The use of biomass in the building renovation: a cost-optimal perspective analysis

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Abstract

Reduction of energy consumption and the use of energy from renewable sources constitute important measures needed to reduce energy needs for existing buildings. Among all different options, the use of biomass could be an efficient strategy worthy of being explored during the refurbishment design. Although their use has been limited in the Italian legislation for environmental issues (particulate and fine dust emissions), the promising low primary energy conversion factor and their low cost (in comparison with other fossil fuels) allow us to investigate this option. A technical and economic analysis of different system refurbishment, framed in the cost-optimal context, has been addressed, in order to evaluate the feasibility of such interventions. Several case studies (single family house, apartment block, a school and a district made of several single and multi-family houses, served by a district heating system based on biomass) and different strategies have been analyzed:

- No interventions on building envelope (installation of a biomass heating system);
- Deep renovation of building envelope, with a "traditional" heating system (condensing boiler or heat pump);
- A standard renovation of the building envelope and the installation of a biomass heating system.

An analysis of the cost of intervention and operation (in terms of euro per kilowatt and euro per kilowatt-hour) is presented, so that it is possible to estimate what the cost-optimal levels are for the different case studies analyzed.

1. Introduction

The work presented is about the technical and economic analysis of biomass plants for the production of thermal energy, in the range of the energetic refurbishment design of buildings with residential and scholastic uses. The starting point (De Angelis et. al., 2014) is the requalification of the building envelope, taken as the reference for the reduction of buildings' energy consumption. The choice about the use of biomass represents a valid alternative to fossil fuels, especially if we consider the increasing need for the reduction of primary energy consumption and the use of energy from renewable sources. The aim of the work is to evaluate the technological feasibility and economic benefits of the intervention on heating plants, by the substitution of the original heat generator with a biomass one, in integration or in alternative with the requalification of the building envelope. We considered different interventions on the building envelope, the so-called 'Deep Retrofit' (Shnapp et. Al., 2013), which implies replacing existing systems in a building with similar ones that are of higher quality and performance, which leads to a better energy performance of an existing building. After the deep retrofit the buildings energy reduction is 50% or more compared to the existing building energy need.

1.1 Biomass

Biomass can be used as fuels in substitution of fossil fuels, for the production of thermal and electric energy. In this work solid biofuels have been considered, and in particular we focused on ''pellets'', which are a product with a cylindrical form of 6 – 8 mm of diameter and 5 – 50 mm of length. This product is a result of a process of densification of the primary element, wood.

At the national level, the use of biofuels is rewarded with a low value of the primary energy conversion factor, which is equal to 0.3 (according

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to Raccomandazione CTI R14/2013). At a local level there are some variations, for instance in Lombardy, where the primary energy conversion factor for biomass is equal to 0.5 (according to ddg. n. 5796/2009)

1.2 Diffusion of biomass plants

The diffusion of biomass plants in Italy has had the following trend, represented in Fig. 1 and Fig. 2. In the graph of Fig. 1 the Mm³ of solid wood equivalent (swe) consumed is presented. The bars of the graph, from left to right, represent the situation in 2010 and the forecasts for 2020, 2030.

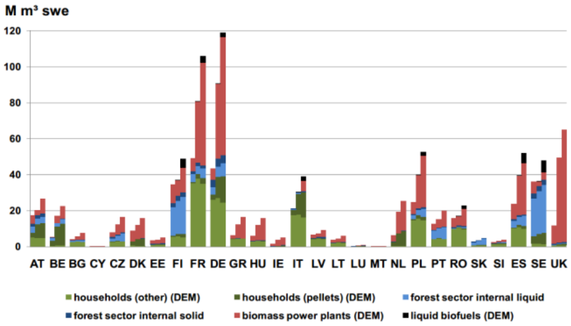

Fig. 1 – Current and future amounts of wood energy (by country and consumer sector) (Source: Mantau et. Al., 2010)

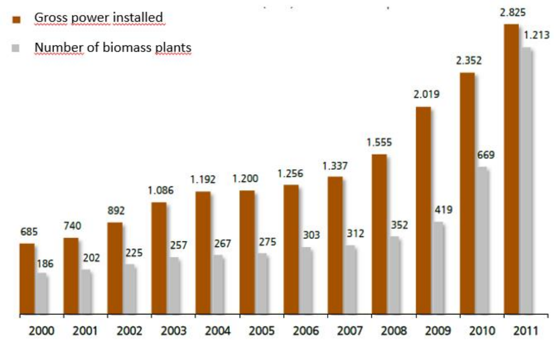

Fig. 2 – Evolution of the number of biomass plants and of the gross power installated in Italy (Source: GSE, 2012)

Data for Italy (Fig. 2) show that from 2000 to 2011 the number of plants increased every year by 19% on average, while for the power an average increase of 14% has been recorded. The last three years are particularly interesting: 2009 for the increase in power (around 500 MW); 2010 for the increase of 260 plants (mainly due to the inclusion, in the survey, of small-scale plants); 2011, for the significant increase both of the number (+544 plants) and of the power (+474 MW).

1.3 Environmental and primary energy issues

The use of wood biomass as fuel involves the emission of several pollutant elements, which can be potentially dangerous for people who come into contact with them (for example fine dust and ultra-fine dust, nitrogen oxide, dioxin). The quantity of emission depends on the fuel used. In Italy, there are some limits for the emissions from biomass plants in civil applications for the production of thermal energy (DLgs 152/2006). The limits presented in Table 1 are referred to a power included from 0.15 MW to 1 MW, for a one-hour operation of the plant and in the hardest conditions of operations, excluding the period of start, stops and breakdown.

At a local level, there could be different limits about the installation of biomass plants. In Lombardy there are some limitations (Dgr 735/2008) for the use of plants fueled with wood biomass in territories at more than 300 m of altitude, and in some other specific areas of the region. In these territories, if a building has other plants with different fuels, it cannot use biomass plants for the heating of the building in:

a) Open chimneys;

b) Closed chimneys, stoves and other devices fueled with wood biomass if they have been bought before 1990, and that has an efficiency lower that 63%. They also have to guarantee low emissions of carbon monoxide, that is ≤0.5 %, with an oxygen standard of 13 %.

It is not strictly precise to consider next to zero the balance of the carbon emissions in the atmosphere, because of the time it takes for cut woods to regrow, if compared with the demand for wood as biofuels. As a consequence, there is not the complete absorption of the carbon emissions due to the wood combustion. If we consider the increase in the demand for wood, this implies that more and more wood is taken from forests, and the consequent increase of time for the absorption of carbon. A valid way to avoid this phenomenon is the re-forestation of fertilization of other areas.

Table 1 – Upper limits for the emissions in biomass-based systems (Source Dlgs 152/2006)

Emission	Dlgs 152/2006	Proposal of recast
Total dust [mg/Nm^3]	100 (*)	30 (**)
Total organic carbon	-	-
Carbon monoxide [mg/Nm^3]	350	250
Ammoniac [mg/Nm^3]	-	5
Nitrogen oxide [mg/Nm^3]	500	300
Sulphur oxide [mg/Nm^3]	200	150

(*) For systems with nominal thermal power ranging from 35 kW to 150 kW, the emission value for the total dust is equal to 200 mg/Nm^3 (*) or 100 mg/Nm^3 (**)

1.4 Economic incentives for the use of biomass plants

For the installation of biomass plants there are some incentives for the production both of thermal and of electrical energy. In this work, we consider the ones about the production of thermal energy, with reference to the regulation in force at the end of 2014. Building renovation interventions can obtain the same incentives, with different rules (which are not stated in this paper).

CONTO TERMICO. The access to the Conto Termico is both for private and for public subjects, in a direct or indirect way by means of an ESCO. The facilitations consist of a subsidy, given over a period of 2 or 5 years (for interventions respectively with less than 35 kW of power and with a power included from 35 kW to 500 kW). The calculation of the amount of the subsidy is the following:

$$I_{a\ tot} = P_n \cdot h_r \cdot C_i \cdot C_e \quad (1)$$

where:

$I_{a\ tot}$ is the annual amount of the subsidy in €;

C_i is the coefficient linked to the promotion of the thermal energy produced, according to the installed technology;

P_n is the nominal thermal power of the plant;

h_r are the hour of operation, linked to the climatic zone considered;

C_e is the coefficient linked to the quantity of dust emissions, according to the installed technology.

For example, in climatic zone E and considering dust emissions (PPBT) lower than 10 mg/Nm^3, the subsidy I_{tot} is equal to 8'032.5 € (for a 35 kW plant power) and 127'500 € (for a 500 kW plant power).

The subsidy (which cannot be higher than 65% of the entire amount of the cost of intervention, according to Dlgs 4/07/2014 n. 102) is given for the substitution of the heating generator with a biomass one, excluding the case where the original fuel is natural gas.

The requirements for obtaining the subsidy are:

- Installation of thermostatic valves (or analogue systems);
- Heating generator compliant with the class 5 of the UNI EN 303-5;
- Thermal efficiency (%) not lower than $87+\log(P_N)$, where P_N is the nominal power of the heating generator;
- Respect of emission limits;
- Installation of a water tank;
- Use of pellet of class A1 or A2 (according to UNI EN 14961-2);
- Biennial maintenance of the thermal generator;
- Energy diagnosis and energy certification (mandatory only if the power is higher than 100 kW), for which is expected a subsidy.

65 % DEDUCTIONS. This incentive consists of a tax deduction of 65%, given over a period of 10 years, for interventions related to the increase in the energy efficiency of the building. To obtain this incentive, it is necessary to fulfill the following requirements:

- Respect the limit value of the energy performance indicator, for heating (DM 11/3/2008);
- Heating generator efficiency greater than 85 %;
- Thermal transmittance of windows lower than 1.8 $W/(m^2K)$, for the climatic zone E.

The maximum deduction is equal to € 100,000.

From 2015 it is possible to obtain an incentive (with a maximum deduction equal to €30,000) even for the case of substitution of the existing heat generator with a biomass one.

50% DEDUCTIONS. This facilitation consists in a tax deduction of 50%, given over a period of 10 years, without the requirements existing for the 65% deduction. The maximum deduction is €48,000.

2. The economic model

The economic analysis has been made evaluating the global cost. The global cost is defined (according to EU Regulation 244/2012) in the following way:

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau}(C_{a,i}(j) \times R_d(i)) - V_{f,\tau}(j)\right]$$

Where:

- τ is the period of the calculation;
- $C_G(\tau)$ is the global cost (referred to the starting year τ_0) in the period of calculation;
- C_I is the initial cost of the investment, for the measure or for the set of measures j;
- $C_{a,i}(f)$ is the annual cost during the year i, for the measure or for the set of measures j;
- $R_d(i)$ is the discount factor for the year i, based on the discount rate r;
- $V_{f,\tau}(j)$ is the remaining value of the measure or of a set of measures j, at the end of the period of calculation (actualized at the starting year τ_0). In this work the remaining value hasn't been considered.

The global costs have been estimated on the base of the following hypothesis:

- Cost of gas: 0.85 €/m^3;
- Lower Heating Value of gas: 9.56 kWh/m^3;
- Annual increase of the cost of gas: 5% (nominal value);
- Annual increase of the cost of pellet: 2% (nominal value);
- Actualization rate: 5% without inflation (nominal value) and 2.94% with inflation del 2% (real value);
- Efficiency of the original heating generator: 85% (90% in the school);
- Efficiency of the biomass heating generator: 93%;
- VAT: 10% for biomass plants, 22% in other cases.

COST OF PELLETS

For pellets in sacks, €4.30 for a 15 kg sack (287 €/t). For the unpackaged pellet delivered by a tanker, costs are represented in the following graph.

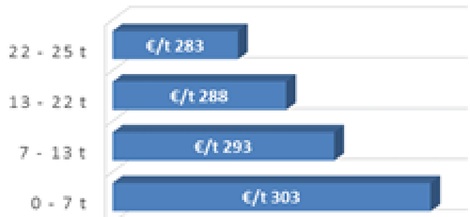

Fig. 3 – Cost of unpackaged pellet delivered by a tanker, transport distance 20 – 30 km. Source: average values from different quotations.

COST OF MAINTENANCE

As regards the maintenance, the cost of ordinary maintenance (emission test, annual controls) has been considered, but not for extraordinary maintenance, such as the necessity of substitution, in future, of the components of plants.

Also for the building envelope, the cost of maintenance, such as the painting of the façade, has not been considered. For the maintenance of the plants, costs (for each year) are represented in Fig. 4. The graph considers the interventions of ordinary and extraordinary maintenance of the plants. In this work we only considered the ordinary ones, represented in the table 2.

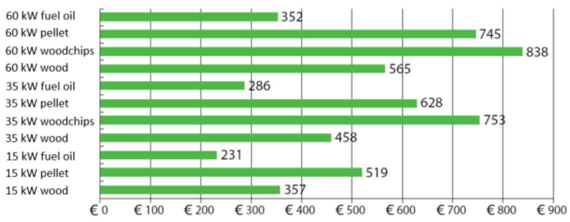

Fig. 4 – Yearly cost of the maintenance for plants with different fuels (Source: Francescato et al., 2009).

Table 2 – Costs of ordinary interventions, assumed in the calculation.

Power	**Interventions**	**Cost**
8 kW – 36 kW	Annual cleaning by a specialist	€300
50 kW – 160 kW	Annual cleaning and 1 – 2 periodical cleans	€450

ELECTRIC ENERGY CONSUMPTION

Regarding the consumption of electrical energy, we considered the following costs: 107 €/year for plants of 35 kW of power or less and 179 €/year for plants with more than 35 kW of power.

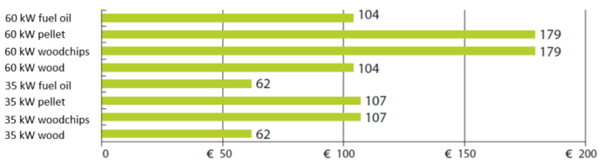

Fig. 5 – Cost of the consumption on electrical energy for plants with different fuels (Source: Francescato et al., 2009).

SET-UP COSTS

For the put-in-service of the intervention, costs are the following ones.

Table 3 – Set-up costs for different plants, assumed in the calculation (Source: Hoval, 2014)

Intervention	**Set-up costs**
Plants with a power included between 8 kW and 36 kW	€320
Plants with a power included between 50 kW and 160 kW	€420
Heat exchangers of the district heating system	€90 each

Following costs (installation and other costs) have been derived from an analysis of different quotations.

INSTALLATION COSTS

For plants with less than 35 kW of power, the cost of installation has been considered 7% of the plant components' costs, while for plants with more than 35 kW of power 12% has been considered.

OTHER COSTS

– Certificate for the Prevention of Fire, plants with power > 116 kW: €2,000; plants with power < 116 kW: €1,000;
– Procedure of control and test made by ISPESL, for plants with power > 35 kW: €500;
– Energy certification: €300 for mono-bifamiliar residences, €600 for the block of flats and €700 for the school;
– Energy diagnosis: €1,500 (considered only for power > 100 kW).
– Design calculation: €450 for plants with power < 116 kW and €950 for plants with power > 116 kW.

For the substitution of the original heat generator with a condensing one, the costs considered are:

- €1,500 for the generator;
- Maintenance: 50 €/year for the annual control and other 50 €/year for the biennial emission test;
- Costs for the consumption of electrical energy and other costs (certification, procedures) equal to the case of biomass plants.

2.1 Plant layouts

In the following graphs are presented the layout of the solutions designed for the heating station and the one of the heat exchangers for the district heating system case.

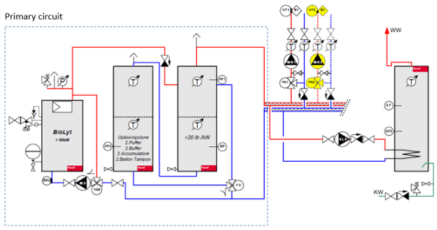

Fig. 6 – Layout of a biomass plant with a single generator and a single tank

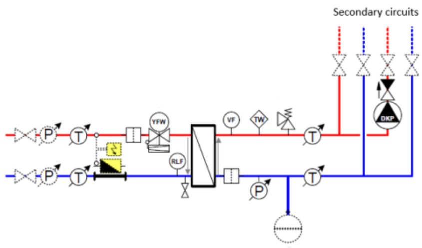

Fig. 7 – Layout of the heat exchangers for the district heating system

The strategy is to intervene on the original heating plants by the substitution of the components of the primary circuit: one or more heating generator fueled by biomass, one or more tanks and the other additional components and valves. These elements constitute the primary circuit, connected to the secondary one, made by the heating circuit and the one for the production of domestic hot water. The substitution of the boiler of the DHW and of the flue is also envisaged.
It is possible to consider also different solutions for the pellet loading:

- Manual loading, for low energy consumption (i.e. a single residence);
- Automatic loading from a textile silo,
- Automatic loading from a dedicated local, for high energy consumption.

2.2 DHW and tank

The need of domestic hot water DHW has been evaluated with a statistic approach, based on a normal level of comfort of the residences, considering a contemporaneity of use of DHW depending on the number of residences served. For the district, the sum of the single needs of DHW has been considered, considering that each building is provided with its own boiler.

Table 4 – DHW needs, as designed.

Case study	N° of residences	l/10min	l/h	l/day
Single residence	1	143	286	343
Block of flats	24	765	1886	5957
District	35	5'005	10'010	12'005

The calculation of the capacity of the tank depends on the power offered by the heat generator: 20 l/kW if the power offered is near to the requested one (until 95%), and 25 l/kW or 30 l/kW if the offered one is less than 90% and 85% of the requested one respectively.

2.3 Cost curves

Following can be seen the curves of costs for the principal and secondary components of the plant. Those curves are obtained from the analysis of quotation and price list of Hoval (Hoval, 2014).

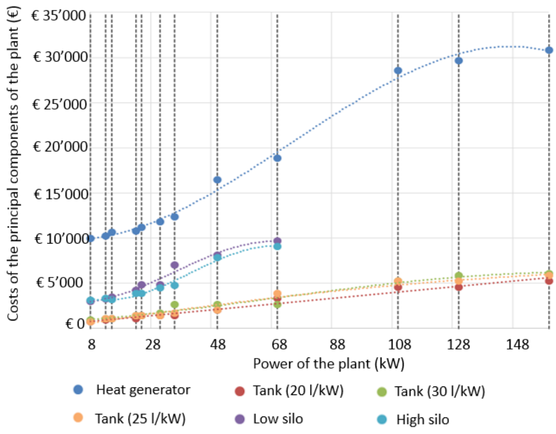

Fig. 8 – Costs of the principal elements of the biomass plants

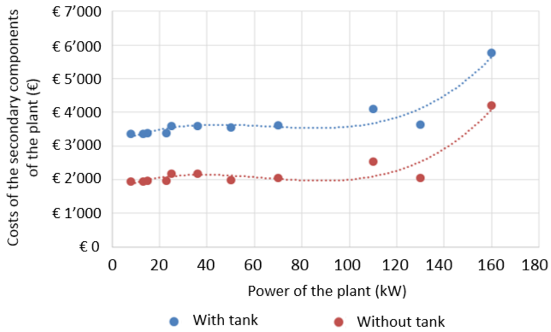

Fig. 9 – Costs of the secondary elements of the biomass plants

3. The case studies

Four different case studies have been analyzed in this work: a portion of a detached house, a block of flats, a school building and a neighborhood (consisting of 40 single and detached houses). For the calculation of energy savings (during the winter season) the quasi-steady state calculation method (ISO 13790) has been used. The values of real energy consumption have been acquired from bills, if available. For every case study a parameter (called *scale factor*) has been derived which represents the ratio between the real consumption of energy and the calculated one at the actual status, so it has been possible to predict the energy consumption for the different scenarios of intervention, scaling the energy savings obtained from the calculation model with the scale factor obtained in the reference case.

The analysis of convenience has been made evaluating the global cost, considering three different duration of time: 10, 20 and 30 years.
The different scenarios of interventions considered are the following:

- CASE 0: no intervention, reference case;
- CASE 1: biomass plant in substitution of the existing one;
- CASE 2: deep retrofit of the envelope; CASE 2A: (in substitution to the CASE 2) condensing heat generator in substitution of the existing one (for the single residence and for the district case);
- CASE 3: deep retrofit of the building envelope and biomass plant in substitution of the existing one;
- CASE 4: retrofit of the envelope; CASE 4A: (in alternative to the CASE 4) retrofit of the building envelope and condensing heat generator in substitution of the existing one (for the single residence and for the district case).
- CASE 5: retrofit of the building envelope and biomass plant in substitution of the existing one.

For the case of the district there we considered:

- CASE 6: district heating system and deep retrofit of the building envelope.

Fig. 11 – (above) NW view of the building (single unit of a detached house) and (below) SE view of the building (block of flats building

A graph has been built where the global cost is compared to the EP_H of the scenarios, in order to evaluate the convenience (represented by the slope of the lines) of the interventions and the potential of renovation (represented by the difference, in terms of global costs, between the actual status and the corresponding scenario).

Table 5 – Main data of analyzed buildings (A: single family house, B: block of flats building, C: school building)

	A	B	C
Net floor surface [m^2]	107	2’046	3’071
Net volume [m^3]	318	5’871	10’450
Gross floor surface [m^2]	129	2’444	3’695
Gross volume [m^3]	424	7’984	14’060
Envelope surface [m^2]	375	3686	5’428
S/V [m^{-1}]	0.88	0.46	0.39
EP_H [kWh/(m^{2}year)]	197.8	246.4	219.0
Scale factor	0.46	0.70	0.75
EPH lim. [kWh/(m^{2}year)]	96.28	60.57	-
EPh, lim for 65 % incentives [kWh/(m^{2}year)]	78.01	49.05	-

4. Results and Conclusions

From the analysis of the case studies it emerges that the installation of a biomass plant in the building renovation is convenient when the power demand and the consumption of energy are high, such as in the case of the block of flats and school buildings.
In the case of the **single house**, it is evident that the most convenient intervention is represented by the substitution of the original heat generator with a condensing one (in each duration period), thanks to the low economic investment and to the higher efficiency of the new heat generator. In this case, the achieved reduction of energy consumption (and primary energy for heating) is equal to 23 %. If we compare the existing scenario to the ‘*deep retrofit + biomass*’ scenario the global cost at 10 year redoubles. The intervention on the building envelope is more convenient than the biomass scenario (this is particularly true if a silo for the storage of pellets is installed, dashed points in the

figure 12.a). The scenario '*deep retrofit*' involves a higher global cost but allows the reduction of primary energy consumptions by 77 %.

The scenario '*biomass*' allows for a reduction of (real) energy consumptions of 9 %.

Considering the case of the block of flats, the "biomass" scenario allows for a reduction of (real) energy consumptions of 9% and a reduction of the global cost of 32% over 10 years. In the scenario "deep retrofit" the primary energy consumption reduction is equal to 74% and the global cost reduction in 30 years is equal to 61%. In the case of "deep retrofit and biomass" the global cost reduction in 30 years is equal to 74%.

Further, attention focused on a neighborhood, made of 40 buildings, which are served by a district heating system, fueled by biomass, after the deep retrofit of the envelope. The buildings are the ones analyzed in the first case study. Five buildings have already been renovated and therefore are not considered in the calculation. As a simplification, average data have been represented and used. It has to be pointed out that usually the users have to pay the duty for the connection (this aspect is not considered in this work); in addition, usually the realization of the plant is in charge of an ESCO. The hypothesis of this work is that the cost for the realization of the plant is divided among the users. It emerges that the cost is nearly the cost for the realization of a single biomass plant for each residence. As a consequence, the global cost for the district heating system scenario (after the deep retrofit of buildings) is almost the same of the global cost for the "deep retrofit and biomass" scenario (where a biomass plant has been considered for each residential unit).

Finally, costs of system intervention (with biomass heating generator) have been represented in the following graph, considering the nominal power of the system. There is an elevated cost for the 13 kW plant, equal to 1,700 €/kW. This cost decreases to 370 €/kW for the 290 kW plant. There is an increase in cost moving from 110 kW to 140 kW, since there is the need to use two heating generators in the second case. It is evident (see Fig. 8) that the cost of the heat generator weights on the final cost in a higher way compared to the other plant components. This fact can be observed also for the 160 kW and 200 kW plants. We can finally observe that the cost of intervention for the deep retrofit of the envelope ranges from 270 €/m² to 210 €/m² (with reference to the heated floor area), respectively for a small building (single residence) and biggest buildings (block of flats and school). The addition of the biomass plant requires an increasing of costs ranging from 185 €/m² (small building) to 27 €/m² (biggest buildings).

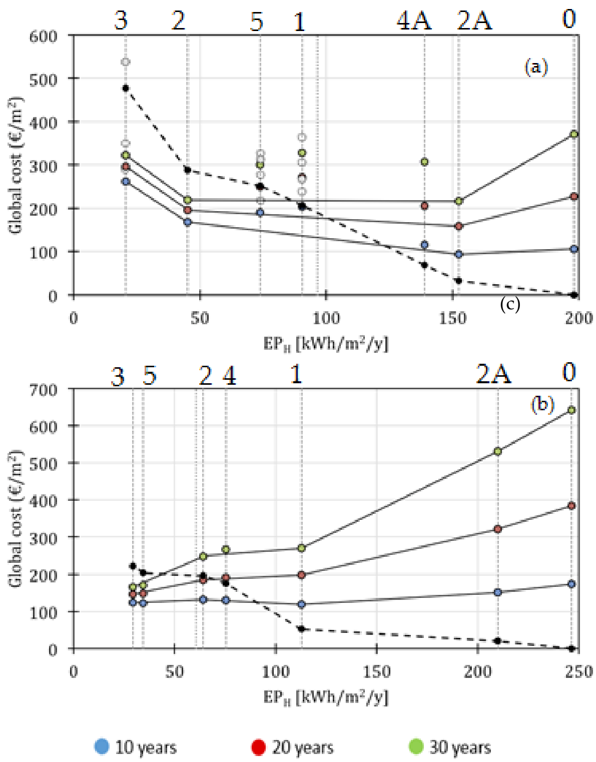

Fig. 12 – Results for the single unit of the detached house (a), and block of flats building (b). Values of the global cost (y-axis) vs EP$_H$ (on x-axis). Dashed lines represent the cost of intervention at τ = 0. Letters above the pictures represent the case studies, as listed in §.3.

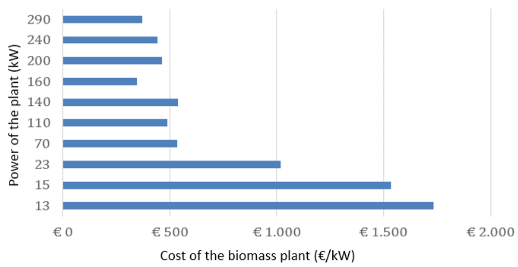

Fig. 13 – Cost of realization of a biomass plant (y-axis) vs the installed nominal power (x-axis).

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