Possible strategies and obstacles in the pathway towards energy transition of residential building stocks in Switzerland

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Abstract. The Swiss strategy for energy transition towards a sober energy world targets a 2000 W per capita society in 2050. This objective for an owner of a building stock is translated to a refurbishment of all existing residential buildings to near zero energy buildings, consuming less than 55 kWh/m² of primary energy for heating with a rhythm reducing the overall energy consumption by an average of 2.6 kWh/m² until 2050. The article analyses energy consumption of 10'000 residential buildings in Geneva Canton since 1994 and shows that the target of energy reduction at this rate has been achieved in the period 1994-2016, decreasing from 187 kWh/m² in 1996 to 134 kWh/m² in 2016. However, projections for the next 3 decades with the current refurbishment rhythm (0.8-1.5%) and the current real energy performance after deep refurbishment and energy upgrading, show that at this rate and with the performance gap not resolved, the final target will not be achieved. Based on the analysis of real energy consumption after refurbishment actions on statistically significant building samples and analysing the potential energy refurbishment actions of a 161 buildings stock, we have simulated possible and realistic ways to achieve the 2000 W society target.

1. Introduction. The 2000W society and strategic energy and CO2 targets.
The Swiss strategy for energy transition took the name of “2000W society”. This idea started in the years 2000 in the academic circles. It was accepted as a political target in the majority of the cantonal energy Laws and communal Energy Regulations. The Swiss Engineers and Architects Association (SIA) edited a documentation describing the targets of this strategy focusing on buildings: exploitation energy consumption, gray energy for construction or refurbishment and mobility [1].

The 2000 W society targets to reduce the 6000 W nonrenewable energy intensity per capita during the year 2000 to 2000 W of non-renewable energy consumption in 2050 and 2000W total energy consumption of which 500 W nonrenewable in 2100. It also targets 2 tons of CO2 emissions per capita by the year 2050 (1 ton in 2100). This energy intensity was experienced in Switzerland in the fifties and it is argued by the promoters of this idea that it is possible to achieve these targets preserving the current comfort and welfare. The world mean energy intensity was 2000 W in the nighties while at present it is around 2500 W. The application of the 2000 W society idea worldwide, considers equal access to energy resources for all citizens of the world.

The SIA documentation 2040 analyzed the Swiss national statistics in terms of surface area per capita for living, working, learning, etc. and translated the global per capita nonrenewable primary energy and CO2 targets to building targets per square meter, distinguishing new and refurbished buildings.
The CO2 emission target for operation is 6 kg/m² for new construction and 8 kg/m² for refurbished residential buildings. These CO2 emission targets are very ambitious and cannot be reached with the use of fossil fuels. For existing residential buildings (multi-family houses), it is illusionary to imagine complete abandon of fossil fuels by 2050, except if there are massive investments in urban infrastructure to provide urban district heating with low CO2 and low nonrenewable primary energy content. Buildings complying to primary energy targets but not to CO2 targets may be considered as “in transition” towards 2000W society. A building may be considered compliant “in transition”, if it may reach the 2000W society targets with future modifications of the technical installations. As in this article we focus on apartment building stocks for housing and the strategic actions of their owners, we focus only on primary energy targets for heating and hot water production. A building complying to primary energy targets, heated provisionally with gas, may be classified “in transition”, because it does not comply to CO2 targets. These targets may be attained with future actions on heat production installations changing the energy source.

As we see on Table 1, refurbished and new buildings have the same total target for construction/refurbishment, operation and mobility. However, as refurbishment impacts less than construction of a new building, it is allowed 10 kWh/m² more primary energy and 2 kg/m² CO2 emissions for operation of refurbished buildings.

Energy for building operation counts heating, hot water, ventilation, cooling, lighting and electricity for housing appliances. SIA 2040 desegregates theses energies providing typical values for each type of use. Using these typical values, and the values of table 1, we may find the targets for heating and hot water consumption: 55-60 kWh/m² of nonrenewable primary energy. This indicator is important because it can be read directly on fuel energy bills for heating and hot water.

This target is coherent with the targets of low energy building labels. Class B buildings corresponds to <63 kWh/m² of final energy and Minergie – Refurbishment to 60 kWhCH4/m² of weighted energy for heating, hot water and ventilation. We keep as refurbishment target value of 2000 W for residential buildings heating and hot water consumption 55 kWhCH4/m² of weighted energy. This value is coherent with Minergie-Renovation targets that takes into account electricity for ventilation and auxiliaries.

In the year 2000 the mean energy performance of residential buildings in Geneva was 181 kWh/m² of weighted energy. To get the target of 55 kWh/m² in 2050 it is necessary to reduce energy consumption by 126 kWh/m² in 5 decades. This means a rate of reduction of 26 kWh/m² per decade or 1.4% per year with basis the 2000 energy consumption.

### Table 1: Surface and primary energy targets for new construction and refurbishment

|                | Surface /person | Embodied Energy | Energy for Operation | Energy for Mobility | Global Target |
|----------------|-----------------|-----------------|----------------------|---------------------|--------------|
|                | [m²]            | [kWh/m²]        | [kWh/m²]             | [kWh/m²]            | [kWh/m²]     |
| New Construction | 45              | 30              | 90                   | 40                  | 160          |
| Refurbishment   | 45              | 20              | 100                  | 40                  | 160          |

2. **Geneva Canton residential building stock energy consumption since 1994**

In Geneva Canton, every residential building owner with more than 5 energy consumers, has the obligation to communicate to the Cantonal Energy Office the heat consumption of the building. These data are collected since 1992, and since 2010 all buildings of a certain importance have to communicate

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1 Weighted energy is a Swiss speciality replacing the primary energy factors with « state energy policy weighting factors », having 2 for electricity, 1 for fossil fuels and 0.6 for biomass instead of 2.69 NRE for electricity, 1.22 for oil, 1.05 for gas and 0.1-0.33 for biomass with unit symbol kWhCH4.
their energy consumption. All these data are public and accessible on the Canton Information Service on the web.

We filtered and analyzed the data of all residential apartment buildings present in the database. The statistical set is composed by 6874 buildings of 12 million m² in 1994 and up to 10’000 buildings, 16.2 million m² in 2016. Every year more buildings are added in the database. This statistical set is constituted of practically the whole stock of residential apartment buildings of the Canton. If we consider 45 m² per inhabitant, this building stock concerns potentially housing of 266’000 people out of 495’000 population of the canton.

![Figure 1. Evolution of the final energy consumption of 10'000 residential buildings, 12 million m², in Geneva.](image)

As we see on Figure 1, in the period 1994-2000 the energy reduction was tiny, -0.85 kWh/m². In the period 2000-2010 the significant boost of energy savings gives an energy reduction of 3.45 kWh/m² per year. After 2010 we observe a deceleration of the evolution with 1.40 kWh/m². During these first two decades of energy transition, 1996-2016, we observe a significant reduction of energy consumption of an overall of 53 kWh/m². This represents a reduction of 28% with a mean rate of 26 kWh/m² per decade. The transition targets towards 2000 W society for the first two decades are achieved successfully, although the reduction rate was not constant during the whole period.

We observe a downturn after 2010 with weaker rate of reduction although the national energy requirements become more ambitious. The lower energy prices of this period and other macroeconomic reasons might play a role for this. Another factor of the downturn of energy consumption reduction is the low refurbishment rate. According to the report of the Cantonal Energy Directors [2], in Geneva Canton, more than 60% of the buildings built before 1990 have not been refurbished the last 30 years. This means a refurbishment rate lower than 1.5%. According to the same source, refurbishment rate of facades is between 1 and 1.1%, roofs 2-2.4% and windows 3.5%. As the energy reduction is due to optimisations and partial interventions rather than global energy upgrading, energy-saving potential is reducing year by year, because the most efficient actions have already been implemented.

2.1. Evolution of the energy classes during the first 2 decades of the energy transition

We classified the buildings according to their specific heat consumption. We calculated the partial class thresholds according to the Swiss national classification regulation. According to this standard, normal heat consumption determining the threshold of class B is 63 kWh/m² (heating and hot water). This determines the module of the x axis of the following graphs.
As we may see on Figure 2 and Figure 3, the residential building stock classification evolves towards lower energy classes. In 1996 there were 3801 buildings out of ~8000 in class G, in 2006 this number was reduced to 2471 and in 2016 they remain only 758 buildings out of ~10'000. The median class was reduced by more than one class during 2 decades. If the energy transition towards 2000 W society continued with the same rhythm until 2050, the energy target would be achieved. The distribution curve of that time might seem like the dotted line, centered on class B with the majority of the buildings, more than 25% of buildings in class A with buildings easy to refurbish with accessible cheap renewables and 25% of class C and some exceptions in class D. These class C and D buildings could be the protected heritage buildings or buildings not yet refurbished.

2.2. Major risks of low refurbishment rate and insufficient real energy performance.

Analysing these graphs, we may identify and quantify 2 major risks:

The first one is the current rate of refurbishment. If during the last 3 decades, only 3500 buildings were refurbished according to [2], what is the driving force that will modify the motivations of the building owners to retrofit 6500 buildings in the next 3 decades? As we see in Figure 1, the rate of energy consumption reduction decelerated, and it is less than the average value since 2010. With the current rate of energy consumption reduction, the targets of 2000 W society cannot be achieved.

The second risk that we may observe on Figure 2, is the few buildings of real energy class A and B. If in 2016 we have only 9 buildings of class A and 185 buildings of class B, someone may question why there are so few low-energy buildings, although there were subsidies since 2010 for deep refurbishment and hundreds of new buildings have been built with high energy standards? What will change so that the building sector may manage to perform for 7’500 buildings in the next 30 years what it has not managed in the past decade?

3. Refurbishment strategies

If we analyse the energy performance distribution of the building stock, we may see that 2/3 of the buildings are of energy class E, F and G. We also know from [2] that more than ~2/3 of the buildings
built before 1994 have not been refurbished over the last 30 years. This means that many of the buildings of class D achieve their energy performance without deep refurbishment and therefore, we may bring the buildings consuming more than the median consumption to the median with partial refurbishment and energy optimisation actions.

![Energy consumption distribution of residential buildings in Geneva and actions to change their energy class.](image)

According to the Swiss Norm SIA 469 [3], we may classify building conservation measures to 3 categories:

- Maintenance with ordinary and extraordinary limited actions.
- Refurbishment, bringing the building components to habitability normal conditions.
- Upgrading, with actions offering better performance.

Optimisation actions do not imply any investment, other than the monitoring cost. Simple settings, like a more adapted heating curve, night setback of the heating and water system, more adapted ventilation rates, correction of dysfunctions of production and distribution systems, optimisation of the operation of existing installations.

A list of building elements may be replaced independently from a deep global refurbishment without compromising future coherence of the energy systems. Windows, ventilation system, roof or ground slab insulation, an installation of solar collectors for hot water preheating, a new smart control of the heating system, or boiler replacement, are such actions. They may generate significant energy savings waiting deep refurbishment in the near or far future.

Concerning deep global refurbishment, some cantonal regulations define it for buildings investing more than 40% of the reconstruction value and apply special complying procedure to the norms. Upgrading actions target higher energy performance than the minimum legal target. Minergie®-Renovation label, Minergie-P® are such labels, but in Geneva and other Swiss cantons there are also regional labels, like HPE and THPE (Haute Performance Energétique and Très Haute Performance Energétique).

We have simulated the most usual refurbishment actions for a typical building of 1965 (Table 2). The building presents the dimensional and energy consumption characteristics of the median non-refurbished building of our cantonal database (3 entrances of 1800 m² each, 20 apartments each, measured energy class E). We calculated the theoretical energy savings of each action or combination of actions. As we are interested in the real impact of the different options on energy savings, we identified sets of buildings of significant statistical sample and tested the real energy saving effect of different actions. We compare the evolution of energy consumption of the test set of refurbished or optimised buildings with evolution of the reference set (generally the whole building stock). This shows the real impact on energy performance due to the action on the test set.

3.1. Monitoring and optimisation actions

We compare the evolution of specific heat consumption of a group of 123 buildings under energy performance contract with the whole building stock. As we may see on Figure 5, the selected buildings
for optimisation consume a bit more energy than the whole building stock before 2014 when optimisation actions started. Before the beginning of the optimisation actions in 2013, the set of optimised buildings consume 149 kWh/m² instead of 143 kWh/m² of the whole building stock. 3 years later, this group consumes 127 kWh/m² instead of 134 kWh/m² of the whole building stock. The whole building stock reduced its energy consumption for heat by 9 kWh/m², 6.3%. As the reference building stock is huge and the deep refurbishment actions insignificant (less than 1% per year) we may suppose that the reference building stock without optimisation is the whole building stock with 10 000 buildings. The optimised group of buildings reduce its energy consumption by 22 kWh/m², 14.8% compared to 9 kWh/m² of the reference set. The pure reduction of the optimisation actions counts for 13 kWh/m², 9.1%. As the results are normalised with a reference meteorological year according to the year heating degree days, we see only the action influence independently from weather variation. Here we simply compare the mean energy consumption of each group. More detailed statistical methods may be used to compare the two groups of buildings.

![Comparison of optimised buildings in 2014 with the whole building stock](image)

**Figure 5.** Comparison of the evolution of specific energy consumption for heat of a group of 123 optimised buildings with the whole building stock

### 3.2. Upgrading actions with deep refurbishment.

Comparison of a significant set of 59 refurbished buildings according to the high and very high energy standards shows the real potential of these actions. The target was 30 kWhCH/m² for the very high energy standard and 60 kWhCH/m² for the high energy standard, including weighted electric energy for ventilation (6-7 kWhCH/m² for buildings with heat recovery and 1 kWhCH/m² for buildings with simple systems). Electricity for ventilation is not included in the measurements of heat consumption in the database. The majority of these high-performance buildings are designed with heat recovery systems. Excluding ventilation, we keep the indicative target of 55 kWh/m² for heat. An official compliance verification certified the design objectives of these buildings.

As we can see on Figure 6, refurbished buildings according to high and very high energy standards, reduce drastically their energy consumption for heat. However, the real energy performance does not achieve the theoretical performance according to the declared objectives and does not meet the 2000W society goals. Although there is a reduction of 85 kWh/m² in heat consumption since 2005 (46%), there are 45 kWh/m² missing to meet the goals.
Figure 6: Comparison of 59 buildings upgraded to high and very high energy standards with the whole building stock of residential buildings built in Geneva before 1991.

The real heat consumption of this set of refurbished buildings is 100 kWh/m² instead of <55 kWh/m² that it should be. The majority of these buildings are still heated with oil or gaz. The following graph shows the energy consumption distribution of these buildings.

The phenomenon of the performance gap of refurbished buildings in Geneva has been studied by several research projects [4][5][6]. According to Khoury [6], in a sample of 26 buildings, targeting 153 kWh/m² energy savings, they realised 101 kWh/m², 65% of the ambitions. These results on a smaller sample, but analysed deeply in detail, are of the same order of magnitude as those of Figure 6. According to [5], the reason for this kind of performance gap is 30% due to bad settings and 30% due to lack of monitoring, resulting overheating of the apartments to >23°C and window openings >15% and poor heat production efficiency. In the following table, we compare the expected energy savings simulated on our typical building according to standard conditions and the energy savings observed on relevant statistical sets.

| Refurbishment Action                  | Calculated savings kWh/m² | Performance gap % | Gap |
|---------------------------------------|---------------------------|-------------------|-----|
| Smart heating control                 | 28                        | 16%               | +   |
| Replacement of windows                | 33                        | 22%               | +++ |
| Roof Insulation                       | 16                        | 11%               | +   |
| Boiler replacement                     | 7                         | 5%                | +   |
| Wall insulation                        | 42                        | 28%               | ++  |
| Demand control ventilation            | 9                         | 6%                | -   |
| Solar DHW preheating                  | 6                         | 4%                | +++ |

Table 2. Theoretical energy-saving potential of most usual refurbishment and optimisation actions and potential performance gap.
4. Simulation of energy transition pathway of a building stock towards 2000W society.
From Table 2 action list we may combine two types of refurbishment strategies for the buildings:

- Optimization and partial refurbishment actions, concerning the buildings of classes E, F, G that are not going to be refurbished in the next 15 years. The theoretical potential target is 100 kWh/m² but the real observed energy performance is ~125 kWh/m².

- Deep refurbishment following a given strategic refurbishment rate. The theoretical potential target is 55 kWh/m² but the mean real observed performance 100 kWh/m². The best refurbished buildings after optimization consume 70-75 kWh/m².

We analyzed a building stock of 161 buildings of the total surface area of 324'032 m². Its energy consumption for heating and hot water in 2016 is 133 kWh/m², very similar to the whole Geneva building stock average. The evolution of the energy consumption since 1994 is following very closely the cantonal building stock evolution. 95 buildings, 59%, are of classes E, F, G with mean energy consumption 150 kWh/m². The current rate of deep refurbishment is less than 1%. However, the investment rate is ~1.5% of the building reconstruction value. This means that almost half of the current investment budget is for partial refurbishment.

We tested 2 refurbishment strategies.

**Scenario 1**: realistic rate of refurbishment according to the current practice, the current budget and available personnel. This is translated to 1.5 buildings per year with deep refurbishment (1%). To this we add 8 buildings per year partially refurbished or optimized for the next 10 years. We use the energy targets observed in reality.

**Scenario 2**: an ambitious scenario, with 8 buildings per year partially refurbished or optimized and 1.5 buildings deeply refurbished until 2029, and 3 buildings per year refurbished from 2030 until 2050 (2% deep refurbishment after 2029). Until 2029 we use the energy targets according to those observed in reality and after, we use the potential theoretical ones.

As we see on Figure 8, the evolution according to the current parameters of refurbishment rate and real energy savings does not lead to a 2000W but to “a 3200W” society (scenario SC1). However, combination of the low current rate for deep refurbishment with partial refurbishment and optimizations may be acceptable to stay on the course for the next decade. In order to approach the resulting energy to the 2000W society targets, it is necessary to double gradually the rate of refurbishment to reach 2% and make the performance gap negligible for the decades after 2029.

5. Conclusions.
In the first 2 decades of the energy transition, 1996-2016, the mean rate of energy consumption reduction was following the objectives, although the rate of reduction was weakened since 2010. For the next decades there are 2 considerable obstacles to meet the goals: the low rate of deep refurbishment and the performance gap. In order to catch the objectives, it is necessary to rise gradually the rate of energy
Refurbishment to 2% per year and reduce the performance gap to obtain a mean of <55 kWh/m² after refurbishment, instead of 100 today.

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