Energy Efficiency Improvement

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The school buildings represent an energivorus sector of the real estate where different efficiency actions are necessary. Literature shows how the design of a multi-energy system offers numerous advantages, however, there are problems related to the integration of cogeneration units with renewable energy sources due to the low flexibility of the first one and the high degree of uncertainty of the latter. The authors provide an alternative solution through the analysis of a case study consisting of a Multiple Energy System on three Sicilian schools, focusing on the system's operational strategy, on design and sizing of components and trying to exploit the energy needs complementarity of buildings instead of integrating the conventional energy storage systems. Not considering school activities in summer, it was decided to install a cogeneration unit sized on winter thermal loads, whereas the electricity demand not covered was reduced with photovoltaic systems designed to maximizing production for seasonal use and with loads concentrated in the morning hours. The effectiveness of this idea, which can be replicated for similar users and areas, is proved by a payback-time less than 11 years and a reduction of 31.77%, of the CO2 emissions.

Multi-Energy System | School Building | Energy district | CHP system | PV System | Dynamic Simulation | Economic analysis.

1. Introduction

Nowadays, the increase in energy efficiency is a priority topic in the world’s scientific community, which mainly focuses its attention especially on those energy-intensive sectors considered weaker from the efficiency point of view. Among the several energy-intensive sectors, the civil sector, generally represented by cities as a whole, covers around 70% of global energy demand, representing one of the most important fields to focus efforts to effectively reduce energy consumption and CO_2 emissions [1][2].

There are many studies carried out in this sector, which involve various modeling approaches and tools [3][4]. In this sense, Keirstead et al. [5] seek to clarify the topic with a review including the analysis of 219 papers examining the opportunities to improve the modeling of urban energy systems. Macarella [6] highlights how the multi-energy systems, abbreviated as MES, on a regional, city or district scale, represents an optimal solution to increase the technical, economic and environmental performance of “classic” energy systems whose sectors are treated separately. To support this thesis, a paper by Connolly et al. [7] highlights how district-scale building energy planning through district heating plants could play a strategic role in the cost-effective decarbonization of the EU’s energy system, reducing CO_2 emissions and using primary energy at a lower cost. Actually, a district approach allows for a transition away from fossil fuel use towards forms of cleaner energy, which alone can reduce the primary energy consumption by about 30–50% [8]. This happen because the district energy systems (DESs) simultaneously supply users with electricity and heat for heating and/or cooling.

2. Impact of Current Solutions to Energy Efficiency Improvement

2.1. Advantages

The advantages offered by these applications in the city network have been proved; these include the possibility of a more accessible energy system, better integration of renewable energy sources (RESs) into the urban energy mix, less dependence on imports of fossil fuel and on the economic and political pressures deriving from it, as well as the several benefits deriving from the reduction of pollution [9]. For these reasons, several countries have made district heating an important reality for the achievement of their environmental goals [10]. For example, since 1990, Denmark obtained a CO_2 emission reduction of about 20%, Paris predicts a reduction of 75% by 2050 and, thanks to the presence of district heating and cooling systems, Tokyo achieved a primary energy saving of 44% if compared to individual heating and cooling systems [8]. Furthermore, the combination of the district energy system with combined heat and power (CHP) systems offers further advantages, because it allows for the reuse of residual heat by reducing the consumption of fossil fuels and promoting an efficient use of available resources [11][12]. As highlighted by Thornton and Monroy [13], with the continuous increase in the population, and the following growth in energy demand, United States has also shown a propensity for the distributed energy generation where the production center is physically close to the district or consumers, thus avoiding losses in the transmission and distribution phase.

2.2. Challenges

However, facing the diversity of existing applications, technologies, interactions between users and/or energy carriers, as reported by Sayegh et al. [9], the main challenge to be faced lies in the development of district heating systems based on more flexible energy systems, characterized by more penetration and integration towards systems powered by RESs [14], coupled with “smart” buildings and with a more dynamic vision of prosumers.

Moreover, despite the evident advantages in the diffusion of these systems, as shown by the sector literature [15][16], there is still some reluctance by some regulators and public utilities that needs to be overcome, as it has numerous technical, regulatory and commercial obstacles [13]. For this reason, several universities, research centers, engineers and experts in energy and sustainability have conducted their research to promote the diffusion of the energy districts through new applications and studies that reduce the reluctances expressed and contribute to the achievement of the environmental objectives. An example is represented by a study conducted by Lizana et al. [17], where a district heating system powered by solar energy systems and by a biomass powered plant serves areas with moderate population density in the Mediterranean, with a payback period of 10–13 years.

Sibilla and Kurul [18] presented an interesting study where, in 23 school buildings in Rome, Italy, a procedure was tested which aimed to reconcile distributed, renewable and interactive energy systems (DRIs) with urban-scale models, providing a positive contribution in the urban design phase. Cortés et al. [19] analyzed a smart energy microgrid district in the Canary Islands characterized by several households and a school building that included photovoltaic plants, domestic hot water (DHW) heaters and a pool for the balance of energy consumption. Alavijeh et al. [16] analyzed the cost-effectiveness of CO_2 reduction strategies in a multi-energy system at the Chalmers University of Technology, for heating, cooling and electrical energy services. Rosato et al. [20] have modeled in a TRNSYS environment [21] a hybrid district heating system based on solar and geothermal energy sources with seasonal storage to satisfy the thermal needs of an energy district consisting of six residential buildings and three schools in Naples. The results show a significant reduction in primary energy consumption, CO_2 emissions and costs compared to “separated” conventional heating systems.

3. Proposed Solution to Energy Efficiency Improvement

The work proposed by D'Amico et. al (Multi Energy School System for Seasonal Use in the Mediterranean Area) fits perfectly within the perspective of promoting energy districts, through new applications and studies by universities, research centers, and experts in the energy sector, which especially involve those companies characterized by large margins of energy saving and high consumption, such as schools, universities and public administration buildings, or in those particular urban contexts where the classic efficiency measures on the building envelope are complex.

On the basis of the potential deriving from the involvement of public structures such as schools and/or university campuses, the authors of this paper analyse the feasibility of an energy district powered by a CHP system totally integrated with Photovoltaic (PV) systems. In detail, it was decided to design a Multiple Energy School System (MESS) in Palermo, a city of the southern Italy, choosing three of the biggest schools and complementary in the energy consumption. These buildings represent the typically building of 50s, built before the law [22] on the energy containment of buildings [23], characterized by an envelope with low-quality, built without paying attention to the occupants comfort and the efficiency of the air conditioning plants.

The MESS, proposed in this work, aims to overcome obstacles mainly due to the coupling of renewable energy systems and he CHP units themselves. In fact, the integration of multiple energy systems would lead, if not carefully designed, to the reduction of the working hours at full load of the CHP unit with the consequent reduction of the efficiency of the unit. In some cases, this hypothesis would make the integration itself and the realization of the multi-energy district not convenient from an energy and economic point of view. Unlike many works, for instance [24], where these critical issues are shown, the proposed study aims to design the CHP unit only for the full satisfaction of the heating load of the total district requirement according to the seasonal use of the buildings and only for the winter climatization when the buildings are open. Electricity consumption that cannot be covered by the CHP are reduced thanks to the installation of large PV systems. This solution, as demonstrated, is sustainable in a highly sunny area like the Mediterranean one.

The approach here presented is an alternative solution compared to other in literature, where, for example the problem of the flexibility of the cogeneration system is partially solved with the installation of thermal storage systems (TES) [25][26] or through technological improvements [27][28]. Otherwise, in the proposed paper, the authors solve the mismatch between the lack of flexibility of the CHP and the uncertain of the RES through an operational, design and sizing strategy that simultaneously takes into account the climatic conditions, the latitude and the intended use.

The here achieved results show that, for all that users with similar intended use, characterized by substantial thermal loads for space heating, by large surfaces where to install PV systems and characterized by high levels of insolation, this design strategy it is absolutely winning and perfectly practicable and replicable.

4. Conclusions

The study proposed the development of an energy district in the city of Palermo.

In detail, the authors provide an alternative solution through the analysis of a case study consisting of a Multiple Energy School System on three 50s Sicilian schools, focusing on the system's operational strategy, on design and sizing of components and trying to exploit the complementarity of the energy needs of the buildings instead of integrating the conventional energy storage systems.

From the analysis of the actual consumptions of the schools and the results obtained from the simulations, it was shown that only two of the three buildings require the CHP unit and this system will be necessary only for the heating period. In fact, the closure of the school buildings from mid-June to mid-September shows that for the remaining days of the entire cooling period, the indoor temperatures are below the design temperature, justifying the choice not to install an absorption machine coupled to the CHP unit. Based on these considerations, the CHP was sized considering only a heating thermal load of about 718,000 kW_t.

From the electric consumption point of view, in order to minimize the consumptions from the national grid, it was decided to integrate the production with the photovoltaic renewable energy. The study considered the percentage of energy produced by the plants during the school's opening hours and during the closing hours. These quantities of energy were valued at the purchase price of electricity from the grid in the first case (self-consumption) and at the sale price to the grid in the second case.

The economic analysis showed the payback time of the three PV investments in less than nine years. This assessment was carried out on the basis of the sensitivity analysis carried out on the interest rate i%, a value that if the plants were built in the absence financing and incentives, is absolutely realistic in the southern regions, which benefit from a high solar radiation. For the year 2017, the year in which the installation was hypothesized, the photovoltaic systems would respectively guarantee 18.18% of the electricity needs for Building 1, 33.48% for Building 2 and 23.47% for Building 3.As for the cogeneration destined exclusively pursue the thermal demand of two schools, it is evident that during the twenty years of useful life it always provides the necessary thermal needs; while there is an inversion of the trend as regards the electricity produced, which is in deficit for the first eight years of operation of the unit, but in surplus for the remaining years. It was also considered that the combined heat and power plant, when it produces more than its needs, will sell electricity to the national grid.

The economic savings obtained at the end of the useful life of the cogeneration system amount to approximately 2,800 k€ compared to the costs incurred to obtain the same energy requirement from separate production. The overall economic saving obtained thanks to the three photovoltaic systems is instead equal to 426,630.65 €.

The integrated cogeneration unit with the three photovoltaic systems also allows to obtain important results in saving the amount of CO_2 released into the atmosphere compared to the production of thermal and electrical energy from traditional systems. The saving amounts to about 5,750 tons of CO_2 avoided in the atmosphere.

Finally, an analysis of the results according to the investment made for the cogeneration unit would fall within a time span from 9.9 to 12.5 years, depending on the variation in the interest rate applied, between 1% and 4%. These long return times are linked to the fact that the system would be active only during the opening hours of the school buildings and therefore for a reduced number of operating hours compared to the characteristic times that allow to reach the maximum cost-benefit ratio. While on the one hand cogeneration allows to obtain valid results from an environmental and energy point of view, as it reduces atmospheric pollution, dependence on fossil sources and allows to recovery of waste thermal energy, on the other, the feasibility economic does not always cross these aspects, since the purchase and management costs are still quite high and therefore presuppose an intense use of the system.

In conclusion, the alternative procedure to sizing the combined heat and power function of the heating thermal loads only is justified by the particular case study and the urban context. This approach, can be used in case of seasonal or non-conventional use, customizing the energy district to the needs of user, avoiding the oversizing and therefore the consequent economic losses that could occur. Obviously, an interesting possibility to increase the operating hours of the combined heat and power could be that of creating a district heating network that includes the residential buildings close to the cogeneration plant; these buildings have a thermal energy requirement even in the afternoon and evening hours. In this way, during the closing hours of the school, the combined heat and power could be in operation by feeding the electricity produced into public grid and providing heating services to nearby buildings; increasing annual operating hours would significantly increase the net present value and at the same time reduce the payback time. This idea will be explored in a future work.

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