ON THE SIZING OF CHP MACHINES, A CASE STUDY OF RETROFIT IN A COMMERCIAL BUILDING

Marco Picco, Vittorio Savoldelli, Marco Marengo
Department of Engineering, University of Bergamo, Bergamo, Italy
Ph. +39 035 2052068, e-mail: marco.picco@unibg.it

ABSTRACT

The present paper analyses a case study of the application of dynamic energy simulation on the energy efficiency improvement process of an existing commercial building, the retrofit of a CHP machine for the combined generation of heat and power is analysed. Great attention is dedicated to the correct sizing of the CHP/CCHP plant both in term of energy efficiency and economic viability.

A detailed building model is developed and used, through dynamic building simulation, to identify the potential energy and economic savings achievable with the installation of a CHP/CCHP sized based on the results of the simulation itself.

The work proves the usefulness of dynamic energy simulation as an evaluation tool for retrofits of CHP plants and provides suggestions on the correct sizing of CHP equipment. It is also meant to prove what could be achieved if those kind of analysis were carried out during the design of the building.

INTRODUCTION

The waste of large amounts of heat is an irrational and unfortunately widespread practice. In Italy, for example, losses of heat in the thermoelectric conversion amount to over 22 Mtoe/year, 53% of primary energy used. Industry, domestic use, transport, agriculture and marine bunkers losses amount to at least 34 Mtoe/year. If we also consider the waste of heating energy in buildings and the available renewable energy for heating and cooling purposes, it is evident that among losses, waste and renewable sources we are dealing with a huge quantity of thermal energy with an enormous and still underestimated potential (Molocchi, 2011).

A Combined Heat and Power (CHP) system allows financial and carbon savings by making use of the heat produced when electricity is generated, which is usually wasted. The heat may be used to meet the thermal demands of a development, for example for space heating and domestic hot water, or used to run absorption chiller to provide cooling, known as a Combined Cooling Heat and Power (CCHP) system or tri-generation.

In recent years, following various international agreements, great emphasis was put on reducing energy use, highlighting the energy efficiency of CHP units. Still these solutions are often dismissed due to the general lack of knowledge, uncertainty of the results and the difficulty in feasibility analyses.

Great care must be taken in sizing a CHP system to match the demands of a development, and in particular the profiles of demand fluctuations. There is a minimum load below which a CHP engine cannot run. If a system is too large, it will not operate often enough; if a system is too small, it will not be providing the full potential carbon and cost savings. It is important to make correct decisions regarding sizing, as poorly-sized systems perform very badly (Evins et al., 2011).

Various studies already proves that the technology can be applied resulting in relevant reductions of carbon emissions and interesting economic return to hospital buildings (Picco et al. 2012, Patania et al. 2012), characterized by steady and strongly coupled demand of heating and electricity. Departing from those ideal characteristics ecological and economical assessment for this kind of technology becomes increasingly difficult and tricky, preventing its wide application to different realities.

This study is based on a medium sized Bingo hall, presenting favourable conditions to the application of CHP/CCHP technologies but at the same time requiring accurate feasibility analysis to determine its advisability, reasons for which those technologies are normally overlooked. One possible solution to facilitate those kind of analyses is through the implementation of dynamic energy simulation.

Energy simulation plays a very limited role in the average application of energy saving technologies, mainly for the lack of control over when and how a particular analysis should be commissioned and the lack of context specific analysis scenarios; thus often recurring to intuitive selection (de Wilde et al., 1999).

It is believed that a more diffuse application of dynamic energy analyses could provide useful information to the design process on the sizing and evaluation of CHP and CCHP equipment, facilitating the implementation of the technology in favourable building configurations. It is therefore essential to support energy efficient design decision with energy analysis able to justify the intervention.

BUILDING DESCRIPTION

The building exam of this study, identified as the "GECH Bingo", is a commercial structure mainly used as a bingo hall; a slot machine room and a betting room are also present in the structure.

The building is situated in Curnasco, in the proximity of Bergamo (Italy) and was recently built in 2010.

The following image (Figure 1) represents the urban context in which it is inserted, through the aid of a top view of the building and the surroundings, with accessory structures, roads and parking slots.

Figure 1 – Top view of the building complex

The building is composed in precast reinforced concrete elements both for horizontal and vertical structures, developed on three levels, an underground floor used as a covered parking lot, the main ground level floor where all the major activities of the building are carried out, and a partly opened top floor where technical rooms and plant equipment are situated.

Below (Figure 2) the layout of the main ground floor can be seen, consisting of all the different playing rooms, offices and accessory spaces.

Figure 2 – Layout of the main floor of the building

The layout consists in one major hall, subdivided in non-smoking and smoking area following Italian regulations, used as a Bingo room (respectively 14 and 15 in Figure 2), a slot machine hall (3 and 4 also non-smoking and smoking area) and a betting room accessible from the outside (5). Linked to those are a number of accessory spaces like entrance hall (1), offices (2), food preparation areas (11, 12 and 13) and other services.

The envelope is composed of modular precast concrete elements already featuring insulation layers and finishes for both horizontal and vertical surfaces. Due to the modularity of the structure only four kinds of constructions are present: the roof characterized by an insulation layer of 10cm of expanded polystyrene and a thermal conductivity of 0.303 W/m^2K, , the floor to the underground parking lot, also characterized by 10cm of expanded polystyrene for a total thermal conductivity of 0.293 W/m^2K, external walls with 7cm of insulation and thermal conductivity of 0.363 W/m^2K and lastly external un-insulated walls to the stairwells with thermal conductivity of 2.251 W/m^2K.

Due to the nature of the building transparent surfaces are limited and only positioned at the entrance and in the betting room, nonetheless, to comply with current regulation (D.Rg. VIII/8745 Lombardy Region), all are double glazed low emissivity windows with thermal conductivity of 1.6 W/m^2K and negligible frame effect.

On the system side the structure is equipped with a full-air system subdivided in five different air loops, due to current regulations for smoking areas, and controlled by five different air handling units, all equipped with a heat exchanger for a 68% heat recovery effectiveness.

All the units are powered by cooling and heating coils linked to two parallel water to water reversible heat pumps connected to a geothermal probes field for a total cooling and heating capacity respectively of 720kW and 686kW. An additional air to water heat pump is installed for backup purposes with cooling and heating capacity of respectively 355kW and 397kW.

Installation of a cogeneration system

During the design of the building one of the hypothesized configurations of the plant involved the installation of a CHP machine. Due to the lack of specific knowledge of the design team and the reluctance to consult external experts the hypothesis was deemed not viable and the installation of geothermal heat pumps prevailed.

Being this a common occurrence during building design due to the difficulties in predicting the outcome of CHP installations and a general distrust in the technology, especially if applied to not established cases, the here present study analyses the installation of a CHP machine both in the condition of a present investment or if done during the construction of the building. Also the additional installation of a CCHP equipment is investigated.

One of the major problems in term of evaluating the correct installation of a CHP unit is the correct sizing of the machine as usually the required data is not available.

It is essential, for the purpose of a correct sizing of the machine, to be able to couple the thermal and electrical needs of the building with the simultaneous production of the cogeneration, otherwise the investment will not be viable.

Overlaying the pattern of needs for electricity and heat for the winter period it can be seen these demands are found to be sufficiently constant and contemporaneous, this condition let assume a suitable environment for the installation and functioning of a cogeneration system.

With some exception, during mid-seasons, the favourable condition that thermal needs are constantly greater than the electrical requirements during the whole winter period is also present. This becomes increasingly important when self-consumption of generated electricity becomes a major aspect of the analysis. In this particular case electricity can be easily stored within the main electricity grid via net metering policies without fear of losing potential production. Nonetheless self-consumption is stimulated by current regulation, granting a larger amount of tax deduction, therefore allowing for a more interesting investment.

This condition also encourages the setting of the cogeneration system in thermal mode, i.e. the co-generator is able to work only when there is enough thermal demand to cover its production, eliminating the potential waste of thermal energy due to the inability to store this energy.

To perform a correct sizing of the co-generator becomes of extreme importance the identification of the thermal power curve of the building (Figure 3).

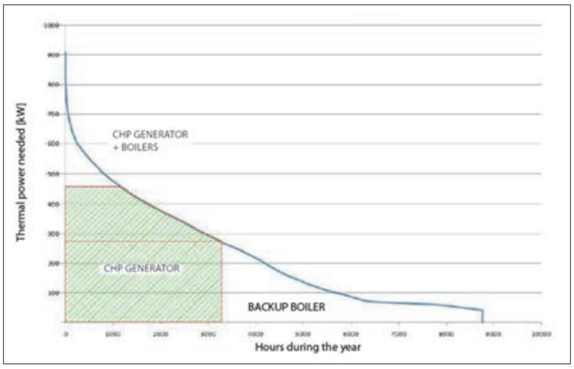

Figure 3 – Example of a thermal power curve and area of operation of the cogeneration system

Assuming an operating limit to guarantee acceptable efficiency of the equipment it is possible to identify the range of operation of the machine, so as to maximize the operating hours of the co-generator, at acceptable efficiencies, as a function of the needs of the structure; the remaining needs should be covered by backup units.

From a solely energy standpoint, the best CHP machine is represented by the one that maximizes the dashed area in Figure 3, which represents the number of operating hours on the x axis and the operating power of the cogeneration system on the y axis.

This assumption does not necessarily represent the best economic choice as specific equipment performance, cost of installation and maintenance of the machine are to be considered.

It should also be noted how, when sizing, a maximum electrical output of 200 kW is imposed to let the CHP machine access the exchange regime previously introduced with the network (D.lgs. 20/07).

Similar assumption can be made regarding CCHP, considering the additional restrain that heating and cooling capacity of a CCHP unit, being it a standalone unit or a combined CHP and absorption chiller plant, are linked as heating energy produced by the CHP is converted in cooling energy by the chiller with a COP that ranges from 0.6 for single effect absorption chiller to above 1.2 for double effect absorption chiller and above. Combining this with the heating and cooling power curves it is possible to identify the optimal size of the CCHP plant by maximizing the energy generation similar to what previously illustrated for CHP units.

SIMULATION MODEL

The simulations needed to evaluate the energetic behaviour of the building under examination are performed under dynamic regime by dedicated software; in the specific instance, the software DesignBuilder is used, which is a user-friendly interface of the calculation engine EnergyPlus.

The geometrical model is developed starting from existing documentation, therefore, the dimensions and geometrical properties of the building are identified through the help of available plans and field surveys.

The volume and footprint of the structure are defined through the modelling of 5 building blocks for a total volume of 19080m^3 and a total conditioned area of 2114 m^2; in addition a number of shading surfaces are modelled such to describe external shading elements present on the structure. No buildings are present in the vicinity that influence the structure under consideration.

Thermal zones that make up the building are then identified. This division is made according to the principle of uniformity of use conditions of the premises and internal set-points, trying to minimize the number of thermal zones constituting the building but impacting as little as possible on its thermodynamic behaviour. A total of 22 thermal zones are identified, of which 17 are subject to occupancy and therefore are thermally controlled.

The individual zones are subsequently characterized in terms of operation, set-points, occupancy, ventilation, electrical load and domestic hot water requirements in 13 different zone types. Each value has been identified by comparing the reference values recommended by current regulation and actual values recorded by the sampling survey in some of the structure's rooms.

The temperature set-point, unitarily defined for the entire structure match at 20°C for the heating period and 27°C for the summer, with corresponding setbacks at 15°C and 30°C, in accordance with the real use of the building. Each type of zone is then characterized by defining a profile of all set-points and usage values as a function of direct observation of the actual behaviour of the structure.

Due to the particular nature of the building the correct interpretation of time dependent variables becomes of extreme importance to properly identify the thermal load profiles and subsequently correctly evaluate the CHP equipment, therefore much attention has been paid in the writing of those profiles through the study of building settings and direct observations of the building behaviour.

The building envelope, being quite uniform, is characterized by the definition of only 4 surface types for the opaque components and 1 window types for the transparent components that describe the individual parts of the envelope as previously identified. Due to the characteristics of the structure a conventional value of air infiltration equal to 0.7 volumes/hour is assumed.

The consumption of domestic hot water is also modelled depending on the intended use of the various areas of the building according to standardized patterns of consumption function of the occupancy. This does not significantly affect the outcome of the analysis as DHW is provided by dedicated electric heaters.

The mechanical ventilation system is modelled through a Unitary single zone scheme in which each zone is characterized by a corresponding air loop, partly echoing the 5 different air loops in the real plant, equipped with heating and cooling coils and an heat exchanger with 68% nominal sensible efficiency. Dehumidification is obtained through a cool-reheat strategy.

Air change rate is modelled in accordance with Italian regulation regarding public structures with particular attention to rooms in which smoking is allowed. This results in the attribution of air change rates equal to 8 l/s for each person where smoking is not allowed and 36 l/s for each person in smoking rooms. Air change rates are modulated based on the effective number of occupants as in the case of the real building.

To better represent the climatic conditions of recent years the annual simulation is parted into two sub-simulations, a "winter" and a "summer" simulation, each one characterized by appropriate climate data from TMY database.

From the simulation the total system loads (Figure 4) are identified, equal to 553MWh for heating and 152MWh for cooling, with a peak power for heating and cooling loads respectively equal to 374kW and 487kW.

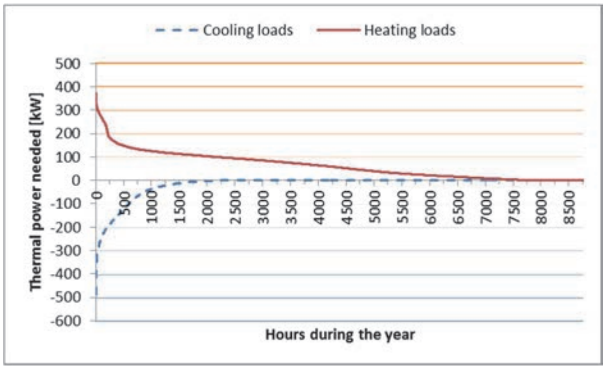

Figure 4 – Total base case heating and cooling loads.

Once the baseline case is identified the study continues with the sizing of various CHP and CCHP machines and a preliminary feasibility analysis in order to assess their effects in terms of reduced primary energy consumption, electricity generation and return on investment.

RESULTS

Once the needs of the structure are identified, the curve of thermal power required for the proper sizing of the cogeneration system (Figure 5) can be traced.

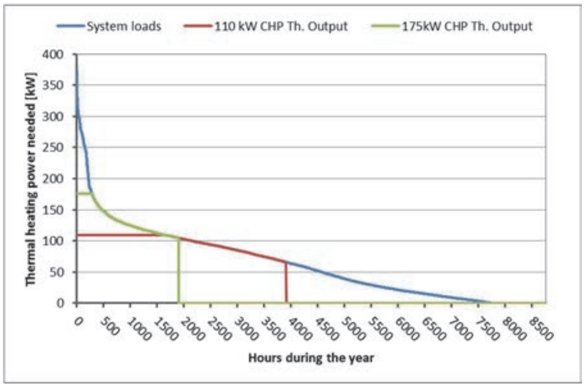

Figure 5 – Thermal power curve and area of operation of the CHP systems

Following the sizing technique previously illustrated a simple spread-sheet program has been developed able to identify the optimal size of the CHP unit based on the thermal power curve of the building and the load limit of the machine, in this case assumed equal to 0.6.

The optimal size resulting for the CHP machine is 110kW of thermal power, able in the CHP hypothesis to cover 68.8% of the thermal loads of the building. For a matter of comparison a second hypothesis of a 175kW CHP unit is also considered, obtained through observation of the monitored consumption available for the building, covering 45.9% of building thermal demand.

As for CCHP hypothesis the optimization is still based only on the heating power curve due to the limited cooling thermal demand of the case study in exam, resulting in the same two previous hypothesis with a single effect absorption chiller added with a COP of 0.6. This results in a coverage of 62.6% for the 110kW model and 46.9% for the 175kW model.

On a first guess all the major characteristics of the CHP units can be linked to the identified thermal capacity, so to obtain a first estimation of savings and performance without the need to resort to technical sheets of real CHP units. This is obtained by multiplying the thermal capacity of the unit by unitary mean values to obtain the various typical characteristics like power generation, consumptions and costs. Table I provides a brief overlook of some of those data.

Table I
Different equipment configurations identified

EQUIPMENT	TH. P. KW	TC. P. KW	EL.P. KW	COST €
110 kW CHP	110	-	72.5	88000
175 kW CHP	175	-	115.5	140000
110 kW CCHP	110	66	72.5	114400
175 kW CCHP	175	105	115.5	182000

Based on those first guess information a preliminary evaluation of the total production of the various configurations can be estimated as function of the power curves obtained by the building simulation.

Table II summarize the obtained results in term of heating thermal energy produced (TH.P.), cooling thermal energy produced (TC.P.), electrical energy produced (EL.P.) and natural gas consumption for the various CHP/CCHP units analysed.

Table II
Different equipment configurations identified

EQUIPMENT	TH. P. MWH	TC. P. MWH	EL.P. MWH	NG.C. M^3
110 kW CHP	381.7	-	247.5	80160
175 kW CHP	254.6	-	160.2	53473
110 kW CCHP	381.7	60.5	313.5	101326
175 kW CCHP	254.6	76.6	243.8	80281

Thermal and electrical energy generated by the CHP/CCHP units and corresponding consumptions have been estimated thanks to a custom developed spread-sheet by post-processing simulation results.

CHP gas consumptions and electrical generation have been calculated as a function of thermal needs obtained by the simulation, thanks to the previously mentioned operation schemes and specific machine performance curves.

Decreasing part load efficiency in power generation of the CHP units has also been taken into account through the application of a polynomial function to the hourly generated power function of the part load ratio at which the unit is currently working.

To identify the polynomial function, trend lines are obtained by mean curves of part load efficiency for natural gas Otto cycle powered engine available in literature.

At first glance it is possible to note how the smaller size CHP unit, sized at an optimal level based on the building heating curve, produces a significantly higher amount of thermal and therefore electrical energy compared to the larger CHP unit, sized based on general observations on the monitored building consumption, this is due to the different number of hours of operation as can be seen in Figure 5.

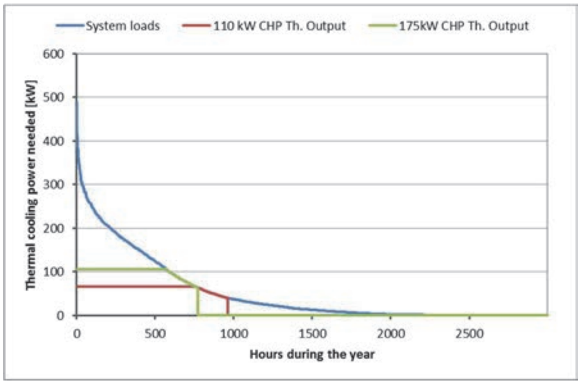

Figure 6 – Cooling thermal production of the two different CCHP units considered

Interesting is also the reversal of this behaviour for cooling energy production, as seen in Figure 6, this is due to the particular curve of cooling loads, consisting in high loads but for limited number of hours, which would suggest for a much higher optimized absorption chiller capacity. However, due to the limited number of working hours of the chiller, this difference is not enough to justify a change in the optimized CHP unit, as changing the chiller capacity would require to also change the heating capacity of the unit.

This variation of the system needs lead to a reduction in primary energy demand equal to 64.56 TOE/y, avoiding the emission of 101 tons/y of CO_2 in the atmosphere, for the optimized CHP unit, 42.15 TOE/y for the 175kW CHP unit, equal to 66 tons/y of CO_2, and 78.23 TOE/y and 59.43TOE/y respectively for the 110kW CCHP and 175kW CCHP schemes, preventing the emission of 122 tons/y and 93 tons/y of CO_2.

ECONOMIC ASSESSMENT

In order to perform the economic evaluation of individual interventions a number of characteristic values of the profitability of the investment are calculated such as NPV, IRR and PB.

The NPV indicates the variation of wealth obtained by investing (1):

$$NPV = -R_0 + \sum_{t=1}^{T} R_t/(1+r)^t \qquad (1)$$

Each investment is associated with an IRR, which is the discount rate that results in an NPV of zero (2).

$$NPV = \sum_{t=0}^{T} R_t/(1+IRR)^t = 0 \qquad (2)$$

Another key parameter in such assessments is the PB, the "breakeven point" of the investment, calculated as follows (3).

$$PB = \min t : \sum_{t=1}^{T} R_t/(1+r)^t > 0 \qquad (3)$$

The economic evaluation of each intervention is performed by calculating the above parameters over a time horizon of 15 years and assuming an opportunity cost of 3.5%.

The evaluations will be conducted according to the BAU HG scenario, Business as usual High Grow scenario identified by ENEA, that envisages an annual increase in the price of natural gas equal to 8% and electricity prices by 6%.

Major role in the economic analysis of those kind of investment assumes the account of all the incentives available. It is therefore of utmost importance the correct identification of them.

There are currently two main incentive methods provided by Italian regulation for cogeneration and trigeneration, both combinable with each other and governed by different regulations.

Energy efficiency titles (TEE), also known as white certificates, certify energy savings obtained through the use of efficient systems and technologies, similarly to what happens with renewable energy and green certificates. Access to such form of support for CHP units is regulated by the ministerial decree 20, 5 September 2011, from the ministry of Economic development. One TEE is emitted by the GME for each ton of oil equivalent (TOE) saved. Although TEEs do not produce a direct economical return they can be sold in the energy market to distributors of electrical energy and gas, which by law (D.M. 20/07/2004 and D.M. 21/12/07) needs to testify a certain amount of energy savings each year to the AEEG, or they can be sold directly to the GSE. For CHP units TEEs are acknowledged for the first 10 years of plant operation as a result of the actual monitored savings. To achieve those incentives the CHP unit needs to be identified as an High efficiency co-generator, all the units considered in this study respect this constrain.

The second incentive method consists in tax deductions for natural gas used for the combined production of heat and power, depending on the gas consumption of the unit compared to its electrical production, and differentiated by its final use category, part of the excise taxes imposed on natural gas can be avoided.

As Energy Efficiency Certificates (TEEs) are normally difficult to manage and, in some cases, only accessible by ESCOs the analysis is performed both considering and not considering the impact of those incentives.

Also TEE regulation has proved to be relatively stable through time, while tax deduction incentives suffered some sudden changes due to the overlapping of various regulatory bodies, sometimes disrupting the marketability of the technology also due to the lack of specific knowledge of the regulator.

For this reason two different and recently occurred tax deduction systems will be analysed, both to prove the strong dependence between government incentives and economical performances of CHP units and the impact a simple change made by different authorities can have to the marketability of the technology.

The first analysed regime is the one set by the note 75649/RU of the Italian Custom Agency, published on 6 September 2011 as a specification on the assessment and payment of the taxes on the energy product used for production of combined heat and power. This note changes the tax deduction calculation allowing tax deduction only on the percentage of natural gas used to produce electrical energy, leaving the remaining portion of the gas subject to normal taxation. Additional considerations on this regime are made after the presentation of economical results.

The second analysed regime is the one set by law 44/12, which restores the tax regime applied previously to the 75649/RU note. This means that tax deduction is applied to the portion of natural gas used for the production of electrical power, considered equal to the mean specific consumption of CHP units installed in Italy, in this case identified by the Electricity and Gas Authority with Resolution no.16/98, and reduced by 12%.

No economic incentives are provided by current regulation in relation to capital costs for the installation of CHP units, in any form, neither on an energy efficiency standpoint nor on a renovation standpoint, both covered by Legislative Decree 201/2011.

The current price of energy is set at 0.75 €/m^3 for natural gas and 0.25 €/kWh for electricity. Considering taxes on domestic use of natural gas are equal to 0.186 €/ m^3, that tax deduction is applied to the first 0.22 m^3/kWhe and that gas consumptions for all cases is assumed at 0.27 m^3/kWhe, this results in a mean price for natural gas of 0.59 €/ m^3 under the current regulation regime.

Following the 75649/RU note the portion of natural gas used for electrical production must be calculated as function of the total energy production of the CHP unit, equal to 40% for all the analysed units and finally resulting in a gas price of 0.68 €/ m^3.

Based on those prices an economic assessment can be performed through yet another self-developed spread-sheet. Gas and electricity price variations, capital and maintenance costs and cash flows are taken into account. Results are reported in Table III without considering the effect of white certificates and under Law 44/12 tax regime.

Table III
Economic assessment under Law44/12

INTERVENTIONS	COST €	NPV €	IRR %	PB Y
110 kW CHP	88000	375510	37	4
175 kW CHP	140000	171287	15	8
110 kW CCHP	114400	427655	33	4
175 kW CCHP	182000	229806	16	8

Those results are compared to the ones reported in table IV always evaluated without accounting for white certificates but under tax note 75649/RU regime.

Table IV
Economic assessment under 75649/RU

INTERVENTIONS	COST €	NPV €	IRR %	PB Y
110 kW CHP	88000	314736	33	4
175 kW CHP	140000	130747	13	9
110 kW CCHP	114400	350835	29	4
175 kW CCHP	182000	168941	13	9

Based on the two previous tables the impact of a sudden change in tax regulations can be evaluated. In this case the introduction of note 75649/RU led to an increase in the final natural gas price equal to 0.09€/ m^3, an increase of 15% compared to the previous price. This led to a decrease in the IRR value varying between 2% and 4%. NVP also decreased due to this change by between 40000 and 70000€ with 16-18% decreases for 110kW CHP-CCHP units and 24-27% decreases for 175kW CHP-CCHP ones. The higher impact on 175kW units is due to the major gas consumptions compared to the lower NPVs of the investments. For both the 175kW units this even resulted in the increase of 1 year in the payback time further impairing the desirability of the technology. Based on those results, the less the unit is optimized for the real building consumption the greater is the impact of price changes in natural gas, leading further toward non-productive investments.

Another interesting note about the tax regime imposed by 75649/RU can be deduced by the calculation method provided for tax deduction, as tax deduction was intended only on the percentage of fuel ascribable to the production of electric energy compared to the total amount of energy produced, therefore summing electrical and thermal energy output, the more the CHP units is efficient, recovering all the wasted heat available, the less is the percentage of fuel allowed to tax deductions, therefore promoting lower energy efficient systems at the expense of more efficient ones.

This is a noticeable conceptual error, going against the very definition of promoting energy efficient technologies, probably caused by the lack of knowledge by the Italian Custom Agency in term of energy efficiency technologies, and is the main reason why the tax regime was subsequently changed back to the previous one with updated parameters.

Aside from those comparisons it is easy to note how, even if all the units result in cost effective investments, the 110kW optimized units perform significantly better on an economical point of view. Also for the specific case study choosing the optimized CCHP unit over the corresponding CHP one corresponds in a decrease in the cost effectiveness of the units, due to the increased capital costs and the scarce amount of hours of cooling required. On the other end the non-optimized 175kW units benefits, albeit slightly, from the coupling with an absorption chiller due to the higher capacity available.

Including TEEs in the analysis the total amount of energy savings in term of TOE/year variation must be calculated accounting for every primary energy variation caused by the units. Each year, for the first 10 years, one TEE is awarded for every TOE saved multiplied by a 1.4 factor due to the size of the units. TEEs are then exchanged on the energy market, a conservative price of 80€/TEE is considered for this analysis.

Table V
Economic assessment under Law44/12 with TEEs

INTERVENTIONS	COST €	NPV €	IRR %	PB Y
110 kW CHP	88000	406067	40	3
175 kW CHP	140000	191241	17	7
110 kW CCHP	114400	464712	37	4
175 kW CCHP	182000	257969	18	7

Also considering the effect of TEEs all the examined units delivers an even greater financial advantage but the introduction of an ESCO in the management of the plant could become necessary.

The same analysis can now be performed using real CHP/CCHP units available on the market, here renamed unit 1 and unit 2. With electrical production of 50 and 125 kW units 1 and 2 have 107 and 175 kW of thermal heating capacity respectively, to which equals a cooling capacity of 75 and 120 kW in

CCHP mode. Table VI summarize the results of the economic assessment for those units.

Table VI
Economic assessment with real units

EQUIP	C. COST €	NPV €	IRR %	PB Y
CHP 1	65760	251750	36	4
CHP 2	142780	138297	14	8
CCHP 1	90870	268380	30	4
CCHP 2	172950	196001	15	7

Results obtained using CHP units available on the market are in line with expectations. Some differences are due to the inability to identify units optimized for the specific needs therefore losing some potential production. The same observations presented for the ideal units can be derived by the results of the real units.

All the previous results are in the hypothesis of intervening on the existing plant. If we consider the hypothesis of installing the units during the construction of the building, therefore suitably reducing the capacity of the current units saving about 20000€ on the capital costs and leading to even higher IRR up to 50% for the optimized CHP unit. All this without even considering the benefits that an energy analysis could bring to the design of the plant in the first place.

CONCLUSION

This work discussed the installation of a CHP/CCHP plant in a commercial building. A full economic feasibility analysis has been performed through the help of dynamic energy simulation to correctly identify thermal and electrical production of the plant, consumption and financial performance.

A series of self-developed spread-sheets have been arranged to identify energy and financial performance of CHP/CCHP units starting from system loads of the building both with default and technical sheet CHP data, making up an interesting analysis tool.

The importance of a correct sizing in the equipment has been highlighted and proved with the analysis of both optimized and non-optimized units in the case study. Suggestions presented on the correct sizing of CHP units are confirmed by obtained results. No economic advantage was found in the implementation of CCHP over CHP units due to the limited number of cooling hours of the building.

Also the importance of an accurate accounting of available incentives is empathized, considering the repercussions resulting from changes in the abovementioned.

Nevertheless the usefulness of energy analysis is highlighted, providing helpful information to obtain energy and economic savings by making optimal, and sometime counterintuitive, choices.

NOMENCLATURE

NPV, Net present value;
IRR, Internal rate of return;
PB, Payback time;
C_t, Net cash flows at year t;
T, Total considered years;
r, Cost of capital;

ACKNOWLEDGEMENT

The authors thanks the graduating student Emilio Cortinovis for his work and inputs on this project. Authors also acknowledges the guidance provided by Daniele Rossetti and Giordano Suardi of Icenova Engineering srl in Brembate, Italy.

REFERENCES

Evins R., Pointer P., Vaidyanathan R., 2011. Optimisation for CHP and CCHP decision-making. Building Simulation 2011, 12th Conference of International Building Performance Simulation Association, Sydney, 14-16 November.

de Wilde, P., G. Augenbroe, M. van der Voorden, 1999: Invocation of Building Simulation Tools in Building Design Practice. Proceedings of the Building Simulation '99, Sixth International IBPSA Conference, Kyoto, Japan, September 13–15, 1999. p. 1211–8.

D.lgs 20/2007. Implementation of Directive 2004/8/EC on the promotion of cogeneration based on a demand for useful heat in the internal energy market.

D.lgs 201/2011. Urgent measures for growth, equity and fiscal consolidation of public finances.

D.M. 5 September 2011. Support system for high-efficiency cogeneration.

D.Rg. VIII/8745 Lombardy Region.: Determinations regarding the provisions for energy efficiency in buildings and energy certification.

Molocchi, A., 2011. "To better exploit the mine of heat ", Nuova Energia 6, 2011.

Patania F., Gagliano A., Nocera F., Galesi A., 2012. Analysis of Performance of CCHP Systems for Large Hospitals. ENERGY 2012 : The Second International Conference on Smart Grids, Green Communications and IT Energy-aware Technologies. March 25-30, 2012 - St. Maarten, Netherlands Antilles.

Picco M., Marengo M., 2012. Energy simulation for energy efficiency improvements of an existing clinic in north Italy. BSO12 Building simulation and optimization, First IBPSA-England conference. 10-11 September 2012. Loughborough, UK.