Energy and Exergy Analysis of Heating and Cooling Systems in the Italian Context

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ABSTRACT

Energy saving and emissions reduction are both affected by the energy efficiency of the built environment and the matching between the quality of the energy carrier and the quality of the required energy. Taking into account qualitative aspects of energy leads to the introduction of the exergy concept. Heating and cooling of buildings require low valued energy, but space climatisation is often provided through high exergy sources.

This study is related to the IEA ECBCS Annex 49 "Low Exergy Systems for High Performance Buildings and Communities". The aim of this paper is to compare different existing technologies for heating and cooling, from both the energy and the exergy perspective. The issue of the exergy of renewable energy sources, such as solar energy and natural heat sinks, is addressed. The sensititivity of the analysis to climatic conditions is studied, by applying it to the main Italian climatic zones. Potential and limits of the energy and the exergy approach are compared and discussed.

1. INTRODUCTION

Exergy analysis has been applied for the evaluation of energy systems since the early '70s with the aim of finding the most rational use of energy. After a period during which almost scientific efforts were concentrated on energy analysis and CO_2 emission balances, in the last years exergy has been rediscovered and evenly applied to new scenarios for energy supply both at building and community levels. Exergy analysis has been applied to design of low-exergy buildings (Schmidt 2004), HVAC systems (Izquierdo Millan 1996, Bilgen 2002, Chengquin 2002, Asada 2003, Asada 2003, Guadalupe Alpuche 2005) and renewable energy sources (Koroneos 2001, Ozgener 2005). The exergy approach is at the basis of the IEA ECBCS Annex 37 Low Exergy Heating and Cooling of Buildings and also of the recently started IEA ECBCS Annex 49 Low Exergy Systems for High Performance Buildings and Communities. This paper is related to the Annex 49.

Main reasons for applying exergy evaluations to heating and cooling systems can be found just in the thermodynamic definition of exergy: a measure of the potential of a system to produce work in a given environment (Moran 1998). Exergy approach then naturally leads to the concept of the quality of energy, and may be used to derive a classification of energy forms, from high-grade (like work, chemical energy, electricity) to low (heat). To follow a low exergy approach means trying to match the quality levels of energy supply and demand, in order to minimize the utilisation of high-value energy resources and the irreversible dissipation of low-value energy into the environment.

In Europe, the energy consumption related to the building sector is about 40% of the total energy consumption and electricity consumption is constantly increasing also due to the cooling demand in summer, in residential buildings too. A large part of this energy requirement could be saved minimizing wastes of energy and promoting a more rational use of primary energy. Globally, these actions could give very valuable results in term of improving comfort conditions both in summer and in winter, control of fossil energy depletion, more equal energy distribution and usage in the World (basic task for the future, considering the energy trend of the emerging Countries) and reduction of greenhouse gases emissions. To that end, it is important to look to exergy analyses in order to increase the overall energy chain efficiency related to heating and cooling systems in the built environment. In other words, exergy analysis can support the selection, improvement and diffusion of the most promising existing - or new - technologies in order to minimize exergy consumption in buildings, giving a quantitative evaluation of the minimization potential.

The last regulations in energy saving field, in Europe (EPBD Directive) and then in each member Country, underline the important efforts made in order to reduce the energy demand of the building stock; the low exergy approach implies satisfying the remaining heating and cooling demand using low quality energy, when these demands have already been minimized. Currently most of the energy consumed by the building sector is used to maintain indoor temperatures in a very strict and small range of temperatures (basically, from 20°C in winter to 26°C in summer), corresponding to a low demand for exergy in space heating and cooling applications. Yet very often this demand is satisfied by high quality energy sources, such as fossil fuels or electricity. The low exergy approach try to invert this trend, proposing a more customized way of energy and exergy supply, taking into account the different final uses with different exergy requirements.

Referring to the Italian context and climatic conditions, and considering only the heating and cooling demand of buildings (no evaluations have been carried out about domestic hot water and electricity for lighting and other appliances), this work analyses the energy and exergy performances of different combinations (see Tables 3, 4 and 5) of energy generation and heating and cooling systems, underlining those that lead to a more efficient use of energy. Main results have been obtained with a steady state analysis related to the heating and cooling design conditions for two climatic sites: Milano (North of Italy) and Palermo (South of Italy).

2. METHODOLOGY

Referring to the Italian context, different energy generation scenarios and commercial systems for heating and cooling have been considered (see Tables 3, 4 and 5). For each system, steady state energy and exergy evaluations have been carried out on the basis of the following assumptions.

2.1 Site and climatic conditions

Two climatic contexts have been considered: Milano (North of Italy) and Palermo (South of Italy). For exergy calculations, a locally and seasonally varying reference environment temperature T_0 was assumed. This temperature was set equal to the design temperature typically used to size HVAC systems (D.P.R. 1052/1977, UNI 10339/2005). Indoor temperatures were set at design conditions according to Italian standards. In short:

in winter:

- same desired inside temperature for Milano and Palermo $T_U = 20$ °C;
- design temperature for Milano $T_0 = -5$°C;
- design temperature for Palermo $T_0 = 5$°C;

in summer:

- same desired inside temperature for Milano and Palermo $T_U = 26$ °C;
- same design temperature for Milano and Palermo $T_0 = 32$°C.

It is important to underline that differences between summer conditions in the two locations cannot be appreciated with steady state simulations carried out under these conditions but could be put in evidence with a dynamic simulation. In this case, dynamic cooling demand should be different in the two cases, as we can suppose considering that climatic conditions, duration of cooling season and day-night temperature range are different in Milano and in Palermo.

2.2 Size of the systems

For both the sites, the heating and cooling peak powers used for selecting the size of each system have been calculated referring to a single residential unit of 96 m^2 gross surface, with envelope performance responding to the new Italian standards (DL 192/2005 and DL 311/2006).

2.3 Boundaries of the analysis and scenarios

For the evaluations of the energy and exergy efficiency, two levels have been considered: energy generation (plant) and cooling/heating supply (system). For the first level, the following primary energy transformations have been considered: electricity generation with the Italian mix, electricity generation with a high performance technology (CCGT), electricity generation through photovoltaic, heat generation through waste heat recovery or through CHP plants. For the second level, different systems have been considered: gas boilers, district heating, solar collectors, heat pumps, absorption chillers, direct ground cooling systems systems (see Tables 3, 4 and 5).

When combining a CHP plant with a district heating system, only the heat production from the plant is taken into account. The thermal efficiency η_{TH} of a CHP plant is usually much lower than that of a traditional heat generation system η, like for example a gas boiler, due to the fact that a combined production of electricity and heat is achieved. A simple comparison between η_{TH} and η would wrongly penalize the CHP. Then in this work, in order to properly account for the more rational conversion of primary energy in a CHP, a “marginal efficiency of heat generation” was introduced and adopted, following the use of a marginal efficiency of electricity generation (Danny Harvey 2006). The concept is to compare the CHP plant with a reference electricity generation plant giving the same amount of electricity W_E, and to relate the heat production to the extra primary energy consumed by the CHP plant compared to the reference. Then the marginal efficiency of heat generation has been defined as follows:

$$\eta_{M,TH} = \frac{Q}{\Delta E_{PR}} = \frac{Q}{{W_E}/{\eta_E} - {W_E}/{\eta'_E}} = \frac{\eta_{TH}}{1 - {\eta_E}/{\eta'_E}} \tag{1}$$

where:

- Q is the heat produced by the CHP plant;
- ΔE_{PR} is the difference of primary energy consumed between the CHP plant and the reference electrical plant;
- η_E and η_{TH} are the electric and thermal efficiencies, respectively, of the CHP plant;
- η'_E is the electric efficiency of the reference electrical plant.

In Tables 3, 4 and 5 whenever a cogeneration plant is considered, the energy efficiency reported is calculated on the basis of Equation 1.

All the scenarios evaluated can be order by the kind of energy source involved as follows:

- fossil: scenarios based on fossil fuels used for electricity or for heating generation (i.e. gas boilers);
- renewable: scenarios based on solar energy for electrical generation and heat production;
- renewable equivalent (category of energy source used in the Italian context): scenarios in which heating is provided by district heating connected to a CHP plant or from waste heat deriving from industrial processes;
- fossil + renewable: scenarios based on fossil fuels and renewables (solar energy, ground source).

2.4 Plants performances

Considering energy generation (plant), energy efficiency is defined as the ratio between the obtained energy output (electricity or heat available for the final uses) and the primary energy input required to produce it. As described before, energy efficiencies are referred to: the Italian mix, state of the art of CCGT plants, and state of the art of photovoltaic poli-crystalline-Si technology. In case of cogeneration, taking into account that thermal and electric performance of a CHP plant could change depending on the type, the size and the configuration of the plant, two different alternatives have been considered: a large CHP plant with a large district heating grid (i.e. ASM Brescia) and a mini CHP plant (i.e. gas engine).

Exergy efficiency ε (ratio between the exergy output and the exergy consumed to produce it) is calculated as follows:

$$\varepsilon = \frac{Ex_U}{Ex_C} \tag{2}$$

where Ex_U is the useful exergy and Ex_C is the exergy consumed.

Because power can be considered as plain exergy, in case of fossil electricity generation, Ex_C is the electricity generated and Ex_C can be considered equal to the lower heating value of the fossil fuel; while, in case of photovoltaic generation, Ex_C can be referred to solar radiation. In this case, exergy efficiency becomes:

$$\varepsilon = 1 - {T_0}/{T_{sun}} \tag{3}$$

where T_0 and T_{sun} are the temperature of the environment and of the sun (as black body) respectively.

2.5 Systems performances

The energy efficiencies (or *COP*) of the several systems taken into account have been drawn from technical literature and catalogues of the most diffuse appliances, referring to the available commercial products nearest to the range of size estimated as mentioned above (Schibuola 2002a, Schibuola 2002b, Hennings 2004, Angelotti 2004).

Scenario with a solar heating system has been implemented evaluating system size and performance for the two locations by RETScreen software (RETScreen SWH3). Further, in this case we assume to meet 50% of the winter heating demand by the solar system and the remaining 50% by a condensing boiler.

Exergy efficiencies at the system level have been calculated starting from Equation 2. Since the systems supply a given heating/cooling demand Q_U to a building at the desired temperature T_U, the useful exergy may be expressed as:

$$Ex_U = Q_U \left| 1 - {}^{T_0}\!/_{T_U} \right| \tag{4}$$

2.4 Overall performances

When considering the entire energy chain, from the primary energy conversion to the heating/cooling supply in the building, an overall energy and exergy efficiency may be defined as:

$$\begin{aligned} \eta &= \eta_1 \cdot \eta_2 \\ \varepsilon &= \varepsilon_1 \cdot \varepsilon_2 \end{aligned} \tag{5}$$

where η_1 and ε_1 refer to the plant level, and η_2 and ε_2 refer to the system level.

3. ANALYSIS AT THE SYSTEM LEVEL

An energy and exergy comparison among different heating and cooling options should be carried out in terms of primary energy and exergy. However, the system energy and exergy efficiency may be used for comparing homogeneous systems, that is systems fed with the same kind of energy source.

As an example we could compare the performances of different kind of electrically driven heat pumps. In Table 1, the *COP* and the ε of different kinds of heat pumps in the design conditions of Milano are reported. Choosing the air-to-air heat pump as the reference case, the ratios COP/COP_0 and $\varepsilon/\varepsilon_0$ are calculated.

Table 1. Energy and exergy comparison between heat pumps (T_0=-5°C)

system	*COP*	ε	COP/COP_0	$\varepsilon/\varepsilon_0$
Air-to-air heat pump	2.82	0.24	100 %	100 %
Air-to-water heat pump	1.79	0.15	64 %	64 %
Ground source heat pump	4.50	0.32	160 %	132 %

As long as we compare the two air source heat pumps, the energy and the exergy efficiencies provide the same information. But if we compare the air source with the ground source, we can see that the advantages, in terms of *COP* increase (+60 %), of the ground source over the air source one are reduced in terms of exergy efficiency (+32 %). Actually the ratio between the exergy efficiencies can be expressed by the following equation, where T_G is the temperature of the ground:

$$\frac{\varepsilon_{GSHP}}{\varepsilon_{ASHP}} = \frac{COP_{GSHP}}{COP_{ASHP}} \frac{1}{1 + \left(COP_{GSHP} - 1\right)\left(1 - \dfrac{T_0}{T_G}\right)} \tag{6}$$

which shows that the ratio between the *COP*s is reduced by a factor taking into account the exergy destruction related to the heat extraction from the ground. This term is present whenever a heat source or sink at a temperature level different from the environment is used. The exergy analysis then provides a measure of the "thermal pollution" of the natural sources.

It is interesting to investigate how the exergy efficiency of an air source heat pump is affected by the outside air temperature T_0. If this temperature changes, the system *CO*P, the heating load of the building and its quality vary. By using typical full load *COP* data at different outside air conditions, the exergy efficiency behaviour of an air-to-air heat pump is calculated and shown in Figure 1.

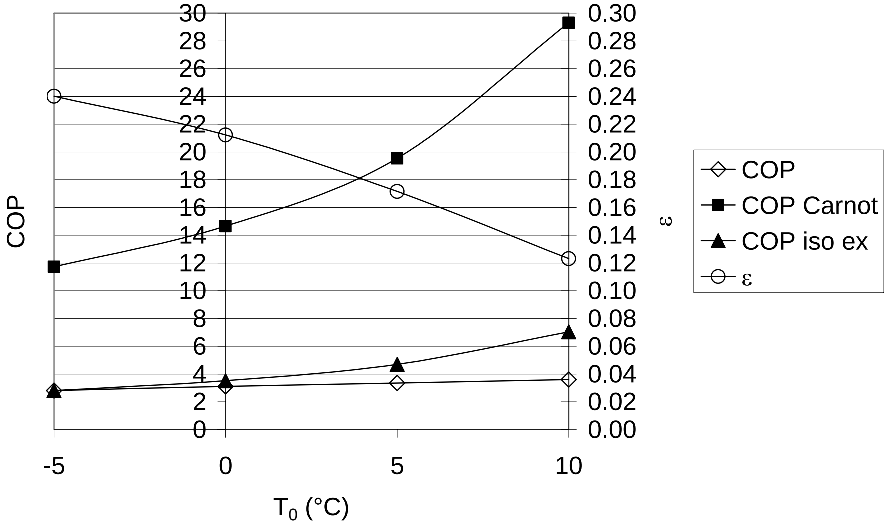

Figure 1. Air-to-air heat pump:
full load *COP*, Carnot *COP*, iso-exergy *COP* and exergy efficiency ε versus outside air temperature T_0.

Figure 1 shows opposite trends for the *COP* and for ε. The exergy efficiency behaviour may be explained by considering that ε is affected by both the *COP* and the quality factor of the heating load (1- T_0/ T_U). In order to have ε increasing with T_0, the *COP* should grow more rapidly, so that it would compensate for the decreasing quality of the building heating demand. In the same graph an "iso-exergy" *COP*, calculated by setting the exergy efficiency constant and equal to the value achieved at T_0=-5°C, is also shown. The iso-exergy *COP* is well below the ideal Carnot *COP* and might represent a stimulus for the technological research. The *COP* data used here do not take into account the effects of part load operation. When considering typical part load performances a distinction must be made between single stage and modulant control systems (UNI 10963, Schibuola 2002b). Generally speaking, we can expect that in the first case the effective *COP* at a given outside temperature T_0 would be lower than the full load *COP*, resulting in a more evident decrease of ε with T_0. In the second case, depending on the *COP* trend, an increasing ε might be possible. These qualitative considerations point out the potential of a dynamic exergy analysis, based on dynamic simulation tools taking into account the building heating load profile during the year as well as the heat pump effective operation.

Among cooling systems, it is interesting to compare single and double stage absorption chillers. As it is shown in Table 2, the energy and the exergy analysis give opposite results. The single stage chiller has a lower *COP* but a higher ε, since it might be fed with lower temperature heat (80°C instead of 150°C). This means also that more heat sources may be coupled with a single stage system, such as solar collectors or typical district heating, while double stage systems require proper temperature waste heat or other heat sources like burners.

Table 2. Energy and exergy comparison between absorption chillers (T_0=32°C)

system	*COP*	ε	COP/COP_0	$\varepsilon/\varepsilon_0$
single stage	0.7	0.103	100 %	100 %
double stage	1.1	0.079	157 %	77 %

4. ANALYSIS AT THE SYSTEM AND PLANT LEVEL

The results of the analysis at the system and plant level for different heating options in Milano and Palermo are shown respectively in Table 3 and Table 4. Each table gives the kind of primary energy source, the generation plant with its energy and exergy efficiency η_1 and ε_1, the heating system with its energy and exergy efficiency η_2 and ε_2, and finally the overall energy and exergy efficiency η and ε. In the tables, options are listed from the most exergy efficient to the less. Several comments may be drawn from these tables:

- the effect of moving from Milano to Palermo is mainly to increase the energy efficiency of air source heat pumps and solar collectors and shift down the exergy efficiencies of all solutions; this shift affects slightly the order of the list, so that best solutions and worst ones in Milano and Palermo are substantially the same;

- the highest overall exergy efficiencies are achieved by those solutions employing waste heat or heat from a cogeneration plant, followed by energy efficient electrical heat pumps fed with the most efficient electrical plants (combined cycle);
- fully renewable solutions (solar systems) are in general the less exergy efficient, due to the great difference between the exergy input (solar exergy) and the exergy output (low temperature heat exergy). In this sense, we can say that the exergy approach is not useful to promote solar energy solutions, since it does not take into account the availability and renewability of this source. The exergy efficiency values could be used instead within solar systems, in order to find the best solar technologies providing space heating;

Table 3. Energy and exergy efficiency comparison among heating options in Milano

source	***generation***	η_1	ε_1	***system***	η_2	ε_2	η	ε
RE equivalent	waste heat recovery	1	1	district heating	0.9	0.319	**0.90**	**0.319**
RE equivalent	small size cogeneration	3.30	0.79	district heating	0.9	0.319	**2.97**	**0.253**
fossil+RE	combined cycle	0.55	0.55	ground source heat pump	4.5	0.318	**2.48**	**0.175**
fossil	combined cycle	0.55	0.55	air-to-air heat pump	2.82	0.240	**1.55**	**0.132**
fossil+RE	Italian electrical mix	0.36	0.36	ground source heat pump	4.5	0.318	**1.62**	**0.114**
RE equivalent	large size cogeneration	1.31	0.32	district heating	0.9	0.319	**1.18**	**0.100**
fossil	Italian electrical mix	0.36	0.36	air-to-air heat pump	2.82	0.240	**1.01**	**0.086**
fossil	√			condensing gas boiler + radiant panels	1.05	0.085	**1.05**	**0.085**
fossil	combined cycle	0.55	0.55	air-to-water heat pump	1.79	0.153	**0.98**	**0.084**
fossil	√			condensing gas boiler + radiator	0.98	0.075	**0.98**	**0.075**
fossil	√			gas boiler + radiator	0.86	0.067	**0.86**	**0.067**
fossil	Italian electrical mix	0.36	0.36	air-to-water heat pump	1.79	0.153	**0.64**	**0.055**
RE	photovoltaic	0.15	0.16	ground source heat pump	4.5	0.318	**0.68**	**0.050**
RE	photovoltaic	0.15	0.16	air-to-air heat pump	2.82	0.240	**0.42**	**0.038**
fossil+RE	√			solar collectors+condens. gas boiler+radiant panels	0.38	0.033	**0.38**	**0.033**
RE	photovoltaic	0.15	0.16	air-to-water heat pump	1.79	0.153	**0.27**	**0.024**

Table 4. Energy and exergy efficiency comparison among heating options in Palermo

source	***generation***	η_1	ε_1	***system***	η_2	ε_2	η	ε
RE equivalent	waste heat recovery	1	1	district heating	0.9	0.217	**0.90**	**0.217**
RE equivalent	small size cogeneration	3.30	0.70	district heating	0.9	0.217	**2.97**	**0.152**
fossil+RE	combined cycle	0.55	0.55	ground source heat pump	4.5	0.197	**2.48**	**0.108**
fossil	combined cycle	0.55	0.55	air-to-air heat pump	3.35	0.172	**1.84**	**0.094**
fossil+RE	Italian electrical mix	0.36	0.36	ground source heat pump	4.5	0.197	**1.62**	**0.071**
fossil	combined cycle	0.55	0.55	air-to-water heat pump	2.51	0.128	**1.38**	**0.071**
fossil	Italian electrical mix	0.36	0.36	air-to-air heat pump	3.35	0.172	**1.21**	**0.062**
fossil	large size cogeneration	1.31	0.28	district heating	0.9	0.217	**1.18**	**0.060**
fossil	√			condensing gas boiler + radiant panels	1.05	0.051	**1.05**	**0.051**
fossil	Italian electrical mix	0.36	0.36	air-to-water heat pump	2.51	0.128	**0.90**	**0.046**
fossil	√			condensing gas boiler + radiator	0.98	0.045	**0.98**	**0.045**
fossil	√			gas boiler + radiator	0.86	0.040	**0.86**	**0.040**
RE	photovoltaic	0.15	0.16	ground source heat pump	4.5	0.197	**0.68**	**0.031**
RE	photovoltaic	0.15	0.16	air-to-air heat pump	3.35	0.172	**0.50**	**0.027**
fossil+RE	√			solar collectors+condens. gas boiler+radiant panels	0.49	0.026	**0.49**	**0.026**
RE	photovoltaic	0.15	0.16	air-to-water heat pump	2.51	0.128	**0.38**	**0.020**

In Table 5 the cooling solutions for Milano and Palermo are ordered by decreasing overall exergy efficiency. In this case we can notice that:

- exergy efficiencies for cooling technologies are generally much lower than for heating technologies, due to the different quality of the cooling/heating demand expressed by the following relation:

$$\left|\frac{Ex_U}{Q_U}\right| = \left|1-\frac{T_0}{T_U}\right| \tag{7}$$

  Equation 7 gives $\left|Ex_U/Q_U\right|$=0.085 if T_0=-5°C and T_U=20°C (heating design conditions in Milano), but gives $\left|Ex_U/Q_U\right|$=0.020 if T_0=32°C and T_U=26°C (cooling design conditions in Milano). This means that, the heating and cooling load being equal, much less exergy is required to maintain summer rather than winter comfort. Since cooling exergy efficiencies are so low, their values should be considered in a relative way rather than absolutely;
- absorption chillers fed with waste heat or cogenerated heat and direct ground cooling coupled with combined cycle have the highest exergy efficiency.

Table 5. Energy and exergy efficiency comparison among cooling options in Milano/Palermo

source	***generation***	η_1	ε_1	***system***	η_2	ε_2	η	ε
RE equivalent	waste heat recovery	1	1	single stage absorption chiller	0.7	0.103	**0.7**	**0.103**
RE equivalent	waste heat recovery	1	1	double stage absorption chiller	1.1	0.079	**1.1**	**0.079**
fossil+RE	combined cycle	0.55	0.55	direct ground cooling	10	0.123	**5.50**	**0.068**
RE equivalent	small size cogeneration	3.30	0.45	single stage absorption chiller	0.7	0.103	**2.31**	**0.046**
fossil+RE	Italian electrical mix	0.36	0.36	direct ground cooling	10	0.123	**3.60**	**0.044**
fossil+RE	combined cycle	0.55	0.55	ground source heat pump	4.5	0.072	**2.48**	**0.040**
fossil	combined cycle	0.55	0.55	air-to-air heat pump	3.46	0.069	**1.90**	**0.038**
fossil	combined cycle	0.55	0.55	air-to-water heat pump	3.25	0.065	**1.79**	**0.036**
fossil+RE	Italian electrical mix	0.36	0.36	ground source heat pump	4.5	0.072	**1.62**	**0.026**
fossil	Italian electrical mix	0.36	0.36	air-to-air heat pump	3.46	0.069	**1.25**	**0.025**
fossil	Italian electrical mix	0.36	0.36	air-to-water heat pump	3.25	0.065	**1.17**	**0.023**
RE	photovoltaic	0.15	0.16	direct ground cooling	10	0.123	**1.50**	**0.019**
fossil	large size cogeneration	1.31	0.18	single stage absorption chiller	0.7	0.103	**0.92**	**0.018**
RE	photovoltaic	0.15	0.16	ground source heat pump	4.5	0.072	**0.68**	**0.011**
RE	photovoltaic	0.15	0.16	air-to-air heat pump	3.46	0.069	**0.52**	**0.011**
RE	photovoltaic	0.15	0.16	air-to-water heat pump	3.25	0.065	**0.49**	**0.010**
RE	Solar collector	0.40	0.06	single stage absorption chiller	0.7	0.103	**0.28**	**0.006**

5. CONCLUSIONS

By applying a steady state exergy analsyis to the entire energy chain, a comparison among different scenarios for heating and cooling supply of buildings in the Italian context was carried out. The best options, from the point of view of the rational use of energy, have been highlighted. In relative terms, the results of the comparison do not depend strongly on the location chosen, represented here by Milano and Palermo.

Some considerations may be derived on the potential and constraints of the exergy approach applied to renewables. On one side, the comparison between air source and ground source heat pumps carried out here shows that the exergy analysis may be useful to account for effective renewability of natural resources, like heat sources and sinks different from the atmosphere. On the other side, the overall performance of heating and cooling systems based on solar energy (either converting it into electricity with phovoltaic generation and using it for electrically driven heat pumps, or converting it into heat through solar collectors and using it in absorption systems in summer or in integration with a gas boiler in winter) is generally very low. This result suggest that fossil and renewable scenarios should be evaluated separately. Following this approach for example in the heating case, we may say that the best options in the fossil scenario are high performing electricity generation (CCGT) coupled with high performing systems (GSHP) or CHP with district heating, while in the renewable scenario best results are obtained with photovoltaic generation coupled with high performing systems (GSHP). The choice between the fossil and the renewable scenarios might depend mainly on strategic (economic and political) decisions.

As already mentioned, this research follows a steady-state approach. The performed investigation on the sensitivity of the exergy efficiency of an air source heat pump to the outside temperature allows foreseeing the potential of a dynamic approach, being able to catch the variation of the energy demand and the part load operation of a system. By applying a dynamic analysis, the overall energy chain in detail might be better considered, including also energy storage and distribution, performance of the envelope and so on. Referring to a given building, absolute values for exergy fluxes and yearly exergy balances might be derived. The dynamic approach might be especially relevant for the summer situation, when inertia and solar radiation generally play an important role.

Then, moving from stationary to dynamic evaluations may be a future development of the present reasearch.

NOMENCLATURE

ASHP	air source heat pump
CCGT	combined cycle gas turbine
CHP	combined heat and power
COP	coefficient of performance
GSHP	ground source heat pump
HVAC	heating ventilating air conditioning
RE	renewable energies

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