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Performance gaps in Swiss buildings: an analysis of conflicting objectives and mitigation strategies

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Abstract

The term "Performance Gap" is used to denote deviations between a building's planned and actual performances. We conducted an international literature search and identified more than 240 relevant references. Here we report our main findings. Currently, mainly the energy performance gap is discussed, which is neither properly standardized or regulated nor precisely defined. In our opinion, the performance gap discussion needs to be extended to the indoor environment and the operation expenses. A more differentiated approach must distinguish between individual buildings and entire building stocks where a statistical interpretation becomes unavoidable. We propose that the evaluation of the building performance should be based on thorough application of statistical methods. At the same time preventions of gaps require an integrated performance and risk management process, for instance through application of the "performance-based building design" and "integrated project delivery" approaches. For Switzerland, this is an invitation to experiment with alternatives to today's economic and contractual practice.

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Keywords: Performance gap, Energy, Indoor Environment, Operational Expenses, System thinking, Stakeholder analysis

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1. Introduction

The “Performance Gap” as the difference between planned and real performance of a building, is a complex and multi-faceted matter that is often treated only in a fragmentary manner. Until recently the issue had received only limited attention in Switzerland [1, 2]. No systematic study for the Swiss building and energy sectors has been made available so far neither for research nor practice.

The performance gap is neither properly standardized or regulated nor precisely defined. In general, a performance gap can be defined as a deviation from a target or as a result of a performance assessment [3]. It is part of the quality assurance, as well as expectation and risk management in which objectives, methods and assessment aspects are defined.

Independent of the view point of the building sector, a performance gap must follow reliably from existing evidence, i.e., there must be both a comprehensible and reliable baseline (objective) as well as a comprehensible, reliable and comparable actual state. Objectives and actual situation can be derived from measurements, models, surveys, evaluations, and comparisons.

2. Approach and Methods

This paper reports on the progress and findings of the “ParkGap“ project, funded by the Swiss Federal Office of Energy (SFOE). In addition to the “Energy Performance Gap”, the project addresses the “Indoor Environmental Quality Gap” and the “Operating Expenses Gap”. The project consists of three parts: (i) An overview of gap definitions as well as the mapping of relationships between the relevant stakeholders, processes and technologies; (ii) an international literary search and comparison of results with Swiss projects; (iii) recommendations for action for the Swiss building stock.

We report mainly on selected results from part (ii). In the literature survey, we considered not only peer-reviewed journals but also academic research reports, dissertations, conference proceedings, project reports of organizations and authorities, as well as relevant guidelines and standards. The publications were evaluated with regards to the following aspects: Nature of the reported gaps, causes, assessment methods, integration in construction and operating processes, recommendations for avoiding gaps.

3. Results

3.1. Overview

The literature survey identified over 240 relevant national and international references, which mainly deal with energy performance gaps. The granularity and depth of detail of the studies vary widely and a large range of empirical methods and models are covered.

3.2. Evidence of gaps

Here, we focus on the numerous studies that relate to energy performance gaps. So far, we have not found any studies that deal with indoor environmental or operating expenses gaps in the context of a “Performance Gap”. However, further research is in progress.

The studies fall into two categories. First, the assessment of individual buildings. Second, the analysis of the energy performance of building stocks. In both cases, energy consumption, usually from measurement or in some cases from simulation, is compared with a given target value or range [1, 4, 5].

The following studies of the first category are of interest:

Cali et al. [6] investigate and compare three buildings of identical construction but with different renovation strategies. Different energy consumptions are found mainly attributable to occupant behavior, location, and building technology problems.

Jones et al. [7] investigate six identical apartments in the same building. The discrepancies between steady-state and transient simulations and measurements are attributed to limitations in calculation methods, different competence of the modelers, and occupant behavior.

Sun et al. [8] explain that defensive design can lead to substantial over-dimensioning of HVAC systems. In operation, this oversizing can reduce the building's energetic performance due to user and operator intervention. A framework of risk-oriented plant dimensioning is developed, based on thermal building simulation combined with uncertainty and sensitivity analyses.

Out of eight found studies on building stocks we discuss the following to account for references to Switzerland and widely differing assessment methods:

The study [9] reports a performance assessment of 214 buildings according to the Swiss building label Minergie® and the Swiss standard SIA 380/1. In 7 of the 11 label categories considered, the median of all energy consumptions is at or below the current limit of the corresponding standard. In two cases, the median is clearly within the range of the limits and in two more cases above the respective thresholds. The spread of the measured energy consumption is greater than the differences between the thresholds of the different label categories.

Khoury et al. [10] examine the energy consumption of 50 buildings in Geneva with 1,100 apartments. They estimate the unused potential of energy renovations according to the Swiss standard SIA 380/1 to 58% (392 GWh/a) for the entire canton of Geneva. In addition to effects by the construction process, the authors discuss the influence of uncertainties of standard values, model inputs and simulation models on the computed performance gap.

Two studies from Germany [11, 12] show that the energy performance gap of a building stock is smaller when (i) refined energy balance models are used to determine target values; and (ii) statistical methods are used to assess how close target values are reached. Both studies show that the statistical averages of the energy consumption of all objects reach the specified targets, although the individual values have a large spread. The user influence on energy consumption is estimated to be ± 50%, independent of the energy standard considered [12].

Zhao et al. [13] draw attention to the interaction effects of building technology and occupant behavior on energy consumption in residential buildings. The study claims that exploitation of efficiency measures in building services is limited to 42%. More than 50% of energy efficiency potentials remains out of reach due to occupant habits.

3.3. Overall context

Here we give an overview of the reviewed studies that places the cause and mitigation of energy performance gaps in a larger context.

Van Dronkelaar et al. [5] present a comprehensive, structured overview of evidence and causes of, and countermeasures for energy performance gaps based on a large literature search for non-residential buildings. De Wilde [14] extends the discussion of the energy performance gap with a proposal for the classification of energy performance gaps based on the selected models and methods of comparison. In an extensive study, Borgstein et al. [4] compile numerous methods for measurement and evaluation of performance gaps, also with a focus on energy.

Voss et al. [15] present a compendium of methods and best practices on different types of performance. In addition, they place the performance evaluation into a larger context. To ensure good building performance, they propose a generic "quality control loop".

3.4. Stakeholder

Only a few papers discuss the role of different stakeholders and their interests within the context of performance gaps. Voss et al. [15] present an overview of stakeholders.

The "PeBBu" project [16] and Bluyssen [3] demonstrate the complexity of performance requirements from the point of view of the stakeholder. Depending on the stakeholder, the performance requirements vary widely and can therefore be broken down into individual, separately defined sub-targets with different actors.

Wagner et al. [17] consider the interests of different stakeholders in planning, construction, and operation from the point of view of user satisfaction in office buildings. A methodological framework for the management of user satisfaction is presented and discussed.

3.5. Causes of performance gaps

The documented causes of energy performance gaps range from detailed, technical arguments to general statements on how buildings are planned, built and operated. In our survey, we have identified the following categories of causes [1, 2, 5, 9, 10, 12, 14, 18, 19], ordered by life cycle phase:

a) Design and planning: Limited understanding of impact of early design decisions, complexity of design, uncertainty in building energy modeling, specification of building and usage scenarios, oversizing of systems;
b) Construction and commissioning: Value engineering, i.e., economically driven decisions overrule design considerations, poor commissioning, measurement system limitations;
c) Operation: Poor practice and malfunctioning equipment, unfavorable interaction between occupant and building technology, occupant behavior, conversion to a new building use.

3.6. Preventive measures

The range of proposed preventive measures (same references as in section 3.5) also extends from relatively specific suggestions to extensive adjustments of the construction process. Ordered by increasing depth of intervention, possible measures relate to: Data collection and monitoring, deployment of commissioning and final testing, operational management, training and education, design improvements, improved communication within design and construction teams, improved communication with investors, owners, and occupants, feedback from continuous commissioning to early design and operation ("Closing the Loop"), use of "Energy Performance Contracts" and "Green Leases", and legislative frameworks.

The project Zero Carbon Hub [19] developed a comprehensive and detailed list of measures. It is, in part, very specific to Great Britain and individual stakeholders.

In 2016, two large-scale, EU-funded projects were launched with the aim of reducing or avoiding performance gaps by improving the quality of the construction process [20, 21].

So far, no holistic strategy for dealing with performance gaps has been developed for Switzerland. Struck et al. [2] discussed its evidence, relevance and mitigation strategies in 2014. The above referenced performance assessment of Swiss building standards [9] addresses causes and proposes individual measures. Another Swiss study quantifies 150 separate measures to improve the energy efficiency of building systems [22].

4. Discussion

4.1. Present situation of building performance discussion

Our research shows growing attention to energy performance (and underperformance) of buildings during recent years, while other performance aspects have not been considered in general.

This is remarkable in that the cost of productivity is estimated roughly at 2200 $/m²a, whereas the cost of energy consumption is only 22 $/m²a. Reducing energy costs in net-energy office buildings may only be in the range of 1% of the occupants' productivity cost [23], and without guarantee of good indoor environmental performance. As far as we know, the problem of the possible "Operating Expenses Gap" is not yet addressed, although 80% of the lifecycle cost of a building is incurred during operation [24].

Balancing performance gaps of the indoor environment, operating cost and energy consumption is a major challenge in today's highly fragmented construction industry. By failing to identify performance gaps and the associated uncertainties, conflicts of interest are avoided and the involvement of all stakeholders is minimized. However, this approach would give away the opportunity of an overall optimization of buildings and building stocks, that is of particular importance to building owners, users and not least to the public (e.g., in connection with energy policy).

To initiate and structure a discussion, we propose to compare the various performance gaps according to the following generic aspects: 1. Stakeholder interest (who is concerned); 2. Definition of the baseline (which objectives should be set); 3. Detection (methods to determine the actual and target states, and to verify how close the target is met); 4. Attribution (determine the causes). The team of authors will continue to work in this direction.

4.2. Energy Performance Gap

In our literature search, we found that most publications focus on technical and methodical aspects of the detection and attribution of energy performance gaps (according to detailed evaluations, not shown here), while stakeholder interests and the definition of a baseline (objective) get little attention or are treated as given.

With regards to the definition of the baseline, we believe it is essential to distinguish between the performance gap of a single building versus that of a building stock. The results presented in section 3.2, as well as seven other publications (not shown) suggest: In the case of individual buildings, specifications of labels and building standards are regarded as *limit values,* that lead to a gap when exceeded during operation. At the level of entire building stock, on the other hand, the label specifications are typically interpreted as the *average values* to be achieved for all buildings of a given class. The above-mentioned statistical studies show a large spread of positive as well as negative (!) gaps, but also clear systematic effects with the expected tendency for lower average consumption in the higher building efficiency classes. Peper and Feist [12] argue that there is no gap on the level of building stocks.

These different viewpoints may lead to conflicting goals and misunderstandings. Therefore, a clarification of interests, objectives and technical terms is desirable. How do we define and interpret the labels and limit or target values precisely? A question in the context of a national energy strategy is: To what extent do we compensate the above-average energy consumption of certain buildings by other, particularly energy-efficient buildings? How relevant is an energy performance gap with predominant use of renewable resources? Under what conditions should such a gap be tolerated deliberately (polluter liability, market forces)? The authors suggest a broadly supported discussion on these issues that goes beyond the technical aspects.

4.3. Mitigation Strategies

The broad spectrum of causes and measures reported in the literature shows the complexity of buildings and of the construction process. Mitigation strategies must reflect those relations and educate stakeholders accordingly. For example, power reserves in HVAC plants should not be exploited for enhancing comfort levels when certain energy performance targets must be met.

Simulation models are powerful tools for avoiding performance gaps. Findings reported suggest that the computed results are sensitive to the modelers' skill. Moreover, they must be understood as expected (average) values under precisely specified, yet inherently uncertain planning assumptions. Uncertainty and sensitivity analyses provide additional value, but the statistical evaluation of simulated versus planned performance indicators is only at its beginning, see e.g. Boxer et al. [26].

For new buildings, the few guidelines to avoid gaps in a systemic way focus on integral processes that cover several construction phases. In our opinion, a “performance-based building design” approach [3, 16] and its implementation by “integrated project delivery” [25] are imperative to better control the risk of gaps of any kind. For Switzerland, this is an invitation to experiment with alternatives to today's economic and contractual practice.

In the literature, a wide range of measures are proposed for existing buildings. We believe that these should be introduced in building operation with a well-balanced combination of regulations, incentives and rewards. This would open up a large potential for the mitigation of various gaps and for new services and products.

5. Conclusions

Most publications in our literature survey examine and discuss energy performance gaps. We propose distinguishing performance gaps for individual buildings and entire building stocks where a statistical interpretation becomes unavoidable.

The roots of energy performance gaps are often found in high safety margins, standard input values and simplifications during the design process. Thus, over-sized HVAC plants may be used to extend comfort levels in operation beyond design intentions and energy consumption targets. Additionally, inconsiderate value engineering during construction may result in deviations from the intended objectives and contribute to gaps. The alternative consists of a systemic, integrated performance and risk management process in which all stakeholders of design, construction and operation are contractually involved and measured at jointly agreed targets.

Depending on the requirements and objectives of the stakeholders, low energy performance does not necessarily have a negative impact on the perceived overall performance of the building. The existing conflicts of objectives between performance gaps for energy, indoor environment and operating expenses must be addressed as well as the conflicts between the performance of individual buildings and building stocks. A comprehensive analysis of all stakeholders involved is still missing.

The assessment of building performance must abandon the concept of static targets and limits. It must rather apply the methods of statistics and probability to accommodate the building as a system changing over time.

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