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Understand, simulate, anticipate and correct performance gap in NZEB refurbishment of residential buildings

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Abstract. The gap between expected and real energy performance of new or newly refurbished residential buildings was an unexpected mine in the way towards a 2000 W society in Switzerland. Previous research has contributed to understand and quantify this gap by providing knowledge for the extent and amplitude of the problem. Now it is necessary to go into detail understanding of this phenomenon, in order to anticipate and correct the problem. This article analyses statistical findings of heating energy consumption in a whole Swiss canton – Geneva – and shows that results of specific research works on limited apartment residential building samples can be generalised. We show that the performance gap may be simulated with simple common tools, used for compliance energy calculations by applying the right conditions of use. We introduce the notion of "standard", "realistic" and "out of control" conditions of use. We simulate energy performance of the most common refurbishment actions on a standard existing residential building using these values and we compare the results with observed values on case studies or statistical samples. We show that simulations with the "out of control" conditions predict the performance gap of refurbished buildings. We may also observe that there are combinations of refurbishment works subject to higher or lower risk of performance gap. Simulating the performance deviation, we show which conditions of use must be better controlled to anticipate and limit the problem.

1. Introduction: the extent and causes of the refurbishment energy performance gap

With refurbishment energy performance gap, we mean the difference between expected energy performance of a refurbishment project according to compliance calculations labelling and measured energy consumption after refurbishment. Khoury et al [1][2] analysed 26 residential buildings, calculated and real energy performance in Geneva region and showed that the mean real energy savings after deep refurbishment do not exceed ~40% of the expected energy savings. This phenomenon should not be generalised in other building uses. Werner Reinman et al [3] showed that the real energy consumption of single-family houses, schools or office buildings labelled with Minergie ® label (new buildings or refurbishment) meet the expected performance for heating, hot water and ventilation. The Vaud Canton Court of Auditors [4] also found in an audit of 10 "sustainable" public buildings that the real performance of high energy performance school and office buildings meet the expected one, except in cases of air conditioned buildings where ventilation and cooling energy consumption generates a significant performance gap of electricity consumption.

Flourentzou and Pantet [5] analysed in detail 2 refurbishment projects Minergie® labelled and found similar results with Khoury [1,2]. While the compliance label threshold for heat consumption was 198 MJ/m^2y and the project designers calculated heat consumption target to 168 and 183 MJ/m^2y, the real heat consumption after refurbishment was 500 and 344 MJ/m^2y respectively. Instead of the expected energy savings >70%, the realised energy savings were 38% and 48%. In the first case energy consumption was +198% and on the second case +89% of the projected values. This analysis showed that there are 3 major reasons for this difference.

- Calculations for label compliance are performed with optimistic standard conditions: 20°C interior temperature, ventilation rate disregarding window opening by the tenants, glazing without shading from blinds or shutters during the heating season. Real conditions of use differ from these conditions after refurbishment.
- Bad control of energy systems resulting in: high distribution losses, low heat production efficiency and high temperature in the dwellings, thus considerably increasing heat losses. Distribution temperature was found to be 50-55°C at external temperature -5°C, instead of 40-45°C for a very well insulated refurbished building.
- User behaviour: great majority of users set thermostatic valves to 4 and 5, instead of 2-3. This amplifies the already high interior temperature and creates overheated indoor environment due to high distribution temperature. This on its hand leads to many occupants leaving their windows open to compensate for the excess heat. This behaviour is not independent from bad control of energy systems.

On figure 1 the left graph shows cumulative distribution of energy classes for the real performance of refurbished buildings with high energy target. As evident from the figure, only 14% of the refurbished buildings comply with energy class B and nearly half of the buildings fall into category D. The blue arrow shows the expected energy performance estimated using the standard conditions of use, according to the Swiss norms (**Table *1***).

The performance gap between compliance calculations and real energy performance is identified in other countries and does not concerns only high energy performance buildings. In a large survey, Visscher et al [6], compares theoretical energy label performance to real energy performance and finds higher real consumption for classes A and B and lower real consumption for classes D, E and F. In Flourentzou [10], analysis of the evolution of heat consumption in almost all residential apartment blocks in Geneva canton built before 1990, showed that the consumption of the building stock is reducing, even for the non-refurbished buildings. Since 1994 the specific heat consumption of residential buildings passed from 188 kWh/m²y to 140 kWh/m²y, from energy class G to class E, with 25.5% reduction. This relativizes even more the energy savings from deep refurbishment actions. In cases with a negative performance gap for the refurbished buildings, there may be a positive gap for the non-refurbished ones. Figure 1 shows the estimated energy performance of the reference building simulated in this paper, according to standard conditions of use (blue arrow on the right graph). A good match between calculated energy consumption and the median consumption of the whole building stock of the canton is observed (143 and 140 kWh/m²y for calculated and median, respectively).

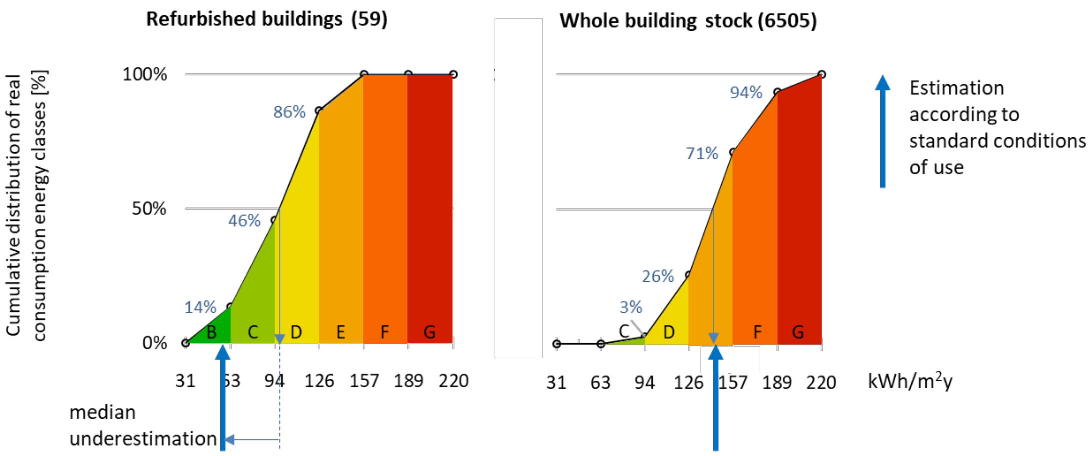

Figure 1. Cumulative distribution of energy classes in Geneva Canton for refurbished buildings (left) and the whole building stock (right). Arrows indicate compliance calculations with standard conditions

of use. The left graph illustrates a significant underestimation of compliance calculations for high performance refurbished buildings and the right graph a good matching with the mean energy consumption of the existing building stock.

2. Standard, realistic and out of control conditions of use to understand the performance gap

After [5] we analysed the conditions of use of 7 more buildings, deeply refurbished according to high energy performance specifications but never monitored to optimise their energy performance after commissioning. The conditions of use were very similar: Interior temperature in the apartments is ~23.6 ±0.2°C, 15 ±5% of the windows are open at every time and ~40% of the blinds or shutters are closed, when there is sunshine during the heating season. These observations consolidate the "out of control" conditions of use observed in detailed in [5].

At the same time, the building with the initial performance gap of +89%, studied in [5], was monitored for 2 years. By optimising the conditions of use we managed to reduce the performance gap to +37%. The mean interior temperature was reduced by 2°C by setting the control curve for heating distribution at 20°C when exterior temperature is 20°C and at 45°C when exterior temperature is -5°C (the initial setting was at 23°C at 20°C and 55°C at -5°C). Another measure was the installation of an intelligent self-learning control for the heating system, adapting the distribution temperature according to meteorological previsions and the mean interior temperature of the dwellings. The reduction of mean interior temperature in the dwellings to 21.5°C (instead of 23.5°C before optimisation) was obtained without significant discomfort claims from the occupants. Reducing the interior temperature was terminated when the tenant complaints for discomfort began increasing.

Table 1. Conditions of use applied in the compliance calculation of refurbishment actions.

	Standard	Realistic	Out of control
Tin for deep refurbishment	20°C	21.5°C	23.5°C
Tin for individual actions	20°C	21°C	22°C
Window opening	+ 0 m^3/m^2h	+ 0.15 m^3/m^2h	+ 0.3 m^3/m^2h
Shading	0%	40%	40%
η heating system	0.8	0.8	0.7
η domestic hot water	0.75	0.75	0.65
COP heat recovery	4.5	3	2
Solar collector production	8.4 kWh/m^2	5.6 kWh/m^2	2 kWh/m^2

For partial refurbishment we do not have statistical observations. For these actions we use the proposed by the norm increased normal conditions when heating control is not perfect: the norm SIA 380/1 [8] proposes 20+1°C when control is based on a representative heated room, and 20+2°C when it is based on the outside temperature.

The additional ventilation flow rates of 0.15 and 0,3 m^3/m^2h for realistic and out of control conditions, respectively, are empirical values, obtained by counting the opened windows several times during the day for each case presented in [5]. System efficiency for heating and hot water production and distribution comes from the Suisse norm SIA 384/3 [7]. The value of 0.8 for heating and 0.75 for hot water corresponds to a condensing gas or oil boiler with modulating power. Out of control conditions correspond to a non-condensing boiler without power modulation. COP for out of control values come from Pétremand [9].

With these experiences and references, **Table *1*** proposes 3 sets of conditions of use: "standard" conditions according to compliance calculation model, "realistic" conditions with the conditions of the optimised case study and "out of control" conditions, with the conditions of the non-monitored and non-optimised refurbished buildings.

3. Simulated and observed performance gap

The total observed performance gap is likely constituted from a number of reasons. Instances where the gap is due to a single reason is also possible although less likely. As described in the previous section, differences in the operating conditions can have a significant meaning for the difference between expected and observed energy performance. This is true both for conditions prior and after refurbishment.

According to statistical finding for energy performance of refurbished buildings, Flourentzou [10], the outcome of global renovations in Geneva canton lays at 100 kWh/m² annually for heating. Renovation of those buildings, on the other hand, was expected to reach the 2000W society goals, equivalent to 55 kWh/m² for heating annually. This is 82% higher than the expected energy demand.

Higher energy consumption than the expected calculated value is one factor overestimating energy savings, but a second factor is overestimating the energy consumption of the initial situation before refurbishment. We first investigate this factor and the effect of incorrect reference case, simulated according to standard conditions with Lesosai tool. Furthermore, we use the same tool to investigate the effect of different conditions of use (Table 1) and expected energy savings of typical renovation actions with this calculation tool. The expected energy savings and the real energy savings observed in different statistical sources are compared to observe the magnitude of the gap.

3.1. Gap imposed by unrealistic reference calculations

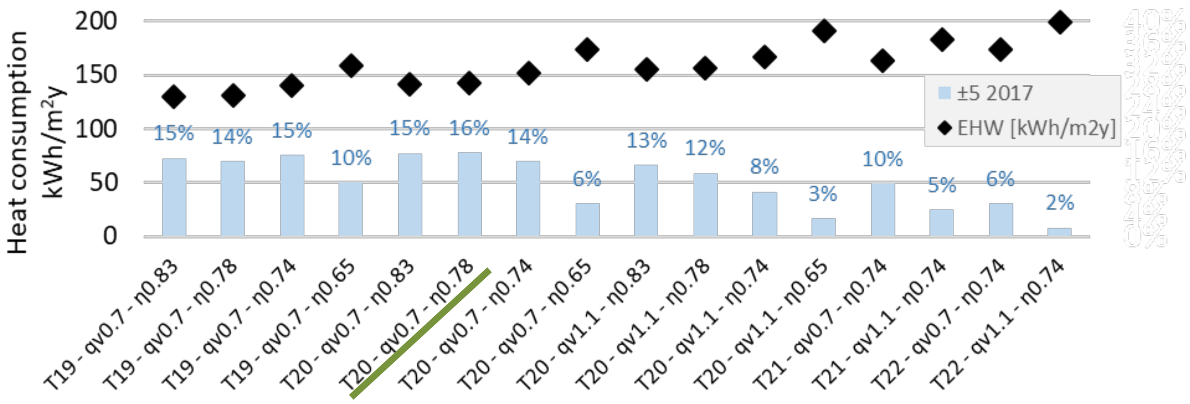

Figure 2. Estimated energy consumption for the reference building before refurbishment with different combinations of conditions of use presented in Table 1 and percentage of the canton building stock consuming this amount of energy in 2017± 5 kWh/m²y. We may see that with Tin 20°C, qv 0.7 m³/m²h, η = 0.74 giving a result of 143 kWh/m²y we may explain 16% of the canton buildings while with Tin 22°C, qv 1.1 m³/m²h, η = 0.74, only 2% of the buildings are approaching the results.

Figure *2* shows calculated energy consumption according to standard conditions for reference calculation before renovation. The percentage represents the buildings of the entire Geneva building stock consuming ±5 kWh/m² the estimated value. We may see on the graph that low system performance <0.74 correspond to a very low percentage of the entire building stock. Higher temperatures also rise the energy consumption too high and the percentage of corresponding buildings is lower than 6%. The underlined conditions of use correspond to the "standard" conditions and there are 16% of the buildings with real performance within 143±5 kWh/m² of the estimated value. Mean heat consumption of the whole building stock is 140 kWh/m², and there is a very significant part of the building stock needing to be simulated with 19°C to make correspond the real and estimated values. Extreme interior temperature and ventilation rate conditions, explaining the performance gap after refurbishment, overestimate energy consumption of existing buildings before refurbishment.

3.2. Observed gap for deep refurbishment and single refurbishment actions

Results presented in **Figure *3*** compare measured [14] and estimated energy savings according to the proposed conditions of use in **Table *1*** for the reference building using the software Lesosai. The results suggest that for deep refurbishment, windows and wall insulation, estimation with out of control conditions fits better to the real energy savings. For roof insulation, out of control conditions are too pessimistic. This is explained from the fact that wall and window insulation affect the interior temperature of all the dwellings making it difficult for convenient control, while roof insulation impacts only the top storey. For actions on installations (boiler replacement and demand control ventilation), standard and realistic conditions are closer, while out of control conditions may exist mostly on existing buildings before intervention rather than after refurbishment. For these actions, it is more important to use the correct conditions of use for the initial energy consumption before refurbishment. For solar domestic hot water situation is more complex. Realistic and out of control conditions fit better to the real performance because during summer the boiler produces mostly high temperature hot water to complete solar energy production. It is well known that condensing boilers are less efficient with high temperatures. However, even with this, real energy savings are lower. Other technical problems due to lack of monitoring decrease solar energy production.

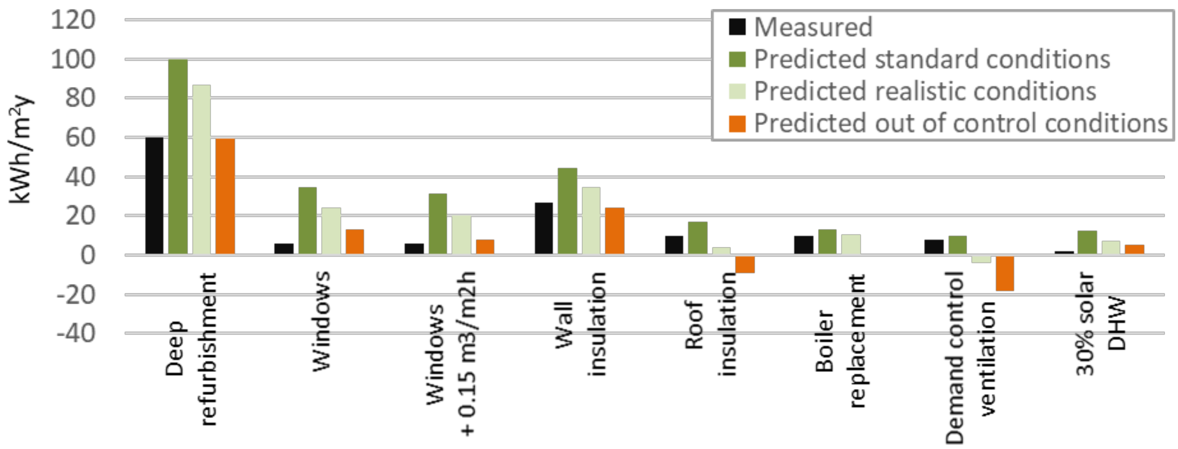

Figure 3. Observed and simulated energy savings according to standard, realistic and out of control conditions of use

3.3. Observed gap for deep refurbishments

On Figure 3 we observe that real energy consumption for deep refurbishment fit perfectly with out of control conditions. This is normal as the great majority of the observed buildings have never been monitored for optimisation. Energy savings using "realistic" conditions of use suggest 87 kWh/m²y instead of 100 of the standard conditions and 60 of the statistical observations and estimation with "out of control" conditions of use. This result fits perfectly with the optimised building mentioned in paragraph 2. This building was consuming after refurbishment in 2012 and 2013 up to 97 kWh/m²y which is very near to the mean of 100 kWh/m²y of our statistical sample. After 3 years of optimisation the energy performance of the building in 2017 was decreased to 69.7 kWh/m²y, saving extra 27 kWh/m²y, similar to the real energy savings suggested by the estimation according to realistic conditions on Figure 3.

4. Conclusions

The paper investigates the performance gap present in residential buildings in the Geneva canton. The results are based on statistical findings for the whole Geneva canton and compliance calculations for varying conditions of use and renovation actions. Results show that it is possible to account for the performance gap with simple compliance tools by using the appropriate conditions of use in the building before and after refurbishment. Single refurbishment actions are predicted with different conditions of use. Deep refurbishment without optimisation of operation conditions create more extreme out of control conditions of use and thus higher performance gap. Optimization of refurbishment actions is possible when knowledge of the operation conditions is available to predict the performance gap reduction. Simple post commissioning optimisation actions like adaptation of the heating control, installation of smart heating control systems, contracting performance optimisation service immediate after refurbishment and continuous monitoring of the building, may provide a significant reduction of the performance gap. Realistic conditions of use still create a performance gap of the order of 30%. More research is needed to obtain lower interior temperatures, lower need for opening the windows and higher production and distribution efficiency.

References

[1] Khoury, J., Rénovation énergéique des bâtiments résidentiels collectifs, Thèse de Doctorat, Université de Genéve, Faculté des Sciences, Genève 2014.

[2] Khoury, J. et al, COMPARE RENOVE : du catalogue de solutions à la performance réelle des rénovations énergétiques, projet OFEN SI/500973-01, Bern, 2018

[3] Werner Reinmann et al, Standards énergétiques dans le bâtiment – contrôle des résultats 2014-2015, OFEN - bâtiment, projet SI/ 401128-01, Berne, 2016.

[4] Cour des comptes du Canton de Vaud, Audit du développement durable dans les bâtiments de l'état de Vaud, rapport 37, http://www.vd.ch/autorites/cour-des-comptes, 2016

[5] Flourentzou, F., Pantet S. , Raisons et remèdes de la surconsommation de bâtiments locatifs après rénovation, Status Seminar, Zurich 2016

[6] Henk Wisscher et al, Performance gaps in energy consumption: household groups and building characteristicsBuilding Research & Information, journal-article, 2018.

[7] SIA 384/3, Installation de chauffage dans les bâtiments – Besoins en énergie, Zurich, 2013.

[8] SIA 380/1, Besoins de chaleur pour le chauffage, Zurich, 2016.

[9] Pétremand Yoan, Analyse des performances de confort et énergétiques (thermique et électrique) de différents systèmes de ventilation simple flux dans l'habitat collectif, diploma theses, EPFL infoscience, 2018.

[10] Flourentzou, F., Possible strategies and obstacles in the pathway towards energy transition of residential building stocks in Switzerland, Sustainable Built Environment Conf., Graz, 2019

[11] SIA 2040, La voie de la SIA vers l'efficacité énergétique, Zurich 2014, eddition 2017

[12] ENDK, Consommation Energétique des Bâtiments, Berne 2014

[13] SIA 469, Consevation des ouvrages, Zurich 2003

[14] Lang Ghislaine, Lanz Bruno, Quels sont les performances énergétiques et les cash-flows réels aprés rénovation ? Rapport d'étape du projet OptiRen, Présentation au séminaire "Planifier la transition énergétique vers la société de 2000W", EPFL 2018.