Bilateral Seminar Paper

Energy Saving

Economic and environmental aspects
of energy systems

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Contents

1 Abstract

This seminar paper investigates the potential for energy savings in households across the Czech Republic and Austria, emphasizing the need for efficient energy use in residential heating to meet the EU's "Fit for 55" targets by 2030. This work provides insight into the residential stock in both countries and introduces the reader to the specific context of each country.

In the Czech Republic, significant energy consumption within the residential sector indicates substantial opportunities for enhancement. The examination includes a segmentation of the housing stock, analysis of prevalent energy sources, and the effectiveness of existing insulation and heating control technologies. The study identifies various challenges, including economic and bureaucratic barriers that hinder the implementation of energy-saving measures. The paper discusses the strategies employed by the Czech government, such as the "New Green Savings" program, which provides financial incentives for energy-efficient renovations.

Similarly, the Austrian segment of the paper looks at the country's housing and heating landscape, discussing the primary energy sources for heating and the impact of governmental strategies under the Energy Efficiency Directive. It assesses the national efforts to promote energy renovations and the use of renewable energies in both new constructions and existing buildings.

Furthermore, the paper compares the energy efficiency landscapes of both countries, considering the architectural and economic contexts that shape their energy use in households. It also introduces a micro-economic model for energy saving, applied in practical case studies from Vienna and Jince(CZ). This model analyzes individual energy consumption scenarios to recommend optimal energy-saving adjustments.

Conclusively, this comparative study underscores the importance of individual and national strategies in achieving energy efficiency. It advocates for educational efforts and policy enhancements to support households in transitioning towards more sustainable energy use practices. This initiative not only aligns with environmental goals but also offers economic benefits by reducing energy costs and dependency on fossil fuels.

2 Introduction

In recent years, as the effects of climate change have become more and more apparent, the quest for ecological and sustainable living have become increasingly urgent. One of the key aspects of this effort is energy saving, especially within households which consume a third of primary energy within the EU. Essentially, energy saving is a deliberate effort to minimizing the amount of energy consumed for energy services while maintaining the desired level of comfort and functionality. Heating typically amounts to two-thirds of the energy consumption in residential buildings in mid Europe [1].

This seminar paper focuses on a comparison of the Czech Republic and Austria. While both nations share geographical proximity and climatic similarities, variations in economic development and policy implementation over the last decades, may have yield to different outcomes regarding the same goal. First, the current state of energy efficiency in both countries will be compared from a macro economic stand point, both in terms of thermal insulation and the type of technology used for heating. Afterwards possible synergies will be highlighted in a bilateral context and also regarding the EU. Last but not least, current modern technologies such as smart heating will be discussed on a micro economic model for energy saving. Although we only implement a rudimentary approach to smart heating, the use of IoT devices and machine learning enables efficient management and planning of consumption and helps the overall stability of the transmission system - both for district heating and the electricity grid since power intensive heat pumps become a more and more common technology.

In general energy saving in the heating sector for private households can be achieved by the three methods:

- Use of more efficient technology i.e. less primary energy for same amount of end energy
- Better thermal insulation
- Adjusting the energy service of a tempered home to the real usage i.e. lower temperatures in an empty house

Although the long term goal is to improve all of these sectors, one interesting question we are trying to answer in the second part of this paper is: What to improve first as an individual private home owner? Thus transitioning from the macro-economic status quo to the individuals who act on the micro-economic level and thus create change. Based on our model we are going to give suggestions on reasonable national standards, subsidies and other alternatives to enhance a transition to an ecological and sustainable future.

3 Situation in Czech Republic

This chapter examines the energy consumption characteristics within Czech households, focusing on how the properties of the housing stock influence energy use and efficiency. A significant portion of the national energy consumption is attributable to residential sectors, presenting substantial opportunities for energy savings.

We begin with an overview of the Czech Republic's housing stock, categorizing residences into family houses and apartment buildings of varying sizes. This segmentation is essential for developing tailored energy efficiency strategies suitable for different dwelling types.

Additionally, we analyze current energy consumption patterns, emphasizing the predominant energy sources and the uptake of modern heating technologies. Given the limited scope for technological change in households reliant on supply heat, we focus on opportunities for improving heating control and modifying consumer behavior.

The chapter also identifies key obstacles to implementing energy-saving measures within the Czech context. These insights are intended to illuminate effective strategies and potential challenges in enhancing household energy efficiency. Unless otherwise cited, all data are from the Czech Statistical Office.[2]

3.1 Overview of the Czech Republic's housing stock

The housing sector in the Czech Republic exhibits a substantial distribution between family houses and apartment buildings. There are 1,709,845 family houses, a significant figure that indicates a strong preference for this type of dwelling. In contrast, there are 207,540 residential buildings that are classified as apartment buildings.

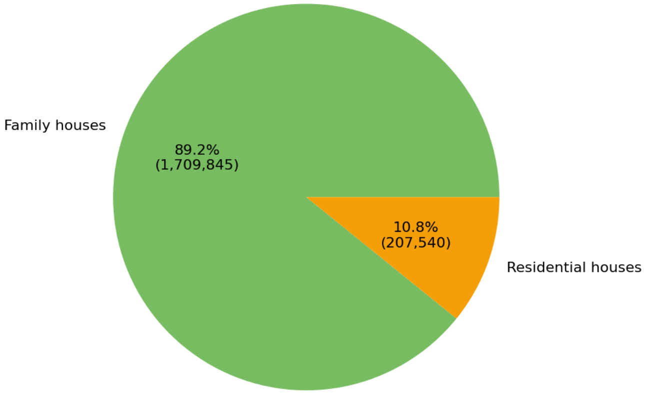

Figure 1: Number of family and residential houses

However, when considering the number of apartments within these categories, we find a total of 1,974,855 apartments situated within family houses, while apartment buildings contain as many as 2,431,918 individual apartments. This data suggests that while the number of standalone family houses is considerable, the number of individuals living in apartments, particularly those within apartment buildings, is even larger, reflecting the density and housing structure within urban areas of the Czech Republic.

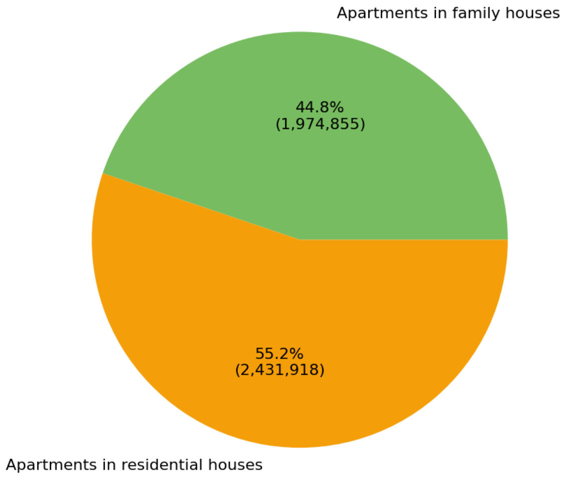

Figure 2: Number of apartments in family and residential houses

Figure 3 depicting the construction and reconstruction of apartments in the Czech Republic indicates a distinct trend influenced by historical context. The period between 1946 and 1970 saw the largest number of apartments constructed, with a total of 926,599. However, this 25-year span overshadows the fact that, on an annual basis, the 1971-1980 period actually witnessed the most intensive construction activity. The decade is marked by the panel building boom, a characteristic of the communist era in Czechoslovakia, which resulted in 818,932 units being built. While previous periods such as 1920-1945 also saw substantial construction due to interwar and postwar needs, accounting for 530,998 units, the subsequent decline after the 1980s is notable. The periods of 1981-1990 and 1991-2000 reflect a slowdown, with 617,148 and 337,880 apartments constructed, respectively. The early 2000s saw a modest increase in construction activities, yet recent years (2011 onward) have demonstrated a more conservative approach.

Figure 4 showcasing the distribution of apartment sizes in square meters across various ranges highlights a notable trend in living spaces. The most common apartment size falls within the 60.0-79.9 square meters range, with approximately 1,188,305 units, reflecting a preference for moderately sized living spaces.

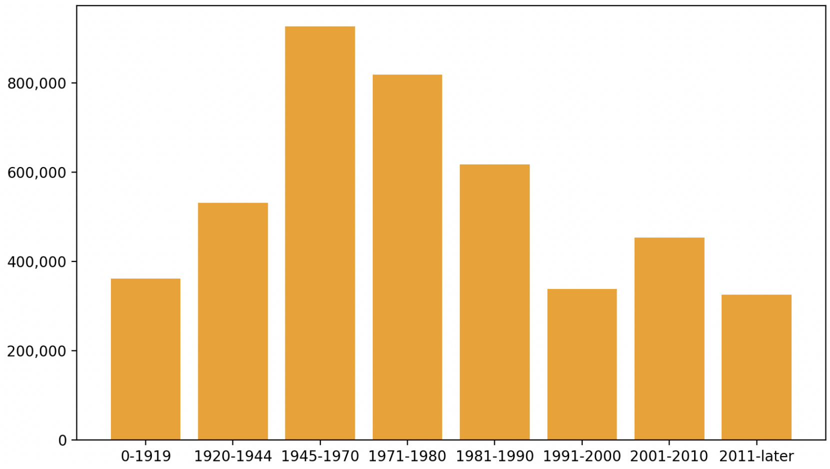

Figure 3: Occupied apartments by house construction period or reconstruction

The next highest category is the 40.0-59.9 square meters range, with 788,211 apartments, suggesting that smaller, more compact apartments also form a significant portion of the housing market. In contrast, the least common are apartments between 100.0-119.9 square meters and those in the range of 120.0-149.9 square meters, with counts of 382,228 and 362,571 respectively.

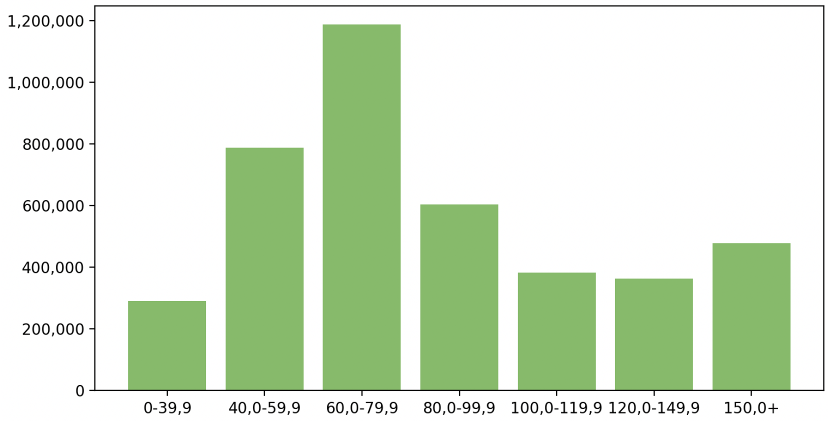

Figure 4: Number of apartments by total area in m^2

3.2 Current energy consumption patterns

The figure 5 of main energy sources used for heating in occupied apartments shows a strong preference for natural gas and district heating, with 1,534,547 and 1,497,565 units respectively, highlighting their prominence in residential heating. Electricity and wood also play significant roles, used in 390,376 and 357,583 apartments respectively, indicating their utility where gas is less accessible. Coal, coke, and briquettes are still used in 240,623 units, reflecting traditional choices. Lesser-used sources like heat pumps and wooden pellets, in 101,982 and 23,953 apartments, suggest a shift towards more sustainable options. This distribution underscores diverse heating preferences shaped by availability, economic considerations, and environmental factors.

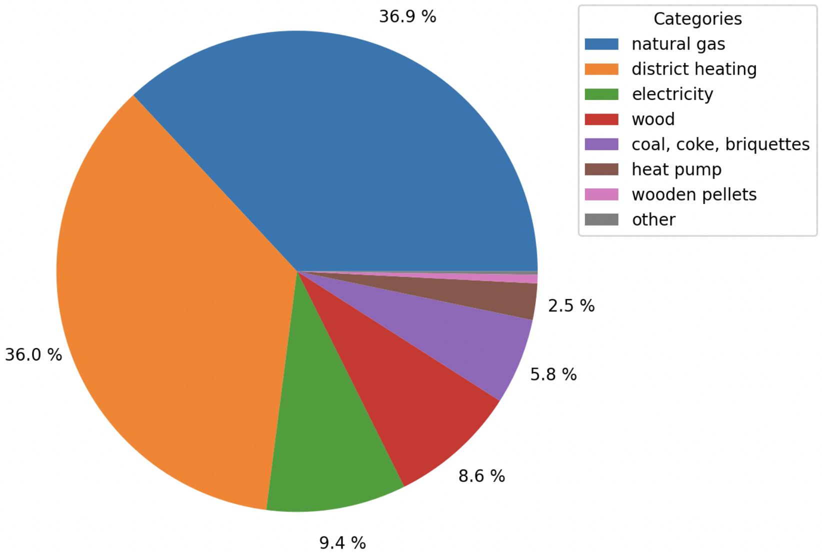

Figure 5: Occupied apartments by main energy source used for heating

In the context of residential heating, the main sources of energy and the prevalence of supply heat play a pivotal role in shaping the opportunities and challenges associated with implementing energy-saving measures. This discussion explores how these factors impact the effectiveness and adoption of such initiatives.

Natural gas and district heating dominate as primary sources for residential heating, as evidenced by their widespread use in the majority of apartments. Natural gas, due to its relatively efficient combustion and existing widespread infrastructure, offers a somewhat cleaner alternative to other fossil fuels like coal or oil. However, while it is more efficient, it is still a significant source of CO2 emissions. When it comes to district heating, the centralization allows for advanced technologies like waste heat recovery and integration with renewable energy sources, which can be more challenging to implement at an individual household level.

Electricity is a flexible heating source that can be produced from renewable resources, making it pivotal for future energy transition strategies. However, its efficiency as a heating source depends significantly on the method of electricity generation and the efficiency of the heating technology, like heat pumps, which can be highly efficient but have high upfront costs. Wood and other biomass sources are considered renewable, but their impact on air quality and CO2 levels can vary greatly based on technology and the type of biomass used.

The extensive use of supply heat, especially in urban areas through district heating systems, can limit individual choices for switching to alternative heating solutions. While these systems can benefit from economies of scale and potentially reduce overall emissions when integrated with renewable energy sources, they also pose significant challenges when it comes to upgrading infrastructure or changing fuel sources due to the scale and complexity of such systems.

The current dominance of natural gas and district heating influences the range of feasible energy-saving measures. For instance, in areas heavily reliant on these systems, significant improvements can be achieved through enhancing network efficiencies and incorporating sustainable energy sources. Conversely, the effectiveness of measures like insulation, window upgrades, and thermostatic controls remains universally beneficial, reducing overall demand regardless of the energy source.

In summary, while the prevalent use of certain main energy sources offers some avenues for efficiency improvements and environmental benefits, it also introduces constraints that require comprehensive strategies encompassing technological upgrades, policy frameworks, and consumer engagement to effectively reduce energy consumption and emissions in residential heating.

3.3 Technological adaptation and control measures

The data from the figure 6 on insulation methods within Czech apartments provides insight into the prevalence of various insulation types. Out of the 4,304,173 total occupied apartments, 2,024,443 (47.0 %) have wall insulation, which is the most common form of insulation reported. Roof insulation is present in 1,447,098 apartments, representing 33.6 % of the total. This suggests a significant opportunity for improving heat retention by increasing the number of apartments with roof insulation. Thermal insulation windows have been installed in a substantial majority, with 3,245,828 apartments (75.4 %) having them, indicating a widespread adoption of this energy-saving measure. However, there remains a considerable proportion, 810,967 apartments (18.8 %), that lack any form of insulation at all, pointing to a significant potential for energy efficiency improvements in the Czech housing stock.

The analysis of heating control technologies and habit changes in the Czech Republic reveals significant opportunities for reducing energy consumption and improving overall energy efficiency in residential buildings.

Firstly, the adoption of advanced heating control technologies, such as smart thermostats and home automation systems, plays a crucial role in optimizing energy usage. These technologies allow for precise temperature control and scheduling based on occupancy patterns, resulting in more efficient heating without compromising comfort. The integration of such systems can lead to

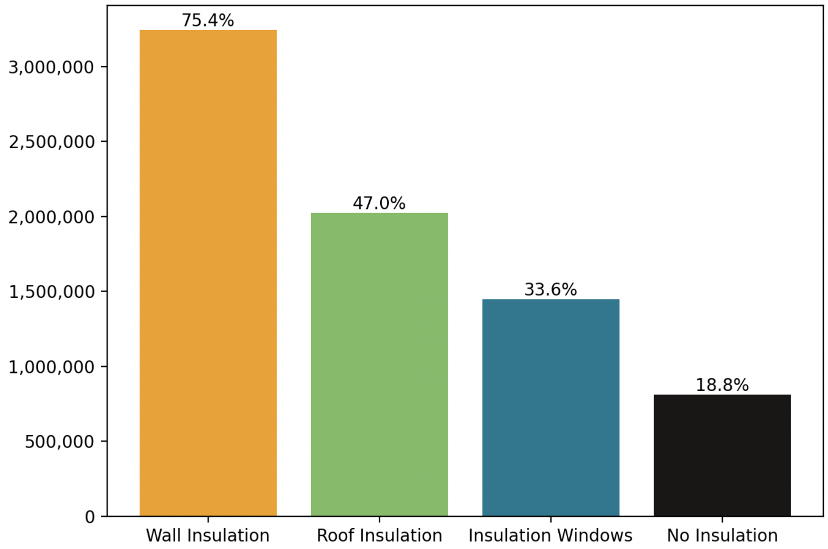

Figure 6: Apartments and their insulation methods

substantial energy savings by avoiding unnecessary heating during periods of absence and adjusting temperatures based on daily routines.

Additionally, habit changes among residents contribute significantly to energy conservation. Public awareness campaigns and incentives have encouraged behaviors like lowering thermostat settings, using energy-efficient appliances, and practicing thermal comfort strategies. These behavioral changes promote conscious energy use and help in reducing overall heating demands. The average heating temperature within homes across the European Union is over 22 °C. Turning down the thermostat at home by just 1 °C would save around 7 % of the energy used for heating. [3]

3.4 Barriers and strategy of Czech Republic

In the Czech Republic, the implementation of energy-saving measures faces specific barriers that hinder progress towards a more sustainable built environment. Economic barriers pose a significant challenge, particularly for homeowners and building managers, due to the high upfront costs associated with retrofitting old houses with energy-efficient technologies. Bureaucratic hurdles, such as complex and time-consuming processes for obtaining building permits, contribute to delays and uncertainty in project timelines.

Notably, a new building law introduced in 2024 aims to address these challenges by streamlining the process of obtaining building permits, potentially reducing the time and administrative burden associated with regulatory approval.[4] These reforms are expected to facilitate the adoption of energy-saving measures by making it easier for homeowners and developers to implement sustainable building practices. However, continued efforts are needed to provide comprehensive support and incentives to overcome economic, bureaucratic, and technical obstacles and promote the widespread adoption of energy-efficient solutions in the Czech Republic.

The "New Green Savings" program is the most effective and long-standing subsidy program aimed at promoting energy savings in family homes and apartment buildings. Since its inception in 2014, the program has allocated funds amounting to several billion Czech crowns to tens of thousands of households during its initial program period. In 2021, the program entered a new phase, expanding its focus to encompass additional areas. By the end of 2022, the "New Green Savings" initiative also incorporated the "New Green Savings Light" program tailored for seniors and households with lower incomes.

At the core of the "New Green Savings" program is the reduction of energy demands in residential buildings through renovations and the construction of low-energy family homes and apartments. There is a growing emphasis on utilizing renewable energy sources within this program. The fundamental support portfolio includes measures aimed at preparing buildings for ongoing climate change and motivating the public to implement energy-saving measures. These measures notably involve rainwater management for residential buildings, replacing non-eco-friendly heating sources, developing infrastructure for electromobility, green roofs, and energy savings during reconstruction and construction of residential buildings throughout the Czech Republic.

Between 2014 and 2021, the program was financed from the proceeds of the sale of EUA (European Union Allowance) and EUAA (European Union Aviation Allowance) emission permits. Since 2021, the funding sources have diversified. They now include the Recovery and Resilience Facility (RRF) through the National Recovery Plan, amounting to 19 billion CZK, and the Modernization Fund established by the European Commission (specifically the HOUSEnerg program, totaling 55 billion CZK). Additionally, funding continues from the share of revenue from auctions of EUA and EUAA emission permits under the EU ETS, estimated at approximately 4 billion CZK annually.

The "Repair Your Grandmother's House" program is a new grant initiative launched by the Ministry of the Environment and the State Environmental Fund of the Czech Republic. This program offers households the opportunity to receive up to 1 million CZK for comprehensive insulation of family or recreational homes, along with additional financial support for other energy-saving measures such as source replacements and photovoltaic installations. An advantageous aspect of this program is that households receive the entire grant amount upfront. Families with children can also benefit from a bonus of 50,000 CZK for each dependent child. Additionally, recipients of the grant will have access to preferential loans from banks and building societies to cover the difference between eligible expenses and the disbursed grant amount, without the need for property collateral. The average grant amount in the "New Green Savings" program is 182,000 CZK. [5]

4 Situation in Austria

In alignment with the preceding chapter's framework, we now turn our attention to examining the state of housing and heating in Austria.

4.1 Overview of Austria's housing stock

The primary source of information is the comprehensive report on housing in Austria for the year 2022, known as "Wohnen 2022," provided by the Austrian main statistical agency [6]. This report offers an intricate analysis of Austrians' main residences (Hauptwohnsitze). Figure 7 illustrates the division between family housing and apartment housing, providing valuable insights into the housing landscape of the country.

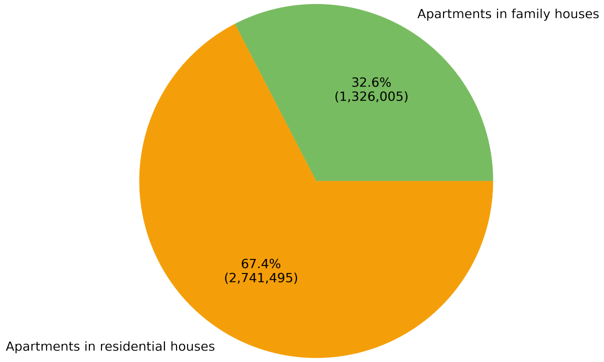

Figure 7: Number of apartments in family and residential houses

By the year 2022, Austria boasted a total of 4,067,500 apartments. It's worth highlighting that nearly two-thirds of residential properties consist of between 3 to 19 apartments, suggesting that roof insulation may have a comparatively lesser impact compared to wall insulation.
Figure 8 provides insight into the construction timeline of these approximately four million homes. The data has been organized to facilitate a straightforward comparison with the situation in the Czech Republic.

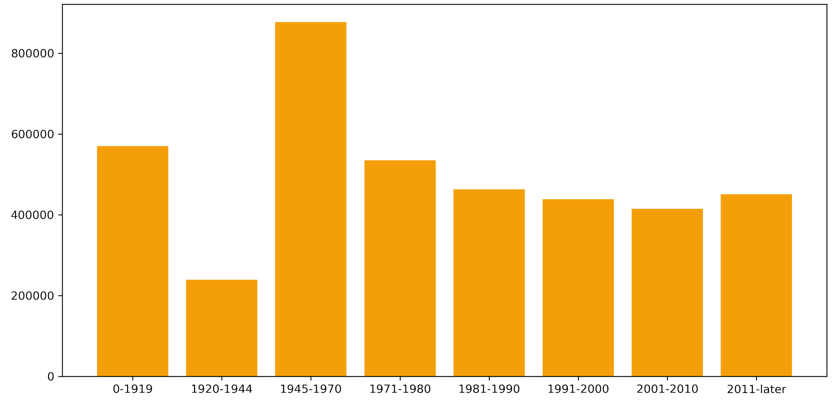

Figure 8: Occupied apartments by house construction period

The data indicates a prevailing trend in the construction of apartments post-World War II. Over a span of 40 years, the average annual growth rate stands at approximately 50,000 new homes, showcasing a notably stable trajectory. Figure 9 presents apartments categorized by their living area, utilizing statistics from the year 2014 [7]. It is evident that the most prevalent type of apartment falls within the range of 60 to 80 square meters, with over one million individuals residing in units of this size.

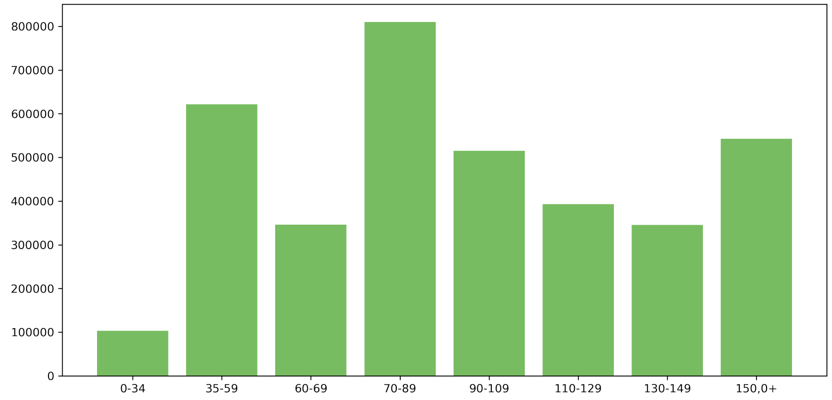

Figure 9: Number of apartments by total area in m^2

4.2 Current energy consumption patterns

The visualization depicted in Figure 10 illustrates the predominant energy sources utilized for heating in occupied apartments, revealing a notable inclination towards natural gas and district heating, collectively constituting more than 50%

of the total heating provision. Notably, heating oil and wood-based heating emerge as widely employed sources, cumulatively accounting for over one third of heating requirements in Austria. Despite the increasing adoption of heat pumps, their contribution remains modest, comprising merely 7.5% of the heating landscape in the year 2019 [8].

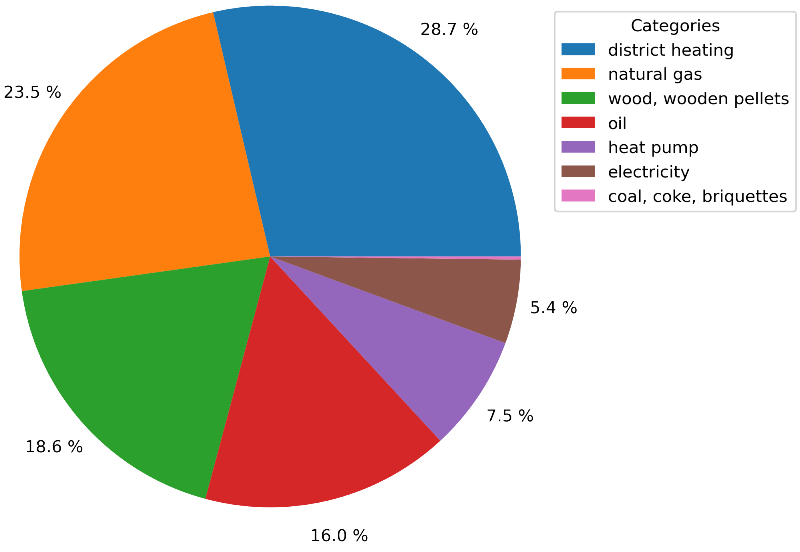

Figure 10: Occupied apartments by main energy source used for heating

4.3 Austria's Strategy

Austria's building renovation strategy is based on the guidelines of the Energy Efficiency Directive (EED) 2012/27/EU. It encompasses a comprehensive analysis of the national building stock, renovation concepts based on cost-effectiveness, strategies to promote comprehensive renovations, and measures to steer investment decisions. Cost-effectiveness is ensured through the OIB document and the National Plan. The housing construction subsidy plays a central role by providing incentives for energy-saving measures and renewable energies in both new construction and renovations. It sets higher standards than the building laws of the states and has been harmonized through an agreement between the federal government and the states. A detailed presentation of the funding conditions and institutions of the federal states is provided [9]. The strategy also includes an evidence-based estimation of expected energy savings and other benefits, divided by building age classes, building types, and heating systems. The calculations are based on data from Statistics Austria and the federal states. The strategy aims to improve the energy efficiency of buildings, reduce greenhouse gas emissions, and promote the use of renewable energies while responding to current circumstances and developments. Every of the nine regions in Austria has its own federal strategy.

5 Comparison of Czech Republic and Austria

Let us first compare the structure of the housing stock in the Czech Republic and Austria. Both countries have a relatively similar number of flats - around 4 million. Unlike the Czech Republic, Austria has a smaller share of flats in family houses - 32.6 % - compared to the Czech Republic, which has 44.8 % of flats in family houses.

In terms of the distribution of housing by year of construction or deeper reconstruction, both countries have a large increase in the postwar years 1945-1970. Austria maintains approximately the same rate of new housing additions every 10 years. The Czech Republic experienced a significant decline in the 1990s and has stagnated in a similar fashion in subsequent years.

Turning to the distribution of apartments by size, both countries have the most significant share in apartments of approximately 80 square metres. Due to the different breakdown in the statistics from the Czech Republic and Austria, it is not possible to compare this structure well. However, in both countries there are a lot of smaller and medium-sized flats and the number of flats decreases with increasing size.

We now compare household heating by energy source. In both countries, natural gas dominates along with district heating. However, in the Czech Republic, this duo occupies approximately 73 % of the total and natural gas slightly leads by approximately 1 %. In Austria, this pair occupies approximately 52 % of the total and district heating leads by approximately 5 %. A major difference between the two countries is the fact that in Austria, heating by means of heating oil is quite widely used. About 16 % of households use this method. Furthermore, electricity and wood are used in both countries. The share of heat pumps in Austria is about 5 % higher than in the Czech Republic.

We do not have data from Austria to compare the level of insulation, but it can be assumed that the values will be approximately similar and better compared to the Czech Republic.

Both countries have similar strategies for renovating their housing stock. More or less, both countries are united by a common goal for the entire European Union. Governments are providing subsidy programmes for the introduction of energy- and emission-saving measures for dwellings that need it most. There is a desire to allocate resources efficiently and thus achieve the greatest improvement at the least cost.

6 A micro-economic model on energy saving

Following the comparison between the two countries, we will now delve into the microeconomic perspective. To this end, a model has been programmed to compute the energy requirements for a winter period (from September 1, 2022, to June 7, 2023), taking into account various input parameters. Initially, we will elaborate the model itself, followed by an examination of the results and their implications.

6.1 The model

The main idea behind the model is to give every house or apartment owner the possibility to feed individual data in and get an individual outcome. Therefore the model is derived from first principal: The Fourier Heat transport law [10].

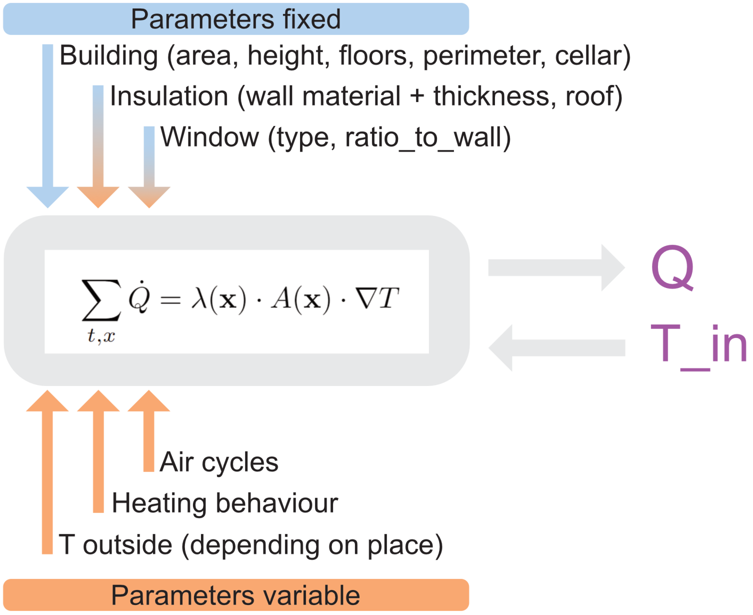

Figure 11: The Model

Figure 11 illustrates the input parameters utilized in the formula of Fourier's Heat transport law. The heat flow ($\dot{Q}$) is contingent upon the heat coefficient (λ) of the materials employed, the area (A) — both of which are reliant on the material and thus serve as positional arguments—and the temperature gradient (in a one-dimensional scenario across a wall, represented as $\frac{\Delta T}{d}$, where d denotes the thickness and ΔT signifies the temperature differential between the exterior and interior). Subsequently, all differential areas (x) distinguishing the exterior from the interior are aggregated, along with the total energy transfer over the course of a year.

The model aims to equate the total heat utilized within the building (Q) for a specific indoor temperature T_{in} with the energy lost to the outside, a value contingent upon the input parameters "Building," "Insulation," and "Window."

Building:

- Ground area (for a single floor)
- Room height
- Number of floors
- Perimeter of the apartment
- Estimation of energy loss through the cellar

Insulation:

- Material of the wall and potential insulation (determining specific heat capacity, thermal conductivity, and density)
- Thickness of the wall
- Estimation of energy loss through the roof

Window:

- Insulation type of the window
- Percentage of window to wall area (calculated as the number of windows multiplied by the area per window)

Information on the insulation potential for all materials and windows is provided in Table 1[1]. Furthermore thermal convection has been implemented with parameters $\alpha_{inside} = 7.7$ and $\alpha_{outside} = 25$ - see [10].

The "Air cycles" parameter provides an estimate of the energy contained within the room air, which dissipates when windows are opened. To counteract this, the model integrates the heat stored in the air at a given temperature over a 24-hour period, effectively averaging across specific airing times.

The "heating behavior" variable encompasses a vector that spans all hours of the year, dictating heating restrictions during certain periods. It's worth explicitly noting that this implementation aims to minimize overall comfort loss. For instance, if the heat is turned off for one hour, any energy lost during that time will be compensated for in the subsequent time interval by additional heating, surpassing what's strictly necessary to offset losses. This approach operates under the assumption that radiators are not constrained in their heat emission. By leveraging the fact that heat flow is proportional to the temperature gradient at any given hour, this mechanism preserves comfort levels even when heating is

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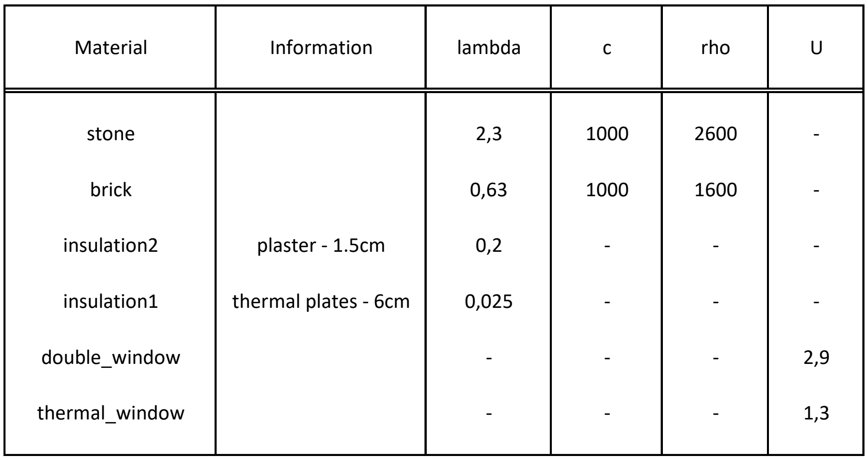
[1] c is the Specific heat capacity, rho the density and U the Thermal transmittance



Material	Information	lambda	c	rho	U
stone		2,3	1000	2600	-
brick		0,63	1000	1600	-
insulation2	plaster - 1.5cm	0,2	-	-	-
insulation1	thermal plates - 6cm	0,025	-	-	-
double_window		-	-	-	2,9
thermal_window		-	-	-	1,3

Table 1: Information on coefficients

inactive, while also conserving energy. In addition to the standard case typically provided by most thermostats, two types of smart heating have been integrated. Heating behaviour:

- Standard case: Allows heating to maintain $T_{\text{in}} = T_{\text{out}}$ throughout all feasible hours. If $T_{\text{in}} < T_{\text{out}}$, heating is turned off. Cooling down is not considered in this model.
- Workweek case: Heating is deactivated Monday to Friday from 8 am to 3 pm, as well as during sleep hours, i.e., every day from 11 pm to 3 am.
- Electric case: Heating is disabled if the electricity price exceeds the threshold price $\tilde{p}$.

The workweek case holds particular relevance for the average person. The aim is to conserve energy during periods when nobody is at home and during the night, when people are sleeping (slightly cooler temperatures even exhibit health benefits). In both scenarios, a warm-up phase has been integrated.

The electric case is useful for individuals who rely on electricity for heating, either directly through radiators or via a heat pump. In this instance, heating is economically contingent upon the prevailing electricity price, often linked to the energy provider (for example, AWATTAR in Austria). The personal advantage lies in the immediate reduction of the electricity bill through the "forceful" conservation of energy. Moreover, if implemented across a large number of homes, this approach can contribute to stabilizing the electricity grid during periods of high demand.

Given the energy crisis during the winter of 2022/23, we shall tacitly assume that electricity is only utilized for heating if the Levelized Cost of Electricity is below $\tilde{p} = 21.35$ cents/kWh (True for 75% of all hours in the period).

Finally, the variable T_{outside} denotes the hourly outside temperature of a residence, covering the period from September 1, 2022, to June 7, 2023. This timeframe will remain consistent throughout the text and be referred to as 'winter 2022/23'.

6.2 Test case I: Apartment in Vienna (AT)

Let's take into account an apartment with two rooms situated in Vienna (details provided in Appendix A - see Table 2).

The model computes that during the winter of 2022/23, the energy required amounts to 10,649 kWh. Comparatively, for the same period in the winter of 2019/20, the figure stands at 10,250 kWh—only marginally lower than the former result[2].

Furthermore, the model can determine the heat needed per week (starting in September 2022), plotted alongside the temperature in Figure 12. The dependency on temperature is evidently depicted.

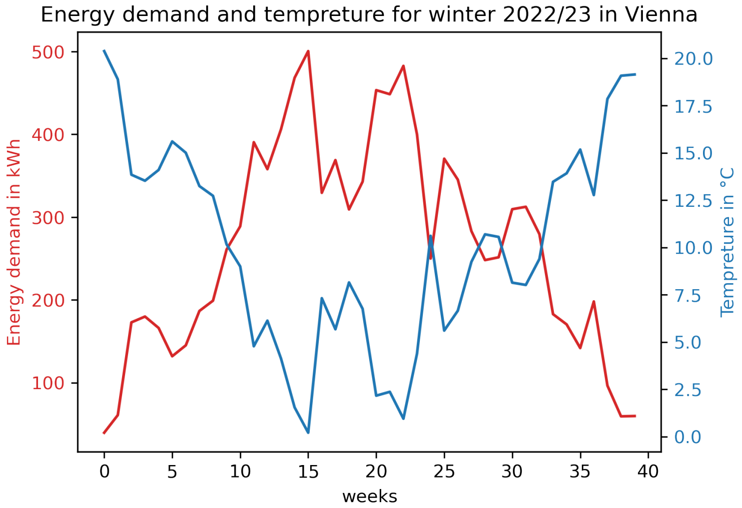


Figure 12: Energy - Temperature dependence

For comparative analysis across different types of flats, we'll adopt the measure of energy needed per square meter of in-use area per year, commonly used for the energy-class [kWh/m^{2}a].

The set of potential modifications will be referred to as the search space, aimed at finding the 'best' improvement, and is outlined in Table 3.

When we plot the energy consumption for every possible configuration within the search space, we obtain Figure 13. The x-axis indicates the number of changes made to the base scenario for each configuration, always representing an efficiency gain—either by sacrificing a portion of comfort/habits or by leveraging technological advancements[3]. It's noteworthy that changes can accumulate,

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[2] While the median temperature of the winter of 2019/20 is 0.1°C higher, this change is negligible when considering other uncertainties. Therefore, a time-average over multiple winters is not conducted here.

[3] A swarm plot illustrates the difference in airing here. Each incremental step to the right per box indicates the number of changes in airing according to the search space.

hence it's not surprising to observe a decrease in energy with an increasing number of modifications.

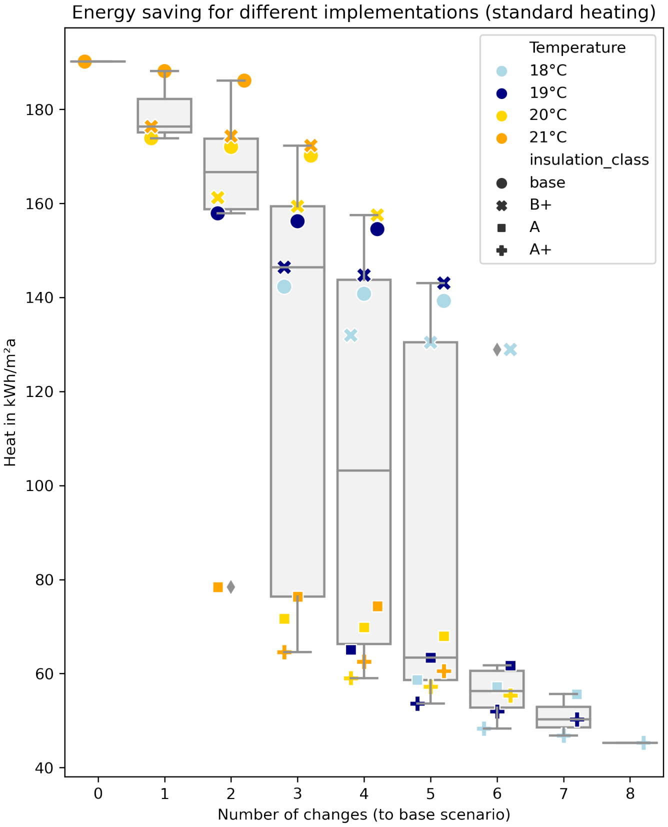

Figure 13: Energy saving opportunities I

The most effective method for energy conservation is upgrading thermal insulation. However, even a one-degree Celsius reduction in indoor temperature yields significant effects, particularly when thermal insulation is subpar. Although the extent of airing does have a discernible effect, it can largely be disregarded.
In the model's final achievement, the ability to deactivate heating during certain hours—referred to as 'heating behavior'—can significantly save energy. Both alternative heating behavioral cases will be compared to the standard case's median energy saved per number of changes. This comparison will elucidate the impact of smart heating, largely independent of other factors.
The results are depicted in Figure 14—note the same box plot for the standard case as in the previously discussed Figure.
It's evident that the two smart heating implementations result in energy savings ranging from 0.3% to almost 12%. The electric case requires an additional

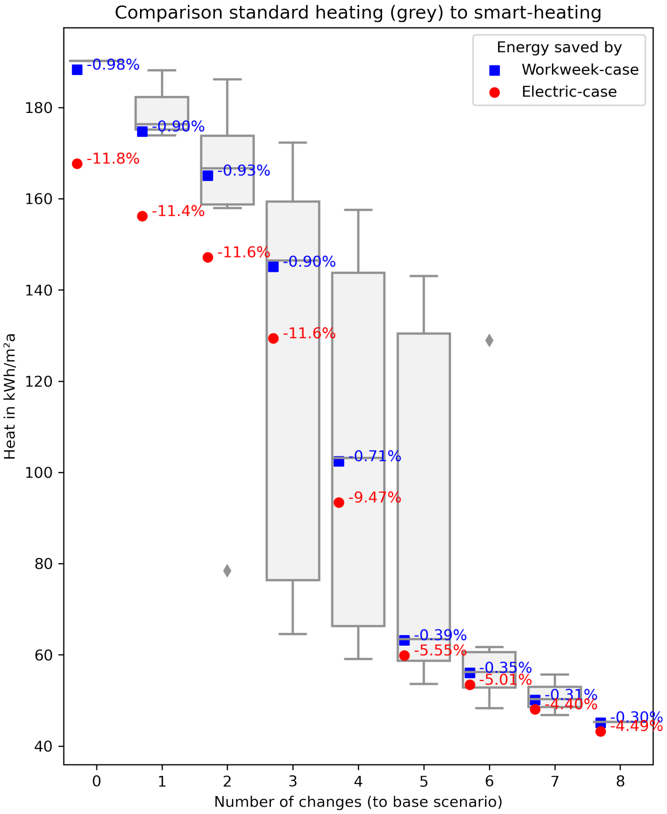

Figure 14: Smart heating opportunities I

comprehensive analysis, encompassing factors such as the power of the electric heating system, the maximum duration without heating, and the advantages associated with electricity contract options. Despite the diminishing returns of smart heating in the presence of superior insulation, they still offer valuable insights for future development, while also generating additional co-benefits (grid stability, ect.).

6.3 Test case II: Old family house in Jince (CZ)

Let's shift our focus to a different region and building type with an example from the Czech Republic. The data for an old family house is detailed in Table 4.

Due to the unavailability of hourly temperature data, the data from Salzburg has been utilized[4]. This yields an energy demand of 19,920 kWh. Once again,

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[4] Salzburg is, like Prague, slightly cooler than Vienna

comparing this value to all potential changes outlined in Table 5 yields Figure 15.

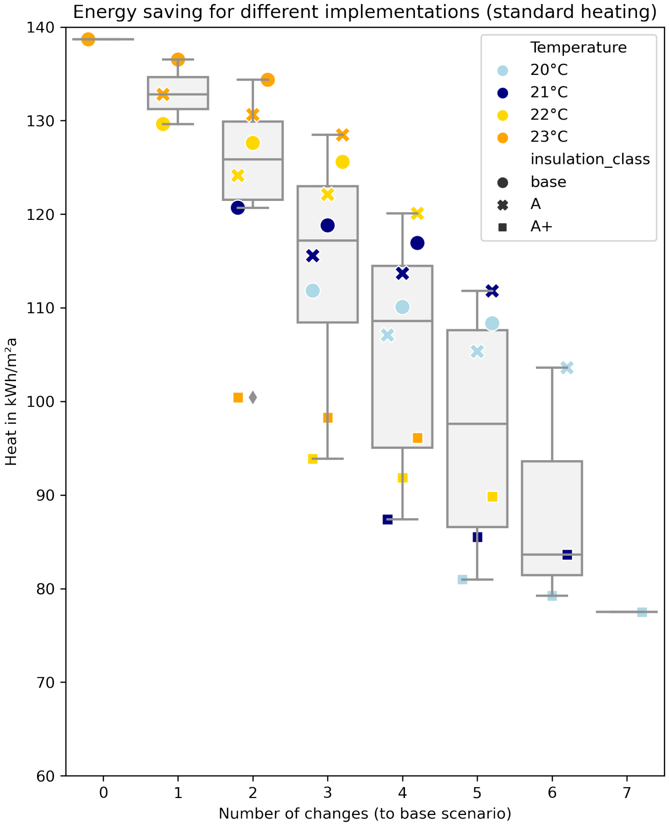

Figure 15: Energy saving opportunities II

In a direct comparison with Figure 13, we observe more continuous clusters for the family house. Interestingly, despite the lower energy per square meter in the base scenario, we cannot reduce the energy to the minimum required for an apartment. One general explanation is that the ratio of Volume to Surface Area is usually unfavorable for stand-alone buildings. In Figure 16, we witness the significant impact of changing the type of heating once again. Furthermore, the electric case appears to be highly dependent on the region of the home, as the decrease in efficiency is much slower for the latter case study.

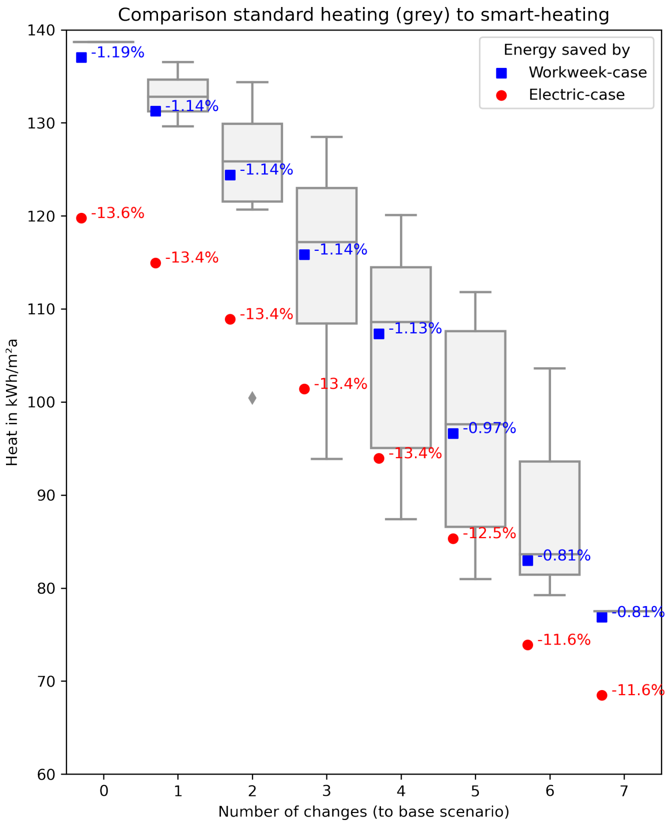

Figure 16: Smart heating opportunities II

7 Discussion

It's evident that for conclusions we require a subjective metric for the changes in our model, one that considers factors like cost and comfort. However, this poses a significant challenge, and we believe it's best left to individuals to determine what works best for them. Moreover, every home is unique, as we elaborated in Chapter 3 and 4, so a one-size-fits-all approach wouldn't suffice either - although improving insulation shows the most impact in energy saving. Our model serves as a very limited prototype of what could potentially be utilized for personalized promoted by a government agency.

We advocate for robust education on energy saving and the provision of appropriate tools, with assistance from experts where necessary. Empowering individuals to optimize their own situations can significantly contribute to our collective goal. Governments can also play a role by offering loans with low interest rates for anything related to thermal insulation, thereby facilitating the adoption of energy-saving measures.

List of Figures

List of Tables

References

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A Model configurations

INPUT parameter	values
Type_of_house	2 room apartment
[°C] float TEMPRETURE	21
city of your home	Vienna
[m2] float GROUND_AREA	56
[m] float room_height	3,8
float floors	1
[m] float perimeter	30
[m^2] avarage_window_area	3
number_of_windows	4
str MATERIAL	brick_insulation2
[m] float wall_d	0,5
str window_type	double window
float air_changes_per_day	1
str roof condition	none
str cellar	none

Table 2: Base Model I

INPUT parameter	values
Type_of_house	2 room apartment
[°C] float TEMPRETURE	21,20,19,18
city of your home	Vienna
[m2] float GROUND_AREA	56
[m] float room_height	3,8
float floors	1
[m] float perimeter	30
[m^2] avarage_window_area	3
number_of_windows	4
str MATERIAL	brick_insulation2,brick_insulation1
[m] float wall_d	0,5
str window_type	double_window, thermal_window
float air_changes_per_day	1 0,5 0
str roof condition	none
str cellar	none

Table 3: Searchspace Model I

INPUT parameter	values
Type_of_house	family house
[°C] float TEMPRETURE	23
city of your home	Jince
[m2] float GROUND_AREA	150
[m] float room_height	3
float floors	1
[m] float perimeter	52
[m^2] avarage_window_area	1,5
number_of_windows	8
str MATERIAL	stone
[m] float wall_d	0,8
str window_type	thermal_window
float air_changes_per_day	0,5
str roof condition	unused attic
str cellar	none

Table 4: Base Model II

INPUT parameter	values
Type_of_house	family house
[°C] float TEMPRETURE	23,22,21,20
city of your home	Jince
[m2] float GROUND_AREA	150
[m] float room_height	3
float floors	1
[m] float perimeter	52
[m^2] avarage_window_area	1,5
number_of_windows	8
str MATERIAL	stone,stone_insulation2,stone_insulation1
[m] float wall_d	0,8
str window_type	thermal_window
float air_changes_per_day	1 0,5 0
str roof condition	unused attic
str cellar	none

Table 5: Searchspace Model II