marinelli et al., 2019).

Nevertheless, there are other factors to consider besides energy consumption to estimate greenhouse gas emissions of a system. Several calculation methods aim to include such indicators. In case of heat pumps the Total Equivalent Warming Impact (TEWI) is widely used (Mota-Babiloni et al., 2020).

Despite the fact that both NZEB regulations and TEWI calculations are widely known, they are rarely observed together. This paper introduces and calculates parameters to define the best performing technical building system out of three up-to-date layouts, namely gas condensing boiler, air-to-water heat pump (AWHP) and air-to-air (AA) heat pump with electric boiler for hot water generation. Section 2 reveals the parameters of the study, and that of the carbon footprints (CF) of the three technical building systems. Section 3 first presents the emission calculations of the different systems for the specific cases, then reveals the certain parameters, where air-source heat pump-based systems perform better than

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the gas condensing boiler system. This is continued with contrasting the air-source heat pump-based systems. Finally, section 4 concludes the results.

2 PARAMETERS OF THE STUDY

2.1 Buildings Under Study

From the perspective of greenhouse gas emission, residential sector of buildings is often considered a more significant emitter than commercial sector (Ge & Friedrich, 2020). In this paper therefore we approach the problem from the residential buildings' perspective. Data of the Hungarian building stock was used, containing 19 types of residential buildings to describe the national typology (Tamas, 2013), out of which 9 types of detached houses (each named by the reference typology) were considered as potential sites for heat pump application. In terms of construction date, selected types fall in the period from the 1950's to today's constructions. In case of the newest types, the original construction itself guarantees NZEB parameters, for the former ones NZEB retrofit actions are considered.

In this paper by NZEB-level buildings we assume buildings with a building shell fulfilling NZEB requirements, not considering if they fulfil additional requirements, such as overall energy performance and renewable energy share.

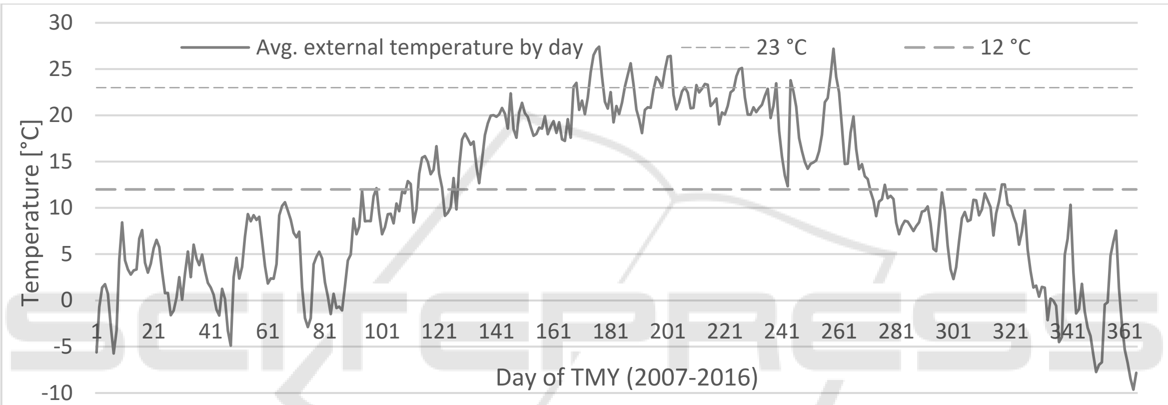

Figure 1: Typical meteorological year of Budapest, Hungary, generated from the data of years 2007-2016 (Poggi et al., 2008).

2.1.1 Energy Needs and Heat Loads

Hungary, located in central Europe, has a temperate seasonal climate. In these circumstances, the role of the technical building system is usually to cover the heating and domestic hot water needs of the houses. Cooling needs are relatively low due to the climatic characteristics and the national building code (TNM 7/2006 Decree) regarding NZEB buildings, aiming to minimize or even exclude active cooling in case of the residential sector, with proper building design (Ministry Without Portfolio of Hungary, 2020). Having a look at Figure 1, representing a typical meteorological year (TMY) of Budapest (European Commission, 2017), it is seen that for a significant part of the year the average external temperature by day is below under 12°C, which is usually considered as the heating threshold temperature.

On the other hand, the number of days with the average above 23°C (which is determined as a cooling threshold temperature with a maximum internal temperature of 26°C and subtracting the maximum allowed overheating temperature difference of 3°C) is much fewer. Considering occupancy schedule as well, it is seen that the number of hours where the external temperature is above 26°C in the period of 17:00 – 07:00 is only 18 hours a year. For the present study cooling, therefore, is not considered.

The design heat load for heating is determined according to the national building code (Ministry Without Portfolio of Hungary, 2020), as well as the net energy needs of heating and DHW production. DHW net energy need is determined as 30 kWhth/m^{2}year, therefore is the same before and after the building reconstructions. On the contrary, net energy needed for heating, calculated with an internal temperature of 20°C, reduces significantly with NZEB level refurbishment. For the various types of buildings, decrease of the sum of the net energy needs comes with different extent but in general for building types 1-5, demand after reconstruction is approximately the third to fourth of the original state, while in case of types 6 and 7 it is 70%. Table 2 reveals, that the extent of it is highly influenced by the ratio of Q_{DHW} and Q_H, as only the latter changes by the retrofit.

2.2 Appliances

Two types of air-source heat pumps were considered in the calculations, as their application comes with a lower limit in terms of the source side, compared to ground-source or water-source heat pumps. One type is the air-to-water heat pump that itself can cover both heating and DHW net energy needs.

The other air-source heat pump type is air-to-air heat pump. For DHW generation electric boilers are assumed. As a reference, emissions of gas condensing boiler systems are calculated as well. Carbon footprint of the listed systems are calculated in the followings.

2.2.1 TEWI of Heat Pump Systems

For the heat pump systems, TEWI calculations are used to approximate the greenhouse gas emissions for the lifetime of the appliance. TEWI considers two types of emissions. Direct emissions are related to the refrigerant used in the heat pump (described with the first two terms of equation 1), while indirect emissions are corresponding to the electricity used by the heat pump (described with the third term) (Mota-Babiloni et al., 2020).

$$\begin{aligned} TEWI = \\ GWP * m * L_{annual} * n \\ +GWP * m * (1 - \alpha_{rec}) \\ +(E_{annual} * \beta_e * n) \end{aligned} \tag{1}$$

In TEWI, GWP stands for the Global Warming Potential (kgCO$_2$eq./kg), m (kg) represents the mass of the refrigerant charge. L_{annual} (% / year) is the annual loss of refrigerant charge through leakages and α_{rec} (%) stands for the amount of charge that can be potentially recovered at the end of life. Factor n (years) appearing is the estimated lifespan of the heat pump.

The indirect emissions part is characterised with E_{annual} (kWh$_e$/year), annual electricity consumption, multiplied with the lifespan and applying the carbon intensity factor β_e (kgCO$_2$eq./kWh$_e$) of the electricity, that describes the greenhouse gas emissions that the generation of 1 kWh$_e$ of power is accounted for.

2.2.2 Parameters of TEWI Calculation

In practice, TEWI is calculated for the heat pump that is subject of the specific calculation. However, to draw conclusions about the emissions of the different heat pump-based systems under various conditions, generalization of these values is necessary. In case of the refrigerant parameters, and therefore the GWP value, it is reasonable to define a type of refrigerant for the study that is widely used. For that reason, refrigerant R32 is taken into consideration, with a global warming potential of 675 kgCO2eq./kg (Choi et al., 2017).

The mass of the charge, though, is also dependant on the specification of the heat pump and is in accordance with the capacity of the appliance. Usually, the specific charge mass is between 0.24 – 1 kg/kW (Poggi et al., 2008). In the study, 0.3 kg/kW is used, just as applied in (Johnson, 2011). Leakage rates vary on a wide scale in different studies, however it is believed that they have a modest effect on the results (Johnson, 2011). In case of the annual leakage rate the value is usually around 6% (Greening & Azapagic, 2012; Johnson, 2011). For recovery rate also many different values can be found in literature. Calculations of this paper assume 80% of recovery rate, which is quite general (Greening & Azapagic, 2012). The expected lifespan of the appliances in the following calculations is 15 year (Mota-Babiloni et al., 2020).

Carbon intensity factor in TEWI is an average value for the electricity used throughout the lifetime. However, when calculating in advance, only estimations could be used. Though carbon intensity is believed to continuously decrease in the future, in this study, carbon intensity of the installation year is used through the lifetime, to rather err on the side of caution.

2.2.3 Energy Consumption of the Heat Pumps

It is often highlighted that the dominating part of greenhouse gas emissions is the indirect part of TEWI, energy consumption related parameters (Greening & Azapagic, 2012; Mota-Babiloni et al., 2020). Annual electricity consumption of this term can be determined various ways. The most precise would be measuring the consumption, however the carbon emission estimation is carried out in advance, therefore it is not possible in our case. Another option could be a detailed dynamic modelling of the heat pumps' performance for the specific cases, which is resource and time demanding. A simpler, though for annual calculations still sufficiently appropriate option is estimating the consumptions with the Seasonal Coefficient of Performance (SCOP) of the heat pumps (Huang & Mauerhofer, 2016), that is applied further on in the paper. E_{annual} is therefore determined as the ratio of the net energy need of heating (Q_H), net energy need of DHW production (Q_{DHW}) and the specific SCOP.

In case of the AWHP this approach is used for estimating the electricity consumption of heating and DHW production, and in case of air-to-air heat pump to determine electricity consumption of heating. SCOP values are considered according to the guide of the Danish Energy Agency for these cases (Energistyrelsen, 2018).

In case of the air-to-water heat pump, the annual energy consumption $E_{AW,ann}$ appears as:

$$E_{AW,ann} = \frac{Q_H}{SCOP_{H,AW}} + \frac{Q_{DHW}}{SCOP_{DHW,AW}} \quad (2)$$

where $SCOP_{H,AW}$ stands for the seasonal coefficient of performance of heating with AWHP and similarly, $SCOP_{DHW,AW}$ is for the characterization of the efficiency of DHW production with AWHP.

Electricity consumption of heating with air-to-air heat pump, $E_{AA,ann}$ is expressed with the denominator of $SCOP_{H,AA}$ that stands for the seasonal coefficient of performance of heating. The electricity consumption of DHW production in case of an electric boiler (EB) is estimated similarly, with using of the efficiency of the boiler, η_{eb} that is considered 100% in the calculations. The annual electricity consumption of the air-to-air heat pump-based system is denoted with $E_{AA,ann} + E_{EB,ann}$.

$$E_{AA,ann} + E_{EB,ann} = \frac{Q_H}{SCOP_{H,AA}} + \frac{Q_{DHW}}{\eta_{eb}} \quad (3)$$

The carbon intensity factor also has a high impact on the results. For this reason, this value should consider future trends in power generation and geographic location. In this study, yearly averages of the present (the same as for the year 2020), 2030 and 2050 electricity mix are considered for the Hungarian electricity grid (Kiss, Kácsor, and Szalay 2020).

2.2.4 Carbon Footprint of the ASHP-based Systems

Knowing the energy consumption of the ASHP based systems, CF of the systems can be expressed. In case of air-to-water heat pump TEWI and the carbon footprint of the system equal:

$$\begin{aligned} CF_{AW} = TEWI_{AW} = \\ GWP * m * L_{annual} * n \\ + GWP * m * (1 - \alpha_{rec}) \\ + \left((E_{AW,ann}) * \beta_e \ * n \right) \end{aligned} \quad (4)$$

For further calculations notation D is introduced for the direct emission part.

$$CF_{AW} = D + \left((E_{AW,ann}) * \beta_e \ * n \right)$$

In case of the air-to-air heat pump-based system, TEWI, however, would only represent the emissions related to heating with the air-to-air heat pump, but not the DHW generation with the electric boiler. For that reason, GHG emission of the electric boiler is approximated with the electricity consumption of the boiler and the carbon intensity factor of the grid. Production phase is neglected (just like in TEWI in case of the heat pumps). As a result, CF of this system can be expressed as:

$$CF_{AA\&EB} = D + (E_{AA,ann} + E_{EB,ann}) * \beta_e * n \quad (5)$$

Assuming the same leakage rates, charge capacity and refrigerant type, direct emissions (D) of the different heat pump systems are considered equal.

2.2.5 Gas Condensing Boiler Emissions

Emissions of the condensing boiler are used as a reference case, to allow distinguishing the effect of the NZEB construction and the selection of heat pumps for technical building system. Greenhouse gas emissions of the gas condensing boiler system are calculated with the help of Ecoinvent database, that is a widely used database for LCAs (Ecoinvent, 2014). Based on that, a carbon intensity factor, β_{ng} is introduced to determine the carbon emissions of the natural gas condensing boiler as

$$CF_{GB} = (\beta_{ng} * E_{GB,ann} * n) \quad (6)$$

where CF_{GB} (kgCO2eq) refers to the carbon footprint of the heat generation with gas condensing boiler, $E_{GB,ann}$ is the final energy consumption of the gas condensing boiler, which, similarly to the other appliances is the sum of energy needed for heating and DHW production divided by the efficiency of the boiler, η_{gb} , that is considered 95% in the calculations.

2.2.6 Sizing the Appliances

As greenhouse gas emissions are dependent on the size of the heat pump (through the introduced scaling factor for the refrigerant charge amount), capacity of the different appliances should be determined. In our research we assumed the capacity of the heat pumps according to the heat load of the analysed buildings.

In case of the AWHP it is presumed that this capacity is sufficient for covering the DHW needs as well. When electric boiler is used for DHW generation, the capacity of the equipment is irrelevant, as in this case, only electricity used has impact on carbon emissions, production of the equipment is excluded from CF calculation (as suggested in section 2.2.4,). sums up all the parameters of the technical building systems used in the study.

Table 1: Values used is Carbon Footprint calculations of the technical building system.

Name	Symbol	Value	Unit
Global Warming Potential of refrigerant R32	GWP	675	$kgCO_2eq./kg$
mass of refrigerant charge	m	0.3 kg/kW * capacity of the ASHP	kg
annual leakage rate of charge	L_{annual}	6	%/year
estimated lifespan	n	15	years
recovered refrigerant amount at end-of-life	α_{rec}	80	%
carbon intensity factor of the Hungarian power grid for 2020, 2030 and 2050 respectively	β_e	0.3769 0.1234 0.0637	$kgCO_2eq./kWh_e$
SCOP of air-to-water HP, DHW production	$SCOP_{DHW,AW}$	3.35	kW/kW
SCOP of air-to-water HP, heat production	$SCOP_{H,AW}$	3.55	
SCOP of air-to-air HP, heat production	$SCOP_{H,AA}$	4.9	
natural gas burning factor	β_{ng}	248.6	gCO_2/kWh_{th}
gas-condensing boiler efficiency	η_{gb}	95	%
electric boiler efficiency	η_{eb}	100	%

3 RESULTS AND DISCUSSION

3.1 Carbon Emissions for the Different Technical Building Systems

In case of the gas condensing boiler system, carbon dioxide emissions are directly proportional to the energy needs of the specific cases, as heating and DHW production are not distinguished from this perspective (equation 6). It provides a representation of a technical building system that is though up-to-date, comes with a limit in terms of reducing GHG emissions as lacks the integration of renewable energy sources.

In Figure 2, it is recognisable, that the gas boiler system represents larger emissions than the ASHP based systems, even with the electricity mix of 0.1234 $kgCO2eq./kWh_e$, that is suggested by a study as the carbon intensity factor of the 2020 electricity mix of Hungary (Kiss, Kácsor, and Szalay 2020).

It is also notable that the amount of carbon emissions saved with NZEB reconstruction of the buildings and of the technical building systems with ASHPs is the same orders of magnitude (applying the 2020 electricity mix).

Potential emission savings, however, are pushed even further with the future electricity mixes of 2030 and 2050 as seen in Figure 3. As more and more renewables are foreseen to be integrated in power production, carbon intensity factor of the power grid (β_e) gradually reduces from 0.3769 $kgCO_2eq./kWh_e$ of 2020 to somewhere around 0.1234 and 0.0637 $kgCO_2eq./kWh_e$ by the years 2030 and 2050 respectively, as a study reveals (Kiss, Kácsor, and Szalay 2020).

3.2 Determining the Best Performing Equipment for an Application

Carbon intensity factor of the electricity consumed by the appliances is an important factor of GHG emissions and as a result also plays a decisive role when it comes to the selection of the system with the lowest carbon equivalent. Noting that ASHP systems appeared with less carbon emissions for all the cases, brings up the question of the conditions where condensing gas boiler technology could result better emission values.

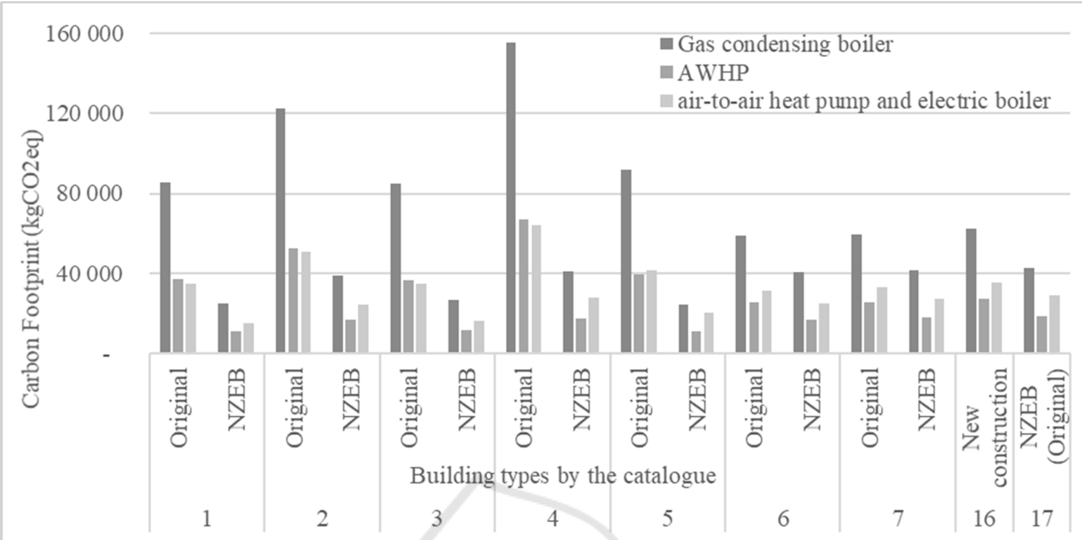

Figure 2: Carbon Footprint of the different technical building systems of the Hungarian detached houses, before and after NZEB-level reconstruction, considering the 2020 carbon intensity factor for the lifetime.

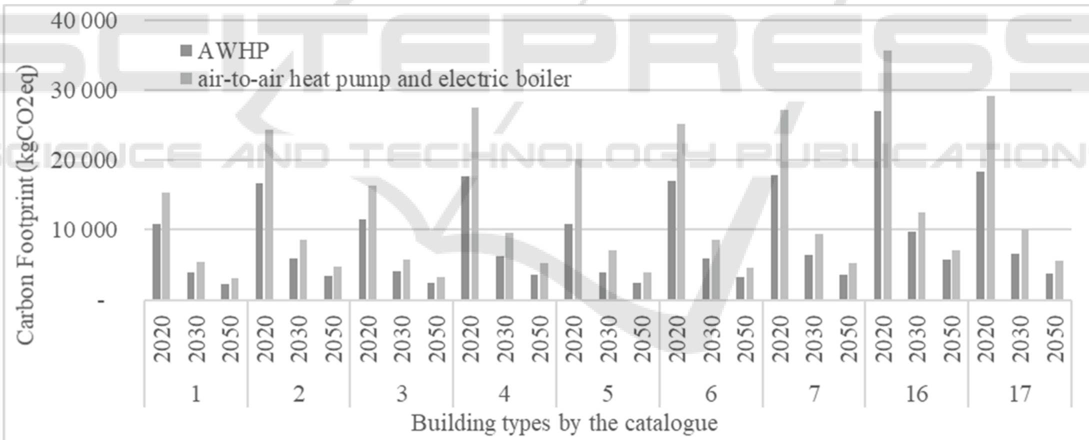

Figure 3: Carbon Footprint of the ASHP based technical building systems of the Hungarian detached houses after NZEB-level reconstruction, considering the 2020, 2030 and 2050 carbon intensity factors.

3.2.1 Comparing ASHP Systems with Gas Condensing Boilers

Both ASHP based technologies are compared with the gas condensing boiler system. For that, equations (4,5,6) describing the CF of the different systems are examined. Comparing the ASHP based systems with the condensing boiler system it is remarkable, that from the perspective of the equipment only the carbon intensity factor (β_e) represents a variable as other values are set by the specifications of the appliances (and the energy needs of the cases (Table 2). This allows to express the equations to the carbon intensity factor, that represents a threshold for the ASHP based technical building systems, when compared to the gas condensing boilers. Carbon intensity values above this threshold would mean that gas condensing boilers are preferred, below this carbon intensity ASHP based systems would result less carbon dioxide emissions for the lifetime of the technical building system. Mathematically, this is expressed with equality between (4) and (6), rearranged to express the carbon intensity, that comes as follows:

$$\beta_{e,AW,GB} = \left(\beta_{gb} * E_{GB,ann} * n - D\right) * \frac{1}{E_{AW,ann} * n} \quad (7)$$

where $\beta_{e,AW,GB}$ represents the carbon intensity which would result the same carbon-dioxide emissions for the AWHP system and the gas condensing boiler system. For the 9 building types observed, this $\beta_{e,AW,GB}$ varies around the value of 0.9 kgCO2eq./kWh$_e$, seen in Table 2. As the carbon intensity of the Hungarian electricity mix is notably lower than this, AWHP provides a better choice than gas condensing boiler for all the observed residential detached houses.

The case of air-to-air heat pump-based system is similar. Direct emission part of TEWI equals with the AWHP system's. However, the indirect part differs as electricity consumption of the air-to-air heat pump and of the electric boiler are both included. Carbon intensity factor to decide whether condensing boiler or air-to-air heat pump, combined with electric boiler performs better is expressed as follows (after rearranging the equality of (5) and (6)).

$$\beta_{e,AA\&EB,GB} = \frac{\left(\beta_{gb} * E_{GB,ann} * n - D\right)}{\left(E_{AA,ann} + E_{EB,ann}\right) * n} \quad (8)$$

$\beta_{e,AA\&EB,GB}$ values appear on a much wider range than that of $\beta_{e,AW,GB}$, from 0.963 kgCO2eq./kWh$_e$ to as low as 0.462 kgCO2eq./kWh$_e$, for types 1 and 7 respectively (seen in Table 2).

As only energy consumption of the appliances change, compared to the previous case, the reason for the alteration of the values has to be in reliance with that. It is notable, that the greater the ratio of the net energy demand of DHW production (Q_{DHW}) and heating (Q_H) is, the higher the emissions of the ASHP based systems will be, as DHW production comes with lower efficiency for both ASHP based systems. Furthermore, in case of the electric boiler, the efficiency of DHW generation (η_{eb}) is significantly lower compared to the heat generation with heat pump ($SCOP_{H,AA}$) , resulting larger alterations in $\beta_{e,AW\&EB,GB}$.

This also explains why $\beta_{e,AW,GB}$ varies in a remarkably more moderate range. Seasonal coefficient of performance of DHW production ($SCOP_{DHW,AW}$) and space heating ($SCOP_{H,AW}$) comes with notably lower difference for that case.

Table 2 sums up the different carbon intensity thresholds for the examined cases of the Hungarian residential building stock. If the carbon intensity is below the threshold of $\beta_{e,AW,GB}$ and $\beta_{e,AW\&EB,GB}$ of the specific cases, ASHP-based systems offer a more favourable way of heating and domestic hot water production, from the perspective of carbon emissions. On the contrary, if carbon intensity factor exceeds these thresholds, then condensing boilers are the preferable.

Table 2: Carbon intensity limits and net energy need ratios for the different detached houses of the Hungarian building typology with the 2020 carbon intensity.

	Building type	1		2		3		4	
		Original	NZEB	Original	NZEB	Original	NZEB	Original	NZEB
Heat load	kW	8.97	2.35	12.13	3.37	8.87	2.41	15.96	3.17
Q_H	kWh$_{th}$/year	20 132	4 707	28 433	7 116	19 780	5 007	36 282	7 148
Q_{DHW}	kWh$_{th}$/year	1 680	1 680	2 727	2 727	1 782	1 782	3 294	3 294
$\beta_{e,AW,GB}$	kgCO$_2$eq./kWh$_e$	0.903	0.896	0.904	0.896	0.903	0.896	0.903	0.896
$\beta_{e,AA\&EB,GB}$	kgCO$_2$eq./kWh$_e$	0.963	0.620	0.935	0.604	0.947	0.621	0.946	0.565
Q_{DHW}/Q_H limit	[-]	0.111							
Q_{DHW}/Q_H	[-]	0.083	0.357	0.096	0.383	0.090	0.356	0.091	0.461
	Building type	5		6		7		16	17
		Original	NZEB	Original	NZEB	Original	NZEB	New constr.	NZEB
Heat load	kW	9.06	2.70	6.14	2.08	5.84	3.36	5.98	3.35
Q_H	kWh$_{th}$/year	20 702	3 529	12 144	7 405	12 028	7 409	12 431	7 378
Q_{DHW}	kWh$_{th}$/year	2 748	2 748	2 853	2 853	3 174	3 174	3 525	3 525
$\beta_{e,AW,GB}$	kgCO$_2$eq./kWh$_e$	0.902	0.883	0.897	0.903	0.898	0.896	0.897	0.896
$\beta_{e,AA\&EB,GB}$	kgCO$_2$eq./kWh$_e$	0.861	0.462	0.719	0.608	0.691	0.580	0.674	0.557
Q_{DHW}/Q_H limit	[-]	0.111							
Q_{DHW}/Q_H	[-]	0.133	0.779	0.235	0.385	0.264	0.428	0.284	0.478

3.2.2 Selection between ASHP based Systems

Comparing the ASHP based systems in Figure 2, reveals that in most of the cases AWHP guarantees better results. Although, there are certain conditions where air-to-air heat pump with the electric boiler prove to result lower emissions. It is notable that it only appears for the original state and never for the NZEB option. In case of these examples (building types 1-4) the NZEB option leads to a technological shift in the terms of the system with the lowest CF. The equations only differ in the amount energy consumed (as a result of the different efficiencies of the specific equipment used). As for the observance, the equality of CF of the ASHP based systems is expressed for the ratio of the net energy needs (9). This therefore defines the circumstances that results in equal emissions for the systems. Above this ratio, AWHP performs better as a result of more efficient DHW production, below this ratio higher SCOP of air-to-air heat pump makes the latter system a more favourable choice.

$$\frac{Q_{DHW}}{Q_H} = \frac{SCOP_{H,AA} - SCOP_{H,AW}}{SCOP_{H,AA} * SCOP_{H,AW}} * \frac{SCOP_{DHW,AW} * \eta_{eb}}{SCOP_{DHW,AW} - \eta_{eb}} \quad (9)$$

The present efficiency values result in a ratio of approximately 0.11 [-] of DHW net energy need and the net energy needed for space heating (SH). For building types 1-4 the same ratios are remarkably lower for the original state, represented in Table 2, which can be explained with the significant decrease of space heating demand as a result of the NZEB retrofit, while the DHW demand remains the same.

As seen, the ratio of the net energy consumption (of types 1-4) prior to the renovation is below the threshold limit of 0.11, while after the renovation is above. This explains why air-to-air heat pumps with electric boilers emit less carbon dioxide before the retrofit, and AWHPs after the NZEB retrofit. The technological swift can be traced in Figure 2.

4 CONCLUSIONS AND OUTLOOK

In this paper three technical building systems were compared to reveal the conditions where a specific system could minimize carbon dioxide emissions. Comparison of carbon footprints justified that heat pump-based systems could provide lower emissions compared to gas condensing boiler system. However, there could be certain applications, with high carbon intensity factors, where the latter is still preferable. In comparison with AWHP, this limit is high, about 0.9 kgCO2eq./kWh$_e$. Comparing with air-to-air heat pump and electric boiler, the limit could appear even as low as 0.462 kgCO2eq./kWh$_e$ in case of the Hungarian residential building stock. The significance of the DHW-to-SH demand ratio of the houses is also highlighted when heat pump-based building technical systems are compared to condensing boiler technology.

When comparing the air-source heat pump-based systems it can be concluded that in contrast only the DHW-to-SH demand ratio matters. The threshold of this net energy need ratio is low, around 0.11, meaning that for residential NZEBs air-to-water heat pumps are more favourable. Nevertheless, under certain circumstances, for instance in case of building functions with low domestic hot water demand, resulting in a lower ratio, air-to-air heat pumps with electric boilers could be preferable.

Results of the study could be essential for environmentally conscious decision-making in legislation on a building cluster level. However, it should be highlighted that the presence of significant cooling needs could modify the threshold of the net energy ratios, therefore further research is needed to extend the parameters with the presence of cooling needs.

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