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Building certificate use for benchmarking and stock modelling - Learnings from Switzerland

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ABSTRACT

With the implementation of more stringent regulation in the building sector, energy performance certificates for existing buildings are becoming more common. These certificates represent a new source of data which can be used for a variety of purposes. This contribution presents and discusses the use of certificate data for energy benchmarking and for building stock modelling based on earlier analyses conducted for Switzerland. It can be concluded that energy performance certificates represent a valuable source of information in spite of the associated shortcomings and that their importance for data-driven analysis is likely to grow.

CCS CONCEPTS

Applied computing; Physical sciences and engineering; Engineering

KEYWORDS

Energy performance certificate, energy modelling, building stock, energy performance gap

ACM Reference format:

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1 Introduction

In order to reach national and international energy and climate policy objectives, energy use in the existing building stock needs to be reduced very significantly. To develop related national and regional policies, a solid understanding of the current energy use by building types is required as first step, followed by analyses about the improvement potential. While past studies addressing this need have been based on a combination of case study data, surveys and aggregated information from statistics, the use of energy performance certificates has been recommended as data source [1]. It is argued that energy performance certificates, which have been in place for several years, provide valuable information about mean building surfaces, U-values and other relevant input data in large sample sizes for the total stock. Since the energy performance certificates are in most cases issued by experts in the field, they should offer a more detailed and accurate representation of the various building elements compared to studies based on surveys which are mostly filled by building owners. Moreover, these databases are typically updated periodically, allowing to continually improve bottom-up analyses depending on detailed information. Against this background, the present paper addresses the question how energy performance certificates can be used for benchmarking and for energy modelling.

For benchmarking, we address in particular the question how the *actual* energy consumption compares to the *theoretical* energy consumption, i.e. how large the so-called energy performance gap (EPG) is. With regard to energy modelling, our question is whether energy performance certificates can serve as data source for models representing in detail the building stock of a country or a province. We answer these questions about energy modelling and benchmarking for the residential sector in Switzerland, thereby making use of insights from our earlier publications [2-9] which were based on the Cantonal Building Energy Performance Certificates (CECB) [10]. In Switzerland, the CECB is generally a voluntary scheme, with some cantons making it mandatory in case of modifications to the building or replacement of the heating systems. The CECB is primarily issued for old buildings whereas other certificates are preferred for new buildings (e.g., Minergie).

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The latter can serve as further data sources (see e.g. [11]) and but they are not subject of the present paper.

Methodology

The CECB reports two types of indicators, one of which only concerns the building envelope (walls, roof, windows, etc.) while the while the other describes the overall energy efficiency including heating system, domestic hot water, and other loads (e.g. appliances). For benchmarking, we use the latter, while we make use of the former for modelling the building stock.
To establish the EPG in our benchmark analysis, we compare the actual energy consumption to the theoretical energy consumption, both in final energy terms. The *theoretical* energy consumption is determined as the building's energy use under the standard conditions of occupation and weather (SIA 2028, 2008; [2]). The heat balances are calculated according to the Swiss standard SIA 380 (2015), in line with the approach of static monthly balances indicated in the European SN EN 13790 (2008). No corrections are hence made for user behaviour (including household size) and outdoor weather conditions. The *actual* energy consumption is established as average of measurements taken in at least three consecutive years, thereby following the standard SIA 2031 (2016).
The original CECB dataset contained approximately 51,300 residential buildings. Filtering out obviously faulty data (e.g. negative U values) as well as outliers, outdated certificate versions and datasets missing either the theoretical or the actual energy consumption resulted in a dataset comprising around 34,800 buildings which were used for the EPG analysis (68% of the initial dataset).
For a smaller sample of buildings, multiple CECB datasets were available, with the newer energy label representing a clearly lower energy use than the older one, hence indicating the occurrence of energy retrofit. After data cleaning, the size of this sample amounted to 1,172 residential buildings.
For energy modelling of the building stock, we used CECB data representing the physical properties of the various building elements (esp. specific thermal heat transfer or the efficiency of the heating system). Building archetypes were defined depending on their age (9 age categories), building types (single-family houses and multifamily houses, i.e. 2 categories), urban settings (urban, suburban and rural, i.e. 3), heating systems (e.g., oil, gas an wood; 6 in total) as well as cantons (26 in total).
To analyse the resulting archetype configurations, further data, such as outdoor temperature and standardized occupant behaviour, were taken into account in order to calculate the monthly steady-state energy demand based on the Swiss standard SIA 380/1. In first instance, the specific energy demand for space heating and domestic hot water were calculated per square meter of floor area. These values were then scaled up to the national demand based on the floor area by archetype according to the Swiss Federal Register of Buildings and Dwellings [12].
By comparing the actual U-values with the expected U-values, it was possible to establish the effect of partial retrofitting of older buildings which occurred in the past years (not presented here; see [5, 9]). The effect of energy retrofit was then calculated (by simulation and optimisation) for different scenarios, thereby adapting U-values and other parameters (e.g. floor area, climate change).
For the techno-economic assessment, three different renovation options were considered, i.e.:
1) Refurbishment at the end of the economic lifetime of a building element. Depending on the type of element and its state, refurbishment may entail a simple repair and paint works (e.g., for walls) or the replacement of the existing heating system with the same technology. As a consequence the energy efficiency of a "refurbished" building (as defined here) does not improve significantly.
2) The existing element is replaced by a more efficient option *at the end of* its economic lifetime or refurbishment cycle. For example, a natural gas heating system may be replaced by a heat pump and a run-down façade may be insulated and covered with cladding.
3) The existing element is replaced by a more efficient technology *before* reaching the end of its economic lifetime. This case is referred to as "early retrofit".

Results

In the following, we first discuss results from the benchmark analysis before presenting some findings of the energy model. The benchmark analysis for the Swiss residential sector according to Figure 1 shows that the actual final energy consumption is significantly lower than the theoretical final energy demand for old buildings whereas buildings constructed as of the year 1980 require somewhat less and for the most recent buildings also somewhat more energy than expected according to the theoretical calculations. This pattern has been confirmed by research conducted by other authors for Belgium France, Germany the Netherlands and for UK [3].

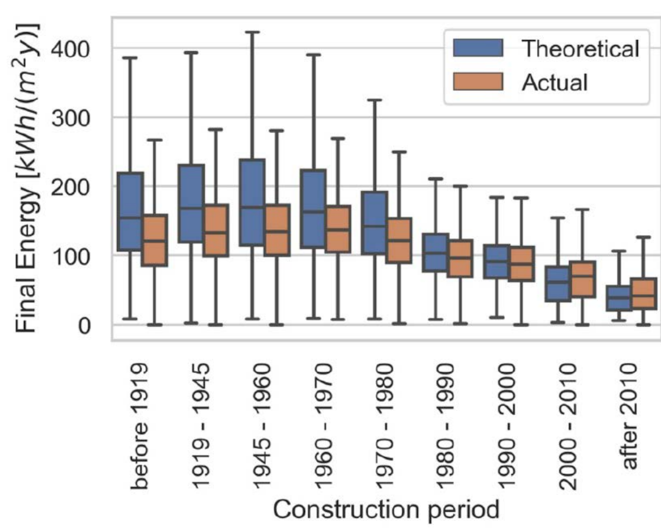

Figure 1: Theoretical and actual final energy consumption for the Swiss residential sector (n = 34,800) [2] (copyright permission for reproduction has been granted)

While the analysis just presented refers to the total Swiss residential building stock, the analysis of retrofitted buildings (n = 1,172) led to comparable finding: both before and after energy retrofit, the actual final energy consumption was found to be significantly lower than the actual final energy demand for the least efficient buildings (energy label F and G). On the other hand, the actual energy consumption tends to be slightly higher for energy efficient buildings (energy label A and B, with the exception of retrofitted label A buildings for which the actual consumption is slightly lower).

Also Streicher et al. [6] found an EPG when analysing the first results of the SwissRes energy model. Based on literature, the indoor temperature is assumed to have the largest influence on the EPG (see references in [6]). In order to arrive at realistic final energy demand values and subsequently also realistic final energy savings, Streicher et al. [6, 9] implemented correction factors for the energy demand by construction period and building type, thereby accounting for the deviation of the indoor temperature from the standard values.

The SwissRes energy model was used not only for simulations, for example leading to Energy Efficiency Cost Curves [7], but also for optimisation of pathways minimising either costs (maximum net present value) or greenhouse gas emissions. Figure 2 displays some results of this powerful analysis. Given the complexity of this graph, selected findings are discussed in the following. The length of each horizontal bar shows the energy reference area (floor area) assigned either refurbishment (white bar section) or energy retrofitting (coloured sections, with colour-coding for the retrofit period).

As expected, the GHG-optimal pathway implies i) more energy retrofitting than the cost-optimal pathway (shorter white bar sections on the right than on the left), ii) it requires earlier retrofitting (larger blue bar sections standing for retrofit activity already in the 2020s) and iii) the retrofit is deeper (more SysP which stands for passive house level). For GHG minimization, deep energy retrofit focusses primarily on the construction period 1950–1970, i.e. on buildings with the highest specific demand of around 160–200 kWh/m^2/year and with somewhat more attention for rural areas, which shifts more to urban and suburban areas in later decades. In the GHG-optimal pathway, more measures are implemented in short-lasting building (i.e. buildings with shorter remaining lifetime) than in the cost-optimal pathway. Deep GHG emission reduction requires much more complete retrofit than the cost-optimal pathway for which step-wise retrofit aligned to the economic lifetime or refurbishment cycle is more common.

This type of analysis can be conducted for each canton, allowing to understand how the policy measures can be locally adapted for optimal goal achievement (for more details see [8] and [9]).

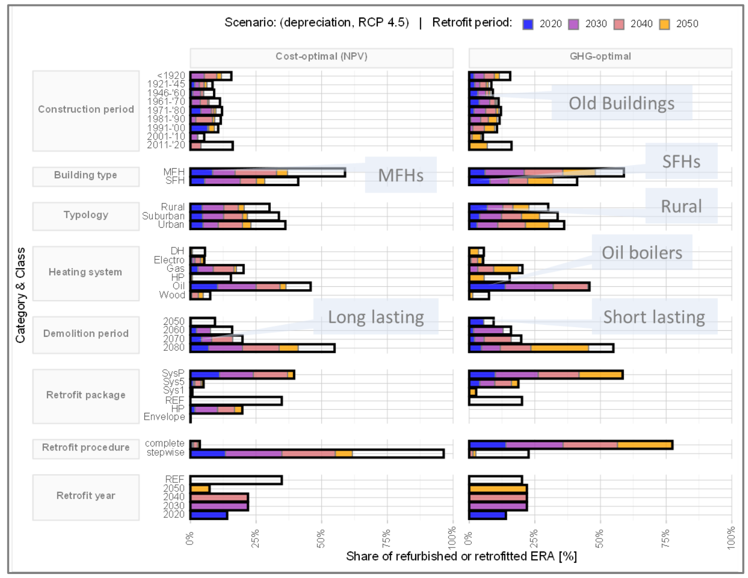

Figure 2: Level of implementation of retrofit options when optimising the Swiss building stock in terms of costs (left) or GHG emissions (right). Slightly adapted version of graph published in [8] (copyright permission for reproduction has been granted).

Another type analysis which can inform policy makes was conducted by Cozza et al. [13] who modelled scenarios for energy label-based retrofit targets for Switzerland's residential building sector for 2050. To this end, a building stock retrofit model was prepared allowing to estimate the potential energy savings by improving the buildings' energy efficiency through increasing energy label rating. Three different theoretical policy implementation strategies were studied, i.e. i) the improvement by three label ratings (e.g. from label F to label C), ii) retrofit of all buildings to label B ("All to B") and iii) retrofit of all buildings to label A. The main novelty of this analysis is that it takes into account the magnitude and uncertainty in the energy performance gap (EPG) by considering the difference between labelled and actual energy consumption. The uncertainty of the scenario "All to B" was found to be particularly high, whereas the other two strategies were found to be more robust. A possible explanation for the higher uncertainty of the scenario "All to B" is that a very deep retrofit is required for most buildings, i.e. it is challenging to reach label B from some initial energy efficiency levels. The lower uncertainly associated with the even more ambitious scenario "All to A" can be explained by the particularly stringent design requirements of this option, which is therefore less affected by the EPG and hence shows better results after retrofit.

Discussion and conclusions

This paper has presented the opportunities associated with the use of energy performance certificate data for energy benchmarking (here discussed with a focus on the EPG) and for building stock modelling.

As perhaps the most important caveat it must be pointed out that the quality of the CECB data is not undisputed. The budget available for each audit is very limited, i.e. CECB experts work under time pressure, explaining why they tend to take over default data instead of cross-checking data or collecting data from scratch. The accuracy of the actual energy consumption data is essentially subject to the CECB Expert's responsibility. A CECB report considered insufficient at the cantonal level can be rejected but on the other hand, no rigorous checks are conducted. In 2017, a quality check program was initiated at the national scale, also with the objective of supporting the CECB Experts to improve their skills and to optimize the online tool. Further use of the data and larger data samples may help to gradually improve the data quality if adequate policies are put into place.

When using this type of data, data filtering is another inevitable potential source of errors, even if special care was taken for the analyses presented (e.g., [2]). For the benchmarking analysis, it is a drawback that the targeted energy label is not known, i.e. the real EPG could be significantly larger than evident from our analysis (the absence of this information indicates a lack of rigour and enforcement which has to be questioned).

Limitations related to the work presented on the building stock model include the focus on technical and economic aspects (while disregarding a host of social constraints and the protection of historical buildings); further caveats and limitations, e.g. the limited number of technical options considered in the model, are given in [8, 9].

While these drawbacks must not be ignored, the present paper demonstrates that energy performance certificates represent a valuable data source for energy benchmarking and for building stock modelling at rather high level of detail. Fundamental data were extracted from the CECB dataset in order create the SwissRes energy model. Some of this data offer interesting insights as such or lend themselves to further analysis. For example, the total area of the various building elements (e.g. roof areas, wall areas, floor areas) have been extracted [15], representing an original source for important indicators such as window-to-wall ratio or the compactness of the buildings (ratio of volume to surface). If studied over longer periods of time (analysis of several versions of the CECB database), trends can be identified and – more importantly – quantified. This can be done not only for the building stock as a whole but also at the level of archetypes. Moreover, while the present paper focusses on the residential sector, this type of analysis can be conducted also for other categories of buildings such as offices, schools or retail (provided that the sample sizes are not too small).

The building stock model developed by Streicher et al. [7] served as basis for energy efficiency cost curves which were developed using three different economic approaches representing different stakeholder perspectives. The building stock model has also been used for pathway analysis, thereby optimizing according to different objective functions (both CO_2 emission reduction and cost minimization) [8]. The level of building-related and spatial detail reached by these models is hardly attainable without a large and detailed data source such as the CECB database. In view of the ever-growing amount of energy certificate data in Europe and worldwide it is likely that more and more attention will be paid to this data source. In future, it may also be found useful for ex-post and ex-ante policy analysis.

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