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Actual energy savings of more than 1000 renovated buildings in Geneva

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Abstract. This study quantifies the annual energy-related retrofit rate of the Geneva building stock (1.7%), based on data concerning the delivered construction permits over the 2010 – 2018 period. By cross-cutting with final energy demand before and after retrofit, we derive an energy-efficient retrofit rate (0.6% for an improvement of 1 class at least, 0.2% for 2 classes at least). Results are analysed as a function of the construction period, as well as of the energy demand before retrofit.

1. Introduction

In December 2020, Geneva released a cantonal energy master plan with the ambitious target of reducing the CO_2 emissions by 60% by 2030, as compared to their 1990 level. This plan implies reaching an annual retrofit rate of 2.5 % for the building stock and reducing the average thermal energy consumption from 450 MJ/m^2/year to 350 MJ/m^2/year.

As far as we know, most of the past research in relation with such issues focuses either on renovation case studies based on precise monitoring of the measured energy savings of specific buildings [1], [2] or on large scale studies focusing on performance gap [3], [4]. The overall energy-related retrofit rate of the Geneva building stock has first been estimated in 2014 [1], but its actual impact on energy consumption has yet not been calculated. This study aims to (i) differentiate the retrofit rate of the Geneva building stock by period of construction, and (ii) estimate the resulting energy savings of these operations, based on actual final energy demand. From these results we define an energy effective retrofit rate for Geneva's collective housing building stock, taking into account only retrofit operations showing significant actual energy savings.

2. Methods and data

2.1. Heat consumption index and building register

In Geneva, actual annual energy demand for heat production for buildings hosting more than 5 dwellings is available in a public geo-referenced database [5]. The IDC value (Indice de Dépense de Chaleur), which includes a climate correction, represents the final energy for space heating and domestic hot water in MJ.m^{-2}.y^{-1}. The calculation procedure is available in [6]. In this paper we only consider the IDC data from 2011 onwards, so as to avoid the effect of a change in methodology which occurred in 2010. The SITG (Système d'Information du Territoire à Genève) platform [5] also provides a detailed building register, with ground surface, height, construction period, affectation, geographical coordinates, and a unique building identifier (called Egid number). We join this register with the IDC database, for estimating the global heated area in Geneva per construction period.

2.2. Construction permits

As a complement, a database with all geo-referenced construction permits in Geneva is also available on the SITG platform. We complete the available information by way of a public web-platform (http://etat.geneve.ch/sadconsult/), from which we download (i) the status of the procedure (*eg.* "accepted", "refused", "being processed") ; (ii) a short title explaining the purpose of the construction permit (free text written by the applicant) ; (iii) dates of request and of delivery. We keep only the entries with status equal to "accepted", "on construction" or "completed", so as to retain only demands leading to effective retrofit (since procedures may require a few years to be closed, a permit with a "on construction" status might actually correspond to a terminated retrofit). We further eliminate all cases concerning operations other than building construction or retrofit (demolition, landscaping, etc.)

Then, we use an algorithm to sort the remaining permits into categories, by looking at 250 specific key-words or combination of key-words in the title of the permit. For example, a large proportion of the permits concerns inner facilities, and we do not expect them to have an impact on the energy consumption. On the other hand, key words like "thermal insulation" lead the permit to be classified as energy-related retrofit. The limitations of this key-words approach are that (i) the accuracy of the classification is limited by the description given by the applicant; (ii) the permit titles do not provide information about the excepted energy consumption after retrofit. Latter information is only available in the application form kept by the administration, which would need to be searched manually.

2.3. Variation in energy consumption

The geographical coordinates of each construction permit are known, however there is no direct relation between the buildings register and the construction permits. For that reason, we compute the distance to the nearby building for each construction permit, and retain the one with the smallest value. If this distance exceeds 2 m we do not create a match, because this association may be irrelevant. Note that this restriction eliminates 5% of the potentially relevant permits. As a next step, for each construction permit and related building in the IDC database, an algorithm searches for a variation in the energy consumption after retrofit. To do this, we determine which year n around the delivery of the permit shows a significant change in the energy consumption. The possible value for n ranges between 1 year before the permit (because in some cases an additional permit is issued after the end of the retrofit, to reflect changes subsequent to the initial project) and 3 years after the permit (2 years granted by the law to complete the retrofit + 1 year to induce a measurable effect on energy consumption). The year n showing the likeliest change in the energy consumption is obtained by maximising the objective function

$$f(n) = \left(\overline{IDC_{before}}(n) - \overline{IDC_{after}}(n)\right)^2 \quad (1)$$

With $\overline{IDC_{after}}(n)$ and $\overline{IDC_{before}}(n)$ being the average value 3 years after (resp. before) the year n.

For the sake of analysis, the resulting data set (1442 cases) is finally separated in most reliable (340) and less reliable data (1102). Latter subset contains cases for which: i) all 3 IDC values before/after retrofit (eq. 1) are not available; ii) an alternative algorithm, which compares the average IDC two years before the delivery of the permit with the average IDC of the two last known years, yields a large divergence with eq.1 (more than the overall standard deviation of these differences, over the entire set); iii) the IDC database includes a change of the heat production system after retrofit, leading to potential variation of final energy consumption, but not necessarily of the building envelope.

2.4. Retrofit rate

Following equations allow to estimate the yearly energy-related retrofit rate, relative either to the total building stock N_{tot} or to the total heated area A_{tot}:

$$r = \frac{N}{N_{tot}}; \; r_A = \frac{A}{A_{tot}} \quad (2)$$

N the number of energy related retrofit permits, and A the corresponding heated surface.

For estimating the energy impact of retrofit, we also define an energy efficient retrofit rate r_i. To do this, we start by estimating following ratios between actual and admissible final energy demand:

$$R_{before} = \frac{\overline{IDC}_{before}}{E_{h,li} + E_{ww}};\ R_{after} = \frac{\overline{IDC}_{after}}{E_{h,li} + E_{ww}} \tag{3}$$

$\overline{IDC}_{before/after}$ is the 3-year IDC average before (respectively after) retrofit. $E_{h,li}$ is the admissible final energy for heating of new buildings, estimated with $E_{h,li} = Q_{H,li} \cdot \eta_p^{-1}$. The useful heat $Q_{h,li}$ is obtained from SIA 380/1 [8], with a form factor $A_{th}/A_e = 1$ and a climate correction for Geneva $f_{cor} = 0.922$. The heat production efficiency η_p is given by the IDC calculation procedure [6]. The final energy for domestic hot water E_{ww} is given by [7].

Preceding ratios are used for conversion of the IDC values into energy classes “A” to “G”, before and after retrofit, by using table 3 of [7]. For every energy related construction permit, we can hence associate an energy class change ΔC_{IDC}. For example, a building retrofit from class “G” to “E” corresponds to class change $\Delta C_{IDC} = 2$.

Finally, the annual energy effective retrofit rate r_i correspond to the number of buildings with a gain of *i* IDC-energy class and is obtained by

$$r_i = \frac{Count(\Delta C_{IDC} = i)}{N_{tot}} \tag{4}$$

$Count(\Delta C_{IDC} = i)$ is the total number of energy related building permits on the year *n* associated with a change of i IDC-energy classes. We further use the notation r_{i+} to indicate the yearly retrofit rate leading to an energy improvement of at least *i* energy classes.

3. Results

3.1. Overview of Geneva buildings energy consumption database

In 2019, the buildings of the IDC database represent 66% of the total heated area in Geneva, as estimated from the cadastre database. The missing area mainly concerns buildings with less than 5 dwellings which are not registered in the IDC database.

Table 1 shows the data for the collective residential buildings (including buildings with mixt allocation) in 2019, as well as the trend over the 2011-2019 period, in relation with the energy-related retrofit permits. In 2019, the total IDC heat demand represents 12.5 PJ for a heated area of $28.4 \cdot 10^6$ m^2.

Table 1. Collective residential building stock (including buildings with mixt allocation)

IDC database, 2019					IDC trend, 2011-2019		
Construction period	IDC [a] (MJ/m^2.y)	Heated area	Heat demand	Nb buildings [b]	Total [c] (% y^{-1})	w ER [c] (% y^{-1})	w/o ER [c] (% y^{-1})
< 1919	480.6	14.4%	14.7%	1742	-0.62%	-1.28%	-0.48%
1919-1945	502.7	8.2%	8.8%	918	-0.67%	-1.40%	-0.48%
1946-1960	521.3	12.2%	13.5%	1509	-0.68%	-1.64%	-0.47%
1961-1970	490.0	18.8%	19.7%	1667	-0.86%	-1.84%	-0.54%
1971-1980	503.9	14.0%	15.1%	1400	-0.45%	-0.70%	-0.40%
1981-1990	466.7	8.1%	7.9%	855	-0.38%	-0.22%	-0.39%
Total < 1991	494.8	75.7%	79.7%	8091	-0.64%	-1.41%	-0.47%
Total < 2020	468.8	100%	100%	10646	-0.52%	-1.39%	-0.35%

[a] Area weighted mean IDC.
[b] Number of buildings with fully completed IDC data 2011-2019
[c] IDC linear trend over the 9 year period: all buildings (Total); buildings with energy-related retrofit (w ER); buildings without energy-related retrofit (w/o ER).

For the collective residential building stock (including buildings with mixt allocation), the area-weighted IDC average shows a linear decrease of -0.52% per year between 2011 and 2019, pointing out that final energy consumption per m^2 for the IDC-building stock is slowly decreasing. Yet, large scale energy retrofit is not the only driver for lowering the mean IDC, because for the non-retrofitted buildings the overall trend is -0.35% y^{-1}. As the calculation of the IDC already includes a climate correction, this global trend of -0.52% y^{-1} reflects: i) energy retrofit operation of older buildings (requiring a building permit); ii) other effects, including optimisation or technical retrofit of old building (without construction permit), as well as behaviours change of the inhabitants, for example related to awareness campaign. Potential imperfections of the climate correction method in the IDC calculation procedure should also be investigated further.

The newest buildings in table 2 (constructed between 1981 and 1990) did not enter a retrofit period yet, and we can assume that the related construction permits concern small interventions not being very significant on the energy consumption. Their average energy consumption per m^2 is slightly decreasing (-0.38 % y^{-1}), nevertheless we notice the same trend for buildings without energy-related construction permit (-0.39% y^{-1}). In others words, this small improvement of energy consumption is mainly driven by technical optimisation or change of behaviour of the inhabitants, but not by energy retrofit.

For the buildings constructed before 1981, the global reduction trend becomes more significant if we include renovated buildings, bringing out visible effect of energy-retrofit. The largest effect is observed for the buildings constructed between 1961 and 1970, with an overall reduction trend of the mean IDC of -0.86% y^{-1}. This trend is -0.54% y^{-1} for the non-retrofitted buildings of this period.

3.2. Energy impact and retrofit rate calculated from the construction permits

Following table shows the IDC reduction of energy related construction permits, as analyzed both on the most reliable cases and the entire data set (see section 2.3.).

Table 2. IDC reduction of energy related construction permits (MJ m^2 $y^{-1)}$

	Mean	Median	Stand. dev.	9th decile	1st decile
Most reliable data (340 cases)	67.9	42.0	98.3	233.7	-31.7
All data (1442 cases)	47.0	36.2	92.7	157.7	-45.7

The IDC reduction on the most reliable data (-67.9 MJ m^2 y^{-1}) is slightly higher than for all the data (-47.0 MJ m^2 y^{-1}). Such might be related to the fact that most reliable cases are computed on 3 yearly values after retrofit, which gives more time for optimization to take effect after retrofit.

The IDC reduction can be analyzed as a function of diverse variables (construction period, type of procedure for permits, …). In this paper we present the correlation between IDC reduction and energy consumption before retrofit (fig 1). Very efficient retrofit operation with a reduction of IDC higher than 250 MJ m^2 y^{-1} correspond to only 6.5% of the total of the energy-related construction permits. At the opposite, 22% of the energy related permits are even followed by an increase of the energy consumption.

We also notice that the effect of energy retrofit is statistically negligible for building with an IDC before retrofit below 500 MJ.m^{-2}.y^{-1}. At the opposite, buildings with high energy consumption before retrofit show the higher energy savings. For example, for buildings with an initial energy consumption higher than 700 MJ.m^{-2}.y^{-1}, 25% of the permits leads to savings higher than 250 MJ.m^{-2}.y^{-1}. We performed an analysis of variance to underline the correlation between energy-savings and consumption before retrofit and we obtained a P-Value $<10^{-12}$, indicating that the distributions are clearly distinct.

As a complement to what is shown in figure 1, we finally highlight that for energy-related retrofit, the initial IDC-derived energy classes are distributed within G (52 %), F (34%) and D (13%), very much alike the distribution of the entire IDC database (respectively 52%, 36% and 9%). Hence, buildings with higher energy consumption are not more retrofitted than others, pointing out that high energy consumption seems not to be a preponderant factor for initiating retrofit.

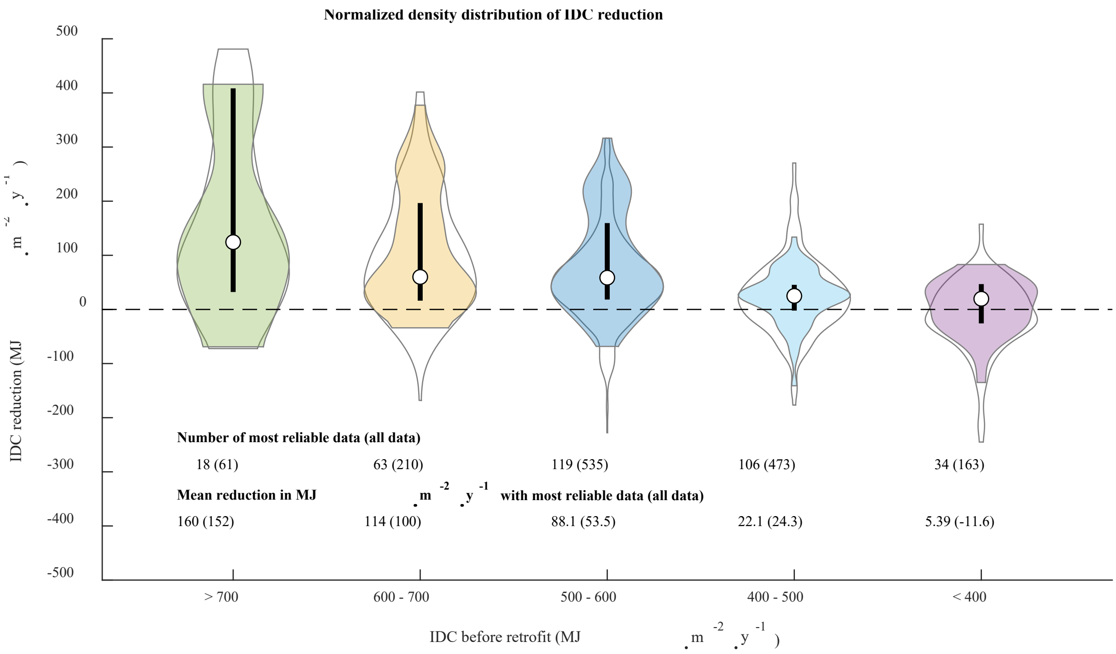

Figure 1. Distribution of IDC reduction by families of IDC value before retrofit, with a comparison between the most reliable cases (colored plot) and all cases (gray outline). For the most reliable data the median value is indicated by the white circle, and the 25-75 percentiles by the vertical black lines.

Table 3. Yearly mean retrofit rate 2010-2018 [a]

Construction Period	Retrofit rate		fraction by energy class improvement: r_i/r (%)						Efficient retrofit rate	
	r	r_A	>2	2	1	0	-1	≤-2	r_{2+}	r_{1+}
Before 1919	1.7%	1.8%	0.6%	5.3%	26.2%	58.2%	8.8%	0.9%	0.1%	0.5%
1919-1945	2.0%	2.0%	0.0%	4.6%	23.2%	62.4%	9.3%	0.5%	0.1%	0.6%
1946-1960	1.7%	2.0%	5.4%	3.5%	27.3%	56.5%	7.3%	0.0%	0.2%	0.6%
1961-1970	2.4%	2.6%	8.1%	8.1%	29.1%	50.1%	4.2%	0.2%	0.4%	1.1%
1971-1980	1.3%	1.5%	3.3%	3.3%	31.3%	48.9%	12.6%	0.5%	0.1%	0.5%
1981-1990	0.4%	0.6%	0.0%	2.5%	37.5%	37.5%	22.5%	0.0%	0.0%	0.2%
Total	1.7%	1.9%	3.9%	5.3%	27.8%	54.4%	8.2%	0.4%	0.2%	0.6%

[a] For each construction period, retrofit rates relates to corresponding the building stock (collective housing, including mixt allocation) of the IDC database.

Over the period 2010-2018 (table 3), the total yearly energy-related renovation rate r amounts to 1.7%, which is identical to the value for the 2011-2012 period, as derived with a methodology similar to ours, but carried out manually [1]. This tendency is slightly higher for larger buildings, as pointed out by the area-weighted retrofit rate ($r_A = 1.9\%$).

Globally, 54% of these energy related retrofit cases actually remain in the same class, while 28% manage to gain 1 class only. The 18% remaining cases are evenly distributed between gains of more than 1 class and losses of 1 or more classes. Phrased differently, energy efficient retrofit globally amounts to only 0.6% for a gain at least 1 classes (r_{1+}) and 0.2% for a gain of 2 or more classes (r_{2+}).

When analyzing specific construction periods, we see that older buildings (built before 1971) have higher energy related retrofit rates than newer ones. The highest rate goes for the 1961-1970 period ($r = 2.4\%$), which fortunately also corresponds to the period with the highest share of heated area and heat demand (see table 1). For this period, the actual efficiency of the retrofit operations is also about twice the one observed at global scale ($r_{1+} = 1.1\%, r_{2+} = 0.4\%$). At the opposite, buildings constructed after 1981 are almost not retrofitted.

4. Conclusion

Since 2011, the annual energy related retrofit rate of the building stock constructed before 1991 has been 1.7%. The highest rate is achieved by buildings constructed between 1961 and 1970 (2.4%) and the lowest by buildings constructed between 1981 and 1990 (0.4%). The retrofit rate is not correlated with energy consumption before retrofit, which highlights that energy consumption is not a major motivation for initiating retrofit.

In terms of efficiency, we observe an average final energy saving of 67.9 $MJ.m^{-2}.y^{-1}$ on retrofit operations with a declared impact on energy. Buildings with high initial energy consumption (> 700 $MJ.m^{-2}.y^{-1}$) achieve the highest average savings (160 $MJ.m^{-2}.y^{-1}$). On the other hand, the ones initially below 400 $MJ.m^{-2}.y^{-1}$ achieve an average saving of only 5 $MJ.m^{-2}.y^{-1}$. We have noticed very few retrofit operations (6.5%) resulting in actual savings higher than 250 $MJ.m^{-2}.y^{-1}$. Conversely, 22% of the construction permits are followed by an increase in energy consumption.

Correspondingly, we establish an energy effective retrofit rate, which is the highest for the buildings constructed between 1961 and 1970 (0.4% for at least 2 energy-class improvement, 1.1% for at least one class). This rate is about twice lower for the other buildings categories.

Finally, we notice a global trend of -0.52% y^{-1} in the energy consumption of the buildings in the IDC data-base. For the non-retrofitted buildings, this trend is -0.35% y^{-1}. These energy savings without energy-related construction permit are to be investigated further to quantify other drivers – e.g. technical optimization of building efficiency, user's behavior, or potential imperfections of the climate correction in the IDC calculation procedure.

In general, our results indicate that the average quality and quantity of buildings energy retrofit is yet not enough to reduce the CO_2 emissions by 60% by 2030. Reaching this target would require the reduction of the total fossil energy of 3.5% per year, as compared to the average saving of 0.52% per year observed over the 2010-2019 period in the IDC data-base.

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