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Executive Summary

GAPxPLORE: Energy Performance Gap in existing, new, and renovated buildings

Learning from large-scale datasets

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Introduction

Buildings are responsible for 40% of the total final energy consumption in Switzerland while 70% of the final energy used in 2016 in the residential sector is related to space heating. In order to reduce this consumption and in line with the other EU energy policies, the Swiss Federal Council has been developing and implementing the Energy Strategy 2050 (ES-2050) since 2011. The ES-2050 is based on three strategic objectives: increasing energy efficiency, increasing the use of renewable energy, and withdrawal from nuclear energy. For residential buildings, this translates for final energy to be reduced by 46% and CO_2 emissions by 77% until 2050 according to the “New Energy Policy”. It is therefore crucial for the success of energy and climate policy to accurately estimate the energy saving potential of the building stock. For this purpose, reliable values of the energy demand of existing and retrofitted buildings are needed. These values are generally established either through measurement or by calculation using a model. However, there is evidence of a significant Energy Performance Gap (EPG) in buildings, defined as the difference between measured and calculated energy consumption. There is a broad agreement in the literature that buildings with poor thermal performance (low energy rating) tend to consume less than predicted, i.e. less that calculated under standardized conditions. Vice versa, buildings with high thermal performance (high energy rating) tend to consume more than predicted.

Several European projects have had the objective to monitor the actual performance of buildings and to reduce the EPG including EPISCOPE (Germany), TRIME (Netherlands), TRIBUTE (Ireland), HIT2GAP (France), UserTEC (Denmark). However, these projects are limited to EU countries and exclude Switzerland. It is unclear whether and to what extent these findings can be applied to the Swiss building stock. Our project GAPxPLORE which covers thousands of buildings is the most comprehensive study so far conducted in Switzerland and aims to offer statistically representative results, providing valuable insight for policy makers and other stakeholders.

Goals and section contents

The GAPxPLORE project aims to evaluate the EPG in the Swiss building stock. It studies how the EPG is distributed among the building typologies (performance level and age). Large-scale datasets from a range of sources containing calculated and real energy consumption data of buildings are analysed. GAPxPLORE also investigates the Energy Savings Deficit (ESD), defined as the difference between expected and achieved energy consumption reductions in renovated buildings. The focus lies on the final energy consumed for heating and domestic hot water in residential buildings. Four data sources were used. First is the Swiss Cantonal Energy Certificate for Buildings (CECB) database, which provides a sample of 50 000 buildings. Second, the Swiss Solar Agency data was used, which was collected from applications for the Swiss Solar prize and consists of new and recently renovated buildings that can be considered as examples of best practice in terms of energy performance. This data includes measured energy consumption information for roughly 150 buildings. The third dataset represents the Swiss Minergie buildings. The fourth dataset is the Energo platform containing measured energy consumption of buildings across Switzerland. However, only a part of each of these datasets was ultimately used after having cleaned and filtered the data (e.g. removal of implausible values). This report consists of one introductory section followed by six sections that present the analyses.

- **Section 2** presents a literature review on the EPG in Europe and Switzerland with the objective of creating an overview of existing findings for Switzerland and to compare these with EU countries.
- **Section 3** explains the data sources used for the analysis and assesses their representativeness. The preliminary cleaning and filtering of the data is presented, as well as the samples sizes used.
- **Section 4** studies the EPG in the Swiss building stock using the CECB database. This provides statistically representative results of the EPG size and findings by building categories.
- **Section 5** studies the correlations between the expected and achieved savings obtained through building retrofit using a sub-sample of the CECB dataset.
- **Section 6** studies the EPG in high efficiency buildings by type of standard (Minergie, Minergie-P, Minergie-A) and by building type. The aim is to understand how the EPG of Minergie-P buildings compares to the EPG found for other labels. This task uses the datasets provided by the Swiss Solar Agency, Energo, and Minergie.
- **Section 7** presents case studies on Minergie buildings from the Energo database. The analysis includes the design phase calculations and post-commissioning, maintenance and optimisation in order to explore the causes of the EPG.

Finally, **Section 8 and 9** present the limitations and the conclusions.

Results

The review of existing research on the Energy Performance Gap has shown that there are a number of different definitions for calculating the EPG, and a large range of values reported. Three definitions can be distinguished, which differ in the way how the calculated consumption (for later comparison with the actual consumption) is modelled: a regulatory, static, and dynamic performance gap. The regulatory performance gap, that compares the performance of a building under standardized national conditions to measured energy use, is the most widely used type of EPG and it plays an important role in this study as well. The variety in metrics and terminology and the resulting challenge of drawing sound conclusions has been identified as an obstacle to closing the EPG. To do so, it would need to be always very clear what is included in the consumption values that are compared and what type of energy is compared (i.e. heating demand or final energy for all energy services in a building). There is some lack of clarity in Swiss literature and legislation, as the building owner or inhabitant is consuming (and paying for) final energy at the meter, while the energy labels (CECB and Minergie) and the related legislation/norms refer to the “weighted final energy” calculated using national factors. These factors, which are collectively defined by the cantons, reflect the cantonal energy policies rather than the performance of the building envelope or heating system.

The project findings confirm the existence of an EPG for Swiss residential buildings, with a median of -11% (i.e. the median building performs slightly better than expected). The total actual consumption of final energy for the entire residential building stock is 6% lower than calculated. This value differs from the median EPG (-11%) as the total consumption delta across the building stock is the result of weighting of the EPG values per building with the total ERAs by building class, and the specific energy consumption per meter square. Furthermore, the data analysis shows a strong correlation between energy rating and EPG. For low performing G-labelled buildings, a negative EPG of -40% was found, while for the higher performing buildings with B-label a positive EPG of +12% was determined. These results support previous findings in the literature according to which higher performance buildings are consuming somewhat more than predicted while lower performance buildings are consuming significantly less than predicted.

A subsample of the CECB dataset was then generated which consisted of residential buildings that had a CECB certification both before and after renovation in order to investigate the relationship between the expected and achieved savings obtained through energy retrofit. This subsample included 1172 buildings. For all these buildings, the Energy Savings Deficit was calculated. Two versions of the ESD have been proposed in this study: the regulatory ESD (ESDr) using the theoretical savings (based on theoretical energy consumption before and after retrofit) as the expected savings, and the anticipated ESD (ESDa) using the anticipated savings (difference between actual consumption before retrofit and theoretical consumption after retrofit) as the expected ones. Independently of the calculation method, it was found that despite an increase of the heated area by 7% in the course of energy retrofit, total final energy use and CO_2 emissions for thermal purposes was halved in the building sample.

The ESDr and ESDa were calculated for the whole subsample, resulting in a median ESDr of 37.3% and a median ESDa of 3.60%. The result for the ESDr implies that based on the theoretical values, only 62.7% (100% - 37.3%) of the expected savings are actually achieved. Instead when using the anticipated values (ESDa), 96.4% (100% - 3.60%) of the expected savings are actually achieved. Moreover, it was found that the ESDr increases with the label improvement, meaning that the energy savings obtained through deep retrofit are about half of the calculated ones. The ESDa, however, showed the opposite trend, decreasing with the increase of the label improvement, until it becomes even negative for very deep retrofit (which means that more energy is saved than anticipated).

Finally, the EPG was studied in a sample of 56 high-performance buildings, focusing on the difference in EPG among the various Minergie standards (Minergie, Minergie-P, and Minergie-A). The Minergie indexes were used as theoretical consumption, thereby representing the total energy consumption for all needs of the buildings (and differing from the theoretical consumption defined in previous parts of the study, which only included space heating and domestic hot water). A median EPG of -14% was found. The results confirm the higher performance of Minergie-P buildings, with an EPG of -12% for new construction and -18% for retrofit, and also of Minergie-A buildings with an EPG of -16% for new construction and -5.3% for retrofit. However, even if the deviation in percent terms seems significant, in absolute values the actual consumption is below the target by only 4 kWh/(m^2y) for Minergie-P buildings and by 6 kWh/(m^2y) for Minergie-A (for the total energy needs of the building).

For the case studies presented in Section 7, the EPG for heat consumption ranged from -44% to +93% and the EPG for electricity consumption ranged from -2.9% to +132%. The main reasons for the EPG for heat are i) the higher temperature of space heating and of the hot water primary circuit compared to the standard values as well as ii) window opening for long periods of time causing temperature drops. The main reasons for the performance gap in electricity are incorrect time schedules of the ventilation systems and high energy consumption for appliances. It was found that one of the greatest uncertainties in determining a building's EPG is not the collection of actual consumption data but the determination of theoretical consumption. In the case studies analysed, between 44% and 76% of the theoretical consumption was calculated with parametric indices and the remaining energy consumption was established in a more precise but non-homogeneous way (e.g. sometimes on an hourly, monthly or other time basis). In fact, the energy calculations carried out during the design phase of a building do not have the objective of forecasting the final total consumption but of evaluating the efficiency of the main design choices and their compliance with energy requirements by respecting the limits established by national standard or laws.

Conclusions

GAPxPLORE confirmed the existence of an EPG in the Swiss residential sector, with buildings with low thermal performance tending to consume less than predicted (negative EPG) and buildings with high thermal performance tending to consume marginally more than predicted (positive EPG). The observed values are smaller than those reported in existing case studies in Switzerland, partly because this is the first stock-level assessment (rather than focusing on small numbers of high efficiency buildings). A further reason may be that building owner applying for a certificate may pay more attention to energy efficiency than the average owner. Finally, the subsamples of the CECB data used for this analysis may not be fully representative of the Swiss building stock for other reasons (e.g. cantonal representation, filtering etc.). It is important to highlight that the different values of the EPG found for low and high energy rating imply very different levels of final energy consumption, as one percent point represents very different energy consumption values in terms of kWh/(m^2y) for the low rating compared to the high rating. For this reason, care should be taken when interpreting the percentage values for EPG for different energy labels.

The results on the energy savings deficit for retrofitted buildings suggest that the regulatory ESD (ESDr) is not a good indicator of the quality of an energy retrofit, as most of the deficit is due to an over-estimation of the consumption of the building prior to retrofit. Therefore, the ESDr reflects the error in the calculation of the theoretical savings rather than the quality of the retrofit itself. Conversely, the anticipated energy savings deficit (ESDa) proves to be a clearly more reliable indicator for judging the success of a retrofit in view of the small error in absolute terms (only 3.60%). The ESDa has the additional benefit that it allows to indicate significant deviations between Anticipated and Actual savings and therefore helps to identify system or operational failures (i.e. if the building does not perform as anticipated, this is likely related to a practical issue rather than an error in the calculation). Finally, the small value of ESDa found suggests that the overall quality of the energy retrofitting performed within this sub-sample is high, indicating, *inter alia*, that on-site workmanship is not a major problem in Switzerland. This analysis furthermore positively reassures that demanding energy savings objectives are often achieved, a finding that also policymakers and investors might find encouraging while keeping in mind that this analysis was based on a relatively small subset of the CECB dataset.

For the Minergie buildings, the analysis yields a negative EPG of -14% (i.e. the median building consumes slightly less than its standard), which provides further support for the initial hypothesis that the most efficient buildings are more robust to the EPG (for the A-label buildings in the CECB sample an EPG for space heating and domestic hot water of -6.2% was found). However, this finding could be partly a consequence of the small sample used (56 buildings) and its characteristics.

To conclude, the finding for the entire Swiss residential building stock, according to which the total actual consumption of final energy is 6% lower than predicted, is reassuring but it is in contrast to some previous studies relying on case studies in Switzerland. Our finding is based on the CECB sample and further research would be required to understand whether the buildings included in this sample perform better than average in Switzerland. Similarly, the overall limited EPG found for high performing buildings is reassuring, with Minergie-P and Minergie-A buildings even outperforming the theoretical values. In view of the origin of the data (Swiss Solar prize) and the smaller sample size, these findings should not be generalized, while nevertheless showing that remarkably high energy efficiency levels can realistically be achieved.