The ORé tool: Decision Support for Defining a Building Retrofit Strategy at Territorial Scale

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Abstract

The heating energy represents 35% of total energy consumption in Switzerland, and private households 60% of this consumption. The retrofit of residential buildings is a fundamental component of local energy policies. However, questions remain unresolved for many Swiss cities such as: How to know the potential in terms of retrofit of the territory? What are the priority buildings and why? What strategy to implement to achieve the objectives and what impacts on energy, costs and climate?

Based on regional data, calculation with the Swiss norm SIA 380/1 per building enriched with data from our own database, the CREM has developed a semi-automatized tool to define a strategy for renovation of housing buildings on any Swiss territory. The method implemented into the tool prioritizes the buildings for retrofit based on potential energy, monetary and greenhouse gas (GHG) savings. The detailed methodology is presented here.

L'énergie de chauffage représente 35% de la consommation totale d'énergie finale en Suisse, dont 60% par les ménages privés. La rénovation énergétique des bâtiments de logements est un volet fondamental des politiques énergétiques territoriales. Cependant, des interrogations restent en suspens pour de nombreuses communes Suisses telles que : Comment connaitre le potentiel de rénovation du territoire ? Quels sont les bâtiments à rénover en priorité et pour quelles raisons ? Comment fixer des objectifs réalistes à l'échelle du territoire, selon quels critères (énergie, CO_2, coûts, climat, etc.) et quelle stratégie mettre en place pour les atteindre?

Sur la base de données territoriales, d'un calcul SIA 380/1 par bâtiment et de base de données (modes constructifs, coût de rénovation) propres à l'institut, le CREM a développé un outil semi-automatisé permettant de définir une stratégie de rénovation des bâtiments de logement pour n'importe quel territoire Suisse. Cet article a pour objectif de présenter la méthode développée pour effectuer une priorisation des rénovations selon des critères énergie, coûts et climat ainsi que quelques résultats obtenus dans le cadre d'études de cas.

1. Scope

The heating energy represents 35% of total energy consumption in Switzerland, and private households 60% of this consumption[1]. The Swiss energy policy, through its energy strategy 2050 and related measures, identifies retrofitting of the building stock as a priority. The Swiss Confederation spends 200 million Swiss francs per year in subsides for building energy retrofitting through the Building Program[2]. Funds are provided under conditions for owners that make a request for their project[3]. Conditions are not based on current heating need, meaning that possessing a poorly insulated building is not a criterion to access subsidies.

Addressing retrofit planning of territories, different methodologies are used at the present time in order to characterize and identify weaknesses of the existing building stock and allow a first comparison among buildings. Thermography is one of them and relies on a thermography associated to a colour scale. This can be realized from different methods: airborne [4] (helicopter, drone, etc.), from ground vehicles, or per building from the inside or the outside or in the context of an energy audit [5]. Expect for a drone based approach, the first two methods do not allow to thoroughly examine a building with all roofs, walls and windows simultaneously due to limited viewing angles and the third one only processes one building at a time, excluding it for a global approach, at a city scale. Thermography approach is qualitative; it highlights heat losses but is limited in determining quantitative equivalents such as lost kilowatt-hours. A second approach consists in visiting a sample of relevant buildings of the concerned real estate and/or completing energy audits on them and then in extrapolating collected information and results to the overall building stock, as implemented in Onex Rénove [6] and [7]. These approaches, accurate for the audited sample, do not allow to always differentiate between two buildings with identical typology and energy reference area but that have different expositions to the sun and different form factors. Finally, a third method used in territorial energy systems consists in estimating a specific need for each building in order to approximate thermal needs for the current and renovated state [8]. Often the energy demand is approximated as a linear function inversely proportional to the outdoor temperature [9]. This last approach does not take into account weather-dependent data such as the orientation, solar gains or buildings compactness while those parameters influence a lot building thermal energy needs [10] [11] [12].

In parallel, quantifying retrofit investment and resulting energy bill reduction are key elements for decision-makers in order to define whether or not a refurbishment is feasible. Previously presented approaches do not provide such indices. In effect, they do not consider territory-specific parameters, for example local weather conditions, solar masks related to surrounding terrain, building's geometry influence for example compactness, thermal bridges or energy source linked to the heating bill allowing to estimate investment costs or energy bill reduction.

To improve retrofit planning quality through a semi-automatized tool, the Oré tool, developed at the CREM, aims to integrate these currently missing components in a single global methodology, in order to define a building retrofit strategy at a territory scale. Oré uses a thermal model of building based on data available for all of Switzerland to define these strategies. By semi-automatized tool, we mean a tool that includes all or part of computer script to automate or semi- automate all of or part of the tasks that can be done by hand. A first application of this tool in a pilot project was carried out with the City of Sion, “Energie Sion Région” (ESR) and the Canton of Valais and is also presented in this paper.

2. Methods

This tool allows, from registers and generic data from communities and Swiss Cantons, specific knowledge from city architects and the cost data base CostDBCREM [13], to classify buildings within a territory according to their simulated retrofit potential and to spatialize them according to different criteria. For this purpose, this tool:

- Performs a calculation based on the Swiss Norm for thermal energy, SIA 380/1 [14], to estimate current heating needs, using standard values for the composition of different envelope components, taking into account each building as a 2.5D geometry and their respective sun exposition.
- Calculates investment costs for retrofit as well as heating-related operating costs.
- Provides techno-economic indicators representing the retrofit potential for each building

In order to perform an SIA 380/1 calculation, different parameters have to be defined for each building. These parameters are the following:

Parameters	Units
SIA category and typology	-
Weather station	-
Heated area	m^2
Wall surfaces and orientation	m^2, °
Floor surfaces and orientation	m^2, °
Roof surfaces and orientation	m^2, °
Window surfaces and orientation	m^2, °
Wall thermal reduction coefficient b	Adimensioned
Floor thermal reduction coefficient b	Adimensioned
Roof thermal reduction coefficient b	Adimensioned
Wall thermal loss coefficient U	W/m^2.K
Floor thermal loss coefficient U	W/m^2.K
Roof thermal loss coefficient U	W/m^2.K
Window frame thermal loss coefficient U	W/m^2.K
Window glass thermal loss coefficient U	W/m^2.K
Solar energy transmission rate g	%
Far horizon reduction coefficient – Fs1	-
Floor thermal bridges length	m
Roof thermal bridges length	m
Intermediate floor thermal bridges length	m
Window thermal bridges length	m
Floor thermal bridges Ψ value	W/m.K
Roof thermal bridges Ψ value	W/m.K
Intermediate floor thermal bridges Ψ value	W/m.K
Window thermal bridges Ψ value	W/m.K
Ventilation typology	Natural, single flow, double flow

Table 1 basics parameters used in Ore for the SIA 380/1 calculation

Each parameter is characterized based on source data. Details of these data, as well as their use, are available in the next sections of this paper.

Used data

Data used by semi-automated tool Oré comes from the Regional Planning and Development Department of communities, federal registers and utilities databases. These 3 data sources imply information with different granularities and electronic formats.

The first one is a buildings digitalized land register from the study area, containing each building's footprint area. Format used in the Oré tool for this data source is the *"shapefile"* (.shp) format, a popular geospatial vector data format. It can be read and processed by geographic information system (GIS) software designed to capture, store, manipulate, analyse, manage, and present all types of spatial or geographical data such as ArcGIS or QGIS. The latter having been chosen due to its *open source* licence. This land register plays a central role in estimating buildings 2.5D geometry. Second data source is the cantonal building and dwellings register, RegBL, managed by the Swiss Federal Statistical Office (FSO). Because of the various information elements this register contains, it is frequently used as a basis in territorial energy planning methods. The following elements were collected from it as part of the Oré project, for each building: number of floors used to calculate heated area and 2.5D geometries, period of construction/refurbishment, building use, energy source for heating and domestic hot water (DHW). All these elements are necessary to define buildings typologies considering construction methods, equipment and usage scenarios. Third and last data source is an extraction from gas consumption measurement readings, used for model calibration.

2.5D Geometry

Buildings 2.5D geometry estimation relies on a GIS processing of the buildings digitalized cadaster coupled with the number of floors provided by the RegBL. First stage consists in a data GIS processing through QGIS software. Digitalized cadaster contains buildings footprint areas defined as polygon. Polygons have to be transformed into polylines and then into points. Thus, it is possible to retrieve (X, Y) coordinates from all the points composing each building, using existing QGIS functionalities (*Field calculator/Geometry/$x* and *Field calculator/Geometry/$y)*. Points are then extracted from each polygon clockwise. Using these data and trigonometric tools, façades orientation angles (referring to compass rose shown in Figure 1) and lengths can be calculated.

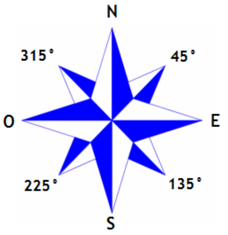


Figure1 Compass rose

Orientation calculation methodology comes from CREM's EnerApi [15] modules technical annexes. As an input, it requires a segment knowing its extremities coordinates. This method considers each segment as the right-angled triangle hypotenuse and applies appropriate trigonometric formulas. For instance, for an [n, n+1] segment, following calculations are used:

Cases	Calculation
Xn+1 > Xn **&** **Yn+1 < Yn**	$\mathrm{Atan}\left(\frac{X}{Y}\right) \mathrm{x} \frac{180}{\pi}$
Xn+1 < Xn **&** **Yn+1 < Yn**	$\mathrm{Atan}\left(\frac{X}{Y}\right) \mathrm{x} \frac{180}{\pi} + 90$
Xn+1 < Xn **&** **Yn+1 > Yn**	$\mathrm{Atan}\left(\frac{X}{Y}\right) \mathrm{x} \frac{180}{\pi} + 180$
Xn+1 > Xn **&** **Yn+1 > Yn**	$\mathrm{Atan}\left(\frac{X}{Y}\right) \mathrm{x} \frac{180}{\pi} + 270$

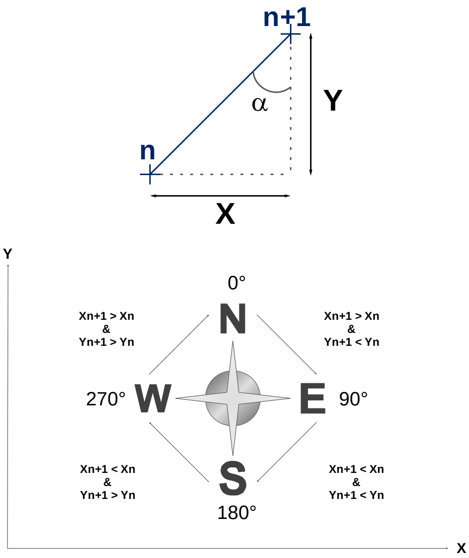


Table 2 Orientation calculation for different cases

- **Façades and floor thermal bridges length**

From these same (X, Y) coordinates, it is also possible to calculate a segment length. As previously described, each segment is considered as the right-angled triangle hypotenuse. The Oré tool then uses Pythagorean Theorem: $X^2 + Y^2 = Z^2$.

Thermal bridge lengths from lower or upper floors are considered as equal and depend on building footprint area perimeter

Each thermal bridge length from intermediate floors is calculated as following:
Intermediate floor thermal bridge length = floor thermal bridge length x (floor number – 1)

- **Glazed and opaque façade surfaces**

Façade surfaces are calculated multiplying their lengths (see previous method) by the building number of floors and a standard floor height set as 3 meters in the Oré project:
Façade surface = façade length x floor number x average height of a floor

Each façade surface is then given a window surface. This depends on façade surface as well as its orientation. Given a lack of data about window surface ratios classification according to periods of construction, we consider equal ratios, regardless of buildings age. Ratios depending on orientation are the following:

Orientation min	Orientation max	Window ratio
0	45	15%
45	90	20%
90	135	25%
135	180	30%
180	225	30%
225	270	25%
270	315	20%
315	360	15%

Table 3 window ratio per orientation

Windows and walls surfaces are calculated as follows:

Window surface = façade surface x window ratio

Wall surface = façade surface – window surface

➢ Windows length and height

Windows lengths and heights are calculated as follows:

Window length = façade length x $\sqrt{window\ ratio}$

Window height = façade height x $\sqrt{window\ ratio}$

➢ Heated Area

Finally, heated area is calculated from building footprint area using QGIS software. We then consider that heated area corresponds to 90% of corresponding building footprint area multiplied by the number of floors. By doing so, surfaces not included in the thermal envelope of the building (SIA 380[16]**)** can be excluded. The 90% ratio is a typical value found in most of building permit requests and comes from CREM experience in their energy controls carried out since 2010. Nevertheless, this value might not reflect all buildings within the considered territory.

Heated area = 0.9 x footprint area x floor number

Buildings Typologies

Each building 2.5D geometry being now available, the task is to define building typologies depending on their periods of construction/refurbishment and their usage type. Typology refers here to walls, floors, roof, windows or thermal bridges, construction methods, as well as equipment and usage scenarios, namely heat emitters, regulation and ventilation types or even number of inhabitants per surface area, indoor reference temperature and ventilation types/flow rates. Data sources about construction methods depending on the period of construction come from field works carried out in [17] and SmartHeat Design, as well as data collected from Sion territory.

U value - W/(m^2.K) and window typology	Initial parameters						
	Floor	Wall	Roof	Frame	Glass	g	Material and Ψ interlayer value
Avant 1919	2.5	1.41	1.6	1.7	1.9	0.65	Inox, 0.06
1919-1945	2.5	1.41	1.6	1.7	1.9	0.65	Inox, 0.06
1946-1960	2.5	1.35	1.6	1.7	1.9	0.65	Inox, 0.06
1961-1970	2.5	1.14	1.6	1.7	1.9	0.65	Inox, 0.06
1971-1980	1.5	0.58	0.8	1.7	1.9	0.65	Inox, 0.06
1981-1985	0.96	0.42	0.54	1.7	1.9	0.65	Inox, 0.06
1986-1990	0.96	0.42	0.54	1.7	1.9	0.65	Inox, 0.06
1991-1995	0.55	0.29	0.35	1.3	1.9	0.65	Inox, 0.06
1996-2000	0.55	0.29	0.35	1.3	1.9	0.65	Inox, 0.06
2001-2005	0.35	0.21	0.28	1.3	1.4	0.6	Inox, 0.06
2006-2010	0.28	0.21	0.28	1.3	1.4	0.6	Inox, 0.06
2011-2015	0.25	0.20	0.18	1.3	1.1	0.55	Inox, 0.06

Table 4 Floor, wall, roof and window thermal parameters

Thermal bridges Ψ value (W/m.K)	Floor	Intermediate floor	Roof	Window
Before 1919	0.00	0.00	0.00	0.00
1919-1945	0.00	0.00	0.00	0.00
1946-1960	0.00	0.00	0.00	0.00
1961-1970	0.00	0.00	0.00	0.00
1971-1980	0.04	0.71	0.00	0.13
1981-1985	0.04	0.71	0.00	0.13
1986-1990	0.04	0.71	0.00	0.13
1991-1995	0.04	0.71	0.54	0.15
1996-2000	0.04	0.71	0.54	0.15
2001-2005	0.00	0.78	0.59	0.20
2006-2010	0.00	0.78	0.59	0.20
2011-2015	0.10	0.00	0.48	0.18

Table 5 Thermal bridges characteristics

The following hypotheses are used for equipment and occupancy scenarios:

Construction period	Heat emitter	Control	Ventilation	Heat recovery efficiency
Before 1919	Radiator : 60°C	Reference room	Natural ventilation	0
1919-1945	Radiator : 60°C	Reference room	Natural ventilation	0
1946-1960	Radiator : 60°C	Reference room	Natural ventilation	0
1961-1970	Radiator : 60°C	Reference room	Natural ventilation	0
1971-1980	Radiator : 60°C	Reference room	Natural ventilation	0
1981-1985	Radiator : 50°C	Reference room	Natural ventilation	0
1986-1990	Radiator : 50°C	Reference room	Natural ventilation	0
1991-1995	Radiator : 50°C	Reference room	Natural ventilation	0
1996-2000	Radiator : 40°C	Reference room	Natural ventilation	0
2001-2005	Radiator : 40°C	Reference room	Natural ventilation	0
2006-2010	Heating floor : 42°C	Reference room	Natural ventilation	0
2011-2015	Heating floor : 35°C	Each room (or supply temperature < 30°C)	Single flow ventilation	0
Après 2015	Heating floor : 28°C	Each room (or supply temperature < 30°C)	Dual flow ventilation with heat recovery	0.8

Table 6 Equipment scenarios per period

Category	Number of persons per m^2	Heat set point temperature	Ventilation rate ($m^3/h.m^2$)
Individual housing	0.017	20	0.7
Collective housing	0.025	20	0.7
Administrative	0.050	20	0.7
Commercial	0.100	20	0.7
Industry	0.050	18	0.7
Gathering places	0.200	20	1
School	0.100	20	0.7
Hospital	0.033	22	1
Installations sportives	0.050	18	0.7
Shed, warehouse	0.010	18	0.3
Other	-	0	0

Table 7 Occupancy scenarios for different SIA categories

Based on these construction methods and thermal bridges per period, equipment and occupancy scenarios per building use, data coming from RegBL and 2.5D geometries per building, it is now possible to model each building and perform an SIA 380/1 calculation for each of them.

Measured gas consumptions and specific consumptions

Based on measured gas consumptions provided by the utilities, specific gas consumption for each building can be calculated dividing its consumption by its estimated heating area. This specific consumption will then be used as a basis for calibration.

In order de valorise these measured data, consumption addresses were joined with RegBL addresses. This resulted in two things. Firstly, heated area calculated in the Oré tool could be retrieved for each gas delivery address and secondly, heating and DHW energy source could also be retrieved from these same addresses. This last part then allowed to exclude buildings whose gas is not the only energy source, in other words, building whose measure gas consumption would not be representative of it. Specific consumptions average per period is presented in figure 2.

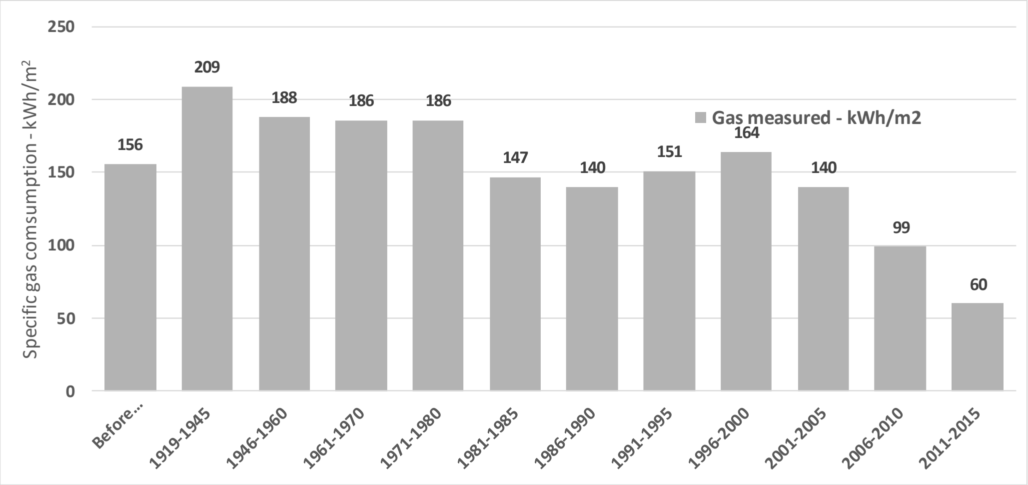


Figure 2 Average measured gas consumption per period

We notice that buildings constructed between 1919 and 1945 consume more than the ones erected before 1919. This can be explained by the fact that new construction methods, such as concrete, appeared at that time. We also notice a second increasing trend around 1996-2000. This could be that buildings from 1996 to 2000 are thermally less well-built than those from 1981 to 1995, or that heated area calculation methods have to be adapted for this period, or finally that gas consumption data are erroneous. However, in the absence of additional information, these are the values which will be used for model calibration parameters.

SIA 380-1 calculation using objective-a

The SIA 380/1 calculation for each buildings is based on the 2.5D geometry and the typologies presented before. This step is realized using the web application Objective-a[18]. The previous data related to the geometry and the typology have to be formatted to be understandable by Objective-A. Currently, the app doesn't allow to save files, but have an import-export functionality for the results in « *json* » (JavaScript Object Notation) format, a language-independent data format.

A software has been developed to achieve the data formatting and the Objective-a use. It first creates a «*json*» file for each building, based on the understable Objective-a data structure. In a second time it calls a web page Objective-a and automatically import data, building per building. This step consists in automatized what a user makes manually on the web page. All the results per building can then be recovered with the «*json*» export. Each file is read and his data automatically pasted in an Excel file. In these data sets, there is the heating need, limit value for heating need and the Hot water need.

Once the thermal needs are calculated, it then estimates the final and primary thermal energy consumption and the CO_2 emissions according to the energy source of each building. Standard technologies and their efficiency value are attributed to each energy source as indicated in the table 8. The estimated consumptions will be used in the model calibration, and compared with measured data.

Energy source *(RegBL)*	**Associated technology**	**Efficiency**	**COP**	**Primary energy ratio *(kWh_{ep}/kWh_{ef})***	**CO_2 emission ratio *($kgCO_2/kwh_{ef}$)***
No data	-	0%	-	-	-
Oil	Boiler	85%	-	1.23	0.297
Coal	Boiler	80%	-	1.67	0.439
Gas	Boiler	90%	-	1.07	0.228
Electricity	Convecteur électrique	93%	-	1.89	0.086
Biomass	Boiler	85%	-	1.21	0.034
Heat pump	Heat pump	-	3	1.89	0.086
Solar thermal	Plan collector	50%	-	1.85	0.039
District heating	Heat exchanger	90%	-	0.869	0.108
Other energy source	-	90%	-	1.07	0.228

Table 8 Energy source properties and associated technologies

The information given in table 8 are based on CREM works[19] for the technology efficiencies powered by oil, electricity and district heating. The ones powered with gas and biomass have been modified in order to be more relevant with the performance's evolution caused by boiler replacement. The COP are drawn from the help of sizing document from energyschweiz[20] and the coal boiler performance arbitrarily fixed. Primary energy and CO_2 emissions ratios comes from KBOB[21], the electricity one consider the electric mix of ESR, and for the other energy sources it has been decided to use the same as gas because of no more information.

Final and primary energy consumption and CO_2 emission are simply calculated.

$$\textit{Final energy consumption} = \frac{energy\ need}{efficiency}$$

$$\textit{Primary energy consumption = final energy consumption x primary energy ratio}$$

$$CO_2\ \textit{emissions = final energy consumption x}\ CO_2\ \textit{emission ratio}$$

Efficiencies and COP are considered as fixed value in the approach.

Model calibration

For each building with available and relevant measured gas consumptions, ORe compare the specific consumptions from his model and the real one. Based on that comparison, a calibration on the model parameters (mainly on the thermal loss coefficient - U values) is realized. It consists in converging ORe results towards real consumptions. This is made per period with near 300 measured gas consumption data. Calibration results are then ventilated on all buildings. The average measured consumption, the estimated before calibration and the after one are represented per period in figure 3.

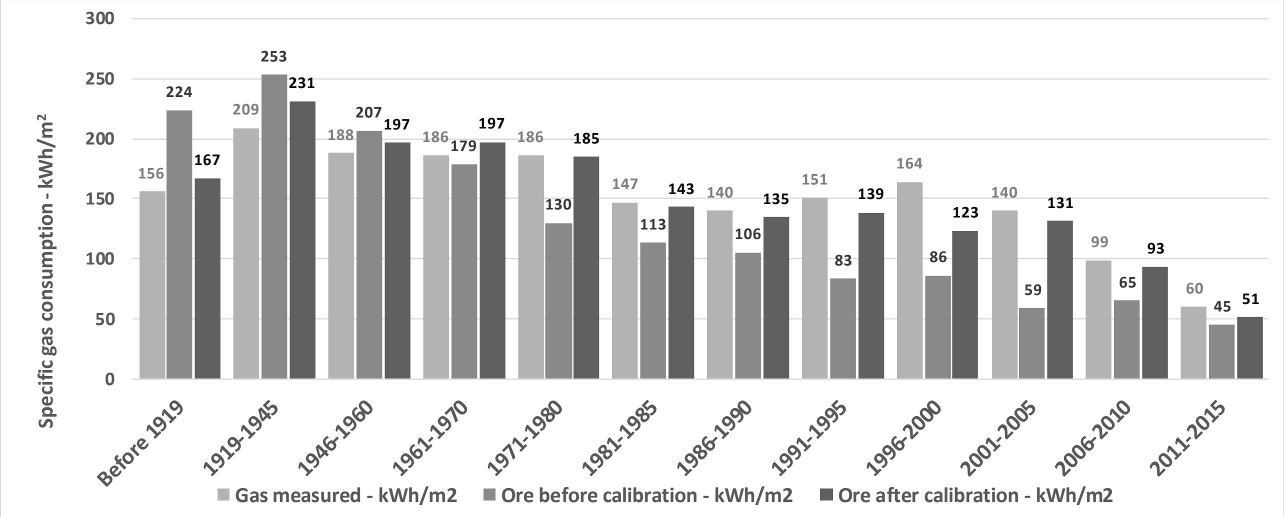


Figure 3 Average gas consumption comparison per period between measured data (orange), Ore estimation before calibrating the model (grey) and after (blue)

The model is calibrated on the thermal loss coefficient because the error distribution of data before calibration were not in adequacy with that provided by the measured data presented in figure 2. Moreover, this error is different for each period, sometimes higher and other times smaller. Considering that conversion technologies have an average lifetime of around twenty years, it results that the middle age of technologies can be approximated as homogenous for each period. For this reason it has been decided to consider that the efficiency is a parameter only linked with the energy source and not with buildings period. For this reason this parameter will not help to correct error distribution. It is important to keep in mind that the calibration is here based on consumptions because of no available data on thermal needs. Yet they are the ones that would provide the rigorous approach to calibrate the model by abstraction of conversion technologies.

The calibration is made by period because this cutting is constrained by data sources: the RegBL.

Once the parameters are calibrated, they are used for thermal calculation of each buildings on the territory. The thermal loss coefficient before and after calibration are given in the table 9.

Thermal loss coefficient - W/(m²·K)	**Initial parameters**			**Calibrated parameters**		
	Floor	Wall	Roof	Floor	Wall	Roof
Before 1919	2.5	1.41	1.6	1.271	1.303	0.556
1919-1945	2.5	1.41	1.6	1.669	1.711	0.730
1946-1960	2.5	1.35	1.6	1.583	1.573	0.739
1961-1970	2.5	1.14	1.6	1.773	1.555	0.887
1971-1980	1.5	0.58	0.8	1.900	1.002	1.037
1981-1985	0.96	0.42	0.54	1.295	0.800	0.819
1986-1990	0.96	0.42	0.54	1.249	0.772	0.790
1991-1995	0.55	0.29	0.35	1.266	0.749	0.801
1996-2000	0.55	0.29	0.35	1.121	0.663	0.709
2001-2005	0.35	0.21	0.28	0.958	0.578	0.677
2006-2010	0.28	0.21	0.28	0.673	0.404	0.481
2011-2015	0.25	0.20	0.18	0.337	0.337	0.337

Table 9 Before and after calibration U value for different periods

Investment and operation costs

Investment costs are calculated for a retrofit at SIA 380/1 standard first and at Minergie in a second time. Investment costs are based on the CostDBCREM that is composed by regression curve extracted from insulation work quotes. The data that it contains and the regressions are given by component as wall, floor, roof and window and for the SIA 380/1 retrofit standard. Their presentation will be the subject of another paper. Because of the lack of detailed information on real construction methods for each building, their investment cost is indicated for a complete thermal envelop insulation. The figure 4 shows an example of regression curve for a wall.

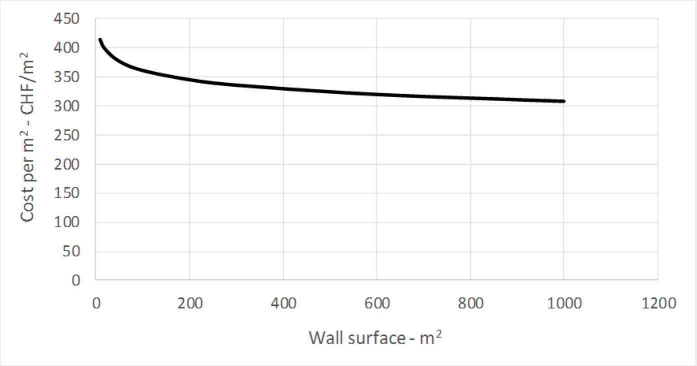


Figure 4 Wall cost regression curve

Knowing the wall surface as calculated with previous methodology (2.5D geometry), the investment cost is calculated as:

Retrofit cost at SIA 380/1 standard = surface x specific retrofit cost per m²

Investment cost at Minergie standard is considered 10% more expansive than the SIA 380/1.

For operating costs, they are considered in the method as current costs[22], they are not affected by an inflation rate and are calculated on a year. Those costs are based on the energy consumption for heating and hot water, estimated for each building, and the price of energy source used. Table 10 provided the price considered in this study.

Energy source	**CHF/kWh**
No data	0
Oil	0.07[23]
Coal	0.11
Gas	0.06[24]
Electricity	0.16[25]
Biomass	0.07
Heat Pump	0.16
Solar thermal	0
District heating	0.13
Other energy source	0

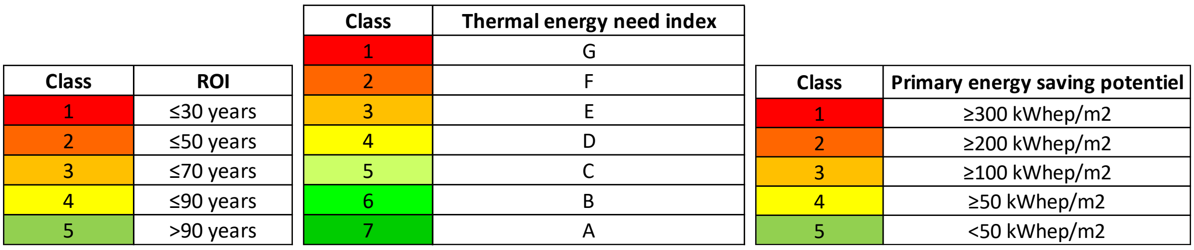
Table 10 Energy prices used in the case study

Finally, operating costs are calculated as:

Operation cost = thermal energy consumption x energy price

Indicators and territorial strategy

Based on all these data, indicators are defined to facilitate the development of retrofit strategies across a territory. For this, all the indicators are calculated for each building and a colour is assigned according to rank. Some indicators and associated classes are shown in Figure 5.



Class	ROI
1	≤30 years
2	≤50 years
3	≤70 years
4	≤90 years
5	>90 years

Class	Thermal energy need index
1	G
2	F
3	E
4	D
5	C
6	B
7	A

Class	Primary energy saving potentiel
1	≥300 kWhep/m2
2	≥200 kWhep/m2
3	≥100 kWhep/m2
4	≥50 kWhep/m2
5	<50 kWhep/m2

Figure 5 Classes use to categorised ROI, thermal energy need index and primary energy saving potential

Calculation methodology is as:

$$ROI = \frac{Refurbishment\ cost}{heating\ bill\ before\ refurbishment - heating\ bill\ after\ refurbishment}$$

$$Primary\ energy\ saving\ potential = \frac{Primary\ energy\ consumption}{heated\ area}$$

Finally the normalized index of heating need is defined according to the SIA 2031 Chapter 5.4. The scales of different indicators are alterable by the user which allows to vary them according to the influence that one wishes to give to each indicator.

3. Results

All data that could identify a single consumer or an individual building is modified to respect the Swiss data protecting laws. Real data is used in all aggregated figures. Table 11 provides an overview of the individual output for each building calculated through the presented methodology. Buildings are georeferenced therefore the results can be shown on a map as well.

Output calculated	Unit	Output calculated	Unit
Heated area	m^2	Current heating energy need	MJ
Thermal envelop / Heated area	-	SIA 380/1 heating energy need	MJ
Floor surface	m^2	Minergie heating energy need	MJ
Roof surface	m^2	Hot water consumption	kWh
Wall surface	m^2	Current heating consumption	kWh
Window surface	m^2	SIA 380/1 heating consumption	kWh
Heating need	MJ/m^2	Minergie heating consumption	kWh
Limit value for heating needs	MJ/m^2	Thermal energy consumption	kWh
Limit value for Minergie heating needs	MJ/m^2	Current heating energy bill	CHF
Hot water need	MJ/m^2	SIA 380/1 heating energy bill	CHF
Investment at SIA Standard - Floor	CHF	Minergie heating energy bill	CHF
Investment at SIA Standard - Roof	CHF	Money saved with SIA 380-1 refurbishment	CHF/an
Investment at SIA Standard - Wall	CHF	Money saved with Minergie refurbishment	CHF/an
Investment at SIA Standard - Window	CHF	Current primary energy	kWh_ep
Investment at SIA Standard - TOTAL	CHF	SIA 380/1 primary energy	kWh_ep
Investment at Minergie - Floor	CHF	Minergie primary energy	kWh_ep
Investment at Minergie - Roof	CHF	Current CO_2 emissions	kg_CO2
Investment at Minergie - Wall	CHF	SIA 380/1 CO_2 emissions	kg_CO2
Investment at Minergie - Window	CHF	Minergie CO_2 emissions	kg_CO2
Investment at Minergie - TOTAL	CHF	Investment/energy saved indicator	CHF/kWh
Heating energy need class	-	Return on investment indicator	Years
		Primary energy saved indicator	$kWhep/m^2$
		CO_2 emissions saved indicator	$kgCO2/m^2$

Table 11 Output given by the tool per building

Figure 6 shows the overall heat demand for each building categorized in construction periods. Compared to the territorial energy planning method, which provides one mean value per construction period, the presented methodology shows differences within the same period of almost a factor 3.5 between the lowest and the highest consumption.

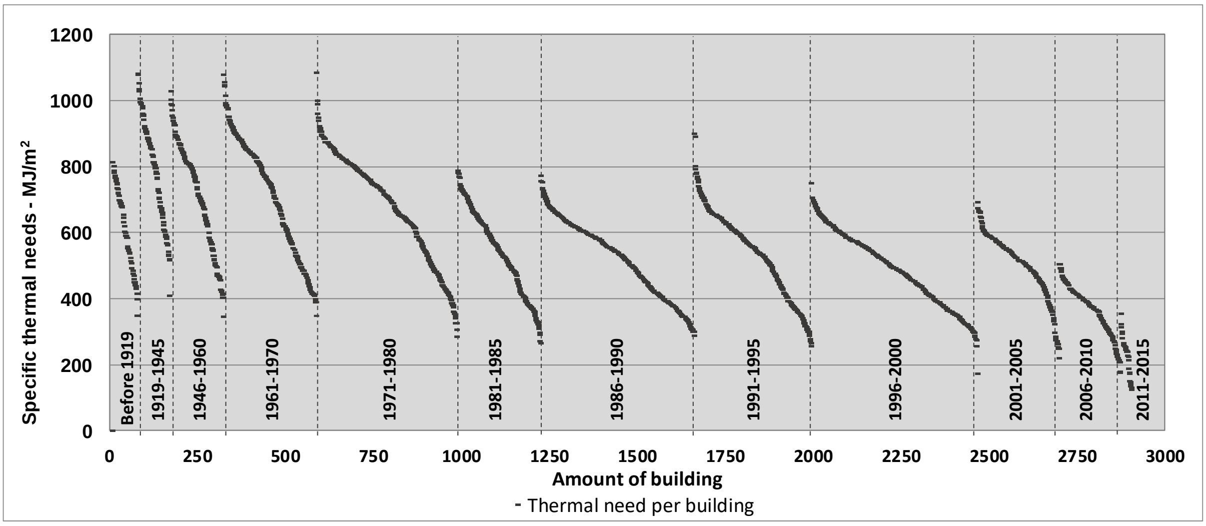
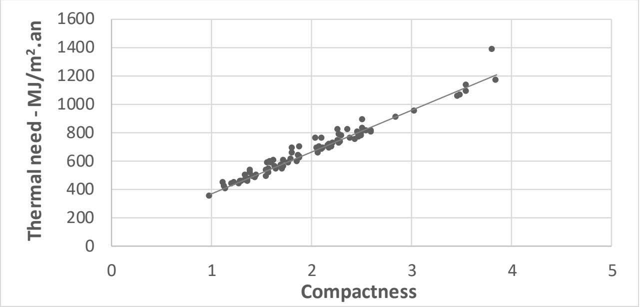


Figure 6 Thermal energy need classified in a descendig order per building and for each period

The fin granularity of the results per building can easily be applied to a whole territory or over whole Switzerland allowing to develop a bottom-up strategy for a given area. The different input values considering the specificity of each building such as thermal bridges or the different compactness's as well as its exposition to solar irradiance lead to a wide spread in output values for the heat energy demand. The compactness has a linear correlation to the overall heat demand (Figure 7) and to the overall investment costs for a retrofit (Figure 8).



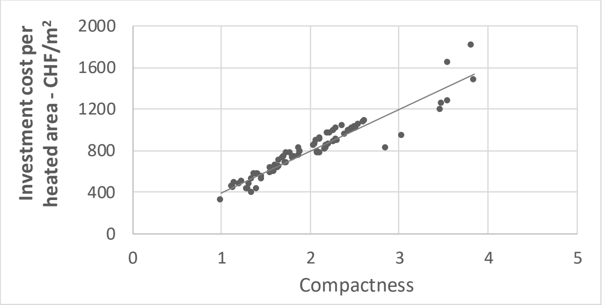
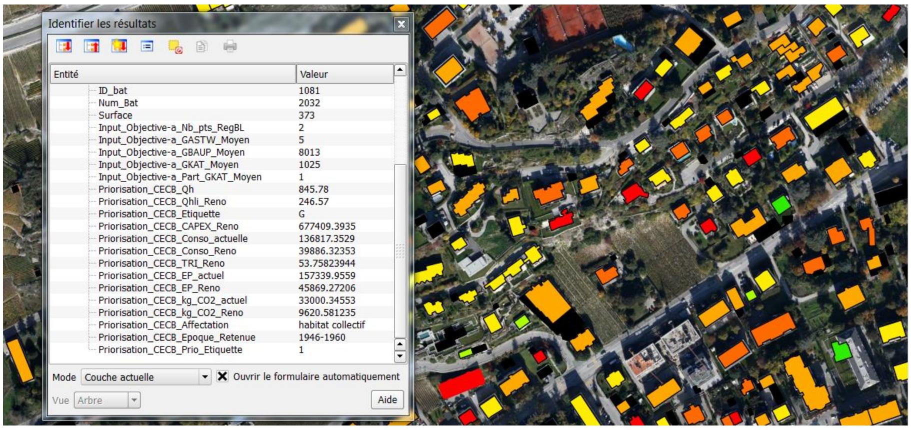


Figure7 Thermal needs as a function of the compactness (Buildings before 1919)

Figure 8 Investment costs as a function of the compactness (Buildings before 1919)

Other key indicators such as the thermal energy need index allow to identify concrete opportunities to realize for energy savings (Figure 9).



Entité	Valeur
ID_bat	1081
Num_Bat	2032
Surface	373
Input_Objective-a_Nb_pts_RegBL	2
Input_Objective-a_GASTW_Moyen	5
Input_Objective-a_GBAUP_Moyen	8013
Input_Objective-a_GKAT_Moyen	1025
Input_Objective-a_Part_GKAT_Moyen	1
Priorisation_CECB_Qh	845.78
Priorisation_CECB_Qhli_Reno	246.57
Priorisation_CECB_Etiquette	G
Priorisation_CECB_CAPEX_Reno	677409.3935
Priorisation_CECB_Conso_actuelle	136817.3529
Priorisation_CECB_Conso_Reno	39886.32353
Priorisation_CECB_TRI_Reno	53.75823944
Priorisation_CECB_EP_actuel	157339.9559
Priorisation_CECB_EP_Reno	45869.27206
Priorisation_CECB_kg_CO2_actuel	33000.34553
Priorisation_CECB_kg_CO2_Reno	9620.581235
Priorisation_CECB_Affectation	habitat collectif
Priorisation_CECB_Epoque_Retenue	1946-1960
Priorisation_CECB_Prio_Etiquette	1

Mode: Couche actuelle
☒ Ouvrir le formulaire automatiquement
Vue: Arbre

Figure 9 Thermal energy need index based on real data modified for publication (Legend: red = high priority, big return of investment to green= low priority, no return of investment)

With spatialized Ore results, it is possible to identify buildings with the highest energy need index. They are represented in red on the figure 9 and they are composed by building with different periods with approximately 10% of buildings with a G index. Their repartition is given in figure 10. Any other information estimated per building is spatialized and can be retrieved on the figure 9 with the information for a building on the left of the figure.

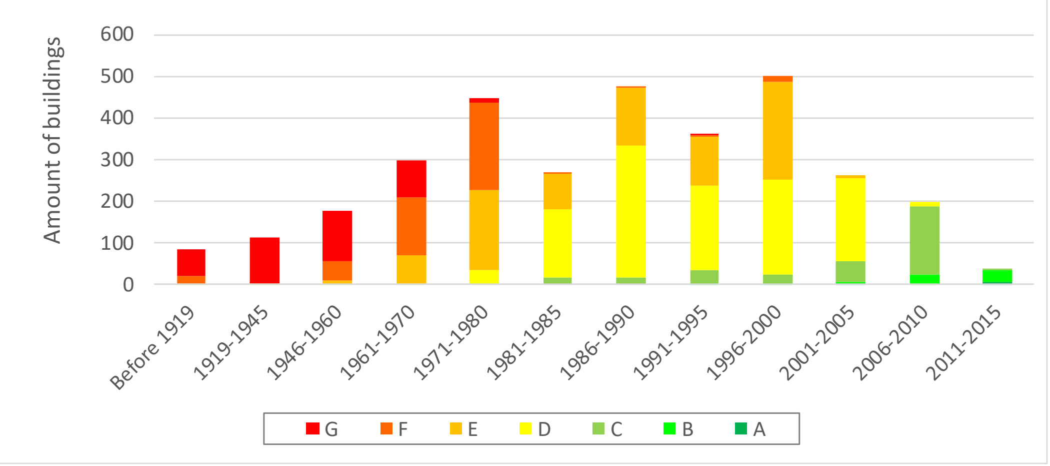


Figure 10 Amount of building per thermal energy index for each period

4. Discussion

Compared to territory wide approaches discussing in the literature, ORé has the following advantages:

1. ORé provides a heating demand calculation that is the most precise calculation possible before a CECB certification which requires an on-site visit;
2. Approximation of the surface size of the thermal envelop with an estimation of the retrofitting costs;
3. Estimation of the thermal energy consumption and the energy bill;
4. Calibration of construction parameters for the simulation based on the energy bills and the energy consumption measurements from over 300 buildings;
5. Establishing a ranking based on the three indicators for decision support for prioritizing retrofitting actions;
6. Replicability thanks to the usage of only Swiss wide available data sets

For a first deployment of the method, the results are encouraging for further tests in other Swiss regions to ensure not only a replicability but test whether individual regions need different construction input parameters.

All studies using data sets that cannot be validated during the project and where neither Meta data characterizing the quality of the data sets exist heavily depend on the quality of it. In particular, the number of floors for a given building can vary leading to a different reference heating surface and therefore to a different heating requirement.

The simplifications made during the ORé model can potentially further influence the results. The heat requirements do not consider potential user misbehaviour. Further the efficiencies of different heating systems are considered to be constant in absence of measurements. Additionally buildings before 1945 might still have and use a wood furnace: the energy bill might therefore be too low, part of the energy might not be counted because the local utility does not have access to this information.

Resuming, the study is based on data sets from federal, cantonal and community level. The provided information could be more precise in terms of content and include data quality indicators. In the absence of very precise data or data quality indicators, a global sensitivity analysis should performed to classify the input parameters by influence. Such a classification can then be used to concentrate data collection efforts.

5. Perspectives

The application of ORé is interested for different actors on a given territory. ORé has the advantage of relying only on public information that especially communities can access for their energy planning. Communities could thanks to ORé:

1. Identify the retrofitting potential on their territory;
2. Define a strategy based on this potential aiming at activating it through direct communication and better suited retrofitting programs
3. Being able to quantify the energy savings and estimate the required investment
4. Define neighbourhoods to be retrofitted and include them into urban rehabilitation projects.

At the cantonal or federal level, subsides for retrofitting could be linked to the results of ORé increasing the impact of the subsidies. A ranking could be made requiring to reach a certain energy savings instead of scattered subsidies. A legal verification might be required before implementation.

Private enterprises, especially in the construction industry, could, based on publicly available ORé results, propose their services in order to reach defined energy savings. Currently the data protection laws do not allow enterprises to obtain the required data for the use of ORé. A business model might be to place the community in the middle that publishes the ranking of all buildings without specifying their address neither the building's coordinates. By only providing general ranges for building parameters such as between one and two floors with a heated surface between 50 to 200 m^2, a company could make an offer that the community transfers to the owner. In combination with local banks that provide lower interest rates for buildings with higher retrofitting priorities, the interest in retrofits could be increased.

An open data initiative for energy related data might also increase the chance for more retrofits.

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