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Establishing building environmental targets to implement a low carbon objective at the district level: methodology and case study

Marine Fouquet[1], Thomas Jusselme[1] and Jérémie Vareilles[2]

[1] COMBO Solutions, Lyon, France;
[2] Milieu Studio, Lyon, France

Abstract: To face climate change, greenhouse gas (GHG) emission targets are specified into national policies. In France, the objective is to divide by 4 (Factor 4) the *GHG* emissions by 2050 comparing to 1990. The built environment, as a main contributor, is targeted by these policies: the future 2020 French regulation will set up *GHG* emissions targets for the building life cycle. However, the implementation of this regulation and its labels into real-estate development is challenging because it is uncorrelated to factor 4, architectural and technical constraints due to these labels are yet unknown and targets are defined at building scale and not at the district scale. This paper offers some answers to this challenges based on a case study from a real estate developer who wanted to implement a 2025 objective to a new district in Lyon, France. It was done thanks to a review on Factor 4 and labels' history, on calculation of *GHG* emissions from 1990s building and objectives for 2050 and illustration of labels' constraints. Finally, objectives were allocated at building scale to meet the overall district ambition.

Keywords: Factor 4, labels, low carbon targets, district

Introduction

In the European Union, the construction sector is responsible for 40 % of the energy consumption and for 36 % of the greenhouse gas (GHG) emissions (European Commission, 2017). In 2012 in France, 44.5% of the final energy consumption was due to this sector (SOeS, 2013). Thus, several regulations has been enforced at the European level and at country scales to lower building energy consumption and environmental impacts (Charlier and Risch, 2012). In France, the objective is to divide by 4 (Factor 4) the *GHG* emissions by 2050 comparing to 1990 (MEDDE, 2013). To that end, a new regulation will be implemented in 2020 to specifically reduce *GHG* emissions during life cycle of new buildings (Boyer and Cleret, 2014). Meanwhile, two labels are already available and prefigure the future 2020 French regulation: BBCA (Low Carbon Building label) (BBCA Association, 2016) and E+/C- (Plus energy and low carbon building label) (MEEM, 2016). However, the implementation of these labels into real estate development project faces many challenges:

1. New labels are uncorrelated with the Factor 4 objective, which decreases their communication impact
2. Architectural and technical constraints from labels' targets are not known yet
3. Label's targets are defined at building scale and not at the district scale

This paper suggests answers based on a case study from a real estate developer who wanted to implement a 2025 objective (regarding Factor 4 for 2050) to a district in Lyon, France (11 buildings, around 32 000 m²).

First, this paper reviews how Factor 4 was integrated in regulation and labels, how the latest were built and the existing tools to evaluate performance at district level. Then, the amount of *GHG* emissions of buildings in 1990 and the objective for 2050 are determined using a linear regression. This helps to understand to which year, according to Factor 4 objective in 2050, the labels are corresponding. Similar projects are used to illustrate the architectural and technical constraints of the labels. Finally, objectives are iteratively allocated at the building scale to respect the district overall ambition.

State of the art

The concept of Factor 4 represents the goal of reducing by 75 % *GHG* emissions by 2050 compared to 1990. It represents the reduction that France should target to keep the mean emission per habitant and per year below 0.6 t_{eq} C. This is to meet the objective of a maximal concentration of CO_2 of 450 ppm and limit the average temperature rise to 2°C (Houghton et al., 2001).

Politics around Factor 4 in buildings mainly focus on reducing energy consumption during the use phase (Villot, 2012). However, as energy carriers do not emit the same amount of *GHG* emissions, this strategy does not permit to reduce efficiently the *GHG* emissions. Moreover, a shift of impacts between use stage and construction stage is observed as the decrease of impacts due to heat requirement (thanks to better insulation) is higher than the increase of impacts due to change in materials or construction technique (Blengini and Di Carlo, 2010) Thus, a new regulation and labels (BBCA and E+/C-) are implemented, which directly evaluate the amount of *GHG* emissions during the building life cycle.

In both labels, two different thresholds are imposed. A first one for *GHG* emitted by the building components and equipment (embodied emissions) and a second one for the overall *GHG* emitted along the overall building life cycle. Moreover, different performance levels are available for each labels which are summed up in Table 1 for offices and in Table 2 for apartment buildings (BBCA Association, 2016; MEEM, 2016).

The objective of the BBCA label is to reduce significantly the *GHG* emissions due to the construction products and equipment while the E+/C- label has more a pedagogic objective in order to encourage the Architecture, Engineering and Construction (AEC) industry to evaluate the *GHG* emissions emitted by new buildings.

Table 1: Levels and corresponding threshold for office buildings for BBCA and E+/C- labels

BBCA label		
Levels	Construction threshold [kg eq CO_2/(m².yr)]	Global threshold [kg eq CO_2/(m².yr)]
BBCA (Standard)	11.66	17.66
BBCA Performant	10.06	15.06
BBCA Excellent	9.06	13.06
E+/C- label		
Levels	Construction threshold [kg eq CO_2/(m².yr)]	Global threshold [kg eq CO_2/(m².yr)]
Carbone 1	21	30
Carbone 2	18	19.6

Table 2: Levels and corresponding threshold for apartment buildings for BBCA and E+/C- labels

BBCA label		
Levels	Construction threshold [kg eq CO_2/(m².yr)]	Global threshold [kg eq CO_2/(m².yr)]
BBCA (Standard)	9.08	25.08
BBCA Performant	7.48	22.48
BBCA Excellent	6.78	18.48
E+/C- label		
Levels	Construction threshold [kg eq CO_2/(m².yr)]	Global threshold [kg eq CO_2/(m².yr)]
Carbone 1	16	31
Carbone 2	15	20

Regarding district performances, tools already exist, for instance Sméo (Lausanne and Canton de Vaud, 2014) or the calculation site sheets from (2000 W Society, 2015). However, they require detailed building information which are not necessarily available at urban early design stages. Furthermore, they cannot set up specific *GHG* emissions targets to be included in the building design briefs.

Methodology

Calculation of GHG emissions from buildings in France in 1990 and objectives in 2050

To our knowledge, the objective Factor 4 was not translate into objective for new building expressed in equivalent kilogram of CO_2 emissions per square meter and no study were found about the *GHG* emissions of buildings built in 1990. Nevertheless, the HQE Performance project study the environmental impacts of 24 offices, 17 residential buildings and 22 individual houses were presented (Lebert et al., 2013). This project aimed to identify the biggest impacts' contributor in buildings and the studied buildings are representative for performant buildings in France in 2012. The average impacts from office buildings from HQE Performance are 20.6 kg eq CO_2/(m².yr) and 22.7 kg eq CO_2/(m².yr) for apartment buildings.

Based on the results from HQE Performance, *GHG* emissions from buildings from 1990 are determined for office buildings and apartment buildings considering the fact that energy regulations before 2020 only applied to the use phase and more specifically on energy consumption of heating, cooling, hot water production, ventilation and lighting, also commonly called "regulated uses". In 2012, the objective of energy consumption for this regulated uses were 50 kWh $_{\text{Primary Energy}}$[1]/(m².yr) for office buildings and 57.5 kWh $_{PE}$/(m².yr) for apartment buildings (JORF, 2013) whereas they were around 380 kWh/(m2.yr) for office buildings in 1990 (Manexi, 2012) and around 173 kWh/(m2.yr) for apartment buildings (Shanthirabalan and Rochard, 2014). Moreover, we also assumed that the impacts of construction or other energy uses did not change. Then, these impacts are summed and add to the one of the "regulated uses" from 2012 multiplied by the ratio for energy consumption for this regulated uses between 1990 and 2012. Overall, impacts from 1990s building might be underestimated. Finally, the impacts calculated from 1990s office buildings are 40.7 kg eq CO_2/(m².yr) and 40.6 kg eq CO_2/(m².yr) for apartment buildings.

Then, we divided by four these results to meet the objectives for 2050: 10.18 kg eq CO_2/(m².yr) for office buildings and 10.15 kg eq CO_2/(m².yr) for apartment buildings. Previous work from Switzerland found a target of 12.3 kg eq CO_2/(m².yr) for an office building in 2050

[1] Primary Energy (PE)

(Hoxha et al., 2016). The results cannot really be compared as the context is different (e.g. LCA database) but the order of magnitude is validated.

Labels and corresponding year according to Factor 4 objective

We used linear regression to position the labels' global thresholds according to Factor 4 objective. Figure 1and Figure 2 show the evolution of *GHG* emissions, respectively for office buildings and apartment buildings, which should be followed to reach Factor 4 for new construction in 2050 and the corresponding year for the labels.

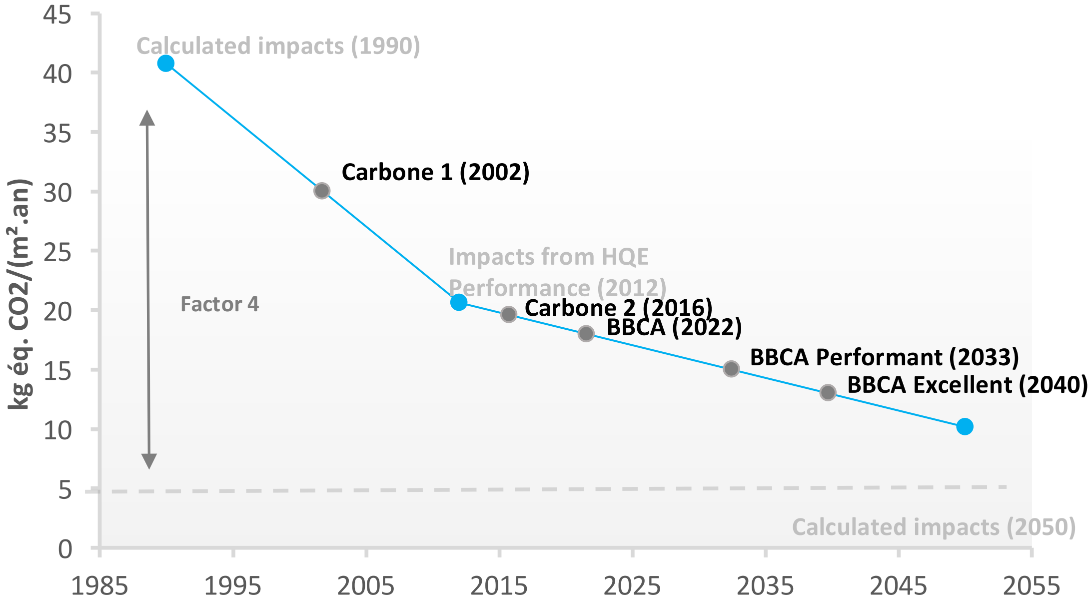

Figure 1: Objectives and labels for office buildings in France

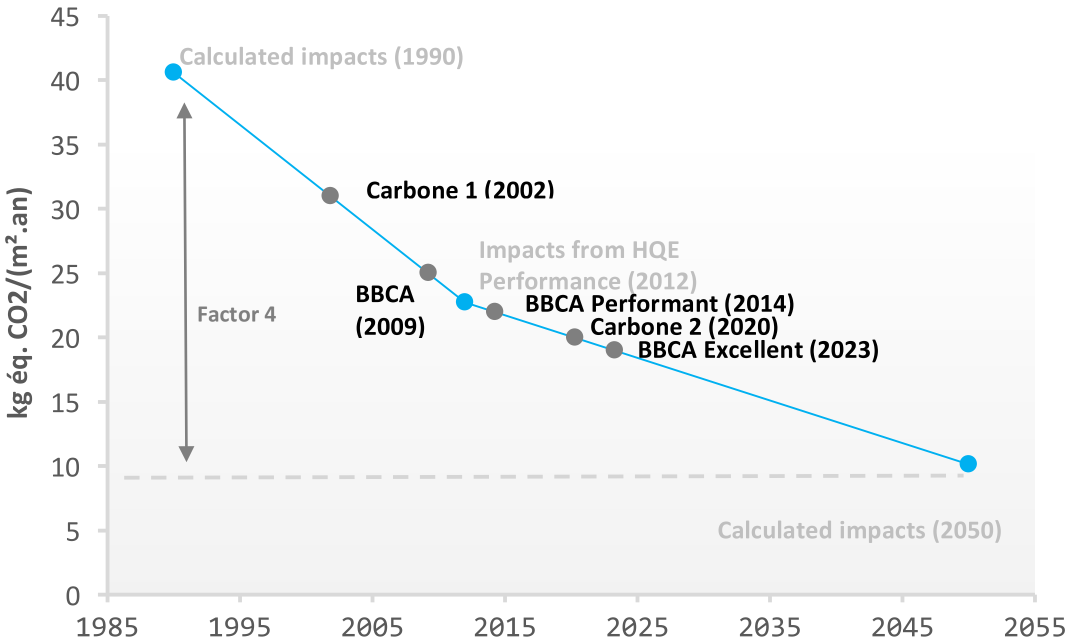

Figure 2: Objectives and labels for apartment buildings in France

For both building functions, improvements through regulations on energy consumption have decreased significantly *GHG* emissions from buildings. Now, the slope is gentlest but the targets for Factor 4 are still ambitious. The different thresholds from the labels are spread and allows the *AEC* industry to choose which performance they want to aim though the labels.

Some levels do not even reach today's objective (Carbone 1 & 2 for offices or Carbone 1, BBCA and BBCA Performant for housing). Moreover, labels are more ambitious for offices, 2040 is reached while for apartment building the best year reached is 2023.

Illustration of architectural and technical constraints of the labels

In order to illustrate the technical and architectural constraints induced by the labels, we chose two performant projects, an office building and an apartment building from the same region as the district and built in the past two years. For both projects, detailed information of the construction products, equipment and quantity used were available, even for different construction types for the apartment building. We did not consider underground parking as the district do not have one. As shown by (Lebert et al., 2013), the biggest impacts' contributor in office buildings are the construction products followed by the energy use during the building's life whereas for apartment building, the biggest impacts' contributors are the same but in the opposite order. Therefore, we choose to study different frame structure and energy systems for each project depending on the questions from the real estate developer and choices made by designers. Elodie software (CSTB, 2015) is used to perform the LCAs and the data describing the LCA impacts of construction products are taken for all the scenarios from the INIES database ("INIES, The French EPD Database for building products," 2004).

Our first study is an office building of 8 storages and a total surface of 8 799 m² built in Lyon and compliant with the current French energy regulation : maximum consumption for "regulated uses" of 66 $kWh_{PE}/(m^2.year)$ (JORF, 2013). We evaluated three frame structures and four energy strategies as summed up in Table 3. For each energy strategy tested, the operational energy for the use phase is evaluated annually thanks to French thermal regulation (JORF, 2013). Numerical results for all construction and energy types for the building can be found in Table 3.

Table 3: Embodied and total *GHG* emissions [kg eq. $CO_2/(m^2.yr)$] for an office building for different frame structures and energy systems

	A. Reinforced concrete	**B. Wood facade and reinforced concrete structure**	**C. Wood façade, horizontal reinforced concrete structure and wood-concrete flooring**
1. Water/air heat pump	Embodied : 13.1 Total : 15.6	Embodied : 12.9 Total : 15.4	Embodied : 11.3 Total : 13.8
2. Water/air heat pump without cooling	Embodied : 13.1 Total : 15.3	Embodied : 12.9 Total : 15.1	Embodied : 11.3 Total : 13.5
3. Water/air heat pump and PV panels	Embodied : 13.1 Total : 15.1	Embodied : 12.9 Total : 14.9	Embodied : 11.3 Total : 13.3
4. Gas boiler without cooling	Embodied : 13.1 Total : 19.8	Embodied : 12.9 Total : 19.6	Embodied : 11.3 Total : 18

Results suggest that the choice of materials has an influence on the impact of climate change but not as significant as the energy carrier. However, the impacts for the construction products and equipment are the main contributor of the total *GHG* emissions. Furthermore, compared to the threshold presented in Table 1, Carbone 1 and Carbone 2 are reached easily except the case A+4 (reinforced concrete with a gas boiler without cooling). For the BBCA standard level, lowest GHG emissions than the global threshold are reached in all cases except for cases A+4, B+4 and C+4. However, the thresholds for construction is exceeded for all cases except C+1, C+2 and C+4. Moreover, for cases C+1, C+2 and C+4, the global threshold for “BBCA Performant” is reached but not the one for construction. Regarding our work on Factor 4, objective years reached vary between 2015 (Case A-4) and 2039 (Case C-3).

The second building studied is an apartment building of 7 storages (21 apartments) and a total surface of 1 993 m² built in Ferney-Voltaire and compliant with the current French energy regulation : maximum consumption for “regulated uses” of 63 $kWh_{PE}/(m^2.year)$ (JORF, 2013). Three different frame structures and three different choices for energy were also assessed as illustrated by Table 4. Numerical results for all construction and energy types for the building are summed up in Table 4.

Table 4: Embodied and total *GHG* emissions [kg eq. $CO_2/(m^2.yr)$] for an apartments building for different frame structures and energy systems

	A. Reinforced concrete	**B. Wood**	**C. CLT**
1. 30 % wood boiler/70 % gas boiler	Embodied : 11.4 Total : 21.9	Embodied : 10.9 Total : 21.4	Embodied : 11.2 Total : 21.7
2. 70 % wood boiler/ 30 %gas boiler	Embodied : 11.4 Total : 16.6	Embodied : 10.9 Total : 16.1	Embodied : 11.2 Total : 16.4
3. Heat network	Embodied : 11.4 Total : 19.8	Embodied : 10.9 Total : 19.3	Embodied : 11.2 Total : 19.6

As for the office building, the choice of the energy system seems to be more sensitive than the frame structure but the impacts for the construction products and equipment are the main contributor of the total GHG emissions. Regarding the thresholds from Table 2, Carbone 1 is reached in every scenario while Carbone 2 cannot be reached with the first energy system. For BBCA and “BCCA Performant”, for all cases, lowest GHG emissions than the global threshold are reached whereas the maximum construction threshold is overtook. The same conclusion is valid for cases A+2, B+2 and C+2 and level “BBCA Excellent”: the overall GHG emissions are lower but emissions for construction are higher than the threshold from the label. Regarding Factor 4 objective, the years reached vary between 2015 (Case A+1) and 2032 (Cases B-2 and C-2).

District case study: iterative allocation of objectives at building scale

For each building of the district (housing or offices) based on their function and their size and on average *GHG* emissions from the HQE Performance project, we calculate the weight of each building in the impact of the district. Some buildings are a mix of different functions so each part of the building is considered separately. The 2012 average performance of the district, based on HQE Performance, should be 692 t eq. CO_2/year. The target of 2025 represents a reduction of 19 % of *GHG* emissions compared to 2012. To reach this objective, iterative targets are set for each building depending on their weight in the impact of the district, the specificity of the program and the architectural ambition. Results are summed up in Table 5 as well as final targeted year for each building and the labels finally reached

Table 5: District building functions, sizes and GHG emissions weights in the district performance based on average from HQE Performance and final targeted year and corresponding label

	Surface [m²]	Storages	Average from HQE Perf. [kg eq. CO_2/(m².yr)]	Total impact [t eq. CO_2/(m².yr)]	Weight in impact of the district (%)	Final targeted year	Label
A – Social housing	1529	4	22.7	35	5 %	2019	BBCA Performant
B- Housing	5113	16	22.7	116	17 %	2032	BBCA Excellent
B- Offices	850	16	20.6	18	3 %	2039	BBCA Performant
C - Housing	1061	3	22.7	24	3 %	2019	BBCA Performant
D – Social housing	2019	6	22.7	48	7 %	2019	BBCA Performant
E - Housing	3184	15	22.7	72	10 %	2032	BBCA Excellent
E - Offices	2374	15	20.6	49	7 %	2039	BBCA Performant
F - Offices	756	3	20.6	16	2 %	2019	Carbone 2
G - Offices	3464	6	20.6	71	10 %	2022	BBCA (Standard)
H – Social housing	2120	6	22.7	48	7 %	2019	BBCA Performant
I - Offices	1200	2	20.6	25	3 %	2019	Carbone 2
J - Offices	5048	8	20.6	104	15 %	2022	BBCA (Standard)
K - Housing	1759	5	22.7	40	6 %	2019	BBCA Performant
K - Offices	1284	5	20.6	26	4 %	2019	Carbone 2

Conclusions

This paper shows how to implement low carbon objective at district level based on Factor 4 objective with targets for buildings depending on their characteristics (types, area and number of storeys). First, the amount of *GHG* emissions of 1990s buildings were calculated: 40.7 kg eq CO_2/(m².yr) for offices and 40.6 kg eq CO_2/(m².yr) for apartment buildings as well as the objective for 2050: 10.18 kg eq CO_2/(m².yr) for office buildings and 10.15 kg eq CO_2/(m².yr) for apartment buildings. Then, existing labels were positioned according to the Factor 4 objective. Carbone 1 & 2 for offices and Carbone 1, BBCA and BBCA Performant for apartment are late as they do not even reached the current objective. Regarding architectural and technical constraints of the labels, it seems that the energy choice is most sensitive than the frame structure. Finally allocation of objectives at the building scale to respect the objective at the district scale was done with an iterative method depending on the weight of each building in the impact of the district, program's specificity and the architectural ambition.

Further researches will be needed to refine the method and include more characteristics as roof solar potential, compactness and mobility connections for allocation of objective at building scale. Moreover, the development of low carbon buildings will lead to new references which could be used to transform year objectives into example of architectural and energy strategy.

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