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Heading towards the nZEB through CHP+HP systems. A comparison between retrofit solutions able to increase the energy performance for the heating and domestic hot water production in residential buildings

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ABSTRACT

Optimizing consumptions in the field of civil construction led to define energy labels for residential buildings. To calculate the building energy demand the EPgl was determined, i.e. the annual consumption per m^2 of primary energy. This paper examines the technical solutions useful to optimize the energy demands for heating during space-heating season and domestic hot water production (thanks to energy analysis softwares as MC11300 and TRNSYS) and, at the same time, to take into account the financial issues those interventions implied. The total inside heated surface of the building case study is 1204.00 m^2, hence the inside heated volume is about 3250.80 m^3. Besides the more traditional interventions concerning the building envelope and its systems, the paper examined the performance of a system obtained through the combination of a cogenerator (CHP) and a heat pump (HP), thus, substituting the conventional boilers of the buildings. CHP+HP solution increases the most the energy label of the building (from a D class with EPgl = 59.62 kW h m^{-2} $year^{-1}$, to an A class, with EPgl = 25.64 kW h m^{-2} $year^{-1}$), determining an annual energy cost saving of 3,114 € $year^{-1}$, allowing to amortize installation costs (54,560 €) in a reasonable payback period, i.e. 15.4 years. This innovative solution in the residential sector can be realized through retrofit interventions on existing buildings, hence it leads the current dwelling towards nZEB with a remarkable benefits for the environment.

1. Introduction

Recent outlooks revealed a constant increase in the global energy consumption until 2040, whatever the economic and political scenarios might be [1]. Right now the residential sector reports an influence of 18% on the entire global energy demand. The new overspreading demand of the emerging economies in the non-OECD Countries is leading to new residential conditions with higher living standards. Hence some other factors will increase in the residential sector as well: heating consumptions, the production of domestic hot water, air-conditioning and lighting. The estimation is that until 2040 the demands of this sector will increase with an average annual rate of 0.4% in developed Countries and 2.5% in the developing Countries, until reaching a 31% of total world residential delivered energy consumption.

To be more specific, in Europe the 2010 residential sector reported a 26.65% of total final energy consumption [2]. According to the geographical location in EU, the energy mix that wants to fulfill the demand is formed by the combustion of fuel and gas derivatives (55% of the total) in the South of Europe, whereas a certain quantity of energy derived from the coal must be added in the Centre and East of Europe (51% of the total) and in the North and West of Europe as well (60%) [3]. Nowadays these energy choices cannot be environmentally sustainable anymore. The solution is to regulate the demand of the residential sector by reducing the exertion of traditional energy sources and at the same time using renewable sources [4]. This is why the EU issued a legislation [5–8] that wanted to promote the energy efficiency in buildings by making homogenous regulations in all those Countries part of the community seeking for new technical solutions that might

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Nomenclature

C	internal heat capacity of the building [J K^{-1}]
CHP	combined heat and power [–]
CO_2	carbon dioxide [–]
COP	coefficient of performance [–]
CTI	Italian Technical Committee [–]
EP_{acs}	energy performance for the production of domestic hot water [kW h m^{-2} $anno^{-1}$]
EPBD	Directive on the Energy Performance of Buildings [–]
EP_e	performances for the air-conditioning in the summer [kW h m^{-2} $anno^{-1}$]
EP_{gl}	global energy index [kW h m^{-2} $anno^{-1}$]
EP_i	energy performance for the heating during cold season [kW h m^{-2} $anno^{-1}$]
EP_{ill}	energy used for the lighting [kW h m^{-2} $anno^{-1}$]
EP_v	energy used for the ventilation [kW h m^{-2} $anno^{-1}$]
HIPs	Home Information Packs [–]
HP	heat pump [–]
I_{el}	power to heat ratio [–]
I_t	global radiation [W m^{-2}]
k_e	coefficient of external adduction [W m^{-2} K^{-1}]
k_i	coefficient of internal adduction [W m^{-2} K^{-1}]
nZEB	nearly Zero Energy Building [–]
PCI	Lower Heating Value [kW h/S m^3]
$P_{el,CHP}$	CHP electrical power [kW]
$P_{el,HP}$	HP electrical power [kW]
P_{fuel}	CHP fuel consumption [kW_t]
$P_{heat,b}$	thermal power necessary to the building for the heating [kW]
$P_{heat,CHP}$	CHP thermal power [kW_t]
$P_{heat,HP}$	HP thermal power [kW_t]
PVC	polyvinyl chloride [–]
Q_{gn}	total heat gains [J]
$Q_{H,ht}$	total heat exchange between confined environment and the outside [J]
$Q_{H,nd}$	heat provided by the system to the confined environment [J]
$Q_{H,tr}$	transmission heat exchange for heating season [J]
$Q_{H,ve}$	ventilation heat exchange for heating season [J]
Q_{int}	internal gains [J]
Q_{sol}	solar gains [J]
Rh	relative humidity [%]
RT	Thermal Regulation [–]
t_a	room temperature [°C]
t_m	average temperature [°C]
U	thermal transmittance [W m^{-2} K^{-1}]
$\eta_{exchanger}$	efficiency of the heat exchanger [–]
$\eta_{h,gn}$	heating utilization factor [–]
$\eta_{heat,CHP}$	CHP heat recovery efficiency [–]

increase the energy performances in new and existing buildings while taking into consideration costs and benefits [9].

1.1. Energy certification of European buildings

The emission of the Directive on the Energy Performance of Buildings (EPBD) [5] was performed after the Kyoto protocol [10], and it was a legislative instrument used by the EU to reduce CO_2 emissions with respect to 1990. Each country, according to both its climatic and constructive features of the existing buildings and its own national regulations, was asked to set the rules to perform the energy analysis of the buildings (both existing and new) with respect to common principles dictated on a supranational level through the European regulations. The goal is to have a decrease in the energy consumptions on a communitarian level in the residential sector, with the objective that in 2020 it will be possible to build only nZEB (nearly Zero Energy Building) [11,12].

According to the national regulation, the amount of specific energy (kW h/m^2) indicates the energy performances and the energy class of the building examined. The resulting value will be in a certain range set by the regulations: with the decrease in the energy demand the building will have a higher energy class (identified by a letter, from A to G, if the class is high it will correspond to one of the first letters of the alphabet). The certificate must present the recommendations for the improvement of the energy performances of the building, that is technical interventions on the building envelope and/or on the energy system used.

In the United Kingdom the energy performance certificates were introduced in 2007 in the documentation Home Information Packs (HIPs). Meant for the owners of domestic apartments, they are the result of the exertion of the [5] in the English legislation through the Housing Act 2004 [13] and The Energy Performance of Buildings (Certificates and Inspections) (England and Wales) Regulations 2007 (S.I. 2007/991) [14]. Denmark made obligatory the energy certificate of the buildings in 1997, before the European Directive, which joined in 2006 [15]. France adopted the European Directive through the 2005-781 regulation [16] which was then updated at the end of 2015 and it is based on the Thermal Regulation TR [17] updated in 2012. Portugal, through the regulation no. 78/2004 [18] realized the Directive, as Italy with the no. 192 in 2005 [19].

1.2. The energy requalification of the Italian house block

In this context the issue that wants to be stressed is the Italian building scenario. Italy is a country whose boundaries extend from the North to the South between the 47° and 35° parallel respectively [20,21]. It is characterized by a variety of different climates which makes harder to have constructive standards both for the optimization of buildings' envelope and planning of the systems meant for the building. For new buildings, planned to decrease energy consumptions, it is possible to have great results in terms of energy performances; on the other hand for existing buildings (which usually were realized through old planning criteria with economic necessities that were different with respect to nowadays demands) is more complicated to improve their efficiency. Statistically speaking, Italy is characterized by a building scenario with old structures. According to the latest Italian census [22], carried out in 2011, the total of the residential buildings presents 12.2 millions structures; 56.7% of them were built before 1970 (that is before 1976 which is when the first law [23] for the restraint of the energy consumption in the buildings was issued), 29.4% of them were built between 1970 and 1990 and only 13.9% was built between 1990 and 2011. This is why most of the structures report a low efficiency with high primary energy supplying costs [24,25].

Then it should be also said that the Italian real estate sector is mainly formed by small owners [22] who often, due to initial investment costs, do not want to perform interventions on their properties to improve their energy efficiency. This is one of the main barriers to the technological refurbishment necessary for a