The Energy Performance Gap in Swiss residential buildings: a roadmap for improvement

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Abstract. This work deals with the Energy Performance Gap (EPG) in buildings, defined as the difference between actual and theoretical energy consumption. This paper investigates how to close the EPG of existing buildings in Switzerland, by which measures, until when, and at which costs. To address these questions an extensive literature review was conducted combined with qualitative interviews in order to better understand practitioners’ experience and to support the findings from the literature. Several approaches have been found to reduce the EPG. These include both measures to make the building consume as expected and to arrive at a more accurate calculation of the theoretical consumption. We highlight the most relevant solutions for the Swiss context.

1. Introduction

This work deals with the Energy Performance Gap (EPG) in buildings, defined as the difference between actual and theoretical energy consumption [1]. Previous research has pointed to the importance of the EPG for the attainability of the energy objectives (like the Energy Strategy 2050 [2]), given that only part of the predicted energy savings in buildings is typically realized [3]. However, it is currently unclear which solutions to close the EPG can be applied to the Swiss building stock, as research so far has focused on a few case studies [4,5] or small samples [6,7], resulting in insufficient understanding about the broader situation. The body of research within Switzerland is continuously growing, calling for an updated overview [8,9]. This paper aims to address the following research questions: How shall the EPG of existing buildings in Switzerland be closed, by which measures, until when, and at which costs?

To address these questions an extensive literature review was conducted. We additionally conducted qualitative interviews in order to better understand practitioners’ experience, to support and cross-reference the findings from the literature. We further reviewed in detail a case study on the practical implementation of these solutions. This work provides valuable insights for policy makers, energy utilities, local authorities, building owners and researchers.

2. Method

This work follows a hybrid roadmapping approach [10] based on literature review (i.e. text-based) combined with expert interviews (i.e. expert-based), to investigate solutions to the EPG. The main source of information used for this study are publications, including journal articles, conference papers, reports, building standards, and national guidelines. All the journal or conference papers should meet the following criteria: peer-reviewed publications; focused on Switzerland; relevant to the
topic. The technical books and guidelines from the Swiss Society of Engineers and Architects (SIA) are also used in this review. Regarding the language, as Switzerland is a multilanguage country, publications written in English, French, German, and Italian were included. A total of 39 publications were collected. After analysing relevant publications, the solutions of the EPG were identified and grouped.

Moreover, we conducted qualitative interviews in order to better understand practitioners’ experience, to support and cross-reference the findings from the literature. In this case, the main focus of the expert-based approach was to draw on the knowledge and experience of the participants to subjectively identify the “best” solutions to close the EPG and specify the quantitative and qualitative attributes of each of these. When choosing the participants, we aimed for diversity with regard their professions including architects, engineers, norms developer, and energy certifiers. We performed 14 interviews, lasting 30-60 minutes each. A semi-structured interview form with open-ended questions was used.

3. Results
The results are presented below in three sub-sections. The first one lists all the solutions found in terms of recommendations to close the EPG. The second and third sub-sections estimate the costs and timelines for implementing each of the recommended solutions.

3.1. Solutions to close the EPG
Several approaches have been found in literature to reduce the EPG. These include both measures to make the building consume as expected and measures to arrive at a more accurate calculation of the theoretical consumption. We have grouped them into eight recommendations for the different phases of the building project, highlighting the most relevant solutions for the Swiss context.

(1) It is essential to spend more time in the initial design phase, to ensure a detailed, robust, and easy-to-implement project in order to move forward more quickly once the building authorizations are received [5]. During this phase of the project, the role of the owner as well as the designer is to properly characterize the ambient conditions, identify the expectations regarding energy performance, and to consider the technical options in conjunction with the available financial resources [11].

(2) It is very important during the design phase to clearly distinguish between the standard conditions of use (calculated according to the standard values of the SIA 380/1 [12]) [13], the optimal conditions of use (those of an energy-optimised building) [14] and the actual conditions of use (those describing how the building is actually used, with the real number of inhabitants and internal conditions, i.e. indoor temperature and ventilation rate) [15,16]. The definition of realistic energy performance objectives (optimal conditions of use) is crucial and it will serve a useful target value during the operation of the building [17].

(3) To ensure good quality of the execution during the construction phase, an adequate level of communication and collaboration between the stakeholders is required [18]. Moreover, at the end of the construction phase it is essential that the commissioning is managed in a professional manner with the involvement of all the stakeholders concerned (designers, inhabitants, energy manager, etc.). It is recommended to involve an expert who is responsible for achievement of energy objectives during the design, construction and operation of the building [7,19].

(4) Integration of User Management Assistance (Assistance à la maîtrise des usages, AMU) [20] can help to achieve the objectives especially for existing buildings. After the construction phase it is important to optimise and adjust the technical installations (see SIA 2048 [21]), as well as to raise inhabitants’ awareness about appropriate behaviour and use of the building systems (optimal adjustment of thermostatic valves, reduction of indoor temperatures, adequate opening of windows and of the shading systems, etc. etc.) [22].

(5) To the extent possible, architectural and technical solutions that are robust and already verified should be implemented (e.g. retrofit packages) [23]. Often new systems do not work as expected, so it
is important to gradually integrate them into the building stock, and test/monitor these new solutions for a sufficient time before applying them [24].

(6) During operation, it is important to regularly monitor the building and to fine-tune the settings in order to maximize energy performance (e.g. hydraulic balancing) [25,26]. Frequent checks ensure proper operation and early detection of any malfunctioning [27]. In addition, assisting the residents in the usage of the systems of the buildings is vital to eliminate the EPG [28].

(7) It is recommended to make use of service contracts, e.g. in the form of an Energy Optimization Contract (for tuning of the installation and its monitoring) or of Energy Contracting solutions (energy supply contracting or energy performance contracting) where good operation is in the contractor’s own interest [29]. In other words, the EPG can be minimized by holding all the actors involved accountable (economically and morally).

(8) A stronger commitment is also required from the national authorities, which can help to clearly reduce energy consumption and the EPG through more rigorous controls on the effective achievement of the construction standards [30], by means of sanctions in the case of non-compliance, by improving some existing procedures (e.g. the energy performance certificate [31]) and implementing new ones (e.g. a compulsory monitoring of actual consumption [32]).

Additional, very extensive research on the state of today’s buildings would be needed in order to establish which of the solutions discussed above should be implemented and to which extent. It is not obvious how the required information could be collected in a reasonable manner. Provided that sufficient interest of the general public for energy and climate issues could be raised for the question how best to improve the energy performance of the building stock, a large-scale survey or citizen-science project would be imaginable.

3.2. Cost
It is currently not possible to specify which solutions should be implemented to which extent. Without this knowledge it is obviously very difficult to determine the cost to be incurred for closing the EPG. In this section we nevertheless compile some relevant cost data in order to offer first insight. As starting point, we rely on two main sources [7,33].

As first step, the current costs of energy retrofitting in Switzerland need to be established because they allow to put any cost on the EPG into perspective. We choose the data published by [7], which are the costliest of the sources consulted, since this source considers (in the case of complete retrofit) the replacement of heating systems, the installation of renewable energy sources (solar thermal or PV) and improvement of the thermal performance of the envelope. In the study, partial energy retrofit (1-2 elements replaced), average energy retrofit (as average of the analysed cases), and complete energy retrofit (>3 elements replaced) are distinguished. The respective investment costs are: Partial retrofit: 700 CHF/m²; Average retrofit: 877 CHF/m²; Complete retrofit: 1 330 CHF/m².

In order to reduce the EPG, it is recommended to involve an expert to ensure a good quality of planning, execution and commissioning of the building (Assistant à Maîtrise d’Ouvrage Énergie, AMOén; [20]). The cost of this solution has been quantified by [33] with an additional cost of 20 CHF/m² (one-time payment). For pre-existing buildings and for energy-retrofitted buildings, other solutions have been proposed, such as the AMU (Assistant à Maîtrise d’Usage) or the energy optimisation contract. After the construction phase it is important to optimise and adjust the technical installations, as well as to raise inhabitant’s awareness about appropriate use of the building systems. [33] quantify the cost of the AMU at about 30 000 CHF for an ERA of 3 000 m², i.e. around 10 CHF/m². However, an AMU would only be involved for larger buildings (e.g. of at least 2 000 to 3 000 m²) and it is important to note that this service is not proportional to the floor area. In the case of larger buildings (5 000 m², +67% than in the previous example) the AMU would cost around 33 000 CHF (i.e., only 10% more than in the first example), as only the initial "door-to-door" phase is influenced by the number of apartments that need to be visited. Afterwards the cost of the AMU is mainly driven by the sessions to which the expert is invited, while the number of people living in the building and/or ERA have very little influence on the costs. Similar remarks can be made for Energy
Optimization Contracts (Contrat d’optimisation énergétique, COE [34]) which mostly imply tuning of the installation (e.g. heating curves) and its monitoring, thereby allowing to pinpoint malfunctioning. Also in this case the cost is primarily related to the energy consumption of a building. This kind of contracts are carried out for a period of 6 years in the case of buildings with a consumption of at least 275 MWh. In this case a start-up cost of 1 200 CHF is considered, plus an annual cost that can vary between 1 500 and 2 000 CHF/year as a function of the building’s energy consumption [33]. Therefore, the cost of the total service over the six years can vary between 10 200 CHF and 13 200 CHF.

Hydraulic balancing is a more rigorous and sophisticated approach of fine-tuning the heating system. Its aim is to optimize the hydraulic (e.g. flow rates, pressure drops) and thermal (e.g. fluid temperatures, room air temperatures) operational conditions of the heating system. The achievable energy savings range from 2% to 25% [35]. In particular, buildings constructed before the 1980s lend themselves to hydraulic balancing and may offer energy savings in the order of 15% [25]. Even for new buildings, the energy savings may amount to approximately 10% [25]. Costs for hydraulic balancing range from 200 CHF/radiator (if thermostatic valves at the radiators are already present) to 350 CHF/radiator (without pre-existing thermostatic valves). Based on the assumption of 0.08 radiators per m² of floor area this is equivalent to an investment of 16 to 28 CHF per m² of floor area. Making a number of further assumptions¹ the CO₂ abatement cost estimate for hydraulic balancing of an oil boiler can be estimated to amount to approximately 80 CHF/tonne CO₂, however with very high sensitivity to the assumptions (consequently resulting in either cost-effective or very expensive measures, e.g. ranging from -60 to +180 CHF/tonne CO₂). Today, hydraulic balancing is hardly implemented. The reasons are: i) lack of expertise, ii) time-intensity, and iii) low energy cost. It is estimated that less than 5% of all buildings have undergone hydraulic balancing, consequently resulting in a very large unexploited optimisation potential.

As discussed in solution 3, quality labels may be introduced for installers having experience with novel technologies (e.g. heat pumps) and/or lists of accredited installers may be published in order to help homeowners when making a choice [36]. While no information is available on the cost of this type of measure, it can be expected to be rather low. A further possible measure to mitigate the EPG would be to run awareness campaigns. We tried to estimate the cost of a campaign to raise inhabitant’s awareness about appropriate behaviour and use of the building systems. To do so, we used as reference the éco-logement program operated by the Genevan utility company SIG [37]. This program aims to reduce the consumption of a building through increased awareness of its inhabitants. Therefore, events are organized in the aisles of buildings to inform the inhabitants about the different solutions to save energy (e.g. efficient equipment, eco-actions) and individual visits are arranged in the apartments (15-20 minutes each) to provide customized suggestions (e.g. adequate opening of windows and of the shading systems). The modalities of this program are quite similar to those that could be followed by a campaign aiming to reduce the EPG. Based on personal communication (SIG-May 2020) the cost of this initiative has been estimated about 60 CHF per apartment involved.

3.3. Timeline for EPG closure

In this section we roughly categorize all the solutions according to the time needed for their application and their effective operation. Based on the literature review and on the interviews with the practitioners, we distinguish three timeframes: 1) short-term (less than one year); 2) medium term (one to five years); and 3) long term (more than 5 years).

The short-term solutions can be applied immediately and they would become effective (at least partly) within less than one year. This concerns in particular Energy Optimization Contracts and

¹ The assumptions are: average fuel oil consumption of around 100 kWh/m²a for a pre-1980 multi-family house, average cost of 275 CHF/radiator, fuel oil savings of 15% by hydraulic balancing, a lifetime of the measure of 20-25 years and a discount rate of 3% and a typical fuel oil price of 790 CHF/1000 litres of fuel oil (price accounts for today’s CO₂ levy of 96 CHF/tonne CO₂).
hydraulic balancing programmes. It should also be possible to set up quite rapidly a first scheme of quality labels for recommendable installers.

Medium-term solutions are those that require the prevailing practices and administrative/governance system to change and consequently the prevailing practices to adapt. They therefore take some years before they become truly effective. For relatively simple heating systems (e.g. for heat pumps in typical single-family houses and for re-occurring circumstances in multi-family houses), “standardized” technical solutions and installation practices should be developed, publicized (e.g. in the form of guidelines) and followed. When innovative technologies are installed careful monitoring should be ensured (e.g. to avoid malfunctioning) and the learnings should be analysed and generalized. Following these lines, monitoring of the performance of i) some special buildings, such as large consumers (MoPEC [38]) and of ii) very efficient buildings (Minergie-P, Minergie-A [39]) was recently introduced. For this solution, time will be needed for large-scale implementation and for drawing broadly valid, generalizable conclusions (to the extent possible). More interaction-oriented medium-term solutions are the implementation of an AMOen and/or an AMU; while these are roles which already exist, they still need to be properly integrated in the building process and the usage of all buildings. A similar reasoning applies for performance/optimization contracts, which are already a reality, but which will still need time before they are accepted by the stakeholders of the building sector (e.g. owner, financial partner, user).

Finally, long-term solutions are those that require not only a change in governance but a real change in the mindset and behaviour of all the stakeholders who are part of the process. Starting with the authorities, which must carry out stricter controls on the achievement of the energy requirements set by the norms and introduce sanctions wherever this is not the case; the construction companies, which must implement the processes needed for ensuring the delivery of buildings for which the planned thermal performance is guaranteed; the owner who must think in terms of energy savings in the long term instead of cost minimisation and profit maximisation in the short term; and finally the inhabitant who must be better informed about the consequences of its choices and who should be incentivized by the most suitable approaches to change its behaviour.

4. Conclusions

The aim of this work was to analyse what the causes for the Energy Performance Gap (EPG, difference between measured and theoretical energy consumption) related to heating of buildings are and how it could be closed. We primarily based our analysis on a literature review and additionally performed a qualitative study through interviews of a limited number of practitioners in the field to support and cross-check the findings of the review. Several approaches have been found in literature to reduce the EPG. These include both measures to make the building consume as expected and to arrive at a more accurate calculation of the theoretical consumption. Researchers and practitioners have proposed many strategies and we highlighted the most relevant solutions for the Swiss context: As of the beginning of the design phase, it is important to clearly distinguish between the standard conditions of use (calculated according to the standard values), the optimal conditions of use (those of an energy-optimised building) and the actual conditions of use, it is recommended to involve an expert to ensure a good quality of planning, execution and commissioning during the construction phase (AMOen). In the commissioning and operation phase, it is highly recommendable to ensure facility management according to state of the art (e.g. regular monitoring) and to involve an expert to optimize planning and usage by tenants (AMU). It is also recommended to put an Energy Optimization Contract in place for simple tuning of the installation and its monitoring (to quickly identify malfunctioning). As complement or as alternative to some of the above-mentioned measures, energy supply contracting, or energy performance contracting can be suitable solutions. Finally, it is recommended to enforce more systematic controls and rigorous enforcement of the rules (including sanctions) by authorities to ensure that the construction standards are respected, free-rider effects related to energy retrofit subsidies are minimized, and that the actors responsible for the EPG are made accountable.
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