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Role of temporary thermostat adjustments as a fast, low-cost measure in reducing energy imports




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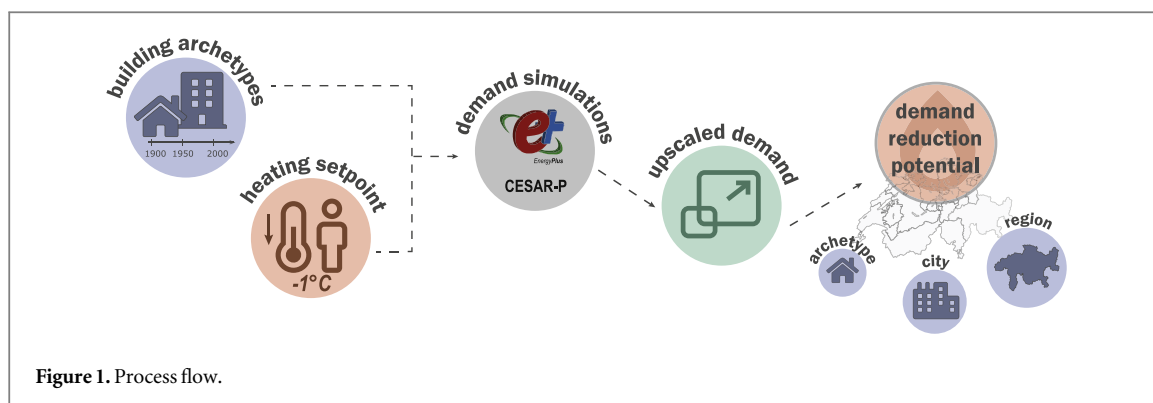
**Abstract**

Efforts to combat climate change involve long-term plans to reduce the energy demand and increase the share of locally generated renewable energy. However, a sudden change in the geopolitical situation may require an even more rapid response to reduce energy imports through energy-efficiency improvements. In the building sector, retrofits to the building envelope and heating systems are effective, yet time- and cost-intensive to improve energy efficiency. A fast, low-cost measure to address this need is to lower the temperature set-points in building heating systems to within comfortable limits. Here, we show the impact of reducing the temperature set-point by 1 °C on heating demand at different scales—building, regional, and national—using demand simulation of 240 Swiss building archetypes and clustering-based upscaling methods. We demonstrate a nearly 6% reduction in the residential space heating demand at the national level, about a third of which is met with natural gas. More importantly, the presented approach highlights potential implications of the proposed measure across a national residential building stock, considering differences in climate and building archetypes, as well as their spatial distribution.

1. Introduction

In response to the climate crisis, countries around the world have drafted long-term energy strategies, highlighting their commitment to reaching carbon neutrality. These include a shift to renewable energy, a reduction in energy demand in buildings, and a move to sustainable mobility. The strategies often feature a slow and steady transition over multiple decades. The European Union approved the European Green Deal to guide Europe's transition to carbon neutrality by 2050 [1]. Similarly, the Swiss Energy Strategy 2050 proposes the necessary steps to reach the net zero emissions target, while maintaining the security and cost-effectiveness of its energy supply [2]. Sudden geopolitical shifts may, however, require an even faster response to reduce the energy dependency [3] before long-term solutions can be implemented. Demand reduction is an important aspect in decreasing that dependency. In the short term, this would also require collective action on the side of individuals/homes. Given the high reliance on fossil fuels to meet heating demand, reducing the heating temperature levels in buildings—and, if possible, maintaining it within comfortable limits—is one potential way to achieve that. Both REPowerEU [4] and IEA 10-point plan [5] include thermostat adjustment as a temporary measure to reduce demand. Assessing the potential impact of thermostat adjustment on demand across a national residential building stock—while considering differences among building archetypes, as well as spatial variations in the building stock and climate—can provide important insight regarding the effectiveness of the proposed measure.

Here we use 240 residential building archetypes representing the Swiss building stock (approx. 1.8 million buildings according to official national statistics [6]) to evaluate the impact of the occupant—setting the temperature setpoint 1 °C lower—on reducing the space heating energy demand. Clustering-based upscaling methods are then used to obtain the demand reduction potential at different scales. The methodology is briefly



outlined in section 2, followed by the presentation and discussion of results in section 3. Finally, the summary of the main findings, including the limitations and additional considerations, are presented in section 4.

2. Methodology

Figure 1 below outlines the process flow for estimating the demand reduction potential of the lowered temperature setpoint. The simplified representation of the Swiss building stock for bottom-up energy demand analysis is obtained using a grouping and clustering approach presented in [7]. The building stock is first grouped by building type, building age and climate region, and then further clustered based on spatial and geometric characteristics (building compactness, size, and density of the surrounding), resulting in 240 residential building archetypes. Their heating energy demands are simulated in the Combined Energy Simulation and Retrofit in Python (CESAR-P) [8, 9], which is based on the EnergyPlus software [10]. In the validated *reference* case, heating temperature setpoints are set according to the Swiss SIA standard for single-family and multi-family buildings (21 °C) [9, 11]. Demand simulations are performed for the weather year 2016. The clustering-based upscaling approach is then used to obtain the demands at different scales (e.g. building, regional, and national). In this paper, we include past building energy retrofits to the model based on the distribution from [12]. Consequently, the modelled national space heating demand results are brought in close agreement to the national statistics [13] and a number of other building energy simulation studies in Switzerland [14–16] (see figure A1).

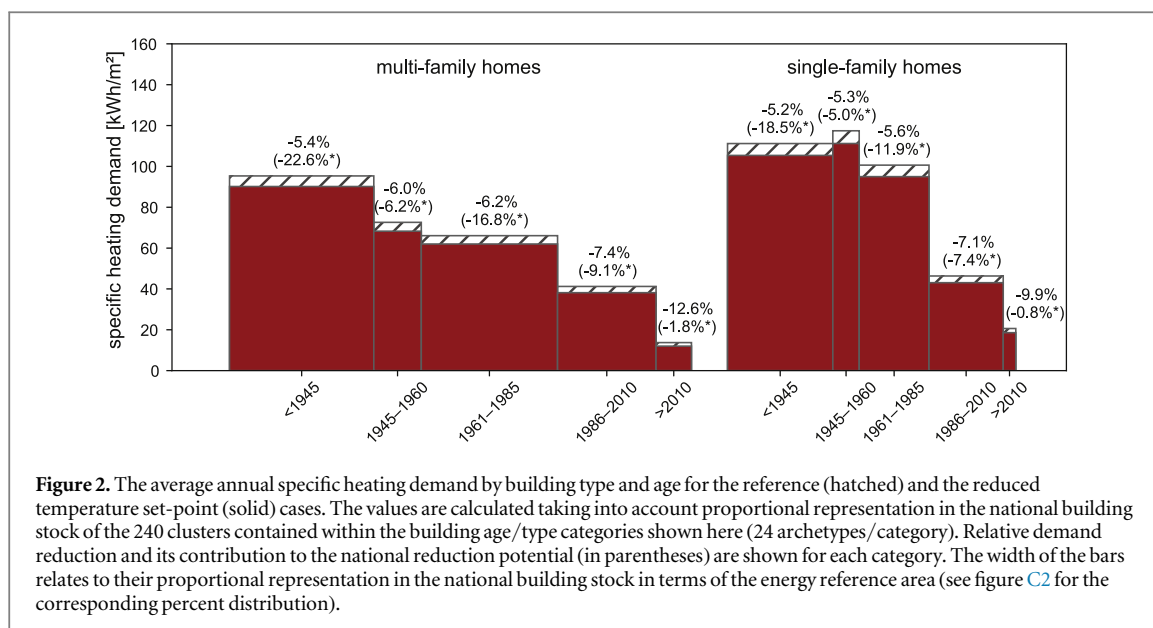
The model is then used to estimate the heating demand reduction potential of the lowered temperature setpoint at different scales. In the new *reduced setpoint* case, we lower the heating temperature setpoint by 1 °C (while keeping the set-back temperature unchanged). The change in temperature setpoint has only a minor impact on the comfort perception of people, which can be easily estimated using the predicted mean vote (PMV) method. While steady-state laboratory experiments on which the method is based may not be quite comparable to those in residential buildings (and can vary according to time-of-year, room type, clothing, activity, etc.) [17], the PMV method provides a simple way to assess the relative impact of the proposed thermostat adjustment. To estimate the predicted percent of dissatisfied people (PPD), we use air temperature in the assessment within the CBE Thermal Comfort Tool [18]. Keeping all other parameters constant, reducing the temperature setpoint by 1°—from 21° to 20 °C—the PMV method estimates that the PPD will increase from 13 to 21% (see appendix B, Table B1, for parameter settings). This change, however, does not take into account that within residential environments occupants may have various possibilities to adapt themselves to reach a desired thermal comfort (e.g. clothing adjustment).

The *reference* and the *reduced setpoint* cases are compared at different levels—building, city, regional, and national—to estimate the demand reduction potential. To estimate the potential impact on the natural gas use, the obtained relative (percent) reduction in demand is applied to the breakdown of energy carriers supplying residential space heating demand for the year 2020 [19].

3. Results and discussion

Here we outline the impact of the reduced temperature setpoint from the building to the national level, including its potential in reducing the overall natural gas use.

Figure 2 shows the impact of the reduced temperature set-point for the upscaled (national) building stock according to different building type/age groups. The results are based on the stock-level evaluation of all 240 simulated archetypes, accounting for the variance within each category (24 archetypes/category). Variations

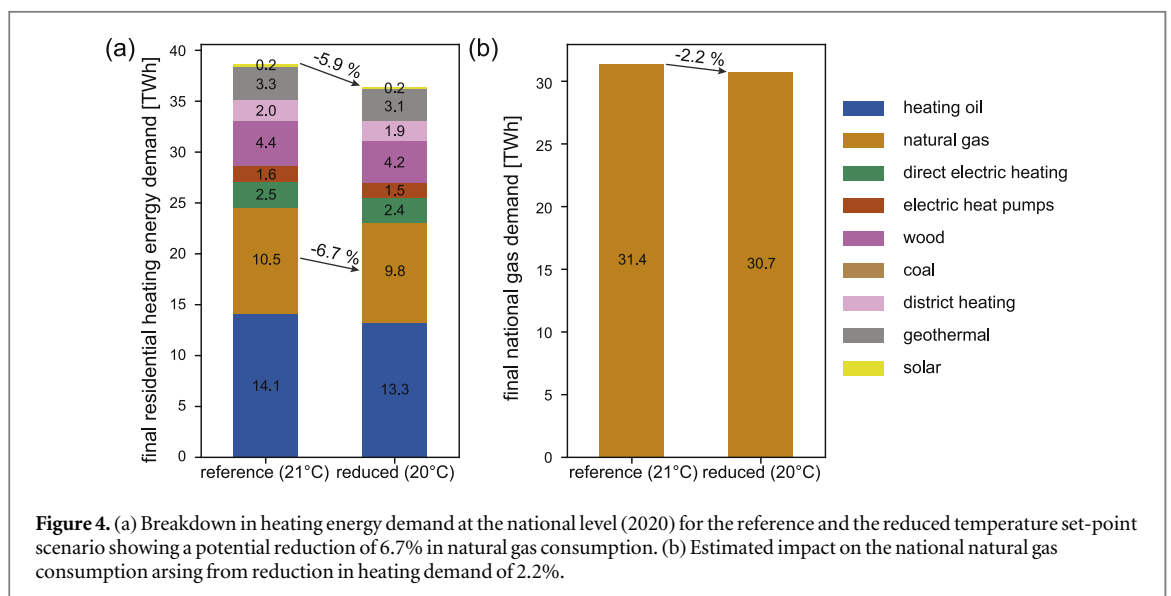
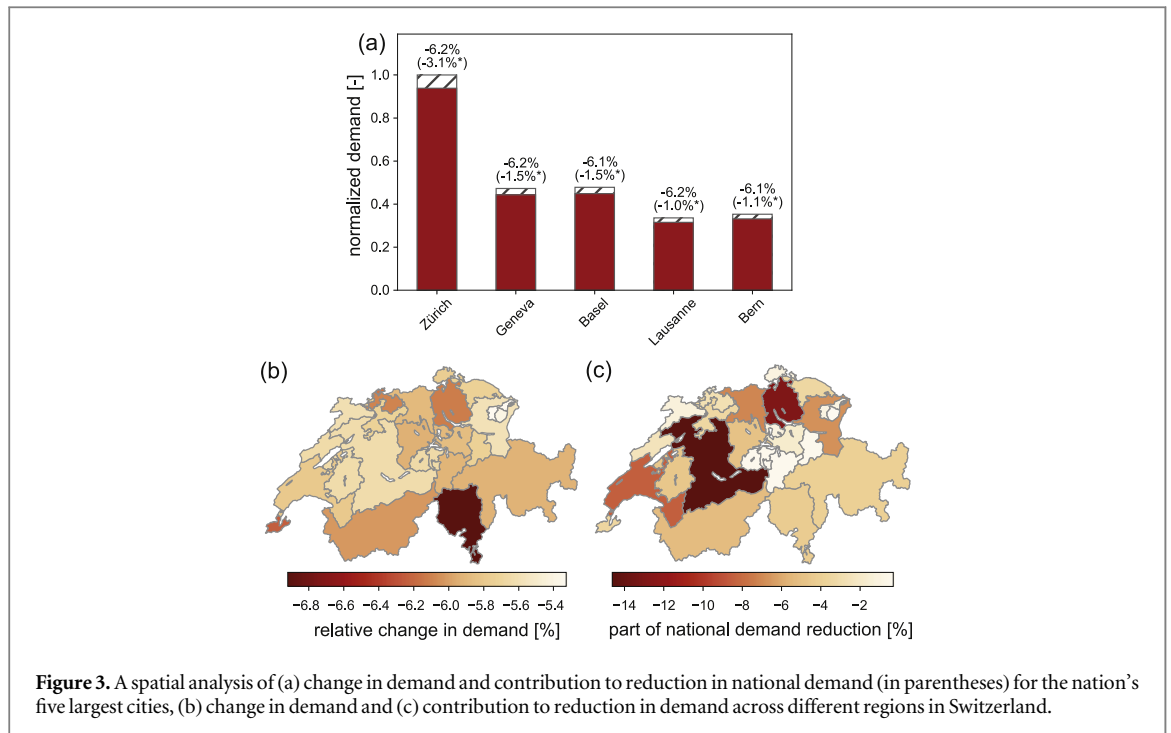


within building type/age groups are included in the appendix (figure C1), and arise mainly due to differences in the climate regions. The annual specific heating demands and the overall trends across building type/age groups for the reference case are comparable to other Swiss studies [15, 16, 20, 21], with differences arising from weather and input data, as well consideration of whether past retrofits are considered in the model. Total heating demands obtained for each category are normalized to their total energy reference area (i.e. heated floor area of buildings, assumed as 90% of the building floor area) to obtain the average annual specific heating demands. The width of the bars relates to their proportional representation in the national building stock in terms of energy reference area (see figure C2 for the corresponding values). Demand reduction is shown using the hatched areas. For each building type/age category, change in the annual specific heating demand is represented by the height of the hatched region (and indicated as percent reduction); the area of the hatched region relates to the total demand reduction potential within the national building stock (indicated in parentheses), which is a factor of the total energy reference area in any specified group and its corresponding magnitude of demand reduction.

The oldest buildings (<1945) show the lowest percent reduction in their annual specific heating demand (5.4% for MFH and 5.2% for SFH) due to their poor thermal performance, but an overall higher absolute specific demand reduction. Taking into account both their large representation within the national building stock (in terms of energy reference area, illustrated by the bar width) and the magnitude of demand reduction, this building age category has the highest heating demand reduction potential (22.6% for MFH and 18.5% for SFH). On the other hand, the newest buildings (>2010) show the highest percent reduction in their annual specific heating demand (12.6% for MFH and 8.9% for SFH) due to their better thermal performance, but an overall lower absolute reduction of their specific demand. A combination of lower relative demand reduction and smaller representation in the building stock (illustrated by the bar width, approximately 6.5% for SFH and MFH combined), this building age category contributes only marginally to the national reduction in demand (1.8% for MFH and 0.8% for SFH).

In figure 3, we show the spatial distribution of demand reduction potential across different cities and regions (cantons) in Switzerland, by taking into account the impact of climate zones (see figure C3 in the Appendix), as well as the spatial distribution of the building stock and their attributes (i.e. represented archetypes). In (a) the impact of the reduced temperature setpoint is shown for the nation's five largest cities with similar relative reductions in demand. While the building stock of each city is modeled separately, similar relative reductions in demand appear related to belonging to the same climate zone ('Large urban agglomerates') and a similar breakdown of building types (see figure C2 in the appendix). Absolute differences between cities can be attributed to the differences in the total building energy reference areas within their municipal boundaries, which in the case of similar urban densities, correlates well to their respective populations. Together they would contribute to 8.2% of the nation's space heating demand reduction potential.

In figure 3(b), we mainly observe the impact of weather on heating demand reduction in different regions, and to a smaller extent, building stock composition (for example, relative proportions of building types). The percent reduction across different cantons varies between 5.3 and 6.9%, with higher changes in demand observed in warmer regions, especially in the south. In figure 3(c), the contribution to the national reduction in demand relates the absolute reduction in each canton to the national reduction in demand, showing the



implication of weather and regional buildings stock size, which correlates to the differences in population. The percent reduction varies between about 0.3 and 14.6%, with the highest potential contribution to reducing demand concentrated within the most populous cantons (Zürich and Bern).

In figure 4, the derived reduction of 5.9% in residential space heating demand at the national scale (useful energy) is uniformly applied to the energy carrier breakdown of residential space heating demand—final energy demand by energy carrier type—for the year 2020. In other words, a 1:1 percent reduction is assumed for the useful and final energy demands. This results in a 6.7% reduction in residential natural gas demand for space heating, and a 2.2% reduction in total (national) natural gas demand. Our results are in close agreement with those obtained by IEA, which estimates a saving of 10 billion cubic meter (bcm) per 1 °C [5]. Taking into account the natural gas use for space heating in EU buildings [22], 10 bcm corresponds to the approximate reduction of 6%–7% (see appendix D, Table D1). Aside from the stated higher temperature setpoint of 22 °C, the details of the IEA method for estimating gas reduction in the EU have not been provided in the report. We can only assume that they are based on heuristic approaches as opposed to complex building stock models. Due to the similarities between Switzerland and the EU-27 in terms of the building stock age [23] and the represented

climate regions (with the exception of the Mediterranean), we expect that our results would be reasonably comparable. Nevertheless, EUs higher reliance on natural gas for space heating (50% versus 30%) [24] would result in higher relative savings from the proposed measure.

The Swiss building and housing registry [6] also suggests that older buildings are more likely to have an oil or natural gas boiler compared to newer ones. However, this data is no longer regularly updated to reflect the change of heating systems. Nevertheless, a detailed analysis of the Swiss Cantonal Energy Certificate for Buildings, which provides a representative sample of the Swiss building stock in terms of building type/age distribution, and more recent data on the installed heating systems [25], showed that while most old buildings have new boilers installed, they largely remain fossil fuel based (74% for buildings built before 1990, where the retrofit was conducted after 1990). At the same time, national statistics show a trend of decreased use of heating oil and an increased use of natural gas to meet space heating demand (from 2000 to 2020, -50.5% +32.6%, respectively) [19]. In newer buildings (built after 2000), heat pumps are the main space heating technology [6]. As a result, older buildings are expected to contribute more to reducing fossil fuel use compared to newer buildings.

4. Conclusion

In this study we estimated the heating demand reduction potential of lowering the temperature setpoint in residential buildings by 1 °C at different scales—building, regional, and national—using demand simulation of Swiss building archetypes and clustering-based upscaling methods. Based on the results, we make the following key takeaways:

- Newer buildings show the highest percent reduction in demand (9.9% for SFH, 12.6% for MFH). This is due to their higher energy efficiency (i.e. better insulation of the building envelope that lowers the heating threshold for the operation of the heating system). As these buildings have both lower absolute demand reduction compared to older buildings and represent a small portion of the building stock (approx. 6.5% of the national energy reference area), they contribute to only 2.6% of the national demand reduction potential.
- Oldest buildings show the lowest relative change in demand (5.2% for SFH and 5.4% for MFH). However, due to their large number (approx. 33% of the national energy reference area) and their relatively high heating demand, they could contribute over 40% to the national reduction in demand.
- Older buildings are more likely to have oil and gas boiler installed (74% of buildings built before 1990 according to one of the recent estimates [25] compared to 64% based on national statistics [19]), and can therefore contribute more in reducing fossil fuel use. In newer buildings (built after 2000), heat pumps are the main space heating technology [6].
- Different regions have varying levels of relative reduction in demand (from 5.4% to 6.8%) due to a combination of climate variations and the building stock composition (i.e. archetype representation). When contribution to the absolute demand reduction is assessed (where changes among regions arise due to the distribution of the building stock), together they reach an estimated demand reduction potential of 5.9% (i.e. overall savings of residential buildings at the national scale).
- Estimated reduction in total natural gas demand arising from temperature setpoint reduction in residential buildings (where residential space heating demand comprises approximately one third of the Swiss natural gas demand) is 2.2%.

This analysis shows a reasonable impact on the space heating demand by reducing the setpoint. However, although absolute energy savings are only moderate, such a reduction of the temperature setpoint can immediately be done at almost no additional cost. Therefore, it may still be an adequate and worthwhile measure as a response to short-term fossil fuel supply issues and/or country's dependency on certain fuel supply sources. However, this is insufficient demand response if a complete offset of the Russian gas imports (47% of the Swiss gas import [26]) is considered: 1 degree thermostat adjustment would only be able to cover 14% of the demand for space heating, and 4.7% of total national demand. In the mid- to long-run, additional measures will be needed to reduce the overall energy demand and provide greater flexibility in addressing short-term shortages. These are discussed in the further considerations section below (section 4.2).

4.1. Limitations

Our simulation is based on standard use conditions (i.e. a reference temperature setpoint of 21 °C). In reality, the temperature setpoints can vary between buildings, and the average temperature setpoint may be much

higher (above 22 °C according to IEA [5]) or lower, and can depend on time of year [17], as well as a combination of building energy efficiency and socioeconomic factors [27]. This could then have a significant impact on the effectiveness of thermostat adjustment on the national scale. Additionally, differences in specific heating energy demand among similar buildings (i.e. belonging to the same archetype) can go beyond differences in the temperature setpoints. The heating demand is particularly sensitive to the variations in ventilation rate [28], which is not considered here.

To estimate the impact of thermostat adjustment on natural gas use, we apply a uniform reduction across all energy carriers based on the building stock results due the limitation on available data relating to heating technology and energy carrier (e.g. according to building type/age). The available building level data is not up-to-date, especially for older buildings in which heating systems may have already been replaced.

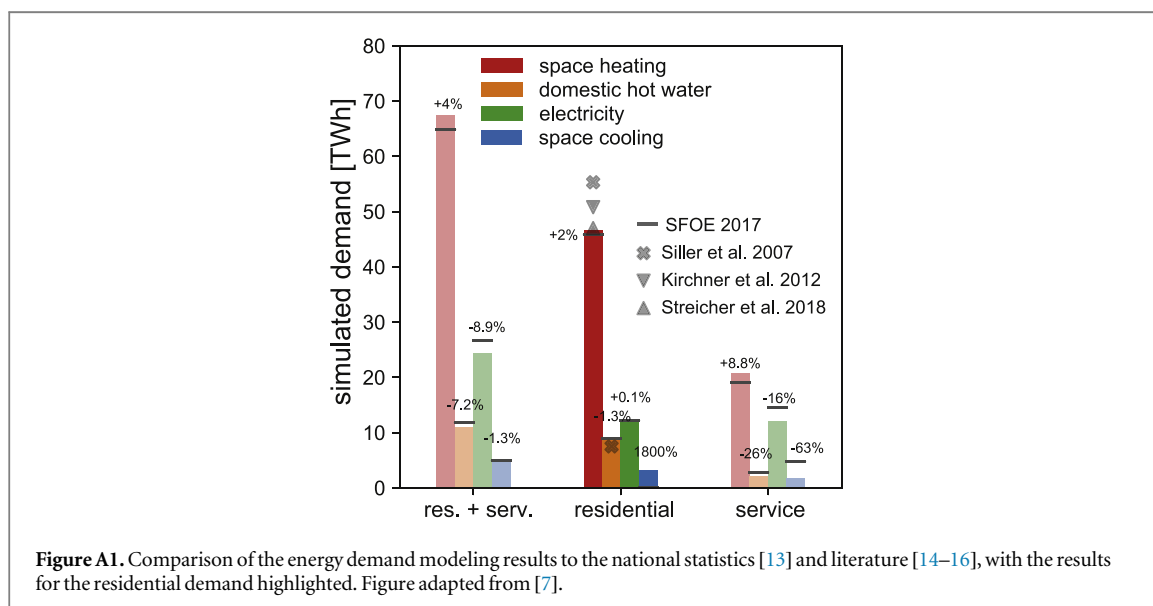
4.2. Further considerations

Decreasing the temperature setpoint in building heating systems by a small amount (1 °C) is one way of reducing demand, while having a minor impact on the perceived comfort of occupants. However, optimizing the use of energy for when and where it is needed most can further reduce demand. Most thermostats are manual, non-programmable spring loaded thermostats often without a temperature readout. They are set to a single setpoint and are often running regardless of occupancy and need. If thermostats in older buildings are replaced by simple rule-based thermostats (with predefined heating schedules set by the occupant) or smart thermostats (that dynamically adjust the setpoints according to the weather forecast and occupancy behaviour while keeping the desired comfort [29]), large energy savings can be achieved (−20%–30% in some cases [30]). In the long run, energy-related building retrofits and updates to the heating systems will be required to increase the efficiency of energy use and reduce dependence on fossil fuels.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

Appendix A. Validation of the results on the national scale



Appendix B. Assumptions in the predicted percentage of dissatisfied (PPD)

The assessment of PPD is performed using the CBE Thermal Comfort Tool [18] under the EN 16 798-1:2019 standard. Air temperature is used in the assessment, with the assumption that air temperature and mean radiant temperature are equal. The air speed, relative humidity, metabolic rate, and dynamic clothing insulation are held constant in the calculation, and are shown in the table below.

Table B1. Assumptions used in PPD calculations.

Parameter	Value (description)
Air speed	1 m/s
Relative humidity	50%
Metabolic rate	1 met (seated, quiet)
Dynamic clothing insulation	1 clo (typical winter indoor clothing)

Appendix C. Archetype, climate, and building stock variations

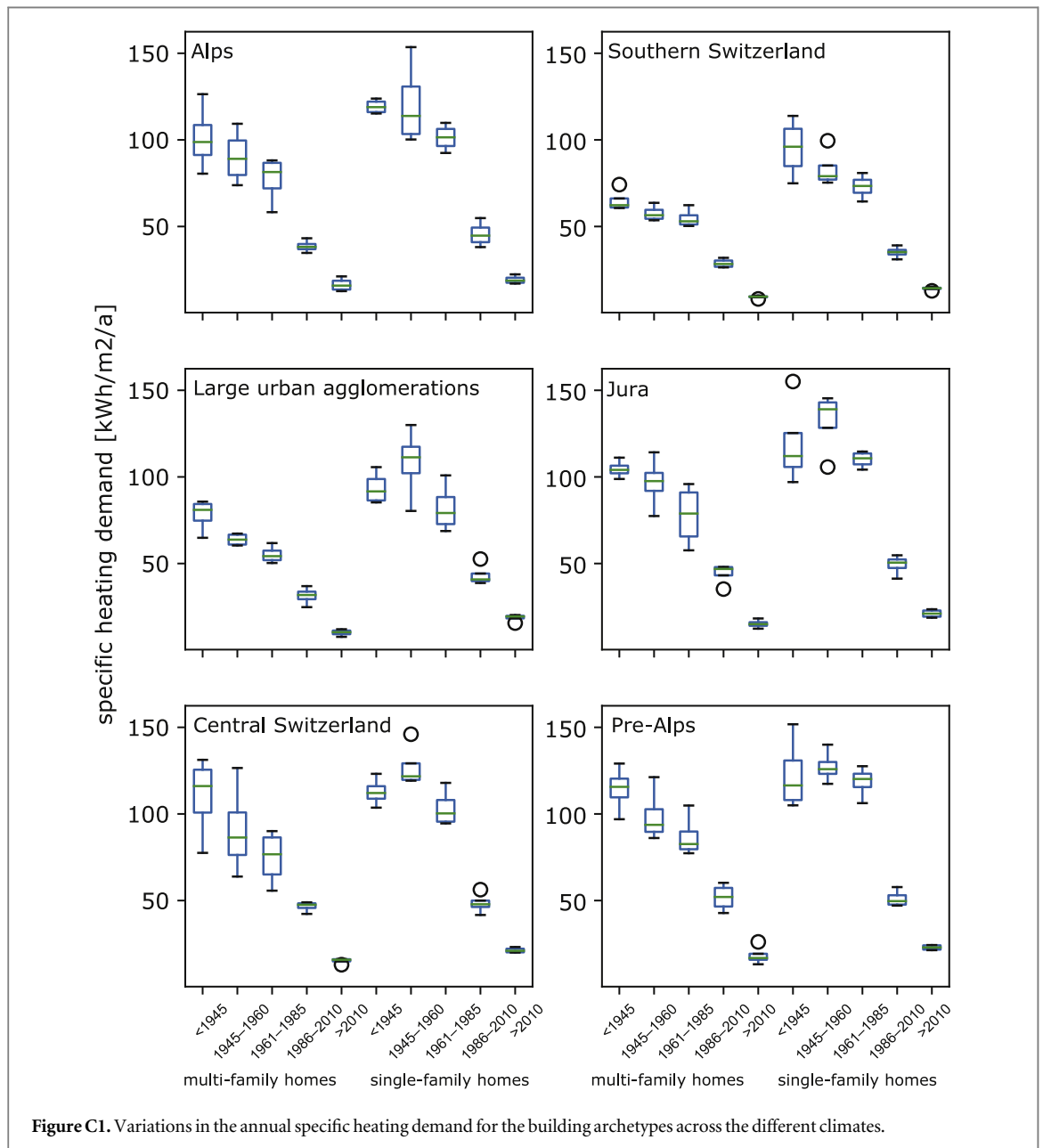
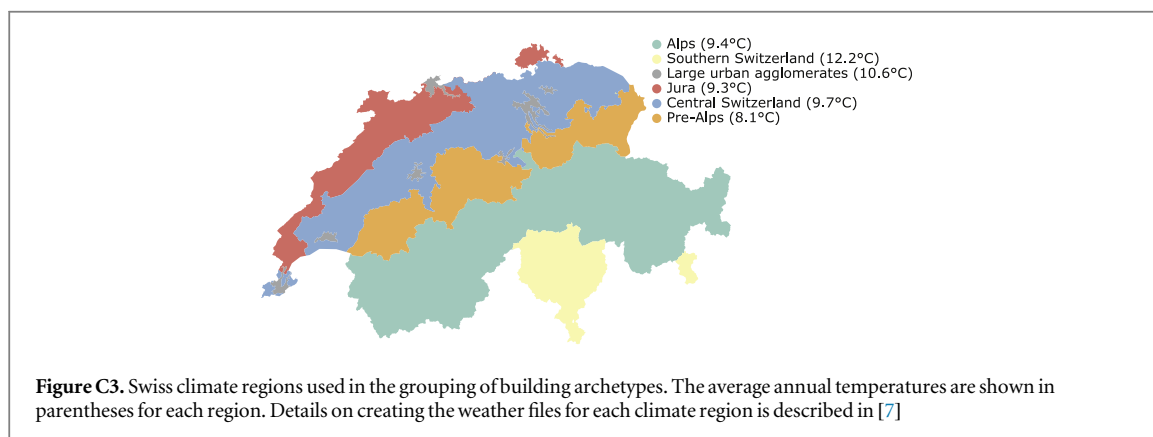
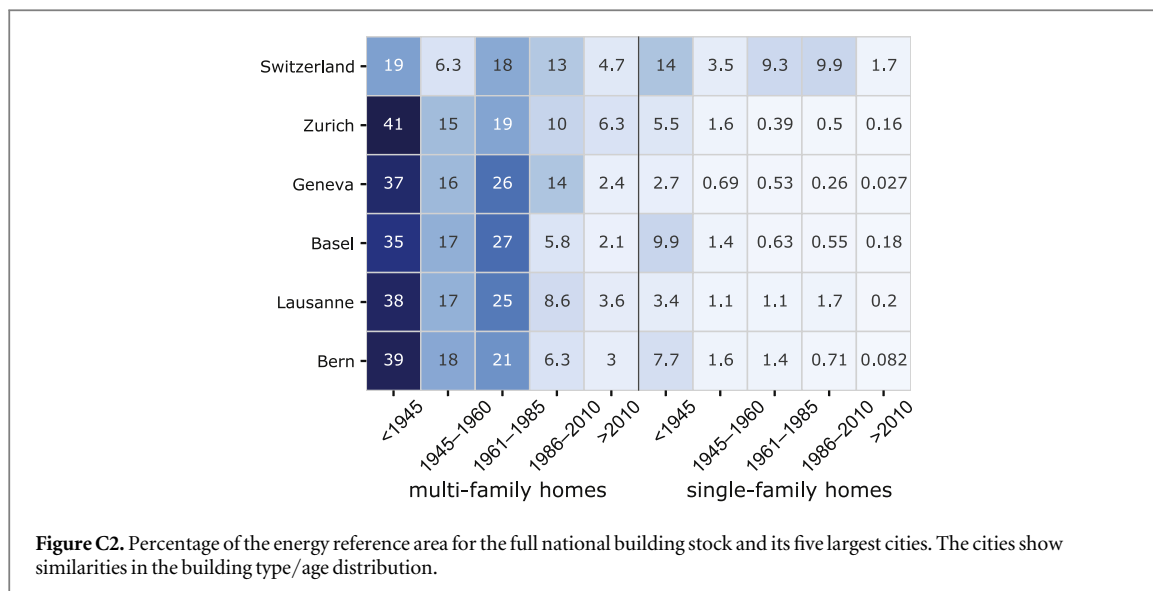


Figure C1. Variations in the annual specific heating demand for the building archetypes across the different climates.



Appendix D. Comparison to IEA values: back of envelope calculation

Table D1. Natural gas use in buildings (EU) in PJ.

Residential space heating (EU-28)	4385 [22]
Residential space heating (UK)	769 [22]
Service/tertiary space heating (EU-28)	1868 [22]
Service/tertiary space heating (UK)	258 [22]
<hr/>	
Total (residential + tertiary, EU-28)	6253
Total (residential + tertiary, EU-27)	5226

The percentage change in energy demand (ΔE_{demand}), corresponding to 10 bcm reduction in natural gas use [5], is approximately:

$$\Delta E_{demand} = \frac{-360PJ^*}{5226PJ} * 100 = -6.9\%.$$

*Conversion factor:

1 billion cubic meter (bcm) natural gas = 36 PJ [31].

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