A HYBRID MICRO GENERATION SYSTEM FOR A SMALL SCALE BUILDING IN URBAN AREA

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Abstract

The rising energy demand and the increased saving needs in building sector pushed in the last years the development of hybrid systems combining different energy sources, which can optimize available renewable resources, exceeding limitation deriving from each source. Research and market pay particular attention on questions resulting from integration of different systems and technical solutions, with the aim of maximizing their viability in terms of yielded energy and compatibility with planning and environmental regulations in any specific installation site. Funded by Italian Ministry of Environment (MATTM) and developed by Department of Architecture of University of Naples Federico II in partnership with two private companies, the research project TeCNaRE experimented a hybrid micro-generation system that exploits soil thermal inertia and wind energy, merging two renewable sources generally not combined. The hybrid renewable micro-generation system investigated in this study is a ground source heat pump which is co-powered by energy provided by a ground mounted micro-wind turbine, to meet the heating and cooling demand of a small building in urban area. Research brought to a prototypal installation on a demonstration building located on Posillipo hill, a valuable area of the city of Naples (Southern Italy), where landscape is strictly preserved and protected.

Keywords: micro-generation, urban areas, small scale buildings, hybrid system

Introduction

It is widely known that buildings are one of the major players in energy consumption, since at global level they consume from 20% up to

40% of energy (Perez Lombarda et Al., 2008); in EU building stock accounts for some 45% of carbon emissions and it has been estimated that 80% of the buildings that we will be occupying in 2050 is already existing (Xing et Al, 2011) Accordingly, many research and policy efforts are addressing practices to increase the overall sustainability of building stock. This is due either to the need for reducing energy demand in order to face insufficient capability of existing energy services, either to the call for reducing the contribution of built environment to the environmental pollution deriving from fossil fuel use in energy production (Anisimova, 2011).

Initially, studies have focused on optimizing energy consumption by mean of energy tariff policies, citizens education and incentives supporting either energy retrofitting interventions aimed at increasing buildings insulation either the purchase of energy efficient appliances (Uihlein & Eder, 2010). Despite a rather positive impact, these measures seem to be not sufficient to achieve intended EU goals of reducing emissions of greenhouse gases by 20%, reaching 20% of renewable energy in the total energy consumption, and increasing energy efficiency to save 20% of EU energy consumption by 2020, as set by the European Union climate and energy package (da Graça Carvalho, 2012). This is for two main reasons: first one relates to the fact that existing building stock is, in future years, in the need of continuous maintenance, upgrading, adaptation and rehabilitation (Ravetz, 2008) but the knowledge of its actual energy performances is not enough reliable for assuring the expected results from retrofitting investments (Menassa, 2011). On the other hand, the increasing comfort expectations and the growing number of powered appliances produces a general rising of energy demand for both domestic and office buildings, finally limiting the real impact of energy saving policies (Ravetz, 2008).

In this framework, a different energy strategy is being pursued, aimed at reducing the environmental impact of energy used by buildings powering them with energy yield from renewable resources. A promising perspective in that direction is given by distributed micro-scale production of energy services (electricity and/or heat) using renewable sources, which has the potential to supply carbon neutral electricity, reducing transmission and distribution losses (Allen et Al. 2008), fostering a more efficient use of energy by buildings in urban areas (Brandoni et Al., 2014)).

Micro-generation and hybrid systems in urban areas

All over the world, energy systems are under reconfiguration, paying an increasing emphasis on the development and deployment of distributed generation, with the installation of micro-generation plants in individual homes or small scale buildings (Watson, 2004).

Micro-generation can be defined as the small-scale production of heat and/or electricity from a low carbon source technologies (El-Khattam &, Salama, 2004). Micro-generation are under development and deployment in association with any possible renewable resources; these technologies (namely: solar thermal, solar photo voltaic, micro-wind, round-source heat-pumps, micro- combined heat and power) are used singularly or in combination, creating the so-called hybrid micro-generation systems (Allen et Al., 2008).

So far, micro-generation technologies have been growing mainly in countries that provide financial incentives to encourage installation and to achieve the required economies of scale to compete with traditional electricity generation technologies. The most established micro-generation technology in urban areas is the solar photo voltaic (PV), since it is the first technology available on the market for small scale installations (Duan et Al., 2014). According to the International Energy Agency (IEA), in 2012 the five countries with the highest installed capacity of solar PV technology worldwide were Germany (32,411 MW), Italy (16,250 MW), USA (7,221 MW), Japan and China (both 7,000 MW). In all these countries, the governments provide financial incentives for adoption. (Richter, 2013)

More recently, in order to overcome seasonal variability of solar photo voltaic energy yield, these systems are combined with micro-wind technology, exploiting the seasonal anticorrelation in the time pattern of the wind and solar resources (Tina et Al., 2006).

In urban areas, especially in historical or environmental protected sites, visual impact of solar PV components is often not compatible with planning or preservation constraints (Fabrizio & Garnero, 2012; Zoellner et Al., 2008), reducing the field of applicability of such kind of hybrid systems.

Also micro-wind turbines may present similar installation constraints (Peacock et Al., 2008), but the availability on the market of many different settings (horizontal rather vertical axis, roof mounted rather than mast of ground mounted turbines) offers the possibility to find a viable building retrofit solution compatible with planning and preservation regulations (Ishugah et Al., 2014)

As consequence, in order to develop the diffusion of hybrid micro-generation systems in urban areas, further combinations using micro-wind turbines are worthy to be investigated. A technology which currently shows a good potential is ground source heat pump, due to the superiorities of high energy efficiency and environmental friendliness (Yang et Al., 2010; Bose et Al. 2002).

Particularly wind energy is based on wind as a horizontal component of air masses circulation which originated from the differences in temperatures, i.e. spatial distribution of pressure. Wind is a consequence of solar radiation, and local factors have a great impact on its characteristics. Geo-thermal energy in the strict sense of the word implies only a part of the energy from the depths of the Earth which reaches the surface of the Earth in the form of hot or warm geo-thermal medium (water or steam), and can be used in its original form or for transformation into other forms (electric power, heat in the heating and cooling systems, etc.) (Cerovic et Al., 2011). Despite the groundwater is not strictly a renewable resource (Preese, 2006), since electrical energy is required for water pumps and heat pumps, if that energy comes from renewable sources, groundwater can be considered to all intents a renewable resource.

The hybrid renewable micro-generation system investigated in this study combines geothermic and wind sources, where a ground source heat pump is co-powered by a ground mounted micro-wind turbine, to meet the heating and cooling demand of a small building hosting a social centre.

An experimental installation of hybrid wind-ground source micro generation system

Funded by Italian Ministry of Environment (MATTM) and developed by Department of Architecture of University of Naples Federico II in partnership with two private companies NHP s.r.l. e Agricola Villanova s.r.l., the research project TeCNaRE was aimed at realizing a hybrid system that, exploiting soil thermal inertia and wind energy, combines two renewable sources for heat pump working in heating and cooling mode for small size buildings.

According to requirements and technical specifications settled during the early stage of the research, the hybrid system has been realized to occupy minimal amount of space, to be affordable and simple to maintain, flexible and repeatable for new or existing buildings application, also in urban contexts and historical cities, regulated by heritage and environmental preservation constraints.

Research brought to a prototype installation on a demonstration building located on Posillipo hill, a valuable area of the city of Naples, in Southern Italy, where a strict regulation on landscape protection and heritage preservation applies. The building is set on an altitude of 140 m above sea level, in a well wind-exposed area that looks out the sea of the Naples Gulf. It is a one floor wall stone building in tuff, which layout is an open space of about 100 square meters. The building was originally a rural annex, today under refurbishment as social centre.

The hybrid system prototype consists of geothermic and micro-wind components combination. For the first one it has been selected a very-low enthalpy geothermal system in which natural ground water at almost 16 °C, extracted from an existing well, flows through an open loop pipe heath pump

(Ground Source Heat Pump – GSHP). The energy needed for powering heath pump is cogenerated by the micro-wind component of the hybrid system, reducing grid power absorption.

Choosing the right turbine design and size to suit hybrid system prototype resulted very dependent on a lot of circumstances, since wind profiles in urban areas tend usually to be turbulent due to the presence of buildings, trees along the streets, and other obstacles. Problems associated to these systems are also noise production, aesthetics, integration into architectural systems, and efficient use of the available wind resource issues (Ishugah et Al., 2014).

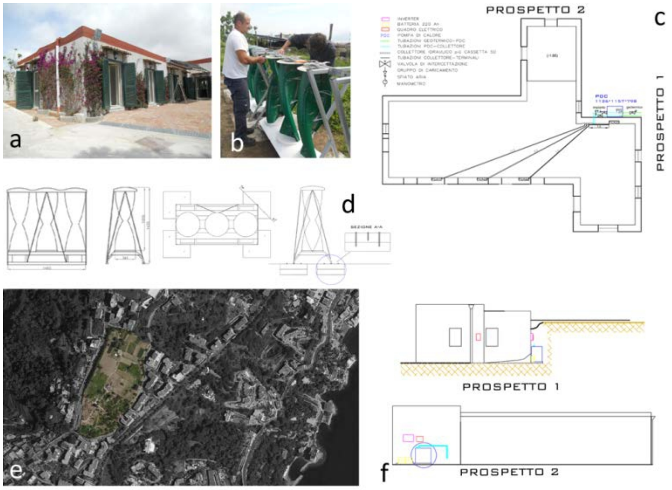
The types of home wind micro turbines are essentially different both for rotation axis of blades both for the way they need to be mounted. Horizontal axis wind turbines (HAWTs) are until now, the common types of wind turbines used in urban environment. Since the propeller-type rotor mounted on a horizontal axis needs to be positioned into the wind direction, HAWTs are particularly sensitive to changes in wind direction and turbulence. Their performance are negatively affected also by problems deriving from their size, that can be dangerous to birds and aircrafts, impacting on landscapes and difficult to maintain.

The vertical axis wind turbines (VAWTs) have a vertical axis of rotation of blades. The advantage of these types of machines, that are usually small sized, is that they do not need to respect wind direction and can capture much higher turbulence and varied wind speeds as compared to HAWTs. Despite they generally generate very little energy as compared to their horizontal axis counterparts, for the above reasons they are considered suitable for urban environment (Ishugah et Al., 2014).

About installation home wind turbines may be roof-mounted or free-standing, mast-mounted or ground mounted. HAWT typology needs high pole, and consequently it has to be set up by foundations with consequent steadiness and landscape impact issues. VAWT can be installed at ground level, since it doesn’t need to capture high level wind flows, making it easy to service and repair apart from being suitable in building mounting in urban environment.

The selected micro turbine model addressing settled research prototype requirements is a VAWT system, preferred for the above mentioned typology performance. The micro-wind generator Turbomill© is described by manufacturer as specifically designed for installation in urbanized area as it works independently on wind direction and needs low cut in speed. It is made up of a set of minimal amount of space micro-wind elements (length 1640 mm, width 850 mm, hight 1430 mm, weight 51,26 kg), whose basic unit consists of three vertical axes micro generator, suitable for roof-mounting and ground-mounting. The presented prototype uses six micro-wind basic units, generating 3 kW in the whole. The micro turbines have been connected to store the energy they produce in a battery.

Thanks to the completely removable micro-wind selected system, which only installation requirement is to be fixed in a plane surface, not mast-needed, the hybrid system results repeatable, maintainable and accessible. It also shows a good suitability to different application contexts for small size of its components and because foundations structures are not need. Given the less than 150 meters height, the micro turbines have a low impact on landscapes and urban skyline, and have been installed without particular license or construction permits.



a) demonstration building; b) turbines installation; c) building's plan with system components layout; d) turbines' installation detail; e) building area; f) building's prospects with system components layout

Fig. 1: Demonstrating installation of the hybrid geothermic and wind sources micro-generation system

Results from the experimentation

Hypotheses about energy needs for demonstrating building heating in winter season, where energy demand is higher, assumes as yearly consumption of heat pump for 1584 kWh. According curves provided by manufacturer, and considering a potential average wind speed of 3-4 m/s, as resulting for the installation site from wind atlas, the installed turbines could provide the whole amount of energy demanded for heating and cooling.

Looking at so far data collected by installation monitoring, the energy provided by the micro turbines accounts for the 10% of the amount of energy needed for the operating heat pump.

For obtaining a standalone system, micro-wind component should be dimensioned in order to increase energy generation for giving heat pump all necessary power. But in this way system would be much expensive, due to the increasing number of necessary micro turbines units, as well as more impacting on building and landscape, due to the increasing size and weight of resulting system.

On site monitored wind data demonstrating the extreme variability in short and long time periods, and the unreliability of statistics and models, suggested that stand alone system is non able to guarantee continuity in energy production. For those reasons, starting hypotheses to connect the system with electricity grid has been confirmed.

For what concerns noise production, measurements under 5 m/s wind conditions show irrelevant effects, since the highest sound value reported is 36 dBa at 1 m of horizontal distance from the turbines. Moreover, periodical probes show that water extraction for groundwater heat pump is not impacting the aquifer depth

Conclusion

The rising energy demand and the increasing saving needs forced in the last years the development of hybrid systems which, combining different energy sources, can optimize available resources, exceeding limitation deriving from each one of them. Research and market declare main attention to integration issues of different systems and to efficiency of energy production. On the contrary, problems concerning how these systems can be set up in existing buildings and how they can impact the environment and landscapes are quite neglected.

The TeCNaRE experimentation has proven that local wheatear and climate micro-conditions in Mediterranean sites can be extremely variable and hardly predictable, especially in urban areas. Furthermore, actual performances of micro-generation turbines are strongly affected by local circumstances and may dramatically decrease with respect to performances declared by manufactures. The above issues represent some key obstacles for the wide penetration of hybrid wind-ground source micro-generation in urban settlements, especially without financial incentives. For what concerns the aesthetic and regulatory acceptability of micro-generation systems in valuable areas, as well as for noise production, it can be concluded that current market trends offer viable solutions for micro-wind installation in urban areas. Therefore, in order to foster the use of this kind of micro-generators, advances in the field would be needed with relation to improved reliability of models for local climate conditions analysis in urban areas (Li et Al., 2013; Peacock et Al., 2008) as well as to increased robustness of market products, in order to overcome limitations of demonstrating and pre-commercialization trials (Allen et Al., 2008).

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