A building stock-level investigation on residential gas consumption setback possibilities in central Europe

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Abstract

Residential buildings, as one of the main contributors to climate change, are regularly in the target of climate change mitigation. The energy crisis in has accelerated the need for cutting natural gas consumption of the sector, hence the necessity for short and middle term measures increased drastically. The focus of this paper is to introduce recent research efforts where possible actions were investigated that could swiftly tackle the problem and lower residential heating energy usage.

Highlights

- The new regulation on natural gas pricing led to higher expenditure and encouraged the residents to spare.
- Dynamic building simulation tool was used to model the energy use of buildings.
- Older family houses (before 1990) account for 67% of the gas consumption in the domestic building stock.
- Medium term gas saving potential of Hungary is 17.1%.
- Short-term savings by a change in consumer habits is 6%.

Introduction

The 2022 gas price shock put an unequal exposure of households all across Europe. In recent years, the price, consumption and dependence on natural gas and the policy implications has been the subject of a number of studies (Erias & Iglesias, 2022; Kotek et al., 2023; Uribe et al., 2022). The expectation is to reduce gas consumption rapidly, which can eventually speed up the transition towards decarbonized energy systems (Pastore et al., 2022).

Households experience high inequality in heating expenses, which originates from the building type, ownership, thermal insulation status, HVAC system and consumer behavior.

According to a German study (Kröger et al., 2023), homeowners who live in their own apartments have higher incentives to carry out energy efficiency measurements than landlords. These measures, such as thermal insulation, correspond with lower gas expenditure. Within the building stock, low-income households can spend a five times higher share of income on gas.

Based on an empirical study (Favero & Grossi, 2023), for households, a 1% increase in natural gas price reduces residential consumption in the range of 0.23-0.51%. The home size and age are essential factors: the study showed that larger-sized homes used more natural gas and newer homes consumed less. The users with self-reading gas meters are aware of their consumption, so they have more incentive to apply energy-saving measures.

The investigation of resilience of residential buildings to unexpected long-term disruption of gas supplies become inevitable. Dynamics simulations can be carried out to simulate e.g., a disruption of gas supply and to investigate the passive and active resilience of buildings (D’Agostino et al., 2023).

In the case of Hungary, gas and electricity prices have been capped since 2014 and did not follow wholesale market prices. Differential between wholesale and retail prices was financed by budgetary expenses and cross-financing between market participants. Due to the high burden of energy soaring prices in 2022, the price regulation was reformed and a block tariff for electricity and gas was introduced. For the lower-than-average consumption, capped prices were sustained, but for any volumes exceeding the average, a sevenfold price was to be paid in gas and a twofold in electricity tariffs. The rise in gas prices significantly exceeded the rise in electricity prices, but none of this was felt in Hungary’s residential segment because of the regulated end-user prices – utility cost reduction (UCR) (Weiner & Szép, 2022) – until July 2022. The essence of the sudden and very short-notice amendment is that the reduced utility cost remains in place for the average residential consumption, defined as 1729 m³/year of natural gas. At the same time, any excess consumption is exposed to so-called “market forces”, which can mean an increase of 7-9 times.

One of the main benefits of the new regulation is that it will send a direct and clear message to consumers to save on natural gas. If they stay below the target level, this consumption will not become more expensive. In addition to saving, the new price regulation also encourages energy efficiency and renewable investments, which have much shorter payback period in high energy price environments.

In the days following the government announcement, there was a spike in searches for energy-related terms. The growing demand for alternative heating systems, fuels, and thermal insulation has also been reported in the press (increased demand for heat pumps, air conditioners capable of heating, firewood). A spike in demand for solar panels was observed and also an increase in the sale of fireplaces, stoves, solid fuel boilers. Demand for thermal...
the modelling and analysis. From the available building typology, virtual buildings were created based on the mean and variance of the surveyed building sample. This survey was used to create the building's thermal envelope, structure and additional variables such as the existence of a basement, heated attic, shading options, and infiltration.

The simulations were used to calculate the buildings' net energy demand and examine the variations in the operation of the building.

After the general analysis, where the net energy demands were simulated, available options for reducing gas consumption were reviewed. We investigated the extent to which these represent a permanent reduction, and the limitations that must be considered (priority orders, duration of construction, lack of skilled labor, etc.) when implementing them. We use this data to estimate the consumption reduction potential of each measure in the short and long term.

Households have several options for reducing consumption:

- Changes in consumer behavior
- Permanent and reliable reduction of energy demand with thermal insulation investments
- Replacement of gas heating with alternative heating methods

To reduce the population's long-term dependence on natural gas, measures that result in a lasting and secure reduction in energy demand with a return on investment over the lifetime are the most appropriate. Measures that can be implemented quickly and at zero or minimal cost are listed in Table 1.

### Methods

An accurate picture of the current domestic housing stock is needed to answer these questions. A previous study (ÉMI Kft., 2015) classified the building stock using 23 measurements by age, size (detached, small, and large multi-family houses), and construction technology (adobe, brick, prefabricated panel). The typology and database, based on a representative survey of 2029 residential buildings, can be used to model the energy use of dwellings, and analyze the impact of different energy-savings measures (REKK 2022).

DesignBuilder 6.1.5.002 (DesignBuilder, 2019) was used with the same boundary conditions and weather files for the UCR revision raises two critical questions:

- Which household segments are best positioned to reduce natural gas consumption in the short term?
- What is the potential natural gas consumption savings in the residential sector?

This study aims to answer these questions with the application of dynamic whole building simulations. In general, studies focus on fewer number of homes; in our research we use an existing building typology to cover the whole Hungarian building stock.

### Table 1: Changes in consumer behavior and low-cost measures that can be implemented in the short term

<table>
<thead>
<tr>
<th>Measure</th>
<th>Impact on energy demand</th>
<th>Feasibility</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumer behavior (heating to a lower temperature, heating fewer rooms)</td>
<td>Price incentive reduces energy requirements to a small or medium extent.</td>
<td>Immediately</td>
<td>Practically zero investment cost.</td>
</tr>
<tr>
<td>Design of heating that can be controlled per room and programmed at least per apartment</td>
<td>Enables partial heating of buildings and requires proper operation.</td>
<td>1-2 months and quick payback</td>
<td>Recommended in addition to all other measures.</td>
</tr>
<tr>
<td>Attic slab insulation</td>
<td>Reduces energy demand reliably, permanently, and significantly.</td>
<td>1-2 months</td>
<td>Attic slab insulation is low-cost and easy to implement with no maintenance costs.</td>
</tr>
</tbody>
</table>

Changes in consumer behavior, such as reducing the room temperature and the heated floor area, have immediate results without investment. Of course, this involves a reduction in comfort level, but it does not represent a health risk. However, in the absence of effective energy prices, residents have no incentive to save energy.

For apartments or central heating, the priority is regulating heating per room and at least programming each apartment. Without this, the most essential conservation measures including partial heating, intermittent heating, and heating according to a schedule, cannot be achieved.

Insulating the attic slab of a detached house is a speedy, low-cost investment that can lead to significant savings. It does not require hiring skilled labor or additional permits. Lighting upgrades are low cost and achieve savings in electricity consumption but does not directly affect gas consumption.

In addition to measures that can be implemented in the short term, it is also important to address longer-term, deeper solutions such as thermal insulation. With only 25% of family houses in Hungary thermally insulated, the potential savings dwarfs other measures. This is a very low figure for the region compared to Austria (80%).
Poland (59%), or even Slovakia (35%) (Pénzcentrum, 2021). The current situation is mostly attributable to end-consumer price controls (the reduction of utility costs) over the past decade that have not triggered private investment and the minimal attention paid by the government to residential energy efficiency programs. In other countries where a comprehensive thermal insulation program has already been implemented, authorities could move onto further measures for greening the building stock, such as renewable energies, smart technologies, and electrification. Unfortunately, Hungary is still at an early stage of thermal insulation and is not ready for these steps yet.

Table 2 presents the essential energy efficiency measures. It should be noted that as a result of the increased demand over the recent period, there are labor and product shortages creating project delays.

Façade thermal insulation permanently, reliably, and significantly reduces the energy demand of buildings. The UCR intervention has led to a significant increase in demand for thermal insulation, which has pushed up prices of materials and services. However, insulation works cannot be carried out during winter. Replacement of windows and doors is a relatively high unit investment for more moderate energy efficiency gains, but it is often carried out for other reasons, such as better acoustic insulation, ventilation, or the obsolescence of previous windows.

Mechanical heat-recovery ventilation and the “smartening” of buildings should be pursued only after thermal insulation and replacement of windows and doors. With only small or medium energy savings, owners tend to make these investments for other reasons, not for energy-saving purposes. On the supply side, replacing a heat-generating appliance (other than a gas boiler) may require disconnecting the building from the gas network or running a parallel system for security of supply. In all of these cases, delays in construction due to labor and product shortages should be expected.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Impact on energy demand</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas boiler exchange for a condensing boiler</td>
<td>Reduces gas consumption but maintains it for at least 10-15 years.</td>
<td>Without adequate maintenance system efficiency deteriorates.</td>
</tr>
<tr>
<td>Heat pump</td>
<td>Reduces gas consumption and (to a lesser extent) increases electricity demand.</td>
<td>Considerable maintenance cost. In the absence of adequate maintenance, system efficiency deteriorates. Cost-effective for low energy demand.</td>
</tr>
<tr>
<td>Solar panel</td>
<td>Only significantly reduces electricity consumption in the summer.</td>
<td>Reduces electricity demand in the summer and increases it in the winter.</td>
</tr>
<tr>
<td>Biomass boiler</td>
<td>Reduces gas consumption but increases air quality risks associated with burning of firewood and waste incineration.</td>
<td>Significant operating and maintenance requirements for modern units that puts system efficiency at risk.</td>
</tr>
</tbody>
</table>

Results and discussion

We simulated the expected monthly net energy (assuming natural gas space heating, hot water supply, and cooking with an average temperature for the 2021-22 heating season) for each building type using averages. These have been converted to gas consumption by typical heating system layouts and their average efficiencies of each building category. Figure 1 shows that family houses built before the regime change (types 1-8) are the most affected by the regulation change.
The new volumetric price ceiling of 144 m³ per month only covers 41-56% of the average annual gas consumption of family homes. In Figure 1, the red bars belong to the market-priced category. Occupants of modern detached houses (categories 11-12) and renovated buildings are comfortably within the state-subsidized volume.

Due to the massive price gap between regulated and market prices, the regulation imposes a disproportionately large burden on those living in apartments in the first 8 categories. For these categories, the utility costs are 7-10 times higher than newer and more modernized buildings that fall within the volumetric limit set by the UCR and therefore have no financial incentive to save.

Detached houses built before the regime change account for 52% of the gas-heated housing stock and consume about 67% of the total annual gas used by the housing stock. If the gas consumption of building categories 1 to 8 were reduced to the preferential volume threshold, this would represent a gas saving of 31%.1 These building categories also have the highest share of non-gas heating users.

After the current gas consumptions were modelled and analyzed, the more conscious, energy-efficient operations were investigated. It can be said that we can comfortably reduce the gas consumption of residential buildings by 10-20%. Further significant reductions are possible, but only at the cost of real comfort losses.

Our modeling results show that reducing the internal temperature of households can achieve heating energy savings of 5-9% per °C. Figure 2 shows the heating demand savings for building type 4 with continuous heating between October 15 and April 15. The exact value depends on the starting temperature, the design and function of the building, the internal air temperature, and the weather. A reduction of 2-3 °C alone can result in savings of up to 14-20%.

(Figure 3) that the buildings largely unaffected by the UCR change are more overheated than single-family houses, and therefore do not receive price signals to manage their consumption levels.

**Figure 2: Net heating demand savings achieved with 1 °C temperature reduction (HH20C_181day=2926 hK)**

According to representative surveys, a significant share of Hungary’s buildings is unnecessarily overheated, so a 1-3 °C reduction in many cases does not represent any health risk with appropriate clothing. However, the ENABLE project (Galev & Gerganov, 2018) finds


1 This assumes that all buildings are considered to be occupied


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**Figure 3: Typical indoor air temperature trends during the heating season according to the residents' opinion**

The complete omission of heating outside the heating season (between April 15 and October 15) can save 10%. According to our non-representative measurements, significant waste is caused by higher ventilation when the heating turns on and off at the beginning and end of the heating season. If households do not heat outside the heating season, ventilation habits will be more sensitive to weather conditions. Another option is to reduce hot water temperatures.

Our modeling results show that intermittent heating (ideally according to a set schedule) in residential buildings can save a few percentage points of savings with economical operation at night or on weekdays (Figure 4). In the case of a non-residential function, much larger savings (10-30%) can be realized with economical operation during non-operational periods (nights and weekends). To achieve this, it is advisable to install a programmable thermostat and check it regularly. It is patently false to claim that no substantial savings can be achieved with intermittent heating because of the higher energy required to heat up.

**Figure 4: Net heating demand reduction with programmed heating (HH20C_181day=2926 hK)**
Limiting the heated floor space lowers heating demand proportionally. There is no available data measuring floor area heated in family houses built before 1990. We assumed that households reduce heated floor area to a minimum with fewer individuals inhabiting the house.

Assessing the energy-saving potential of renovation

The available savings varies from building to building, as shown in Figure 5. Façade thermal insulation for single-family houses has higher savings potential than larger buildings, meaning that the heat supply system or heat recovery ventilation may be more economic for apartment buildings. The savings potential is also lower for newer buildings. The lower the building savings are the greater the potential for roof or attic insulation.

Figure 5: Energy savings can be achieved with the most common measures for individual family house types

We also examined the investment cost, the available savings, and the payback times of the most impactful refurbishment measures. The results showed that for buildings significantly exceeding the UCR limit, the payback time is an order of magnitude shorter than for other buildings. Based on this, the recommended focus can be clearly identified: thermal insulation of family houses built before 1990 and improvement of heating control systems. Although the investment costs have risen since the data was collected, payback periods will remain short even with double the investment costs.

The total savings potential for the most important measures (including measures affecting consumer behavior) for gas-heated building types (1-8.) are summarized in Table 3. In the table, within behavior change, measures A-E are net energy demand values derived from dynamic simulations; combined effects contain estimates. The first four options are the results of dynamic simulations within refurbishment, and the last two are estimations. Quick and easy measures (B-D) can be carried out with a minimal decrease in comfort to save 6.6% of the total natural gas consumption. Reducing the heated floor area by 20% adds an additional savings of 9% but would significantly reduce comfort. In the medium-term, complex refurbishment and proper usage would save 17.1% without loss of comfort.

In theory, the long-term savings potential for the entire residential segment is 3.9 billion m³/year, 34.5% of the total Hungarian natural gas consumption, with heat pumps and extension of measures to other building types.

2 The amount of this is considerably smaller if the unheated room is “heated around” or if the building has good thermal insulation. Savings are effective if the heated and unheated rooms are hermetically sealed.
Heat pumps and direct electric heaters (e.g., electric heating panels, electric underfloor heating, electric boilers) can, in principle, achieve 100% gas savings, though not for cooking, but this significantly increases electricity demand load, as shown in Table 4 (excluding indirect gas demand for electricity).

Table 4: Impact of electric heating to achieve gas reduction of 100 million m³/year

<table>
<thead>
<tr>
<th>Modernization alternatives aimed at refurbishing family houses built before 1990</th>
<th>Number of renovated buildings (= apartments)</th>
<th>Natural gas savings potential for 1 year</th>
<th>Electric energy demand increase for 1 year</th>
</tr>
</thead>
<tbody>
<tr>
<td>heat pump, 1-8. type</td>
<td>46849</td>
<td>1.1%</td>
<td>100</td>
</tr>
<tr>
<td>thermal insulation + window + heat pump, 1-8. type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>electric heating panel, 1-8. type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>thermal insulation + window + electrical heating panel, 1-8. type</td>
<td></td>
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</table>

Conclusion
The rapid reduction of gas consumption for this winter and more gradual gas substitution are matters of strategic importance for Hungary as a country highly dependent on Russian gas. In the first eight months of 2022 leading up to the heating season industry significantly curtailed, leading to a drop in production that triggered job losses and an economic downturn. Gas substitution in the electricity sector typically means switching to polluting coal and oil. The more the building sector can contribute to reducing gas heating demand across Europe, the cheaper prices will be for industry and power sectors to operate as needed.

The July 2022 UCR price revision provides a price incentive to residential gas consumers for the first time since its inception nearly a decade ago. The study highlights the selectivity of the regulation, which mostly affects people living in family houses built before 1990. These older family houses account for 67% of the gas consumption in the domestic building stock. Due to deferred energy efficiency investments, this stock is in very poor condition by European standards. This also means it has the greatest energy-saving potential, but the
available income level and investment potential of this segment needs further analysis and was not the subject of this paper.

According to the modeling, available short-term savings in the building sector by a change in consumer habits (reducing the room temperature, reducing the heated floor area, intermittent heating, increased attention at the beginning and end of the heating season) is 6%.

Most buildings have been overheated up to now, and resolving this may require a low-cost technical intervention in the form of adjustable heating for each room. However, there is a risk that the savings will go beyond the threshold for health and comfort (which is a decrease of 1-2 °C). Especially in poorly insulated and outdated buildings, the heat sensation will always be lower than in a well-insulated modern building. Due to the low temperature, unhealthy conditions (lack of ventilation, mold formation) can also increase.

Because residents living in apartment buildings are only marginally if at all affected by the UCR revision, their contributions were not considered in this study. For district heating, the service providers and the municipal owners are exposed to higher gas prices and therefore could respond with central reduction where this is technically possible. Such a measure can be justified and communicated in terms of social solidarity.

A permanent reduction in gas demand can be achieved through technical measures that reduce energy consumption. According to our calculations, medium term gas saving potential of Hungary (complex renovation of family houses built before 1990 and efficient use that does not involve significant comfort loss) is 17.1%. Updating household heating control is an essential and cheap first step, though the savings potential is limited. With a targeted information campaign, this can be sensibly implemented by this winter. More significant long-term savings can be achieved with cost-effective thermal insulation, including attic slabs.

Changing the energy source (switching to firewood where it is possible) is a short-term remedy and should not be widespread. It is not an alternative to reducing energy needs in the medium term.

The current high sensitivity of the public to this issue is an excellent opportunity to launch an effective information campaign to dispel misconceptions, to convey the expected impacts of measures on efficiency, savings potential, the scale of costs, proper operational upkeep, importance of energy management, air pollution, etc. To promote the spread of quality information, energy consulting services and information platforms should be better supported and developed, especially at the local level.

The imposition of the UCR revision will be extremely challenging for some segments of society already categorized as or becoming energy poor. Thus, decision-makers will need to prioritize investment programs aimed at reducing energy use based on the return on investment to support them.

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REKK 2022 The impact of the changes in the utility cost reduction system on the gas consumption of the Hungarian residential sector (in Hungarian: A rezsicsökkentés szabályváltozásának hatása a magyar lakóépületszektor gázfogyasztására) (g-2204-63907 project)


