Potential in GHG emissions abatement through an effective energy policy: the Reggio Emilia case

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Abstract

Enhancing buildings' energy performance is one of the key actions that should be pursued to achieve the Kyoto target. In Italy, energy requirements of the residential sector, in fact, represent about forty percent of the overall energy balance. The majority of this consumption could be avoided by simply providing strict building-design guidelines and promoting energy efficiency in existing buildings through proper energy retrofit interventions. The achievement of higher standards for households' heating and cooling has the highest potential to lower the related primary energy consumptions and green house gases (GHG) emissions. This article focuses on an original energy policy that has been issued in the municipality of Reggio Emilia, Italy, called *riduCO2*. Several reasons make this project innovative. First, the certification method has been processed through and verified by a quality international agency; secondly the procedure is assisting financial-incentive policies both on mandatory (European Directive 2002/91/CE) and voluntary basis (Municipality Protocol ECOABITA); finally it allows us to obtain eligible credits for avoided emissions that can be negotiated on the CO_2 exchange market. Acknowledging the amount of actions that are normally scheduled in the municipality throughout a year the benefit has been evaluated, in terms of environmental improvement, that should descend from *riduCO2* protocol, projecting their trend in future years up to 2020 as well. The entire procedure has been developed in accordance with the parameters given by UNFCCC for these kinds of analyses.

Keywords: households' energetics; GHG abatement; support energy policies.

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1 Introduction

The Municipality (Comune) of Reggio Emilia has recently adopted a voluntary building energy-consumption certification method called ECOABITA®, aiming to promote energy efficiency in buildings over its jurisdiction.

The project ECOABITA integrates the national legislation, on a voluntary basis, with further requirements acknowledging the conclusions given by a previous Agreement Protocol [1] stipulated by local public and private Subjects. Specifically, an ECOABITA certified building requires, for winter heating, not to exceed the 70% of the limit value (related to each specific building typology) calculated in accordance to the Legislative Decrees on building energy efficiency (192/05 and 311/06 [2]). This article reports and explains methodologies and objectives of the project riduCO2, built under the ECOABITA framework.

The expected Carbon Dioxide reduction, achieved thanks to the improved energy efficiency in buildings, allowed by the application of ECOABITA rules, is assessed with reference to a set of quantitative and qualitative performance criteria. The main scope of riduCO2 project is to make ECOABITA procedure compliant to the requirements of the regulation UNI ISO 14064-2 [3] with regard to the methodology of quantification, monitoring and reporting the reduction of CO_2 emissions, through a proper procedure.

Hopefully, this protocol will allow us to verify the effective GHG emission reduction possibly attaining CO_2 credits on the energy stock market.

2 Methodology and definition of the baseline

In reference to the mitigation of carbon dioxide emission from building, at a global scale, Levine et al. [4], highlighted through a forecast over the period 1990-2020, there is a risk, with no strict regulation, that CO_2 emissions will nearly double. Lee and Yik [5] state the importance of such norms and regulations. Their study underlines the importance of promoting energy efficiency in buildings on a voluntary basis. Milou Beerepoot and Niels Beerepoot [6] conducted an analysis evaluating the necessity, as a next step of improvement of the governmental regulation on energy efficiency, of promoting innovation in the building technology manufacturing sector, toward the objective of a strong reduction of CO_2 emission. As preliminary survey over the territory of the entire region Emilia Romagna, the 2007 report of Repro [7], a project conducted within the IEE framework by Regione Emilia Romagna with the partnership of ECUBA, is a relevant database of energetic assessment to start from.

In order to assess the effectiveness of such an energy policy, estimating the expected energy and environmental benefits, it was required to depict the state-of-the-art scenario characterizing the city. A deep survey of the territory has been hence pursued with the aim of identifying this reference scenario. At a second stage, the main CHP thermal-electric plants, which provide electricity and heating to the city net, had to be investigated by developing both an energetic and exergetic analysis finally outlining the energetic and emission profile of the city.

The Municipality of Reggio Emilia, together with local energy providers have completed, in April 2007, a survey over the household in the municipal territory, especially focusing on the energy efficiency of their envelopes. The results of these audits are presented in two documents: the first reports statistical data on local buildings, the second evaluates energy consumption for heating and domestic hot water of a sample of 1400 houses and buildings connected to the net of district heating. The findings of the previous analysis, even if affected by approximation coming from the heterogeneous sample, give a first reference value of 170 kWh/m^2 year as the average thermal energy demand associated to indoor heating.

A similar analysis, even if based on the survey of a smaller group of buildings, had already been conducted in 2006 by the Municipality of Reggio Emilia in relation to the upcoming modification to the building code of the Municipality. In that case, it had been surveyed the energy consumption for heating supply of 120 houses, built in the municipal area, more recently (from 1991 on) than the many case-studies mentioned above. The results, divided by building typology, identify an average energy consumption value, related to heating supply, around 130 kWh/m^2 year. Personal communication from Enìa [8], the main local energy provider, gives fundamental information about the energy balance of the residential sector. The Enìa database provides the amount of natural gas consumptions related to domestic uses (*e.g.* cooking and sanitary water), domestic indoor heating, office indoor heating and district heating for the period 2001-2006. A study [9] preliminary to the Official Municipal energy plan [10], confirms the previous data, also extending the database to the 1995-2000 period. Other important references used in the analyses are the latest yearly Environmental Balance reports produced by the environmental offices of Comune di Reggio Emilia [11].

All the previously cited data have been organized and transformed into homogeneous tables and datasheet by the recently finished Official Municipal energy plan [10]. The primary energy demand and the GHG emissions related to the district heating have been accounted to residential, rather than industrial, sector since the district net mainly serves this kind of end uses.

The use of other kinds of fossil fuel in the dwelling sector is rather moderate; a first report issued by local municipalities and energy providers [12] shows an esteem of the buildings heated by oil-fed or liquid petroleum gas (LPG)-fed boilers in the whole territory of the Provincia di Reggio Emilia. This data have been adapted to the smaller size of the Municipality of Reggio Emilia by proportioning them to the number of inhabitants.

This assessment of the general frame has endorsed the subdivision of thermal energy consumers, concerning the dwelling and service building sector until the year 2006, in three groups:

- group A: 59053 end users (70,1%) provided by individual gas-fired boilers.
- group B: 1405 end users (1,7%) provided by boilers fed by different fossil fuels (843 gasoline-fired boilers, 562 LPG-fired boilers).

- group C: 23769 end users (28,2%) provided by a district heating (fed by heterogeneous fuels: 87% natural gas *versus* 13% rubbish fuel) consisting of both CHP and simple thermal plants.

Once defined the technological characteristics of the plant systems set for the different groups (Table 1), it has been possible to evaluate the energy balances with reference to the baseline scenario.

The reference thermal efficiency proposed for the systems connected to the city district heating has been determined in accordance with the following expressions:

$$\eta_{tC} = \frac{E_T}{\alpha_T E_P} \tag{1}$$

where:
E_P is the primary energy required to feed all the power plants needed by the net of district heating (reference year 2006);
E_T is the whole thermal energy provided to the final consumers by the net of district heating (reference year 2006);
α_T thermal exergy allocation coefficient

Table 1: Systems main characteristics.

Group	System	Thermal efficiency η_t
		%
A	gas-fired boilers	85
B	other boilers	85
C	district heating	*
* determined in accordance to the procedure defined in paragraph 3.3		

Stated the energy balances, the related emission scenario has been determined in reference to the forecast of CO_2 emissions given by the UNFCCC, by the Directive 2004-156-EC [13], by the databank APAT [14], and by the literature reference [15]. The conversion factor are shown in table 2:

Table 2: Fuel coefficients and net calorific value.

	CO_2 emission factor	oxidation / conversion factors	net calorific value
	[t_{CO2}/MWh]		[kWh/smc]
Natural gas	0.200	0.995	9.81
			[GJ/t]
Gasoline	0.268	0.990	42.62
Liquid petroleum gas	0.225	0.990	46.15
Waste	0.176	0.980	15.00

3 Energy balance of the baseline scenario

3.1 Group A: end users provided by gas-fired boilers

This group accounts for the grates part of the users, and comprehends consumers belonging to the dwelling and service building sector. Since the year of building completion and of HVAC system installation ranges significantly, it is necessary to provide a simplified approach.

Hence, for the group it has been assumed the installation of a heater characterized by an average thermal efficiency of 85%.The energy balance gives:

$$Q_{PA} = \frac{Q_{TA}}{\eta_{tA}} \tag{2}$$

where:
Q_{PA} is the primary energy requirements for buildings in group A;
Q_{TA} is the thermal energy requirements for buildings in group A;
η_{TA} is the thermal efficiency of the gas-fired boilers providing heating to households in group A.

In reference to the values in table 2, the specific emissions related to the production of thermal energy are:

$$e_A = 0.236 \text{ kgCO}_2/\text{kWh}_t$$

3.2 Group B: end users provided by different fossil fuels

This group is relatively marginal. As for group A, the difficult classification of the real range of building completion and HVAC system installation, endorses the assumption of a reference system characterized by an conventional thermal efficiency of 85%. The energy balance yields:

$$Q_{PB} = \frac{Q_{TB}}{\eta_{tB}} \tag{3}$$

where:
Q_{PB} is the primary energy requirements of buildings in group B;
Q_{TB} is the thermal energy requirements of buildings in group B;
η_{TB} is the thermal efficiency of the gas-fired boilers providing heating to households in group B.

Similarly, regarding the values in table 2, it is possible to determine the specific emissions related to the production of thermal energy for these kinds of end uses:

$$e_{B\text{-}Gasoline} = 0.318 \text{ kgCO}_2/\text{kWh}_t$$

$$e_{B\text{-}LPG} = 0.267 \text{ kgCO}_2/\text{kWh}_t$$

while the same factor weighted in relation to the percentage of end users given in Section 2,

$$e_B = 0.298 \text{ kgCO}_2/\text{kWh}_t$$

3.3 Group C: end users directly connected to district heating

The evaluation of the energy balance for group C is particularly complex due to the heterogeneous technologies involved in the district heating. The district heating supply is allowed by three CHPs (one combined-cycles plant and two single-cycle-plants, among which fed mostly by natural gas and in minimum part by city waste) and three other thermal plants fed by gas. Hence, each power plant is identified by its own technological characteristics (*i.e.*: different efficiencies, sizes, emissions, possibility of cogeneration and trigeneration).

Therefore it was required the definition of a procedure capable of a comprehensive evaluation of the energy balance and the net emission scenario.

Three main references have been considered for this scope: two personal communications from Enìa [8], a study on the environmental impact of the new combined cycle plant [16] and a report on the activities of Enìa [17] in the years 2007-2010.

The main complexity regards the definition of the weight, in terms of primary energy consumption and polluting emissions, that has to be assigned to the production of thermal energy in this heterogeneous scenario, where the plant systems supplying the city net are many and diverse.

Therefore, the net has been considered as a unique large technological powerplant, supplied by different fuels, whose thermal and electrical energy productions were equal to the sum of the output values of each powerplant.

However, electrical and thermal energy should not be considered in the same way, being the first more valuable since it can be use for multiple purposes. Consequently, an exergy analysis has been developed, making homogeneous all the different forms of energy appearing in the balances. The basic principles of such an analysis aim to evaluate the exergy introduced in the process (at first approximated equal to the fuel chemical energy), the exergy related to the provided electrical energy (assumed equal to the electrical energy itself), and the exergy associate to the provided thermal energy, the last evaluated in accordance to the thermal level of the fluid available at the condenser through the Carnot coefficient τ:

$$\tau = 1 - \frac{T_{AMB}}{T_{MU}} \tag{4}$$

where:

T_{AMB} is the ambient temperature, assumed equal to 293 degrees Kelvin

T_{MU} is the logarithmic mean temperature of the thermal user, assumed equal to 373 degrees Kelvin (assuming, coherently with the study, to use the heat produced by thermal-electric plants only for district heating, and not for industrial processes).

The exergy allocation coefficients, to be used to give the proper weight to the different forms of energy, in order to accurately evaluate the energy and environmental benefits, can be calculated applying the following formula [16, 18]:

_ electrical exergy allocation coefficient (2006 value):

$$\alpha_E = \frac{\eta_E}{(\eta_E + \tau \cdot \eta_T)} = \frac{\eta_E}{\left(\eta_E + \left(1 - \frac{T_{AMB}}{T_{MU}}\right) \cdot \eta_T\right)} = 0{,}860 \tag{5}$$

where:
η_T = 0,260 is the thermal efficiency of the district heating plants park (2006),
η_E = 0,341 is the electrical efficiency of the district heating plants park (2006),
_ thermal exergy allocation coefficient (2006 value):

$$\alpha_T = 1 - \alpha_E = 0{,}140 \tag{6}$$

The calculated efficiency data and coefficients represent a reference for the whole six district heating plant park, and are clearly influenced by the three boilers (not thermal-electric production).

The energy balances governing the district heating park can be simply resumes throughout the two following expressions:

$$E_P = \frac{E_T}{\eta_T} \tag{7}$$

$$E_P = \frac{E_E}{\eta_E} \tag{8}$$

where E_E is the sum of the electrical energy produced by the thermal-electrical systems and the one saved thanks to cold provided by district heating in summer (minimizing the work of the compression chillers).

Given the amount of electricity and thermal energy provided by the district plants to the end users of group C, thermal exergy allocation coefficient, and the demand of primary energy used to fed the six plants, it is possible to find the characteristic emission factors of group C simply applying the factors of table 2.

$$e_C = \frac{\alpha_T G}{E_T} = 0{,}140 \ \ \mathrm{kgCO_2/kWh_t} \tag{9}$$

where:
G = 269,7 kt CO_2 represents an esteem of the total amount of CO_2 emissions from the district plant park.

4 Energy and environmental analyses - results

Assuming 130 kWh/m^2 year as the average reference value, given by literature [7], of indoor heating in recent buildings, it is possible to evaluate the energy and environmental benefits that should occur, at first, as a requirement of the national norms, then from the voluntary application of ECOABITA constraints. All these procedures have been continuously monitored, and finally certified by the independent international certification agency Bureau Veritas®.

Before calculating the expected energy benefits from the application of the Italian norms it is necessary to the defined the sample of the esteem. For this aim, the municipality of Reggio Emilia has provided a report [19] estimating the yearly average numbers of new lodgings (1100) and of buildings subjected to refurbishment in recent past. By considering an average indoor net surface of 75

m^2 for each lodging, the following assumptions have been considered in the analyses:
- indoor floor surface of new lodgings yearly built in the municipality of Reggio Emilia: 82500 m^2
- indoor floor surface of households yearly subjected to refurbishment in the municipality of Reggio Emilia: 25000 m^2.

It is reasonable to assume that a total amount of S = 107500 m^2 of indoor surfaces of new lodgings and refurbishment buildings will be yearly subjected to the national norm D.Lgs. 311/2006 [2].

4.1 The mandatory requirements from the national norms

Two recent National laws have fixed mandatory requirements for energy consumptions of new buildings and households subjected to considerable refurbishment [2]. Different threshold values for building heating have been given depending on the location of the buildings (*i.e.* through the definition of a parameter describing how severe is the winter climate of the site) and on a shape coefficient describing the compactness of the structures (*i.e.* through a parameter given by the ratio of the sum of the surfaces constituting the frontier of the building envelope and the volume heated in the same building). The same thresholds will become more and more severe from 2008 to 2010.

For instance, the heating energy yearly required for a building with a medium aspect ratio of 0,5 m^{-1} (meaning that the sum of the frontier surfaces of the building envelope equals one half of the heated volume), located in Reggio Emilia, must be as much as 76 kWh/m^2 year for new buildings and refurbishments undertaken in 2008, 2009, decreasing at 67 kWh/m^2 year in 2010 (Tab. 3). These upper thresholds are called *Epi* (Energy Performance index) [2].

Table 3: Thresholds values given by Italian norms [2] (*Epi*) and by ECOABITA, for a building in Reggio Emilia, characterized by an aspect ratio of 0,5 m^{-1}.

	D.Lgs.311-2006		voluntary reduction	ECOABITA	
	2008 - 2009	2010	%	2008 - 2009	2010
	[kWh/m^2*y]	[kWh/m^2*y]		[kWh/m^2*y]	[kWh/m^2*y]
Class C	76	67	70	53	47
Class B			50	38	34
Class A			30	23	20
Class A+			15	11	10

The following hypothesis have then been adopted in the analyses:
- indoor floor surface of sample of the buildings: 107500 m^2 (equal to the total surface of indoor spaces yearly subjected to the new national norm [2]);
- average aspect ratio of the buildings: 0,5 m^{-1} ;

- energy efficiency of the buildings: the lodgings simply feature *Epi* limits given by the norm;
- reference value for older trend of building energy efficiency: 130 kWh/m^2 year.

The energy benefits are evaluated simply computing the avoided consumptions allowed thanks to the adoption of the new more severe mandatory regulation with respect to the older trend.

$$E_S = S[130(kWh/m^2 year) - E_{pi}] \tag{10}$$

where:
E_S is the primary energy saved thanks to the application of the Italian norm [2] in the lodgings of Reggio Emilia municipality.

To determine the environmental benefits in terms of avoided CO_2 emissions, it should be considered that heating is provided by different plants distributed in the sample, in proportion to the value given in Section 2. Acknowledging the specific emissions related to the different technologies, it is immediate to calculate the CO_2 emissions reduction Δ_{CO2} :

$$\Delta_{CO2} = 0{,}701 E_S e_A + 0{,}017 E_S e_B + 0{,}282 E_S e_C \tag{11}$$

Where 0,701, 0,017 and 0,282 are the distribution factors in the examined sample, respectively of gas-fired boilers, other-fuel-fired boilers and district heating.

Table 4 sows results in terms of primary energy savings and CO_2 emission abatement that is expected to be gained by simply respecting the new national norm [2] in the period 2008-2010.

Table 4: Primary energy savings and CO_2 emission abatement from the respect of the national norm.

	2008	2009	2010
	[MWh/m^2*y]	[MWh/m^2*y]	[MWh/m^2*y]
E_S	5805	5805	6773
	[kt_{CO2}*y]	[kt_{CO2}*y]	[kt_{CO2}*y]
Δ_{CO2}	1219	1219	1422

4.2 The ECOABITA protocol

A similar procedure has then been adopted to evaluate the further benefits that should be obtained by the application of ECOABITA voluntary certification.

However, in this new procedure it is necessary to change the reference value from the one given by the older trend of building energy efficiency [7] to the one expected by the respect of the national norm [2]. The ECOABITA certification system, in fact, introduces 4 energy-classes, from C to A+, keeping the same two parameters (climate parameter and aspect ratio) adopted by the national norm, certifying growing upgrading of the building energy efficiency with respect to the limits given by D.Lgs311-206 [2].

Table 3 provides the various thresholds values for the 0,5 m^{-1}-aspect-ratio building considered in the analyses.

Furthermore, since ECOABITA works on a voluntary basis, it is relevant to try to forecast the distribution in energy-classes of the building run through the certification system.

Two main references have been considered in the elaboration of this prediction: a study undertaken at the Faculty of Architecture of the University of Ferrara [20], which demonstrated the highest cost effectiveness of class B buildings, and moreover, the application of the new Local Building Code [21]. The last hypothesis is based on the concern that any new building will require the ECOABITA certification, as a consequence of the adjustment to the Local Building Code which has modified the attainment of the volumetric benefit for buildings, to the achievement at *minimum* of the class C. Hence, the embraced hypothesis plans a progressive increment of class B from 10% to 20%, without considering classes A and A+, in line with the following trend for energy-classes of new/retrofitted buildings in the period 2008 to 2010:

Table 5: Energy-classes of new/retrofitted buildings in the period 2008 to 2010.

	ECOABITA		
	2008	2009	2010
	[%]	[%]	[%]
Class C	90	85	80
Class B	10	15	20
Class A and A+	0	0	0

Again, the following hypothesis have then been adopted:

- indoor floor surface of sample of the buildings considered in the analysis: 107500 m^2 (the same of paragraph 4.1);
- average aspect ratio of the buildings: 0,5 m^{-1} ;
- energy efficiency of the buildings: the lodgings reach ECOABITA classes in accordance with the scenario depicted in table 5;
- reference value for older trend of building energy efficiency: respect of *Epi* limits given by the norm (Tab. 3).

The energy benefits are then computed with reference to the scenarios defined in Table 5.

$$E'_S = S[(E_{pi} - E_{pi-classC})f_C + (E_{pi} - E_{pi-classB})f_B] \qquad (12)$$

where:

E'_S is the primary energy saved thanks to the application of the ECOABITA protocol in the lodgings of Reggio Emilia municipality,

$E_{pi\text{-}classC}$ is the threshold value for class C given by ECOABITA,

$E_{pi\text{-}classB}$ is the threshold value for class B given by ECOABITA,

f_c is the fraction of the lodgings reaching class C,

f_B is the fraction of the lodgings reaching class C,

The same procedure of paragraph 4.1 has been adopted to determine the amount of avoided CO_2 emissions, considering that heating is provided in the sample in accordance to the plant distribution defined in Section 2.

The environmental balance yields the CO_2 emissions reduction Δ'_{CO2} :

$$\Delta'_{CO2} = 0{,}701 E'_S e_A + 0{,}017 E'_S e_B + 0{,}282 E'_S e_C \qquad (13)$$

Table 6 finally shows the primary energy savings and CO_2 emission abatement obtained in the period 2008-2010, thanks to ECOABITA protocol adoption.

Table 6: Primary energy savings and CO_2 emission abatement from ECOABITA protocol application.

	2008	2009	2010
	[MWh/m^2*y]	[MWh/m^2*y]	[MWh/m^2*y]
E_S	2634	2714	3397
	[kt$_{CO2}$*y]	[kt$_{CO2}$*y]	[kt$_{CO2}$*y]
Δ_{CO2}	553	570	713

5 Discussion and conclusions

This paper presents the first results and forecasted benefits, achieved by *riduCO2*, an energy policy issued by the municipality of Reggio Emilia, Italy, aiming to evaluate CO_2 emissions reduction in relation to building energy consumption. The evaluation method has been developed in accordance to the parameters given by UNFCCC and finally certified by an by an international agency (Bureau Veritas). The innovation lays in its financial-incentive policy: operating both on mandatory and voluntary basis (Protocol ECOABITA), possibly it will allow to obtain eligible credits for avoided emissions that can be negotiated on the CO_2 exchange market. The same procedure has been recently applied to the Official Municipal Energy Plan of Comune di Reggio Emilia.

Following a survey of the state-of-the-art of the territory and an assessment of the reference scenario, an energetic and exergetic analysis have evaluated the benefit, in terms of environmental improvement, that should descend from *riduCO2* protocol, projecting their trend in future years up to 2020. A similar method has then been adopted to evaluate the further benefits that could be obtained by the application of ECOABITA voluntary building certification system. The reduction of carbon dioxide emission and the energetic savings, by lower usage of fossil fuel, will be finally accounted as white certificates, paying-off the agencies (such as ESCO) that promote and accomplish them.

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