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Sustainable Building Envelopes (Ecobuildings, Retrofit, Performance Gap)

Techno-economic potential of large-scale energy retrofit in the Swiss residential building stock

Kai Nino Streicher[a,*], David Parra[a], Meinrad C. Buerer[a], Martin K. Patel[a]

[a] *Chair for Energy Efficiency, Department F.-A. Forel for environmental and aquatic sciences (DEFSE), University of Geneva, Switzerland*

Abstract

A statistical analysis of more than 6,000 energy performance certificates including retrofit options proposed by experts for different building elements is performed. This provides an overview of the most commonly suggested renovation measures and their estimated investment costs and U-Values. Based on an energy model of the Swiss residential building stock (SwissRes), the theoretical energy savings are estimated. Together with the estimated investment costs, the levelized costs of each renovation measure is then determined in order to identify the most cost-effective measures. It is shown that a large-scale energy retrofit of the residential building stock would result in theoretical energy savings of up to 84% regarding the current simulated energy demand. Yet, existing technical and social constraints would lower the expected energy savings significantly. None of the selected measures is cost-effective, but under a more optimistic scenario, the cost-effective share reaches up to 85% of the total potential energy savings.

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Keywords:
Building Energy, Retrofiting, Investment Costs, Levelized Costs

1. Introduction

The building sector represents about 37% of the Swiss final energy use [1]. A reduction of the space heating energy demand by up to 64% was therefore identified as a key element of the Swiss Energy Strategy 2050 [2]. However, the rate of renovations per year is still below 1% and therefore insufficient to reach the targets set by the Swiss Energy Strategy 2050. The aim of this paper is to analyse the techno-economic potential of commonly used renovation measures for energy savings in the Swiss residential building stock. For this, a statistical analysis of more than 6,000 energy performance certificates including expert-based renovation proposals for different building elements is performed. This provides an overview of the most commonly suggested renovation measures along with their average estimated investment costs and resulting U-Values for different groups of building elements. Based on an energy model of the Swiss residential building stock (SwissRes), the theoretical energy savings from a large scale

* Corresponding author. Tel.: +41 22 379 00 11
E-mail address: kai.streicher@unige.ch

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Table 1. Selected renovation measures and derived median values of the CECB. (n = sample size, Ic = specific investment cost [CHF/m2], U = U-Value [W/m2K], L = lifetime [a])

Measure	Element	Element Type	Measure Type	n	Ic	U	L
Gr-Ex-Ex	Ground	Exterior	Exterior Insulation	1387	225	0.20	50
Ro-Ex-Ex	Roof	Exterior	Exterior Insulation	7942	325	0.18	40
Wa-Ex-Ex	Wall	Exterior	Exterior Insulation	31606	225	0.19	50
Gr-So-In	Ground	Soil	Interior insulation	1901	150	0.25	50
Wa-So-In	Wall	Soil	Interior insulation	1329	125	0.23	50
Gr-Un-In	Ground	Unheated	Interior insulation	9872	150	0.24	50
Ro-Un-In	Roof	Unheated	Interior insulation	3355	150	0.21	40
Wa-Un-In	Wall	Unheated	Interior insulation	7652	100	0.25	50
Wi-Ex-Ne	Window	Exterior	New built	52956	850	1.00	30

renovation programme are estimated [3]. Together with the estimated investment costs, the levelized cost of each renovation measure is then determined. In the final step, the results of the techno-economic analysis are summarized in the form of an Energy Efficiency Cost Curve (EECC), which shows the levelized cost of a measure together with its expected potential of reduction of energy consumption. While the archetype approach of the SwissRes model allows to calculate the cost supply curves for 48 archetype categories in the residential sector, this paper focuses on the differences between Multi-Family (MFH) and Single-Family Houses (SFH) in terms of techno-economic potential.

2. Methods

The input data for this techno-economic potential analysis is derived from a statistical analysis of building data provided by the Swiss Cantonal Energy performance Certificates for Buildings (CECB) [4]. These certificates are issued following an assessment of the energy performance of buildings either before or after retrofit and they are mandatory in some Cantons. The assessment is based on the judgment of certified experts. Beside the standard CECB, an advanced certificate (CECB Plus) can also be issued which includes a proposal for different retrofit strategies and their economic viability. In a previous study, the detailed building data of 12,000 standard certificates was classified according to different archetype categories[1] representative for the Swiss residential building stock [5]. This analysis allowed to develop a detailed bottom-up energy model that can simulate the annual space heating energy demand for the current stock as a whole, but and also by archetype and by building elements [3].

2.1. Common retrofit measures

As first step of this study, the most common retrofit measures suggested by CECB experts are determined using the CECB Plus certificates featuring 6,000 buildings. In general this database allows to differentiate between the building elements (i.e., wall, ground, roof and window) and their specification (i.e., facing against exterior, soil or unheated). Beside the element specification, the CECB furthermore differentiates between different types of renovation measures, such as interior or exterior insulation. For this study only the most common measure per element category in the CECB data is taken into account (see Table 1). For instance, in 67% of all cases the expert was proposing an exterior insulation for walls facing the exterior, which makes this the most frequently proposed measure in that category. This paper does not include a differentiation of investment costs, U-Values and lifetimes by archetype category. However, there are no statistically significant differences between MFH and SFH for these values. Moreover, a test of the Pearson Correlation between investment costs and the expected U-Value after renovation showed no significant results. Therefore, it was decided to take the median investment costs, U-Values and lifetimes for each measure as input data for the techno-economic analysis. In future research we will study the influence of additional parameters, such as the insulation material or construction period of the buildings, on the estimated investment costs.

[1] 48 archetypes are defined based on 8 construction periods, 2 building types and 3 spatial categories depending on the share of the core urban population in each Canton

2.2. Simulated Savings

The U-Values determined in the previous step allow to simulate the energy demand of the entire building stock, applying the SwissRes Energy Model [3]. This also includes the current share of heating supply systems in the archetypes. The bottom-up model allows subsequently to virtually retrofit the whole building stock with the identified measures instantly. In this study, only measures which reduce the energy losses through the building envelope are considered. Moreover, well performing building elements which were constructed or renovated after 2000 were excluded from the retrofit programme, since the original building elements already fulfilled a high standard for energy efficiency [6].

The SwissRes model then calculates the new annual final energy space heating demand for the renovated building stock for all the archetype buildings and heating supply systems.[2] By subtracting the new demand from the current simulated demand of the building stock (53.5 TWh/a), the theoretical energy savings for the selected measures can be estimated [3].

2.3. Energy Efficiency Cost Curve

The Energy Efficiency Cost Curve (EECC) approach allows to illustrate the techno-economic potential of different technology options or energy saving measures in a graphical form [8–10]. The basic principal is to show the specific or also called levelized cost (LCOE) of these different technology options or measures over the expected energy savings potential and therefore providing a visual ranking of the cost effectiveness of measures in a certain sector. To begin with, the initial investment costs of each measure are calculated based on the specific investment costs in CHF per square meter element from the CECB database (see Table 1) multiplied by the surface of the element in the stock, after Eq. (1).

$$I = \sum_{e=1}^{m} (Ic_e \cdot A_e) = \sum_{e=1}^{m} (Ic_e \cdot A_{ERA} \cdot ERA) \tag{1}$$

This surface is estimated with the specific surface (A_{ERA}) per Energy Reference Area (ERA)[3] provided by the statistical analysis of the CECB database [5], multiplied by the total ERA[4] of the affected archetypes in the stock based on the dwelling surfaces provided by the Swiss Federal Statistical Office [11]. In the next step, the cash flows for each year need to be calculated after Eq. (2)

$$CF_t = Costs_t - Benefits_t = (I_t + OM_t) - \sum_{i=1}^{n} (\Delta E_{i,t} \cdot p_{i,t}) \tag{2}$$

The estimated annual costs are composed of the initial investment costs in CHF (I_t, only occurring in the first year of the lifetime) and the operation & maintenance costs for the measure in CHF (OM_t, which are negligible for envelope retrofit). Annual benefits of the different measures are then subtracted. These are determined by multiplication of the saved final energy demand ($\Delta E_{i,t}$) in MWh by the energy price ($p_{i,t}$) in CHF/MWh for this year and the different heating systems i. The energy price development over the lifetime for all required energy carrier is adopted from the new energy perspective scenario included in the PROGNOS study on future energy development in Switzerland commissioned by the Federal Office of Energy [12]. The discounted sum of these annual cash flows using the discount rate f_{DR} gives the net present value (NPV) of the measure over the lifetime following Eq. (3).

$$NPV = \sum_{t=2016}^{L} \left(\frac{Costs_t - Benefits_t}{(1 + f_{DR})^{t-2016}} \right) \tag{3}$$

[2] The SwissRes model calculates the energy losses and gains for given heating degree days (HDD) for each month of the year in the different archetypes, based on the Swiss SIA 380/1 building energy norm [6]. The HDDs are based on norm temperatures (1980-2010) provided for each Canton in Switzerland [7]

[3] The effective heated surface of the building

[4] ERA for SFHs are estimated to be 186 million m^2 and 226 million m^2 for MFHs respectively in the SwissRes model [5].

The final LCOE in CHF/MWh is then calculated with the NPV and the expected total energy savings (ΔE) after Eq. (4).

$$LCOE = \left(\frac{NPV}{\Delta E} \cdot \frac{f_{DR}}{1-(1+f_{DR})^{-L}}\right) \quad (4)$$

The Base Scenario assumes a discount rate (f_{DR}) of 6%, from a house owner's perspective. Additionally, an Optimistic Scenario was developed adopting a discount rate of 3% as well as accounting for economies of scale which reduces the overall investment costs by 30%.

3. Results

3.1. Simulated Savings

When the selected measures are applied to the building stock in the SwissRes model, the simulated final space heating energy demand is reduced by up to 40% by each measure individually. Fig. 1 shows the simulated final energy savings for each of the measures for Single Family Houses (SFH) and Multi Family Houses (MFH) respectively, for the Base Scenario. The highest overall savings can be achieved by insulating the outside walls of SFHs (8.4 TWh/a) and replacing the windows (8 TWh/a) in MFHs. This is followed by external insulation on walls (6.8 TWh/a) in MFHs and windows (6 TWh/a) in SFHs. Retrofit measures focusing on elements facing soil are barely contributing to the expected energy savings in the Swiss residential building stock. Next to the final energy savings in Fig. 1, the estimated energy cost savings of the different measures and building types are presented, showing a very similar pattern. In general the highest energy savings are expected in buildings heated by oil, gas or wood, while for the cost, expenses in oil, gas and direct electric heating are the dominant factors.

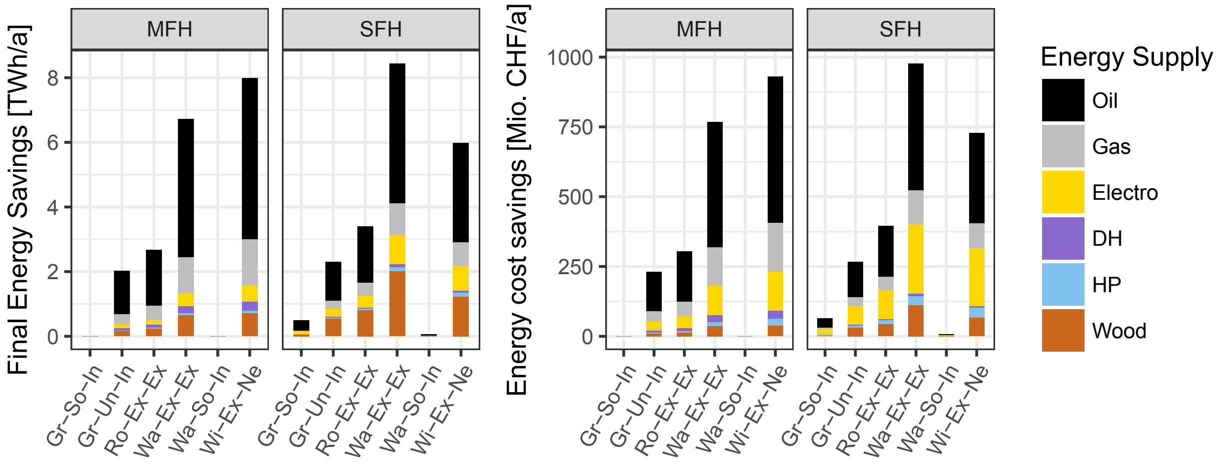

Fig. 1. Simulated annual savings for selected measures in terms of final energy and energy cost savings (without taking into account upfront investment costs) by building type for the Base Scenario. (Electro = direct electric heating, DH = district heating, HP = heat pump)

3.2. Energy Efficiency Cost Curve

Given the estimated investment costs, energy savings and annual benefits, the LCOE for the different measures and building types can be calculated. Fig. 2 shows the resulting EECC for the selected measures and given parameters, both for MFHs and SFHs, thereby excluding all measures which are contributing less than 0.5% of the total savings. As important finding, none of the selected renovation measures is cost-effective over the assumed lifetime in the Base Scenario. The measure with the lowest cost of energy savings is the internal insulation of the ground plate against unheated areas with 23-38 CHF/MWh, followed by windows (50-70 CHF/MWh) and outside walls (82-96 CHF/MWh). According to the EECC, retrofit measures on roofs are having the highest specific costs (266-286 CHF/MWh) in the current simulated Swiss residential building stock. As for the differences between MFHs and SFHs, except for ground insulation, the measures in MFHs are featuring up to 40% lower specific costs, while saving only around 10% less energy in the total stock.

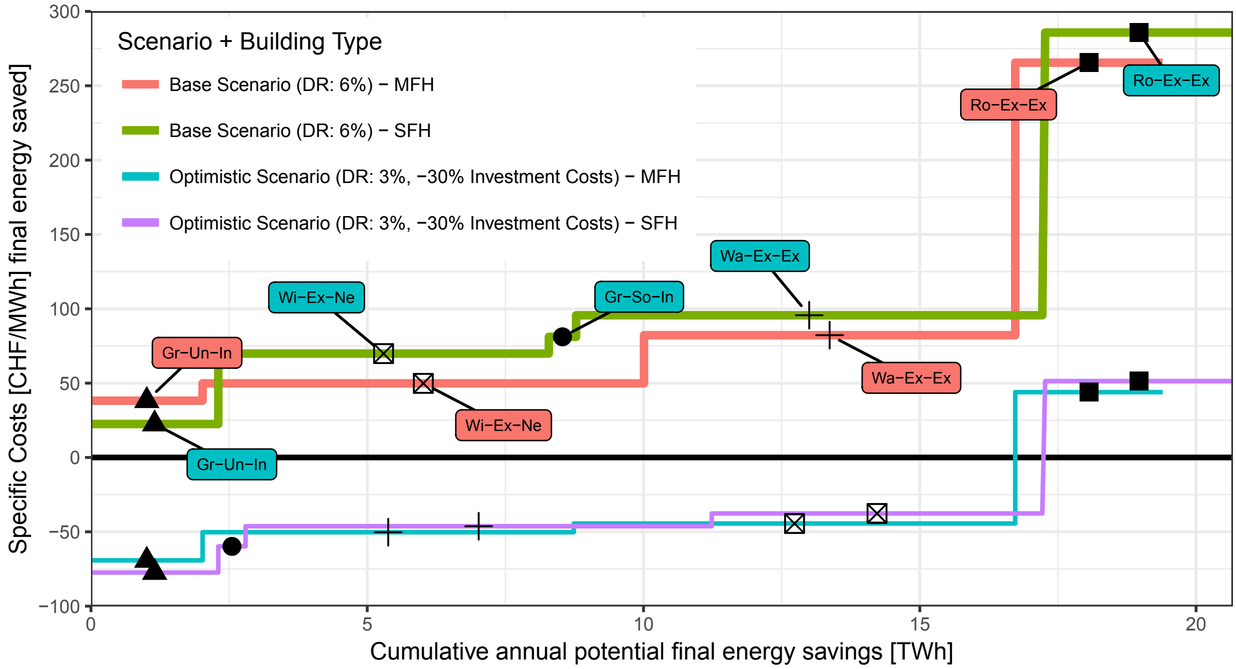

Fig. 2. Energy Efficiency Cost Curve for envelope retrofit measures in the Swiss residential building stock by building type

When the parameters of the Optimistic scenario are adopted for to the EECC calculations, the cost-effectiveness of all measures improves significantly (see Fig. 2). Except for the exterior insulation of the roofs, all the remaining measures lead to actual cost savings over the assumed lifetime. This means that approximately 85% of the theoretical energy savings could be reached in a cost-effective manner for both MFHs and SFHs in the optimistic scenario.

4. Discussion

Given the results in Fig. 1, a combination of all measures for both SFHs and MFHs would results in approximately 43 TWh p.a. of final energy savings for the space heating demand in the Swiss residential building stock. This would account for a decrease of around 84% compared to the current simulated energy demand of the stock. In theory, a large-scale retrofitting of the building envelopes would therefore be sufficient to reach the 64% goal of the Swiss Energy Strategy 2050. Additionally, retrofitting the envelope should usually also entail an adjustment or even replacement of the heating system with more efficient technology, such as heat pumps, which would lead to even higher final energy savings. However, it should be taken into account that this study is only showing the theoretical potential for energy savings and their related economic performance, without considering technical or social constraints. Naturally, such a large-scale retrofit programme could not be planned and implemented instantly, but would require several decades. Moreover, buildings with a complex structure as well as listed buildings would require different retrofit measures, and the expected energy savings might not be achievable for this sort of buildings. In addition, several studies showed that there can be a significant performance gap between modelled and actual energy consumption after retrofit, which could lower the expected savings substantially [13,14].

The results show also that high energy savings related to improvements on the building envelope cannot be reached in a cost-effective manner, in the Base Scenario. This would potentially mean high restrictions on any large-scale retrofit in the building stock. However, changes in the assumed input parameters such as economy of scale for the investment costs and a lower discount rate or increased lifetimes of the elements, result in an improved cost effectiveness of the selected measures, as seen in the Optimistic Scenario. Moreover, a more detailed analysis of the EECC for all archetypes, as the SwissRes model allows, would help to identify and subsequently remove archetypes for which a retrofit would not be economically feasible, increasing the overall cost effectiveness of the measure.

5. Conclusion

The results of this study confirm a high theoretical potential for large-scale energy retrofit of the building envelope in the Swiss residential building stock, reducing the space heating energy demand by up to 84%. However, technical or social constraints will lead to lower savings than the projected results of the SwissRes model indicates. The EECC shows that the considered retrofit measures are not cost effective over their assumed lifetime in the Base Scenario. But under a more optimistic scenario accounting for economies of scale, cost-effective retrofit measures are identified, which can achieve up to 85% of the total saving potential. The results of this study provide a basis for simplified renovation scenarios towards the Swiss energy efficiency targets. It could be shown that these scenarios allow to identify the cost-effectiveness for different archetypes, building elements and measures. Finally, it can be stated, that the EECC approach coupled with the SwissRes model can contribute to the development of a road map for a large-scale energy retrofit of the Swiss residential building stock.

References

[1] Kemmler, A., Piègsa, A., Wüthrich, P., Keller, M., Jakob, M., Catenazzi, G.. Analyse des schweizerischen Energieverbrauchs 2000 - 2014 nach Verwendungszwecken. Tech. Rep.; Prognos AG, Infras AG, TEP Energy GmbH, Swiss Federal Office of Energy SFOE; Bern, Switzerland; 2015.

[2] SFOE, . Energiestrategie 2050: Erstes Massnahmenpaket. Tech. Rep.; Swiss Federal Office for Energy SFOE/Office fédéral de l'énergie OFEN/Bundesamt für Energie BFE, Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation UVEK; Bern, Switzerland; 2012.

[3] Streicher, K.N., Padey, P., Parra, D., Bürer, M.C., Patel, M.K.. Distribution of the Space Heating Demand and Saving Potentials in the Swiss Residential Building Stock: Bottom-Up Model of Archetype Buildings. Unpublished Manuscript 2017;.

[4] Conférence des directeurs cantonaux de l'énergie, . Qu'offre le CECB® ? http://geak.ch/Pages/Light/System/InformationPage.aspx; 2016.

[5] Streicher, K.N., Padey, P., Parra, D., Bürer, M.C., Patel, M.K.. Statistical Analysis of Energy Performance Certificates and Archetype Buildings in the Swiss Residential Building Stock. Unpublished Manuscript 2017;.

[6] SIA 380/1, . Thermische Energie im Hochbau – Norm SIA 380/1, Ausgabe 2007. Tech. Rep.; SIA; Zürich; 2007.

[7] MeteoSchweiz, . Datenportal für Lehre und Forschung. http://www.meteoschweiz.admin.ch/home/service-und-publikationen/beratung-und-service/datenportal-fuer-lehre-und-forschung.html; 2017.

[8] Bättig, R., Ziegler, M.. Swiss greenhouse gas abatement cost curve. Tech. Rep.; McKinsey&Company; Zurich, Switzerland; 2009.

[9] Pielli, K.. Clean Energy Solutions Center — Understanding Cost-Effectiveness of Energy Efficiency Programs: Best Practices, Technical Methods, and Emerging Issues for Policy-Makers. Tech. Rep.; U.S. Environmental Protection Agency. Office of Air and Radiation. Climate Protection Partnerships Division; 2009.

[10] Zuberi, M.J.S., Patel, M.K.. Bottom-up analysis of energy efficiency improvement and CO2 emission reduction potentials in the Swiss cement industry. Journal of Cleaner Production 2017;142, Part 4:4294–4309. doi:10.1016/j.jclepro.2016.11.178.

[11] Federal Statistical Office, . Swiss Federal Statistical Office. http://www.bfs.admin.ch/bfs/portal/en/index.html; 2016.

[12] Kirchner, A., Bredow, D., Ess, F., Grebel, T., Hofer, P., Kemmler, A., et al. Die Energieperspektiven für die Schweiz bis 2050. Energienachfrage und Elektrizitätsangebot in der Schweiz 2000 - 2050. Tech. Rep.; Prognos AG, Bundesamt für Energie; 2012.

[13] Khoury, J., Hollmuller, P., Lachal, B.M.. Energy performance gap in building retrofit : Characterization and effect on the energy saving potential 2016;.

[14] Majcen, D.. Predicting energy consumption and savings in the housing stock: A performance gap analysis in the Netherlands. A BE — Architecture and the Built Environment 2016;6(4):1–224. doi:10.7480/abe.2016.4.