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Assessing Heating Demand Flexibility in the Swiss Building stock

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Abstract

The use of flexibility for demand shifting will play a vital role in the future Swiss power system that mainly relies on non-dispatchable generation. Space heating currently accounts for around 30% of final energy consumption in Switzerland. This proportion is expected to remain similar until 2050. With increased rates of electrification projected for the heating sector (i.e. replacement of fuel-based systems with heat pumps), heating demands and the interplay with building thermal mass have the potential to serve as an important source of flexibility. To ensure that flexibility does not come at the expense of occupant comfort, the overall flexibility potential needs to be first evaluated at the building scale before being upscaled to the national level. The aim of this article is to quantify the flexibility that results from using a building's thermal mass at the archetype level. Representative buildings archetypes for the Swiss building stock are simulated using the Urban Building Energy Modeling (UBEM) tool CESAR-P for different patterns of the indoor temperature set point. These preliminary results are used to identify the parameters mainly impacting the power demand reduction and the indoor temperature reduction during different demand response events. Future work should enable the generation of representative profiles of the flexibility potential for the different groups of Swiss buildings.

Introduction

As a consequence of the Paris Agreement, most countries have put forth plans for the decarbonisation of their energy systems. These plans include electrifying fuel-based sectors (e.g. heating and mobility) while increasing the share of renewable electricity generation in their power systems. However, a large part of renewable electricity generation is non-dispatchable (mainly solar and wind). To ensure a balance between electricity consumption and production, some of the flexibility services currently provided by dispatchable power plants should be shifted to the demand side of the energy system. Space heating currently accounts for around 30% of final energy consumption in Switzerland (Prognos et al., 2021). This proportion is expected to remain similar until 2050. Space heating systems can be easily switched on and off from a few minutes to several hours, while maintaining an acceptable level of comfort for the occupants. Consequently, the use of flexibility via demand shifting for space heating will play a vital role in the future Swiss energy system and needs to be evaluated at the building, district and national level. The energy flexibility quantification in buildings is a highly active domain of research and several journal papers are published on this topic. For instance, Li et al. (2021) reviewed 85 journal articles about methods to quantify energy flexibility in residential buildings. Li et al. (2022) posed and answered 10 questions concerning energy flexibility in buildings. Le Dréau et al. (2023) reviewed methodologies and tools to analyse the main barrier to the development of building energy flexibility. Finally, Li et al. (2023) reviewed data-driven key performance indicators and datasets for building energy flexibility. However, the literature reviews cited previously highlighted that the representability of the diversity in the building stocks is rarely taken into account.

The space heating demand is often evaluated at the national scale by scaling up the demand evaluated for representative buildings archetypes. Eggiman et al. (2021) applied this method to the Swiss building stock. In this article, this methodology is adapted to evaluate the flexibility potential of Swiss building archetypes. The representative building archetypes for the Swiss building stock are simulated using the UBEM tool CESAR-P for different patterns of the indoor temperature set point. These preliminary results are used to identify the parameters mainly impacting the energy demand reduction, and the indoor temperature reduction during demand response events. Future work should enable the generation of representative curves for the different groups of Swiss buildings.

Application of simulation method

Urban Building Energy Modelling

CESAR-P (Combined Energy Simulation And Retrofitting - Python) is an open source Urban Building Energy Modelling (UBEM) tool based on the building energy simulation program EnergyPlus (Orehounig et al., 2022). The CESAR-P tool allows the evaluation of Swiss transformation strategies for decarbonisation in terms of building and district energy demands. CESAR-P evaluates the final energy demand using a bottom-up approach. Few inputs are needed: buildings footprint and height, year of construction, building type (residential, office, etc.) and an hourly EnergyPlus weather file. EnergyPlus is a whole-building simulation software that uses mass and heat balance equations to model the energy flows through the thermal zones of a building. CESAR-P generates a set of building models, and the corresponding temperature setpoints and occupant behaviour models to run EnergyPlus models for each building in the district. According to the building footprint, the building type, and the year of construction, a set of building models to be simulated in EnergyPlus is generated with different thermal envelopes and glazing ratios. Each floor of each building is represented in EnergyPlus as a single thermal zone. CESAR-P takes into account interactions with neighbouring buildings (e.g. shading and solar inter-reflections). If the additional inputs required by EnergyPlus are not provided by the user (occupant behaviour, glazing ratio, daily DHW demand, etc.) , they are generated by CESAR-P using the SIA2024-2016 data. The building type influences the daily appliances profile and the occupancy profile, which are related to the use of the building. The building area influences the number of people concerned by the appliance and occupancy profiles. To generate diversity in the occupant behaviour model, variability is added to the amplitude of the parameters such as the area per person or the level of the appliances. Passive cooling by means of window shading is applied when the indoor temperature reaches a minimum of 24°C.

By default, CESAR-P does not include an internal zoning or internal mass. For this article, internal walls were added using the zoning method from the ASHRAE Standard 90.1–2016 with a maximum value of 15 feet for the perimeter zone depth. In EnergyPlus, it is possible to multiply with a coefficient the thermal capacitance of the air of the rooms to include the internal mass of the furniture. Johra and Heiselberg (2015) reviewed the methods to model internal mass in buildings. They found air capacitance multiplied by 1.2, 5 or 8. In this article the air capacitance was multiplied by 8.

Scale up from representative buildings to the national level

The current performance of the UBEM tool is not sufficient to be able to carry out a thorough bottom-up simulation of the national building stock. Therefore, national-level space heating demands are usually evaluated by combining bottom-up methods with grouping techniques. The aim is to identify typical buildings representing the national stock. The UBEM is simulated solely for the building archetypes, and then the heating demand is scaled up significantly reducing simulation time.

Goy et al. (2021) identified three principal grouping approaches to analyse a country's building stock: supervised, un-supervised, and semi-supervised. In the supervised grouping, building groups are initially defined based on a set of features. In contrast, unsupervised methods, also known as clustering, do not have pre-defined groups. Instead, the building stock is divided using an algorithm that relies on graphical and/or numerical criteria such as distance minimization between group members. Finally, hybrid methods, known as semi-supervised techniques, employ both supervised grouping and clustering on the building stock.

In this article, the method developed by Eggimann et al. (2021) is used. Grouping is initially based on building type (multiple or single family houses), age (<1945, 1945-1960, 1961-1985, 1986-2010, >2010), and climate zones (large urban agglomerations, southern Switzerland, central Switzerland, Pre-Alps, Alps, Jura). Next, clustering is performed on each group by considering the compactness, density, and size of the buildings, resulting in 240 clusters for the residential building stock. In Eggimann's article, the 50 building archetypes chosen to represent a group are the ones with the less dissimilarities with the other elements of the group. To decrease the simulation time, in this article, only 7 buildings are simulated from the most representative cluster of each group. Consequently, the residential building stock is represented with 420 archetypes. In future work, the simulation will be performed for a larger number of archetypes.

Heat pump modelling

In this article, the heat pump performance was modelled based on specific manufacturer data. The COP of the heat pump is given for an evaporator inlet temperature of both 7°C and -7°C and for multiple condenser outlet temperatures. Under non-nominal conditions, the heat pump matrix of performance is adjusted using the method from EN 15316-4-2. However, the detailed heating system is not modelled in CESAR-P and a constant temperature of 55°C is chosen for the condenser output.

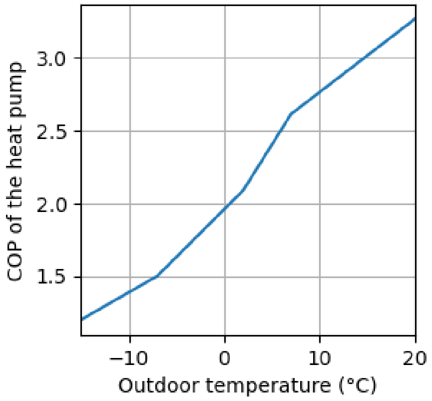

Figure 1: COP of the heat pump for different condenser outlet and evaporator inlet temperatures

The obtained relation between the outdoor temperature and the COP of the heat pump used in the model is presented in Figure 1.

Metrics definition

The main goal of this article is to provide a first estimate of the flexibility potential of the residential space heating demand in Switzerland using the internal thermal mass of the building stock. To evaluate the flexibility, first, the representative building archetypes are simulated assuming a constant temperature set-point of 21°C. The result of these simulations form the reference case to be compared with the results of a second simulation that considers changes in the temperature set-point (decrease in the temperature set-point of 3°C or 1°C during 1, 2 or 3 hours, alternated by 9 hours of reheat time). The following metrics were selected to estimate the flexibility potential:

- Energy savings during the temperature set-point decrease of 3°C in MWh/m²
- Indoor temperature drop at the end of the temperature set-point decrease in °C
- Energy savings during the temperature set-point decrease of 1°C in % of the energy consumption

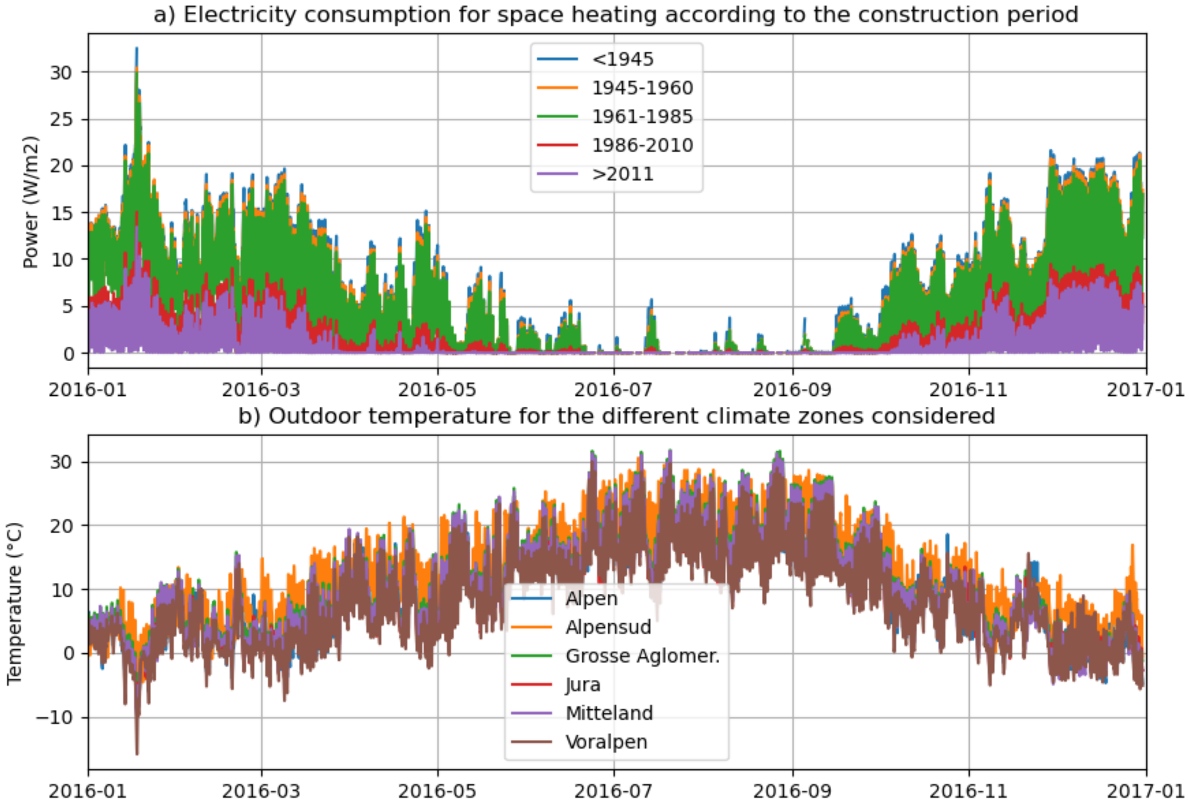

Figure 2: Representative space heating demand for the residential buildings and average outdoor temperature for the different climate zones in 2016

Results

Electricity consumption for space heating

Figure 2a represents the evaluated average electricity consumption for space heating for the Swiss residential buildings for the different age classes for the year 2016. Figure 2b represents the averaged outdoor temperature during the same period for each climate zone. Figure 2a shows that in summer, space heating may still be needed in older buildings when the outdoor temperature drops below 10°C. The overall objective of this work is to evaluate the corresponding flexibility potential profiles of these building archetypes.

3°C decrease of the temperature set-point

Figure 3 presents the energy savings during the temperature set-point decrease of 3°C depending on the 6 hours-rolling average of the outdoor temperature across multiple buildings of the different age classes. The decrease of 3°C was chosen to simulate shutting down the system. The energy savings seem strongly correlated with the outdoor temperature, the age of the building and the duration of the demand response events. However, additional variables like solar radiation, air change rate, or the difference of insulation between the buildings simulated for the same age class should be added to explain the variation in the energy savings. In the case of a decrease of the temperature set point of 3°C, the heating system is always turned off during the complete duration of the event. These savings correspond then to the totality of the space heating demand during this time.

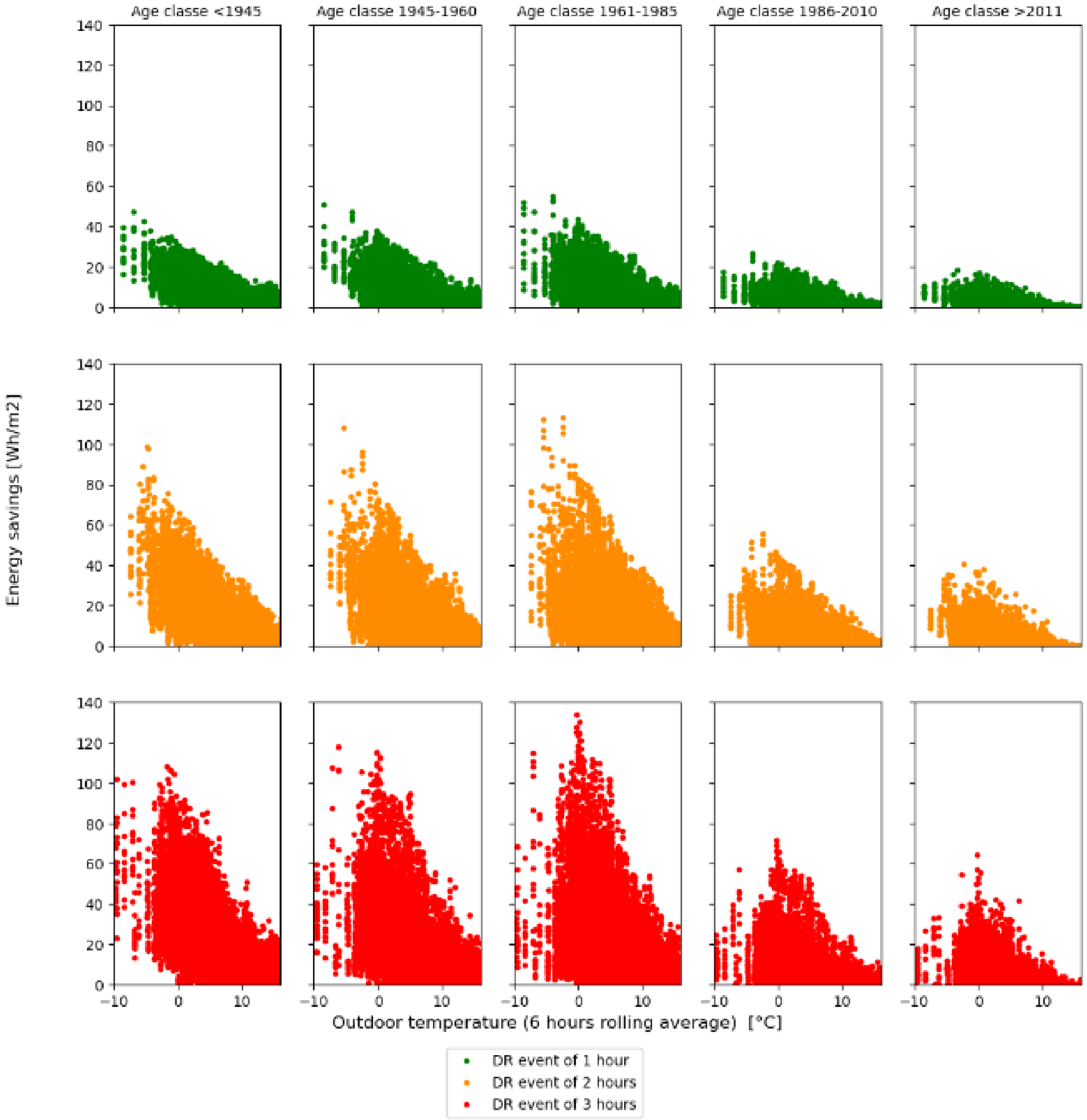

Figure 1: Energy savings during the decrease of the temperature set-point

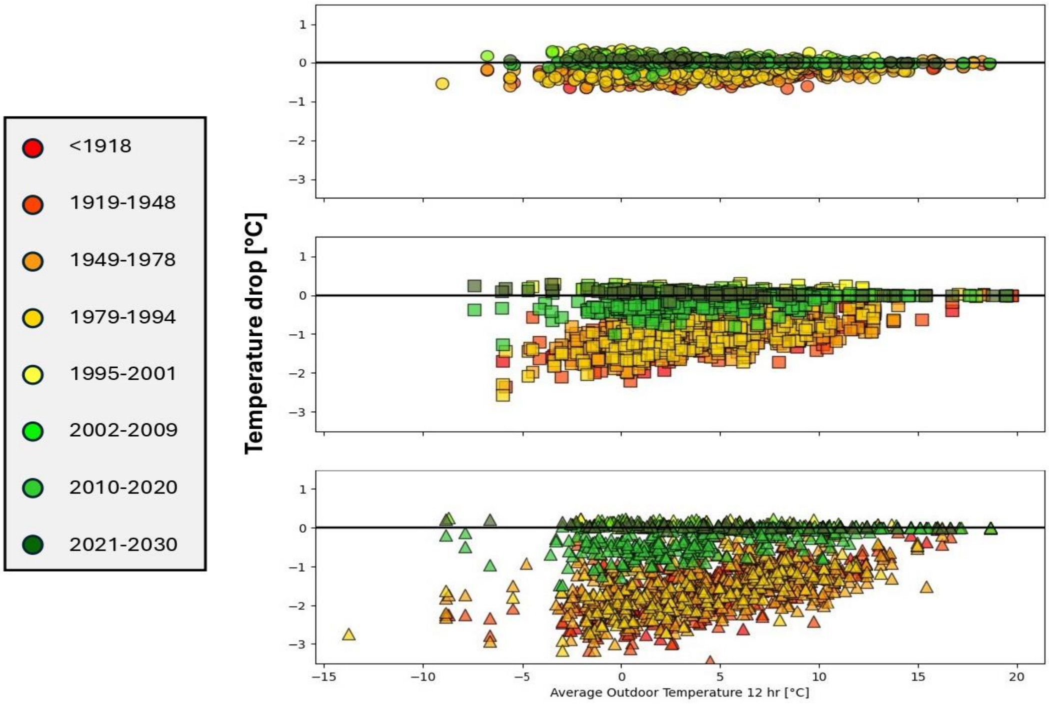

Figure 4: Ambient temperature drop at the end of the temperature set-point decrease

Figure 4 represents the temperature decrease in the buildings after the demand response event. It is important to consider the temperature drop in the buildings when considering the passive flexibility of the internal mass. In the older buildings, the temperature drops quickly, which could decrease the acceptability of the demand response event. In future work, the acceptability rate of such DR events should also be evaluated and taken into account.

1°C decrease of the temperature set-point

Figure 5 represents the energy savings realized during a decrease of the temperature set-point of 1°C. These savings are expressed in percent of the electricity consumption without demand response event during this time. For a temperature decrease during 1 hour, the temperature drop in the buildings stay below 1°C. Consequently, the energy savings are not impacted. For longer DR events, there is a reduction of the energy savings. However, the temperature drop are also lower, probably leading to a better acceptability of the flexibility events. In future work, it will be crucial to model explicitly the acceptability of the flexibility applied to the space heating in order to identify the best national strategies. Complete shut-down of the space heating systems could lead to high decrease of the peak demand. However, applying temperature set-point reduction of 1°C could increase the acceptability of the measures and the global comfort of the occupants. However, it would require aggregating more buildings to reach the same flexibility level at the national level.

Conclusion

The aim of this article was to evaluate the flexibility in space heating demand due to the thermal mass of various building archetypes. Building archetypes representing the Swiss building stock were simulated using the UBEM tool CESAR-P for different patterns of the indoor temperature set point. These preliminary results were used to identify the parameters mainly impacting the power demand reduction, and the indoor temperature reduction. Future work should enable the generation of representative profiles of the flexibility potential for the different groups of Swiss buildings. However, the current model presents some limitation that should be addressed:

- There is no diversity in heat emitter (radiators or heated floor), in the behavior of the occupants (schedule or reference temperature set point), or models of heat pumps
- Retrofits before the installation of a heat pumps should be considered
- Detailed heating system models should be coupled with CESAR-P.

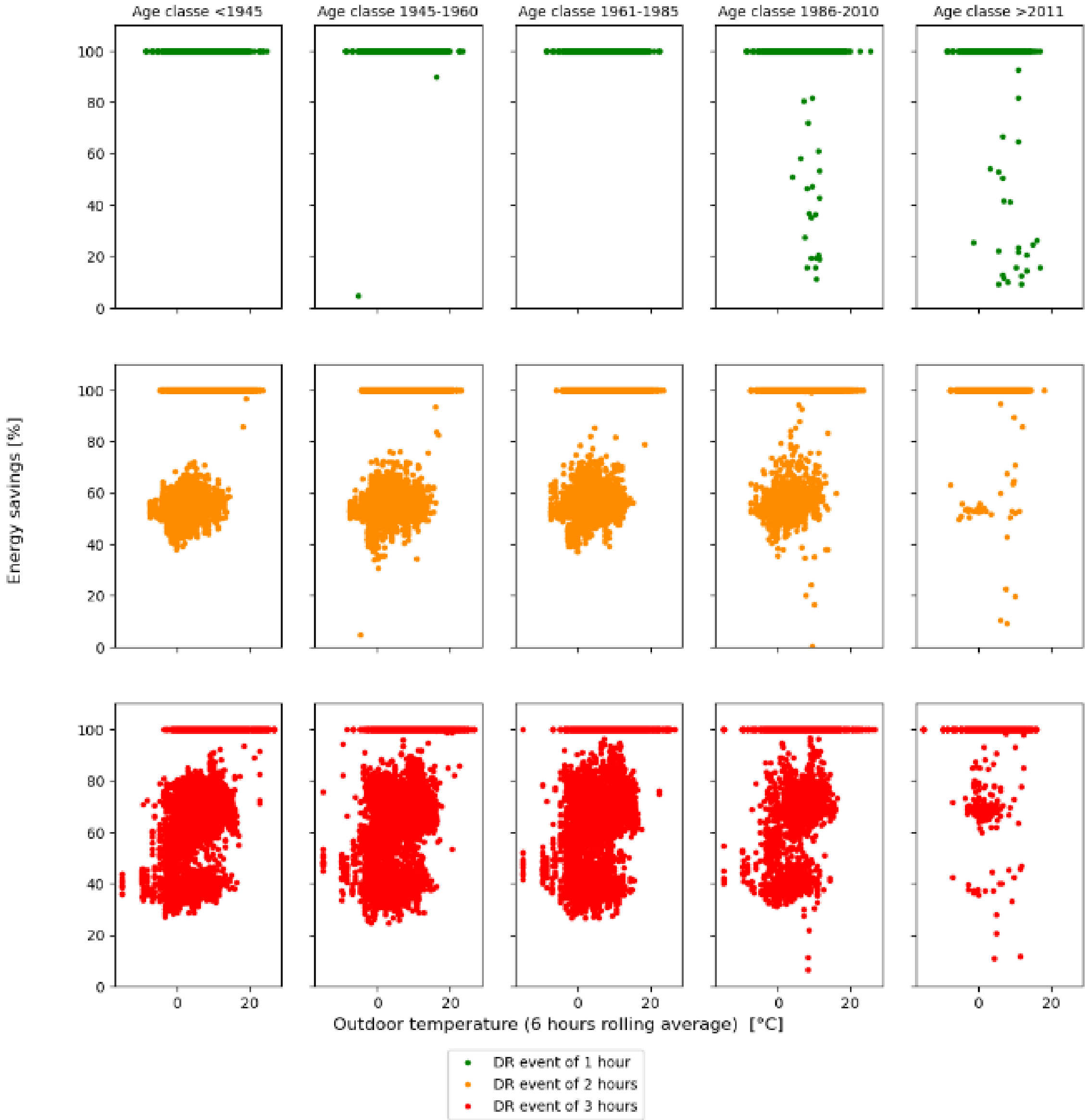

Figure 5: Energy savings during the decrease of 1°C of the temperature set-point

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