Energy Self Sufficiency with Renewable Sources a Biomass System with Advanced Control Strategies in the Rehabilitation Project of an old Rural Building Complex

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Abstract

BEST Dept. was involved with Regione Sicilia in a research work of the UE MéRITE program for the development of integrated territorial management experiences in pilot areas. Main project goal was to design appropriate retrofit solutions and technologic systems for the rehabilitation of an old rural building complex in Sicily (Italy), reaching the energy self sufficiency with renewable sources.
After the first phase of the research, due to the abundance of wood biomass from the near forests, the potentiality of a co-generation system based only on biomass source, with the aim of a sophisticated control system for reducing the electric peaks, has been evaluated.

Keywords: Renewable energy, Rehabilitation project, Biomass, Stirling motor, Control system

Introduction

The present paper regards the case study of the rehabilitation of an old rural building complex located at Monti Sicani (in the centre of Sicily, between Palermo and Agrigento).
Main steps of the project were: weather data elaboration, energy potential evaluation, energy analysis of buildings, identification and comparison of energy systems alternatives [Butera and Caputo, 2004].

Elaboration of the meteorological data file:

After statistic elaborations reported in [Butera and Caputo, 2004] and fig. 1, monthly data adopted for site meteorological condition characterisation were:

- monthly mean temperature (by statistical trend curve)
- monthly mean relative humidity and monthly mean beam and diffuse solar radiation (by measurement in nearest meteorological station).

Due to the building conditions and to the aims of the project, a dynamic hourly model was used for the evaluation of buildings energy behaviour. To that end, monthly mean data were used for calculating hourly data by means of a stochastic model (by MeteoNorm program; see fig. 2 for hourly temperatures representation).

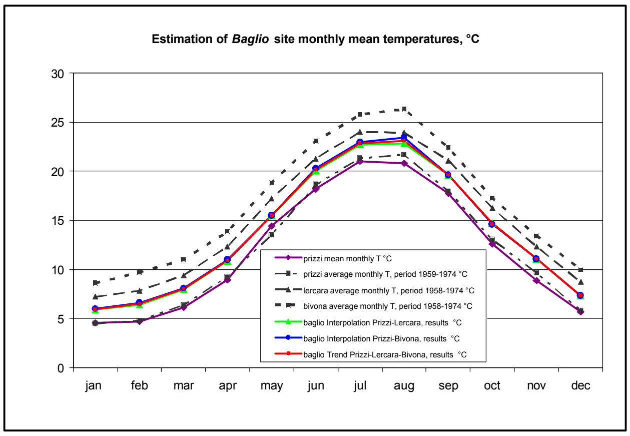

Figure 1. Monthly mean temperatures for the 3 stations considered and results of statistic evaluations for temperature estimation in site

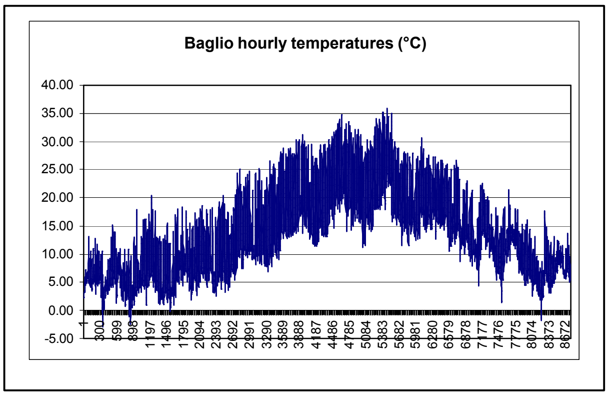

Figure 2. MeteoNorm elaboration results; Baglio site hourly external temperatures

Energy analisys of the building complex

The characteristics of geometry and materials have been elaborated [Butera and Caputo, 2004] and thermal zones repartition have been defined (table 1).

For the envelope, the following U-values have been defined referring to the documentation collected and to hypotheses for improving the energy characteristics [Butera and Caputo, 2004].

In order to carry out energetic simulations, internal loads (lighting [Butera, 1995], equipment and occupancy), temperature set points and schedules for lighting, equipment, occupancy and plants have been assumed [Butera and Caputo, 2004].

Table 1. Zones, surfaces and volumes

Zone	Expected use	Surface m^2	Volume m^3	Zone	Preliminary destination	Surface, m^2	Volume, m^3
1	Technical zone	33.2	174.0	7	Reception	95.2	461.7
2	Naturalistic laboratories	94.4	495.3	8	Conference room	189.4	1022.7
3	Visitor centre	107.1	358.8	9	Museum	141.1	712.6
4	WC	39.1	144.7	10	Offices	114.9	483.0
5	Classrooms	107.5	521.5	11	Guestroom	141.1	557.0
6	Exhibition room	268.1	1086.0		Sum	1331.1	6017.3

Dynamic simulations were carried out implementing data (weather, geometry, thermal characteristics, internal loads and schedules) in TRNSYS in order to:

- determine energy demand and peaks of heating, cooling and electricity
- evaluate alternative renewable energy systems
- choose the most suitable system taking into account available local resources and landscape and aesthetic problems.

On the basis of the TRNSYS simulation results, such as hourly temperature for each thermal zone and hourly energy demand (heating and cooling) for each zone, the following parameters of building performance have been evaluated (fig. 3 and table 2).

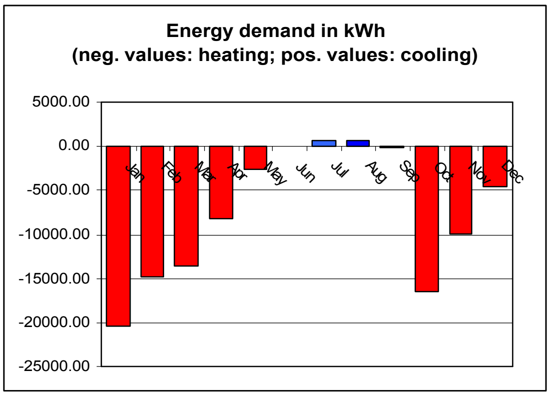

Figure 3. Total thermal energy demand monthly values

	Heating	Cooling	Electricity
Energy demand; kWh/m^2 year	68	2	20
Peak power; kW	100	11	30

Table 2. Total heating and cooling demands and peaks

The average electricity power during a year, based on reported results, is around 3 kW, 10 times less then the peak.

Energy system alternatives, Renewable energy sources

At the moment, the buildings complex is not connected to the electrical grid and to the natural gas grid. For this reason and for the aims of the project, a RE based solution was assumed. Available renewable energy sources are sun, wind and wood biomass from the near forests. On the basis of these RE sources, six energy system alternatives have been defined and evaluated [Butera and Caputo, 2004] including economical and environmental pros and cons for each alternatives. A summary is reported in table 3.
The conclusion of the first phase was that best choice could integrate more than one alternative and will depend on overall project goals and social-economical-environmental effects and considerations.

Biomass solution with advanced control system for electrical loads
The wood biomass based solution

In the second phase, in order to valorise the most abundant and the most steady available RE and in order to promote low cost solutions, a biomass based alternative has been evaluated. Due to the storage possibilities, biomass, wood in this case, is the most continuously available renewable source and can be used for heating and power generation by means of boilers and Stirling engines. If storage could be carried out adequately, on the basis of the biomass demand, and the availability of biomass could be sufficiently steady during the year, grid connection could be advised but not necessary.
Despite nowadays information about performance of biomass Stirling engines are not complete, this solution represent a new way to produce heat and power from biomass at reduced scale. That means to evaluated a plant solution with use of biomass energy for heating and electricity generation.

Table 3. Summary of pros and cons of each energy supply

Alternatives	Pros	Cons	Notes
Wood chips+mini-wind	Low cost Well established technologies	Visual impact Wind speed not optimum (4-6 m/s) Need for grid connection	Nominal rotor performances with higher wind speed
Wood chips+micro-wind	Well established technologies	Visual impact Wind speed not optimum (4-6 m/s) Need for grid connection	Easier landscape integration for micro-rotors Higher Cost Nominal rotor performances with wind speed >10 m/s
Wood chips+pv	Well established technologies	High cost Visual impact for solar tiles architectural integration Need for grid connection	
Wood chips Stirling	Use of an abundant resource presently wasted No need for grid connection No visual impact	Technology not yet mature Grid connection would be wise	Need for wood biomass chain management and control
Wood pellets Stirling	Use of an abundant resource presently wasted No need for grid connection No visual impact Possible activation of new economic activities	High cost Technology not yet mature Grid connection would be wise	Need for wood biomass chain management and control Benefits: start of pellet market Costs: need for wood treatment plant for pellet production Technical and economical feasibility only for oversize pellet production
Wood chips (or other wood biomass) Seebeck effect	Use of an abundant resource presently wasted No need for grid connection No visual impact	High cost Technology not yet mature Grid connection would be wise Need for heat sink	Electricity generation due to Seebeck effect with $?_{el}/?_{th}$ = 1/10 Need for wood biomass chain management and control

Biomass Stirling engines permit to produce decentralized, CO_2-neutral thermal and electric energy from wood (waste material) [Hegele, 2004].

Two experimental solutions have been considered:
1. Use of biomass boiler for heating and pellets Stirling engine for electricity and heating [Luft, 2004]
2. Use of Stirling engine integrated into a wood boiler for electricity and heating [Hegele 2004].

It must be underlined that in the first case pellets production system is needed, while in the second case wood from forest will be *lightly* treated only to reach physical-chemical conditions suitable for the combustion process. Both alternative are at the end of the testing phase; but for the first there are more results at not pilot scale (figure 4).
Furthermore, the adoption of wood boilers has been designed in order to valorise the high quantity of wood waste from the surrounding forest, with a simple wood combustion system, without using particular wood-based fuel such as pellets. After the fuel preparation, wood boilers will ensure the casing of the heating demand and the attainment of the wanted thermal comfort conditions.
Nowadays, wood combustion for domestic use represents a consolidate technology and there are many company in the market for boilers production and selling.

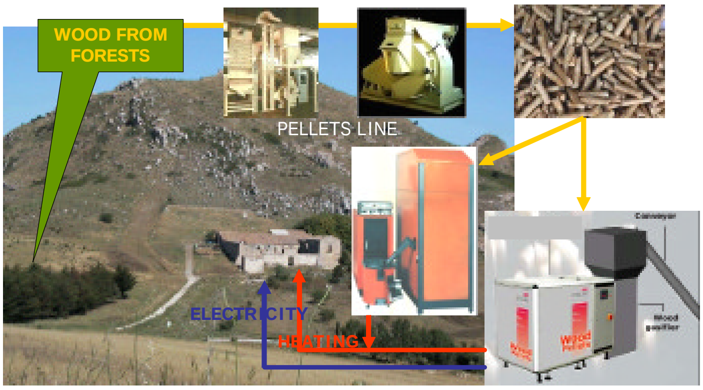

Figure 4. Scheme of the biomass solution considered

The control system for reducing electricity peak

After the preliminary plant design, for reducing the number of Stirling engines, not only for costs and logistic reasons, but also because the occupancy of the different zone of the building complex will be sporadic, an advanced control system for adapting dynamically instant power consumption to instant power production has been proposed.
It has been assumed to install a domotic integrated control systems for household appliances. With an easy to use interface, not only surveillance devices, but also energy saving measures and maximum power control (simple wiring, incorporating a central digital bus and a micro-processor in every control device, assures communication between all appliances and systems) can be integrated. This automation system can supplement heating and lighting systems, security systems, scenario controllers and communications.
The integrated control system can operate and manage all the electric appliances, with the main aim of energy saving, improving comfort conditions when and where needed (comfort on demand; integration of lighting and day-lighting, switching off lights when not needed; switching off appliances momentary when power is not available and re-starting when power is available, etc).
The concept is: in this situation, electricity demand represents the most problematic supply; for this reason the control of the electricity demand could be the most smart intervention. In this situation, an electrical peak of about 30 kW was calculated, against an average electrical

power needed of about 3 kW, with a very changeable occupation of the different thermal zone and with a very infrequent occupation of almost the whole buildings complex during the year. That's why the power generation system has been dimensioned to fit about 15-18 kW, corresponding to 5 o 6 times the average electrical power needed during a year. The idea is to rollover the demand-supply relationship: appliances, lighting etc can be switched on only when power from the electricity generator (consist of 2 adequate Stirling engines) is available. This challenge could not be possible without such a sophisticated control system.

Further developments: wood gasification

Another biomass based solution could be analysed: the gasification of wood. The collected wood could be gasified and then treated and cleaned to be used as gas (such as natural gas) in engines, not only Stirling engines. Small scale gasifiers have to be studied in depth for the technical-economical evaluation (typically, bio-gas *versus* pellets) of this alternative.

Conclusions

This case study represents an opportunity for the integration of the renewable energy in retrofit interventions. The results demonstrate the possibility of stimulating renewable penetration and socio-economical development of rural area with a low cost and low energy interventions. Energy conservation is possible because the envelope measures have been finalized to reduce the U-value and to adopt advanced technical solutions for energy saving in respect of heating, cooling and electricity supplies, whenever possible. Benefits of renewable energy systems have been evaluated according to the global energy analysis of the buildings and of the site. Renewable energy integration is possible because building will be equipped with a biomass energy system. In order to reduce the power peak and to fit electricity demand to electricity supply, a smart control system has been provided.

Despite nowadays information about performance of biomass Stirling engines are not complete, this solution represent a new way to produce heat and power from biomass at reduced scale. The progressive electricity market liberalization and the demand for environmentally conscious technologies could facilitate their diffusion in Italy in the next future.

Even though there is still need of testing activities and efficiency improvement, this system is going into the market standards. Stirling engines are expected to become competitive with the diesel generation in isolated areas with abundance of wood biomass.

Stand alone with energy storage and grid connected solutions have been evaluated. Further surveys have to be carried out to develop tools and investigate and verify technical solutions for including RE power plants as active components of the power supply system.

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