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Evaluating the Environmental Impact for a Small Apartment: Using Traditional Wall-mounted Gas Convector vs. Transitioning to Heat Pump

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Abstract
The replacement of old, fossil fuel-based heating systems is of paramount importance. In households of the European Union, space heating accounts for the largest share of final energy consumption, making the method of heat production critical. Various studies estimate that approximately 120 million buildings in the EU require some form of refurbishment, either passive or active, to comply with the latest energy performance directives. Existing regulations focus primarily on efficiency and aim to reduce heat losses, suggesting the replacement of outdated systems and the upgrading of building envelopes. However, they rarely consider the environmental impact of other life cycle stages except use stage of the newly installed building elements. This situation may escalate to the point where considering the whole life cycle of an improvement or replacement is no longer justified solely by emissions and energy use. The Energy Performance of Buildings Directive, and its localized regulations in Hungary impose criteria that require the renovation of existing buildings, often making compliance achievable only through heating system replacements. Hence, this study investigates the background of heating system changes in a small traditional flat, assessing their benefits in terms of emissions and energy use over the full life cycle.

Keywords
LCA, energy retrofitting, heat pump, wall-mounted gas convector, phase-out of fossil fuel

1 Introduction

According to 2022 data, total final energy consumption (FEC) of the households in EU (27 countries) was 2820 TWh (Eurostat, 2024a). The composition of this consumption is represented on Fig. 1 (Eurostat, 2024b).

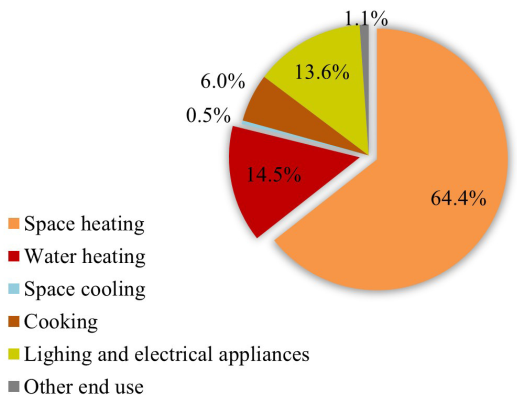

Fig. 1 FEC by type of end use in households

It can be concluded that space heating has the highest energy demand of all, with the largest share of energy used for heating in residential buildings. Table 1 presents the energy sources used for different types of activities in households in the EU (Eurostat, 2024c).

The rationale behind changing heating systems is understandable and justified by the significant impact on the overall emissions of residential buildings. Decarbonization of the building stock had been set as an ambitious goal which reflects on the massive potential reduction. In 2022, according to European Environment Agency (European Environment Agency, 2024), 400 290 ktCO_2eq GHG was released by residential and commercial sectors, and it can be proven that most of it originates from heating.

A report published by the International Energy Agency (IEA) (International Energy Agency, 2022) states that transitioning heating systems, including space and

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Table 1 FEC activities in households covered by types of energy sources in 2021 [TWh]

	Space heating	Space cooling	Water heating	Cooking	Lighting and electrical appliances	Other end use	Total
Solid fossil fuels, peat, peat products, oil shale and oil sands	70.9	n/a	6.0	0.9	n/a	0.0	77.8
Natural gas	771.2	n/a	189.5	58.8	n/a	0.0	1019.5
Liquefied natural gas	n/a	n/a	n/a	n/a	n/a	n/a	0.0
Oil and petroleum products	221.9	n/a	40.6	21.4	n/a	5.8	289.6
Liquefied petroleum gases	n/a	n/a	n/a	n/a	n/a	n/a	0.0
Other kerosene	10.5	n/a	2.3	0.0	n/a	0.1	12.9
Gas oil and diesel oil	181.7	n/a	25.8	0.0	n/a	0.9	208.4
Renewables and biofuels	572.1	n/a	61.2	8.4	n/a	4.0	645.6
Solar thermal	2.5	n/a	22.2	0.0	n/a	0.0	24.8
Ambient heat (heat pumps)	81.2	n/a	7.4	0.0	n/a	0.2	88.8
Primary solid biofuels	485.1	n/a	31.2	7.5	n/a	2.0	525.8
Biogases	2.5	n/a	0.3	0.0	n/a	0.0	2.8
Electricity	118.7	13.8	84.6	91.6	414.7	24.0	747.4
Heat	204.5	n/a	58.3	0.0	n/a	0.0	262.8

water heating, to heat pumps could save around 500 million tons of CO_2 emissions globally by 2030. However, this report focuses only on the operational carbon emissions, reduced by abandoning the fossil fuels (FF) and exploiting ambient heat. Assessing the whole life cycle of such replacements in particular cases may give a more detailed result.

1.1 Legislation background in the EU and its goals regarding the building stock

The European Green deal highlighted large-scale goals to decarbonize the economy of the EU. Achieving climate neutrality by 2050 and reducing net greenhouse gas (GHG) emissions at least 55% by 2030 were written into law (The European Parliament and the Council of the European Union, 2021), which specifically mentions the building sector as one that must contribute.

The rationale of energy refurbishment of the building sector can be traced back to various reasons identified by the EU institutions and agencies. There are sociological, political, and environmental initiatives aimed at reducing energy consumption in buildings, increasing the share of green energy while decreasing the use of FF and mitigating losses. The legal framework imposes binding criteria and serves as guidelines for these efforts (non-exhaustive list):

- Improving energy efficiency of the buildings: (The European Parliament and the Council of the European Union, 2010)
- Use energy more efficiently; efficiency targets for all sectors; labelling system; to boost renovations: (The European Parliament and the Council of the European Union, 2023)
- EU's clean energy transition; renewable energy targets: (The European Parliament and the Council of the European Union 2018)
- Funding for energy efficiency and heat pumps; diversifying energy supplies; extending energy performance standards: REPowerEU Plan (European Commission, 2022)
- Renovation works strategy: (European Commission, 2020)
- Energy labelling: (The European Parliament and the Council of the European Union, 2017)

Providing key points and narratives such as envelope renovation, heating system replacement and phasing out of FFs, all the listed elements above influence the shaping of an energy refurbishment concept for buildings.

1.1.1 Life Cyle Assessment in Energy Performance of Buildings Directive

As stated in the latest revised Energy Performance of Buildings Directive (EPBD) Decree (7) Chapter (The European Parliament and the Council of the European Union, 2024), life cycle assessment (LCA) must be conducted not only in cases of new constructions but in case of refurbishments. In Article 1, the calculation and disclosure of the life-cycle global warming potential (GWP) of buildings' as a criterion was established. The reduction of embodied carbon (EC) must also be addressed, and its policies must be included in the Member States' national building renovation plans. The idea behind this study strongly refers to the new standpoint set in lawmaking, but somewhat contradicts the notion that suggests phasing-out of FFs as soon as possible.

1.2 Localized legislation background

The Decree No. 9/2023. (V. 25.) of the Minister of Innovation and Technology came into force on the 2nd of November 2023, reflecting the aforementioned EPBD. This decree repeals the previous decree, introducing a new calculation method and extending nearly-zero energy buildings (NZEB, KNE in Hungarian) criteria to all new buildings. It also defines and sets criteria to building elements, engineering systems, and buildings that are to be refurbished or expanded. Replaced engineering systems must comply with the regulation in force and must reach at least "normal" category, according to Government Decree No. 176/2008. (VI. 30.). Currently, Hungarian law does not impose restrictions on the use of FFs in buildings.

Regarding the future, according to the revised EPBD (The European Parliament and the Council of the European Union, 2024) , all forms of on-site emissions must be phased out for publicly owned new buildings by 2028 and for all other new building by 2030. It also states that stand-alone boilers will not be eligible for public support as of 2025 and envisages the banning of heating systems based on FF sources.

Even though a potential heating system replacement does not come along with an obligatory phase-out of FF, all indications suggest transitioning to other sources. Due to the specific characteristics of the subject of this study, district heating or heat pump are the versions that fit into this narrative and likely to be chosen in an active energy refurbishment.

2 Background assessment and literature review

2.1 Heat pump

Trends in legislation, energy prices, technological advancements and designer's persuasion, novel technologies becoming increasingly prevalent in the field of building service engineering. The main goal is to comply with legislation, reduce emissions, and save on energy expenditures. The transition of heating systems to heat pumps (HP) in households shows exceptional growth in both stock and sales.

Fig. 2, based on a report published by European Heat Pump Association (Nowak and Westring, 2023), shows the current rise in HP use in residential and commercial sector. Consequently, it was reported that the nearly 20 million HPs could replace the use of 4 billion cubic meters of natural gas (NG), meaning that this trend may result in a total 21 billion cubic meters of NG savings by 2030.

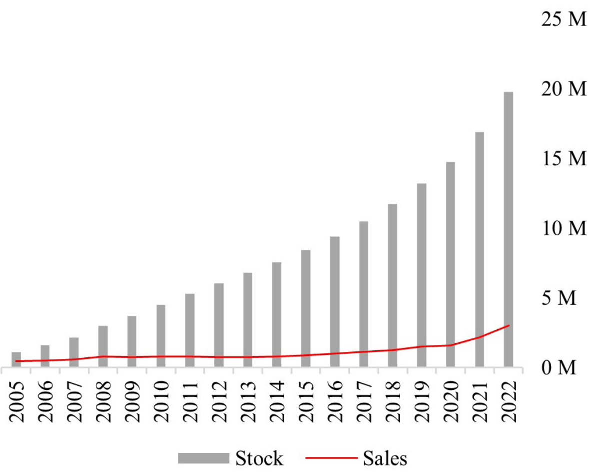

Fig. 2 Heat pump stock and sales in Europe [Million]

2.2 Literature review

Building services engineering systems with higher efficiency and the constant increase in building envelope performance result in the increasing importance of embodied carbon (EC). Projects aiming to reduce the overall impact often shift the focus and carry out extensive investigations regarding EC.

A study (Naumann et al., 2022) analyzing impacts of a condensation gas boiler (CGB) and air-source heat pump (ASHP) in Germany concluded that manufacturing accounts for 21% of the total impact of a HP used for space heating and domestic hot water (DHW) production with 5 kW heat output and 3.6 seasonal performance factor (SCOP). Another 78% of total impact was attributed to its operation, in which GWP was mainly (81%) attributed to electricity mix, and 19% was attributed to refrigerant leakage. The GWP of the manufacturing and disposal regarding to CGB was negligible, as the operation was almost entirely responsible for its emissions. Total GHG emissions for NG combustion were calculated at 76.9 g CO_2eq/MJ heat.

Another study (Khan et al., 2024) concluded that an air-source heat pump with a 6 kW nominal net heating capacity and DHW production considering 17-year lifetime accounts for 1010 kgCO_2eq EC from the assembly phase, 81 kgCO_2eq from the transport phase, 34 992 kgCO_2eq from the operational phase and 175 kgCO_2eq from the end-of-life phase. This adds up to a total of approximately 35 800 kgCO_2eq emissions in the global warming potential impact category.

A paper (Masternak et al., 2024) recently investigated the overall impact of transitioning to HP on a country level and concluded that out of 18 countries in Europe, the impact could be improved in 17. It is stated that for either HP or natural gas boiler (NGB), the biggest contributor to climate change is the operational phase, with manufacturing being the second. It is notable that older dwellings have less capacity for improvement.

3 Methodology of study

3.1 Building and apartment

As most of the buildings located in this district can be attributed to a specific period, this traditional residential building might have been built around the turn of the previous century. Its licensing documentation was submitted by Mórné Hoffmann and approved by the authority in 1896 (Ney, 1896), and as in case of many other buildings in the street, its apartment blocks were rented out. A picture was found from an eventful period showing restoration works in 1954 (see Fig. 3), possibly directly related to World War II. The architect and original plans remain unknown.

Although, its façade and ornament suggest a rather prestigious appearance compared to contemporary plain surfaces, its primary function was to accommodate workers in need. Initially, wet blocks were not included in every flat in its time. However, current residents have partially adapted them to modern standards wherever possible. Presently, all units in this building are municipally owned and are occupied exclusively by disadvantaged tenants.

Due to limited number of resources, renovations usually took place individually rather than in a holistic, centralized manner. Covering all aspects of necessary refurbishment poses a financial burden. Based on questionnaires and on-site inspections, it can be stated that occasionally tenants themselves allocate money for improvements to increase comfort level in their flats. Another reason for undertaking energy refurbishments is when a flat is needs to meet certain conditions before a tenant moves in. This is similarly implemented as the previous case and results in only stand-alone refurbishments.

The most common reason for installing an air-to-air heat pump is to prevent overheating during the cooling season, and to complement existing heater or even to replace it. District heating (DH) is hardly to be found, due to difficulties individuals would encounter during installation.

The subject of this study is an apartment accommodating three people and has a total net floor area of 34.94 m^2, see Fig. 4. It is located on the ground floor; its only exterior envelope surface faces a courtyard. All other surfaces bounded by unheated spaces, cellar, upper neighbor, and staircase.

3.2 Methodology

Fig. 5 shows which two cases (first two boxes with dotted outline) were compared to convince decision makers about the necessity of a coordinated intervention (third box). The investigation focuses solely only space heating and does not address any other heat demands.

To assess the benefits of installing a heat pump or using the already installed device, an LCA must be performed. Steps of this were carried out according to the handbook "Life Cycle Assessment" (Hauschild et al., 2018) and relevant standards, ISO 14040:2006 (ISO, 2006a) and ISO 14044:2006 (ISO, 2006b).

Fig. 3 Restoration works in 1954 (Keveházi, 1954)

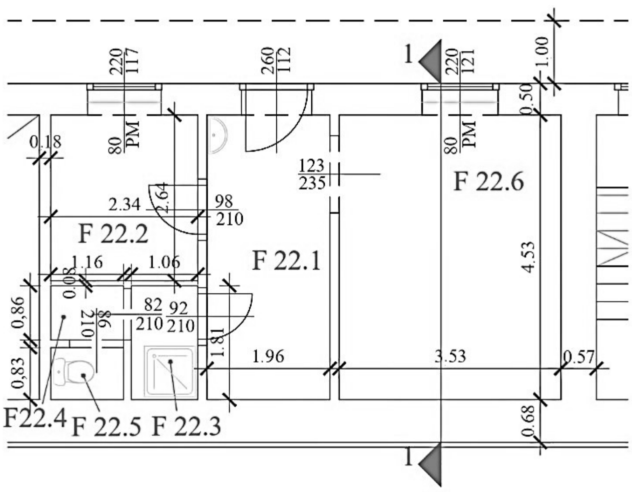

Fig. 4 Floorplan of the apartment

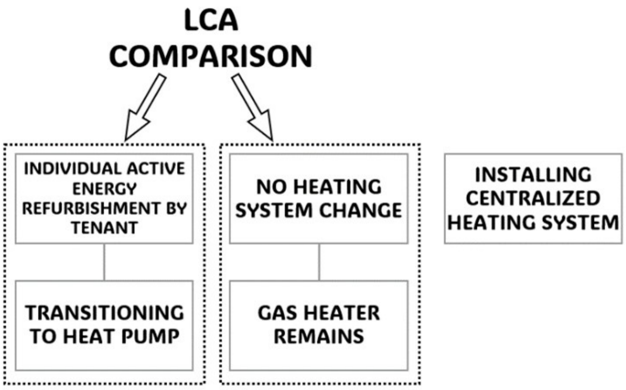

Fig. 5 LCA comparison of the two product systems

Since the analysis is subsequent to the functional unit, system boundaries were drawn to ensure that both cases provide the same function.

The current situation deals with the functional unit, regardless of the pre-use period of the wall-mounted gas convector. Leaving it in operation would not cause any additional impact; however, its replacement would necessarily involve more EC. As a result, it will be determined whether using the old wall-mounted gas convector or replacing it with a HP is more beneficial over its 20-year lifetime, especially when a holistic refurbishment is not feasible.

3.3 Life Cycle Assessment, goal and scope definition

The first phase of the assessment, which is determining its goal and limiting its scope, consists of the following main points according to ISO 14040:2006 (ISO, 2006a) and LCA handbook (Hauschild et al., 2018):

- Intended application.
- The reason for carrying out the study.
- Limitations due to methodological choices.
- Intended audience.
- Whether comparative assertions to be disclosed to the public.

The second phase is for determining what product systems are to be assessed and how. The relevant ISO 14040:2006 standard (ISO, 2006a) regarding the scope suggests the followings to be elaborated:

- The product system and its functions to be studied.
- Functional unit.
- System boundaries.
- Allocation procedures.
- Initial data requirements.
- Impact categories and methodology of impact assessment.
- Data requirements, assumptions, limitations.
- Type of critical review, type and format of the report required for the study.

4 Goal and scope

4.1 Intended application of the result; decision context and reasons for carrying out the study

Direct application of the result is part of strategic planning regarding energy refurbishments and aims to help decision-makers, owners, and maintainers in advising tenants when a holistic energy refurbishment is not feasible or cannot be financed. Without this guidance, tenants may refurbish their homes according to their own intention and ideas, without considering the life cycle (End of Life phase is excluded) of a heating system. The assessment also aims to convince stakeholders of the necessity of an active refurbishment by demonstrating the weight of the results. The preliminary assumption is that while the old system remining in use may result in higher operational carbon emissions, adding the EC of the new system may eventually lead to an overall higher impact after the intervention. This can be attributed to the following conditions:

- The social block consists of relatively small apartments, with small net heated area. This means that small apartments not only use less heat, but one HP must be installed for every 30–35 m^2 of useful surface area in the building. Fig. 6 shows the distribution of flats with different heated floor areas. In this scenario, it would necessitate installing 103 individual HPs in this building.
- The urban fabric is dense, with most flats surrounded by heated premises or at least by enclosed compartments, resulting in low heat losses. This condition, combined with the smaller size of the heated area, further reduces the heating demand.
- Both cases of the comparison share every condition:
- Regarding the aim of both systems, the same net heating demand must be covered as per the relevant Hungarian energy performance directive.

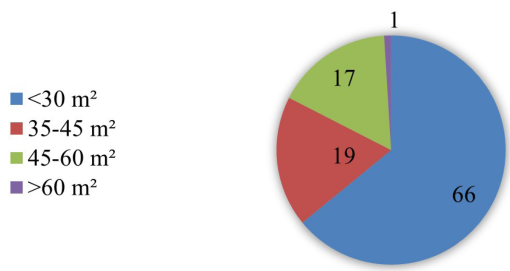

Fig. 6 Distribution of flats in the building by their size

- The net heating demand is determined by summarizing heat losses and heat gains. For each month over the next 20 years, data from present ÉKM (Építési és Közlekedési Minisztérium – Ministry of Construction and Transport - Decree 9/2023. (V. 25.) of ÉKM on the determination of the energy characteristics of buildings) Decree and interpolated Meteonorm (Meteotest AG, 2024) data for 2050 was used. Direct solar radiation is not considered significant in this context and was not omitted from calculations.
- Operational emissions related to HP strongly correlate with the future electricity generation mix (EGM), which was derived from a study published by the Ministry for Innovation and Technology (Ministry for Innovation and Technology, 2021) and National Energy Climate Plan (NECP) draft (European Commission, 2023) . Figs. 7 and 8 shows the two scenarios that were considered in the LCA, with values between the projected ones being interpolated. Regarding the share of renewables in the EGM, the NECP was used as a basis because it showed a more stable data.
- The domestic hot water production will continue to be provided by an electric boiler and will not be replaced by HP.

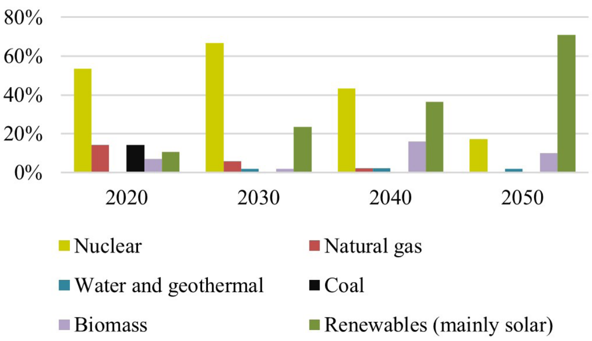

Fig. 7 Electricity generation mix according to early-action scenario

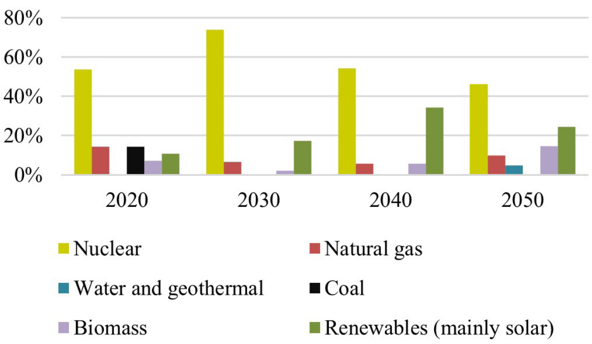

Fig. 8 Electricity gen. mix according to business-as-usual scenario

Ultimately, this study evaluates whether the flat, with the attributes mentioned above, has a lower environmental impact after transitioning to HP or not.

4.2 Limitations due to methodological choices

4.2.1 First methodological choice: determining net heat demand according to ÉKM Decree and future assumptions

Since the boundary of this study is stretched and the paper precisely defines the current case, it is hardly applicable to general situations. Some limitations arise from the relatively inaccurate simplified calculation of energy performance:

Heat losses and gains were determined according to simplified method of ÉKM Decree:

- Internal heat gains are calculated based on an approximation per square meter.
- Direct solar radiation was not exactly calculated considered because calculation method would overestimate its importance, and indirect solar radiation was neglected.
- Thermal bridges were considered as a deteriorated U-value of the building's envelope.

ÉKM Decree calculates only with monthly data:

- Only sum of the monthly gains and losses are calculated.

Assumptions regarding future outside mean temperature and decarbonization of electricity generation mix influence the determined net heating demand and total operational carbon (OC) of the HP. For the electricity mix, 2 different scenarios (business as usual and early action scenario) were given in the report and serve as a base for the assessment.

4.2.2 Second methodological choice: scope of LCA

The scope of this LCA is limited to comparing a new system installation with the existing one. It is assumed that the wall-mounted gas convector is already installed. Everything except its OC and waste treatment/recycling is excluded, maintenance and replacement are also not considered. In contrast, the HP contributes its whole life cycle impact to the comparison.

4.2.3 Third methodological choice: boundaries of the retrofit

This study investigates a case where only the heating system is replaced, without improvements to the building envelope and DHW production. This approach is taken for the following reasons:

- With an improved building envelope, the LCA would provide indisputable results in favor of the HP. Dwellings like the one in focus often have only one outer surface, making insulation seem unnecessary or unjustified.
- The most affordable and easiest phase-out of FF is transitioning to HP, especially to an air-to-air one. Upgrading the DHW system is not common.

4.3 Target audience and disclosure of the assessment

The target audience of this investigation is the owner or operator of the building who seeks to apply environmental considerations. On the other hand, results published can be a guidance for homeowners facing renovations.

Current investigation focuses on one common situation occurring in a dense urban area and could represent a reasonable number of urban dwellings.

4.4 Product systems and its functional unit

Table 2 shows the in- and output flows of the product systems.

4.4.1 Wall-mounted gas convector

The existing and potentially replaced product system is a wall-mounted gas convector with a performance of 4.5 kW. Fig. 9 shows a typical unit; main parts are an internal heat exchanger and concentric tubes penetrating the wall, serving as the air intake and flue. According to a census conducted in 2022, more than 60% of the dwellings use NG in some form for space heating and over 500 000 dwellings use this type of heating system (Hungarian Central Statistical Office, 2022).

Table 2 Input and output flows by heating systems

		Heat pump	Wall-mounted gas convector
Input flows	Materials	Plastic, metal, others	-
	Energy	Electricity	-
	Resources	Ambient heat	Natural gas, Air
Output flows	Energy output	Heat or cold*	Heat
	Waste to treatment		
	Emissions	Depends on electricity production**	Flue gas

* Since natural wall-mounted gas convector does not provide option for cooling, nor cooling via heat pump can substituted with other device, cooling process is not considered;
** Current and future electricity mix in Hungary

Fig. 9 Wall-mounted gas convector (Ventil Épületgépészeti Kft., online)

The system's input flows are only natural gas and air, it is mainly composed of steel, containing other non-reusable elements in small quantities.

Based on the manufacturer's proposal, there is no mandatory requirement to regularly change any part. However, orderly cleansing of the device is advised, including dust removal in nozzle, flue and combustion chamber before each heating season.

4.4.2 Air-to-air heat pump

The most common type of HP used when refurbishing these types of traditional apartments hosted by a densely built in district (especially for households with lower income) is air-to-air HP or split air conditioners with heating option. There are several reasons for this:

- Traditional apartments were not equipped with radiators and pipework previously, as these buildings are built in an era when mainly coal was used for space heating.
- Extra cost of pipework, an air-to-water HP with DHW production's high cost deters tenants transition of DHW production may eve not be seen crucial.
- Tenants may want to improve comfort level during summertime; therefore, cooling is the main motive of a HP installation.

An air-to-air HP's input flows in this case are electricity from the grid and the heat of the ambient air. For this case study, an air-to-air HP (see Fig. 10) was chosen with a 4.6 SCOP value, A++ ErP categorization (for heating) in this climate zone and performance of 2.4 kW. Total mass

Fig. 10 Investigated air-to-air heat pump (PEP ecopassport, 2023)

of the inner and outer unit is 33 kg, provided with a 3 kg of packaging material.

4.5 Functional unit

First, the functional unit in both cases is to cover the same amount of net heating demand, and this was calculated according to the ÉKM Decree. Table 3 shows the U-values of the building envelopes, Table 4 lists the calculated net heating demand and Table 5 the FEC of both heating systems for the 20-year period. The following equation describes the heat balance in the dwelling:

$$Q_{heating,net} = \left(Q_{losses} - \eta_F \cdot Q_{gains}\right)$$

Table 3 Corrected U-values of the building envelope

Surface/Element	U-value [W/m²K]	Area [m²]
Window 1	3.834	2.574
Window 2	3.988	2.662
Entrance door	2.863	3.360
Floor	0.514	34.940
Ceiling	1.034	34.940
Wall (outer)	1.368	28.142
Wall (to the neighbor)	2.226	15.805
Wall (to the staircase)	0.914	16.535
Wall (to neighboring building)	2.226	28.142
Total		167.100

Table 4 Net heating demand by month, present

Month	Q_{losses} [kWh]	η_F	Q_{gains} [kWh]	$Q_{heating,net}$ [kWh]
Jan	1 916.319	1.000	129.977	1 786.352
Feb	1 943.602	1.000	117.398	1 826.209
Mar	1 766.440	1.000	129.977	1 636.475
Apr	942.792	0.999	125.784	817.097
May	342.582	0.979	129.977	215.274
Jun	−82.883	−0.66	125.784	0.000
Jul	−203.408	−1.57	129.977	0.000
Aug	−107.057	−0.82	129.977	0.000
Sep	227.928	0.94	125.784	109.559
Oct	1 252.566	1.000	129.977	1 122.629
Nov	1 284.683	1.000	125.784	1 158.930
Dec	2 151.845	1.000	129.977	2 021.874
Total				10 694.399

Table 5 Final energy consumption of the heating systems for a 20-year period with corrected future outside mean temperature forecast data

Year	Wall-mounted gas convector [kWh]	Used natural gas [m³]	Heat pump [kWh]
2024*	17 967	1 855	2 972
2025	17 835	1 841	2 950
2026	17 704	1 828	2 928
2027	17 573	1 814	2 907
2028	17 442	1 801	2 885
2029	17 311	1 787	2 863
2030	17 180	1 774	2 841
2031	17 048	1 760	2 820
2032	16 917	1 747	2 798
2033	16 786	1 733	2 776
2034	16 655	1 719	2 755
2035	16 524	1 706	2 733
2036	16 392	1 692	2 711
2037	16 261	1 679	2 690
2038	16 130	1 665	2 668
2039	15 999	1 652	2 646
2040	15 868	1 638	2 625
2041	15 736	1 625	2 603
2042	15 605	1 611	2 581
2043	15 474	1 598	2 560
2044	15 343	1 584	2 538
Total	349 750	36 108	57 850

Due to losses (control loss, storage loss, transport loss), the following equation is used to determine the final energy consumption of the specific heating system:

$$Q_{heating,final} = \sum \begin{pmatrix} Q_{heating,net} \cdot \varepsilon_{heating,control} \\ +Q_{heating,transport} \\ +Q_{heating,storage} \end{pmatrix} \cdot \varepsilon_{heating}$$

Table 6 lists the primary energy consumption and CO_2eq operational carbon emissions for both heating systems.

Second, controlling the heating system can also be accounted for a functional unit. This incorporates the uncertainty of covering the net heating demand evenly or adequately in time and quantity. This is handled by the ÉKM Decree in a way that a less sophisticated system with less control options is degraded by a loss factor representing the deficiencies. Therefore, net heating demand is multiplied by the factors shown in Table 7.

5 Life Cycle Impact Assessment and Impact Categories

Regarding the HP, necessary elements according to the Fig. 11 for life cycle impact assessment (LCIA) is provided by PEP ecopassport (PEP ecopassport, 2023) page. The impact categories belonging to the A1; A2; A3; A4; A5 and B2 life cycle stages (LCS) (according to EN 15978) were supplemented by the eco passport. The stage B6, belonging to operational energy use was calculated for both building services systems.

Impact categories considered were originated from Environmental Footprint (EF) method 3.1.

6 LCA Results

Results were calculated with the above mentioned LCSs, period and functional unit, considering the changing temperature, two scenarios regarding the improving the electricity mix and the effect of one replacement HP.

Table 6 Primary energy consumption and CO_2eq OC emission of the heating systems for a 20-year period based on ÉKM Decree with corrected future outside mean temperature data

Heating system	PEC [kWh]*	CO_2eq emission [t]**
Wall-mounted gas convector (natural gas)	384 725	104
Heat pump (electricity)	150 410	26

* Calculated with the present conversion factors given in the ÉKM Decree in force;
** Calculated from the FEC and with the own coefficient of the ÉKM Decree, the current electricity mix was presumed.

Table 7 Loss and performance factors due to control losses and efficiency of different the heating systems

Heating system	Loss factor for control losses	Performance factor
Wall-mounted gas convector	1.2	1.4
Heat pump	1.042	0.267

6.1 Scenarios

Tables 8 and 9 shows the result of LCA in BaU and EA scenario. Red cells indicate the worse values, and bold lines highlight the major differences between the two scenarios regarding the multiplication factors of values.

7 Discussion

This research aims to highlight one cornerstone of energy refurbishments: the viability and the return on financial and ecological investment in such projects due to possible deviations from common beliefs. In the investigated case, a close result was achieved regarding whether to perform an active energy refurbishment or not.

This close result is attributed to (in favor of HP):

- Relatively small heat losses compared to the impact of a HP manufacturing process,
- Improving weather conditions, meaning that the built-in capacity will become superfluous in the future (the future FEC of the heating system is 85% of the present consumption), although the installation for peak capacity remains necessary,
- Maintenance of the gas convector is almost negligible and there is only a mandatory cleaning is prescribed. Parts usually do not have lifetime due to simplicity.
- Constraints that must be mentioned:
- Cooling capability was not considered in the functional unit,
- Bivalent or multivalent cases were not considered, only a complete transition,
- It is assumed that this used gas convector will run for another 20 years.

Phases depicted on Fig. 11 were considered only.

Investigating an active energy refurbishment alone may seem unnecessary. However, it is a typical situation that due to legal disputes or insufficient funding, a complete passive refurbishment cannot be carried out for a multi-family residential building. A possible future research direction would be to consider a complete passive refurbishment, the implementation of a bivalent or multivalent systems, and to put more emphasis on the human factor.

8 Conclusion

It can be concluded that, in specific cases, transitioning into HP results in only a slightly better performance in terms

Table 8 Impacts of the two systems in BaU scenario

EF 3.1 impact category	Heat pump	Wall-mounted gas convector	Factor
Acidification [Mole of H+eq]	(−)1.64E+01	(−)2.52E+01	1.54
Climate Change - total [kgCO$_2$eq]	(+)4.67E+03	(=)2.23E+04	4.78
Climate Change, biogenic [kgCO$_2$eq]	(+)2.19E+02	(−)2.32E+02	1.06
Climate Change, fossil [kgCO$_2$eq]	(−)4.45E+03	(+)2.21E+04	4.97
Climate Change, land use and land use change [kgCO$_2$eq]	(−)2.76E+00	(+)8.77E+00	3.17
Ecotoxicity, freshwater - total [CTUe]	(−)6.73E+04	(−)2.68E+04	2.51
Ecotoxicity, freshwater inorganics [CTUe]	(−)6.69E+04	(−)2.65E+04	2.53
Ecotoxicity, freshwater organics [CTUe]	(+)4.20E+02	(−)3.56E+02	1.18
Eutrophication, freshwater [kgPeq]	(+)1.39E−01	(−)9.83E-03	14.19
Eutrophication, marine [kgNeq]	(−)6.06E+00	(+)1.06E+01	1.75
Eutrophication, terrestrial [Mole of Neq]	(−)5.35E+01	(+)1.16E+02	2.16
Human toxicity, cancer - total [CTUh]	(−)2.45E−06	(+)8.66E−06	3.53
Human toxicity, cancer inorganics [CTUh]	(−)5.60E−07	(+)7.83E−06	13.97
Human toxicity, cancer organics [CTUh]	(+)1.89E−06	(−)8.32E−07	2.27
Human toxicity, non-cancer - total [CTUh]	(−)5.58E−05	(+)9.07E−04	16.24
Human toxicity, non-cancer inorganics [CTUh]	(−)5.47E−05	(+)8.88E−04	16.22
Human toxicity, non-cancer organics [CTUh]	(−)1.11E−06	(+)1.91E−05	17.18
Ionising radiation, human health [kBqU235eq]	(+)9.26E+03	(−)3.08E+01	300.94
Land Use [Pt]	(+)2.06E+05	(−)4.34E+03	47.51
Ozone depletion [kgCFC11eq]	(+)1.78E−06	(−)1.95E−09	911.82
Particulate matter [Disease incidences]	(−)1.51E−04	(−)2.16E−04	1.43
Photochemical ozone formation, human health [kgNMVOCeq]	(−)1.18E+01	(+)3.76E+01	3.18
Resource use, fossils [MJ]	(−)4.64E+05	(+)1.49E+06	3.21
Resource use, mineral and metals [kgSbeq]	(+)7.77E−03	(−)3.53E−03	2.20
Water use [m^{3}worldequiv]	(−)6.21E+02	(−)7.84E+01	7.92
Total score	15	10	

Table 9 Impacts of the two systems in EA scenario

EF 3.1 impact category	Heat pump	Wall-mounted gas convector	Factor
Acidification [Mole of H+eq]	(+)1.76E+01	(+)2.56E+01	1.45
Climate Change - total [kgCO$_2$eq]	(−)4.22E+03	(=)2.23E+04	5.29
Climate Change, biogenic [kgCO$_2$eq]	(−)1.59E+02	(+)2.38E+02	1.50
Climate Change, fossil [kgCO$_2$eq]	(+)7.50E+03	(−)1.77E+04	2.36
Climate Change, land use and land use change [kgCO$_2$eq]	(+)3.70E+00	(−)7.97E+00	2.15
Ecotoxicity, freshwater - total [CTUe]	(+)9.77E+04	(+)5.47E+04	1.79
Ecotoxicity, freshwater inorganics [CTUe]	(+)9.74E+04	(+)5.43E+04	1.80
Ecotoxicity, freshwater organics [CTUe]	(−)3.24E+02	(+)4.07E+02	1.26
Eutrophication, freshwater [kgPeq]	(−)1.04E−01	(+)7.10E−02	1.46
Eutrophication, marine [kgNeq]	(+)6.57E+00	(−)1.05E+01	1.60
Eutrophication, terrestrial [Mole of Neq]	(+)6.40E+01	(−)1.10E+02	1.71
Human toxicity, cancer - total [CTUh]	(+)3.65E−06	(−)7.69E−06	2.10
Human toxicity, cancer inorganics [CTUh]	(+)1.91E−06	(−)6.28E−06	3.29
Human toxicity, cancer organics [CTUh]	(−)1.75E−06	(+)1.41E−06	1.24
Human toxicity, non-cancer - total [CTUh]	(+)2.17E−04	(−)7.27E−04	3.35
Human toxicity, non-cancer inorganics [CTUh]	(+)2.13E−04	(−)7.12E−04	3.34
Human toxicity, non-cancer organics [CTUh]	(+)4.16E−06	(−)1.50E−05	3.60
Ionising radiation, human health [kBqU235eq]	(−)6.74E+03	(+)1.31E+03	5.13
Land Use [Pt]	(−)1.66E+05	(+)1.11E+05	1.50
Ozone depletion [kgCFC11eq]	(−)1.42E−06	(+)5.58E−07	2.54
Particulate matter [Disease incidences]	(+)1.60E−04	(+)2.21E−04	1.38
Photochemical ozone formation, human health [kgNMVOCeq]	(+)1.57E+01	(−)3.31E+01	2.11
Resource use, fossils [MJ]	(+)6.05E+05	(−)1.22E+06	2.01
Resource use, mineral and metals [kgSbeq]	(−)6.63E-03	(+)5.27E-03	1.26
Water use [m^{3}worldequiv]	(+)1.06E+03	(+)5.71E+02	1.86
Total score	16	9	

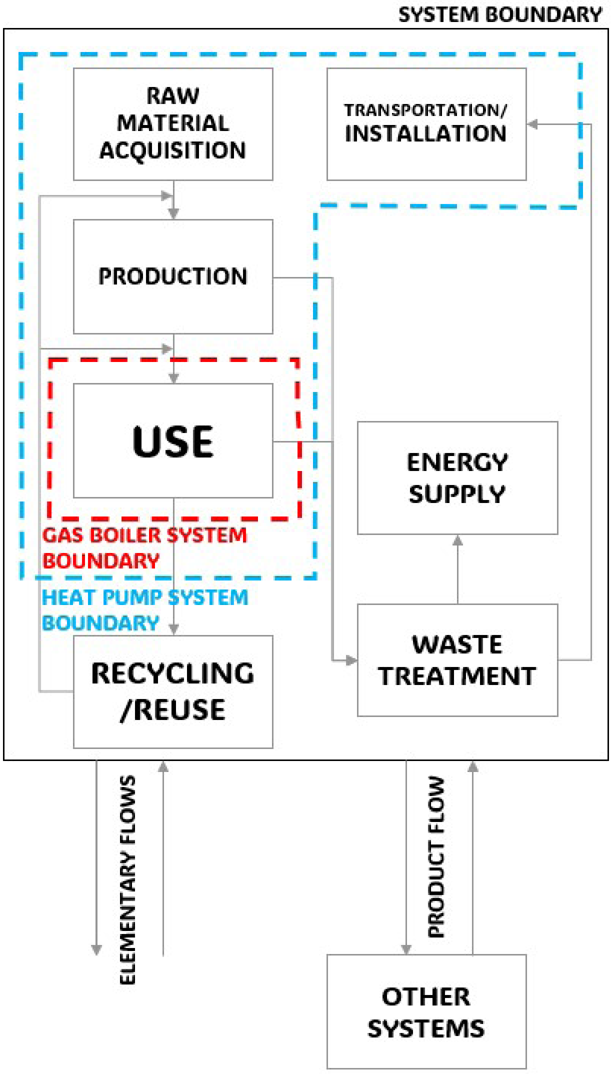

Fig. 11 System boundaries by heating system type

of LCA. Furthermore, it can be stated that, due to the manufacturing phase, new equipment falls significantly behind in the race of sustainability and catching up later depends largely on what source of its used energy comes from. In the BaU scenario, both HP and gas convector result in worse performance by an order of magnitude in 4 categories each. In the EA scenario, where measures to clean electricity generation mix were considered, the factors decreased drastically in 8 cases. The values associated with the impact categories (indicated by +/– signs when compared to the other scenario) worsened in 16 cases in EA scenario and in 13 cases in case of the gas convector, compared to BaU scenario. There are impacts with higher values in EA compared to BaU as well, but to a much lesser extent.

Under the given conditions, transitioning to HP is still more beneficial than using gas convector, moreover, transitioning with a gradually improving electricity generation mix means a largely better trade off. However, there was no major change regarding the total CO_2eq emissions in different scenarios and in both scenarios, transitioning meant a five times less environmental impact in favor of the HP.

Nomenclature

CTUe	Comparative Toxic Unit for ecosystems
CTUh	Comparative Toxic Unit for humans
Disease incidences	Number of disease incidences
kBqU235eq	Kilobecquerel of U-235 equivalents
kgCFC11eq	Kilograms of CFC-11 equivalents
kgCO_2eq	Kilograms of CO_2 equivalent
kgNMVOCeq	Kilograms of non-methane volatile organic compounds equivalents
kgNeq	Kilograms of nitrogen equivalents
kgPeq	Kilograms of phosphorus equivalents
kgSbeq	Kilograms of antimony equivalents
ktCO_2eq	Kilotons of CO_2 equivalent
MJ	Megajoules
Mole of H+eq	Moles of hydrogen ion equivalents
Mole of Neq	Moles of nitrogen equivalents
Pt	Points
W/m^{2}K	Thermal transmittance

Abbreviations

CGB	Condensation Gas Boiler
DH	District Heating
DHW	Domestic Hot Water
EC	Embodied Carbon
EF	Environmental Footprint
EGM	Electricity Generation Mix
EPBD	Energy Performance of Buildings Directive
EEA	European Environment Agency
ES	Energy Source
EU	European union
ÉKM	Hungarian name of the Decree No. 9/2023. (V. 25.) of the Ministry of Construction and Transport
FEC	Final Energy Consumption
FF	Fossil Fuel
GHG	Greenhouse Gas
GWP	Global Warming Potential
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment

LCI	Life Cycle Inventory	NG	Natural Gas
LCS	Life Cycle Stage	SCOP	Seasonal Coefficient of Performance
NECP	National Energy and Climate Plan	OC	Operational Carbon
NZEB	Nearly Zero-Energy Building (KNE in Hungarian)		

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