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Analysis of potential energy, economic and environmental savings in residential buildings: Solar collectors combined with microturbines

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HIGHLIGHTS

- ▶ Centralization of energy systems for a group of buildings improves profitability.
- ▶ Thermal solar systems are economically interesting even in low radiation locations.
- ▶ Regulations currently in force determine the feasibility of high efficiency energy systems.

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ABSTRACT

This paper presents an analysis of a combined solar-cogeneration installation for providing energy services in a set of four residential buildings. Different configurations as regards the number of collectors and their orientation, the number of buildings grouped together, the type of microturbines used in the cogeneration system and their daily and annual operating period are studied from the legal, economic and environmental perspectives. The installation that fulfils the minimum requirements of the solar system coverage and the cogeneration system efficiency currently in force, and simultaneously leads to the highest energy, economic and environmental savings is the one that integrates both technologies and centralises the installation for the four buildings together. A payback period lower than 8 years is obtained that makes this investment recommendable, but it is also concluded that maintaining the existing subsidies for these technologies and lowering the costs of the equipment, are essential factors to ensure the feasibility of this type of installations.

1. Introduction

Residential and commercial buildings constitute about 40% of the European Union's final energy consumption, and this figure is still increasing. The main objective of European Parliament Directives 2002/91/EC and 2010/31/EU on the energy performance of buildings [1,2] is to boost energy efficiency in Member State buildings, taking into consideration climatic conditions and other local characteristics combining both factors in a balanced cost-efficiency relation. In compliance with the implementation of these directives, the Technical Building Code (TBC) [3] came into effect in Spain in November 2006. On the one hand, the TBC increases the quality of the required thermal building enclosure. On the other, it requires the installation of thermal solar collectors for domestic hot water (DHW) production in every type of building, the minimum annual solar energy production depending on the climatic conditions of the region and the domestic hot water demand of the building.

Thermal solar collectors for DHW production currently constitute the most widely employed equipment worldwide [4]. There are numerous referenced studies addressing the use of this technology in regions with high solar radiation [5–9]. However, applications in places where solar radiation is moderate, as in the north of Spain, where there is also a high seasonal dependence, have been less extensively studied. When some characteristics of the building could limit the amount of the solar energy captured, other technologies that also reduce the environmental impact of fossil fuel consumption [10–12] could complement the solar installation to achieve the minimum annual energy production required in the TBC.

Combined Heat and Power (CHP) is one of the technologies most widely used at present to meet energy needs in buildings, mainly as a result of the promotion policies of efficient and distributed energy generation that have been implemented in some European countries (Spain, Portugal, Italy, Denmark, Germany, Austria, among others) [13]. The requirements to qualify an instal-

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Nomenclature

A_c	aperture area of the collector (m^2)
C	fuel consumption (Nm^3)
D_1, D_2	coefficient in the f-chart method
EEE	equivalent electrical efficiency (%)
f	coverage of the solar system
F	fuel energy consumption (kW h PCI)
$\dot{F}$	fuel consumption rate (kW)
$F_R\tau\alpha$	optical efficiency factor of solar collector
F_RU_L	loss heat transfer coefficient of the solar collector (W/m^2 K)
g_1, g_2	functions in the f-chart method for calculating coefficients D_1 and D_2
$I_{s,h}$	global solar radiation on the horizontal surface (kW h/m^2)
I_s	solar radiation on the collector surface (kW h/m^2)
LHV	lower heating value (kJ/kg)
N_c	number of solar collectors
$N_{\mu T}$	number of microturbines
P	cost of purchasing energy (€/kW h)
PB	payback (year)
PES	percent energy saving (%)
Q	thermal energy (kW h)
$\dot{Q}$	heat transfer rate (kW)
Ref_E	reference value of efficiency for separate electricity production
Ref_H	reference value of efficiency for separate heat production
T	temperature (°C)
V	volume (m^3)
W	electrical energy (kW h)
$\dot{W}$	velocity of electrical energy (kW)

Greek symbols

η	efficiency (%)
ρ	density (kg/m^3)

Acronyms

CHP	Combined Heat and Power
DHW	domestic hot water
μT	microturbine
TBC	Technical Building Code

Subscripts

ac	accumulation
amb	ambient
b	boiler
d	demanded
e	electrical
g	global
heat	heating
i	index indicating domestic heat water (i = DHW) or heating (i = heat)
m	month index (m = 1,...,12)
s	solar
th	thermal
w	water distribution system

lation for this special regimen vary depending on the country, but they are in general related to the installed capacity (micro-scale and small-scale units are usually favoured) and the efficiency of the plant.

The interest in micro-scale and small-scale cogeneration units has resulted in the development of new technologies such as small gas engines, micro-gas turbines, Stirling engines, fuel cells and organic Rankine cycles. Among them, the use of micro-gas turbines as primary movers in cogeneration plants is now increasing, not only in industry, but also in the building sector [14–18]. The characteristics of reduced power and low noise levels of commercial units make them more suitable than other thermal motors for their application in all kinds of buildings [19–25].

The objective of the present paper is the design of an installation for covering the energy needs of a set of four residential buildings that fulfils the requirements of the Spanish legal framework affecting the technologies used. The buildings are located on the northern coast of Spain, a region that is noted for receiving substantially lower solar radiation than the average value of the country. Additionally, other factors related to the location of the buildings in the centre of a city contribute to reducing the available solar radiation: limited space for installing solar collectors, shadows from neighbouring buildings and orientation determined by the urban layout. For this reason, the installation combines thermal solar collectors for producing domestic hot water (mandatory in the TBC) and micro-gas turbines for combined heating and electricity to be sold to the grid. As the optimal design of installations based on renewable or high efficiency technologies is largely influenced by the legal framework and economic aspects are also involved, different configurations of both systems (solar and cogeneration) are analysed, calculating for each of them different indexes of energy efficiency, economic profit and environmental savings.

2. Present state of the buildings

The study has been applied to a set of four 20-year-old residential buildings, named as A, B, C and D in Fig. 1, located on a crossroads in the centre of the city of Gijón (Asturias, Spain), latitude 43°32′N, with two differently oriented main façades facing onto the street. The orientation of the façades is expressed in terms of the angle from the south direction to their normal direction.

Fig. 1 shows also the space available on the flat roof of the buildings for installing thermal solar collectors (shadowed regions) and their orientation, indicated by arrows that represent the horizontal projection of the normal direction to the collector's surface.

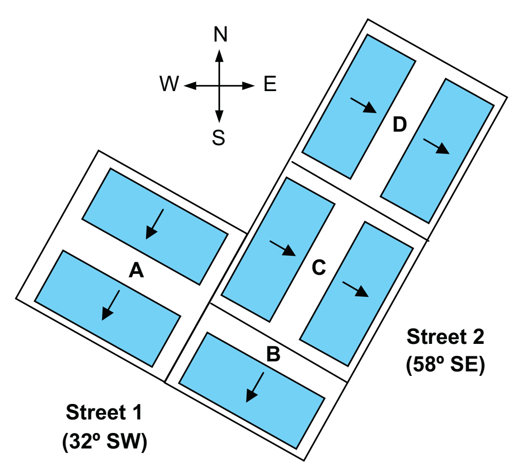

Fig. 1. Plan view of the buildings and space available on the flat roof for installing solar collectors.