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Distributed generation and trigeneration: Energy saving opportunities in Italian supermarket sector

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ABSTRACT

This paper presents an analysis of the potential for introducing distributed generation systems in the supermarket sector in the light of Italian legislation (inasmuch as concerns tax incentives and regulations) with a view to arriving at some generally applicable criteria. The energy users in question are characterized by a strong demand for energy for refrigeration for food preservation and for ambient air-conditioning during the summer.

This makes supermarkets particularly suitable for trigeneration applications with the prime mover coupled with absorption systems. This study analyses the feasibility of implementing trigeneration systems for the combined production of electricity and ambient heating and air-conditioning energy or, alternatively, for the combined generation of electrical energy and refrigeration for the preservation of food. Finally, the hypothesis of combining trigeneration systems with photovoltaic systems aimed at maximizing the energy saving achievable was also considered. This paper analyses the various technologies from a technical, economic and environmental standpoint, enabling advantages and disadvantages to be identified in relation to a real case.

1. Introduction

The term distributed generation (DG) includes various fossil fuel or renewable energy generation and/or cogeneration technologies located in the vicinity of the point where the energy is used. Using DG systems offers a number of advantages, such as a reduction in the energy costs for the user and for the domestic and international economies as a whole, fewer losses in transmission, fewer carbon dioxide emissions, a better quality electrical energy generation and a less vulnerable electrical system [1].

Based on data presented by Terna, the Italian national grid owner [2], the proportion of electrical energy consumption deriving from public and commercial services in Italy amounts to 25% and, according to an investigation conducted by the International Energy Agency [3], supermarkets represent the principal consumer in the commercial services sector. It is consequently useful and interesting to analyze potential energy saving alternatives for this area. A supermarket's energy requirements are characterized by a strong demand for electrical energy, which represents a mean 80% of its total demand, and the need for ambient heating energy that is concentrated in the winter months. Based on research conducted by the Canadian Energy Efficiency Office [4] on energy consumption in supermarkets, Fig. 1, the refrigerated food counters are one of the main energy consumers, followed by lighting and the electrical energy needed for air-conditioning in summer.

The present paper assesses the feasibility of using trigeneration systems to guarantee the generation of electrical, heating and air-conditioning energy. The system analyzed consists of a natural gas powered primary motor, an internal combustion engine or a micro-turbine system, coupled with a lithium-bromide (LiBr)/water absorption system able to cope with the air conditioning load. Using the absorber has a useful boosting effect on the generation of heat and electricity, affording a considerable improvement in the profitability of the system [5].

Given the great demand for refrigeration for foodstuff preservation, as a second solution combining cogeneration systems with absorption systems for refrigerating the chilled food units was considered as well. Ammonia/water refrigeration systems are the only solution capable of guaranteeing low temperatures (0 °C to −40 °C), but although they are the oldest type of refrigeration technology known, they are less widespread and standardized than LiBr/water systems, and are generally only installed in large-scale industrial plants [6].

This paper therefore analyses also the feasibility of replacing the compression refrigerators with the ammonia/water absorption systems for the chilled food units while keeping compressor refrigeration for the frozen food units [7].

Finally, with a view to polygeneration in order to maximize the energy saving, combining trigeneration systems with photovoltaic systems has also been considered. In accordance with the provi-

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Nomenclature

AC	air-conditioning
AEEG	Autorità per l'energia elettrica ed il gas (Italian Electricity and Gas Authority)
C	costs
CHP	combined heat and power plant
CO_2ER	CO_2 emission reduction
COP	coefficient of performance
DG	distributed generation
E	expenditure
F	cash flow
HVAC	heating ventilating and air conditioning
I	cost for interests
ICE	internal combustion engines
K_i	net heating value (kW h/N m^3)
L_{th}	thermal limit
$\dot{m}$	flow rate (N m^3/h)
η	efficiency
μ_{CO2}	emission factor (g/kW h)
μGT	micro-turbines
NPV	net present value
O&M	operation and maintenance
PBP	payback period
PES	primary energy saving
PV	photovoltaic system
Q	thermal power (kW)
r	interest rate
R	cooling power (kW)
Re	revenue
REFR	refrigeration
STC	standard condition
TCO_2ER	trigeneration CO_2 emission reduction
TOE	ton of oil equivalent
TWC	tradable white certificate
W	electrical power (kW)

Subscripts

c	cooling
el	electrical
eq	equivalent
f	fuel
k	current year
pv	photovoltaics
ref	reference
SP	separated production of electrical and thermal energy
th	thermal

sions of the EU decision makers (Directive 2001/71/EC [8]), Italy is promoting the generation of electrical energy from solar energy, which is considered strategic for its great potential, especially in consideration of the climatic features of the Country, and southern Italy in particular.

The photovoltaic system is assessed on the basis of the "feed-in-tariff" (DM 19/2/2007 [9]), a scheme of trading account incentives for promoting the use of electricity from solar sources that awards an economic incentive as a function of the kW h generated by a plant.

2. Technical and economic assessment: case study

2.1. Baseline case

The analysis was developed on the basis of the consumption of a typical supermarket situated in central-northern Italy, characterized by a sales area of 10,000 m^2. Table 1 shows the characteristic parameters of the energy user in question.

The electrical energy demand for all the other uses and electrical energy demand for food is characterized by a major demand for electricity for refrigeration, aimed at food preservation (Fig. 2), which is almost constant throughout the year, while the demand for central heating is concentrated in the winter months.

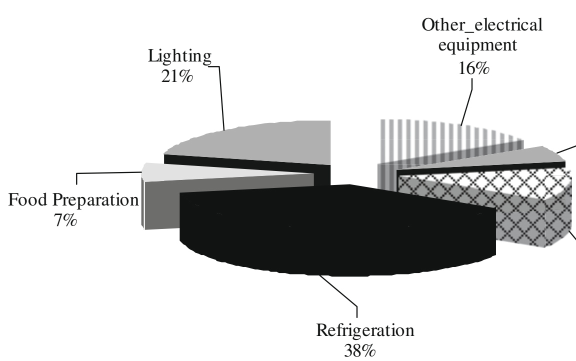

Fig. 1. Electrical energy demand according to end-uses in a supermarket [4].

There is also a clearly evident increment in the electrical energy demand during the summer months due to the need for air-conditioning and to the worse performance of the refrigerators because of the higher condensing temperatures in summer.

For a proper sizing of the distributed generation systems, we cannot fail to consider the daily distribution of the energy consumption. Fig. 3 shows the results of monitoring daily electrical energy consumption for air-conditioning and refrigerated food preservation in various months of the year. There is a clearly different time distribution of the energy consumptions recorded, with the electrical energy demand for air conditioning concentrated during the supermarket's opening hours, whereas the consumption of the refrigerators for food preservation is continuous, around the clock.

The present energy procurement system is managed separately, electrical energy being purchased from the national grid, while the refrigeration energy is produced by the vapor compression type refrigerators and the heating energy by a condensing boiler. The parameters for the current management system are given in Table 2.

Adopting the methodology presented in [10–12], in the present study 4 possible distributed generation solutions for the supermarket in question are analyzed, using for comparison the current energy procurement system.

Starting from the energy needs, the ideal solution for each scenario, assessed from a technical and economic point of view, has been identified.

The economic analysis was conducted on an existing supermarket, with the baseline system already in operation. The investment costs considered in the analysis consisted therefore in the cogenera-

Table 1
Characteristic parameters of the supermarket under study

Parameters	
Sales area (m^2)	10,000
Opening days per year (days)	310
Annual electricity consumption (MW h)	5093
Mean electrical capacity (kW)	828.5
Maximum electrical capacity (kW)	1050
Annual thermal energy consumption (MW h)	880
Mean thermal capacity (kW)	280