Report on behalf of

The Ministry of Environment and Water of the Republic of Hungary

CARBON DIOXIDE MITIGATION POTENTIAL IN THE HUNGARIAN RESIDENTIAL SECTOR

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1 EXECUTIVE SUMMARY

The residential sector is the key target for climate mitigation policy in Hungary. In 2004, this sector was responsible for 30% of total national carbon dioxide (CO_2) emissions, that is, the largest share among all energy end-use sectors in Hungary. At the same time, the residential sector embraces the highest potential for CO_2 emission reductions among all energy end-using sectors in the transition economies as estimated by the IPCC IV Assessment Report. Investments in the residential mitigation and energy efficiency can yield a wide spectrum of co-benefits beyond the value of reduced CO_2 emissions.

The present research aims to estimate and to analyze CO_2 mitigation potential in the residential sector and associated costs resulting from application of the energy efficient technologies and practices as well as the use of fuel switch options from the demand side. In addition, the study aims to identify the most promising options in terms of cost-effectiveness and CO_2 reduction potential. To address the aim, the authors conducted the bottom-up assessment of efficiency and low carbon options applicable in the Hungarian residential sector. The principal outcome of the research is a supply curve of conserved CO_2, which characterizes the potential savings from a set of CO_2 mitigation measures as a function of the cost per unit of CO_2. The supply curve method allows estimating the total potential excluding double-counting of the mitigation potential supplied by individual options.

The list CO_2 mitigation measures covered by the report includes improvement of the thermal envelope of selected types of existing buildings, application of the passive energy design to new built dwellings, installation of high efficiency and low carbon space heating solutions, installation of heating controls and individual heat meters, exchange of dedicated water heaters and combined space and water heating solutions, installation of water saving fixtures, and exchange of electric appliances and lights with more efficient analogues. The analysis of space heating and insulation opportunities was conducted separately for the building types having different architectural and thermal characteristics. The model does not consider improvement of the thermal envelope and heating systems of buildings constructed during 1993-2008. Also, the report leaves for the future research several mitigation options. These are consideration of reduced air leakage, efficient cooking, efficient air-conditioning, efficient motors (lifts), and efficient small electric appliances. The research does not consider the effect of more efficient biomass heating systems because biomass is referred as a sustainable source of energy and, thus, reported with zero CO_2 emissions.

The results of the analysis of the mitigation options are presented in Table 1. Table 1 details the potential CO_2 savings which result from implementation of individual options independently and the associated costs of conserved CO_2. There are two important notes to the Table. First, **the potential from individual options can not be summed up**. Second, the results of the Table can be applied to the analysis of the energy efficiency and energy conservation potential in the residential sector with great caution: the most efficient options in terms of the amount of saved CO_2 (as baseline share) or in terms of CO_2 mitigation cost-effectiveness are often not the same as the most efficient options for saving energy and energy conservation cost-effectiveness. For instance, installation of a pellet boiler for space and water heating to a household can improve heating efficiency by 5% - 25% depending on the reference technology but pellet combustion neutralize 100% of CO_2 emissions due to its zero emission factor.

Table 1 Potential available through application of individual options, 2025

Technological options	**CO_2 avoided**	**Cost of mitigated CO_2**	
	1000 tCO_2/yr.	EUR/ tCO_2	1000 HUF/ tCO_2
Thermal retrofit of industrialized buildings: space heating and insulation			
Installation of thermostatic radiator valves (TRVs)	74	-225	-56
Wall insulation in houses	332	-115	-29
Installation of condensing central building gas boilers	5	-108	-27
Basement insulation	37	-96	-24
Roof insulation	38	4	1
Window exchange	128	158	40
Individual metering of district and central heat	148	307	77
Door exchange	21	1684	421
Thermal retrofit of traditional buildings: space heating and insulation			
Installation of TRVs	19	-233	-58
Basement insulation	116	-169	-42
Installation of programmable thermostats	52	-154	-38
Installation of condensing central building gas boilers for space heating	26	-104	-26
Roof insulation	103	-89	-22
Individual metering of consumed district and central heat	39	91	23
Window exchange	337	125	31
Installation of condensing central gas dwelling boilers for space heating	79	204	51
Door exchange	23	1462	366
Thermal retrofit of family houses built until 1992: space heating and insulation			
Installation of programmable thermostats	193	-191	-48
Basement insulation	1514	-146	-36
Wall insulation	2367	-100	-25
Roof insulation	1338	-82	-21
Installation of condensing gas boiler for water and space central dwelling heating	579	86	22
Window exchange	1100	88	22
Installation of pellets boilers for water and space central dwelling heating	3054	110	27
Installation of solar collectors backed up with pellet boilers for water and space central dwelling heating	3054	233	58
Installation of pumps for water and space central dwelling heating	1833	487	122
Door exchange	75	1151	288
Thermal retrofit of family houses built after 2008			
Application of passive energy design	705	-89	-22
Thermal retrofit: water heating systems			
Installation of water saving fixtures in households with domestic hot water systems	400	-354	-88
Installation of water saving fixtures in households with district /central hot water	202	-298	-75
Improved combi- space & water heating systems / dedicated water heating appliances	553	-51	-13
Options related to electric efficiency (excluding water heating): appliances and lights			
Exchange of incandescent bulbs with compact fluorescent lights	305	-1066	-267
Reduction of energy consumption by TV and PC-related equipment in low power and off – modes (LOPOMO)	266	-613	-153
Efficient freezers	67	-391	-98
Efficient refrigerators	107	-297	-74
Efficient clothes washes	54	-275	-69

Table 1 attests that technological options supplying the potential for CO_2 mitigation at negative costs are available for each building type and each energy end-use. The top negative-cost measure in terms of cost-effectiveness is an exchange of incandescent lighting bulbs with compact fluorescent lights. It is followed by obligation to reduce electricity consumption of TV- and PC- related equipment in the low power mode and efficient appliances. Installation of heat and hot water demand controls such as low flow fixtures, TRVs, and programmable thermostats ranks the third. Almost all options aimed to insulation of building components (walls, basements, and roofs) fall to the list with negative mitigation cost; the same concerns actions towards installation of condensing central building gas boilers. Application of passive energy design to newly built buildings and installation of improved water heating systems and appliances are the last in the list of measures with negative costs of CO_2 mitigation. The technological options with the costs in the interval 0-100 EUR/tCO_2 options include window exchange, installation of condensing gas boilers for water and space dwelling heating to family houses, and installation of individual meters for district and central heated households in traditional buildings. The rest of the options are considered as expensive and have the mitigation costs higher than 100 EUR/tCO_2.

In terms of the size of avoided CO_2, improvement of the thermal envelope and heating efficiency in old family houses is able to supply the largest potential in the residential sector. Thus, installation of pellet boilers or solar thermal systems backed-up with pellet boilers supplies the largest amount of potential, app. 3.1 million ton of CO_2 as compared to the baseline emissions. Installation of pumps and condensing boilers to this type of households can provide also a very considerable potential up to 1.8 and 0.6 million tons of CO_2 respectively. These heating options exclude or reduce the penetration of each other if applied in turn. Insulation of walls, roofs, and basements and a window exchange in old family houses may result in CO_2 savings of 2.4, 1.5, 1.4, and 1.1 million tons of CO_2 respectively. Passive energy design construction, improved water heating systems in all household stock, and installation of water saving fixtures could save 0.6 – 0.7 million tons of CO_2. The rest of the measures supplies less than 0.5 million tons of CO_2/option.

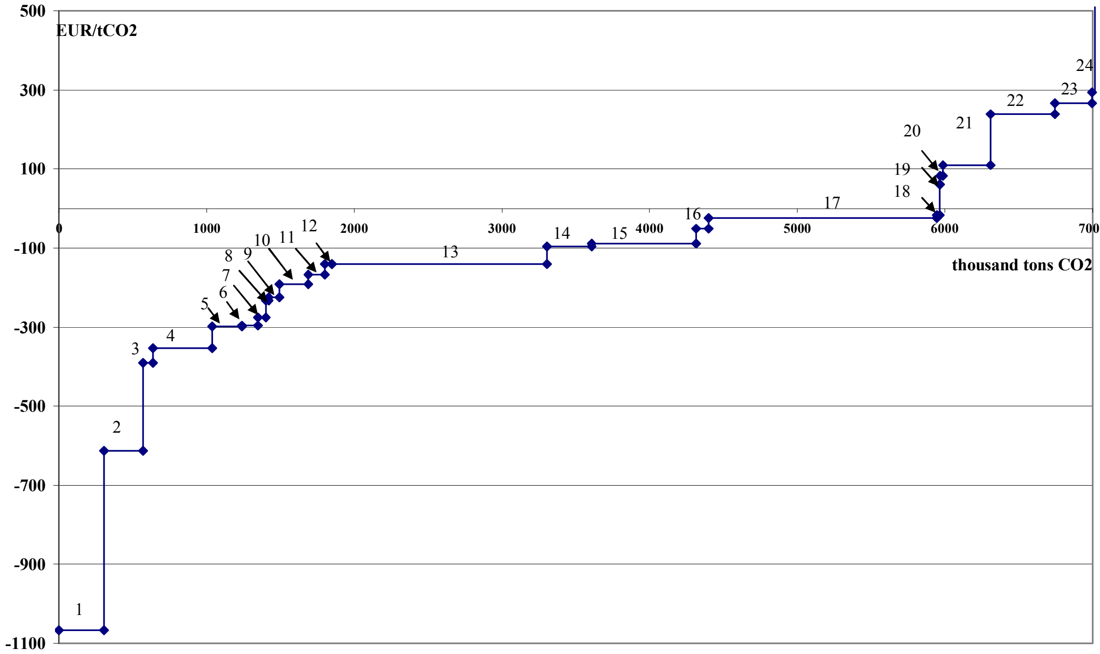

Figure 1 Supply curve of CO2 mitigation for the residential sector of Hungary, 2025

Figure 1 illustrates the potential for CO_2 abatement as a function of costs for investigated technological options for CO_2 mitigation. The advantage of the supply curve method is that it allows estimating the total potential avoiding double-counting of the mitigation potential supplied by individual options targeted to the same baseline technologies and energy end-uses. Table 2 decodes the numbered measures and provides the detailed data on associated CO_2 mitigation potential and costs. The Figure demonstrates that there is a wide range of opportunities for negative cost CO_2 mitigation in all studied types of the residential buildings. The Figure depicts that such technological options as efficient appliances and lighting technologies, heating and water flow controls, equipment with reduced electricity consumption in the low power mode, construction according to the passive energy design, and the majority of insulation options supply the potential for CO_2 mitigation at negative cost in 2025.

Table 2 Potential and costs of CO_2 mitigation estimated with the supply curve method, 2025

N	**Technological options**	**CO_2 savings**	**Cost of mitigated CO_2**	
		1000 tons CO_2/yr.	EUR/ tCO_2	1000HUF/ tCO_2
1	Exchange of incandescent bulbs with CFLs	305	-1066	-267
2	Reduction of energy consumption by TV and PC-related equipment in LOPOMO	266	-613	-153
3	Efficient freezers	67	-391	-98
4	Installation of water saving fixtures in households with domestic hot water systems	400	-354	-88
5	Installation of water saving fixtures in households with district / central hot water	202	-298	-75
6	Efficient refrigerators	107	-297	-74
7	Efficient clothes washes	54	-275	-69
8	Installation of TRVs in traditional houses	19	-233	-58
9	Installation of TRVs in houses built with industrialized technology	74	-225	-56
10	Installation of programmable thermostats in old family houses	193	-191	-48
11	Basement insulation in traditional houses	114	-167	-42
12	Installation of programmable thermostats in traditional houses	48	-141	-35
13	Basement insulation in old family houses	1455	-140	-35
14	Wall insulation in houses built with industrialized technology	304	-96	-24
15	Application of passive energy design to newly built buildings	705	-89	-22
16	Roof insulation in traditional houses	86	-52	-13
17	Wall insulation in family houses	1546	-25	-6
18	Condensing central building gas boilers for space heating in traditional houses	18	-17	-4
19	Condensing gas boilers for space heating in industrialized houses	3	61	15
20	Basement insulation in houses built with industrialized technology	20	83	21
21	Combi- space and water heating systems and dedicated water heating appliances	322	109	27
22	Roof insulation in old family houses	438	239	60
23	Window exchange in traditional houses	251	266	67
24	Roof insulation in houses built with industrialized technology	20	294	73
25	Individual metering of consumed district and central heat in traditional houses	16	624	156
26	Window exchange in houses built with industrialized technology	64	631	158
27	Condensing central gas dwelling boilers for space heating in traditional houses	42	641	160
28	Pellets boilers for water and space central dwelling heating in old family houses	731	710	178
29	Individual metering of district and central heat in industrialized houses	60	1227	307
30	Installation of pumps for water and space central dwelling heating in old family houses	202	1507	377
31	Door exchange in traditional houses	11	3479	870
32	Door exchange in houses built with industrialized technology	8	5309	1327
33	Window exchange in old family houses	60	5415	1354
34	Door exchange in old family houses	3	30954	7738

If negative cost options are implemented, they will cumulatively reduce CO_2 mitigation by 6 million tons in 2025. This is about 53% of the total baseline CO_2 emissions emitted by modeled energy end-uses (please note that it is not the total baseline of the residential sector). Implementation of these mitigation options at negative cost of CO_2 will result in energy saving of 28 TWh/yr., which is about 54% of the total final energy consumption of modeled energy end-uses of the residential sector in 2025. Realization of this potential requires the total investments over 2008 – 2025 of about 12 billion EUR but saves 19 billion EUR in energy costs.

Additionally to the potential at negative costs, at least 19% of the total baseline CO_2 emissions emitted by modeled energy end-uses can be avoided at costs up to 500 EUR/tCO_2. These figures represent the additional CO_2 reductions of 2 million tons of CO_2 in 2025. The potential at the costs level higher than 500 EUR/tCO_2 does not supply a significant amount of the potential. The CO_2 mitigation potential in cost categories, associated energy savings, and required investment costs are presented in Table 3. The total maximum potential possible to achieve due to implementation of all investigated measures is estimated as app. 73% baseline CO_2 emissions projected for modeled end-uses in 2025. In absolute terms, these savings represent about 8.2 million tons of CO_2/yr. The total investments over 2008 – 2025 needed to realize the maximum potential are about 39 billion EUR.

Table 3 CO_2 mitigation potential in cost categories, associated energy savings, and required investment costs

CO_2 mitigation potential in cost categories	**CO_2 abatement potential in 2025**				**Energy saving potential**				**Investment costs over 2008 - 2025**	
	Cumulative		By cost category		Cumulative		By cost category		Cumul-ative	By cost category
	%BL of modeled end-uses	million tCO_2/yr.	%BL of modeled end-uses	million tCO_2/yr.	%BL of modeled end-uses	TWh/yr.	%BL of modeled end-uses	TWh/yr.	Billion EUR	Billion EUR
< 0 EUR/tCO_2	52.8%	6.0	52.8%	6.0	53.5%	28.1	53.5%	28.1	11.8	11.8
0 - 100 EUR/tCO_2	53.0%	6.0	0.2%	0.0	53.8%	28.2	0.2%	0.1	11.9	0.1
100 – 500 EUR/tCO_2	71.9%	8.1	19.0%	2.1	64.8%	34.0	11.1%	5.8	31.1	19.1
> 500 EUR/tCO_2	72.7%	8.2	0.7%	0.1	66.5%	34.8	1.7%	0.9	38.6	7.5

Note: The baseline share is abbreviated as %BL

While the authors tried to cover as many mitigation options as possible, the analysis covers only those options which provide the largest potential for CO_2 mitigation. Therefore, the research could be further improved by considering a wider list of mitigation opportunities. There are also many ways to reduce uncertainties and clarify assumptions applied in the research which can improve significantly the quality of the results.

2 INTRODUCTION

2.1 Importance of the residential buildings for the Hungarian climate policy

The residential sector is the key target for climate mitigation policy in Hungary. In 2004, this sector was responsible for 30% of total national carbon dioxide (CO_2) emissions (ODYSSEE, 2007), that is, as Figure 2 shows, the largest share among all energy end-use sectors in Hungary.

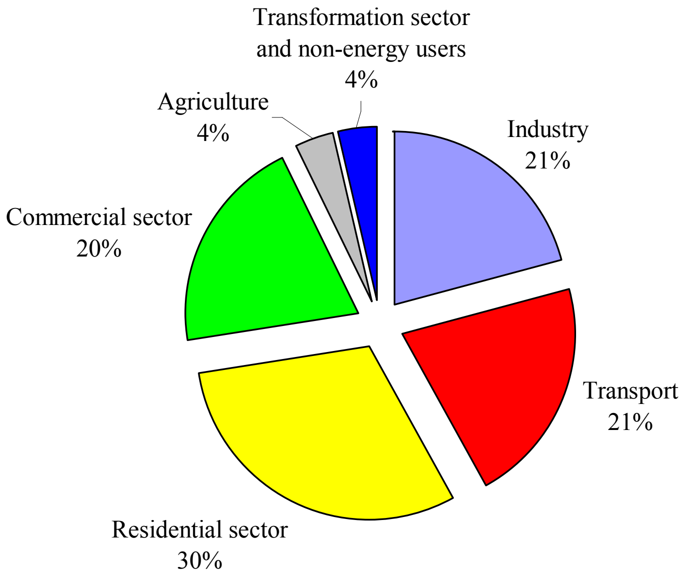

Figure 2 CO_2 emissions[1] by final energy end-users in Hungary, 2004

Source: constructed based ODYSSEE (2007)

The residential sector embraces abundant opportunities of CO_2 emission reductions. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Levine et al., 2007) identified that at least 29% of the business-as-usual emissions in 2020 are available for mitigation in the buildings sector in transition economies (the Former Soviet Union (FSU) and Central and Eastern Europe (CEE)). This is the highest estimate of the potential for CO_2 mitigation among all energy end-using sectors as Figure 3 illustrates.

Investments in the residential mitigation and energy efficiency can yield a wide spectrum of co-benefits beyond the value of reduced CO_2 emissions. Most importantly for Hungary, energy efficiency investments help households cope with the burden of paying increasing utility bills and, thus, improve social welfare (Novikova, 2007). Saved energy costs could be spent by population for other consumer goods, thus, stimulating the GDP growth (so called multiplier effect). Additionally, inhabitants can enjoy higher comfort at homes. Production, installation,

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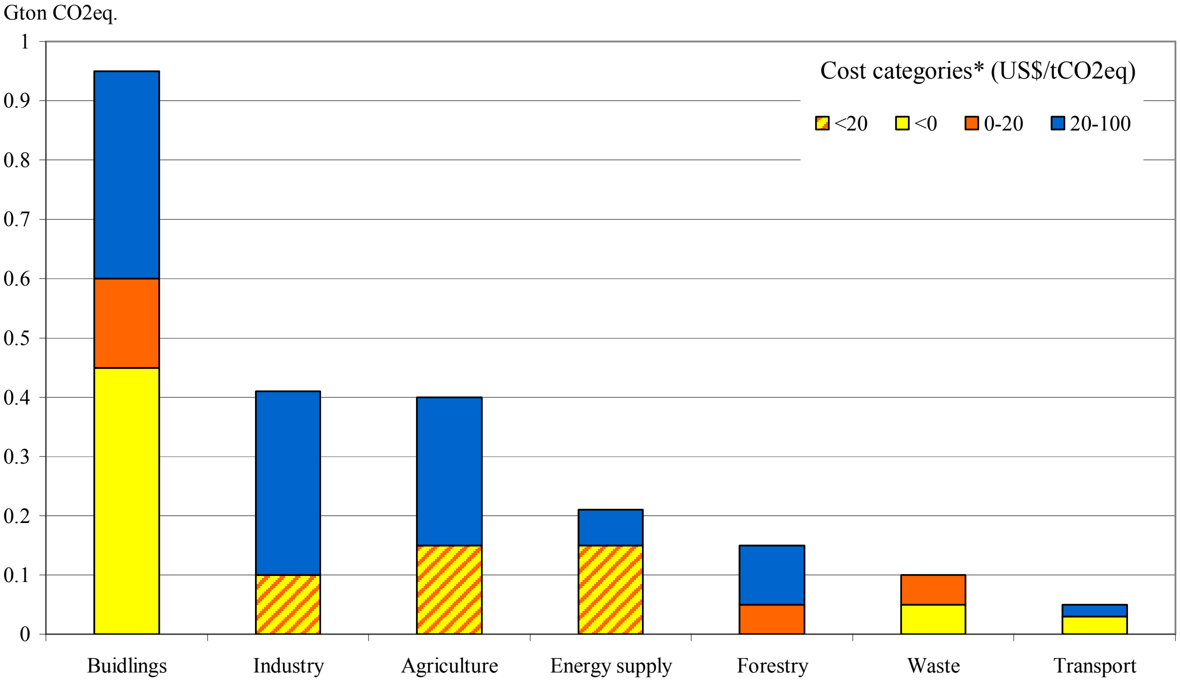
[1] Including emissions associated with electricity use consumed by the sectors.

and maintenance of better building shells and equipment open the window to new business opportunities and, thus, create job places. Finally, energy saving reduce damage to public health, building materials, and agricultural crops in Hungary (Aunan, et al., 2000).



* For the buildings, forestry, waste and transport sectors, the potential is split into three cost categories: at net negative costs, at 0-20 US$/tCO2, and 20-100 US$/tCO2. For the industrial, forestry, and energy suppy sectors, the potential is split into two categories: at costs below 20 US$/tCO2 and at 20-100 US$/tCO2.

Figure 3 Estimated potential for CO_2 mitigation in economies in transition at a sectoral level in different cost categories in 2030

Source: constructed based on IPCC (2007)

While climate mitigation strategies are well investigated in developed countries and, sometimes, in developing countries[2], there are limited research activities in transition economies. There are two pieces of research so far which detail mitigation opportunities in the buildings sector of Hungary. These are the study on "Economics of Greenhouse Gas Limitation" (Szlavik et al., 1998) and Ecofys/EURIMA study for new EU member states (Petersdorff et al., 2005). The former is a very comprehensive piece of research, however, it was conducted already ten years ago. The latter focuses only on insulation and gas central heating options. These options are among the most important for Hungary, however, the list of promising mitigation options is much wider.

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[2] In some developing countries, the topic has been investigated well with the support of such organizations as United Nations Environmental Programme and the Asian Development Bank.

2.2 Research questions and structure of the report

The research aims to assist the evidence-based design of the most cost-effective new policies targeted at CO_2 emission reductions in the Hungarian residential sector. The project goal is to estimate and to analyze CO_2 mitigation potential in the residential sector and associated costs resulting from application of the energy efficient technologies and practices as well as the use of fuel switch options from the demand side. In addition, the study aims to identify the most promising options in terms of cost-effectiveness and CO_2 reduction potential.

Research questions are:

i) Preliminary estimate of the baseline CO_2 emissions trends of the residential sector

ii) Preliminary identification of the key low-carbon technologies and practices applicable in the residential sector of the country

iii) An estimate of the CO_2 emission abatement potential from application of individual options and associated societal mitigation costs

iv) An estimate of the mitigation potential as a function of the cost of CO_2

The report is structured in seven chapters. After justification of the importance of the research and stating its aims and tasks in the first chapter, the methodological chapter provides the description of the selected modeling approach, main equations, and assumptions of the research. The third chapter details how the household stock was modeled, it also describes the main characteristics of households by different building types. The fourth chapter describes the most important thermal options for CO_2 mitigation which include the more efficient thermal envelope, advanced heating and water heating technologies, and heating and water flow controls. The fifth chapter identifies the major electric options for CO_2 mitigation excluding those discussed in the thermal efficiency chapter. The sixth section presents the results of the research ranking individual mitigation options in terms of their cost-effectiveness and the ability to mitigate CO_2. The chapter discusses the cumulative potentials from realization of the options in different cost categories and calculates the necessary investment costs for realization of these potentials. In conclusion, the chapter identifies the areas for further research needs.

3 METHODOLOGY

3.1 Modeling approach: a supply curve method

There are two major approaches to mitigation assessment (as well as to any analytical task): top-down and bottom-up analyses. Typically, the top-down models examine interactions between the energy sector and macroeconomic indicators on the national level; they do not detail concrete technological options. In contrast, bottom-up models assess the cost-effectiveness of technological options which aim to conserve energy, to improve efficiencies of energy conversion, transmission, distribution, and consumption or to emit less carbon.

For the purposes of the report, the bottom-up model is constructed. The principal outcome of the model is a supply curve of conserved CO_2, which characterizes the potential savings from a set of CO_2 mitigation measures as a function of the cost per unit of CO_2. The method of mitigation supply curves has been developed as an analogue to supply curves for commodities used in economics literature. For instance, a supply curve for energy sources ranks various reserves of energy depending on their exploration costs. A supply curve of conserved CO_2 as an analogue shows the sequence of mitigation measures, their size in terms of CO_2 conserved and costs.

Typically a CO_2 potential supply figure has a shape as illustrated in Figure 4 below. Each step on the curve represents a type of measure. A measure X can save as much emission reductions as ΔCO_2 at the indicated mitigation costs. Negative costs of conserved CO_2 mean that results of measures are greater than the cost of implementing the action, therefore the society as a whole benefits from introducing this mitigation action instead of paying for it (Halsnaen et al. 1998).

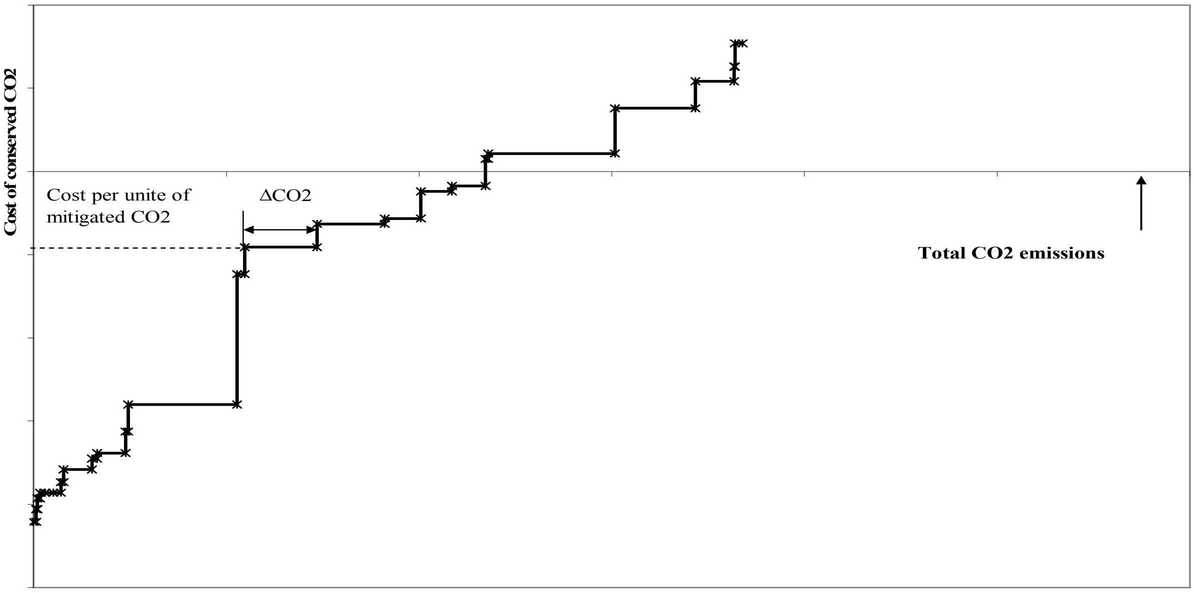

Figure 4 An example of CO_2 conservation supply curve

The advantage of the supply curve method is that it allows estimating the total potential avoiding double-counting of the mitigation potential supplied by individual options targeted to the same baseline technologies and energy end-uses. An example of the mentioned phenomena is insulation improvement which reduces the need for space heating and, thus, improvement of heating efficiency would have larger potential if the buildings would not be insulated.

The key methodological principle of the supply curve method which helps solve the problem of this double-counting is that the potential from application of mitigation options is not summed up directly but is stacked incrementally according to the order of their cost-effectiveness. In other words, the method includes the following steps. First, potential and costs of mitigated CO_2 are estimated for each technological option individually. The second step is picking up the measure characterized with the lowest costs of mitigated CO_2 and to construct the new baseline scenario making an assumption that this measure is applied. For the rest of the options, new energy and CO_2 savings as well as costs of mitigated CO_2 are estimated based on this new baseline. The third step is to select the measure characterized by the lowest mitigation costs among the measures left, to build again a new baseline assuming that this option is applied in its turn, and to estimate new energy and CO_2 reductions and associated costs for the rest of measures. The process keeps going until all measures are ranked according their cost-effectiveness. After this procedure, it is typical that the ranking of options differs from the one based on individual implementation of measures. The changing order is observed for interdependent measures such as insulation measures and other heating options, but this is not the case for independent options such as improvement of washing machines and lighting technologies.

3.2 Modeling framework

Figure 5 represents a step-by-step process applied in the research for building up the sectoral supply curve of mitigated CO_2. As the first step, two model blocks are built: these are the household stock model with space and water mode split and the spreadsheets estimating the CO_2 emission factors for electricity and heat. Based on the results of these modeling blocks as well as other collected external input parameters, the baseline for final energy consumption and associated CO_2 emissions is developed. The CO_2 mitigation potential is estimated individually for the most promising mitigation technologies (i.e. those which occupy a significant share of CO_2 emissions or which promise to save much of CO_2) selected from by the created technological database. As the final step, these selected mitigation options are economically evaluated and amalgamated to the supply curve of conserved CO_2.

A number of ready models were considered to implement the research tasks. The choice was limited, however, with the high price of software. Taking into account that the application of ready software tools is also constrained due to the lack of many input parameters, the choice was made for the MS Excel-based spreadsheet analysis which allows variation of modeling methods depending on available data.

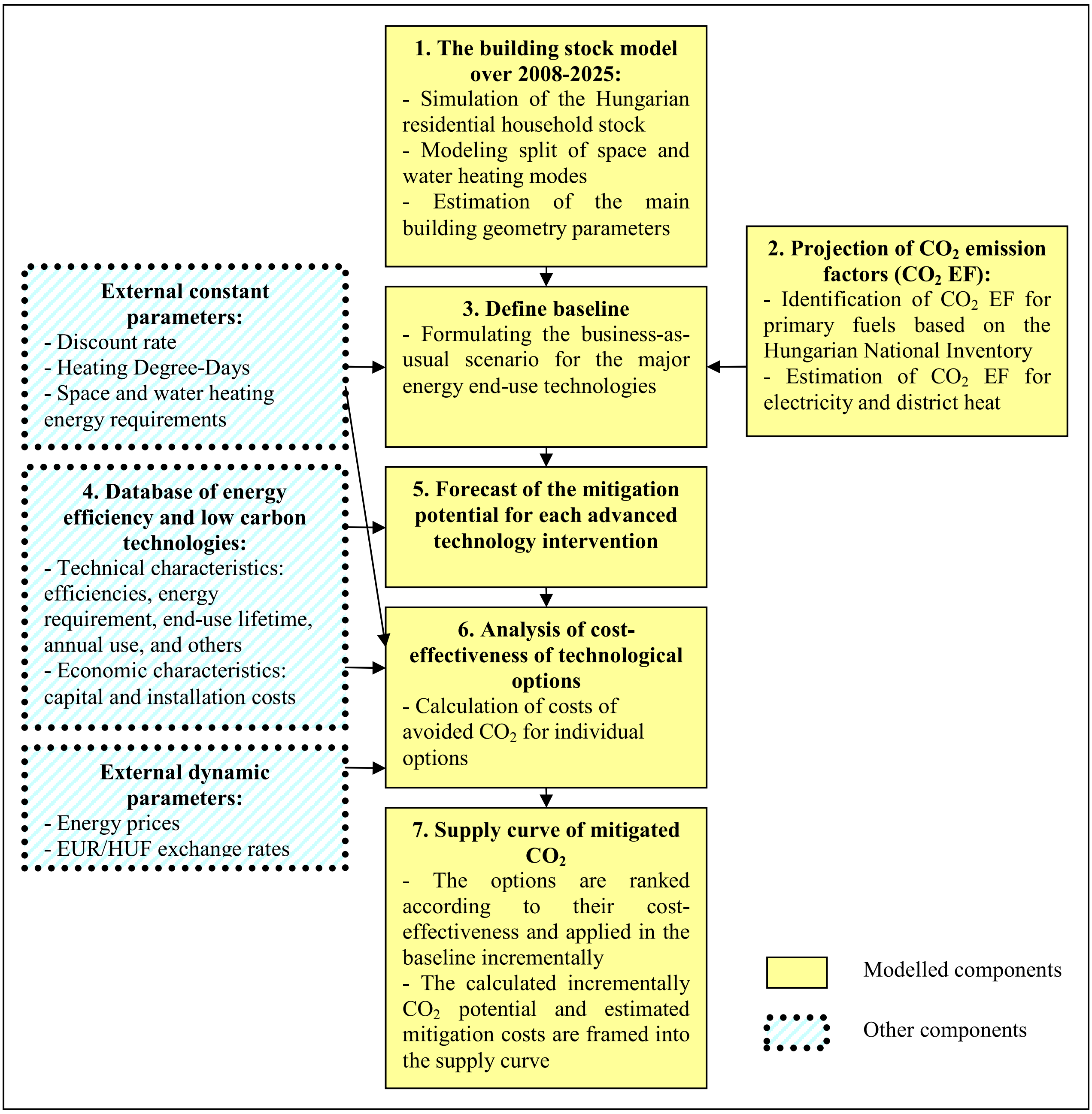

Figure 5 The bottom-up model for estimation of the CO_2 mitigation potential in the Hungarian residential sector

3.3 Building types

For the modeling purposes, the Hungarian buildings stock was split into five main buildings types, which possess different architectural and thermal characteristics. The building types will be characterized in details in section 4.2 and are only listed in this section for a better understanding of the modeling methodology. These building types are:

(i) Traditional multi-family houses built mainly at the end of the 19th century and during the inter-war years

(ii) Multi-family buildings constructed with the industrialized technology built until 1992

(iii) Single family houses in suburban and semi-urban areas built until 1992

(iv) Single and multi-family houses built during 1993 - 2007

(v) Single and multi-family houses built after 2008

3.4 Scope of the study

The research covers only those energy end-uses which have high penetration rates and consume large shares of final energy consumed by the residential sector. The modeling structure of energy end-uses is presented on Figure 6.

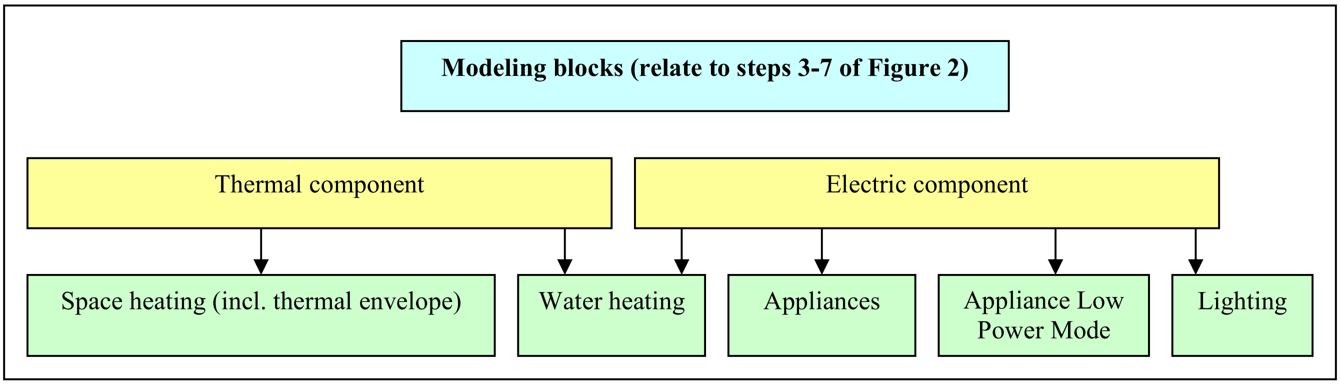

Figure 6 Modeling structure of energy end-uses

The thermal component of the model includes the next opportunities to reduce the energy heating requirement, to improve the thermal envelope[3], to improve space heating efficiencies, and to switch to fuels with lower CO_2 emission factors:

- Improvement of insulation levels of walls, roofs, and cellars (including such factor as thermal bridges)
- Improvement of thermal properties of windows and doors
- Application of the passive energy design to new built houses

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[3] Thermal envelope refers to the shell of the building as a barrier to unwanted heat or mass transfer between the interior of the building and the outside conditions.

- An exchange of gas and coal premise (room) and dwelling heating systems with high efficiency (condensing) gas dwelling heating (and in some cases water heating) systems or space and water heating pumps, or biomass (pellet) space and water heating systems, or solar thermal space and water heating systems backed-up with biomass (pellets)

- An exchange of building central gas conventional systems with high efficiency (condensing) gas building central heating systems

- Installation of space heating control systems such as thermostatic radiator valves (TRVs) and programmable thermostats depending on the type of a heating system

- Installation of individual heat meters to households connected to district and central block (building) heating

The model covers the next opportunities to reduce CO_2 emissions through water heating:

- Improvement of efficiencies of water heating combined with space heating systems (according to the options described in the space heating opportunities)

- An exchange of dedicated water heating appliances (electric storage boilers, gas storage and instantaneous water heaters) with more efficient analogues

- Installation of water saving fixtures (showerheads and sink faucets)

The list of options considered to improve electric efficiency includes:

- Higher efficiency cold appliances[4] (refrigerators and freezers)

- Higher efficiency clothes washers

- Reduction of electricity consumption of TV- and PC- related appliances in the low power mode

- An exchange of incandescent lighting bulbs with efficient lighting technologies

The model does not consider:

- Improvement of the thermal envelope of the buildings constructed during 1993-2008 and an exchange of heating technologies in buildings constructed after 1993 (for explanation why these options were excluded please see sections 4.2.4 and 4.2.5)

- Reduced air leakage and heat gains of windows and doors

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[4] Not air-conditioning

- Efficiency improvement of biomass heating systems presently installed in the family houses

- Better insulation of pipes delivering district and central heat and district and central water insight buildings

- Efficiency improvement of electric appliances and equipment other than those listed above

- Cooking

- Air-conditioning

- Motors (lifts)

- Very unusual options (but sometimes having considerable potential): for instance, construction of roofs under inner yards of traditional multi-family (Budapest-type) buildings. This would allow increasing the yard temperature by several degrees, thus, reducing the heat loss of the cooling surface of buildings and decreasing the heating requirement of households having common walls with yards.

3.5 Formulating the baseline

The estimates of the potential available for CO_2 emission mitigation is the most useful if it is compared to the baseline scenario, i.e. the information of what would happen without special energy efficiency and climate mitigation policy interventions. There are different types of baselines considered by the analytical literature. These are, most often, frozen efficiency, low efficiency/low carbon, and business-as-usual (BAU) scenarios. A frozen efficiency scenario implies that no energy efficiency improvement and no reduction of specific energy consumption occur. A low efficiency/low carbon scenario typically assumes some (low) penetration level of energy efficiency/low carbon technologies. A BAU scenario assumes that no new energy efficiency and low carbon policies are implemented additionally to those which have been already realized and energy and carbon intensities change because of the market forces.

For the purposes of the research, the BAU scenario is considered. The BAU scenario covers only those building types and only those energy end-uses which are described in the previous section 3.4. Modeling the BAU scenario for the thermal energy end-uses assumes that the evolution of the thermal-related reference technologies happen quite slowly and their characteristics in the future will be approximately as today. In contrast, modeling of the BAU scenario for electric technologies (except water heating) assumes that their characteristics change quicker than the thermal options over the projection time. More details of the BAU assumptions for each of the energy consuming energy end-use such as penetration rates, efficiency levels, and their costs, are described are the related sections.

For the further discussion, the scenario which implied the realization of all mitigation options described by the present study (i.e. the total amount of the potential not regarding its costs found by the study is realized) is referred as the mitigation scenario. The main assumption for both the BAU baseline and the mitigation scenario is that an understanding of energy end-use services will not change over the projection period of time. For instance, people will continue cleaning their clothes in washing machines, refrigerating the food, etc (rather than cleaning the clothes with bacteria, consuming not getting out of order food, or requiring other services which presently can be hardly imaginable but can come in the future).

3.6 Data sources

The data used to reconstruct the present energy balance is collected from several sources:

- As concerning the electric energy end-use, the data was collected from electricity use metering campaigns conducted by Central European University (REMODECE, 2007), and such sources as the Status Report on Electricity Consumption and Efficiency Trends by Bertoldi and Atanasiu (2007), the task reports of the Ecostandby project (Fraunhofer IZM, 2007), and other references

- As regarding the thermal energy end-use, the data were collected from the numerous publications of the Hungarian Statistical Central Office, the task reports of the Ecohotwater project (Kemna et al., 2007), the EURIMA/ECOFYS report (Petersdorff et al., 2005), interviews with experts (Kovacsics, 2007; Csoknyai, 2007; and Sigmond, 2007), and other referencs.

The database of efficiency and low carbon retrofit options is built based on:

- Such comprehensive publications as Levine et al. (2007), Harvey (2006), IEA (2006)

- Labeling and standardization programme reports (ADEME, 2000; CECED, 2001; SAVE, 2001a, 2001b, 2002)

- Equipment catalogues and pricelists (Danfoss, 2007; Duplo-duplex, 2007; Gavron, 2007; GIL-TRADE, 2007; Mega-öko Kazánfejlesztő-gyártó Kft, 2007; Megatherm, 2007; Novoferm, 2007; ORIS Consulting; Saunier Duval, 2007; Szalontai and Sonnencraft, 2007)

- Reports, market reviews, and presentations of production associations and consultancies (Adam, 2007; Trnka, 2004; DBO, 2007; EHPA, 2007; Weiss et al., 2007)

- Interviews and correspondence with experts (Kovacsics, 2007; Csoknyai, 2007; Sigmond, 2007; Hermelink, 2005; Kocsis and Beleczki, 2007).

3.7 Modeling equations

This section reviews the mains steps and calculation procedures applied in the model. To simplify the discussion, first, the analysis of the energy savings and emission mitigation on the household level is described. Later, it is explained, how the household analysis was extrapolated to the level of the country. The calculation procedures were derived based on such sources as Vorsatz (1996), Harvey (2006), Petersdorff et al. (2005), ADEME (2000), Fraunhofer IZM (2007), Kemna et al. (2007), SAVE (2001a, 2001b, 2002).

Step 1. Calculation of final energy savings and mitigation CO_2 from application of individual measures to a household

- *Insulation options, exchange of building components*:

$$\Delta FE_{i,m,j} = \frac{HDH_i \times \Delta U_m \times IA_m}{\eta_{i,j}},$$

$$\Delta CO_{2i,m,j} = \Delta FE_{i,m,j} \times EF_{i,j}$$

where:

$\Delta FE_{i,m,j}$, [kWh/hh-yr. – kilowatt-hours per household per annum] – saved final energy due to a measure in year i in a household which belongs to a building type m heated with space heating technology j

$\Delta CO_{2i,m,j}$, [g CO_2/hh– yr. – gram CO_2 per household per annum] – avoided CO_2 due to a measure in year i in a household which belongs to a building type m heated with space heating technology j

HDH_i , (Heating Degree Hours), [Kh/yr – Kelvin-hours/annum] - a cumulative over year difference between daily average air temperature and the reference temperature of 18°C in year i,

ΔU_m , [W/Km^2 – Watt/Kelvin per m^2] – a difference between U-values (thermal transmittance coefficients) before and after insulation of a building shell component in a building type m

$\eta_{i,j}$, [%] - efficiency of heat production and distribution for j heating technology in year i

IA_m , [m^2] – insulated area of a household which belongs to a building type m by the option

$EF_{i,j}$, [g/kWh – grams of CO_2 per kiloWatt-hour] - CO_2 emission factor of fuel used for space heating technology j in year i

- *Exchange of a space heating technology*

$$\Delta FE_{i,m} = FE_{i,m,j} - FE_{i,m,k},$$

$$\Delta CO_{2i,m} = FE_{i,m,j} \times EF_{i,j} - FE_{i,m,k} \times EF_{i,k}$$

$$FE_{i,m,j} = \frac{HA_j \text{ x } UE_m}{\eta_{i,j}},$$

where:

$\Delta FE_{i,m}$, [kWh/hh-yr. – kilowatt-hours per household per annum] – saved final energy due to a switch between space heating solutions in year i in a household which belongs to a building type m

$\Delta CO_{2i,m}$, [g CO_2/hh– yr. – gram CO_2 per household per annum] – avoided CO_2 due to a switch between space heating solution in year i in a household which belongs to a building type m

$EF_{i,j}$ and $EF_{i,k}$, [g/kWh – grams of CO_2 per kiloWatt-hour] - CO_2 emission factors of different space heating technologies j and k in year i

$FE_{i,m,j}$ and $FE_{i,m,k}$, [kWh/hh-yr. – kilowatt-hours per household per annum] –final energy consumption of heating technologies j and k to satisfy the same heating energy demand in year i in a building type m

UE_m, [kWh/m^2 -yr. – kilowatt-hours per m^2 per annum] – energy heating requirement (useful energy demand) for a building type m

$\eta_{i,j}$, [%] - efficiency of heat production and distribution for j heating technology in year i

HA_j, [m^2] – heated area of a household with j heating technology (change in the case of switch from premise heating to central heating)

- *Installation of space heating controls*

$$\Delta FE_{i,m,j} = \frac{HA_j \text{ x } HDH_i \text{ x } \Delta\%UE_m}{\eta_{i,j}}$$

$$\Delta CO_{2i,m,j} = \Delta FE_{i,m,j} \text{ x } EF_{i,j}$$

where:

$\Delta FE_{i,m,j}$, $\Delta CO_{2i,m,j}$, HDH_i, $\eta_{i,j}$, and $EF_{i,j}$ - have the same meaning as in the paragraphs describing estimation of insulation options

$\Delta\%UE_m$, [%] - useful energy savings as a share of energy heating requirement due to the installation of a space heating control

- *Installation of water saving fixtures*

$$\Delta FE_{i,j} = \frac{V_i \, x \Delta\%V \text{ x } UE}{\eta_{i,j}},$$

$\Delta CO_{2i,j} = \Delta FE_{i,j}$ x EF_i

where:

$\Delta FE_{i,j}$, [kWh/hh-yr. – kilowatt-hours per household per annum] – saved final energy in year i due to a measure in a household having water heating technology j

$\Delta CO_{2i,j}$, [g CO_2/hh– yr. – gram CO_2 per household per annum] – avoided CO_2 in year i due to a measure in a household having water heating technology j

UE , [kWh/liter – kilowatt-hours] - energy requirement to heat 1 liter of water

V_i , [l - liters] – hot water consumption per annum of a household in year i (changes over the time because the household size decreases)

$\Delta\%V$, [%] – the share of reduced water consumption due to installation of water saving fixture

$\eta_{i,j}$, [%] – efficiency of a water heating technology or appliance j in year i

$EF_{i,j}$, [g CO_2/kWh – grams of CO_2 per kiloWatt-hour] - CO_2 emission factor of fuel used for a water heating technology j in year i

- *Exchange of a water heating technology*

$\Delta FE_i = FE_{i,j} - FE_{i,k}$,

$\Delta CO_{2i} = FE_j \text{ x } EF_{i,j} - FE_k \text{ x } EF_{i,k}$

$$FE_{i,j} = \frac{V_i \text{ x } UE}{\eta_{i,j}},$$

where:

V_i and UE - have the same meaning as in the paragraph describing estimation of water saving fixtures

$FE_{i,j}$ and $FE_{i,k}$ [kWh/hh-yr. – kilowatt-hours per household per annum] –final energy consumption of water heating technologies j and k to satisfy the same hot water demand in year i

ΔFE_i , [kWh/hh-yr. – kilowatt-hours per household per annum] – saved final energy due to a switch between water heating solutions in year i

ΔCO_{2i} , [g CO_2/hh– yr. – gram CO_2 per household per annum] – avoided CO_2 due to a switch between water heating solution in year i

$EF_{i,j}$ and $EF_{i,k}$, [g/kWh – grams of CO_2 per kiloWatt-hour] - CO_2 emission factors of different water heating technologies j and k in year i

$\eta_{i,j}$, [%] - efficiency of hot water production and distribution with j water heating technology in year i

- *Exchange of electric appliances and lights:*

$\Delta CO_{2i} = \Delta FE_i \times EF_i$,

where

ΔFE_i , [kWh/yr.- kilowatt per annum] – difference in electricity consumption in year i due to installation of a less energy consuming appliance, installation of an appliance having lower consumption in low power mode[5] (LOPOMO), or a switch between lighting technologies ; ΔFE_i is defined for different types of electric measures individually below

ΔCO_{2i} , [g CO_2/hh– yr. – gram CO_2 per household per annum] – avoided CO_2 in year i due to installation of a less energy consuming appliance, installation of an appliance having lower consumption in LOPOMO, or a switch between lighting technologies

EF_i [g CO_2/kWh – grams CO_2 per kilowatt-hour] – electricity emission factor in year i

cold appliances:

$\Delta FE_i = \Delta EEI_i \times UEC_{ref}$,

where:

ΔEEI_i– a difference between energy efficiency indices[6] (EEI)of cold appliances in the business-as-usual scenario and the efficiency scenario in year i

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[5] Please see the definition in section 6.6.

[6] EEI indicates an appliance’s energy consumption relative to a reference model. For domestic cooling appliances the energy efficiency index (EEI) for a reference model was set at 102 for the average model on the market in year 1992.

UEC_{ref} , [kWh/yr. – kilowatt-hour per annum] – weighted average unit energy consumption of cold appliances sold in 1990-1992 in the EU-15 taken as a reference to define appliance' EEI

washing machines:

$\Delta FE_i = \Delta UEC_i \times L \times T$,

where:

ΔUEC_i , [kWh/kg – kilowatt-hours per 1 kilogram of clothes] – a difference between unit energy consumption per 1 kilogram of washing load of washing machines in the BAU baseline and the mitigation scenario in year i

L , [kg – kilogram] – washing load

T – number of washes per year

LOPOMO:

$\Delta FE_i = \Delta W_i \times Time$,

where

ΔW_i , [W - watt] – difference in LOPOMO wattage of reference and advanced appliances in year i

Time, [h/yr. – hours per annum] – time in LOPOMO of an appliance

lighting:

$\Delta FE_i = \Delta W_i \times Time$,

where

ΔW_i , [W - watt] – different in wattage of reference and advanced appliances in year i

Time, [h/yr. – hours per annum] – time of using a specific lighting technology

Step 2. Calculation of total investment costs for each measure

$IC = CC + IC$,

where

IC [EUR] – total investment costs of a measure technology

CC [EUR] – capital costs of a measure

IC [EUR] – installation and maintenance costs of a measure (the maintenance costs are included where available according to the best knowledge of the authors)

Note: Investment costs take into account only additional costs associated with advances options, i.e. they exclude costs associated with the business-as-usual case.

Step 3. Calculation of annualized investment costs

$\Delta ICA_i = ICA_{i,j} - ICA_{i,k}$

$ICA_{i,i} = IC_{i,i} \text{ x } a_j,$

$$a_j = \frac{(1 + DR)^{n}{}_{j} \text{ x } DR}{(1 + DR)^{n}{}_{j} - 1},$$

where

ΔICA_i , [EUR/yr. – EUR per year] – difference in annualized investment costs between reference technology k and advanced technology j in year i

$ICA_{i,j}$ and $ICA_{i,k}$, [EUR/yr. – EUR per year] – annualized investment costs of reference technology j and advanced technology k in year i

a_j- annuity factor

DR – discount rate,

n_j – technology end-use lifetime,

Note: the actual technical lifetime of the products may exceed the projected lifetime increasing economic and environmental benefits (Petersdorff et al., 2005).

Step 5. Estimate of saved energy costs

$\Delta C_{i,j} = \Delta FE_{i,j} \text{ x } P_i$,

where

$\Delta C_{i,j}$, [EUR/yr.- EURO per annum] – saved operation costs in year i due to installation of an advanced technology j (maintenance costs are considered in the total investment costs); saved operation costs in our model imply saved energy costs only

$\Delta FE_{i,j}$, [kWh/yr. – kilowatt-hours per annum] –saved final energy consumption due to installation of an advanced technology j in year i

P_i , [EUR/kWh - EURO per kilowatt-hour] – the fuel price for the residential end-users (including the value added tax and the energy tax) in year i; please see section 3.8.3 more assumption about the fuel prices including their projection of the considered period of time.

Step 5. Costs of conserved CO_2 and cost of conserved energy

$$CC_{i,j} = \frac{\Delta ICA_{i,j} - \Delta C_{i,j}}{\Delta CO_{2i,j}},$$

where

$CC_{i,j}$ [EUR/g CO_2 - EURO per gram of CO_2] – cost of avoided CO_2 of a measure in year i

Additionally to the cost of conserved CO_2, the cost of conserved energy was calculated to help an understanding of the magnitude of investments needed to save a unit of energy. This indicator was estimated as:

$$CCE_{i,j} = \frac{\Delta ICA_{i,j}}{\Delta FE_{i,j}},$$

where

$CCE_{i,j}$ [EUR/kWh – EURO per kWh saved] – the cost of conserved energy of a measure j in year i

Step 6. Calculation of the country-wide indicators

To extrapolate the analysis on the household level to the country level, the following procedures are applied:

a) Substituting in above formulas household system efficiencies, household emission factors, and energy prices with country average system efficiencies, emission factors, and energy prices (weighted according to the final energy consumption) employed in the considered building types for space consumption assessment (including insulation options and controls).

Country average system efficiencies for building types are calculated as:

$$\eta_{i,m} = \frac{\sum \eta_{i,j} \text{ x } FE_{i,m,j} \text{ x } Stock_{i,m,j}}{\sum FE_{i,m,j} \text{ x } Stock_{i,m,j}},$$

Country average emission factors are calculated as:

$$EF_{i,m} = \frac{\sum EF_{i,j} \text{ x } FE_{i,m,j} \text{ x } Stock_{i,m,j}}{\sum FE_{i,m,j} \text{ x } Stock_{i,m,j}},$$

Country average energy prices are calculated as:

$$P_{i,m} = \frac{\sum P_{i,j} \text{ x } FE_{i,m,j} \text{ x } Stock_{i,m,j}}{\sum FE_{i,j} \text{ x } Stock_{i,m,j}},$$

where

$\eta_{i,m}$, [%] – average efficiency of heating solutions (weighted according to the final energy consumption) in year i in Hungarian households housed type-m buildings

$EF_{i,m}$ [g/kWh – grams of CO_2 per kiloWatt-hour] – average CO_2 emission factor (weighted according to the final energy consumption) of fuel used for space heating in year i in Hungarian households housed type-m buildings

$P_{i,m}$, [EUR/kWh - EURO per kilowatt-hour] – the average fuel price (weighted according to the final energy consumption) for the residential end-users in year i housed type-m buildings

$\eta_{i,j}$, [%] – efficiency of heat production and distribution for j heating technology in year i

$FE_{i,m,j}$, [kWh/hh-yr. – kilowatt-hours per household per annum] –final energy consumption in year i of heating technology j in a building type m

$Stock_{i,m,j}$, [absolute value] - is the stock of installed reference/mitigation technology j in year i in a building type m

$EF_{i,j}$, [g/kWh – grams of CO_2 per kiloWatt-hour] - CO_2 emission factor of fuel used for space heating technology j in year i

$P_{i,j}$, [EUR/kWh - EURO per kilowatt-hour] – the fuel price for the residential end-users in year i heated with j heating solution

b) Substituting in above formulas the space heating requirement with average space heating requirement weighted by the number of the households in a modeled type of buildings as (the country average space heating requirement changes over time because as the time goes by the buildings are insulated requiring less energy for space heat) :

$$UE_{i,m} = \frac{UE_{i,r,m} \text{ x } S_{i,r,m} + UE_{i,nr,m} \text{ x } S_{i,nr,m}}{S_{i,r,m} + S_{i,nr,m}},$$

where

$UE_{i,m}$, [kWh/yr. – kilowatt-hours per annum] –the average household space heating requirement (weighted-average by the household stock) in a building type m in year i

$UE_{i,r,m}$ [kWh/yr. – kilowatt-hours per annum] –the household space heating requirement for a retrofitted household in building type m in year i

$UE_{i,nr,m}$ [kWh/yr. – kilowatt-hours per annum] – the household space heating requirement for a not retrofitted household in building type m in year i

$S_{i,r,m}$ – the stock of retrofitted households in a building type m in year i

$S_{i,nr,m}$ – the stock of not retrofitted households in a building type m in year i

A similar formula is applied to calculate the country average heating degree days[7] of households (weighted by the number of the households in a modeled type of buildings).

c) The country-wide energy saving potential, CO_2 emission mitigation potential, and investment costs are the products of energy saving potential, CO_2 mitigation potential, and investment costs, which are calculated for an average household taking into account the modified above formulas, and the stock of the households:

$\Delta NFE_{i,m} = \sum S_{i,m} \text{ x } \Delta FE_{i,m}$, $\Delta NFE_i = \sum S_i \text{ x } \Delta FE_i$

$\Delta NCO_{2,i,m} = \sum S_{i,m} \text{ x } \Delta CO_{2i,m}$, $\Delta \ CO_{2i} = \sum S_i \text{ x } \Delta \ CO_{2i}$

$\Delta NIC_{,i,m} = \sum S_{i,m} \text{ x } \Delta IC_{i,m}$, $\Delta NIC_i = \sum S_i \text{ x } \Delta IC_j$

where

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[7] Less heating temperature and shorter heating time will be required for increasingly insulated stock of households.

$\Delta NFE_{i,m}$, $\Delta NCO_{2i,m}$, $\Delta NIC_{i,m}$ – national potential for energy saving and CO_2 emission mitigation, and national investment costs in year i due to installation of a measure in building type m (for insulation and space heating)

ΔNFE_i , ΔNCO_{2i}, ΔNIC_i – national potential for energy saving and CO_2 emission mitigation, and national investment costs in year i due to installation of advanced electric options and water heating solutions

$S_{i,m}$ – the household stock housed in building type m in year i

$\Delta FE_{i,m}$, $\Delta CO_{2i,m}$, $\Delta IC_{i,m}$ – potential of a household for energy saving and CO_2 emission mitigation, and investment costs in year i due to installation of a measure in building type m (for insulation and space heating)

ΔFE_i , ΔCO_{2i}, ΔIC_i –potential of a household for energy saving and CO_2 emission mitigation, and investment costs in year i due to installation of advanced electric options and water heating solutions

S_i – stock of electric appliances and water heating solutions in year i

d) To calculate the annualized investment costs on the national level, the investment costs for a household are multiplied with the total number of the retrofitted stock. Here is an example for insulation options:

$NICA_{i,m} = ICA_{i,m} \times S_{i,m}$,

where

$S_{i,m}$ – stock of retrofitted households in a building type m in year i

$NICA_{i,m}$ [EUR/yr. – EURO per annum] – national annualized investment costs in year i due an insulation option in a building type m

$ICA_{i,m}$ [EUR/yr. – EURO per annum] –annualized investment costs of a household in year i due an insulation option in a building type m

The rest of the indicators such as final energy consumption and CO_2 emissions on the household or national level and others are calculated based from above formulas or based on their simple extrapolation of the household indicators to the national level.

3.8 Main assumptions

3.8.1 CO_2 emission factors

CO_2 emissions are estimated as final energy consumption multiplied by emission factors.

Emission factors of primary fuels, i.e. natural gas, fuel oil, lignite, and hard coal are taken from the Hungarian National Inventory (Hungarian Ministry of Environment and Water, 2007). According to the same source, amounts of biomass used as fuel should be included in the national energy consumption but the corresponding CO_2 emissions are not included in the national total (even though they are significant) as it is assumed that the biomass is produced in a sustainable manner. Emission factors of primary fuels do not change significantly over time (see the Hungarian National Inventories prepared over 1987 – 2005), therefore, they are assumed as constant over the projection period.

There is an uncertainty in regard to the future emission factors of electricity and district heat production and distribution. Their estimates were derived based on the analysis of two documents. This is, first, the National Allocation Plan of Hungary (NAP I, 2007) which described the expected capacity, efficiency, and CO_2 emissions of district heat installations until 2012. And this is, second, the MAVIR capacity plan during 2005 – 2020 (MAVIR, 2007) which contains a forecast of the future fuel mix for power generation and heat production, a forecast of an expected share of cogeneration in power and heat production, and estimates of efficiencies of future power and heat production technologies for the years 2005, 2010, 2015, and 2020. Based on these two documents and the emission factors of primary fuels provided by the Hungarian National Inventory, the emission factors for electricity and heat were estimated for the years 2005, 2010, 2015, and 2020 and interpolated between these years. It was assumed that the emission factors during 2021 – 2025 will be the same as in 2020 given a high uncertainty of the fuel mix for electricity and heat production over twenty years. The results of modeling emission factors for electricity and heat are presented in Figure 7 below.

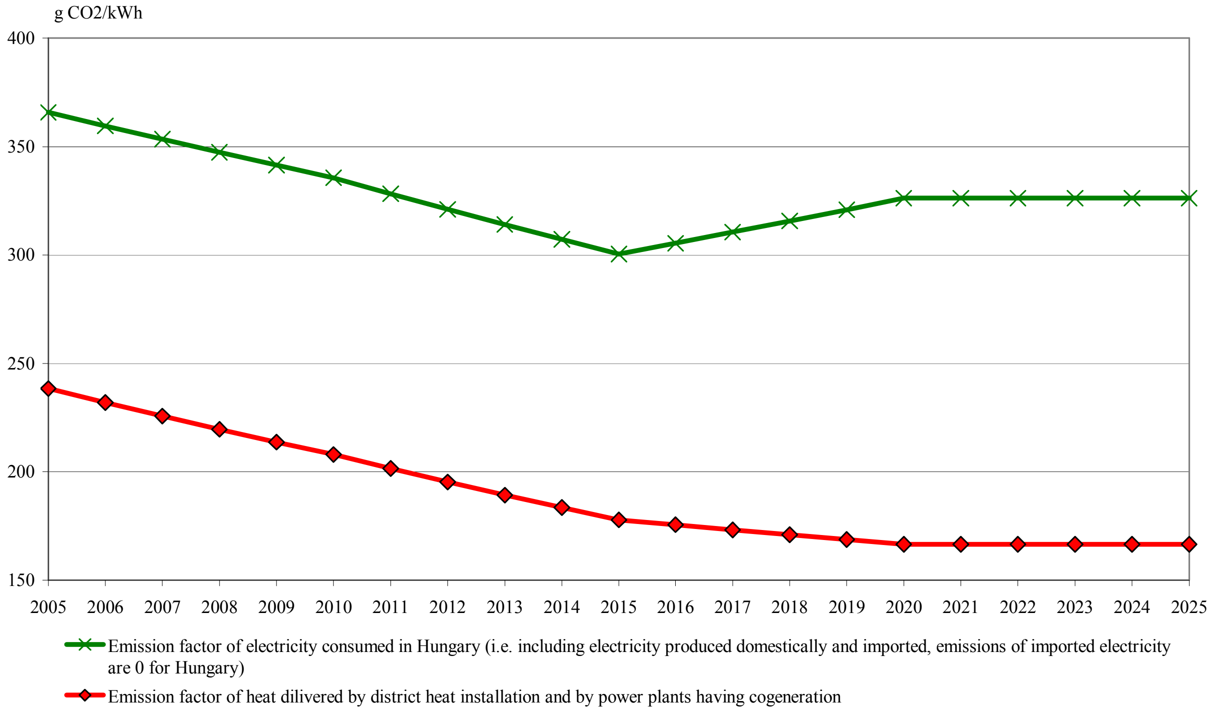

Figure 7 Projected emission factors for electricity and heat over 2005 – 2025 in Hungary

3.8.2 Discount rate

The major part of costs for energy conservation is paid by the households. Additionally, some of these spendings are supported by the Governmental programmes (for instance, for building renovations). This is why, it is important to understand the discount rate for the household sector as well as for the Government.

In an ideal situation, a household compares the internal rate of return of spendings for energy conservation with the long-term interest rate of a bank deposit. As of August 2007, such rate at the Hungarian Central Bank[8] was 3.09%. This level of the long-term interest rate is very close to that in the EUR-area (see European Central Bank website). Despite in the beginning of 2007, the long-term interest rate of the Hungarian Central bank was slightly above 1%, it is assumed that the interest rate will be at least as high as it is presently. In reality, the discount rate of the household sector is higher than the long-term interest rate provided by banks due to numerous barriers associated with efficiency improvement in the households. For the purposes of the research, it is assumed that the discount rate is higher than the internal rate of spendings for energy conservation approximately twice, i.e. it is about 6%.

If Governmental agencies support the household sector, the discount rate for them is at least as high as the base rate of the Central Bank, which was 7.75% as of August 2007. It is expected that in the medium term future, the financial indicators of Hungary will improve (Government of the Republic of Hungary, 2006) and the base rate should somewhat decline. While, there is an uncertainty about fluctuation of the base rate to 2025, it is reasonable to assume that it will be close to the discount rate assumed for the household sector.

The proposed discount rate of 6% is in line with other case studies performed in the CEE region. EURIMA report (Petersdorff et al. 2005) analyzed the impact of the EU Directive on Energy Performance of Buildings concerning the heating-related CO_2 reduction potential and its cost-effectiveness in the New EU Member States[9] in comparison to the frozen efficiency scenario over 2006 – 2015 with the discount rate 6%. Other two reports available in the CEE regions were written significant time ago. The Hungarian country study developed in the frame of the UNEP series entitled “Economics of GHG Limitations” (Szlavik et al., 1999) considered the residential and public sectors with the discount rates of 3-5% over 2000 – 2030. The Estonian country study prepared in the frame of the same UNEP series (Kallaste et al., 1999) studied measures the residential and commercial sectors with the discount rate of 6% over 2000 - 2025.

3.8.3 Fuel prices

As mentioned in section 3.8.2, the major part of costs for energy conservation is paid by the households and since the policies measures are designed to support their decisions, the assessment is conducted taken into account the fuel prices for the residential end-users (including the value added tax and the energy tax where applicable).

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[8] For EUR deposits because the currency considered by the research is EUR.

[9] Hungary, Slovakia, Slovenia, Estonia, Latvia, Lithuania, Poland, and the Czech Republic.

There is a large uncertainty associated with the future dynamics of energy prices. Since saved energy costs (calculated as final energy savings times fuel prices) influence directly on the level of the costs of avoided CO_2, more detailed research is needed to reduce the uncertainty of the fuel price evolution. In agreement with other pieces of research, which focused on the CEE region (Waide 2006; Petersdorff et al. 2005), energy prices were assumed to grow by 1.5%/yr. in real terms. Fuel prices in 2007 were taken from the National Allocation Plan of Hungary (NAP I, 2007). They are presented in Table 4 below.

Table 4 Energy prices for the residential end-users of Hungary in 2007

Fuels	Energy price, EUR/kWh	References
Natural gas	0.044	Hungarian Energy Office, 2007a
Agripellet	0.030	Estimate based on DBO, 2007
Brown coal	0.024	Estimate based on Hungarian Energy Office, 2007b
Firewood	0.012	Estimate based on DBO, 2007
District Heat	0.041	Call Centre FŐTÁV, 2007
Electric energy	0.155	Hungarian Energy Office, 2007c

3.9 Other assumptions

3.9.1 Start year

Based on the data availability, the year 2004 is set as a starting point for formulation of the energy balance of the sector. The year 2007 is s start for modeling input parameters while introduction of mitigation options will start from the year 2008. Due to the fact there is an uncertainty with emerging energy end-use technologies over a period longer than 20 - 25 years, the model covers the time until 2025 only.

3.9.2 Heat released by domestic appliances and lights

The model does not consider the heat released by domestic appliances and lights. Even though often omitted, this heat contributes a notable share to satisfaction of space heating needs, however, more research needed to quantify it accurately.

3.9.3 Life-cycle emissions

The research considers only emissions resulting on the operation stage of the employed technologies. The research, thus, does not consider the life-cycle costs which include emissions during the manufacture of the technological solutions, from the mining of the raw materials used in their production and distribution, possible re-use or recycling, and their disposal.

3.9.4 Heading degree hours

Heating degree houres are expected to go down due to the warming effect. The total costs of heating will drop along with heating need resulting in slower pay back of investments into thermal technologies and, thus, higher cost of avoided CO_2. More research is needed to identify this effect for Hungary. The constant heating degree-hours are considered by the model until more data is available.

3.9.5 Lifetimes of equipment and building components

The lifetime of appliances, lights, space and water heating systems, and building component were estimated based on several sources as presented below in Table 5.

Table 5 Lifetime of building components, household equipment and appliances

Equipment and materials	**Lifespan**
Insulation materials	30 years
Windows and doors	30 years
New built buildings	100 years
Space heating systems, combined space and water systems, dedicated water heaters	20 years
Heating controls and water savings fixtures	20 years
Refrigerators	20 years
Freezers	25 years
Washing machines	25 years
Television sets, VCRs, Antennas/Satellites	10 years
DVD playerss	9 years
Desktop, monitor, router	6 years
Printer	4 years
Incandescent bulbs	1 000 hours
CFLs	6 000 hours

Sources: Petersdorff et al., 2005; Invert, 2005; Bertoldi, 2005; Meli, 2004; Fraunhofer IZM, 2007; IEA, 2006b.

3.9.6 Formation of district heat prices

To be consistent across the methodologies for estimation energy saving costs of space heating options, it is considered that the district heat price is 100% flexible. In practice, only half of the district heat price is variable: it is depends on heat consumption of a building distributed among heat payers. Another half of the price is not variable (Sigmond, 2007).

3.9.7 Financial operations

The financial analysis was conducted based on real prices, i.e. not taking into account the expected inflation. Since the costs for energy conservation are invested mostly by households, the investment costs into technological options are estimated at the final price including the value added tax (and other taxes included into the price).

3.9.8 Disregarded space heating options

Not significant shares of space heating solutions such as, for instance, non-gas heating in multi-family houses (0.3% of the total stock) and households heated with electricity (about 2.5% of the total household stock) are disregarded by the model.

3.9.9 Rebound effect[10]

Switch to a better heating technology, it is often that a household exchanges its premise (room) heating with central dwelling heating. In this case, the heated area increases by factor 2-3 (due to the switch from heating the main rooms to heating the whole house) and the total energy consumed for heating is increasing, even though it is supplied with a technology of higher efficiency. This effect was covered by the model. Other rebound effects are not considered.

3.9.10 Water demand and energy requirement for water heating

Based on Kemna et al. (2007), the demand for sanitary hot water was estimated as 25 liters/person/day of 60°C water for Hungary. The average energy requirement for water heating to supply water at 60°C is 0.06 kWh/liter. Therefore, the net energy demand for water heating is about 548 kWh/person per annum.

It is important to note that while this requirement is assumed to be constant per person, hot water requirement for a household will change over time because the number of persons per households is decreasing. Based on Kemna et al. (2007), it was estimated that if a household has two water heaters, the average water consumption from the secondary heater is about a third of the total water consumption.

3.9.11 Split of investment costs to space heating and water heating for combined systems

For those systems which supply both space heating and hot water, the investment costs allocated for space heating are 92%, calculated as the share of heating energy requirement for space heat of an average Hungarian household[11]. The rest investment costs are allocated for water heating.

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[10] The IPCC (2007) defines the rebound effect as a phenomenon when demand for energy services grow along with improved energy-efficiency.

[11] Calculated as the dwelling heating energy requirement [calculated as the product of the average heating requirement (220 kWh/m^2-yr.) and the average size of a dwelling (74m^2)] divided by the dwelling energy requirement [the same as just described] plus the household water heating requirement [calculated as the energy heating requirement for water heating [0.06 kWh/liter] multiplied by 65 liters/household consumed per day and multiplied by 365 days/yr.].

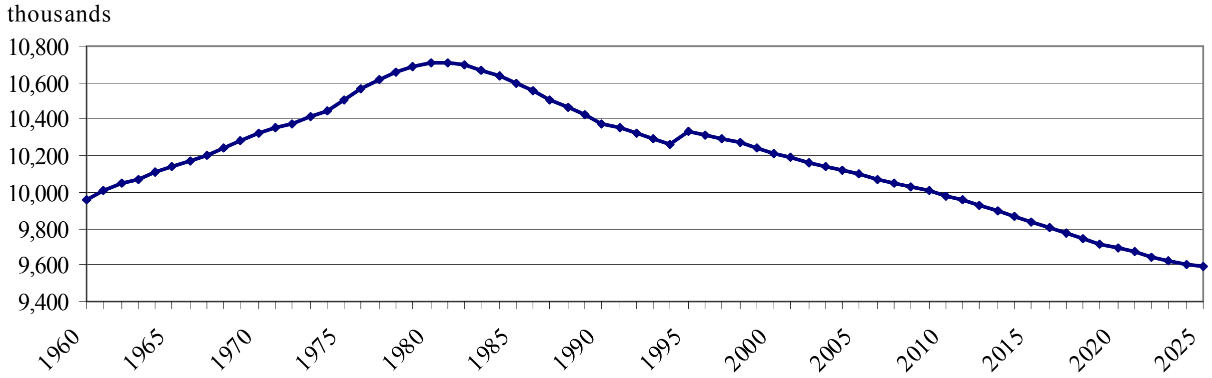
4 HOUSEHOLD STOCK

This section details the research aimed to project the future building stock and its characteristics. The section describes the main building types, their thermal properties and energy heating requirements. Overcoming a large uncertainty associated with the evolution of the building stock, the section presents the results of modeling the household stock by different building types split according to installed space heating solutions.

4.1 Modeling the household stock

4.1.1 Dynamics of population and the dwelling stock

The historical dynamics and the forecast of population were taken from the Hungarian Statistical Central Office (KSH, 2006a) and the EUROSTAT official population forecast (2007). The population dynamics based on these two sources is presented in Figure 8.



Annual growth rates

1965-1975	1975-1985	1985-1995	1995-2005	2005-2015	2015-2025
0.4%	0.1%	-0.3%	-0.2%	-0.3%	-0.3%

Figure 8 Population dynamics in Hungary, 1960 - 2025

Source: constructed based on KSH (2006a) and EUROSTAT (2007)

The historical data shows that despite the population decline since 1983 the total number of dwellings has been growing. During 1990 – 2004, the annual growth rate of the total dwelling number was 0.7% which is the same as the average EU rate (calculated based on KSH, 2006b). This is due to improved living standards and the phenomenon of "independent home" described by Ball (2005). Many households have more than one dwelling – a independent home – which is not rented out in the privately rented sector on the permanent basis. Another factor is also a large share of the low quality and, this is why, not occupied dwelling stock. Assuming that the annual growth rate of dwellings will stay the same until 2025, Table 6 describes the results of dwelling projections based on this indicator.

Table 6 Dynamics of dwelling indicators, 1965 – 2025 (point data)

Indicator	**Units**	**1965**	**1975**	**1985**	**1995**	**2005**	**2015**	**2025**
Population, total	thousand persons	10,140	10,501	10,599	10,330	10,096	9,834	9,588
Persons per dwelling	persons/unit	4.23	3.56	2.93	2.60	2.42	2.24	2.08
Dwellings per population	unit/persons	0.24	0.28	0.34	0.38	0.41	0.45	0.48
Total number of dwellings	thousand dwellings	2,397	2,947	3,614	3,971	4,173	4,396	4,610

4.1.2 Projection of building and cessation dynamics

The projection of cessation of dwellings was based on the historical trends. Figure 9 exemplifies the phenomenon that since 1988 the cessation of dwelling has dropped down to the level when dwellings are exchanged extremely slow. Since it took app. 20 years for the rate of cessation to drop down to such low level, for the purposes of the research, it was assumed that by 2025 the average rate of cessation will reach its typical level estimated as an average during 1951 – 1988. This level of the dwelling turnover was app. 200 years.

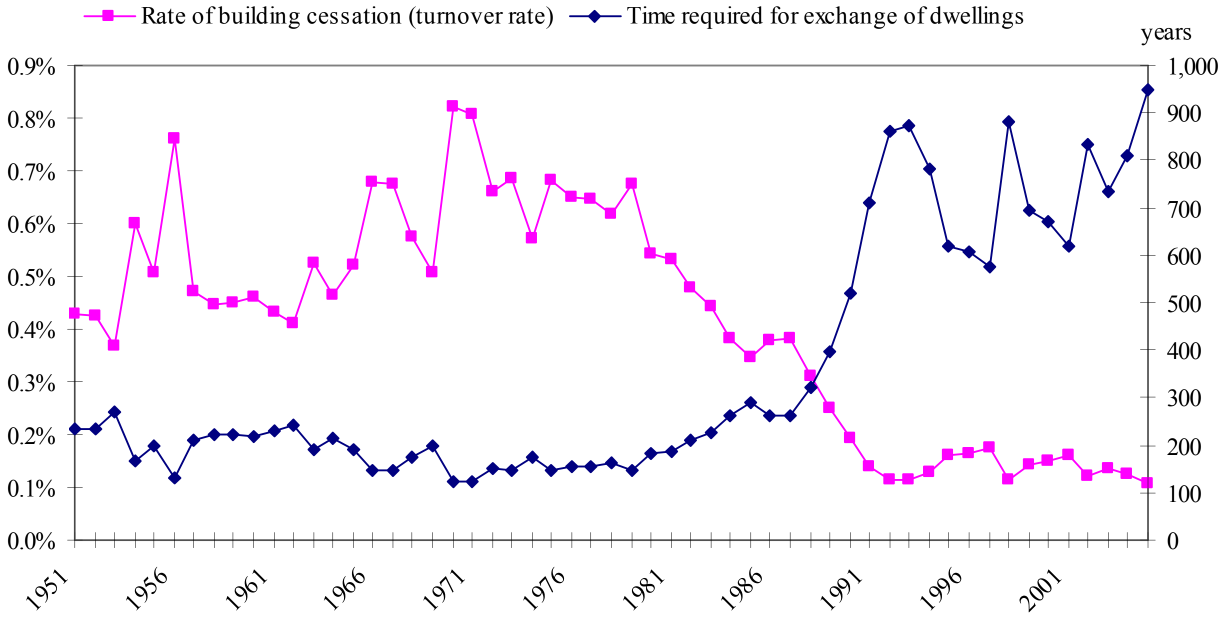


Figure 9 Rate of building cessation and time required for buildings stock for exchange

Source: Constructed based on KSH (2006b)

New built dwellings are calculated as those which are required to cover the gap between the total expected number of dwellings and ceased dwellings. The results of projections are presented in Table 7.

Table 7 Dynamic of built and ceased dwellings

Indicators	**Units**	**1965**	**1975**	**1985**	**1995**	**2005**	**2015**	**2025**
Total number of dwellings	thousand dwellings	2,397	2,947	3,614	3,971	4,173	4,396	4,610
Dwellings built	thousand dwellings/yr.	55	100	73	25	41	29	48
Dwellings ceased	thousand dwellings/yr.	12	20	12	6	4	10	23
Dwelling replacement time[12]	years	192	146	289	618	949	434	198

Source: 1965 – 2005: KSH, 2005; 2015 – 2025 – projections.

The analysis of Table 7 shows that the Hungarian dwelling stock is characterized with an extremely low turnover. As Ball (2005) explains one of the reasons behind is the low level of people mobility. An average person in Hungary changes his/her living place 2.7 times in his/her life as compared to 6 or 7 times in Western Europe. The low level of people mobility slows down the process of moving from housing from “worse” to “better” conditions and badly affects new households (Ball, 2005).

The low rate of dwelling replacement is a warning that the partial or full reconstruction of dwellings is one of the top national priorities. According to Ball (2005) with the reference to the Central Statistical Office, only ¼ of dwellings does not require repair presently. At least one fifth needs full restoration and two fifth requires partial restoration. The rest 13% of dwellings is not economic to reconstruct or repair and must be demolished. The housing quality is illustrated in Figure 10.

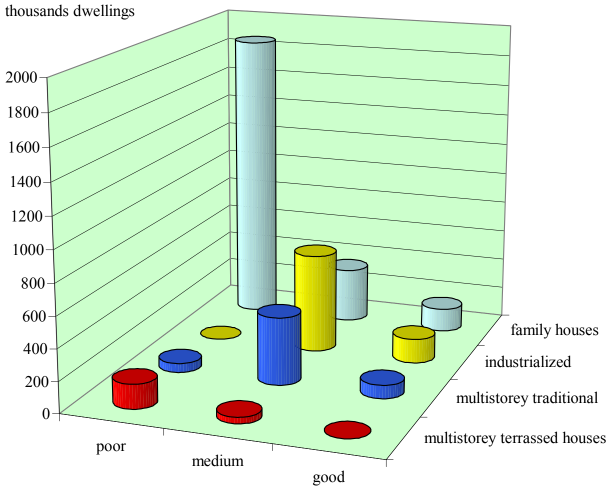


Figure 10 *Distribution of the existing dwelling stock from the point of view of the thermal insulation level in Hungary*[13]

Source: Matolcsy et al., 2005

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[12] Estimated as the reverse of the dwelling cessation rate.

[13] The authors of the figure (Matolcsy et al. (2005)) make the difference between the multi-storey terraced houses and multi-storied traditional houses, but we do not do that in our study.

4.1.3 Projection of the household stock

A large share of the dwelling stock in buildings characterized with poor conditions led to a considerable share of not occupied dwellings. If before 1996, the share of non-occupied dwelling stock was about 4-5%, then starting from 1997 this indicator is about 8% in average. For the future modeling purposes, it was assumed that this share does not go higher and, thus, the share of households (i.e. occupied dwellings) is 92% of the total dwelling number. Despite non-occupied dwellings should be heated to some minimum degree to avoid structural damage of buildings, their energy consumption for space heating is considerably lower than that of occupied households in average. It is reasonable to assume that non-occupied dwellings do not consume energy for other purposes. Due to these reasons, modeling of energy use for all end-uses is based on the number of occupied dwellings (households) rather than on the number of dwellings.

4.2 Building types for thermal energy modeling

For the modeling purposes, the Hungarian household stock was split into five buildings types, which possess different architectural and/or thermal characteristics. These are:

(i) Multi-residential traditional houses built mainly at the end of the 19th century and during the inter-war years
(ii) Multi-residential buildings constructed with the industrialized technology (include panel, block, and cast buildings) built mostly in 1960s – 1980s
(iii) Single family houses in suburban and semi-urban areas built until 1992 (i.e. before the Buildings Standard 1991 was applied)
(iv) Single family houses and multi-residential buildings built during 1993 – 2007
(v) Single family houses and multi-residential buildings which will be constructed after 2008 until the end of projection period, i.e. 2025

The projection of the household stock by types of buildings is based on the estimated dynamics of the total household stock, construction and cessation rates and the data from such sources as Várfalvi and Zöld (1994), KSH (2006a, 2006b). The results are presented in Figure 11 below.

The next sections describe the main types of buildings and their geometric characteristics and provide the projections of installed heating modes. The geometrical characteristics were assumed based on observation of the Hungarian modeling stock, actual metering of selected representative dwellings, and the statistical publication (KSH, 2006b). The projection of heating modes was constructed with references to such sources as KSH (2004, 2005, 2006a, 2006b), NAP (2007), Várfalvi and Zöld (1994), GFK (2004), and ODYSSEE (2007). The main assumptions behind the projections are following:

i) For industrialized buildings the main factor of the changing number of households heated with different solutions is the rate of building cessation
ii) For traditional buildings the dynamics of heating modes is determined by building cessation and by switch from premise gas heating to central dwelling heating. By 2025 premise gas heating will stay in app. 75% of households presently having this type of heating; the lower share is unlikely due to technical limitations, the size of dwellings, and high prices of dwelling central systems

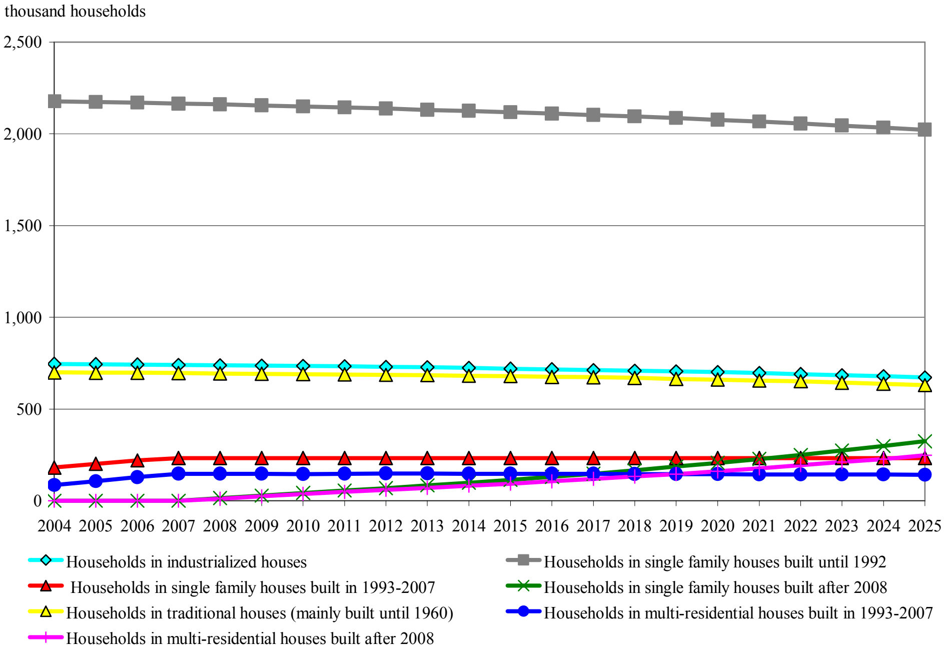

Figure 11 The projected household stock by building types

iii) For family houses built before 1992 oil heating will be removed by 2008 (due to high oil prices), about a half of presently installed premise gas, coal, and biomass systems will be replaced by central dwelling systems fired with the same fuel (i.e. no substitution among fuels). The factor of building cessation is also applicable to removal of old heating systems. It is assumed that new advanced systems are not installed in the BAU scenario (advanced systems presenting in the stock are rather installed in new houses built during 1993 – 2007: from the beginning of 1990s, the new buildings were largely dominated by single family houses constructed according to the individual designs, this gives a thought that probably new home owners have financial resources to purchase new homes with advanced heating systems rather than owners of old houses)

iv) The heating modes in buildings built from 2008 are projected based on the structure of presently being installed heating solutions. Additionally, it is assumed that the growth of the number of pellet systems will be at least 10%/yr.and the growth of the number of solar thermal and pump systems will be about 5%/yr. for each type of these systems[14]. The increased number of all advanced heating systems is allocated to new built household stock

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[14] The assumed growth rates are based on the following consideration. The market review of solar heating (Weiss et al., 2007) estimated the growth rate of the technology penetration in Hungary as app. 5%/yr. before 2004 and this figure was also assumed until 2025 (from app. 6 to 15 thousand households over 2008 - 2025). The heating pumps have a comparable to solar heating penetration rate and investment costs in Hungary; and due to these reasons, it was assumed that the heating pump penetration will grow up with the same rate as the solar heating, 5%/yr. (from app. 4 to 10 thousand households over 2008 - 2025). The pellet heating is a new technology in Hungary (only 2-3 year old) but it has already occupied a twice larger share of the heating solution stock as compared to heating pumps; the stock of pellet heaters is assumed to grow at app. 10%/yr. (from app. 8 to 50 thousand households over 2008 - 2025).

4.2.1 Multi-residential traditional buildings

A significant part of urban multi-residential buildings was constructed within nearly 100 years from the middle of the 19th century to the middle of the 20th century and represents the architectural and historical heritage of the country. Due to historical and aesthetic value of their look, it is hardly possible to conduct an overall reconstruction of these buildings; however, improvement of some parts of the buildings shell is possible (Kovacsics, 2007). Added thermal insulation may change the appearance of the façade of these buildings and, therefore, options to improve the thermal performance of these buildings are focused on other building elements than walls, i.e. improving characteristics of windows and roofs as well as insulation of upper and ground floors (cellar ceilings or basements). The geometrical pattern of modeled traditional buildings is illustrated in Figure 12 and described in Table 8 (based on measurement of a few selected representative Hungarian buildings by the authors and KSH, 2006b).

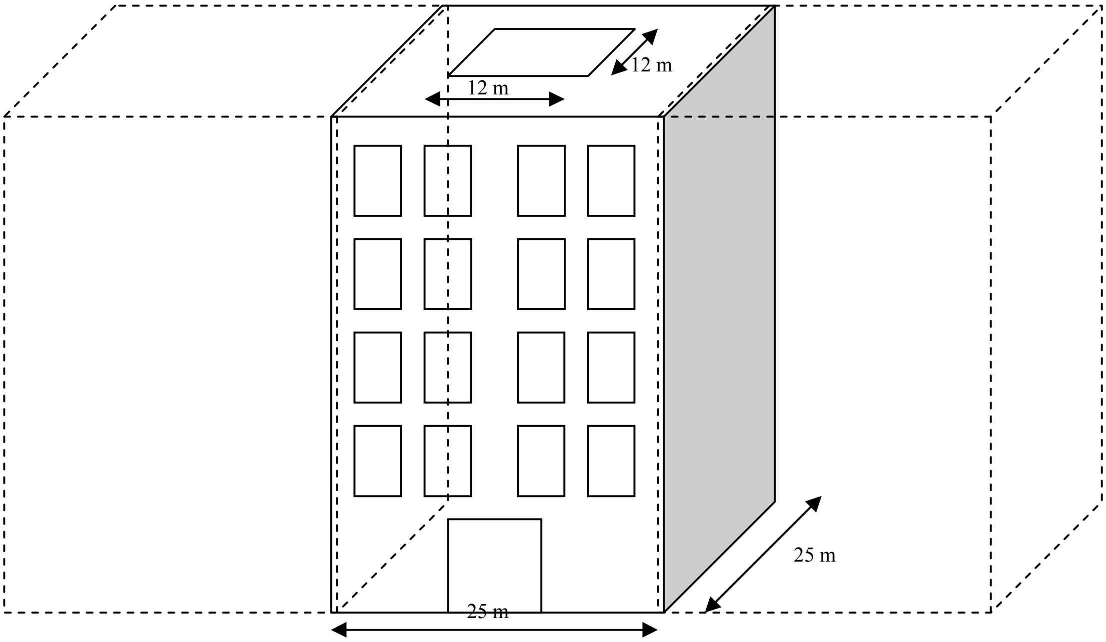

Figure 12 Pattern of traditional building

Table 8 Assumed characteristics of traditional buildings

Component	Meaning	Unit
Number of floors	4	
Number of flats per floor	6	
Wall length, side 1	25	m
Inner wall length, side 1	12	m
Wall length, side 2	25	m
Inner wall length, side 2	12	m
Height of a building	16	m
Floor area per dwelling	70	m2
Windows/terrace/balcony doors (30% of surface)	470	m2
Exit doors of dwellings	48	m2
Heated area if premise heating	35	m2

A part of traditional multi-residential buildings is connected to district heat and district hot water (Várfalvi and Zöld, 1994; KSH 2004, 2005, 2006a, 2006b). This is why, one of the major options is reduction of space and water heating demands through controls. Many of these buildings are located in the urban areas and fuel switch is often not possible due to necessity to transport and store such fuels as biomass. For a small share of buildings having a centralized natural gas boiler, installation of condensing boilers is feasible. However, more than a half of these buildings still have premise heating limited to one or two rooms (Várfalvi and Zöld, 1994; KSH 2004, 2005, 2006a, 2006b). For these households, more efficient centralized dwelling heating systems is an alternative (which, however, will result also in some increase of heating energy demand due to a larger heated area). The projected split of heating modes in households of traditional buildings is presented in Figure 13.

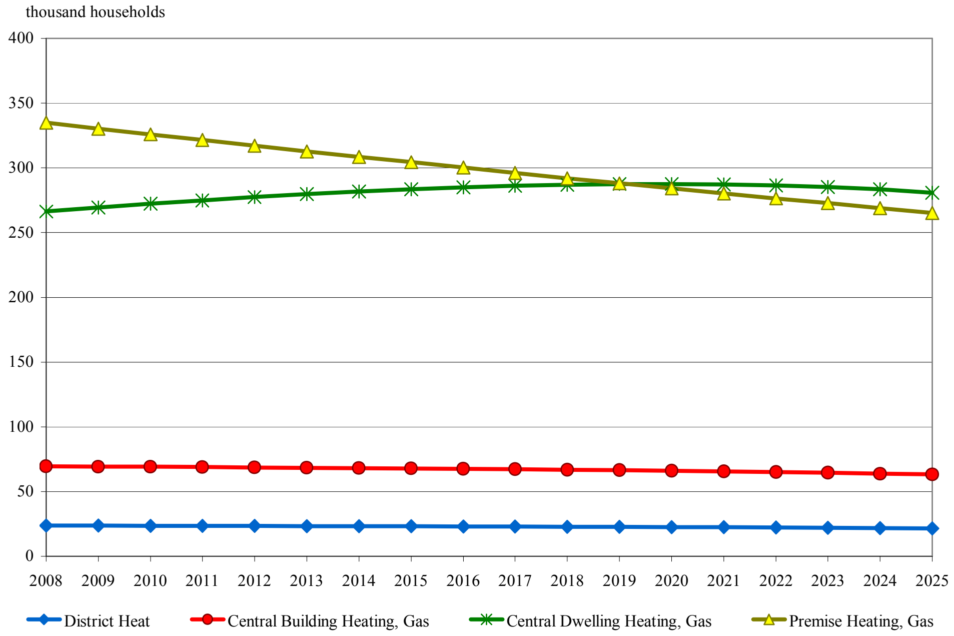

Figure 13 Split of heating modes of households in the traditional buildings

Source: derived based on assumptions and references listed in the beginning of the section 4.2.

4.2.2 Buildings constructed with the industrialized technology

The industrialized large panel and other concrete system building technologies were developed in Western Europe in the decades after the World War II. After 1960s, they were applied to the majority of buildings in Europe and in the former Soviet Union. Western Europe quickly realized disadvantages of panel buildings while in CEE and FSU regions continued using it until approximately 1990. The category of buildings made with the industrialized technology contain the so called "panel buildings", but also those living-houses, which were built by other type of industrialized technology (e.g. block-, cast-, tunnel-shuttered-, ferro-concrete skeleton-houses). All these type of buildings are often referred as "panel buildings" as they consist of about ¾ of the total industrialized buildings (Csoknyai, 2005).

Panel-rehabilitation is one of the most acute questions of the CEE region because the expected lifetime of the holding structures are still above 50-100 years whereas the windows, building finishes and building service systems have reached the end of their physical lifetime (for instance the lifetime of windows, doors and insulation materials is typically about 30 years) (Csoknyai, 2005). The panel buildings are criticized for their high heating energy consumption, uncontrollable heating systems, very poor thermal comfort especially in summer, low acoustic value, untight building envelope and building physical problems. Depreciation of panel buildings stock causes also social problems by moving in of inhabitants who can afford to live only in flats with poor conditions leading to creation of "poverty islands" (Nagy, 2007). This problem results in a vicious cycle as a growing concentration of low income people in deteriorating housing will result in lower ability of these people to invest in renovation of their housing conditions. It is hardly possible to dissolve the concentration of poverty in such houses, therefore, this problem would be better to solve before an exchange of inhabitants.

This large stock of deteriorating panel buildings requires mass modernization. At the same time, the advantage of such buildings is that they can go through a very similar complex renovation of the building shell. In contrast to the traditional buildings, renovation of the industrialized buildings can embrace all building components. The example of SOLANOVA project (Hermelink, 2005; SOLANOVA, 2007) shows that very significant energy savings are possible in the panel buildings with significant co-benefits for its inhabitants. Zöld and Csoknyai (2005) highlight the importance of retrofitting the walls of panel buildings due to high thermal bridges between the joints of construction panels. The building geometry of industrialized technology buildings is described in Figure 14 and in Table 9 below (based on measurement of a few selected representative Hungarian buildings by the authors and KSH, 2006b).

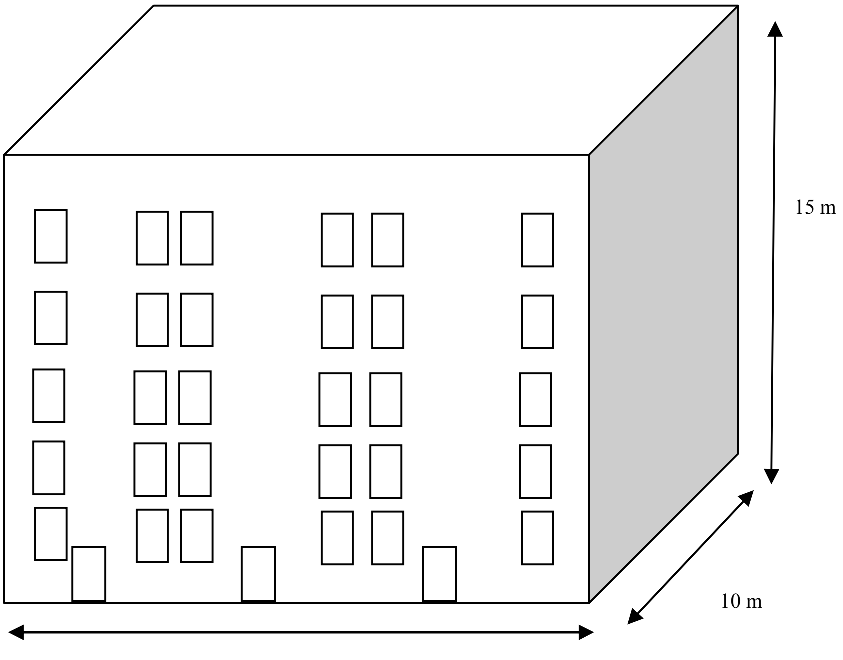

Figure 14 Pattern of buildings built with the industrialized technology

Table 9 Assumed characteristics of buildings built with the industrialized technology

Component	Meaning	Unit
Number of floors	5	
Flats per floor	3	
Number of porches	3	
Wall length, side 1	10	m
Wall length, side 2	50	m
Height of a building	15	m
Floor area per dwelling	53	m2
Area of windows/terrace/balcony doors (20% of wall surface)	360	m2
Exit doors of dwellings	90	m2

Similar to traditional buildings, the majority of industrialized buildings are connected to district heat and district hot water while the rest of the buildings are linked with central building boilers (Várfalvi and Zöld, 1994; KSH 2004, 2005, 2006a, 2006b). This is why, retrofit options of the panel buildings are similar to those identified for traditional buildings, i.e. reduction of space and water heating demand with installation of controls and individual meters, and installation of better efficiency centralized central building boilers. The projected number of households in the panel buildings heated with different heating solutions is presented in Figure 15.

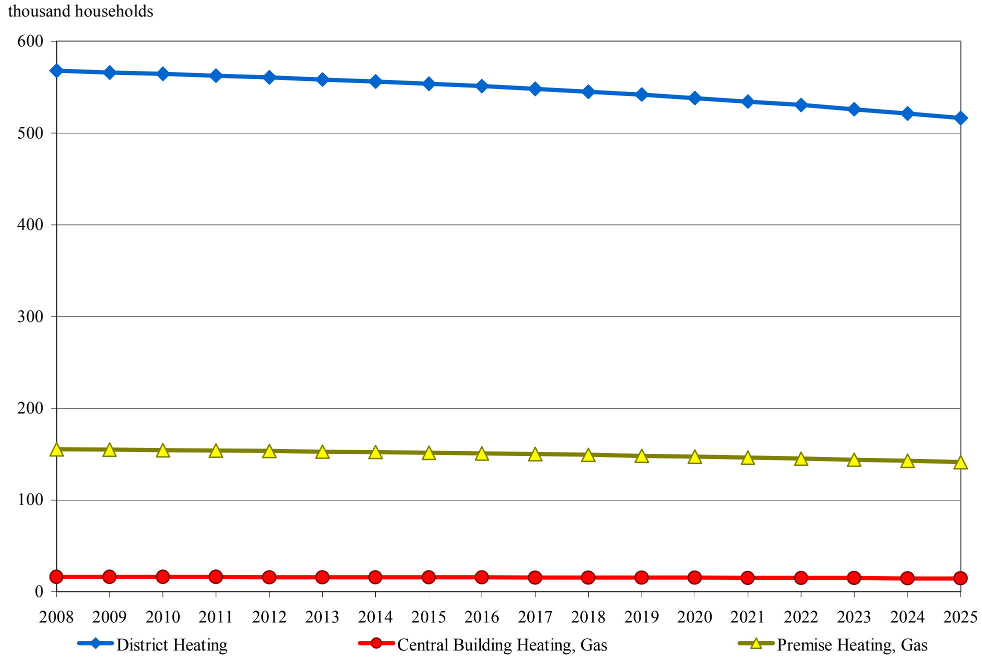

Figure 15 Split of heating modes in households in the buildings constructed with the industrialized technology

Source: derived based on assumptions and references listed in the beginning of the section 4.2.

4.2.3 Single-family houses built until 1992

Single-family houses dominate the Hungarian households representing about 70% of their total number (Várfalvi and Zöld, 1994; KSH 2004, 2005, 2006a, 2006b). The main advantage of single-family houses for our study is that almost each type of measures is available for them (Kovacsics, 2007). Due to the large cooling surface, the complex reconstruction or improvement of insulation levels of walls, roofs and basements are very attractive. The geometrical pattern of a typical Hungarian single-family house built before 1992 is illustrated in Figure 16 and described in Table 10 (based on measurement of a few selected representative Hungarian buildings by the authors and KSH, 2006b).

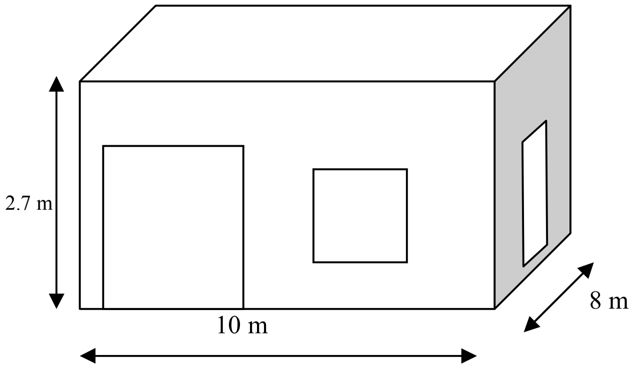

Figure 16 Pattern of a single-family house built before 1992

Table 10 Assumed characteristics of single-family houses

Component	**Meaning**	**Unit**
Wall length, side 1	8	m
Wall length, side 2	10	m
Height of a house	2.7	m
Gross floor area	80	m2
Windows and balcony doors (20% of wall surface)	19	m2
Exit door	2	m2
Heated area if premise heating	40	m2

The majority of single-family houses are located out of the city centers and there is no limitation of transportation and storage of fuels. Thus, switch to biomass, for which the transportation and storage factor is important, is very attractive for these types of buildings. This option is especially important for climate mitigation policies if it is a complement for the solar thermal space and water heating systems. Since single-family houses usually have some space around their house, installation of ground, water, geothermal, or air pumps for space and water heating is also feasible. If both options are not welcomed by households for any reasons, the vast majority of households, 94%[15] (KSH, 2004), are gas-connected and, this is why, installation of high efficiency (condensing) gas boilers is almost always possible for them. Especially, substitution of highly polluting coal premise and central dwelling heating systems is important. The projected number of single-family houses heated with different heating solutions is presented in Figure 17.

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[15] As of 2004.

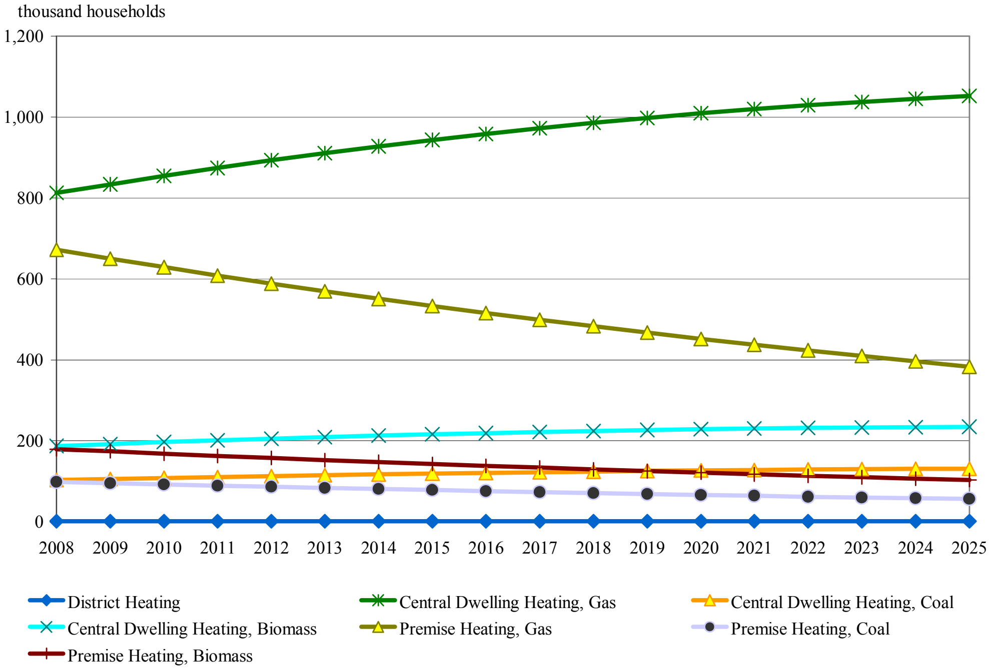

Figure 17 Split of heating modes in households in single family houses built before 1992

Source: derived based on assumptions and references listed in the beginning of the section 4.2.

4.2.4 Single-family houses and multi-residential buildings built during 1993 – 2007

The buildings constructed during the last 15 years are already up to the moderate standards. They are not the best in terms of performance, but extra insulation will not pay back as quickly as in other types of buildings. Systems are mostly either gas-fired or connected to central/district heating and not too much improvement is possible (Kovacsics, 2007). This is why, improvement of the thermal envelope and heating efficiencies of single family houses and multi-residential buildings built during 1993 – 2007 is not considered by the model and detailed consideration of patterns and characteristics of these buildings is out of the scope of the present research.

4.2.5 Single family houses and multi-residential buildings built after 2008

The new building will be designed according to the 2006 Building Code (unless revised), which is more advanced as compared to the previous the Building Standards, however, there are still good opportunities for further heating requirement reduction. This opens the window for application of low (integrated) energy design to future homes.

The projected split of heating modes in the buildings constructed in 2008 – 2025 is presented in Figure 18. Among the building geometry characteristics, those important for modeling are the floor area of family houses and flats in multi-residential buildings which are estimated as 105 m^2 and 57 m^2 respectively (KSH, 2006b).

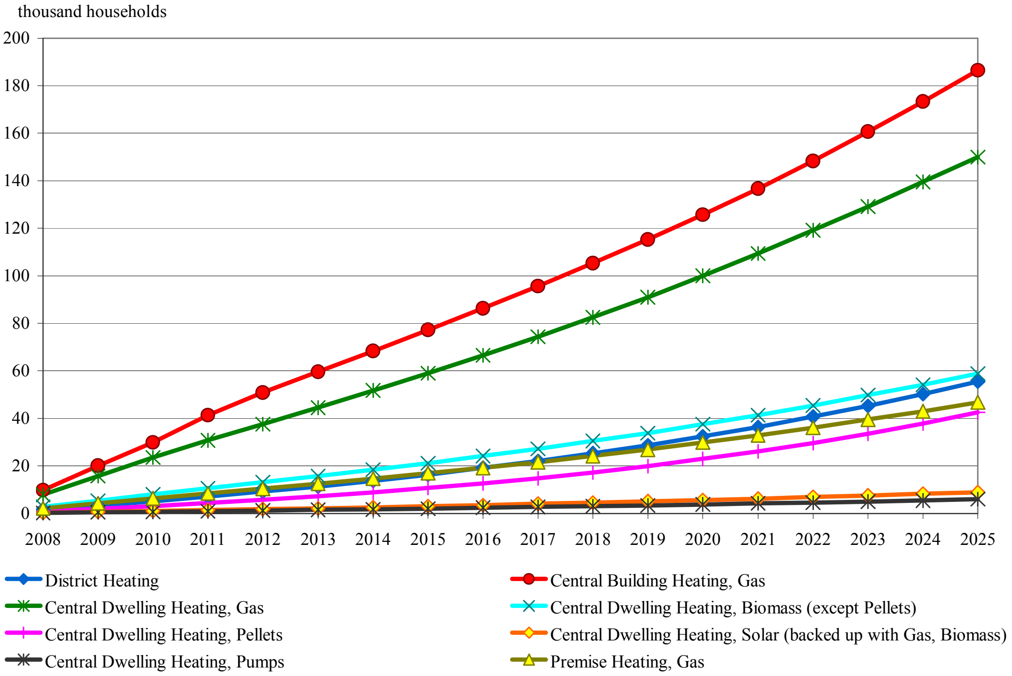

Figure 18 Split of heating modes of households in the buildings constructed during 2008 – 2025

Source: derived based on assumptions and references listed in the beginning of the section 4.2.

4.2.6 Properties of the thermal envelope and household heating requirement for different building types

The heating energy requirements of households located in different types of buildings are identified based on the interviews with T. Csoknyai (2007), I. Kovacsics (2007), Gy. Sigmond (2007), F. Kocsis and A. Beleczki (2007) and presented in Table 11.

Table 11 Energy heating requirement for space hating in different building types

Types of buildings	**Type of heating**	**Energy heating requirement, kWh/m2**
Single-family houses built before 1992	Central dwelling	180
	Premise	250
Traditional houses	Central dwelling	150
	Premise	200
Industrialized technology buildings	Central dwelling	166
	Premise	233
Buildings built after 2008	Central dwelling	105
	Premise	147

Thermal properties of the building components of different types of buildings (Table 12) were estimated based on the interview with T. Csoknyai (2007) and the range of publications (Petersdorff et al., 2005; Csoknyai, T. 2004, 2005; Várfalvi and Zöld, 1994; Harvey, 2006).

Table 12 Assumed present U-value, W/m^{2}K

Parameter	Family houses built before 1992	Traditional houses	Industrialized technology buildings
External wall	1.65	1.65	2.00
Roof surface	0.99	0.99	0.77
Cellar surface	1.32	1.32	0.99
External windows	3.50	3.50	3.50
Door	2.60	2.60	2.60

5 BASELINE AND MITIGATION OPTIONS: THERMAL MODERNIZATION

Levine et al. (2007) concluded that the key energy and CO_2 efficiency strategy for buildings is in, above all, reducing energy loads and selecting systems with the most effective use of ambient energy sources and heat sinks followed by using of efficient equipment and effective controls. The present research inherits these principles and starts the analysis of CO_2 mitigation opportunities from considering options for minimization of the demand for space and water heating through thermal insulation. Then, the renewable energy sources for space and water heating are assessed. The review of efficient fossil-fired and heating controls finishes the discussion on thermal modernization.

5.1 Thermal energy consumption in the residential sector

The residential sector emitted about 29% of direct CO_2 emissions[16] in 2004 that was slightly lower than emissions of the transportation sector having the lead (Figure 19). The residential direct emissions are mainly associated with combustion of fossil fuels for space and water heating and for cooking.

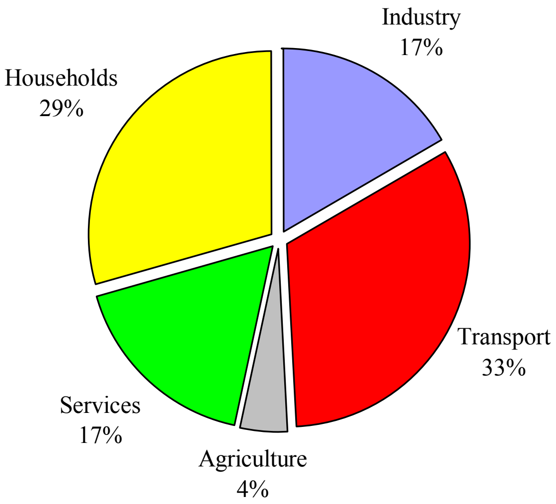

Figure 19 Break-down of direct CO_2 emissions by final energy users in Hungary in 2004

Source: ODYSSEE (2007)

The World Energy, Technology and Climate Policy Outlook 2030 (Directorate-General for Research Energy, 2003) expects that the thermal energy use per household will decrease in the EU in the long-term future. However, despite this trend, the authors think that space and water heating will stay the largest consumer of final energy in the residential sector of Hungary in two forthcoming decades.

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[16] I.e. emissions from combustion of oil, gas, and coal

5.2 Options for improvement of the thermal envelope

The thermal envelope refers to the shell of the building as a barrier to the loss of interior heat (Harvey, 2006). Insulation of thermal envelope which refers to walls, windows, doors, roofs, and basements can significantly reduce the energy demand for space heating.

5.2.1 The business-as-usual scenario

The input parameters of modeling thermal insulation were identified with the help of the recent study on thermal insulation and selected heating options conducted by EURIMA/ECOFYS (Petersdorff et al., 2005). The study describes the main insulation techniques applied in the CEE region, thermal properties of insulation materials, and the investment costs associated with application of thermal insulation. The BAU rate of annual retrofit of the household stock was assumed on the level of this indicator during 2003 – 2004 based on KSH (2005). For the mitigation scenario, it was assumed that all household stock, which will not be retrofitted in the BAU scenario and which stay at least until 2025, is retrofitted during 2008 - 2025 by equal portions per annum.

The section also considers application of the passive energy design for the household stock to be constructed during 2008 - 2025. For these types of households, the baseline scenario assumes that these dwellings have the same energy requirement as the dwellings built presently, i.e. 100-110 kWh/m^2 (Kocsis and Beleczki, 2007). The costs of construction for the BAU case were estimated based on the Yearbook of housing statistics of Hungary (KSH, 2006b) and communication with experts (Kocsis and Beleczki, 2007) as app. 700 EUR/m^2.

5.2.2 External wall insulation

According to Petersdroff et al. (2005), the most common method for external insulation in the CEE region is attaching the insulation material to the outer surface of external walls. This is typically realized through attaching the insulation material to the wall and coated by a final layer. The capital and installation costs of insulation options are estimated as the average prices representing the mix of the most representative insulation materials usually used in retrofit projects in the CEE region (i.e. this statement also refers to cellar/basement and rooftop insulation). The main assumptions for technical and financial analysis of wall insulation are presented in Table 13.

Table 13 Technical and financial parameters of external wall insulation

Types of dwellings	**U-values before retrofit in 2007**	**U-values after retrofit**	**Investment costs**	**Retrofit rate, BAU**	**Retrofit rate in the mitigation scenario**
	W/m^{2}K	W/m^{2}K	EUR/m^2 of insulated area	Share of household stock	Dwelling number
Family houses built before 1992	1.65	0.35	45	1%	Dwellings not retrofitted in BAU which stay in 2025 are retrofitted by equal portions
Traditional houses	Not assessed	Not assessed	45	1%	
Industrialized buildings	2.00	0.35	51	1%	

Source: estimated based on Csoknyai, 2004, 2005, 2007; Várfalvi and Zöld, 1994; Petersdorff et al., 2005; and KSH reports.

5.2.3 Cellar/ground floor insulation

The method of insulating the ground floor depends on whether a building/house has a cellar. In buildings with a cellar, the insulation can be applied under the cellar ceiling or, with more complex technical implications, on top of the ground floor. The main assumptions for technical and financial analysis of the measure are presented in Table 14.

Table 14 Technical and financial parameters of cellar surface insulation

Types of dwellings	**U-values before retrofit in 2007**	**U-values after retrofit**	**Investment costs**	**Retrofit rate, BAU**	**Retrofit rate in the mitigation scenario**
	W/m^2K	W/m^2K	EUR/m^2 of insulated area	Share of household stock	Dwelling number
Family houses built before 1992	1.32	0.46	18	1%	Dwellings not retrofitted in BAU which stay in 2025 are retrofitted by equal portions
Traditional houses	1.32	0.46	18	1%	
Industrialized buildings	0.99	0.46	18	1%	

Source: estimated based on Csoknyai, 2004, 2005, 2007; Várfalvi and Zöld, 1994; Petersdorff et al., 2005; and KSH reports.

5.2.4 Roof insulation

For the analysis of roof insulation, it was assumed that the insulation is applied to the exterior surface of the roof and is covered by a waterproof layer. The main assumptions for technical and financial analysis of roof insulation are presented in Table 15.

Table 15 Technical and financial parameters of roof surface insulation

Types of dwellings	**U-values before retrofit in 2007**	**U-values after retrofit**	**Investment costs**	**Retrofit rate, BAU**	**Retrofit rate in the mitigation scenario**
	W/m^2K	W/m^2K	EUR/m^2 of insulated area	Share of household stock	Dwelling number
Family houses built before 1992	0.99	0.23	27	1%	Dwellings not retrofitted in BAU which stay in 2025 are retrofitted by equal portions
Traditional houses	0.99	0.23	27	1%	
Industrialized buildings	0.77	0.23	27	1%	

Source: estimated based on Csoknyai, 2004, 2005, 2007; Várfalvi and Zöld, 1994; Petersdorff et al., 2005; and KSH reports.

5.2.5 Exchange of windows and balcony doors

The heat flow through a window depends on conduction of heat through glass, through air between panels, through the frame and spaces between panels, transmission of solar radiation, and other factors (Harvey, 2006). Nowadays, a broad range of window technologies can save up to 65-75% of the heat loss of standard non-coated double-glazed windows (Levine et al., 2007). This includes using of multiple glazing layers, low-conductivity gases between glazing layers, low-emissivity (low-E) coatings on one or more glazing surfaces, and use of framing materials with very low conductivity.

Windows installed in Hungary before 1990s are characterized with the average U-value of 3.5 W/m^{2}K whereas the presently installed double-glazed windows have this value of 1.3-1.5 W/m^{2}K. Gas-filled windows having a 3 layer glass with the heat transmission as low as 0.9-1.0 W/m^{2}K are available on the Hungarian market. Capital investments to a window exchange start at 100 EUR/m^2 for a typical window and goes up to app. 160 EUR/m^2 for an advanced window. Low-E windows (with the U-value lower 0.7 W/m^{2}K) also present on the Hungarian market with the investment costs above 300 EUR/m^2. Such high installation costs are explained by not mature market of low-E windows: even though low-E windows have existed for more than a decade, their market should be stimulated to gain the size when the competition will decrease the product prices. As for now, low-E windows are not considered by the model. The technical and financial characteristics of a window exchange are described in Table 16.

Table 16 Technical and financial parameters of window and balcony door exchange

Types of dwellings	**U-values before retrofit in 2007**	**U-values after retrofit**	**Investment costs**	**Retrofit rate, BAU**	**Retrofit rate in the mitigation scenario**
	W/m^{2}K	W/m^{2}K	EUR/m^2 of a window	Share of household stock	Dwelling number
Family houses built before 1992	3.50	0.95	190	1%	Dwellings not retrofitted in BAU which stay in 2025 are retrofitted by equal portions
Traditional houses	3.50	0.95	190	1%	
Industrialized buildings	3.50	0.95	190	1%	

Source: estimated based on Csoknyai, 2004, 2005, 2007; Várfalvi and Zöld, 1994; Duplo-Duplex (2007); and KSH reports.

5.2.6 Exchange of exit doors

Wood and glass doors, often used in Hungary, are aesthetical, but have a little insulation value, and, thus, need replacement. A typical 6cm think wood slab has a U-value of 2.6 W/m^{2}K according to Harvey (2006). Similarly to windows, there are very efficient door technologies on the market. For instance, an insulated steel slab in a wood frame has U-value of about 1.0 W/m^{2}K. Typically, households install new doors in Hungary while exchanging windows to keep common design or for safety reasons. Safety doors represent a multi-beneficial solution because besides safety characteristics they have better thermal properties due to thickness or material characteristics. For modeling purposes, the thermal and cost characteristics of efficient doors were estimated based on several production catalogues. These characteristics are presented in

Table 17.

Table 17 Technical and financial parameters of exit door exchange

Types of dwellings	U-values before retrofit in 2007	U-values after retrofit	Investment costs	Retrofit rate, BAU	Retrofit rate in the mitigation scenario
	W/m^{2}K	W/m^{2}K	EUR/m^2 of a door	Share of household stock	Dwelling number
Family houses built before 1992	2.60	0.9	540	1%	Dwellings not retrofitted in BAU which stay in 2025 are retrofitted by equal portions
Traditional houses	2.60	0.9	540	1%	
Industrialized buildings	2.60	0.9	540	1%	

Source: estimated based on Harvey, 2006; Novoferm, 2007; GIL-TRADE, 2007; Gavron, 2007; and KSH reports.

5.2.7 Application of the passive energy design

Construction of buildings according to the passive energy principle, which aims to use at maximum the passive energy emitted by the sun, people, and appliances, can generate savings up to 90% of conventional design (Barta, 2006). The passive energy design considers southern orientation, strong insulation of building components (U-value no more than 0.15 W/m^{2}K) and low-E windows, reduced air leakage and other features. Despite the common believe about expensiveness of low energy houses, in reality they could cost not much more than the conventional design buildings. Since, the passive energy design is still a very new technology on the Hungarian market; the construction costs of such buildings are up to app. 1150 EUR/m^2 versus app. 700 EUR/m^2 for conventional building. However, as the experience of more mature market shows that the costs of passive energy and conventional do not differ significantly. For instance, Trnka (2007) estimated that the construction costs of passive energy housing in Austria are only 8% higher than those of the conventional design buildings, even though the incremental costs could range from 0 to 337 EUR/ m^2.

In the mitigation scenario, it was assumed that the new-built from 2008 dwelling is designed according to the passive energy principles. The potential to avoid CO_2 emissions was estimated if the energy heating requirement would become as low as 15 kWh/m^2 and the costs of passive energy construction would be app. as 750 EUR/m^2 (i.e. approximately 8% higher than the conventional design taking the Austrian experience as a benchmark).

5.3 Options targeted to space heating efficiency and fuel switch

A number of high efficiency and low carbon options are available for space heating (see Figure 20). Envelope measures combined with optimization of passive solar heating opportunities and other efficiency options are able to reduce heating levels from 250-400 kWh/m^2-yr. to less than 15 kWh/m^2-yr. in existing buildings of the CEE region (Levine et al., 2007).

Figure 20 Technologies for efficiency in domestic heating

Source: Schild, 2006

In Hungary space heating is generally provided by district heating systems, central block (building) heating system, dwelling central heating systems, and premise heating systems. The best strategy is to maximize the use of heat supplied by renewable energy sources. Otherwise, high efficiency fossil technologies minimizing energy losses during production and distribution of heat could be used. Each of advanced options has technical limitations on installation however, almost for any type of households there is at least one advanced heating solution.

5.3.1 The business-as-usual scenario

The heating solutions installed in the baseline scenario for studied building types are district heat, central block (building) heat, central dwelling and premise gas and coal heating. The presently installed efficiencies for space heating systems are estimated based on interviews with experts (Kovacsics, 2007; Csoknyai, 2007). These are 65% for premise and central dwelling non-gas conventional heating, 85% for premise and central dwelling gas heaters, and 80% for central building gas heaters. Efficiencies of all heating systems installed in the BAU scenario except district heating are 85% (estimated based on Petersdorff et al., 2005; Mega-öko Kazánfejlesztő-gyártó Kft., 2007). Modeling of the BAU efficiency of supplied district heat (at the building entrance) is described in section 3.8.1. It increases from 78.2% in 2008 to 87.4% in 2025. The distribution losses of district and central heat inside the multi-residential buildings are estimated to decrease from 6.6% in 2008 to 5% in 2025.

Investment costs are estimated as app.:

- EUR 1250/flat for a new standard gas dwelling central boiler
- EUR 1500/household for a new gas-fired central dwelling boiler with instantaneous water heating
- EUR 3500/household for a new biomass central dwelling boiler with storage water heating

- EUR 1050/household for a new coal central dwelling boiler
- EUR 7900/building for a new standard gas central boiler for multi-residential buildings

In the case when a household switches from a direct heater or premise heating to central dwelling heating, additional costs for installation of radiators are allocated as app. EUR 500/flat in multi-residential buildings and app. EUR 700/house in family houses (the difference is due to the larger number of radiators in family houses as compared to flats in multi-residential buildings).

5.3.2 Biomass for heating: pellets

Hungary is generously endowed with biomass resources which can be utilized for heating purposes. The bad news is, however, that the EU Renewable Directive focuses on only renewable electricity leaving aside the support for renewable heat. In the beginning of 2000-es the biomass-waste use for heating purposes jumped to app. 8% of the total final energy of the residential sector, however, it does not grow up higher (KSH, 2006c). At the same time, it is wiser to utilize biomass for heat rather than for electricity production (Kovacsics, 2007). Efficiency of biomass burners for power production is about 30% while for heat production it is about 90%. Utilizing biomass for heat would save more gas for electricity production which efficiency is at least 40%.

Biomass burners include burners fired with pellets, wood chips, woodcuts, corn, and with vegetable parts. Among these, agripellets from residuals of agricultural products can win a big niche in Hungary. Pellets from energy grass/crops are especially important because they can be a sound substitution for agricultural production. The potential for production of these two types of pellets is very significant (see Table 18). Some agripellets have a higher heating value and a lower price as compared to those of woodpellets (DBO, 2007). Another advantage of agripellet production is a possibility to produce the raw material for agripellets on annual basis, while there is at least 15 years needed for reproduction of a tree to produce woodpellets and woodcuts. Presently, woodpellets are not produced in Hungary. They are imported from the factories settled mainly in Transylvania, Slovakia, Poland and the Czech Republic and in a lesser extend in Austria and Italy. There is a Hungarian firm that produces agripellets from the mixture of domestic raw material: straw, reed, and oily plants (DBO, 2007).

Domestic pellet boilers were introduced in Austria in 1994 and have rapidly grown in popularity. Pellet burners appeared on the Hungarian market only two or three years ago (DBO, 2007). The demand for them is growing but it is constrained with the high capital costs of burners. The price of a pellet burner capable to heat an average Hungarian family house (20-40W) runs from app. EUR 1500 to 8000 exclusive of VAT (DBO, 2007). The costs of the additional equipment, a hot water-tank and the installation costs are not included into these prices. The high prices are due to the dominance of imported expensive equipment (mainly from Austria, Germany, Slovakia, Czech Republic, Poland and Italy) and low competition on the domestic market (DBO, 2007). The Hungarian market has a great potential for production of pellet-burners, but more incentives and measures are needed to help the market grow.

Table 18 Biomass utilization potential and volumes in Hungary

N	Biomass type	Quantity of biomass, thousand tons/yr.	Energy potential, PJ/yr.
1	Straw	2400 – 2800	28 – 34
2	Corn-stalk	4000 – 5000	48 – 60
3	Crape-cane, fruiter scobs	350 – 400	5 – 6
4	Energy grass	500 – 600	6 – 7
5	Energy crops	1200 – 1800	25 – 30
6	Biogas substrat	8000 – 10000	7 – 9
7	Rape for biodiesel	220 – 250	3.5 – 3.8
8	Corn for bioethanol	2000 - 3000	24 – 27

Source: Gőrös (2005) in ACCESS (2007)

One of disadvantages of biomass for heat is a need for a large storage for biomass (2-7 tons for an average single family house). Also it is difficult to transport biomass to central districts of cities due to heavy traffic and local air pollution issues. This is why biomass heat is difficult to apply for multi-family buildings and family houses in the city center area. The best perspectives for renewable heat relate to heating of family houses located out of the city centers. Due to this reason, for modeling purposes it was assumed that only a half of family houses can switch from the BAU technologies to biomass heating until 2025. Based on the review of the pellet market (DBO, 2007) and the production catalogues (Szalontai and Sonnencraft, 2007) the investment costs of pellet burners were estimated as app. EUR 9145/system with efficiency of 92%. Since the pellet boilers supply both space heating and hot water, the investment costs allocated to space heating are as app. EUR 8410/system (see section 3.9.11).

5.3.3 Solar thermal energy

The use of solar collectors for space and water heating is a mature alternative to conventional technologies. The vast majority of installed solar systems in Hungary are “combi” systems producing hot water and space heating (Weiss et al., 2007). Solar systems sold in Hungary are designed to cover up to 80% of hot water demand and up to 30% of space heating demand of an average family house (see catalogues of Szalontai and Sonnencraft, 2007). This is why, a solar combi- system needs a conventional back-up system (a fossil-fuel boiler, heat pumps, or a wood boiler) which covers the rest of the heating requirement. Biomass heating systems can provide a zero carbon complement to solar heating systems. This is why, solar systems backed-up with biomass were assessed in the research.

Analogously to biomass for heating purposes, it was assumed that only a half of family houses can switch from the BAU technologies to solar backed-up with pellet boilers until 2025. The capital and installation costs into a solar system including the back-up pellet system is estimated as EUR 16300 (Szalontai and Sonnencraft, 2007). The efficiency of a pellet system is 92% while for solar it is 100% (i.e. no heat production and distribution losses). The ability to cover space and water heating demand from solar energy is 30% for space heating and 80% for water heating. Since the solar systems supply both space heating and hot water, the investment costs allocated to space heating are estimates as app. EUR 15000/system (see section 3.9.11).

5.3.4 Heating pumps

Heat pumps can turn the direction of heat from a lower to a higher temperature using a relatively small amount of energy. Thus, electric heat pumps for heating buildings can supply 100 kWh of heat with app. 20-40 kWh of electricity (EURELECTRIC, 2004). The heat sources can be the air, ground or water, as well as industrial or domestic wastes. Adam (2007) highlights an importance of installation of geothermal heat pumps in Hungary. Theoretically, heat pumps can be installed at any building but practically, there are some technical constrains such as a possibility to drill the ground near the building and space needed for the loop for ground or water pumps and others. This is why, a heating pump is a good opportunity for family houses, but probably not for multi-residential buildings. Taking mentioned above constrains, it was assumed that it is possible to install heating pumps in app. 50% of family houses.

The bad news, however, is that the heat pumps are very expensive to install in Hungary. Almost all heat pump systems are imported, mainly from Germany. This is why, this opportunity is very difficult to realize for an average Hungarian household. The average investment costs into the ground heat pump were estimated as EUR 12900/system (EHPA, 2007), of which app. EUR 11865/system are allocated to space heating (see section 3.9.11). The coefficient of performance (ratio between the heat produced and supplied work) is 3.0.

5.3.5 Condensing gas boilers

In both gas boilers and gas furnaces for space heating, efficiencies higher than 88% require the condensing operation (Harvey, 2006). A condensing boiler is designed in a way to recover more waste heat, particularly the heat from water vapour produced during the combustion of fossil fuels. Despite their evident advantages over standard gas boilers, condensing boilers have a very low share on the market of Central Europe (Petersdorff et al., 2005). Installation of gas-fired heating systems is the most popular solution in Hungary and, this is why, stimulating sales of high efficiency condensing boilers will contribute to improved overall heating efficiency and, thus, reduction of CO_2 emissions.

For modeling purposes, two types of condensing gas boilers were considered. First, condensing boilers were suggested to substitute standard gas boilers for central building heating in multi-residential traditional and industrialized buildings according to the equipment stock turnover rate. Second, condensing boilers were modeled for substitution of standard gas boilers for dwelling central heating in traditional buildings and family houses.

According to Petersdorff et al. (2005), the investment costs of a condensing central building boiler for space heating with efficiency of 97% were estimated as 9950 EUR/system. Additionally 500 EUR/household were allocated for installation of larger radiators[17]. Based on production catalogues (Saunier Duval, 2007) the investment costs of a 97%-efficiency condensing gas boiler for central dwelling heating in flats were estimated as app. 1570 EUR/system, additionally 500 EUR/flat is allocated for larger radiators. Based on the same

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[17] Radiators linked condensing gas boilers should be larger than those linked to conventional gas boilers because the temperature of circulated water in condensing system is lower.

source the investment costs of a condensing gas boiler for central dwelling heating and for instantaneous water heating for a single family house with 97% boiler efficiency is estimated as app. 1860 EUR/system, analogously app. 700 EUR/house is allocated for installation of radiators. About 2350 EUR/house is located to space heating and the rest to water heating (see section 3.9.11).

5.4 Heating controls and meters

Harvey (2006) estimated that improved controls could reduce energy costs by over 20% for space heating. As regarding to particularly the CEE region, Živkovi et al. (2006) described the experiment of installation of heat flow meters and space heating controls in Serbian standard panel buildings connected to district heat. The households of these buildings paid the same fixed tariff for space heating (based on the flat size) before and after installation of heat meters and controls. They were not stimulated financially and only adjusted the heating loads according to their comfort levels. Even though the buildings had relatively good insulation levels (U-values of 0.7-0.9 W/m^{2}K), the experiment showed a reduction in demand for heating energy for 10.5% - 15% depending on the building and the heating season.

5.4.1 The business-as-usual scenario

Typically heating controls and individual heat meters are installed in new homes with up-to the market heating systems and they are not installed in dwellings of old houses. This is why, the BAU scenario assumes zero penetration rates for heating controls and individual heat meters in existing buildings built before 1990s.

5.4.2 Individual heat metering

The household stock connected to district heating is the largest consumer of heat in Hungary (see Figure 21 below). This is not only due to the high energy heating requirement of the buildings built with the industrialized technology (which constitute the largest share of buildings connected to district heat) but also due to the lack of possibility to regulate the wanted heating levels and due to the lack of possibility to pay according to the actual heat consumed[18].

Installation of separate heat exchangers and heat meters to individual flats allows households regulating their heat consumption according to the comfort level and according to their ability to pay. This is a quite expensive option which requires rearrangement of the hot water pipe system within the building, installation of some new pipes, individual heat exchangers and heat meters. Based on the interview with experts (Sigmond, 2007), the estimated useful energy savings could be as high as 20% whereas the total investments are up to 2000 EUR/household. The estimate of useful energy demand savings is based on consideration of who typically inhabits the district heated flats. These are usually young families for whom the purchase of social housing in

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[18] Typically, the heat consumed by a multi-residential building is metered at the entrance of the building and associated costs are distributed among households according to dwelling floor area. Half of the costs of district heat consumed by the building is fixed (capacity costs) and half of them varies depending on the heat consumption of a building.

prefabricated building is an affordable option or elderly people who received such flats some 20-30 years ago. In both cases, households relate to the low or middle income class and are, therefore, concern about an opportunity to economize on energy costs. In the first case, it is likely that young people leave their homes to work for at least eight hours and can switch off space heating for this period of time. This would save app. 30% of consumed energy for heating. Elderly people are mostly at home and, moreover, they request higher heating temperature due to their physical preferences. They are very interested to save energy due to very high related costs for them, but probably would be able only to regulate the heating load in some extend, presumably by 10%. The average figure between the estimates of energy savings made for these two prevailing types of households is 20% of useful energy demand. In the mitigation scenario, it was assumed that all households heated with district or central building heating in traditional and industrialized buildings are upgraded with individual heat exchangers and heat meters by equal portions annually until 2025.

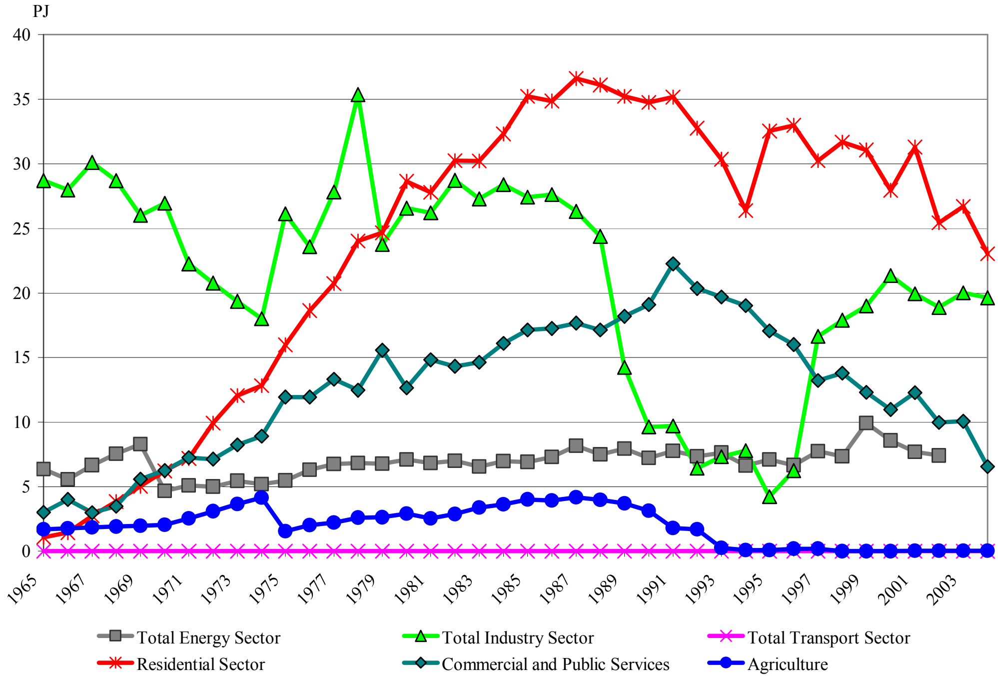

Figure 21 Heat consumption in Hungary during 1965 – 2004 yr.

Source: constructed on the base of IEA (2004) and IEA (2006a).

5.4.3 Programmable room thermostats

The installation of programmable room thermostats help to keep the room temperature at set levels, for instance with lower and higher temperatures depending on the occupancy and life cycle in a household. Typically, a room thermostat is installed in the most representative room of the houses. In households where all family members are working, it is reasonable to switch off space heating during 9 a.m. – 6 p.m. and set the thermostat, for instance, to 18 °C during 11 p.m. – 6 a.m. The Project MEEPH – Monitoring (2007) gives an estimate that 1°C lowering of the overall room temperature is able to save 5% or more of energy for heating.

For the modeling purposes, it was assumed that the total capital and installation costs of a programmable thermostat are about 140 EUR/household (based on Saunier Duval catalogue, 2007). The useful energy savings of thermostats are estimated as 5% of energy requirement for space heating based on the information provided by the website of MEEPH – Monitoring (2007). In the mitigation scenario, it was assumed that all dwellings in industrialized and traditional buildings and family houses heated by all dwelling systems except coal and traditional biomass fueled are retrofitted with thermostats until 2025.

5.4.4 Thermostatic radiator valves

While installation of the room thermostats were modeled as the most suitable control option for dwelling heating systems, installation of the thermostatic radiator valves (TRVs) is considered to be the convenient solution for controlling consumed heat supplied by district heating system or by central building (block) heating system. The TRVs regulate the heat flow through radiators and allow households to regulate the desired heating levels in different rooms.

The energy savings from installation of TRVs are estimated as 10% of useful energy requirement for heating based on the described experiment conducted by Živkovi et al. (2006). This figure was set based on the experiment with the Serbian buildings described above. The similarity of the experiment and installation of the TRVs is in possibility to adjust dwelling heat loads in different rooms according to comfort feelings without a possibility to influence on the energy costs. In the mitigation scenario, it was assumed that all households heated with district or central building heating in traditional and industrialized buildings are retrofitted with TRVs by equal portions annually until 2025.

It was assumed that installation of TRVs to app. five radiators per flat (an average estimated number) would costs app. 100 EUR/household if it can be realized without installation of bypass pipes into the radiator networks (possible in app. 50% of flats) and twice of this amount if dwellings need bypass lines (the rest 50% of flats). The illustrative explanation of necessity to install additional bypass lines is presented in Figure 22 below. According to an often-met design in many Hungarian multi-residential buildings, hot water is circulated through radiators located in turn (from the highest building floor to the lowest) and installation of TRVs which stop un-wanted heat flow through at a household will result also in stopping heat flow to next households. The cost estimates are based on production catalogues (Megatherm, 2007; Danfoss, 2007) and personal interviews (Sigmond, 2007; Kovacsics, 2007).

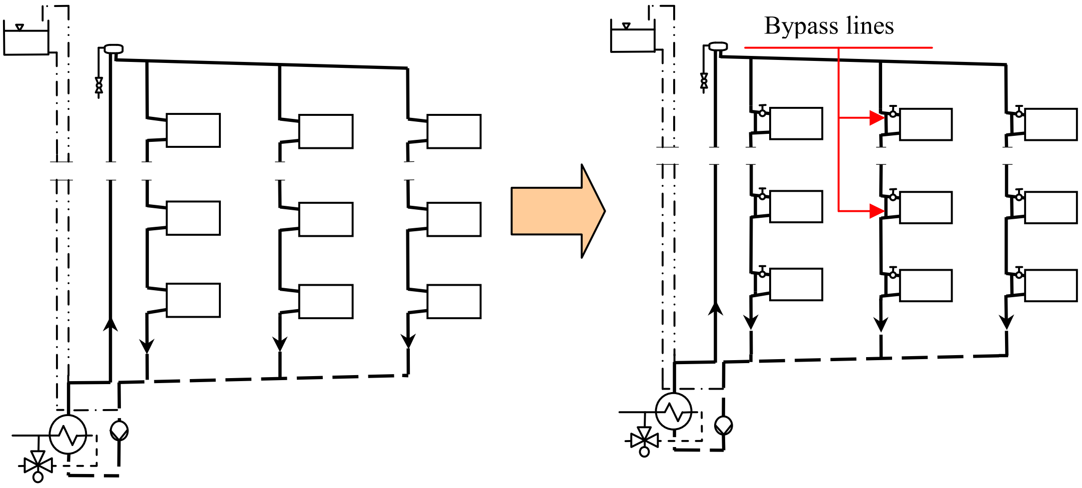

Figure 22 Scheme of a series-loop one-pipe down-feed hot water distribution system before and after installation of TRVs with bypass lines

Source: Courtesy of Sigmond (2007)

5.5 Options for efficiency improvement of domestic water heating

After space heating, domestic water heating is the largest energy consuming end-use in the residential sector. Water heating is characterized by lower efficiencies than space heating and it is a source for significant energy savings. Typically, primary energy spent for production and supply of hot water for an average three person household, is app. 3 to 5 times the actual energy content of the hot water consumed by household members (SAVE, 2001a). These losses result from water heating appliance/system, the distribution system, the type of faucets and other sources. SAVE (2001a) estimated that the economical and technical potential for domestic water heating appliances is in the range of app. 20%-35% taking into account the efficiency options with the pay-back period of less than 10 years, whereas the technical potential is about 50%.

Projection of the stock of dedicated water heating appliances, water heating appliances linked to space heating systems, and the number of households with district and central building hot water was made based on such sources as KSH (2006a), Kemna et al. (2007), and the projection of combined space and water heating systems described in sections 4.2 and 5.3. The projected stock is presented in Figure 23 and Figure 24 below for the top three water heating options (in terms of the number of water heating appliances) and the rest of the water heating options respectively.

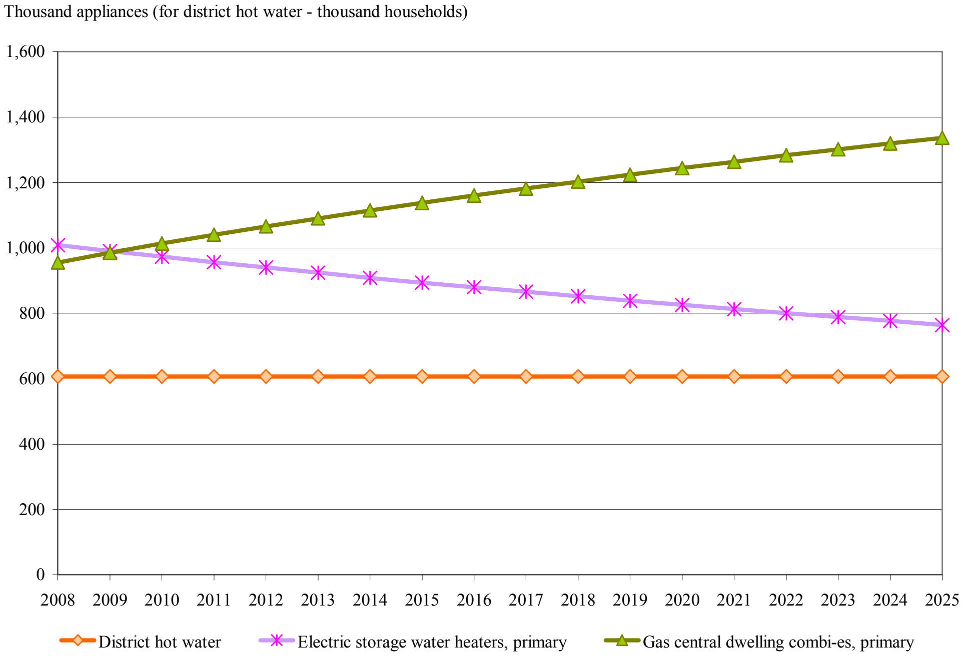

Figure 23 The projected stock of dedicated water heating appliances, water heating appliances linked to space heating systems, and the projected number of households with district and central building hot water, Part 1 – top three modes (in terms of the number of systems)

Source: projected based on assumptions and sources listed in the beginning of section 5.5.

Hungary has a long tradition for using electric and gas storage[19] boilers produced by domestic companies. The share of primary electric instantaneous[20] water heaters (usually imported) is not significant, however, there is a small share of secondary instantaneous gas water heaters. As Figure 23 and Figure 24 show, it is expected that households will prefer to install combined space and water heating systems and the stock of these systems will be replacing the dedicated water heating appliances. Due to this trend, supplementary secondary water heating will not be needed by households. The projections are in line with the overall European trends which show lowering sales of electric storage water heaters and gas instantaneous and storage water heaters and growing sales of combined systems for space and water heating (SAVE, 2001a).

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[19] A storage water heater is a water tank which keeps a constant temperature by the burner which starts when the temperature in the tank becomes lower than the temperature required by the thermostat (MEEPH – Monitoring, 2007).

[20] An instantaneous water heater is a water heater which starts the burner to heat the water when the user opens the tap (MEEPH – Monitoring, 2007).

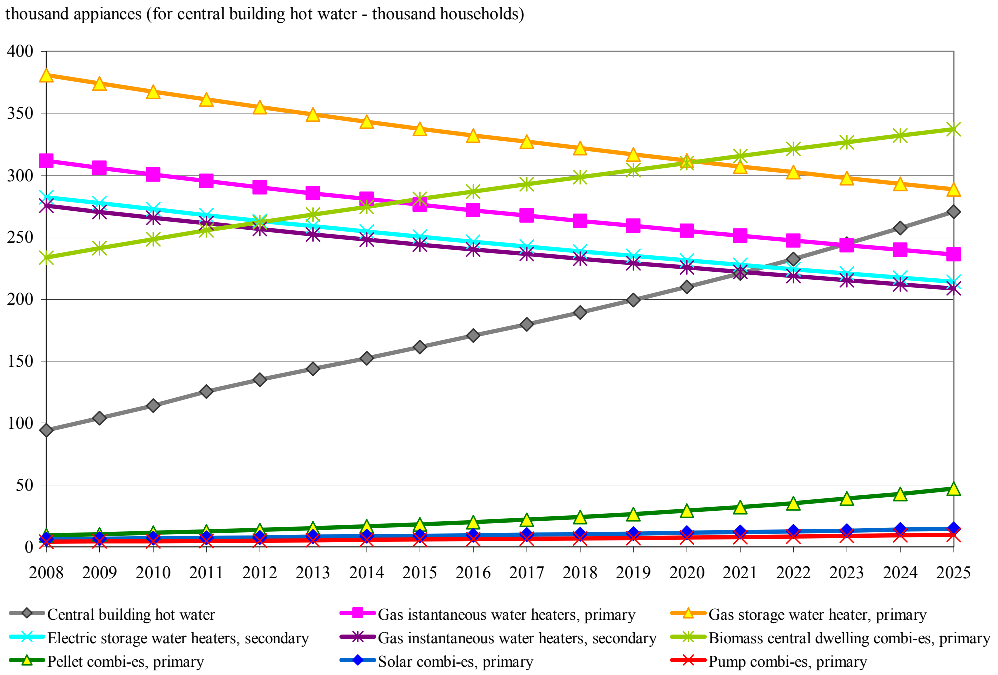

Figure 24 The projected stock of dedicated water heating appliances, water heating appliances linked to space heating systems, and the projected number of households with district and central building hot water, Part 2 – modes excluding top three (in terms of the number of systems)

Source: projected based on assumptions and sources listed in the beginning of section 5.5.

There is a wide range of water heating technologies on the Hungarian market. Among them, the key opportunities to unlock the CO_2 mitigation potential are:

(i) Using of more efficient and better insulated electric and gas storage water heaters
(ii) Using of better tankless instantaneous gas water heaters, located close to the points of use, to eliminate standby and reduce distribution heat losses
(iii) Using of advanced systems linked to solar thermal, biomass (pellet) boilers, and heating pumps

The individual options for CO_2 reduction through water heating include an exchange of combined space and water heating systems with advanced combined space and water systems as described in the section 5.3 and an exchange of dedicated water heaters with dedicated water heaters of higher efficiency.

5.5.1 The business-as-usual scenario

The data on efficiencies of dedicated water heaters in the baseline and mitigation scenario and the estimates of associated investment costs are derived based on Kemna et al. (2007). The data on efficiencies and costs of water heaters linked to space heating systems are based on sources listed in section 5.3. More details on the BAU efficiencies and the costs are described as opposed to advanced options in next sections 5.5.2 - 5.5.4.

5.5.2 Better electric storage boilers

An electric storage water heater is one of the most commonly installed solutions for water heating in Hungary. The overall system efficiency of the installed stock is estimated as 65% for both primary and secondary electric storage water heaters.

Based on the market data presented in Kemna et al. (2007) it was assumed that a typical primary electric boiler has a volume of 120 liters while a typical secondary boiler has a volume of 30 liters. Electric storage boilers installed in the BAU scenario were estimated as having heater efficiency of 100% and standby losses of app. 548 kWh/yr. and 244 kWh/yr. for primary and secondary boilers respectively. For the mitigation scenario, it was assumed that households can switch to primary electric storage boilers of a lower volume, i.e. 80 liters (based on considerations that if a household has in average 2.5 persons, the daily consumption of hot water is about 65 liters/day). The best available options on the market are available to supply hot water with the same heater efficiency and standby losses of app. 288 kWh/yr. and 179 kWh/yr. for primary and secondary boilers respectively. The investment costs for primary and secondary boilers were estimated as app. EUR 115 (30 liters) and EUR 275 (120 liters) per appliance for the BAU scenario and app. EUR 120 (30 liters) and EUR 220 (80 liters) per appliance for the mitigation scenario.

5.5.3 Better gas storage and instantaneous water heaters

The overall system efficiency of the installed appliance stock is estimated as 55% for primary gas instantaneous water heaters, 45% for primary gas storage water heaters, and 50% for secondary gas instantaneous water heaters.

For gas-fired conventional and condensing storage boilers (the volume of both is 80 liters) modeled in the BAU and the mitigation scenarios, the heater efficiencies are 85% and 97% and standby losses are app. 960 kWh/yr. and 471 kWh/yr. respectively. The investment costs of conventional and condensing gas storage boilers are estimated as 340 and 460 EUR/system respectively.

The efficiency of conventional gas-fired instantaneous water heaters purchased in the BAU scenario is estimated as 78% against 97% for condensing water heaters in the mitigation scenario. The investment costs are app. EUR 310 and EUR 190 for the primary and secondary BAU instantaneous water heaters versus EUR 420 and EUR 260 for the condensing primary and secondary instantaneous water heaters modeled in the mitigation scenario.

5.5.4 Water heating linked to solar thermal, biomass (pellet) boilers, and heating pumps

The overall system efficiencies for water heating of the installed combined systems were estimated based on Kemna et al. (2007) as 50%-55% depending whether it is a combined system or water is heated in the indirect cylinder. The BAU scenario assumes that standard gas and biomass boilers for space and water heating are installed due to the stock turnover as well as instead of dedicated water heaters. In the mitigation scenario, it is assumed that instead of the reference technology households install condensing gas boilers, or pellet boilers, or solar thermal systems back-up with pellet boilers, or heat pumps for space and water heating. The rates of penetration of these reference and mitigation technologies are the same as described in the related sections on space heating (see section 5.3).

The heater efficiencies of combined systems are described in the space heating section 5.3. The additional standing and other energy losses of combined combi- boilers providing instantaneous water heating are app. 210 kWh/yr., whereas for systems having a storage tank (biomass boilers and solar thermal systems) they are app. 470 kWh/yr. For heating pumps the standing losses were estimated as 5% of energy input according to Kemna et al. (2007). The investment costs of combi- systems are described in the section 5.3 and as detailed in the methodology (section 3.9.11) are app. 13% of the total system investment costs.

5.6 Options for water demand reduction

5.6.1 Water saving fixtures

The same tasks and hygiene procedures can be often made with considerably smaller amount of hot water without sacrifice to the comfort levels. Reducing hot water use for showering and washing by at least factor of 2 is possible if efficient fixtures replace standard fixtures (Harvey, 2006). According to this author, installation of low flow fixtures to showers and faucets would reduce water use from 10-20 and 10-20 liters/minute to 5-10 and 2-8 liters/minute respectively.

Based on Harvey (2006) estimates, it was assumed that low flow faucets and showerheads save about half of water demand in households with district or central house water supply and in households with instanteneous water heating appliances. In storage water heaters, savings in hot water energy use are partically diluted while hot water is stored in tanks due to standby losses (Harvey, 2006); for this reason it was assumed that water saving fuxtures save about 25% of water in households having these appliances. Based on the product pricelist (ORIS Consulting, 2007), the average investment costs of a fixture is estimated as app. 30 EUR. Despite this important and simple option has been know for many years (for instance, see the estimates in Szlavik et al. (1998)), it is not a very common retrofit measure for the Hungarian households. This is why, zero penetration rate is assumed in the BAU scenario whereas the mitigation scenario assumes that all water heating system and appliances retrofitted with low flow fixtures until 2025.

6 BASELINE AND MITIGATION OPTIONS: ELECTRIC EFFICIENCY

The chapter studies selected electric end-uses which have high penetration rates and consume large shares of final energy consumed by the residential sector. As opposed to the thermal energy, it is expected that electricity consumption will grow due to the growing spending power of the Hungarian population, growing demand for amenities, the increasingly busy lifestyle, widening assortment of appliances and other factors. Switch to higher efficiency appliances can supply CO_2 savings quicker and easier than installation of many insulation and heating technologies due to the fact that appliances are driven by electricity having significant production and distribution losses and due to the shorter lifetime and, thus, the higher exchange rate of appliances.

6.1 Electric energy consumption in the residential sector

The residential and commercial sectors of Hungary are the only two sectors increasing electricity consumption steadily over the last 40 years (Figure 25). During 1994 - 2004, the Hungarian residential electricity use grew in average by 1.1%/yr. These trends resulted in growing CO_2 emissions from 3.6 million tons/yr. in 1994 to 4.0 million tons/yr. in 2004.

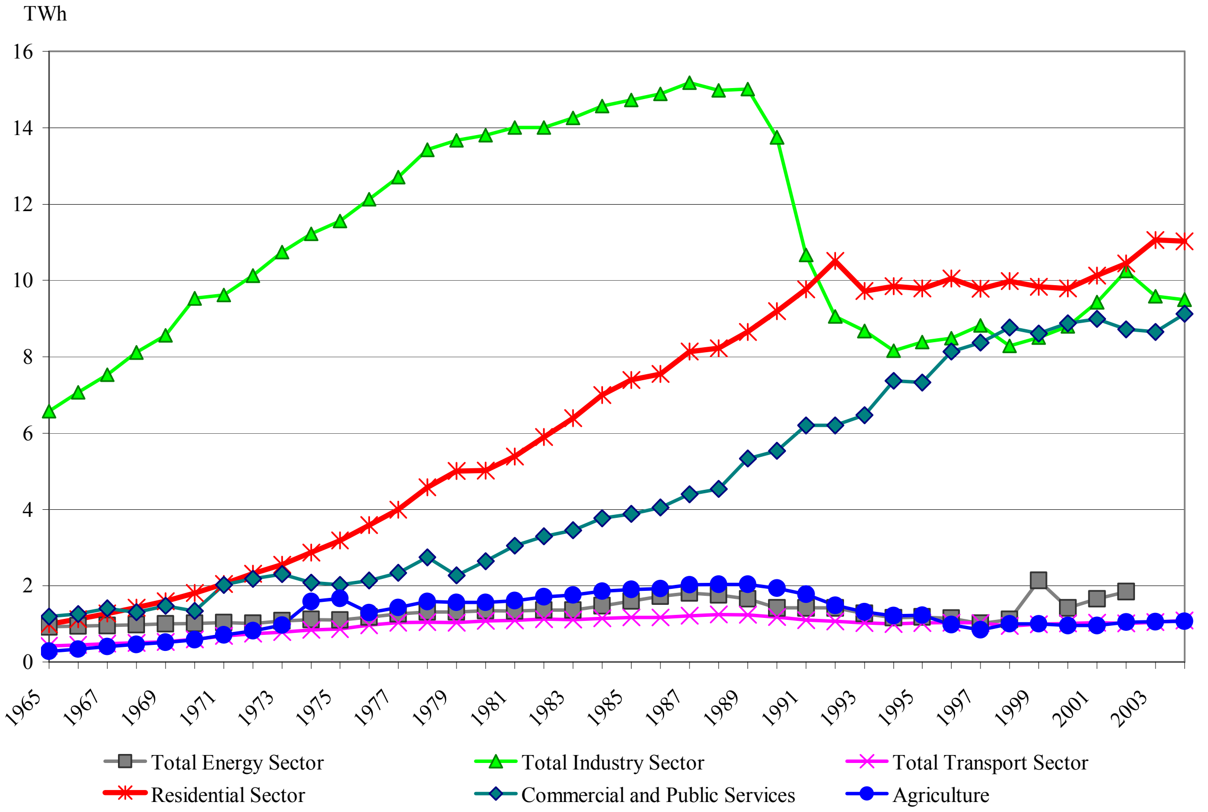

Figure 25 Electricity consumption by end-use sectors in Hungary, 1965-2004 yr.

Source: constructed based on IEA (2004) and IEA (2006a).

Even though according to the World Energy, Technology and Climate Policy Outlook 2030 (Directorate-General for Research Energy, 2003) the efficiencies of domestic appliances and lights grow, the electric appliances are expected to significantly raise the energy use in Europe. This is the result of the following trends (Bertoldi and Atanasiu, 2007):

i. Higher penetration of “traditional” appliances (e.g. dishwashers, tumble driers, air-conditioners, personal computers) which are all still far away from saturation levels
ii. Introduction of new appliances and devices, especially consumer electronics and information and communication technology equipment (set-top boxes, DVD players, broadband equipment, cordless telephones, etc.) having considerable standby consumption
iii. Increased use of “traditional” equipment: more hours of television watching, more hours of use of personal computer (driven by increased use of the Internet), more washing and use of hot water
iv. The increased number of double or triple appliances, mainly television sets and refrigerators-freezers
v. Larger family houses and apartments resulting in higher requirement for lighting, heating and cooling
vi. Aging population requiring higher indoor temperatures for all-day heating in winter and cooling in summer spending more time at home

6.2 The business-as-usual scenario

Modeling the BAU scenario, the major assumption is that intensities and penetrations rates of electric appliances and lights in Hungary are driven by the presently implemented the EU labeling and standardization programs. For the mitigation scenario it is assumed, that purchased appliances are up to the best available (presently known and estimated) technology which will be available on the market in the projected year. It was assumed that the costs in real terms of the BAU and the best available appliances do not change over time (i.e. the presently efficient appliances are becoming cheaper in the future and the new-coming efficient appliances are taking over their price). The efficiency and cost details of the appliances and lights purchased in the BAU scenario are described as opposed to their efficient analogues in sections 6.3 - 0.

6.3 Efficient cold appliances (refrigerators and freezers)

Despite significant improvement in the past, the potential for efficiency improvement of cold appliances is far from to be exhausted and it is still believed as one of the largest electricity saving opportunities. Bertoldi and Atanasiu (2007) estimated that there has been already a 27% net efficiency improvement of cold appliances sold after introduction of minimum energy performance standards on the EU market compared with pre-labeling efficiency levels. This resulted in decreased electricity consumption of cold appliances from app. 450 kWh/year in 1990-92 to app. 264 kWh/year. Additionally to these savings, Bertoldi and Atanasiu (2007) surmises that the share of cost effective electricity savings of cold appliances may be 40%-50% of the total existing potential in residential electricity consumption.

Table 19 Technical and financial parameters of the stock of refrigerators in Hungary

Input parameters	Units	2008	2025	Sources and comments
Equipment rate of households	% of household	96%	107%	Estimated based on ODYSSEE, 2007 and CECED, 2001
Lifetime	years	20	20	Estimated based on Meli, 2004
BAU scenario IEE, sold appliances		0.59	0.40	Estimated based on Bertoldi and Atanasiu (2007) and ADEME (2000)
Mitigation scenario IEE, sold appliances		0.38	0.17	Estimated based on Bertoldi and Atanasiu (2007) and ADEME (2000)
Unit energy consumption (UEC) of the installed stock	kWh/yr.	366	366	REMODECE, 2007
BAU scenario UEC, sold appliances	kWh/yr.	185	127	Estimated based on above indicators
Mitigation scenario UEC, sold appliances	kWh/yr.	120	54	Estimated based on above indicators
Price of the purchased appliance in the BAU	EUR/piece	321	321	Estimated based on Bertoldi and Atanasiu (2007)
Price of the purchased appliance in the mitigation scenario	EUR/piece	408	408	Estimated based on Bertoldi and Atanasiu (2007)

Table 20 Technical and financial parameters of the stock of freezers in Hungary

Input parameters	Units	2008	2025	Sources and comments
Equipment rate of households	% of household	70%	70%	Estimated based on ODYSSEE, 2007 and CECED, 2001
Lifetime	years	25	25	Estimated based on Meli, 2004
BAU scenario IEE, sold appliances		0.69	0.38	Estimated based on Bertoldi and Atanasiu (2007) and ADEME (2000)
Mitigation scenario IEE, sold appliances		0.42	0.22	Estimated based on Bertoldi and Atanasiu (2007) and ADEME (2000)
UEC of the installed stock	kWh/yr.	1075	1075	REMODECE, 2007
BAU scenario UEC, sold appliances	kWh/yr.	297	161	Estimated based on above indicators
Mitigation scenario UEC, sold appliances	kWh/yr.	180	94	Estimated based on above indicators
Price of the purchased appliance in the BAU	EUR/piece	318	318	Estimated based on Bertoldi and Atanasiu (2007)
Price of the purchased appliance in the mitigation scenario	EUR/piece	403	403	Estimated based on Bertoldi and Atanasiu (2007)

The average model sold in 2005 on the Hungarian market had the energy efficiency index (IEE[21]) of app. 0.62 for refrigerators and 0.80 for freezers (between A and B classes for both appliances), whereas the best models on the market were rated A++ with the EEI below 0.30 for both refrigerators and freezers (Bertoldi and Atanasiu, 2007). The background document for the revision of the EU labeling and standardization program (ADEME, 2000) estimated that the lowest technically achievable energy efficiency indices in the long term are 0.16 – 0.18 for refrigerators, 0.19 – 0.23 for refrigerator-freezers and 0.22 – 0.26 for freezers. These indices were set as the potential targets for the mitigation scenario in 2025. The business-as-usual IEE was estimated based on the scenario reported by ADEME (2000), which takes into account the EU labeling scheme, the minimum energy performance standard, and the fleet targets which are

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[21] For domestic cooling appliances the energy efficiency index (EEI) was set at 102 for the average model on the market in year 1992.

close to the present level[22]. Summary of model input indicators for refrigerators and freezers are presented in Table 19 and Table 20 respectively.

6.4 Efficient clothes washers

For washing machines, the weighted average sold appliance had the IEE[23] of 0.24 kWh/kg (between classes A and B) in 2005 in Hungary (Bertoldi and Atanasiu, 2007). The BAU IEE was estimated based on the scenario reported by the background document for the revision of the EU labeling programs and targets for washing machines SAVE (2001b), which takes into account the EU Labeling Directive and the CECED commitment on the fleet target as of 2004. As regarding to the mitigation scenario, presently there is significant potential for efficiency improvement between the average model and the best model available on the market (A++). In the future, there is a large potential for electricity conservation switching to lower washing temperatures due to better detergents and washing techniques. SAVE (2001b) estimated that the lowest technically achievable IEE in the long term is 0.085 for washing at 40 ° C which was set as the potential target in 2025. The summary of estimated model input indicators for washing machines is presented in Table 21.

Table 21 Technical and financial parameters of the stock of washing machines in Hungary

Input parameters	**Units**	**2008**	**2025**	**Sources and comments**
Equipment rate of households	% of household	77%	100%	Estimated based on ODYSSEE (2007)
Lifetime		25	25	Estimated based on Meli, 2004
BAU scenario IEE, sold appliances	kWh/kg	0.20	0.19	Estimated based on Bertoldi and Atanasiu (2007) and SAVE (2001b)
Mitigation scenario IEE, sold appliances	kWh/kg	0.16	0.09	Estimated based on Bertoldi and Atanasiu (2007) and SAVE (2001b)
UEC installed stock	kWh/yr.	124	124	REMODECE, 2007
BAU scenario UEC, sold appliances	kWh/yr.	109	101	Estimated based on above indicators
Mitigation scenario UEC, sold appliances	kWh/yr.	84	46	Estimated based on above indicators
Price of the purchased appliance in the BAU	EUR/piece	325	325	Estimated based on Bertoldi and Atanasiu (2007)
Price of the purchased appliance in the mitigation scenario	EUR/piece	386	386	Estimated based on Bertoldi and Atanasiu (2007)

6.5 Efficient lights

The lighting consumption occupies 25% of the total residential electricity consumption in Hungary in 2004 (Bertoldi and Atanasiu, 2007). The major trends of the growing lighting market are determined by larger houses and apartments, decorative aspects and fashion, among other factors (Slek, 2004). The efficiency of the tungsten filament lamp in the form of visible light is about 5 % of the input energy, however, this technology is the most popular in Hungary. The incandescent lamps with halogen-gas-filling which are 1.5 to 3 times more efficient than classic incandescent lamps are also widely used in the Hungarian households. The compact fluorescent

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[22] As of September 2007

[23] For washing machines the EEI is expressed as the energy used per kg of washed cloths in a standard 60ºC cotton cycle (kWh/kg).

lamp (CFL) emits 28% of input energy in the form of visible light and is presently the best available technology on the Hungarian market. There is still only one CFL per household in average among 18 lighting points of a typical Hungarian household. The structure of the six most consuming bulbs installed in Hungary in 2007 is presented in Figure 26 below.

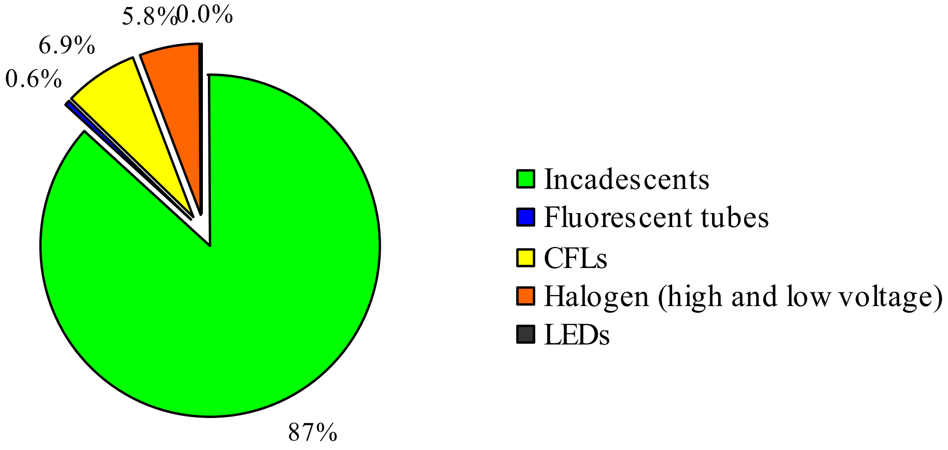

Figure 26 Structure of installed lamp stock in Hungarian households, 2007

Source: constructed based on preliminary data of REMODECE (2007)

As EURELECTRIC (2004) reports that there are still many ways to improve CFLs such as reduction of voltage distortion, improvement of colour rendering, faster start-up, insensitivity to the number of lightings, and other characteristics. Also, according to the report the insufficient number of luminaries is designed specifically for CFLs. With an average exchange of luminaries as high as one per households per year (the data are for the EU, EURELECTRIC, 2004), the penetration rates of CFLs are constrained. The present report estimates only an exchange of the most used incandescent lamps with CFLs, however, the potential for electricity savings from CFLs goes beyond this option facing, though, numerous market barriers.

Taking into account that the CFLs present in 47% of households (REMODECE, 2007), it was assumed that the structure of the stock does not improve further in this regard without additional incentives in the BAU scenario. The EURECO (2002) cited in IEA (2006b) concluded that, if the lights are exchanged in order of use (most used first), replacing six lamps will produce about 85% of the total energy savings savings associated with lighting in households. This is why, in the mitigation scenario an exchange of only the most used six lamps was analyzed. The technical characteristics of the analyzed lamps such as their wattage and usage were estimated for the Hungarian households based on the preliminary results of the REMODECE project (REMODECE, 2007). The capital investments are assumed as 0.7 EUR/60-W incandescent lamps and 7 EUR/17-W CFL.

Table 22 Technical characteristics of six most used lighting points

Ranking of lighting points according to the use	**Usage, hours/day**	**Share of incandescent lamps**	**Typical wattage of incandescent lamps**	**Share of CFLs**	**Typical wattage of CFLs**	**Share of other types of bulbs (HAL, FLUO)**
	Hours/year	% of the installed bulb stock	Watt	% of the installed bulb stock	Watt	% of the installed bulb stock
Lighting point 1	4.0	70%	60	20%	13	10%
Lighting point 2	3.0	55%	60	25%	15	20%
Lighting point 3	2.5	55%	60	25%	18	20%
Lighting point 4	2.3	50%	60	20%	17	30%
Lighting point 5	2.1	50%	60	25%	14	25%
Lighting point 6	1.9	70%	60	10%	15	20%

Source: estimated based on REMODECE (2007)

6.6 Low standby consumption

For the purposes of this report, the standby definition was assumed as consumption of appliances and equipment in passive and off (often referred as low) power modes (LOPOMO). Valentova (2007) estimated that within the 95 households participating in the Hungarian survey, the average LOPOMO power of was found to be 30W, the average LOPOM electricity consumption of reaching 236kWh per year, which is 8% of the households' average electricity consumption.

Bertoldi and Atanasiu (2007) claimed that consumer electronic and information and communication equipment is the fastest growing electricity end-use in the residential sector and the largest standby consumption is attributed to them. Due to the uncertainty with input parameters for the full range of LOPOMO consuming domestic appliances and equipment, the present report focuses only on reduction of electricity consumption from standby in personal computers and TVs and related peripheries (listed in Table 23).

According to the methodology of the Ecostandy project (Fraunhofer IZM, 2007), efficiency improvement of installed equipment stock in the BAU scenario is assumed 1%/yr. According to the same source, authors estimated energy consumption in LOPOMO for the mitigation scenario and additional capital investments to produce equipment according to low level of LOPOMO. The summary of the input parameters is presented in Table 23.

Table 23 Modeling parameters of PC- and TV- related equipment in LOPOMO

Indicator/ Assumption	**Equipment penetration**		**Lifetime**	**Time in passive and off-mode**	**Passive and off mode consumption of installed equipment, BAU**		**Passive and off model consumption of new purchased equipment, the mitigation scenario**		**Additional capital investment**
Units	% households		years	hours/ day	Watt		Watt		EUR/piece
Year	2008	2025			2008	2025	2008	2025	2008-2025
TV	156%	238%	10	18	6.3	5.3	1.0	1.0	1
VCR[24]	38%	0%	10	21	6.0	6.0			
DVD	34%	228%	9	19	3.3	2.8	1.0	1.0	1
Antenna/Satellite	70%	107%	10	23	6.0	5.0	3.0	1.0	3
Desktop	44%	105%	6	15	5.2	4.3	1.0	1.0	1
Monitor	44%	105%	6	18	1.5	1.3	1.0	1.0	1
Printer	21%	66%	4	20	3.7	3.1	1.0	1.0	1
Modem/router	20%	93%	6	22	5.3	4.4	3.0	1.0	3

Sources: KSH (2004, 2006a) and Fraunhofer IZM (2007) for penetration rates; Fraunhofer IZM (2007) for lifetime; REMODECE (2007) for the time in LOPOMO state and LOPOMO consumption of installed equipment in 2008; estimates of LOPOMO consumption of installed equipment in the BAU scenario and purchased equipment in the mitigation scenario and additional investments are based on REMODECE (2007) and Fraunhofer IZM (2007).

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[24] VCRs are not produced any more.

7 DISCUSSION OF RESULTS

7.1 Summarized research boundaries

This chapter describes the results of the research starting with identification of the key energy efficiency and low-carbon technologies and practices applicable in the residential sector of Hungary. Before describing the results, it is important to summarize the boundaries of the study. The studied options are listed in Table 24:

Table 24 Key CO_2 mitigation options covered by the research

Options	**Households in**				
	multi-residential traditional buildings	**multi-residential industri-alized buildings**	**in family houses built before 1992**	**multi - residential buildings/ family houses built in 1993 - 2007**	**multi-residential buildings/ family houses to be built from 2008**
Thermal envelope					
Insulation of walls, roofs, and cellars		X	X		
Exchange of windows and doors	X	X	X		
Application of passive energy design to new built houses					X
Heating efficiency					
Exchange of conventional building central gas systems with condensing gas building central heating systems	X	X			
Exchange of gas and coal premise and dwelling heating systems with condensing gas dwelling heating (and for family houses water heating) systems	X		X		
Exchange of gas and coal premise and dwelling heating systems with space and water heating pumps			X		
Exchange of gas and coal premise and dwelling heating systems with pellet space and water heating systems			X		
Exchange of gas and coal premise and dwelling heating systems with solar thermal space and water heating systems backed-up with pellets			X		
Heating controls					
Installation of TRVs (for district and centrally heated dwellings only)	X	X			
Installation of programmable thermostats (except district and central heating and coal heating systems)	X		X		
Individual metering (for district and central heated dwellings only)	X	X			

Options	Households in				
	multi-residential traditional buildings	multi-residential industri-alized buildings	in family houses built before 1992	multi - residential buildings/ family houses built in 1993 - 2007	multi-residential buildings/ family houses to be built from 2008
Water heaters					
Improvement of efficiencies of water heating combined with space heating systems (according to the options described in the space heating opportunities)	X	X	X		
Exchange of dedicated water heating appliances with dedicated more efficient water heating appliances of the same class (electric storage boilers, gas storage and instantaneous water heaters)	X	X	X	X	X
Installation of water saving fixtures (showerheads and sink faucets) to all water heating systems and appliances	X	X	X	X	X
Electric appliances and lights					
Higher efficiency cold appliances (refrigerators and freezers)	X	X	X	X	X
Higher efficiency clothes washers	X	X	X	X	X
Reduction of electricity consumption in low power mode of TV- and PC- related appliances (television sets, DVDs, antennas and satellites, computer desktops and monitors, printers, modems and routers)	X	X	X	X	X
Exchange of incandescent lighting bulbs with CFLs	X	X	X	X	X

The model does not consider improvement of the thermal envelope and heating systems of buildings constructed during 1993-2008. This is because the thermal envelope of these buildings is more efficient than that of buildings built before the 1991 Building Code was introduced. The heating systems in these buildings are up to the present market technologies (even though not up the best available technologies). As the results, the potential for CO_2 mitigation in these newly built buildings is less significant than that in the old buildings and it is much less cost-effective.

The report leaves for the future research several mitigation options due to several reasons. First, consideration of reduced air leakage and heat gains of windows and doors is constrained presently due to the scarce of data for this option. Due to sever lack of data, cooking, air-conditioning, and motors (lifts) are not studied. Some options having presumably lower potential as compared to the studied options were not investigated. These are for thermal options, for instance, insulation of pipes delivering district and central heat and water insight buildings and households. As for electric efficiency, improvement of efficiency of electric appliances and equipment other than cold appliances, washing machines, TV and PC-related equipment in low power mode, and lights is not studied. Also the research does not consider the effect of more efficient biomass heating systems because biomass is considered as a sustainable source of energy and, thus, reported with zero CO_2 emissions.

Due to these research limitations, the baseline energy and CO_2 emissions estimated in the research do not include energy consumption and associated CO_2 emissions of buildings constructed during 1993-2008 and of biomass heating systems buildings and, therefore, they are lower than the real energy consumption and associated CO_2 emissions of the Hungarian residential sector.

7.2 The potential of the key individual CO_2 mitigation options

This section describes the results of the bottom-up mitigation assessment conduced to mitigation options independently from each other. The Table 25 details the potential CO_2 savings which result from implementation of individual options and the associated costs of conserved CO_2. The options related to space heating (including insulation) are grouped according to the building types, while options related to water heating and electric efficiency (excluding water heating) are grouped in separate categories. The options are ranked according to their cost-effectiveness within their groups. **The potential from individual options is not additive because of its possible double-counting if the options are targeted to the same baseline technologies and energy end-uses** (see section 3.1).

The Table attests that technological options supplying the potential for CO_2 mitigation at negative costs are available for each building type and each energy end-use. The top negative-cost measure in terms of cost-effectiveness is an exchange of incandescent lighting bulbs with CFLs. This is in line with conclusion of other studies conducted in economies in transition and worldwide according to Levine et al. (2007). It is followed by obligation to reduce electricity consumption of TV- and PC- related appliances in the low power mode and efficient freezers, refrigerators, and clothes washers which application is justified by the high electricity price in Hungary. Installation of heat and hot water demand controls such as low flow fixtures, TRVs, and programmable thermostats ranks the third. Almost all options aimed to insulation of building components (walls, basements, and roofs) fall to the list with negative mitigation cost as well as actions towards installation of condensing central building gas boilers. Application of passive energy design to newly built buildings and installation of improved water heating systems are the last in the list of measures with negative costs of CO_2 mitigation.

The technological options with the costs in the interval 0-100 EUR/tCO_2 options include window exchange, installation of condensing gas boilers for water and space dwelling heating to family houses, and installation of individual meters for district and central heated households in traditional buildings (all options at app. 90 EUR/tCO_2).

The rest of the options are considered as expensive and have the mitigation costs in the interval of app. 100 – 500 EUR/tCO_2, except a door exchange in all building types with the costs higher than 1000 EUR/tCO_2. The list of expensive options include all alternatives for advanced space heating in family houses, these are (in the order of increasing costs): pellet boilers, condensing gas boilers, solar collectors backed-up with pellets, and pumps. The list also includes installation of individual meters for district and central heated households in industrialized buildings and window exchange in traditional and industrialized technology households. It is important to note that the potential of window and door exchange is underestimated due to omitted calculation of reduced air leakage. If this factor would be considered, the potential and cost-effectiveness of more efficient windows and doors would be higher than it is presently estimated.

In terms of the size of avoided CO_2, improvement of the thermal envelope and heating efficiency in old family houses is able to supply the largest potential in the residential sector. Thus, installation of pellet boilers and solar space and water heating systems back-up with pellet boilers supplies the largest amount of potential, app. 3.1 million ton of CO_2 as compared to the baseline emissions; installation of heat pumps and condensing boilers to this type of households can provide also a very considerable potentials up to 1.8 and 0.6 million tons of CO_2 (please note that these options exclude or reduce the potential of each other if applied in turn). Insulation of building components such as walls, roofs, and basements and window exchange may result in CO_2 savings of 2.4, 1.5, 1.4, and 1.1 million tons of CO_2 respectively. Other options related to thermal efficiency in this type of buildings, i.e. installation of programmable thermostats and better doors, can save up to 0.2 and 0.1 million tons CO_2 respectively.

Among other attractive options is application of passive energy design to newly built buildings which can save 0.7 million tons of CO_2. Improved water heating systems, installation of CFLs, installation of water saving fixtures, exchange of refrigerators, and the ban for TV- and PC-related equipment having high low power mode could save 0.1 – 0.6 million tons of CO_2/option. Options related to improvement of the thermal envelope in traditional buildings such as window exchange, insulation of basements, and roofs can save 0.1 - 0.3 million tons of CO_2/option. The same options in the industrialized technology buildings can save 0.4 – 1.0 million tons of CO_2/option, additionally about 0.3 and 0.1 million tons of CO_2 are supplied by savings due to wall insulation and installation of individual heat meters in this type of buildings. The rest of the options supplies less than 0.1 million tons of CO_2/option.

The Table also presents the energy savings from implementation of CO_2 mitigation options and associated costs of conserved energy. If compared to the energy prices in 2025, the costs of conserved energy of an option justifies whether it pays back from energy cost savings. In other words, if the costs of conserved energy are higher than the expected energy price in 2025, this option does not pay back in 2025 from energy cost savings. **It is important to highlight that the most efficient options in terms of the amount of saved CO_2 (as baseline share) or in terms of CO_2 mitigation cost-effectiveness are often not the same as the most efficient options for saving energy and energy conservation cost-effectiveness.** For instance, installation of a pellet boiler for space and water heating to a household can improve heating efficiency by 5% - 25% depending on the reference technology but pellet combustion neutralize 100% of CO_2 emissions due to its zero emission factor. Therefore, the results of the research can be applied to the analysis of energy efficiency options with great caution.

Table 25 Potential available through application of individual options installed separately, results for the year 2025

Technological options	**CO_2 avoided**	**Cost of mitigated CO_2**		**Energy savings**	**Cost of conserved energy**	
	1000 tCO_2/yr.	EUR/tCO_2	1000 HUF/ tCO_2	GWh/yr.	EUR/kWh	HUF/kWh
Thermal retrofit in industrialized buildings: space heating						
Installation of TRVs	74	-225	-56	441	0.02	4
Wall insulation in houses	332	-115	-29	1931	0.03	8
Installation of condensing central building gas boilers	5	-108	-27	25	0.04	9
Basement insulation	37	-96	-24	215	0.04	9
Roof insulation	38	4	1	219	0.05	14
Window exchange	128	158	40	746	0.08	20
Individual metering of district and central heat	148	307	77	882	0.10	26
Door exchange	21	1684	421	124	0.34	86
Thermal retrofit in traditional buildings: space heating						
Installation of TRVs	19	-233	-58	100	0.01	3
Basement insulation	116	-169	-42	579	0.02	6
Installation of programmable thermostats	52	-154	-38	259	0.03	7
Installation of condensing central building gas boilers for space heating	26	-104	-26	130	0.04	9
Roof insulation	103	-89	-22	512	0.04	10
Individual metering of consumed district and central heat	39	91	23	200	0.07	18
Window exchange	337	125	31	1679	0.08	21
Installation of condensing central gas dwelling boilers for space heating	79	204	51	392	0.10	25
Door exchange	23	1462	366	114	0.35	88
Thermal retrofit in family houses built until 1992: space heating						
Installation of programmable thermostats	193	-191	-48	957	0.02	5
Basement insulation	1514	-146	-36	6680	0.02	5
Wall insulation	2367	-100	-25	10446	0.03	8
Roof insulation	1338	-82	-21	5903	0.04	9
Installation of condensing gas boiler for water and space central dwelling heating	579	86	22	2017	0.07	18
Window exchange in family houses built before 1992	1100	88	22	4853	0.07	18
Installation of pellets boilers for water and space central dwelling heating	3054	110	27	1110	0.52	129
Installation of solar collectors backed up with pellet boilers for water and space central dwelling heating	3054	233	58	4771	0.23	57
Installation of pumps for water and space central dwelling heating	1833	487	122	9572	0.09	22
Door exchange	75	1151	288	330	0.31	79
Thermal retrofit in family houses built after 2008						
Application of passive energy design	705	-89	-22	4689	0.04	9
Thermal retrofit: water heating systems						
Installation of water saving fixtures in households with domestic hot water systems and appliances	400	-354	-88	1942	0.00	1
Installation of water saving fixtures in households with district /central hot water	202	-298	-75	1213	0.00	1
Improved combi- space and water heating systems and dedicated water heating appliances	553	-51	-13	1140	0.09	22
Options related to electric efficiency (excluding water heating): appliances and lights						
Exchange of incandescent bulbs with CFLs	305	-1066	-267	935	-0.15	-36
Reduction of energy consumption by TV and PC-related equipment in low power and off - modes	266	-613	-153	815	0.00	0
Efficient freezers	67	-391	-98	206	0.07	19
Efficient refrigerators	107	-297	-74	328	0.11	26
Efficient clothes washes	54	-275	-69	167	0.11	28

7.3 Country-wide potential for CO_2 mitigation and its supply curve

This section discusses the results if the bottom-up mitigation assessment of mitigation options conducted with the supply curve method. The advantage of the supply curve method is that it allows estimating the total potential avoiding double-counting of the mitigation potential supplied by individual options targeted to the same baseline technologies and energy end-uses (for instance, insulation improvement reduces the need for space heating and, thus, also reduces the energy saving potential from installation of more efficient heating system). For more details about the methodology please see Section 3. Therefore, the principal different of the results described in this section from the previous one is **avoiding double-counting of the potential supplied by technological options**.

Figure 27 illustrates the potential for CO_2 abatement as a function of costs for investigated technological options for CO_2 mitigation. Table 26 decodes the numbered measures and provides the detailed data on associated CO_2 mitigation potential and costs. The table also gives the estimates to energy saving which would result from implementation of mitigation options.

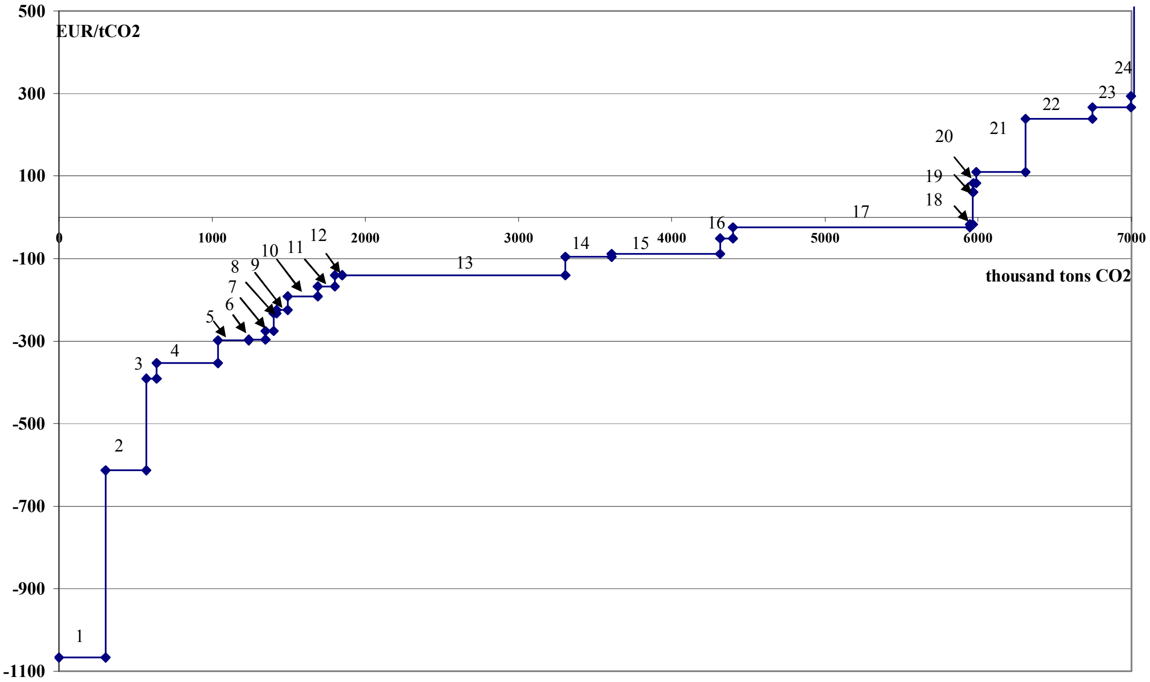

Figure 27 Supply curve of CO2 mitigation for the residential sector of Hungary, results for the year 2025

The figure demonstrates a wide range of opportunities for negative- and low- cost CO_2 mitigation in all studied types of the residential buildings. The thermal options supply the more significant savings in absolute values as well as the share of their baseline emissions than electric efficiency options except lights.

The Figure depicts that such technological options as efficient appliances and lighting technologies, heat and water flow controls, TV- and PC- related equipment with reduced electricity consumption in low power mode, construction according to the passive energy design principles and the majority of insulation options supply the potential for CO_2 mitigation at negative cost in 2025. If all these options were implemented, they would cumulatively reduce CO_2 mitigation by 6.0 million tons in 2025. This is about 53% of total CO_2 emissions emitted by modeled energy end-uses (please note that it is not the total baseline of the residential sector). Implementation of the mitigation options at negative cost of CO_2 would result in energy saving of 28.1 TWh/yr., which is about 54% of the total final energy consumption of modeled energy end-uses of the residential sector in 2025. Realization of this potential requires the total investments over the period 2008 – 2025 of about 11.8 billion EUR but saves 18.8 billion EUR in energy costs during.

There is the limited number of options with associated mitigation costs in the interval from 0 to 100 EUR/tCO_2 in 2025 which supply not significant amount of the CO_2 abatement potential. The list of "expensive" options, which abatement costs are in the range of 100 – 500 EUR/tCO_2, includes improved water heating systems and appliances, a few insulation options and window exchange, installation of individual heat meters, and the retrofit of heating systems. These "expensive" options are able to supply app. 19% and 11% of baseline CO_2 emissions and baseline energy consumptions of modeled energy end-uses. These savings correspond to additional 2.1 million tons of CO_2 and 5.8 TWh/yr. savings in 2025. "Expensive" options would cost in total about 19.1 billion EUR over 2008 – 2025 (see Table 27).

The rest of investigated options have the costs above 500 EUR/tCO_2 but does not supply a significant amount of the CO_2 abatement potential. This, however, does not mean that, if these options are implemented individually, they are also expensive (see the previous section). The list of very expensive options mainly includes exchange of small building components of the building stock. The reason is that the thermal properties of buildings are already improved with the previous options and they already need small amount of energy for space heating. This is why, additional options can save significantly smaller amount of energy if applied in turn and, therefore, their energy cost savings pay back much slower.

It is important to mention that the supply curve does not include solar thermal solutions and condensing gas boilers for old family houses because pellet boilers and heat pumps are also applicable to these buildings and they are more cost-effective (and this is why, they replace the reference technologies).

The total maximum potential achieved due to implementation of all investigated measures is estimated as high as app. 73% and 67% of baseline CO_2 emissions and energy consumption projected for modeled end-uses in 2025. In absolute terms, these savings represent about 8.2 million tons of CO_2 and 34.8 TWh/yr. The total investments over 2008 – 2025 needed to realize the maximum potential are about 38.6 billion EUR.

Table 26 Potential and costs of CO_2 mitigation estimated with the supply curve method, results for the year 2025

N	Technological options	**CO_2 savings**	**CO_2 savings cumulative**	**Cost of mitigated CO_2**		**Energy savings**	**Energy savings cumulative**
		1000 tons CO_2/yr.	1000 tons CO_2/yr.	EUR/ tCO_2	1000HUF/ tCO_2	GWh/yr.	GWh/yr.
1	Exchange of incandescent bulbs with CFLs	305	305	-1066	-267	935	935
2	Reduction of energy consumption by TV and PC-related equipment in low power and off - modes	266	571	-613	-153	815	1750
3	Efficient freezers	67	638	-391	-98	206	1955
4	Installation of water saving fixtures in households with domestic hot water systems and appliances	400	1038	-354	-88	1942	3897
5	Installation of water saving fixtures in households with district /central hot water	202	1240	-298	-75	1213	5110
6	Efficient refrigerators	107	1347	-297	-74	328	5438
7	Efficient clothes washes	54	1401	-275	-69	167	5605
8	Installation of TRVs in traditional houses	19	1420	-233	-58	100	5705
9	Installation of TRVs in houses built with industrialized technology	74	1494	-225	-56	441	6146
10	Installation of programmable thermostats in family houses built before 1992	193	1688	-191	-48	957	7104
11	Basement insulation in traditional houses	114	1802	-167	-42	569	7673
12	Installation of programmable thermostats in traditional houses	48	1850	-141	-35	235	7908
13	Basement insulation in family houses built before 1992	1455	3305	-140	-35	6390	14298
14	Wall insulation in houses built with industrialized technology	304	3609	-96	-24	1763	16060
15	Application of passive energy design to buildings to be constructed from 2008	705	4314	-89	-22	4689	20749
16	Roof insulation in traditional houses	86	4400	-52	-13	430	21179
17	Wall insulation in family houses built before 1992	1546	5947	-25	-6	6786	27966
18	Installation of condensing central building gas boilers for space heating in traditional houses	18	5964	-17	-4	87	28053
19	Installation of condensing gas boilers for space heating in houses built with industrialized technology	3	5967	61	15	13	28066
20	Basement insulation in houses built with industrialized technology	20	5987	83	21	117	28182
21	Improved combi- space and water heating systems and dedicated water heating appliances	322	6309	109	27	273	28455
22	Roof insulation in family houses built before 1992	438	6747	239	60	1922	30377
23	Window exchange in traditional houses	251	6998	266	67	1250	31627
24	Roof insulation in houses built with industrialized technology	20	7017	294	73	114	31740
25	Individual metering of consumed district and central heat in traditional houses	16	7034	624	156	84	31824
26	Window exchange in houses built with industrialized technology	64	7098	631	158	369	32193
27	Installation of condensing central gas dwelling boilers for space heating in traditional houses	42	7139	641	160	206	32399
28	Installation of pellets boilers for water and space central dwelling heating in family houses built before 1992	731	7870	710	178	320	32719
29	Individual metering of district and central heat in houses built with industrialized technology	60	7930	1227	307	357	33077
30	Installation of pumps for water and space central dwelling heating in family houses built before 1992	202	8132	1507	377	901	33978
31	Door exchange in traditional houses	11	8143	3479	870	53	34031
32	Door exchange in houses built with industrialized technology	8	8150	5309	1327	43	34074
33	Window exchange in family houses built before 1992	60	8210	5415	1354	732	34806
34	Door exchange in family houses built before 1992	3	8214	30954	7738	39	34845

Table 27 Annual investment costs into mitigation options, million EUR

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
Thermal retrofit of households in traditional houses																			
Installation of TRVs	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13
Basement insulation	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	184
Installation of programmable thermostats	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	78
Roof insulation	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	276
Condensing building central gas boilers	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	54
Window exchange	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	1900
Individual metering	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	169
Installation of condensing dwelling central gas boilers for space heating	25	25	25	25	25	25	25	25	25	25	25	25	24	24	24	24	24	24	442
Door exchange	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	551
Thermal retrofit of households in industrialized houses																			
Installation of TRVs	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	80
Wall insulation	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	890
Base insulation	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	109
Condensing building central gas boilers	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	10
Roof insulation	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	163
Window exchange	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	827
Individual metering for DH and CH	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	1062
Door exchange	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	587
Thermal retrofit of households in family houses built before 1992																			
Installation of programmable thermostats	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	204
Basement insulation	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	1905
Wall insulation	249	249	249	249	249	249	249	249	249	249	249	249	249	249	249	249	249	249	4485
Roof insulation	159	159	159	159	159	159	159	159	159	159	159	159	159	159	159	159	159	159	2858
Pellet boilers for space and water heating	402	396	391	386	382	378	374	370	367	363	359	356	353	349	346	343	340	337	6593
Pumps for space and water heating	222	222	222	222	222	222	222	222	222	222	222	222	222	222	222	222	222	222	3995
Window exchange	272	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	4925
Door exchange	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	1429
Thermal retrofit of family houses built after 2008																			
Application of passive energy design	126	128	127	121	121	125	130	135	142	149	157	167	177	187	197	207	216	222	2,834
Appliances and lights																			
Efficient fridges	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5	73
Efficient freezers	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20
Efficient clothes washers	11	11	12	12	12	12	12	13	13	13	14	14	14	14	15	15	16	16	239
LOPOMO of TV and PC equipment	4	4	4	4	4	4	5	5	5	5	6	6	7	7	8	8	9	10	103
Exchange of incandescents with CFLs	87	0	0	0	0	0	0	87	0	0	0	0	0	0	87	0	0	0	261
Water heating																			
Combi- space and water heating systems and dedicated water heating appliances	62	62	62	62	62	62	62	62	62	63	63	63	63	64	64	64	65	65	1131
Water saving fixtures / households with domestic hot water systems /appliances	12	12	12	11	11	2	2	2	2	2	2	2	2	1	1	1	1	1	78
Water saving fixtures / DH/CH hot water	9	9	9	9	9	1	0	1	1	1	1	1	1	1	1	1	1	1	51
TOTAL	**2226**	**2136**	**2131**	**2121**	**2117**	**2100**	**2101**	**2190**	**2107**	**2111**	**2117**	**2124**	**2132**	**2140**	**2235**	**2156**	**2163**	**2168**	**38577**

Table 28 Energy consumption in the baseline and the mitigation scenario (maximum realized potential) and the potential energy savings

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Baseline energy consumption, GWh/yr.																		
Space heating in traditional houses	7259	7222	7184	7143	7100	7054	7005	6954	6899	6840	6777	6710	6633	6556	6474	6385	6288	6184
Space heating in Industrialized houses	6635	6574	6511	6447	6382	6316	6247	6178	6106	6032	5956	5878	5774	5696	5615	5531	5443	5352
Space heating in family houses built until 1992	25215	25112	24998	24873	24739	24596	24442	24278	24104	23919	23724	23519	23303	23076	22839	22590	22329	22057
Space heating in households built after 2008	255	513	774	1034	1279	1524	1775	2035	2306	2588	2885	3198	3524	3875	4246	4637	5045	5471
Appliances	6548	6461	6371	6280	6184	6086	5986	5885	5794	5701	5608	5514	5426	5339	5263	5260	5261	5286
Water heating	9082	9005	8929	8858	8782	8707	8633	8562	8493	8427	8364	8303	8234	8182	8133	8087	8043	8057
Total	54994	54887	54768	54635	54467	54282	54089	53892	53701	53508	53315	53123	52893	52725	52570	52489	52410	52405
Potential energy consumption in the mitigation scenario, GWh/yr.																		
Space heating in traditional houses	7,066	6,841	6,617	6,394	6,172	5,950	5,728	5,507	5,284	5,061	4,837	4,611	4,380	4,150	3,917	3,680	3,439	3,194
Space heating in Industrialized houses	6,454	6,213	5,970	5,727	5,484	5,239	4,993	4,746	4,497	4,247	3,996	3,742	3,473	3,220	2,963	2,704	2,441	2,174
Space heating in family houses built until 1992	23,359	21,594	19,975	18,473	17,068	15,746	14,494	13,302	12,162	11,068	10,015	8,999	8,016	7,063	6,138	5,239	4,363	3,509
Space heating in households built after 2008	36	73	111	148	183	218	254	291	329	370	412	457	503	554	607	662	721	782
Appliances	5,580	5,389	5,204	5,016	4,823	4,630	4,433	4,244	4,062	3,879	3,694	3,536	3,377	3,216	3,063	2,981	2,898	2,836
Water heating	8,504	7,860	7,234	6,630	6,041	5,888	5,740	5,598	5,463	5,335	5,214	5,100	4,990	4,895	4,809	4,733	4,667	4,629
Total	50999	47970	45111	42387	39771	37670	35642	33687	31798	29960	28168	26445	24739	23097	21497	19999	18529	17123
Potential energy savings, GWh/yr.																		
Space heating in traditional houses	192	381	567	749	928	1,104	1,277	1,447	1,614	1,779	1,941	2,099	2,253	2,407	2,557	2,705	2,849	2,990
Space heating in Industrialized houses	181	361	541	720	899	1,077	1,255	1,432	1,609	1,785	1,960	2,136	2,300	2,476	2,652	2,827	3,002	3,177
Space heating in family houses built until 1992	1,856	3,518	5,024	6,401	7,671	8,849	9,948	10,976	11,942	12,851	13,709	14,520	15,287	16,013	16,701	17,351	17,967	18,548
Space heating in households built after 2008	219	440	663	886	1,097	1,306	1,521	1,745	1,977	2,219	2,473	2,741	3,021	3,322	3,640	3,975	4,325	4,689
Appliances	968	1,071	1,167	1,264	1,361	1,456	1,553	1,641	1,731	1,822	1,913	1,978	2,049	2,122	2,199	2,279	2,363	2,450
Water heating	578	1,145	1,695	2,228	2,741	2,819	2,893	2,964	3,030	3,093	3,150	3,203	3,245	3,288	3,324	3,354	3,376	3,428
Total	3994	6917	9657	12248	14696	16612	18447	20205	21903	23548	25147	26678	28154	29627	31072	32491	33881	35283
Potential energy savings, baseline share																		
Space heating in traditional houses	3%	5%	8%	10%	13%	16%	18%	21%	23%	26%	29%	31%	34%	37%	39%	42%	45%	48%
Space heating in Industrialized houses	3%	5%	8%	11%	14%	17%	20%	23%	26%	30%	33%	36%	40%	43%	47%	51%	55%	59%
Space heating in family houses built until 1992	7%	14%	20%	26%	31%	36%	41%	45%	50%	54%	58%	62%	66%	69%	73%	77%	80%	84%
Space heating in households built after 2008	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%
Appliances	15%	17%	18%	20%	22%	24%	26%	28%	30%	32%	34%	36%	38%	40%	42%	43%	45%	46%
Water heating	6%	13%	19%	25%	31%	32%	34%	35%	36%	37%	38%	39%	39%	40%	41%	41%	42%	43%
Total	7%	13%	18%	22%	27%	31%	34%	37%	41%	44%	47%	50%	53%	56%	59%	62%	65%	67%

Table 29 Baseline CO_2 emissions in the baseline and the mitigation scenario (maximum realized potential) and the potential CO_2 savings

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Baseline CO_2 emissions, thousand tons CO_2																		
Space heating in traditional houses	1471	1462	1452	1442	1432	1421	1410	1398	1387	1374	1361	1347	1331	1316	1299	1282	1262	1241
Space heating in Industrialized houses	1434	1389	1346	1300	1255	1211	1169	1128	1104	1080	1055	1031	1003	989	975	961	946	930
Space heating in family houses built until 1992	5799	5769	5738	5704	5669	5631	5592	5550	5506	5460	5411	5360	5307	5252	5194	5134	5072	5006
Space heating in households built after 2008	42	84	127	169	207	245	284	323	364	406	450	496	543	594	648	705	763	823
Appliances	2274	2206	2138	2061	1985	1911	1839	1768	1769	1770	1770	1770	1770	1742	1717	1716	1716	1724
Water heating	2067	2016	1967	1916	1865	1816	1768	1723	1707	1691	1676	1661	1644	1628	1613	1598	1584	1578
Total	13087	12927	12768	12592	12414	12236	12062	11890	11836	11780	11723	11665	11599	11522	11447	11395	11342	11303
Potential CO_2 emissions, thousand tons CO_2																		
Space heating in traditional houses	1,432	1,384	1,338	1,291	1,245	1,199	1,153	1,107	1,062	1,017	972	926	880	833	787	739	691	642
Space heating in Industrialized houses	1,395	1,313	1,234	1,155	1,079	1,006	936	869	815	763	711	660	608	564	520	475	430	384
Space heating in family houses built until 1992	5,183	4,621	4,122	3,675	3,271	2,904	2,570	2,264	1,988	1,734	1,502	1,288	1,093	912	747	596	461	339
Space heating in households built after 2008	6	12	18	24	30	35	41	46	52	58	64	71	78	85	93	101	109	118
Appliances	1,938	1,840	1,746	1,646	1,548	1,454	1,362	1,275	1,241	1,204	1,166	1,135	1,102	1,049	999	972	945	925
Water heating	1,922	1,733	1,554	1,381	1,218	1,146	1,078	1,013	970	928	888	850	812	775	741	709	680	655
Total	11875	10903	10012	9172	8390	7744	7139	6574	6128	5705	5303	4930	4572	4219	3886	3593	3316	3063
Potential CO_2 savings, thousand tons CO_2																		
Space heating in traditional houses	39	77	115	151	187	222	257	291	324	357	389	421	452	483	513	542	571	39
Space heating in Industrialized houses	39	77	112	145	176	206	234	260	289	317	344	371	395	425	455	485	516	39
Space heating in family houses built until 1992	616	1,149	1,616	2,030	2,398	2,727	3,022	3,286	3,518	3,725	3,909	4,072	4,215	4,340	4,448	4,538	4,611	616
Space heating in households built after 2008	36	72	109	145	178	210	243	277	312	348	386	425	465	510	556	604	654	36
Appliances	336	366	392	415	437	457	477	493	529	566	604	635	668	692	717	744	771	336
Water heating	145	283	413	535	647	669	690	710	737	763	788	811	832	853	872	889	904	145
Total	1211	2024	2756	3420	4024	4492	4922	5316	5709	6076	6420	6735	7028	7303	7561	7802	8026	1211
Potential CO_2 savings, share of baseline																		
Space heating in traditional houses	3%	5%	8%	10%	13%	16%	18%	21%	23%	26%	29%	31%	34%	37%	39%	42%	45%	48%
Space heating in Industrialized houses	3%	6%	8%	11%	14%	17%	20%	23%	26%	29%	33%	36%	39%	43%	47%	51%	55%	59%
Space heating in family houses built until 1992	11%	20%	28%	36%	42%	48%	54%	59%	64%	68%	72%	76%	79%	83%	86%	88%	91%	93%
Space heating in households built after 2008	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%
Appliances	15%	17%	18%	20%	22%	24%	26%	28%	30%	32%	34%	36%	38%	40%	42%	43%	45%	46%
Water heating	7%	14%	21%	28%	35%	37%	39%	41%	43%	45%	47%	49%	51%	52%	54%	56%	57%	58%
Total	9%	16%	22%	27%	32%	37%	41%	45%	48%	52%	55%	58%	61%	63%	66%	68%	71%	73%

7.4 Future research needs

This section describes the opportunities for reducing the limitations of the research and improving the quality of its results.

7.4.1 Background statistics for the residential sector

A model can be only as good as its input data (SAFE, 2002). Unfortunately, the background statistics for the residential sector and the market information about the Hungarian technological trends is scarce, contradicting, uncertain, and, thus, is difficult to trust. Moreover, if such information is available, it is often difficult and very expensive to obtain. In this context, the model can be improved significantly with better data support. The authors found especially difficult to obtain the information for the important energy end-use options such as space and water heating consuming at least ¾ of the residential final energy. For better results, the authors think that the key data to collect are:

i. The age structure of the buildings stock by types of buildings in dynamics

ii. Better information about energy consumption of not occupied dwelling stock

iii. The average thermal properties of dwellings and building geometry by building types

iv. Energy heating requirement by building types

v. The space and water heating mode split in dynamics

vi. Energy requirement, fuel mode split in dynamics and installed efficiencies for cooking

vii. Installed heating and water heating equipment efficiencies

viii. Installed efficiencies of small household appliances and air-conditioners, review of market trends of these appliances for Hungary

7.4.2 The wider list of mitigation options

While the authors tried to cover as many mitigation options as possible, their scope was limited to only those which provide undoubtedly the largest potential for CO_2 mitigation. This does not mean, however, that other options are always less significant.

First, it is important to cover the left out thermal options for buildings constructed during 1993-2008. Even though their potential is likely to be significantly lower than that of other building types, these buildings are also criticized for their high energy use.

Second, exclusion of the factor of reduced air leakage results in significant underestimation of the potential of window and door exchange. Even though, this option is likely to be still quite expensive to save CO_2 if the air leakage is considered, it can be easily implemented and stimulated in households.

Increasing demand for amenities and entertainments is expected to boost the electricity consumptions of small electric appliances. Even though, presently they occupy less than app. 20% of electricity demand (GFK, 2004), they are expected to be the major contributors to the future growing electricity consumption trends, and this is why are important for the future research initiatives.

Due to the lack of data, efficiency options related to cooking and motors (lifts) were not studied. It is not yet clear how much these energy end-uses contribute presently to the final energy demand of the Hungarian residential sector and how high their present efficiencies are. As regarding to cooking, it is often believed that the importance of energy for cooking is going down due to the changing lifestyle, food preferences (more prepared and canned food), and other factors. As for lifts, the authors have never seen this energy end-use included into the Hungarian statistics, even though, lifts should contribute significantly to the electricity demand in multi-floor buildings. It is important to study these options for a better understanding of energy end-use and related CO_2 emissions in the residential sector which may also host the potential for CO_2 mitigation.

Increasing demand for air-conditioning is mainly the driver for electricity use in the European southern countries due the fast penetration of small residential air-conditioners (Bertoldi and Atanasiu, 2007), however, with warming climate air-conditioners can be more and more often seen in the Hungarian residences. Although it is unlikely that Hungary will reach as high level of air-conditioning penetration as in the US or the South of Europe due to cultural differences, it is already the reason for extremely high peak loads in summer. If the intensive building stock retrofit program will be realized, reduced air infiltration will result in the need for more air ventilation and conditioning.

Finally, for better understanding of the residential energy consumption baseline it is worth to include into the research buildings and houses heated with biomass even though their emissions are considered zero (due to the fuel sustainability).

7.4.3 Limitation of uncertainties

There are many ways to reduce uncertainties and clarify assumptions applied in the model. This includes but not limited to investigation of an expected decrease of heating degree hours and an expected increase of cooling degree hours for Hungary, consideration of the heat released by domestic appliances and lights, better research for energy price dynamics over 2008 – 2025, investigation of the price dynamics of the reference and advanced technologies, research on the market trends for space and water heating technologies in Hungary, research on CO_2 emission factors for electricity and consumed heat in households, and other parameters.

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