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HEAT TRANSITION OPTIONS FOR THE LEAST PERFORMING BUILDINGS OF HUNGARY

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1. THE CONTEXT OF HEAT TRANSITION: REQUIREMENTS AND POSSIBILITIES

European legislative framework

The building sector has outstanding potential for energy savings and greenhouse gas mitigation as consumption can be drastically reduced through cost-effective measures.[1,2] There is a broad scientific consensus that retrofit measures to improve the energy efficiency of the residential building stock have negative or zero costs over the life cycle of the building without considering non-energy benefits, such as the positive impacts on health, the labour market and indoor environmental quality.[1,3]

Public energy efficiency investments have significantly higher returns when implemented among low-income households relative to middle and higher-income groups, and low-income households benefit more from energy efficiency.[4] Energy efficiency investments have multiple benefits, including higher employment, which translates to increased tax revenue for central budgets. Savings on energy costs increase the disposable income that can be spent elsewhere. Improved housing conditions result in better health outcomes for individuals and create important savings for the health budget. Healthier homes mean fewer sick days, which boosts personal well-being, school, and work performance, and benefits the economy as a result.[5] In most EU27 countries, the reduction in energy bills associated with energy efficiency improvements is expected to be more beneficial for lower-income households (especially those in the lowest 20 per cent quintile) than higher income households.[6] Energy bills disproportionately burden lower-income groups due to their higher proportion of income spent on electricity and gas compared to wealthier households. The implementation of energy efficiency measures for the poorest households could decrease the share of overall consumption spent on energy from 7.2% to 5.9% by 2030, compared to a reduction of 4.5% to 3.7% for the richest households. 'A study using data from New Zealand's Warm Up NZ: Heat Smart programme evaluation indicated significantly higher monetised benefits among families on low to modest incomes of USD 519 per year after the retrofitting compared to USD 183'.[7] Retrofitting homes of predominantly low-income communities in New Zealand suggests that total benefits are one and a half to two times the magnitude of the cost of retrofitting insulation.[8]

This is reflected in both global and national policies and measures. The EU has set a strategic goal of achieving a carbon-neutral economy by 2050. This is at the heart of the European Green Deal and is in line with the global climate change commitments made in the Paris Agreement.[9,10] The literature shows that countries have already made significant efforts towards mitigation, but that these efforts are still far from sufficient to meet these targets.[11] Reviews of the international literature on the subject leads to the conclusion that a more complex coordination of technical, financial and awareness-raising policies is needed to achieve these objectives, leading to a continuous tightening of policy and increasingly ambitious targets.[11,12,13,14]

The legislative framework established by the EU is therefore aligned with this strategic objective, the most important of which is the Energy Performance of Buildings Directive (EPBD). The EPBD has been setting policy since 2002[15] and has been amended twice since its creation, in 2010 (EPBD recast 2010)[16] and in 2018 (EPBD recast 2018).[17] The Directive includes a scheme for energy certification, a set of requirements for both new buildings and major renovations, the requirement of new buildings to meet near-zero energy requirements from 2021, the concept of deep renovation and a number of other policy incentives. The EPBD recast 2018 states that the European building stock should be transformed into a 'highly energy efficient and decarbonised building stock by 2050, facilitating the cost-effective conversion of existing buildings into near-zero energy buildings'.[17]

The latest draft amendment to the EPBD goes further, with a particular focus on the phasing out of worst performing residential buildings from the building stock. 'Each Member State will adopt its own national trajectory to reduce the average primary energy use of residential buildings by 16% by 2030 and 20-22% by 2035, allowing for sufficient flexibility to consider national circumstances. Member States are free to choose which buildings to target and which measures to take. The national measures will have to ensure that at least 55% of the decrease of the average primary energy use is achieved through the renovation of the worst-performing buildings'[18] Worst-performing buildings are defined rather widely, as 43% of buildings with the lowest energy performance in the national building stock.[19] The requirement of member states to reduce the energy needs of existing residential buildings marks a historic step as it has not been directly addressed by EU regulation until now.

Article 8 of the recast in 2023, set annual energy saving targets for member states. They require them to reach those targets by implementing energy saving measures through the prioritisation of people affected by energy poverty. Member states should also ensure 'that share of the required amount of cumulative end-use energy savings among people affected by energy poverty, vulnerable customers, people in low-income households and, where applicable, people living in social housing. This share should at least be equal to the proportion of households in energy poverty as assessed in their national energy and climate plans'. One method of reaching energy-saving targets among vulnerable groups is to reduce the energy needs of their homes by improving the efficiency of both their building and their heating system.

Article 25 of the directive also requires the preparation of heating and cooling plans, though only for settlements with a population higher than 45,000. This excludes smaller settlements from the obligation of heating and cooling planning. However, the current set of targets creates the risk that the least-performing stock, the residential buildings that are the hardest to renovate, will be left behind. The current wide definition of worst-performing stock (45%) is itself problematic in that it does not reflect the large differences in energy efficiency ratings within such a large percentage. This could lead to the selection of lower-hanging fruits so to speak, prioritising easier, shallower renovations in buildings that are in fact closer to the average.

This study aims to examine the Hungarian building stock and focus, in particular, on its worst-performing types. It also aims to explore cost-effective strategies to reduce energy needs and provide clean and affordable heating to those individuals occupying the worst-performing homes. It is hoped that this report will demonstrate the urgency with which we must dedicate our focus to the renovation of worst-performing stock and highlight the various factors that must be taken into consideration during this process.

2. THE HUNGARIAN BUILDING STOCK

This chapter presents both the statistical data and energy characteristics of the Hungarian building stock and examines a number of important surveys. The peculiarities of the Hungarian authority's gas price regulation are also discussed, before an examination of why the current pricing policy remains one of the biggest obstacles to modernisation. Finally, this chapter identifies the worst-performing building stock and concludes by describing a range of typical energy consumption indicators.

Energy statistics of the residential building stock

Buildings account for 40% of total energy consumption in Europe. The largest share of energy consumption in residential buildings is used for space heating (EU: 64%, Hungary: 71%), followed by lighting and electrical equipment (EU: 15%, Hungary: 11%), heating (EU: 14%, Hungary: 13%), cooking (EU: 6.4%, Hungary: 5.0%) and cooling (EU: 0.4%, Hungary: 0.2%, Greece: 1.24% - these low figures make these statistics questionable) (Figure 1).[13] Heating as a share of energy consumption is more significant in Hungary than the EU average, which may be explained by climatic reasons and/or the inferior energy performance of its buildings. The low value for cooling is difficult to believe, and it is likely that a portion of the share allocated to lighting and electrical equipment is actually used for cooling. Although the energy demand for space cooling looks statistically small, it is steadily increasing, tripling between 1990 and 2019.[13]

Figure 2 shows energy use per energy carrier for some EU countries and the EU as a whole. The largest energy use is related to natural gas (EU: 33%, Hungary: 49%), followed by electricity (EU: 25%, Hungary: 18%), firewood (EU: 18%, Hungary: 22%), oil (EU: 12%, Hungary: 1%) and district heating (EU: 9%, Hungary: 8%).[20] The role of coal and oil is insignificant in Hungary. The chart does not include renewables other than firewood (e.g. solar, heat pumped ambient heat), nor does it reflect the energy mix of electricity and district heating. The role of gas use in Hungary is dominant, one of the most significant in Europe. This is partly due to geopolitical reasons, as for a long time there was a lack of any competitive alternative to cheap Russian gas, leading to the development of an extensive natural gas infrastructure in the

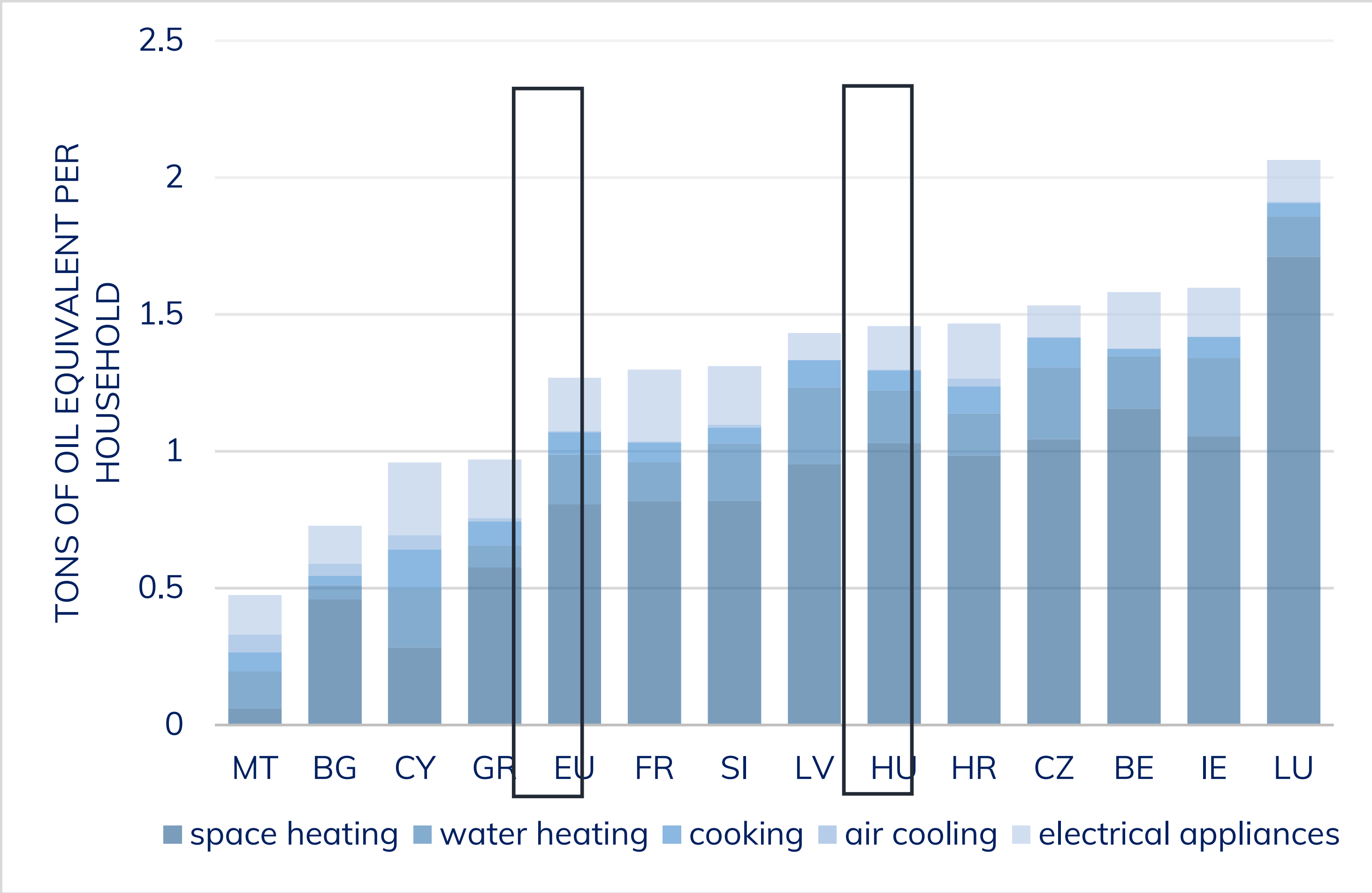


Figure 1: Household energy use by purpose for some EU countries and for the EU as a whole, per permanently occupied dwelling, 2019 (own filtering from database [20])

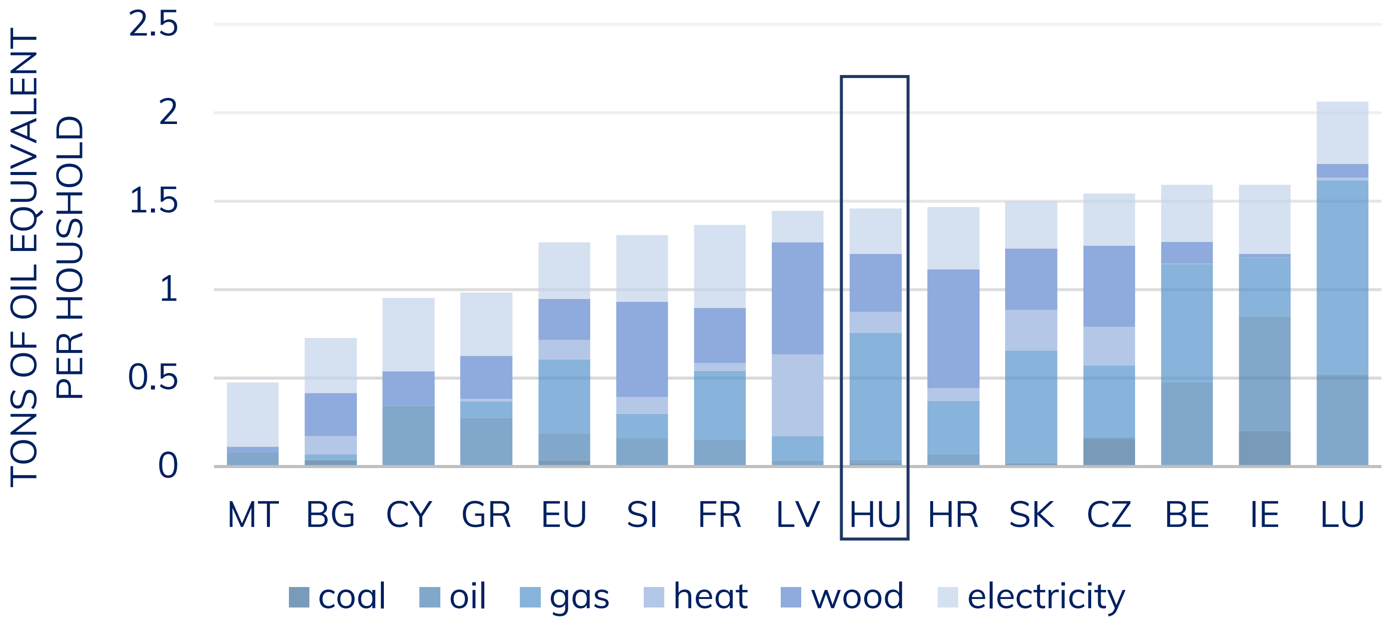


Figure 2: Household energy use per energy carrier for some EU countries and the EU as a whole, per permanently occupied dwelling, 2019 (own filtering from database [20])

Energy Carrier	EU	Hungary
Space Heating	64%	71%
Lighting and Electrical Equipment	15%	11%
Hot Water Supply	14%	13%
Cooking	6.4%	5.0%
Space Cooling	0.4%	0.2%

Table 1: Household energy use per energy carrier for some EU countries and the EU as a whole, per permanently occupied dwelling, 2019 [21

country. The use of firewood is also significant, as it is a typical fuel-source in underdeveloped regions that do not have any form of gas network and instead rely on outdated stove heating systems.

Regulatory framework in Hungary

As mentioned before, on an EU level the main regulatory framework for buildings is the Energy Performance of Buildings Directive, known by its acronym EPBD, which has been amended twice since its first version (91/2002/EU) (Directives 31/2010/EU and 2018/844/EU).19,20,21 The third amendment is in the pipeline for 2024, although the draft is already widely known.

Energy requirements were first introduced for new buildings and were also linked to the building permit procedure. Later, the requirements were extended to both building renovations and extensions, distinguishing between major and minor renovations/extensions.

In Hungary energy requirements are constantly being tightened, largely due to the EPBD. Important 'tightening' steps in Hungary have come in 1991, 2006 and 2018. Since 2006 the most important energy performance requirement has been related to the specific primary energy consumption. In 2018, the 'cost optimal requirements' were introduced, significantly decreasing the energy need. This was followed by the introduction of the 'nearly zero energy buildings' requirements, initially introduced in 2021, but postponed in Hungary until November 2023. Minimum energy performance requirements are laid down in national legislation and are generally respected in the case of new buildings. However, in practice, they are difficult to enforce and monitor, particularly for renovations. Where subsidies are involved in the retrofit, the requirements are strictly controlled. Experience shows that strict requirements often discourage applying for public funds, which can be counterproductive.

One of the basic legal acts of the Hungarian implementation was the frequently amended TNM Decree 7/2006 (24.V.2006),[22] which contained both the energy requirements for buildings and the calculation method for determining the most common use of energy consumption in Hungary. This act has been substituted by 9/2023 (V.25.) Decree of Ministry of Construction and Transport.[23] Another piece of relevant basic legislation is Government Decree 176/2008,[24] which describes the rules for the energy certification of buildings, the calculation method of which is also based on 9/2023 (V.25.) Decree.[23]

The Hungarian energy efficiency law ((2015. Évi LVII. Törvény Az Energiahatékonyságról [Act 2015/57 on Energy Efficiency], 2015) is) sets the criteria for assessing the number of households in energy poverty. It defines a 'household to be supported' as a 'vulnerable household whose annual energy cost for heating the dwelling to 20°C and producing hot water in the dwelling house exceeds 25% of the household's annual income'. [Act 2015/57 on Energy Efficiency], para. 1/28.b). This definition supports the 'official' energy poverty indicator through which the Hungarian government complies with the requirements set by the Clean Energy Package (CEP) (Regulation on the Governance of the Energy Union and Climate Action, 2018, art. 29) Member States (Ms), when assessing the number of households in energy poverty, shall establish a set of criteria which 'may include low income, high expenditure of disposable income on energy and poor energy efficiency' (Directive 2019/944 on the Common Rules for the Internal Market for Electricity, art. 29).

To comply with the requirement of the European Energy Efficiency's Directive, Article 12/a of the Hungarian Energy Efficiency Law Hungary introduced its energy-saving obligation scheme (EEO), aiming to incentivise the renovation of buildings. The incomes from the scheme should be spent on increasing energy efficiency for vulnerable households or in public buildings. Subsidies for energy modernisation are not yet available; the current government envisages energy renovation of residential buildings under the EEO. However, the first year of the domestic EEPR (Energy Efficiency Performance Regulation) and international experiences highlight that addressing residential energy renovation and energy poverty solely within the domestic EEPR is insufficient.

Energy efficiency projects abroad predominantly target low-return industrial or large-scale, non-complex building renovations, neglecting the fragmented and challenging nature of energy-poor households' home renovations. This issue, which typically falls outside the scope of obligated parties, results in no savings in the first year of the ERA (Energy Renovation Action) from residential and public building renovation. Existing housing-related support schemes lack suitability for addressing energy poverty, lack energy efficiency requirements, social criteria, and often require upfront financing. Furthermore, there is a notable absence of any emphasis on providing information to potential renovators, a crucial factor identified by researchers as a key source of motivation and trust-building. Notably, a survey revealed that a one-stop shop is preferred over a soft loan for initiating energy renovations, underscoring the importance of comprehensive support beyond financial incentives.[25]

The Energy Performance of Buildings Directive (2010/31/EU) and its subsequent revision in 2018 (2018/844/EU) mandates EU countries to develop long-term renovation strategies as integral components of their National Energy and Climate Plans (NECPs). Hungary, in compliance with these requirements, has submitted and updated its renovation strategies. Hungary's submission and periodic updates of its renovation strategies demonstrate a commitment to fulfilling its obligations under the EPBD. However, a closer examination reveals a lack of robustness in the policies outlined. While the strategies describe overarching goals and objectives, the specific measures for renovating the worst-performing building stock remain inadequately defined. The absence of any concrete, targeted policies along with the inadequacy of the financial and institutional framework to support the ambitious renovation goals raise concerns about the country's ability to achieve the outlined renovation targets.[26]

This study delves into the Hungarian building stock, focusing on its worst-performing segments, to identify key features and propose cost-effective renovation and decarbonisation options. The aim is to address the specific challenges associated with the prevalent building types within Hungary's worst-performing stock, outlining strategies that balance environmental impact and economic feasibility.

3. KEY CHARACTERISTICS OF THE STOCK, AGE, TYPES, PERFORMANCE, ETC.

Building typology

The most reliable survey of the housing stock in Hungary was conducted in 2015, in which the Hungarian housing stock was classified into 23 building types by age, size (single family houses - SFHs, small and large multi-family buildings - MFHs) and construction technology (adobe, brick, prefabricated).[27] Based on a representative field survey of 2029 dwellings, a typology of the housing stock (Annex: Table 4 and Table 5) and its database were prepared. As well as ensuring representativeness, this study is considered to be the most reliable of its type, as its surveys were carried out by energy experts. The database created is suitable for modelling energy use in dwellings and for analysing the impact of different energy saving measures.

Building envelope

The following figure shows the specific heat loss coefficient by building type, which is the specific heat loss per 1 m3 of heated volume, corrected with solar gain. The figure shows that, for both the smaller the absolute size of the building, and for the older the age of the building, the worse the specific heat loss coefficient. Thus, the highest values for heat loss coefficient are for detached houses built before 1990 (types 1-8, see types in Table 4 and Table 5), representing 52% of the dwelling units in Hungary.

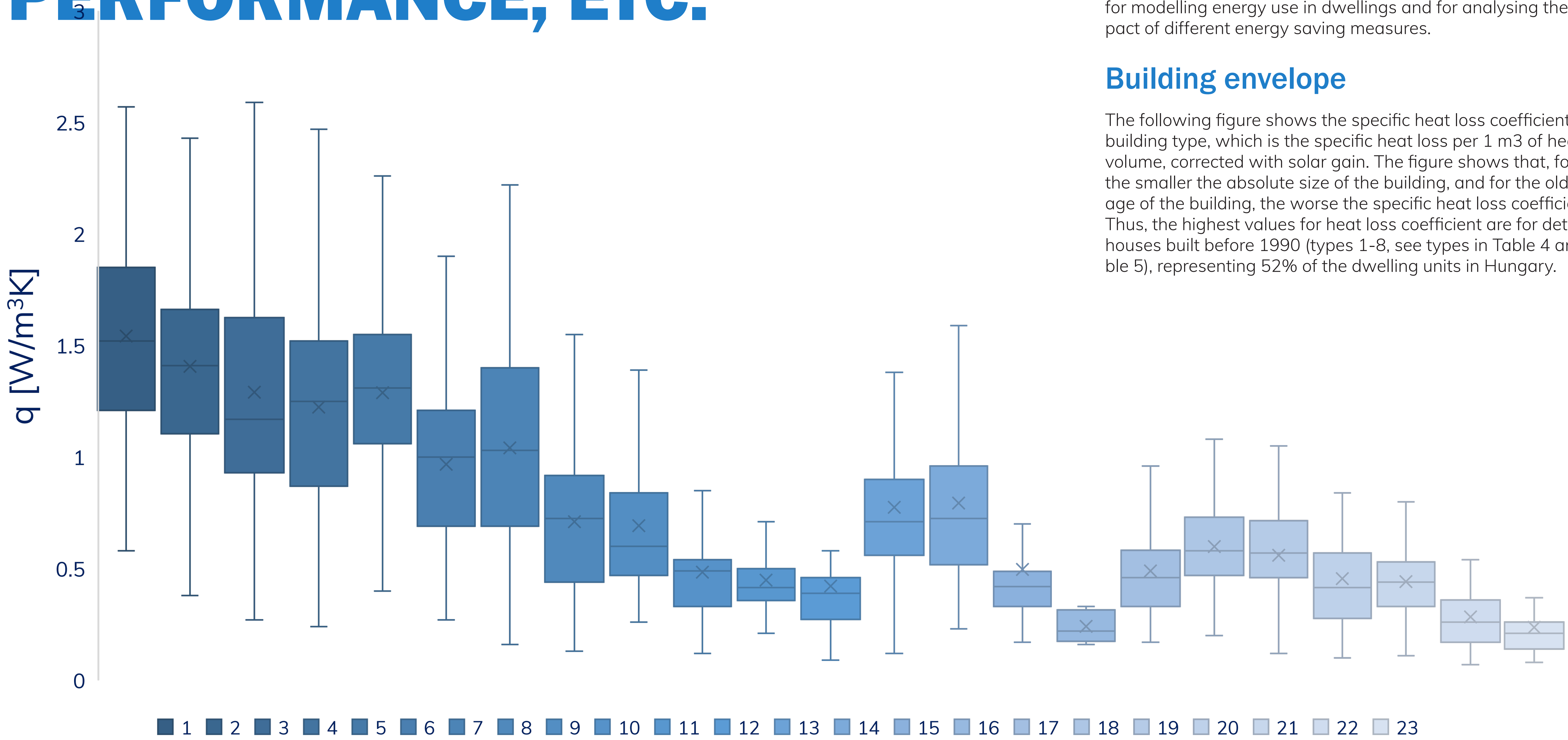


Figure 3: Specific heat loss coefficient by building type ([28] based on database from [27])

TYPOLOGY OF DWELLINGS - SINGLE FAMILY HOMES

Construction year	Small	Large	Adobe type one	Adobe type 2
-1944	 3			
1945-1959	 4			
1960-1979	 5	 6	 1	 2
1980-1989	 7	 8		
1990-2005	 9	 10		
2006-	 11	 12		

Table 4: Illustration of the typology of family houses [27]

TYPOLOGY OF DWELLINGS - MULTI-FLAT HOUSES

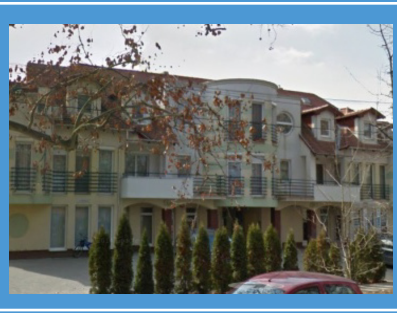
	Small	Large		
Construction year		Traditional	Panel	Other prefabricated
-1944	 13	 17		
1945-1959				
1960-1979	 14	 18	 20	 19
1980-1989			 21	
1990-2005	 15	 22		
2006-	 16	 23		

Table 5: Illustration of the typology of housing associations [27]

Energy sources for heating and heating systems

The graph below shows the both the distribution of building types by number of dwellings in the country, and the energy source used for heating by building-type. From the graph, we see that 62% of the housing stock are SFHs (types 1-12), and almost 60% are SFHs built before 2006 (types 1-10) and 52% are SFHs built before 1990 (types 1-8). There are also a significant number of apartments (28%) within large MFHs built before 1990 (types 17-21).

As demonstrated by the figure below, natural gas accounts for a significantly large proportion of all energy carriers for heating purposes in Hungary. Biomass use is also significant, especially in the case of lower types of detached houses. For larger apartment buildings, the importance of district heating is significant, especially for types 20-21, which include buildings built with prefabricated sandwich panels that dominated the residential construction sector in Eastern Europe during the seventies and eighties. Electric heating and the use of renewable energy sources other than biomass were negligible in 2015.

A 2022 questionnaire survey, which included the responses of approximately 1000 people, also examined the condition of the Hungarian housing stock.[28] A weakness of this survey however, in comparison to the one undertaken in 2015, was that the surveyors did not have a large degree of knowledge of building energy and in the case of some building types, the number of sample dwellings was relatively low. This was particularly true for new types and small MFHs, so it is difficult to say that results for these dwellings are representative. In this study, the 23 building types previously reported, were decreased to 14 types, as some of these dwell-ing-types were merged due to similar characteristics.

The survey confirms the dominance of gas heating, with a more significant share of wood burning than in 2015, but here 2.6% heat pumps (including split air conditioning) appear as the primary heat generators. Observing the national distribution of heat generators used for space heating as a primary heat source (Figure 5), it can be stated that in October 2022, shortly after the shock caused by the energy crisis (1st August 2022), biomass-based, typically ineffi-

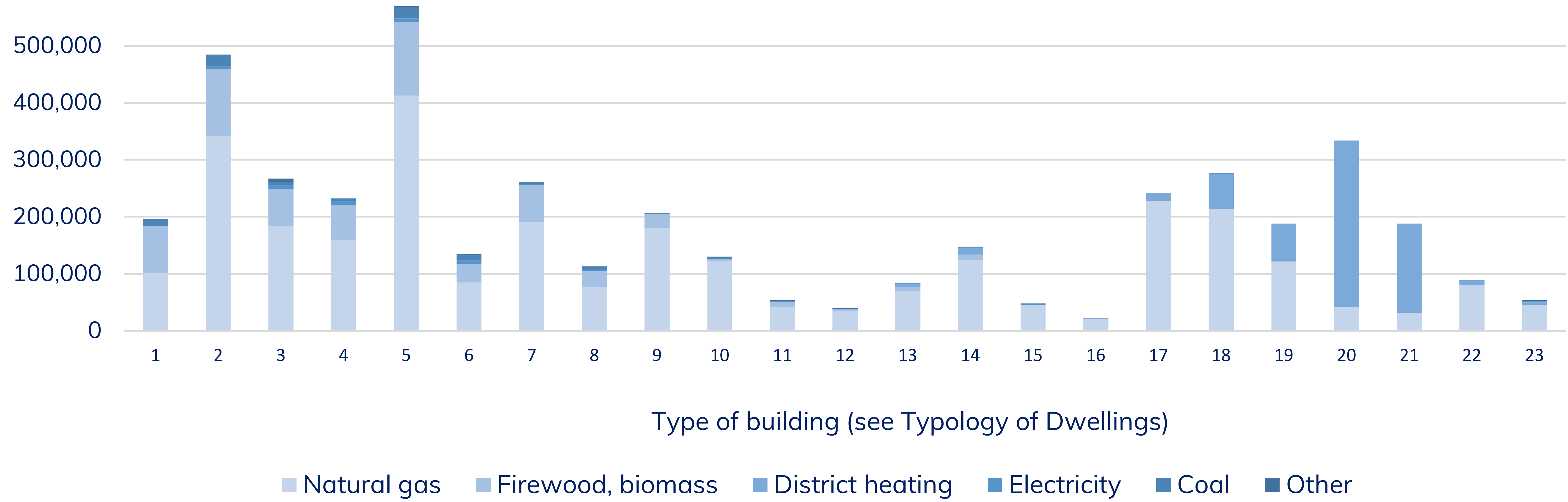


Figure 4: Number of dwellings (units of dwellings) and the distribution of primary energy carriers for heating purposes by building type in Hungary (2015) ([29], [30] based on database from [27])

cient combustion plants were present in 30% of dwellings. The share of natural gas-based gas convectors, which are also inefficient, was 23%, and the share of old-type gas boilers was 14%. Approximately 17% of the respondents used a condensing boiler, 2.6% used a heat pump or split air conditioner, and the proportion of district heating was 12%. The higher proportion of biomass compared to 2015 (Figure 4) indicates that many people quickly switched from gas to biomass combustion, suggesting that this equipment was already present as a backup heat generator.

As shown in Figure 6, firewood use is typical of single-family homes, and the older the building, the higher the share of stoves and biomass boilers is. This is strongly linked to energy poverty and poor energy performance: these building users have responded fastest to the increase in gas prices, although they have used the most firewood in the past as well. It is also clear that gas convectors are very widespread, not only in SFHs, but also in MFHs. These are typically inefficient devices, often at least 30 years old, with low thermal comfort level and poor control options. One of their primary issues is that they are difficult to be replaced with other gas appliances as they are not connected to a chimney, a feature which these types of buildings do not usually have. Often, only split air conditioning can be considered instead, but it is often insufficient due to the high heat loss propensity of the building. In this case, complete thermal insulation would also be required, which is hindered by the lack of financial sources.

According to the survey, heat pumps have a high penetration rate in new building types, especially in large apartment buildings. However, the national share of these buildings is very low and as mentioned before, the representativity of this survey is questionable.

It should also be noted that, according to the more technically sound 2015 survey, heat pumps have barely been installed in buildings since 1990 (Figure 8). This calls into question the reliability of the results of the 2022 survey, as such a large change in these building categories could not have occurred in 8 years, as the number of buildings built since 2015 is much lower than the number of buildings built between 1990 and 2015. It is likely that in the 2022 survey, post-2015 buildings were over-represented within the category.

It should also be mentioned that many buildings have a secondary heat generator, which function partly as an auxiliary heater and partly as a security heater. More than half of SFHs have such heat generators, in MFHs their proportion is slightly lower. Their distribution by type and energy carrier is diverse and balanced as presented in Figure 9 and Figure 10.

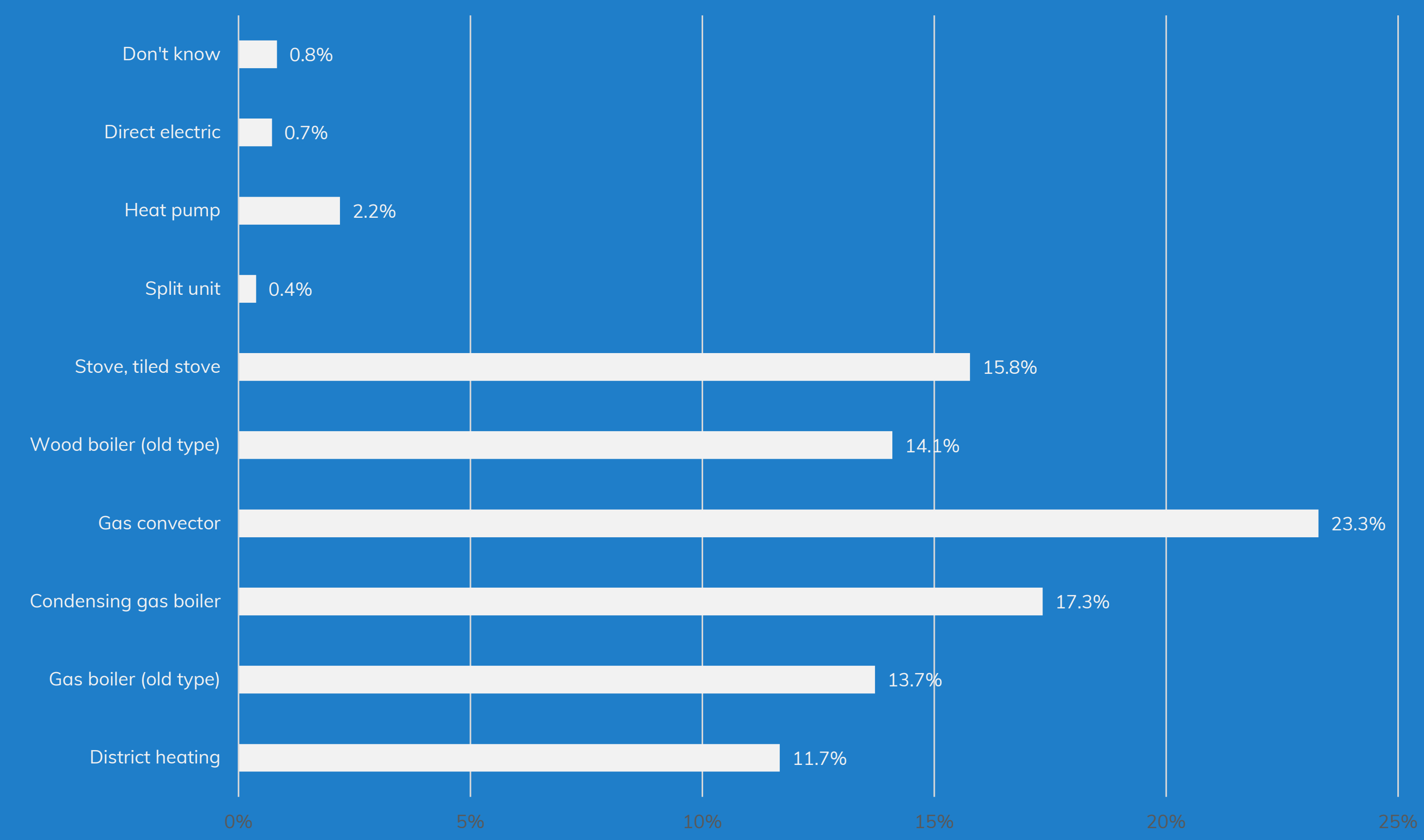


Figure 5: Applied heating system types in Hungarian dwellings, 2022, [29]

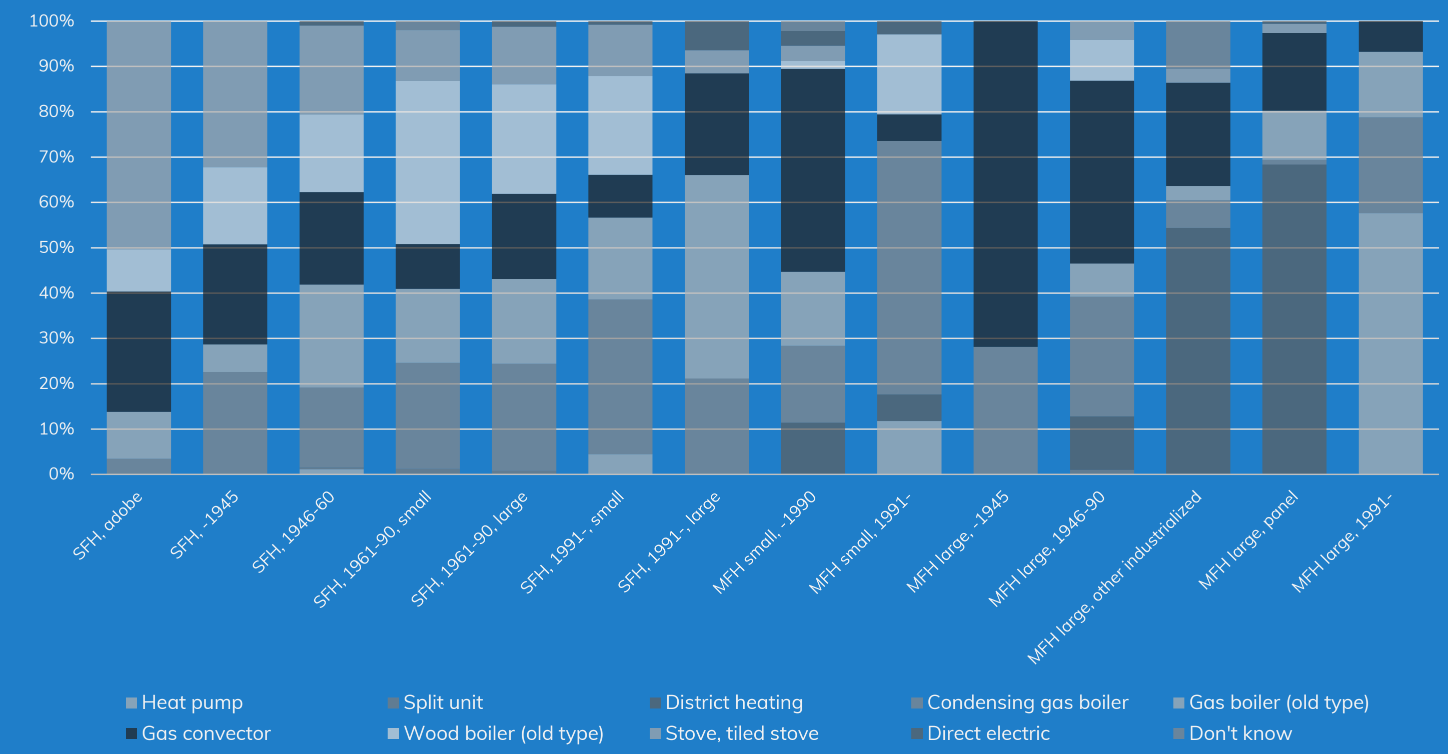


Figure 6: Applied heating system types used as primary heat generators according to building type, 2022, [29]

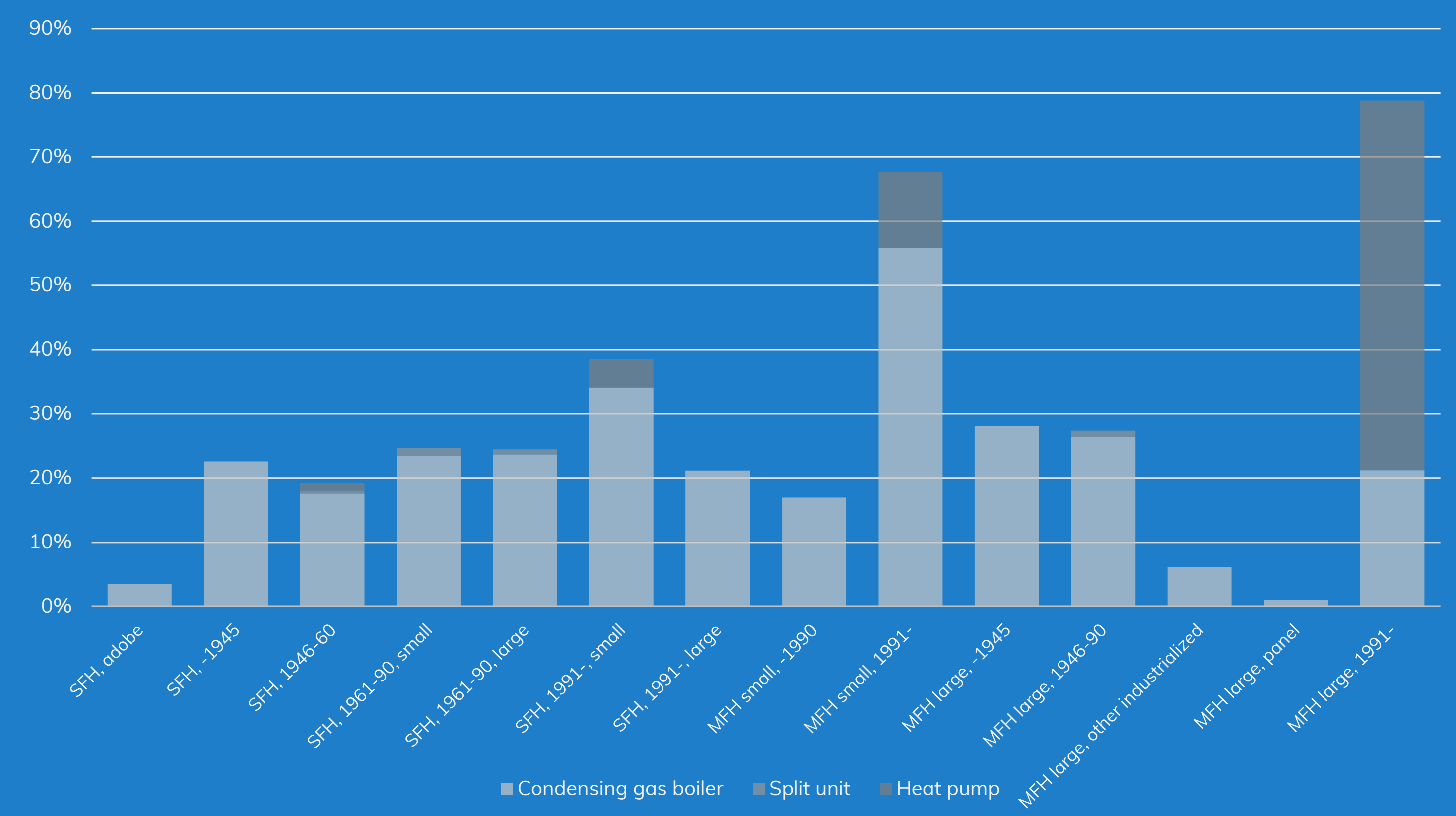


Figure 7: Share of heat pumps, split units and condensing boilers applied as primary heat generators according to building type, 2022, [29]

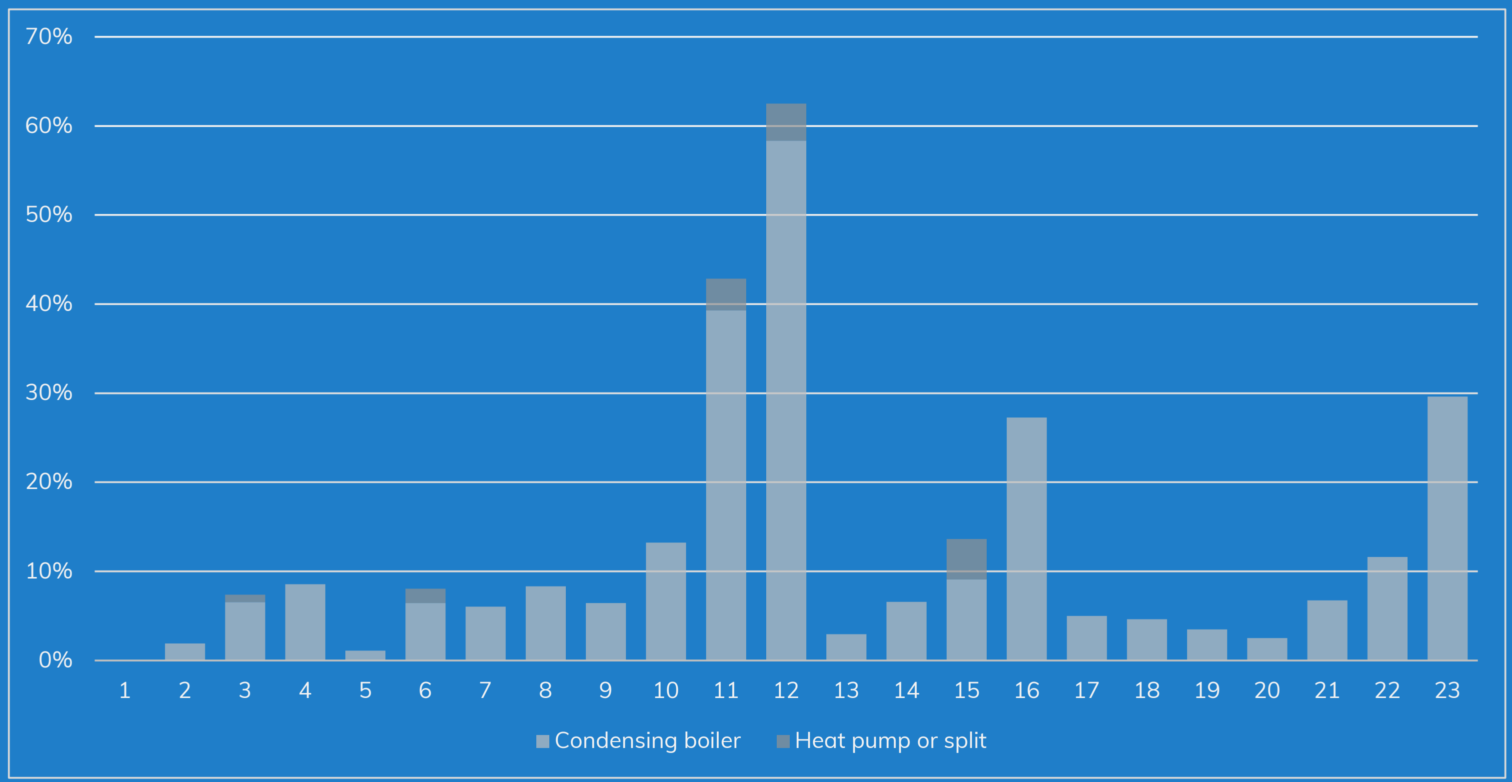


Figure 8: Share of heat pumps or split units and condensing boilers applied as primary heat generators according to building type, 2015, (based on database of [27])

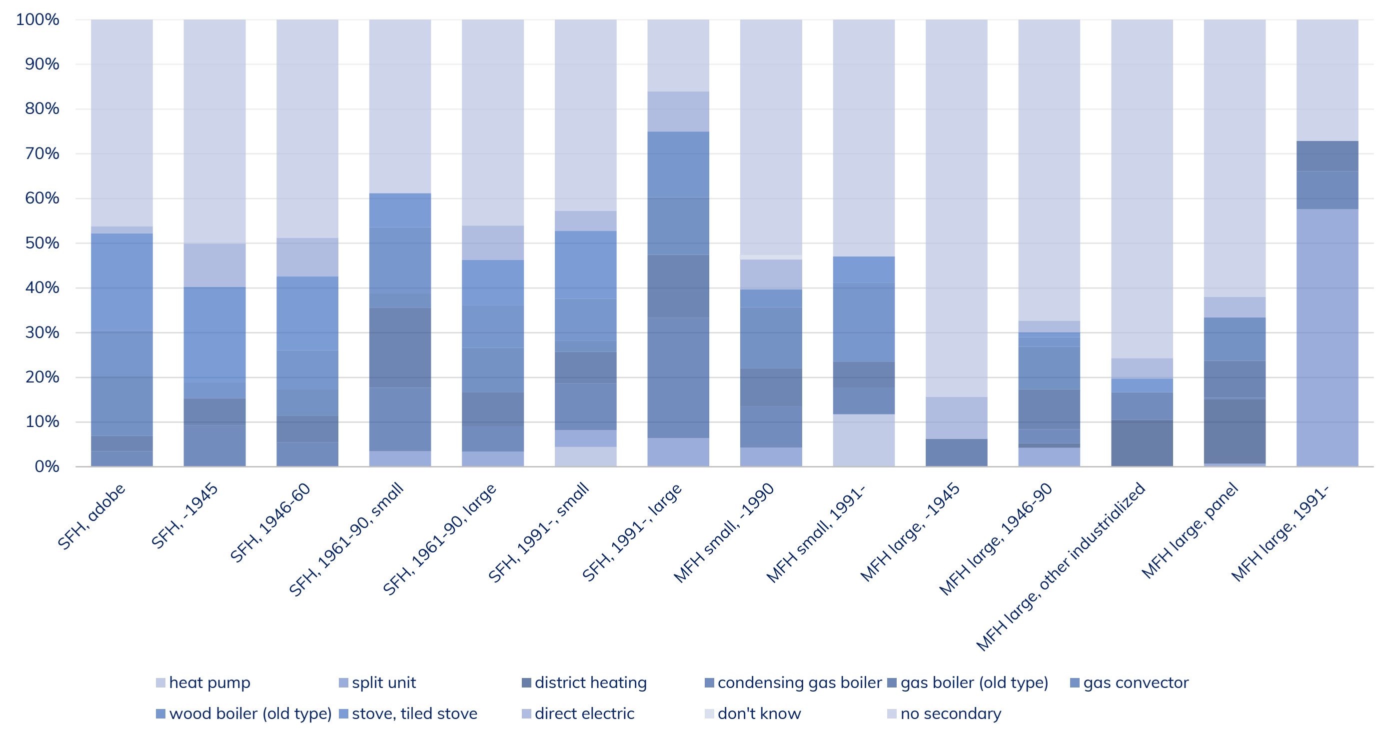


Figure 9: Applied heating system types used as secondary heat generators according to building type, 2022, [29]

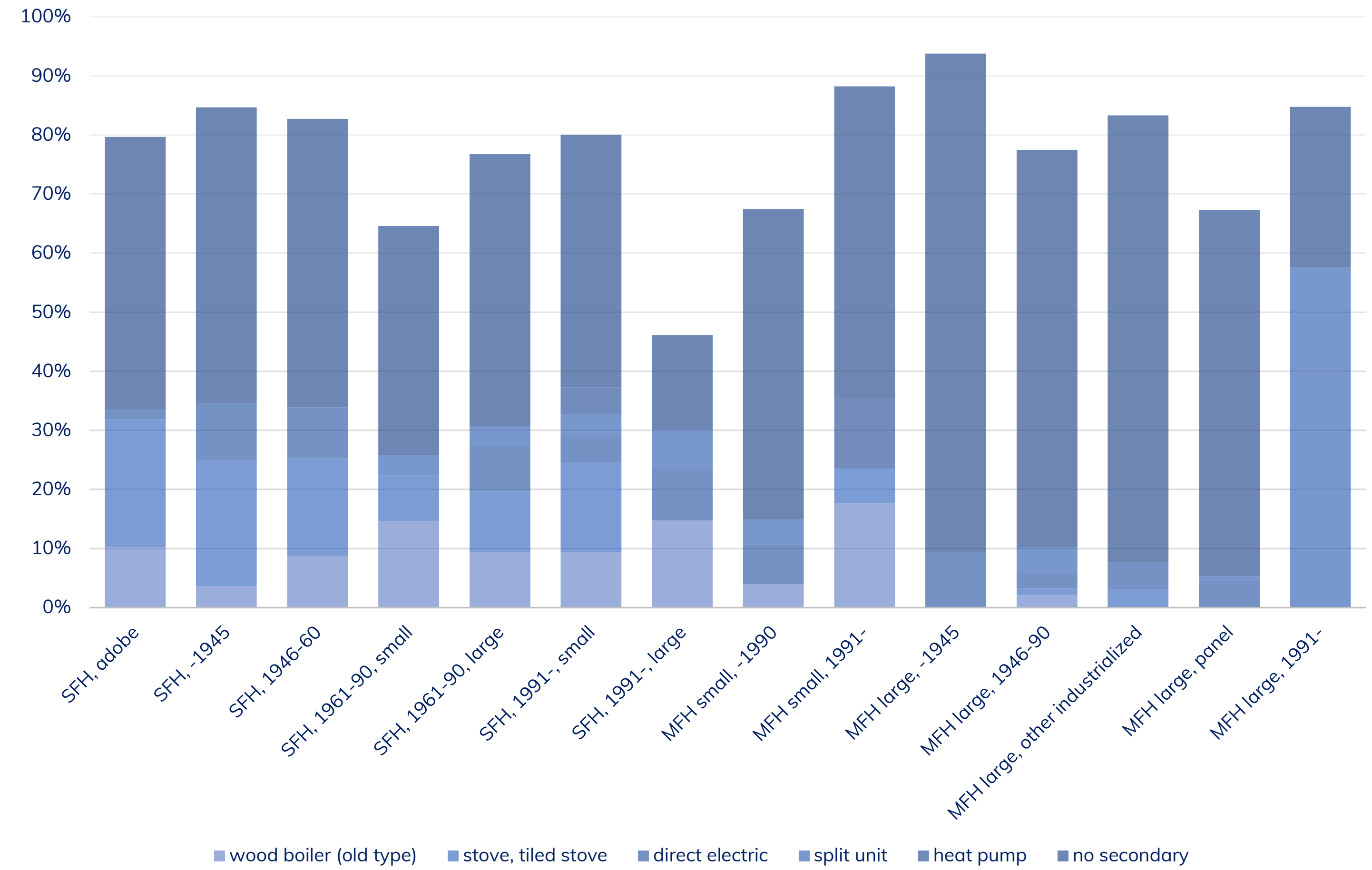


Figure 10: Share of biomass systems, heat pumps, split units applied as secondary heat generators according to building type, 2022, [29]

Energy performance per building types

The following figure shows the specific primary energy consumption per square metre of heated floor area for the sample surveyed (Figure 11). It demonstrates that consumption depends predominantly on age and size. The older a building is and the smaller it is, the higher its specific energy consumption. Carbon dioxide emissions also show a strong correlation with primary energy use. Again, the specific heating energy consumption of family houses built before 1990 (highlighted in box in Figure 11) is much higher than the average.

Consequences of current Hungarian residential energy pricing [19], [20]

Utility pricing scheme in Hungary

Since 2010, Hungary has implemented measures that detached residential gas prices from the actual market price of gas. Initially, prices were frozen, followed by gradual reductions in 2013, decreasing by increments of 10% and then 6.5%. In 2013, Hungary boasted the second-lowest residential natural gas price in the EU. By July 2022, the final consumer price in Budapest, became the cheapest in the European Union, partly attributed to the weakening Hungarian forint. Concurrently, the cost of electricity and gas for a

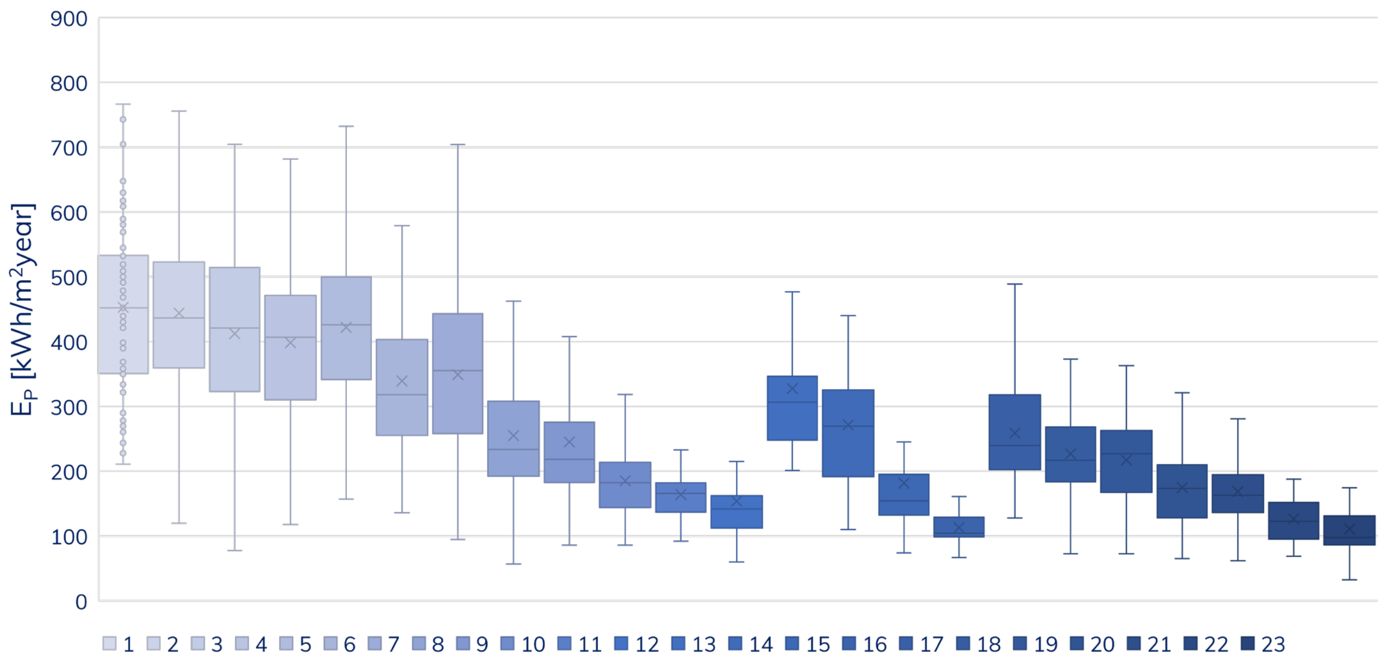


Figure 11: Specific primary energy use [kWh/m2year] of residential building types ([28] based on database from [27], for building types see Table 4 and Table 5)

typical Hungarian household with dual incomes decreased from 7% to 2.6% over the same period, according to calculations by the Hungarian Energy and Public Utility Regulatory Authority (MEKH).

This pricing system's sustainability relied on a fortuitous convergence of external factors, notably the global gas market's oversupply between 2014 and 2020. However, in the spring of 2022, the cap on residential prices became unsustainable as global prices surged due to the conflict in Ukraine. This prompted political action in mid-summer.

The amendment, introduced abruptly and with short notice, stipulates that reduced utility costs for gas apply up to the average residential consumption. Beyond this threshold, consumers will pay the "market price," potentially resulting in a 7-9-fold increase. While the "market price" is regulated, it aligns more closely with actual wholesale prices than the previous reduced utility costs.

The new regulation aims to send a clear message to consumers to conserve natural gas. Staying below the target consumption level keeps costs stable, thereby incentivising energy efficiency and renewable investments, which offer quicker returns with higher prices.

However, the regulation lacks a social element and state-funded energy efficiency programs, and it directly impacts only a specific group of consumers.29

For both residential natural gas and electricity pricing, the subsidised utility price applies up to the level of consumption corresponding to the average residential consumption, and a higher price applies above that. However, in the case of electricity, there is no significant price difference between the unit price below and above the overhead limit, which makes it much more favorable to choose electric or biomass heating to gas in cases of above average consumption.

Identification of households with the highest energy costs

As previously mentioned, natural gas heating is the dominant primary heating method in all types of residential buildings. The threshold for the subsidised gas price is 144 m3 /month (1729 m3 / year), which is set out in the regulations and has different effects for different building types.

The expected monthly gas consumption for each building type, assuming average parameters, has been calculated. Figure 12 shows that the buildings most affected by the change of regulation

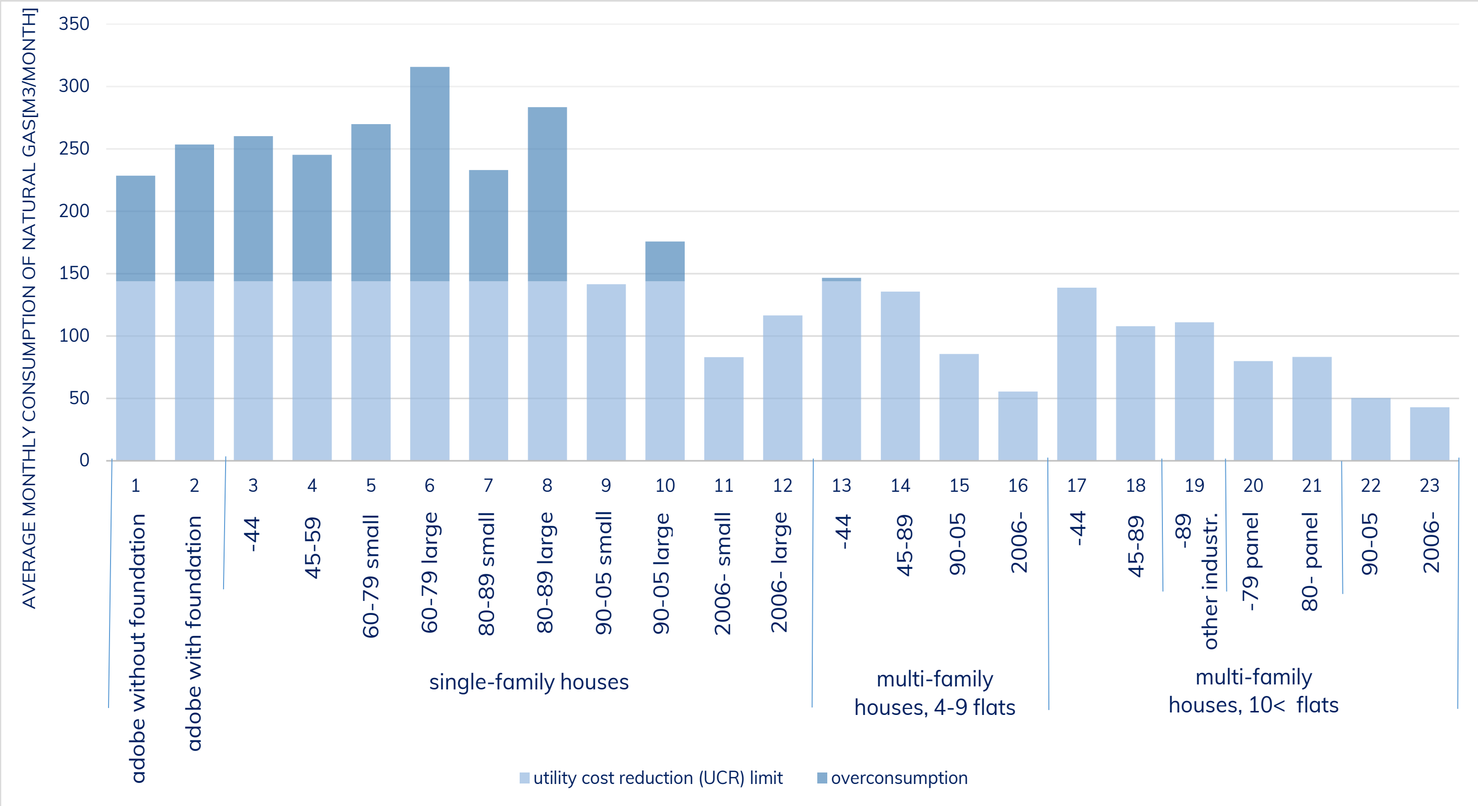


Figure 12: Modelled average natural gas consumption by type of dwelling [m3 /month], assuming natural gas space heating, hot water supply and cooking (based on average temperatures for the 2021-22 heating season) ([29], [30] based on database from [27])

are single family houses built before 1990 (types 1-8, highlighted in box). For these categories, only 41-56% of the annual gas consumption can be covered by the average monthly reduced amount of 144 m3, and the part above that - marked in orange in the figure, falls into the market price category. Occupants of modern, new detached houses (categories 11-12) comfortably fit within the subsidised amount, as do those who have already renovated their buildings.

Detached houses built before 1990 account for 52% of the gas-heated housing stock and consume around 67% of the total national annual gas consumption. At the same time, it should not be forgotten that biomass burning is very important for the same types of buildings, often as a secondary heat source in addition to gas. The easiest way for residents of these buildings to react to increasing gas prices is to switch to inefficient, environmentally polluting wood burning. This in turn leads to skyrocketing firewood prices, penalising the households relying entirely on firewood, heavily overrepresented in the lowest income quintile.

The worst performing building stock

Based on the results of the 2029 buildings examined in the 2015 survey, the worst performing 15% in terms of energy efficiency can be

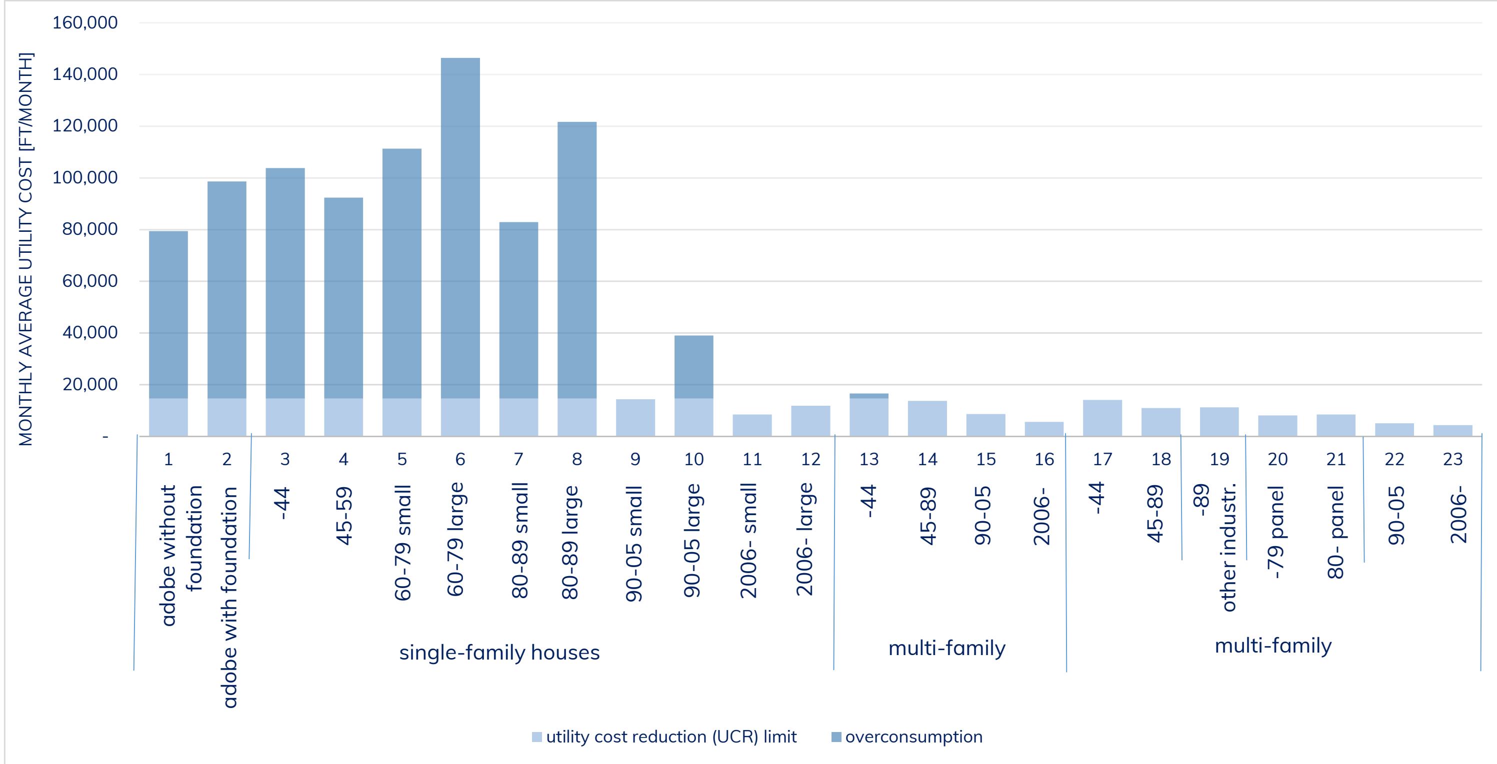


Figure 13: Expected cost of natural gas by type of dwelling [HUF/month], assuming natural gas-based space heating, hot water and cooking (without service fee) ([29], [30] based on database from [27])

defined. As a result, the limit value can be established as non-renewable primary energy use of 476 kWh/m2 year. The research was performed on the assumption that buildings were inhabited and fully heated to 20 degrees.

It is worth highlighting the three types of worst-performing building in terms of low energy performance. These are types 1-2, 5 and 7. Types 1-2 are adobe village houses, which are typically one-storey high, mostly built before World War 2 and often cannot be renovated economically. These buildings traditionally rely on stove heating, but many have now been connected to gas networks as well. Building types 1 and 2 differ only in that type 1 does not have a foundation. Type 5 has the largest number and has a square-shape layout. These are one-storey buildings, that dominated the SFH construction sector in the 60s and 70s. They can be characterised with a slightly higher comfort stage than Types 1 and 2, originally equipped with gas convector or gas boiler heating. Type 7 is a multi-storey building, typical of the 80s, built for two generations. In many cases, the younger generation has now left, meaning these houses are unnecessarily large, and only a part of the floor area is heated. All of these building types have a high cooling surface and very poor insulation levels. Technical building systems have usually been exchanged in these buildings, but the new systems are already outdated as well.

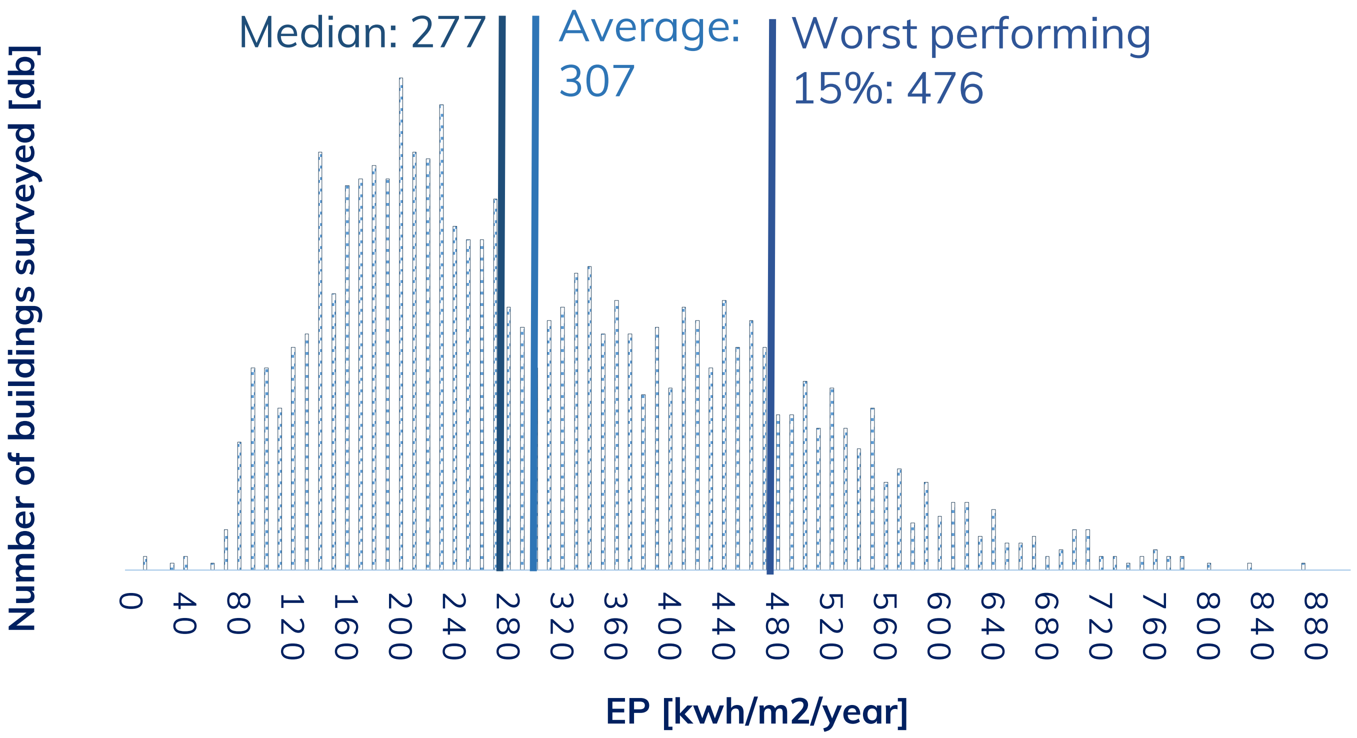


Figure 14 : Specific total primary consumption of the 2029 surveyed buildings without lighting and appliances ([28] based on database from [27])

Energy efficiency and energy poverty

In the 2022 questionnaire survey, individuals were asked about their household income, the results of which are shown in the following figure. When compared to the previous energy demand diagrams, it can clearly be established that income shows an inverse relationship with the age of the building. That is why the single family houses built before 1990 are in the worst situation (highlighted in box in Figure 16), since there, in addition to the outstanding energy costs (highlighted in boxes in Figure 11, Figure 12, Figure 13, the income conditions are also very unfavourable.

Summary

This section demonstrated that heating plays a decisive role in residential energy use. It also showed that natural gas is the dominant energy carrier, but that the inefficient use of firewood is also significant. The greatest potential for energy savings belongs to single-family houses built before 1990. This is the sector where the strongest motivation exists to save energy due to the peculiarities of the energy pricing structure, but unfortunately it is also the sector where the financing conditions are least available. Therefore, many people living in these houses can only save energy by operation, at the cost of decreased thermal comfort.

THREE WORST PERFORMING BUILDING TYPES

TYPE 1

TYPE 5

TYPE 7

Figure 15: The three worst performing building types in Hungary

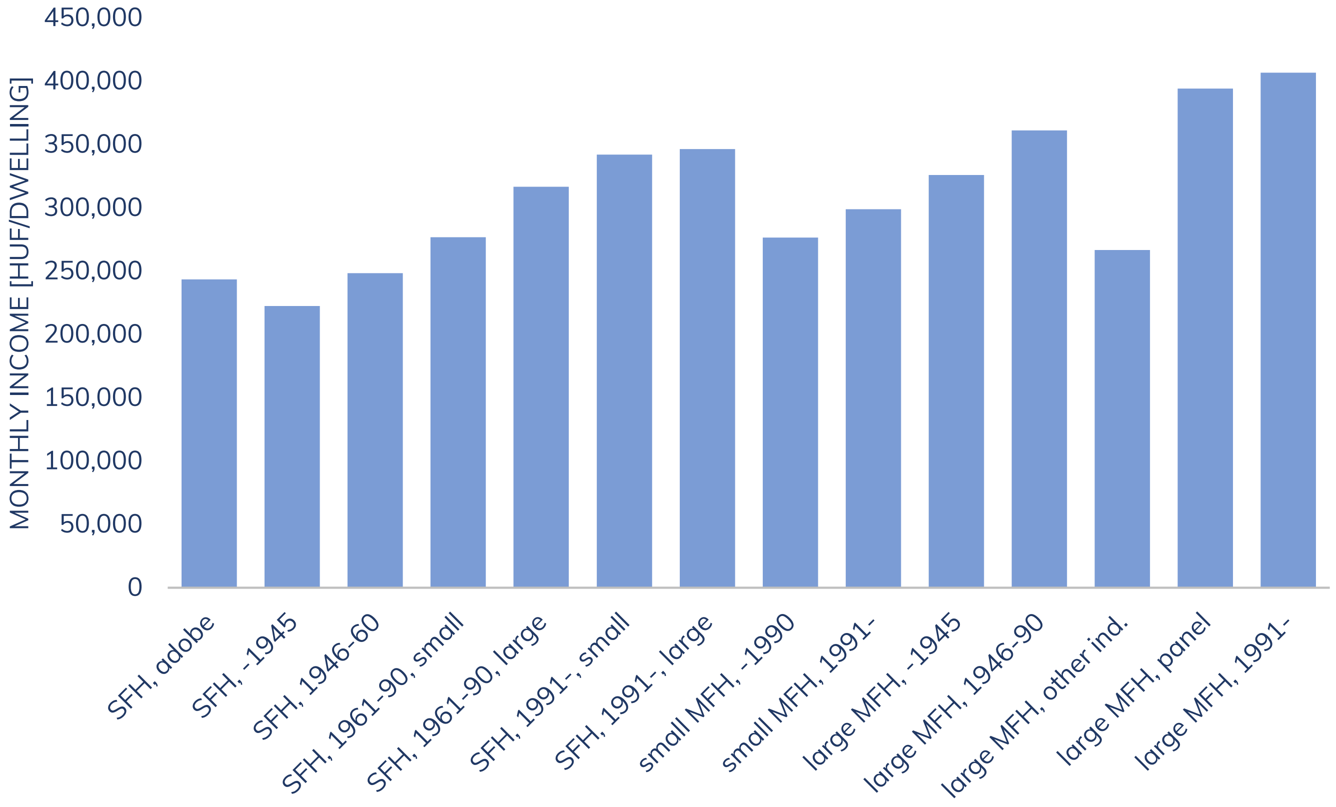


Figure 16 : Monthly income per dwelling according to building types [29]

4. ANALYSIS OF HEAT TRANSITION ALTERNATIVES FOR THE SELECTED WORST-PERFORMING BUILDING TYPES

The previous chapter described the current state of the residential building stock. This chapter will review possible modernisation measures and their expected impact.

Overview of decarbonised and clean heating solutions

In the previous chapter, it was concluded that the largest decarbonisation potential is in the pre-1990 single family housing sector. However, this same sector is also the most socially disadvantaged and is therefore the least able to finance modernisation measures.

These buildings are typically located in rural areas, often in villages, in dispersed, decentralised locations, where individual heat supply solutions per building unit can typically be implemented in an economical way. It should be mentioned that the EED Directive requires the development of heating and cooling plans, but only for municipalities with more than 43,000 inhabitants. However, most local governments in Hungary are unable to give financial support to their residents as financial sources are highly centralised.

Decreasing the heating demand: retrofit of the building envelope

In Hungary, the most typical measures undertaken when modernising residential buildings are: the replacement of windows and doors, the replacement of boilers with condensing boilers, the insulation of attic ceilings, the insulation of façades, and in some cases, the installation of roof insulation. The savings caused by retrofit measures vary from building to building, as shown in Figure 14. 'HVAC' means switched to condensing boiler and an improved control system. The highest saving potential is in the worst performing building types, single family houses built before 1990 (types 1-8). In these buildings 60-70% of heating energy can be saved by simply improving the building shell and installing a better heating system control, assuming that the building is fully heated. Newer buildings (SFH building types 9-12) also exhibit the potential for lower savings.

Several studies have provided information on the renovation of the building envelope, the most recent of which shows that 35% of buildings nationwide are considered fully insulated. For attic floor slab insulation, this number rises to 45%. With regards to windows and doors 52.5% of dwelling units have insulated windows, of which 10% are triple glazed. Old windows are nearly all

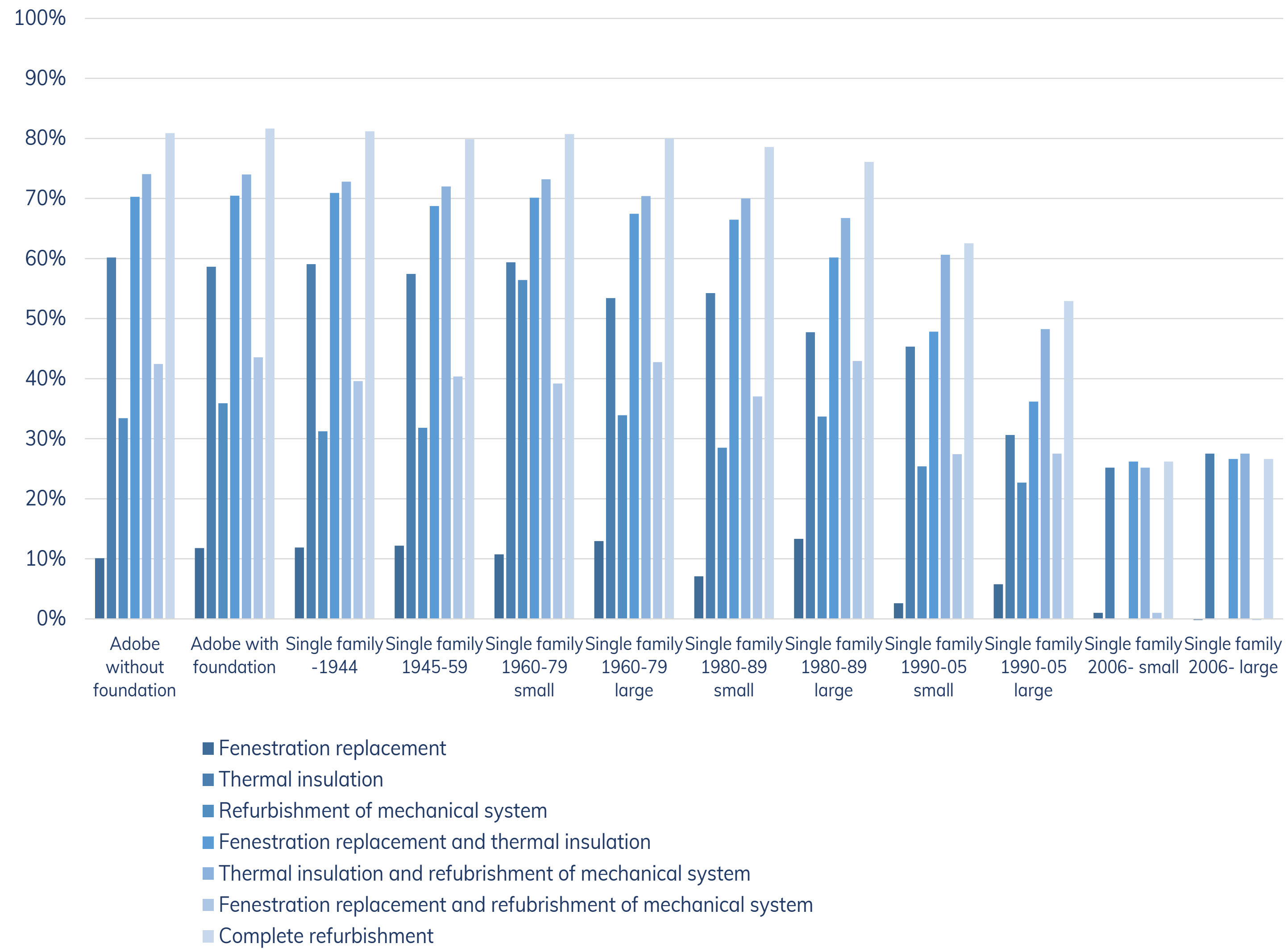


Figure 17 : Primary energy savings from the most common measures for each type of family house ([28] based on database from [27])

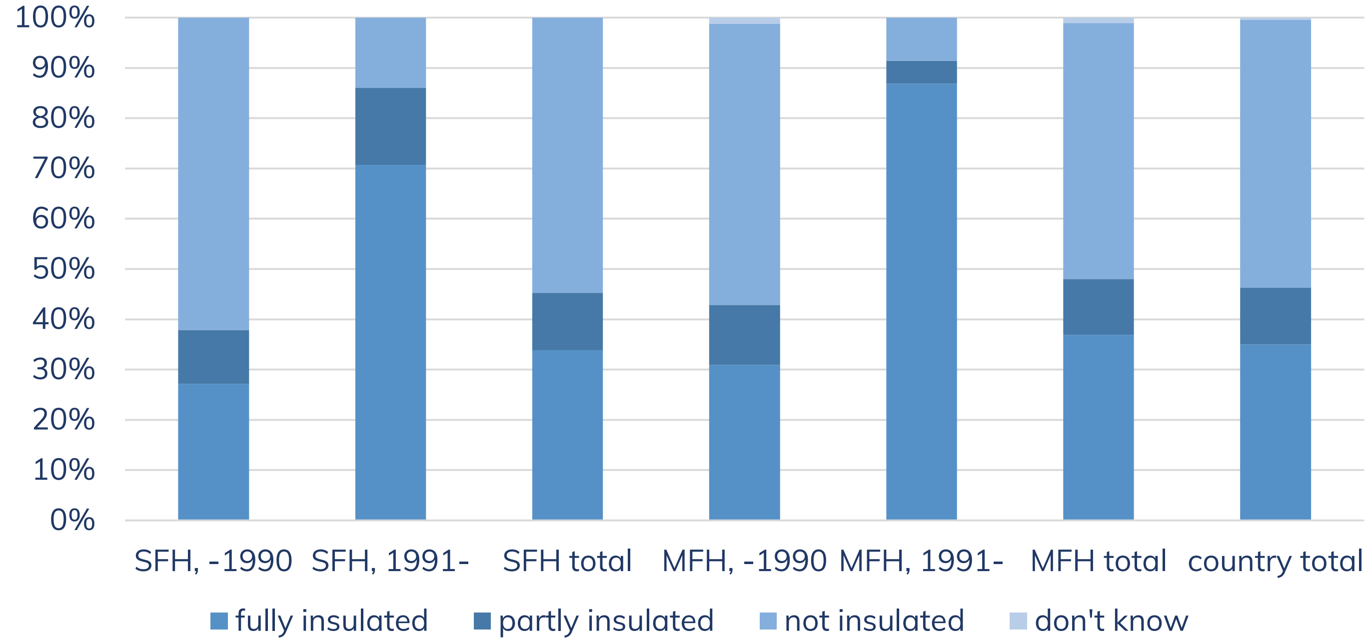


Figure 18 : Insulation of external walls [29]

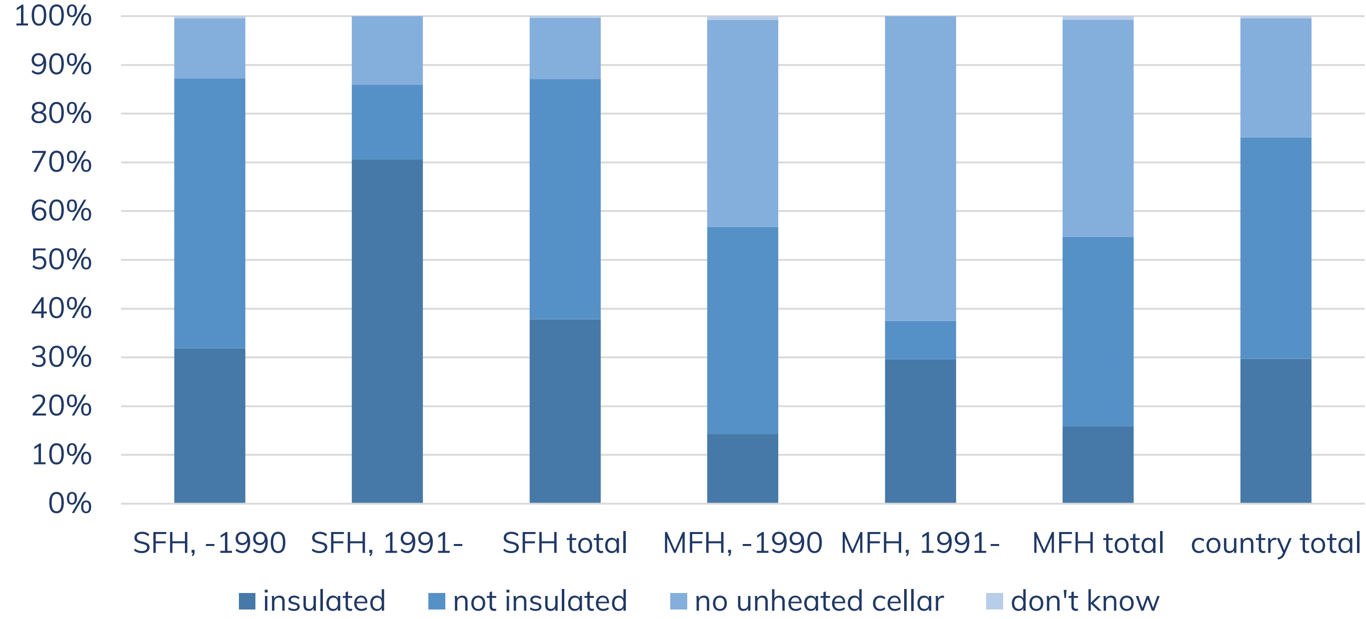


Figure 19 : Insulation of attic slabs [29]

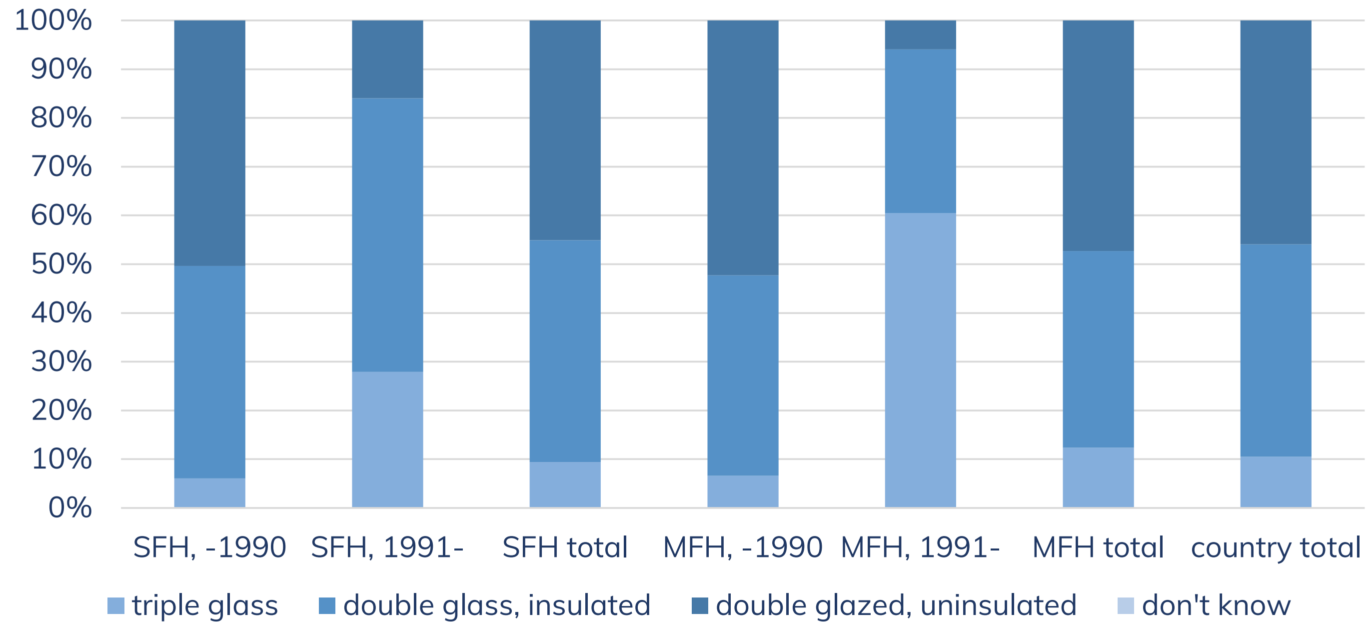


Figure 20 : Window types [29]

double glazed in Hungary. The figures vary by type, as the graphs show, and it is also clear that the older the building the worse the situation.

The figures show that there is a huge gap in the renovation of the building envelope. They also show that the most important step towards decarbonisation would be to improve it, as installing electric heating in a building with high heat demand is not recommended, even when there is a heat pump system.

Direct electric heating

The switch to direct electric space heating seems to be an attractive solution from a consumer point of view, due to its simple technical design and low investment costs. However, due to the relatively high price of electricity and its high non-renewable primary energy content, it is currently not recommended. Nevertheless, it is still worth examining in order to consider the risks of it spreading. However, in the long term (20-30 years), in the event of both a large-scale decarbonisation of the source mix of electricity generation and an increase in renewable electricity generation capacity, it is not impossible that this will become a realistic alternative.

Ground and water source heat pumps

The heat pump is an efficient alternative to electric heat supply and is the only thermodynamically justifiable alternative. Of the various alternatives, ground source heat pumps are the most efficient, but studies have shown that they are not applicable in more than two thirds of cases (for SFH: half of the cases, Figure 21) and their investment costs are much higher than those of air source heat pumps. Moreover, this cost overrun is expected to persist in the future due to the associated earthworks. The implementation of ground source heat pumps is not a competitive alternative in the SFH sector built before 1990. The other non-air heat pump technologies (e.g. water, waste water, process heat) may not be a viable solution at the building scale, or may only be viable in some areas. We have therefore limited our focus to air source heat pumps as they are the most widespread in practice.

Difficulties with switching to air-to-water heat pumps

The COP of heat pumps largely depends on the forward temperature at supply side. Previous gas boiler heating systems often used radiators, which require heating water at high temperatures (60-70 °C) or, in the case of condensing boilers, medium temperatures (45-55 °C) near design outdoor temperature. Most heat pumps with high operating temperatures have poor COP or are

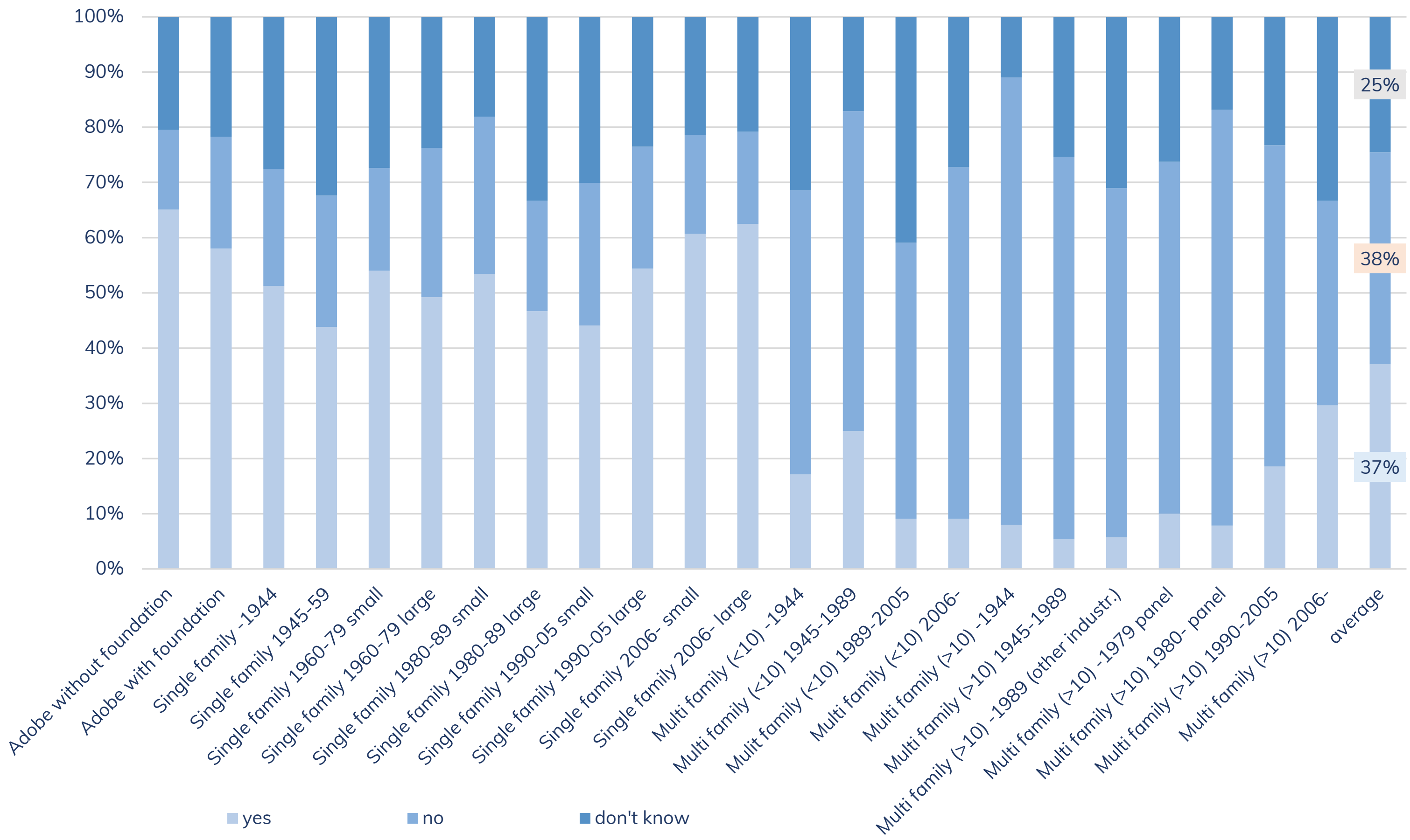


Figure 21 : Possibility of installing soil probes (yes : soil probes can be installed) ([28] based on database from [27])

simply unable to adequately heat up the building in the first place. However, this does not mean that a radiator system cannot work efficiently with a heat pump in all cases. The heating system, which operates at part load for most of the year, does not require such a high water temperature that it would be impossible to use a heat pump. However, during the coldest periods there would certainly be a need for a secondary heat source. The ideal solution is that old buildings are completely insulated before installing the heat pump in the first place. In these cases, the radiator system originally designed for medium heating water temperature could remain and as they are likely to be suitable for low-temperature heating, i.e. efficient heat pump operation as well (Figure 22).

Certainly, the ideal option would be a switch to surface heating. However, floor heating is difficult to implement in existing buildings due to the various architectural alterations that must first be made (increases in slab thickness). The easiest solution would be to install ceiling heating panels, which is not ideal from a thermal comfort point of view, but it has the advantage of also being suitable for space cooling. However, switching to surface heating is very expensive and is out of the question due to the low-income level of affected households.

Air-to-air heat pumps

Air-to-air heat pumps (split or multi-split solutions) are most likely to take-off if electrification is the goal, and are the cheapest equipment that can be installed. However, if full heating is the goal, they are not ideal. If the occupants want an indoor unit in every room, the costs and necessary modifications are significant. They spread relatively quickly in Hungary as they are built as a supplementary option for heating or cooling, in a maximum of one or two rooms, which makes them a relatively low cost-option.

Another problem related to these devices is that they are relatively uncomfortable for people to have in their household. The temperature distribution in the room is unfavorable due to droughts

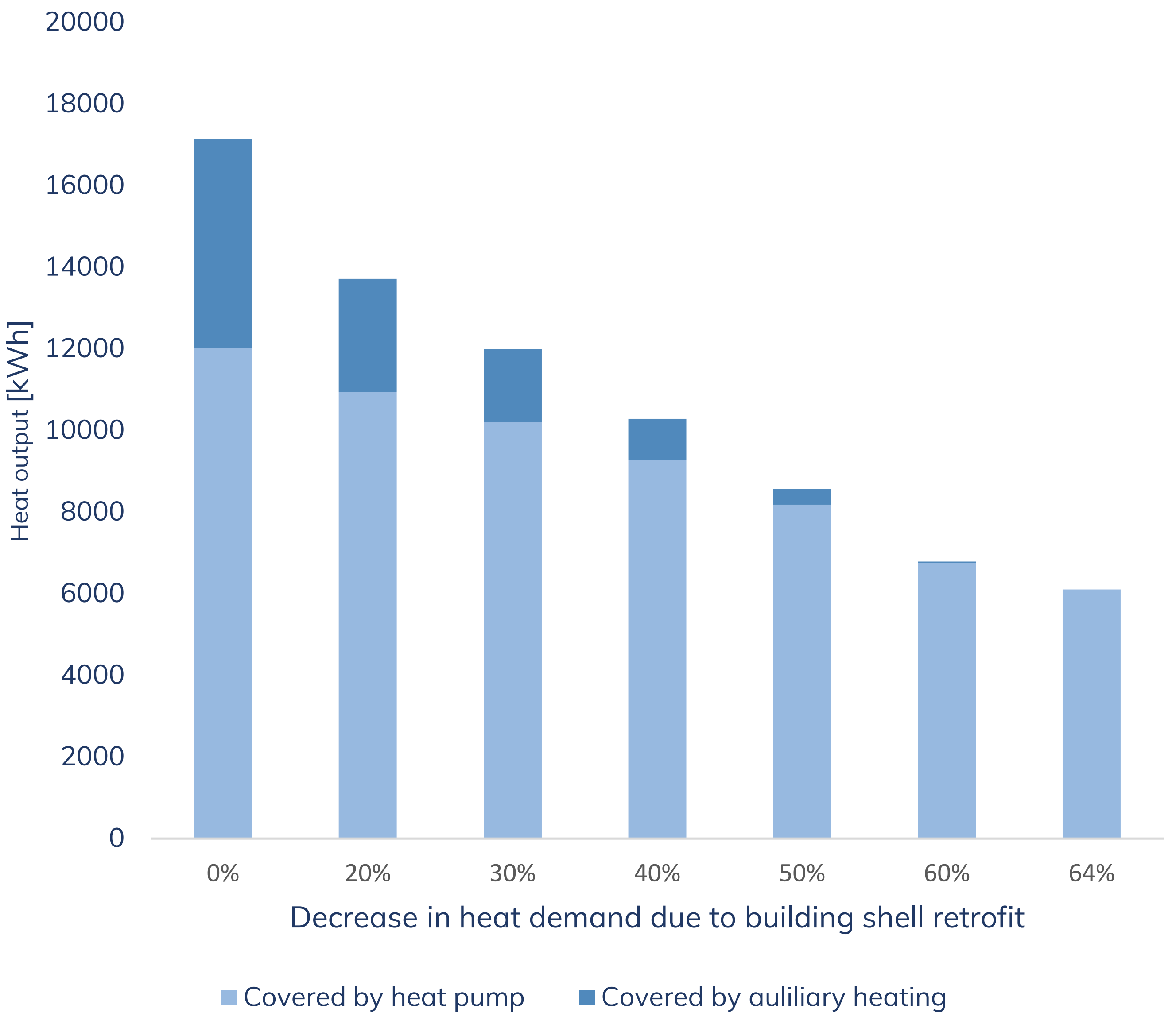


Figure 22: Heat output covered by heat pump and the need of auxiliary heating and the impact of building shell retrofit

caused by the continuously moving air. There is also the constant indoor noise, a major inconvenience which leads many people to only use the device intermittently. However, comfort can be improved by installing higher quality products, but that is likely to increase the price and make alternative solutions more competitive and appealing.

Lastly, similar to air-to water heat pumps, air-to-air heat pumps are unable to fully heat up uninsulated buildings in cold periods and there is a need for an auxiliary heating system. Or rather, vice versa: the heat pump performs the function of the auxiliary heating in addition to an existing radiator system with a boiler heater.

It should also be mentioned that air-to-air heat pumps have one shortcoming compared to systems equipped with water-based heat emitter solutions, namely that they are not capable of producing domestic hot water, which must be solved by an auxiliary DHW-system, leading to extra costs. This can be a solar collector or an electric boiler with a heat pump.

To conclude, for full electrification, the building envelope should be completely retrofitted first and only then will heat pumps become a rational heat generation solution.

Solar PV combined with electric heating

The installation of solar panels has been incredibly widespread in recent years, often for heating purposes in combination with electric heating panels due to net metering. However, in 2022, net metering was replaced by gross metering and subsidies were abolished, which in practice put an end to solar panel installations. There is nothing to suggest this situation couldn't change in the future however, so it is worthwhile examining the issue.

In order to examine the interaction (matching) between solar panels and heating, the total monthly electricity demand of the building must be compared with the monthly solar panel production. It was assumed that all roof area that is exposed to sun is covered by PV panels. Since demand and production are seasonally asynchronous in the case of electric heating (peak demand in winter, peak production in summer), seasonal calculation is inadequate. The calculations had to be broken down on a monthly basis.

Building Type 1, shown below in Figure 22, has the best conditions for solar energy utilisation as it has the highest roof space to floor area ratio. Based on the Figure 23, it can be concluded that in the case of Building Type 1, most of the energy produced cannot be utilised in the building in the summer season, while production in the winter period is far below demand. Even in the case Figure 24.

Based on the monthly balances, the annual photovoltaic production was determined in two ways, by type and by modernisation option. In the first case, the energy production that is not utilised in the building on a monthly basis was taken into account, assuming that it is absorbed by the grid and used elsewhere. In the other case, energy production not utilised on a monthly basis was not taken into account. The results are shown in Figure 25 for the most unfavourable case (building envelope will not be renovated, direct electric heat supply and mechanical cooling without shades) and in Figure 26 for the most favourable case, where the same buildings are fully retrofitted and supplied by an air-to-water heat pump. It can be seen that the monthly balance approach significantly degrades the result and coverage ratio in the case of types characterised by higher specific energy yield (SFH).

Overall, it can be concluded that in Hungary, it is not viable to use solar panels as a heating method unless seasonal storage is solved. This is due to the fact that it is not possible to cover the needs during the winter period, even in cases of excessive solar panel oversizing and the application of a heat pump, regardless of renovated state. Solar panels should be designed to cover other energy needs.

Biomass heating

According to [17] and [18], biomass-based heat supply is predominantly possible in the case of SFHs, given the logistical

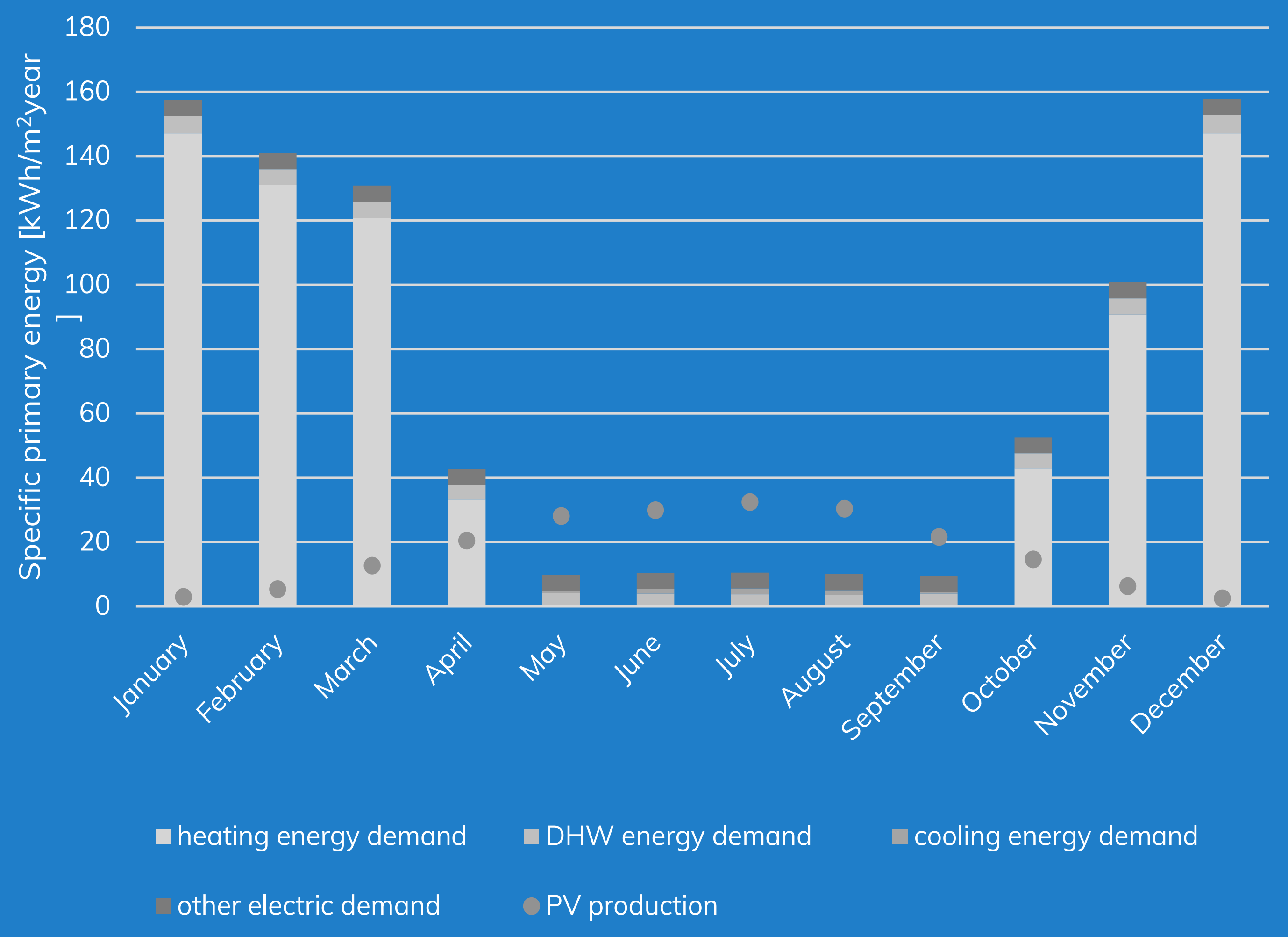


Figure 23 : Comparison of specific primary energy demand with the primary energy that can be covered by solar panels (all exposed roofspace used) by month : building type 1, original structure, direct electric heat supply, mechanical cooling, without blinds ([28] based on database from [27])

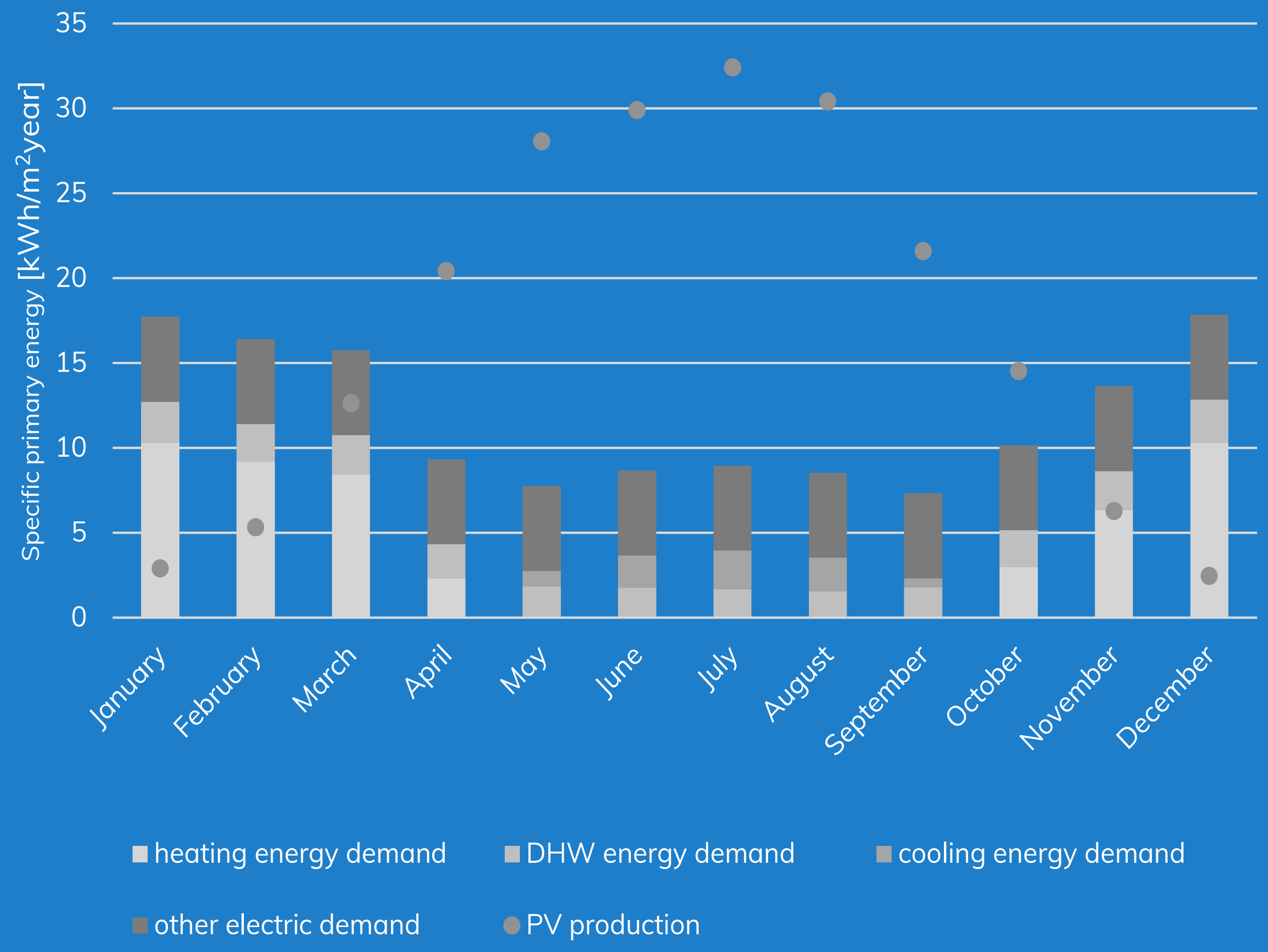


Figure 24 : Comparison of specific primary energy demand with the primary energy that can be covered by solar panels (all exposed roofspace used) by month : building type 1, retrofited building shell, air-to-water heat pump, mechanical cooling, without blinds ([28] based on database from [27])

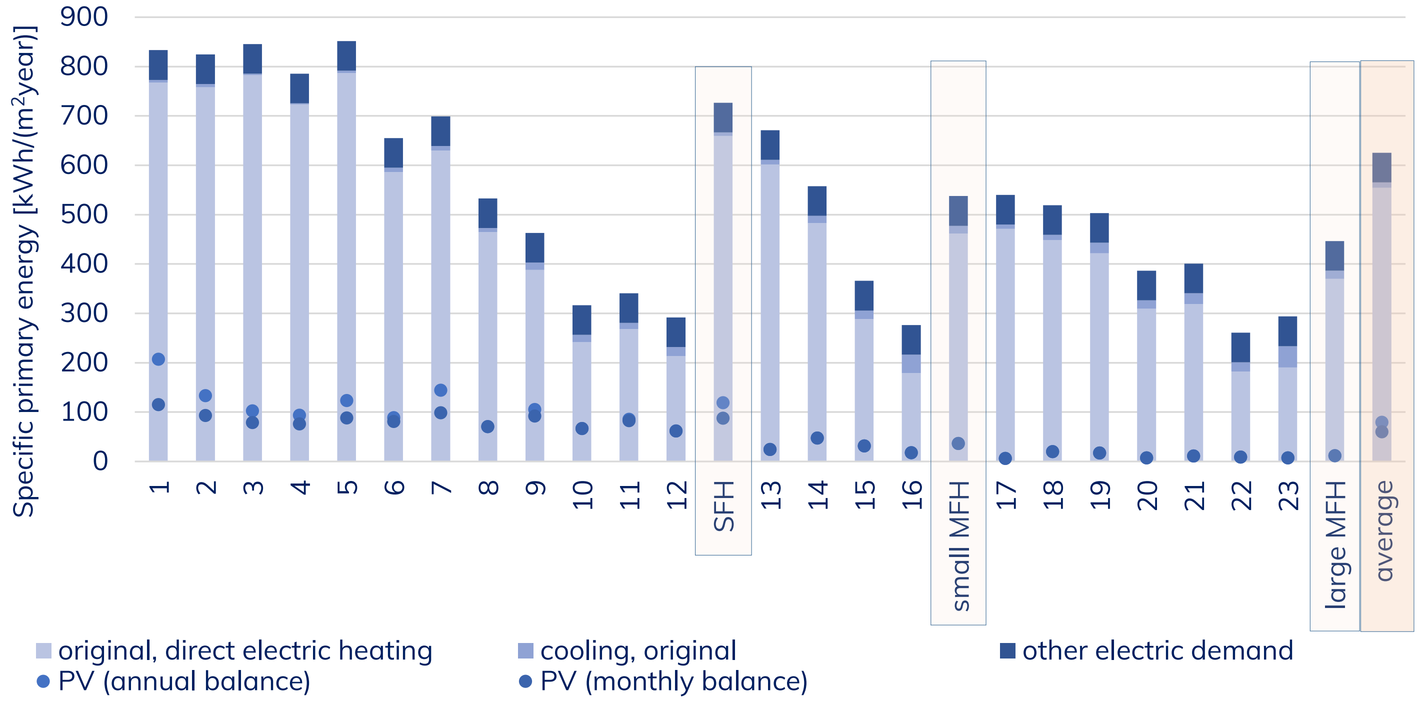


Figure 25 : Comparison of specific primary energy demand with the primary energy that can be covered by solar panels (all exposed roofspace used) : building envelope in original state, heating by direct electric panels (dark blue), optional mechanical cooling without shading (orange) taking into account the consumption of lighting and electrical appliances (light blue) ([28] based on database from [27])

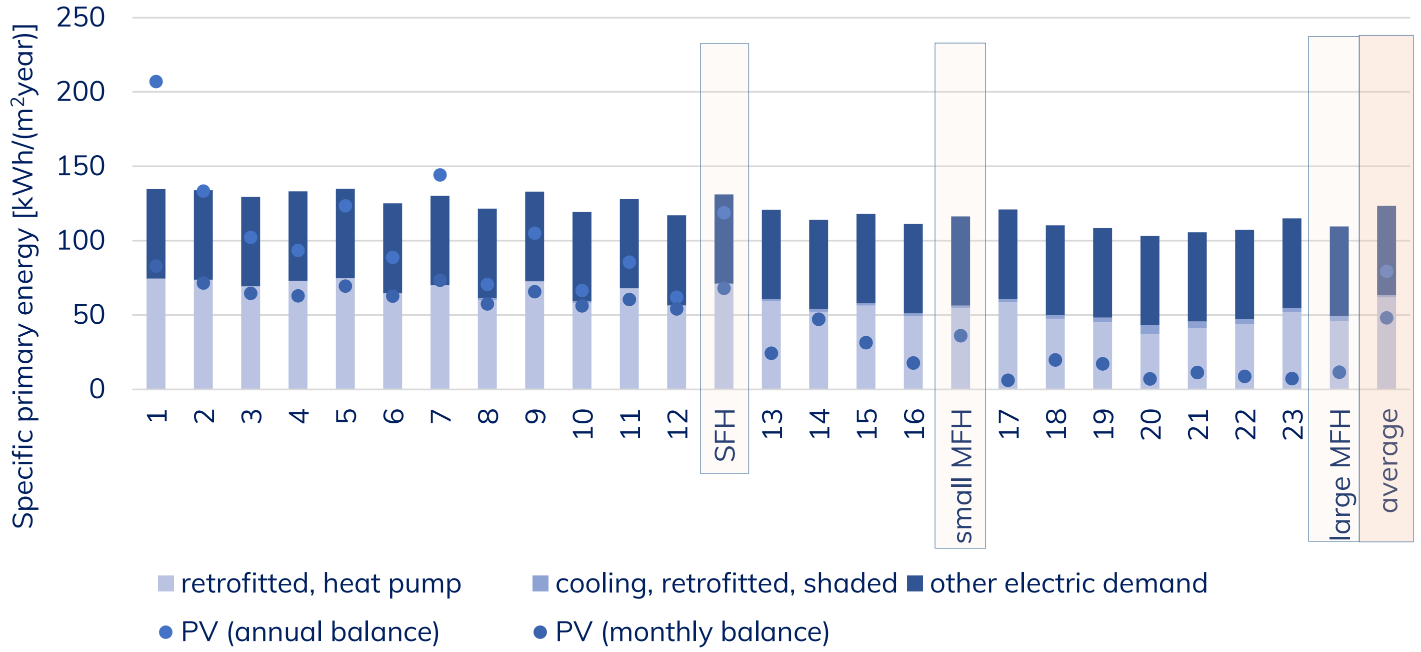


Figure 26 : Comparison of specific primary energy demand with the primary energy that can be covered by solar panels (all exposed roofspace used) : building envelope fully retrofitted, air-to-water heat pump heat supply (dark blue), optional mechanical cooling with blinds (orange) taking into account the consumption of lighting and electrical appliances (light blue) ([28] based on database from [27])

(transportation, storage) difficulties of solid fuel in the case of MFHs. In 70-90% of the surveys, biomass combustion/heating is a realistic option for family houses, unlike for MFHs (Figure 27). Indeed, biomass use is widespread in SFH buildings built before 1990 (Figure 4, Figure 5, Figure 6 and Figure 10).

Biomass combustion practice in residential areas is often criticised in Hungary from both a health and environmental perspective, as pollutant emission limits are often exceeded. The main problem is that wood is typically burned in cheap, inefficient stoves, tiled stoves or mixed-fuel boilers. Particulate matter (pm10 and pm2,5) and carbon-monoxide emissions are particularly problematic. This is largely due to the fact that widely used outdated biomass stoves and boilers have a much higher specific emission of these contaminants than modern, rarely used wood gasifying or pellet boilers. NOx emissions are independent from the generator type and SO2 depends on the fuel type rath-

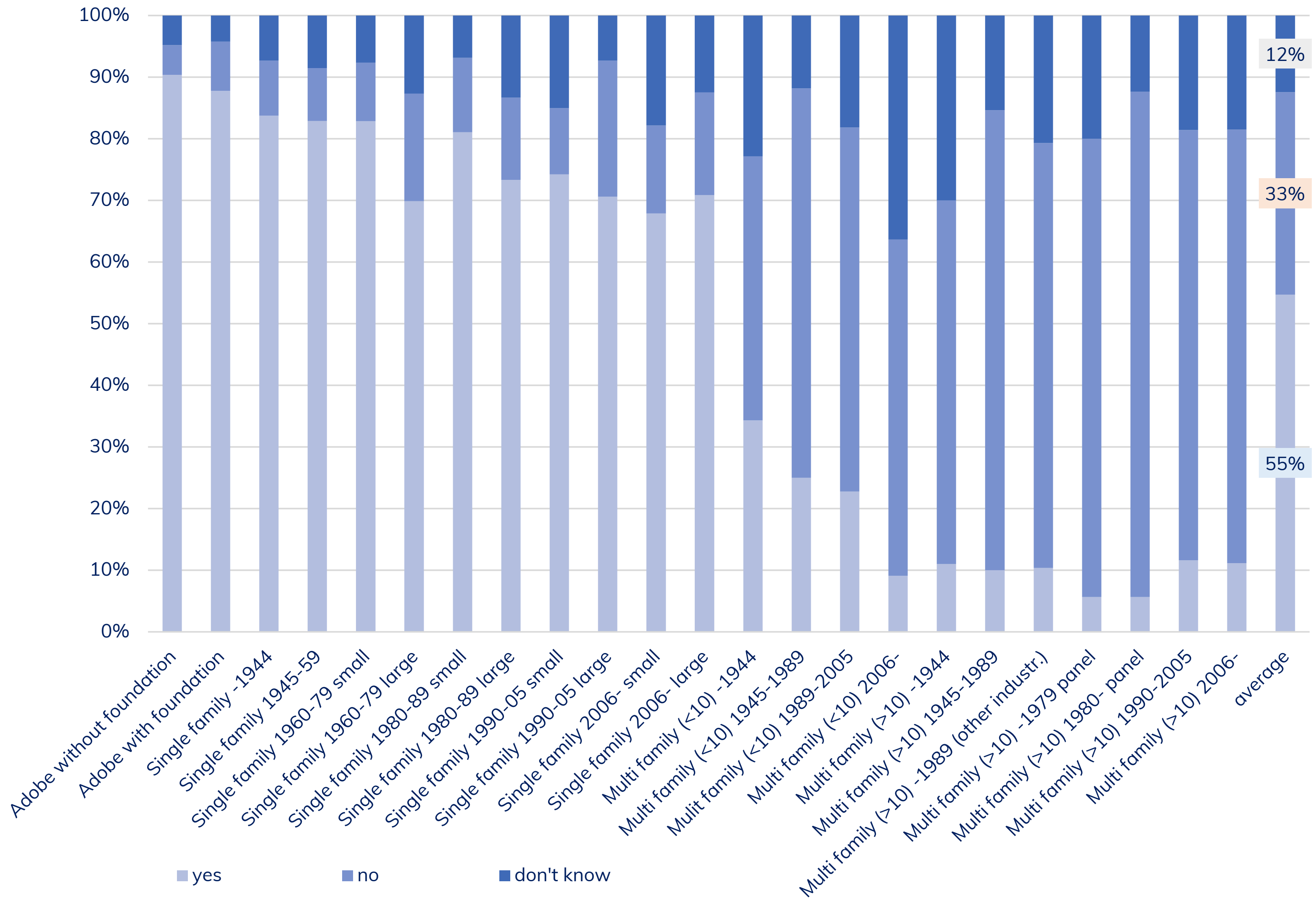


Figure 27 :Possibility of building a wood log storage space ([28] based on database from [27])

er than the system. If wood logs are used SO2 is not significant, but the problem rises in the case of wooden chips or herbaceous plants. Unfortunately, waste incineration is a major problem in regions of energy poverty, which is prohibited but difficult to control.

In cases of switching to biomass firing, the values of final biomass energy consumption are presented in orange in Figure 28. As a reference case, the specific non-renewable primary energy demand of the original (mostly gas-heated) state is also indicated in blue. If the entire family house stock is converted to biomass firing with non-efficient boilers whilst the building envelope is not retrofitted, then, a significant increase in firewood demand would have to be expected on national level (only a part of the buildings are characterised by wood burning in their original state). This cannot be solely compensated with modern wood gasification boilers, which also leads to an increase in the national demand for firewood. Firewood mitigation is only possible in combination with the modernisation of the building envelope.

A fundamental question for biomass, which goes far beyond the building sector, is how appropriate it is to achieve decarbonisation goals using wood as a heat source. Without going into the details, it is obvious that the use of firewood should not lead to a reduction in forest area, so we can only propose a solution that does not result in an increase in current biomass use (not mentioning the consequences on air quality and on human health). As we have seen, this can only be achieved if, in addition to switching to biomass, complete building envelope insulation is carried out and modern wood gasification or pellet boilers are used.

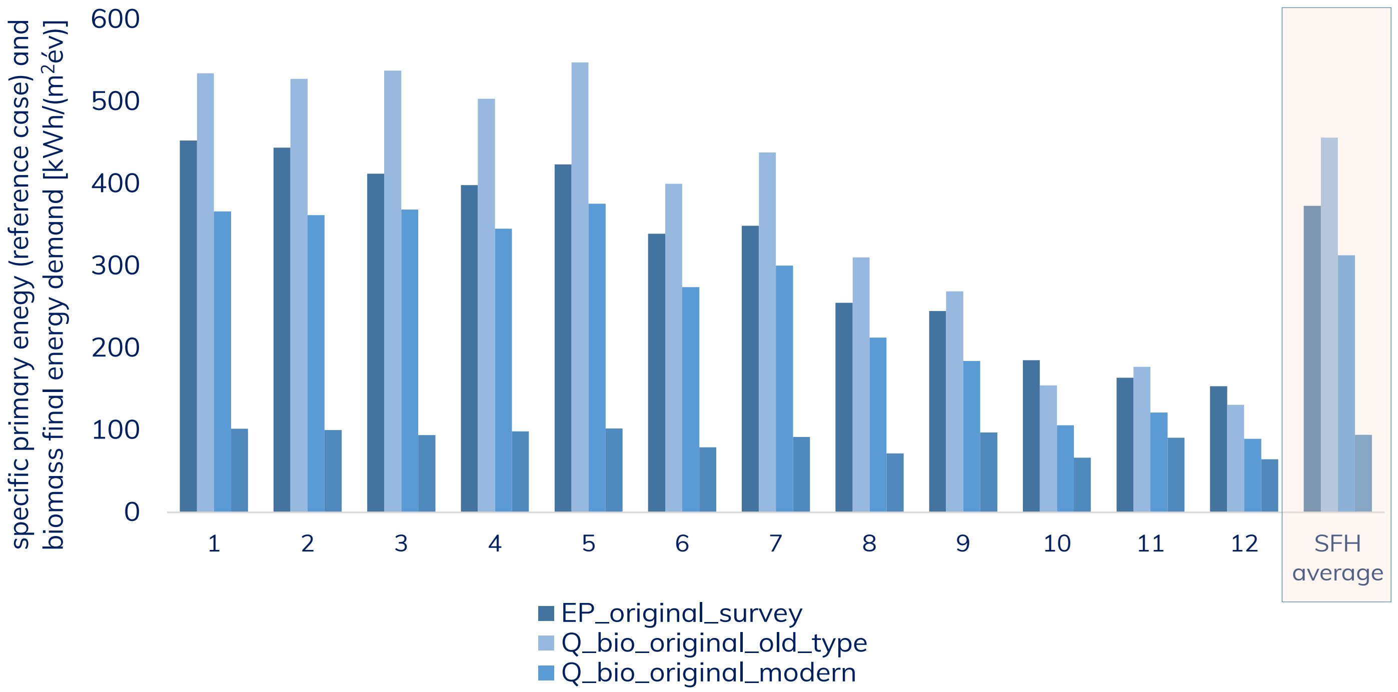


Figure 28: Specific annual primary energy demand for original state (national average) and specific final energy demand for different biomass heating options (Q_bio_original_old_type: switch heating to old type biomass boiler or stove without retrofitting the building shell, Q_bio_original_modern: switch heating to high efficient type biomass boiler without retrofitting the building shell, Q_bio_retrofitted_modern: switch heating to high efficient type biomass boiler with retrofitting the building shell) ([28] based on database from [27])

As a first step, we recommend using it only in buildings that have already used biomass. Once these have been converted, further parts of the SFH stock gas-heated buildings may then be considered to be converted to biomass heating under the above conditions.

Economic considerations

Investment costs, savings and payback periods of the main modernisation options have been calculated, with the results presented in the tables below. Considering the payback times, there is a special situation in Hungary, namely that in the case of buildings consuming above the subsidised threshold (types 1-8), the payback periods are an order of magnitude lower than those consuming near or below the subsidised threshold (types 9-10). This is a very good indication of how much the payback time depends on the price of the energy carrier and how much it can be influenced by a subsidy.

It should also be pointed out that the payback period of a measure is significantly influenced by the time order of the other measures, since if another measure brings heating costs below the subsidised threshold, the payback period of further measures

Type	full insulation (wall + attic slab)	attic slab insulation	exchange of windows	condensing boiler	controlable heating	window + insulation	insulation + condensing boiler	windows + condensing boiler	insulation +windows+ condensing boiler	heat pump (no building shell retrofit)	insulation +windows+ heat pump
	HUF	HUF	HUF	HUF	HUF	HUF	HUF	HUF	HUF	HUF	HUF
1	2 991 170	424 586	1 748 790	2 222 500	400 000	4 739 960	4 978 670	4 371 290	6 727 460	5 207 000	10 346 960
2	2 991 170	424 586	1 748 790	2 222 500	400 000	4 739 960	4 978 670	4 371 290	6 727 460	5 207 000	10 346 960
3	2 991 170	424 586	1 748 790	2 222 500	400 000	4 739 960	4 978 670	4 371 290	6 727 460	5 207 000	10 346 960
4	3 444 113	645 490	2 183 130	2 222 500	400 000	5 627 243	5 431 613	4 805 630	7 614 743	5 207 000	11 234 243
5	4 774 260	1 097 966	3 486 150	2 222 500	400 000	8 260 410	7 861 760	7 208 650	11 347 910	5 207 000	14 967 410
6	4 774 260	1 097 966	3 486 150	2 222 500	400 000	8 260 410	6 761 760	6 108 650	10 247 910	5 207 000	13 867 410
7	3 565 550	818 388	2 343 150	2 222 500	400 000	5 908 700	5 553 050	4 965 650	7 896 200	5 207 000	11 515 700
8	3 565 550	818 388	2 343 150	2 222 500	400 000	5 908 700	6 653 050	6 065 650	8 996 200	5 207 000	12 615 700
9	3 590 150	721 538	2 343 150	2 222 500	400 000	5 933 300	5 577 650	4 965 650	7 920 800	5 207 000	11 540 300
10	3 590 150	721 538	2 343 150	2 222 500	400 000	5 933 300	6 677 650	6 065 650	9 020 800	5 207 000	12 640 300

Table 2 : Initial investment costs retrofit measures, 2022 ([29], [30] based on database from [27])

Type	full insulation (wall + attic slab)	attic slab insulation	exchange of windows	condensing boiler	window + insulation	insulation + condensing boiler	windows + condensing boiler	insulation +windows+ condensing boiler	heat pump (no building shell retrofit)	insulation +windows+ heat pump
	year	year	year	year	year	year	year	year	year	year
1	3,6	1,2	9,4	3,6	5,6	5,8	5,6	7,7	6,2	11,4
2	2,9	1,1	7,3	3,0	4,5	4,6	5,2	6,2	4,9	9,1
3	2,7	1,1	7,1	3,4	4,2	4,4	5,3	5,9	4,7	8,6
4	3,6	1,8	9,2	3,6	5,7	5,5	6,1	7,5	5,3	10,6
5	4,1	2,7	15,0	1,9	6,8	6,5	8,5	9,2	4,4	11,7
6	3,7	2,6	11,1	2,7	5,2	4,2	5,9	6,3	3,3	8,2
7	4,2	2,6	18,3	4,3	6,8	6,3	7,4	8,8	6,0	12,2
8	3,6	2,5	8,5	3,2	4,7	5,1	6,8	6,8	4,0	9,1
9	56,3	33,3	640,8	62,2	88,2	65,4	128,7	90,0	56,1	95,6
10	12,2	5,8	40,0	9,7	19,6	21,0	21,8	27,8	13,9	31,8

Table 3: Payback time of retrofit measures, 2022 ([29], [30] based on database from [27])

increases significantly. Although payback periods are favourable for building types 1 to 8, the initial investment cost is very high for packages with higher savings, considering that the real estate value of many buildings in disadvantaged regions may be even lower.

Aspects of the electric power supply of a heat pump system

In the case of SFHs, the replacement of equipment covering heating and domestic hot water needs with a heat pump system also has implications on the electrical supply side that we present through a case study.

The subject is a single family house with an area of 80 m^2, built of solid brick with a moderate insulation level (not exceeding 5cm). The heat pump system of the house operates in monovalent operation, meaning that there is no other heat source that takes over the heating role with lower outside temperature values. Thus, it is necessary to choose heat pump equipment that can operate even at the external design temperature and can provide the required thermal performance. The approximate electrical power requirement of equipment with calculated power that can provide capacity in monovalent operation is 3-4 kW.

The installation of such a device requires not only technical building system and architectural modernisation, but also high-current system related modifications, since the supply of outdoor and indoor units from new circuits must be built, the distribution box has to be expanded with the necessary protection equipment, the distributor feed line has to be replaced, and the existing service provider connection is expected to be enlarged.

- Feeding the outdoor unit: The outdoor equipment shall be supplied from the presumed existing distribution equipment via a circuit with a circuit breaker recommended by the manufacturer. In this case, it is assumed that it is placed outdoors in such a way that a heated condensation tray is not required, thus reducing the required performance and improving overall efficiency.
- Changing the distribution box: The distribution box of the apartment also needs to be expanded. This is necessary to ensure the protection of supply lines and heat pump equipment. If these protective devices cannot fit in the existing box, the distribution box itself must also be replaced.
- Replacing the line supplying the distribution box: The additional power of the heat pump system is also expected to require an increase in the power line of the distribution equipment supplying the heat pump.
- Extend the service connection: Due to the increased demand, additional power must be requested from the service provider. This can be ensured by the service provider if it can still be covered from the network supplying the area. If the network needs to be expanded, the benefits and effects of the necessary technical solution must be assessed individually in each case.

Overall, the high-current technical and economic consequences of the transition of households to heat pumps do not primarily concern the consumer, as the power costs within the site are an order of magnitude lower than the heat pump equipment itself. The real challenge is the power limit of the electricity distribution grid. The question is whether increased performance can be ensured for all consumers, and what kind of infrastructure transformations this requires. The examination of this problem goes far beyond the level of buildings, but the general opinion is that the Hungarian electricity network needs significant modernisation to be able to connect the large number of heat pumps and on-site PVs that is necessary for heat supply electrification.

Summary

The focus of the analysis of retrofit options was limited to single-family houses, because they have the greatest savings potential, the worst-performing buildings, and the greatest motivation to save energy (single-family houses built before 1990), although financing possibilities are lacking in this sector. The saving measures were reviewed and it was concluded that the most important step would be the thermal insulation of buildings and the implementation of controllable heating. Once the heat demand is sufficiently reduced, further mitigation can be achieved through the use of heat pumps, but it would also be necessary to develop the electrical network infrastructure and decarbonise the network electricity. Biomass combustion is not a suitable option, it is only worth upgrading where wood burning has already been used.

5. CONCLUSION

In conclusion, we have seen that Hungary has a significant exposure to natural gas and, accordingly, has a well-developed gas network infrastructure. In addition, the use of firewood is significant in villages and suburban areas, but unfortunately, this is typically implemented through the use of inefficient simple appliances with high pollutant emissions. It also creates the issue of uncontrollable household waste incineration. The use of electricity for heat supply is not significant and is mainly used as auxiliary or backup heating, through direct electric heating solutions. Direct electric heating is unacceptable for decarbonisation because the non-primary energy factor of network electricity is around 2,3 in Hungary. Heat pumps and their spread are typical only in new buildings and have only become an option in the past 5-10 years. The use of split air conditioners for heating purposes are somewhat more widespread in the case of existing buildings, but only as an auxiliary solution and their share is not yet significant.

The most significant problem for the Hungarian residential building stock is the low level of thermal insulation, the drastic improvement of which would be essential to meet its decarbonisation goals. At the same time, it is also an opportunity to avoid the lock-in effect that has occurred in other countries due to the use of suboptimal thermal insulation thicknesses in the past.

The inadequate thermal insulation level also hinders the efficient use of heat pumps, since a building with high heat demand cannot be efficiently heated with a heat pump without changing existing heat emitters.

It has been highlighted that the current household energy pricing system only motivates owners to reduce higher-than-average consumption below the average, which is far from sufficient to achieve decarbonisation targets, as smaller measures (low-hanging fruit) are usually sufficient. The part of the residential building stock that belongs to the lowest performing category has been identified, these are single-family houses built before 1990, more than half of the dwelling stock belongs to this group. Unfortunately, they are also characterised by energy poverty, so they can only achieve cost savings by reducing comfort or diversifying energy sources, e.g. using electric radiators, wood stoves or split units. The market value of these buildings is often lower than the cost of a deep renovation, which further hinders modernisation by a very significant extent.

Another important course of action should be to gradually replace fossil fuel energy source subsidies with support for deep renovations. However, a controlled change is very important in making sure a sharp increase in energy poverty is avoided. With regards to the technical measures, the first step should be to solve the thermal insulation issue and improve the control of heating systems, then switch to heat pump heating or split units. However, for this to be successful the electrical network should be modernised, as it is currently incapable of supplying a high number of new heat pumps.

We have also seen that solar heating cannot cover heating needs, and should therefore be designed to cover electrical needs outside of the heating season instead. Increasing the use of wood as a heat source is generally not recommended and should only be considered in houses that already burn wood or in houses where gas is not available. In these buildings, either modern wood gasifying boilers or heat pumps should be used.

The use of geothermal heat is recommended in cities where district heating already exists. However, it is unrealistic to consider the widespread heating of individual houses by geothermal heat pumps due to the high investment costs. It should also be noted that, despite the fact that Hungary's geothermal conditions are better than average, that there have been relatively few successful examples of its use so far. This is due to the very high initial investment costs and the large degree of opposition to it as an energy solution. Another problem is that it is difficult to convince residents to connect to district heating, as its price was incredibly between 2000-2010, a fact that many people still remember to this day.

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