Aesthetic aspects for building integrated solar and wind energy systems

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Abstract: The design of nearly Zero Energy Buildings (nZEB), building skins can be based on effective integration of solar energy and wind energy systems. These systems can provide heat and electricity and be combined with geothermal heat pumps and biomass boilers. In this paper, aspects and considerations regarding the effective building integration of solar energy systems, as solar thermal collectors, photovoltaics, hybrid photovoltaic/thermal (PV/T) systems and also of small wind turbines, are presented and discussed. The solar energy and the wind energy systems are directly visible systems to everyone and their design should adapt the building architecture and surrounding environment. The solar and wind energy system designers, the architects, engineers, physicists and other contributors to building energy covering, should consider the holistic concept, where the buildings are part of the new formed social human environment, in a very closed relation with the natural environment. The built sector, together with the other energy consumption sectors (industry, agriculture and transportation) has to be seen as a new field for aesthetic creation, forming a new urban landscape. Developed designs for building integrated solar and wind energy systems are included in this work and can be considered examples for application to new buildings.

1. Introduction

Solar energy systems, other renewable energy sources and energy saving technologies, can contribute to adapt the energy targets of EC for 2020 and 2030. The changing in the energy mix that is planning for the next decade is not easy to be achieved and several difficulties should be overcome. Energy saving should be of priority and the built sector is the first one that should contribute, with most important the introduction of the nearly Zero Energy Building concept from 2020. The external surface of buildings constitutes the surface area for an effective, multifunctional building skin. Towards the design of such buildings, alternative skin designs have been suggested with effective integration of solar energy systems, as well as of wind energy systems. These systems can provide heat and electricity and combined with geothermal heat pumps and biomass boilers, can adapt energy building needs.

Buildings can be designed according to bioclimatic architecture, using new heat-insulating materials and smart windows, which reduce effectively thermal losses during the winter and energy for cooling during summer. The installation of energy devices and active solar energy units is related with their cost increase and their harmonization with the architecture of the buildings. The solar energy and the wind energy systems are directly visible systems to everyone and their design should adapt the building architecture and surrounding environment. On the other hand, the external view of the buildings should not be covered by same solar and wind energy systems, as monotony in shape and color is not a concept of beauty. Therefore, the solar and wind energy system designers, the architects, engineers, physicists and other contributors to building energy covering, should consider the holistic concept, where the buildings are part of the new formed social human environment, in a very closed relation with the natural environment. The built sector, together with the other energy consumption sectors (industry, agriculture and transportation) has to be seen as a new field for aesthetic creation, forming a new urban landscape.

2. Building integration aspects

The integrated solar energy systems should be of high aesthetics because they are directly visible. It is also important to use new heat-insulating materials and special glasses, which reduce thermal losses of buildings during the winter and the energy consumption for cooling during the summer. BISTS (Building Integrated Solar Thermal Systems) and BIPV (Building Integrated PhotoVoltaics) can be combined with other energy systems. A classification of solar energy systems can be related to the form of building design or components utilized, pre-fabricated or customized. Solar thermal collectors can be incorporated into buildings by superimposition, with attached system on building envelope or integration, to form a part of the building envelope, while saving of materials results to lower the cost below that of traditional elements. Mounting solar collectors directly to the wall without an air gap causes a modification of vapor transfer [Probst and Roecker, 2011].

3. Suggested solar energy systems for building integration

The BISTS provide thermal energy to the building in the form of hot water and space heating and cooling. Additionally, other forms of renewable energy systems may contribute to the buildings energy balance, as from PVs, photovoltaic/thermal (PV/T) collectors, small wind turbines, biomass boilers and geothermal heat pumps. PV panel temperature increases by the not converted into electricity solar radiation, causing a decrease in their efficiency. This undesirable effect can be partially avoided by heat extraction with a fluid circulation, achieved by the hybrid photovoltaic/thermal (PV/T) collectors [Tripanagnostopoulos et al, 2002]. These solar energy systems can provide electrical and thermal energy, thus achieving a higher energy conversion rate of the absorbed solar radiation.

3.1 Integrated Collector Storage (ICS) systems

Integrated Collector Storage (ICS) systems can be applied by open or closed water circulation. In ICS systems a cylindrical storage tank, or a mechanically reinforced storage vessel of rectangular shape, is coated with a solar radiation absorbing surface. The storage per collector aperture of 50-100 l/m^2 is incorporated into the collector. Water is directly heated without the need for a pump and control system. Improved ICS solar water heaters have been developed [Tripanagnostopoulos and Souliotis, 2004] using cylindrical collector-water storage tank inside compound parabolic concentrating (CPC) reflectors, presenting efficient water heating during day time and satisfactory heat preservation during night. These ICS systems can be integrated to building roofs and balconies because of their low height. The absorbers of the cylindrical tank ICS systems could be painted with other than black color to adapt aesthetically the architecture of modern and traditional buildings (Fig. 1).

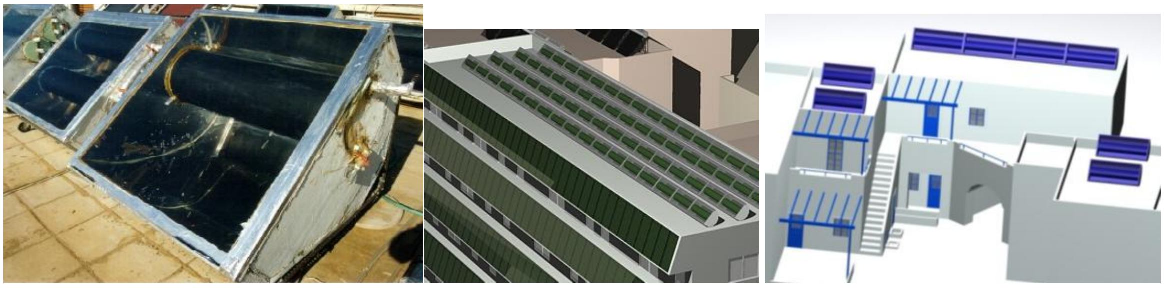

Fig. 1 ICS solar water heaters that can be effectively integrated to buildings

3.2 Colored solar thermal collectors

By colored absorbers it is aimed to avoid the monotony of the black color collectors by using absorbers of blue, red–brown, green or other color. These collectors are of lower thermal efficiency than usual black type collectors, because of the lower collector absorbance, but they are of more interest for applications on traditional or modern buildings. The application of solar collectors with colored absorbers is a new concept, where the cost increase of total solar system is balanced by the achieved aesthetic harmony with the building architecture [Tripanagnostopoulos et al, 2000, Probst et al, 2010]. The difference in energy is balanced by the improvement in aesthetics and this implies the use of proportionate larger collector aperture areas for same energy output, as that of typical black colored collectors (Fig. 2).

Fig. 2 Colored solar thermal collectors which can give new views to buildings

3.3 Hybrid photovoltaic/thermal collectors

In Building Integrated hybrid Photovoltaic Thermal (BIPVT) solar energy systems the production of electricity is of priority, therefore it is necessary to operate the PV modules at low temperature in order to keep PV cell electrical efficiency at a sufficient level. This requirement limits the effective operation range of the PV/T thermal collector unit (Fig. 3) to low temperatures, thus, the extracted heat can be used mainly for low temperature applications as space heating and natural ventilation of buildings, air or water preheating, etc [Tripanagnostopoulos et al, 2002].

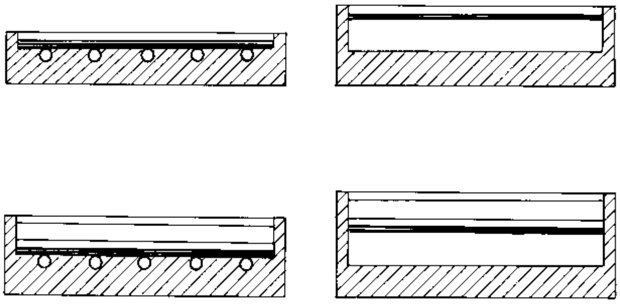

Fig. 3 Cross section of water and air type hybrid PV/T solar collectors

Air-cooled BIPVT systems have been recently applied on building inclined roofs or façades. By these systems building space heating needs during winter can be covered and also building overheating during summer is avoided. Natural or forced air circulation is a simple and low cost mode to remove heat from PV modules, but it is less effective at low latitudes where ambient air temperature is over 20°C for many months during the year.

3.4 Building integration of CPC solar energy systems

Apart from the typical forms of solar thermal collector units and PV modules, new designs of building integrated CPC collectors have been studied (Fig. 4). In new buildings or retrofitting the emphasis is to passive and active solar energy systems, to partially or entirely cover natural lighting, space heating and cooling, air ventilating, domestic hot water and electricity.

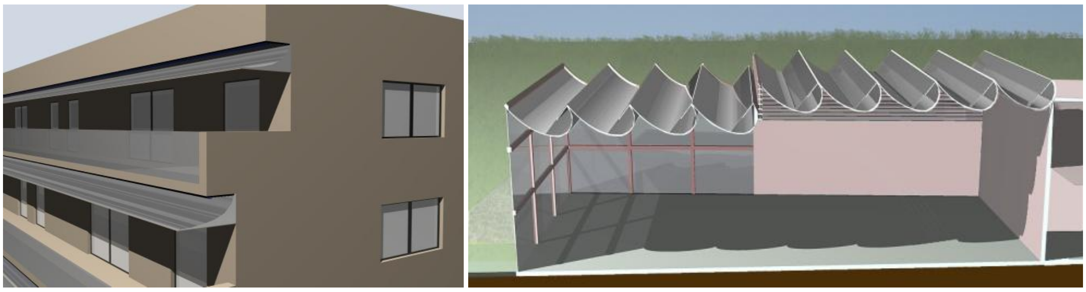

Fig. 4 Building integration of CPC reflector solar energy systems

The building integrated concentrating solar energy systems are not many and among them some specific architectural designs are those included in the works of Tripanagnostopoulos, in 2014 and 2015. The integration of CPC solar thermal collectors, PV and PV/T systems give an alternative form of building architecture, which opens a new field in building design.

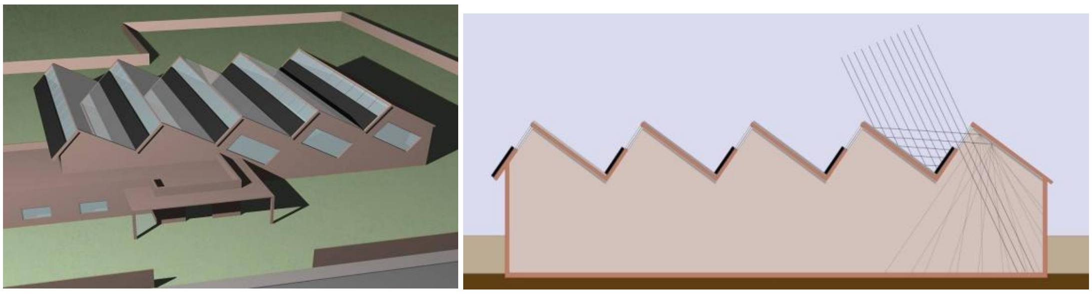

Fig. 5 Suggested installation of booster reflectors combined with natural lighting of the building

Flat booster reflectors can be used between the parallel rows of the collectors on building roof (Tripanagnostopoulos and Souliotis, 2005) to increase thermal output or achieve higher operating temperature (Fig. 5). For thermal collectors the reflectors are specular, while for photovoltaics they have to be diffuse (Fig. 6), to avoid electrical efficiency reduction due to non homogenous distribution on panel surface.

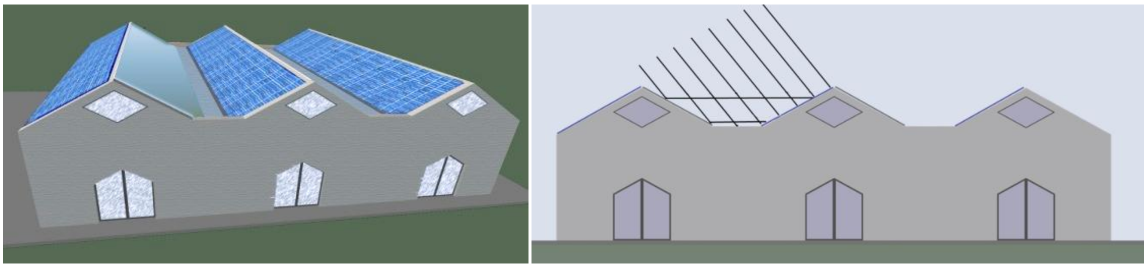

Fig.6 Integration of PV panels, combined with booster reflectors, on building roof

Based on the investigated CPV and CPVT systems, some new architectural designs have been suggested, giving an idea about their aesthetic integration on building structure. The building balconies can be used to put the reflectors, which can have the parabolic form and the reflected radiation to be focused on the back of the front building [Tripanagnostopoulos, 2015]. In Fig 7 the basic design of the reflector follows the geometry of the asymmetric parabolic reflector with axis towards winter solstice. It should be noticed that the reflectors can be mounted on building balconies or be moving using stationary absorber mounted on the top of the front placed building.

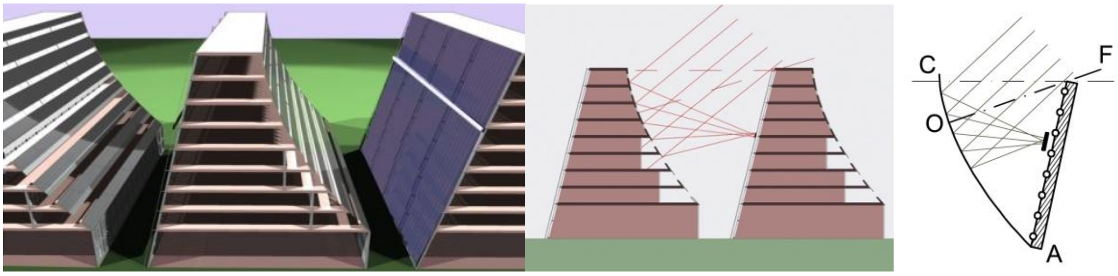

Fig. 7 CPC reflectors with tracking absorber on opposite building and ray tracing indication

3.5 **Fresnel lens systems**

Fig. 8 Integrated of Fresnel lenses to building roof and balcony

Linear Fresnel lenses can achieve illumination and temperature control of buildings and are suitable to extract the surplus solar radiation from the interior space in the form of electricity and heat, by using PV/T absorbers (Figs. 8 and 9). This system can be consisted of thermal, PV or PV/T tracking absorbers, to achieve light and temperature control of building atria [Tripanagnostopoulos et al, 2007 and Tripanagnostopoulos 2014 and 2015].

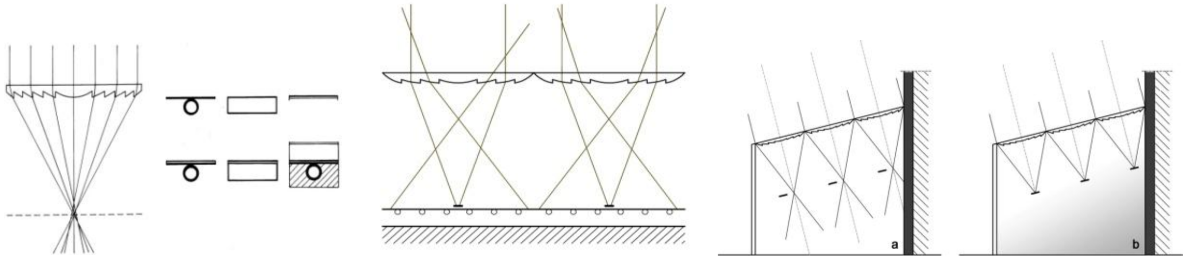

Fig. 9 Fresnel lens system for energy conversion (left) and building solar control (right)

4. Building Integration of Small Wind Turbines

The use of small wind turbines in buildings is an interesting but also difficult issue, regarding integration and performance aspects. The wind turbines are not yet widely applied to buildings, as they are the solar thermal systems and the photovoltaics. The lower wind velocity potential, due to the wind turbulence in urban and suburban areas and the instability of velocity level and wind direction, are the main reasons for this case. Therefore the success of applying small wind turbines to buildings must be assessed in terms of their economic benefits. It is important to have been accurately determined the best location, to adapt cost effectiveness requirements for building integrated wind turbines.

To determine the wind potential in urban areas it is necessary to consider many parameters as of anemometers, wind maps and CFD studies. It is first important to consider the topography and texture of the area for several kilometers around the target site, studying therefore the roughness and the general turbulence in the local environment. Most important is the need to consider local effects, factoring for the size, shape, height, and distance of various obstructions. This incorporates the wind energy impacts of nearby trees, buildings, and other structures to understand how much the wind is blocked, what turbulence is created, and in some cases, how much the wind speed is increased. Small wind turbines are often installed at locations with frequent windy conditions. Based on the wind data, a suitable type of wind turbine and suitable location can be determined to maximize the electricity generation. One important criterion is to match ambient wind conditions with a wind turbine's cut-in wind speed, rated wind speed and cut-out wind speed. Further, if mounting a small wind turbine on a building, it is critical to account for effects from the building external structure, details such as its surface, roof edge, and roof features such as towers or chillers. For example, when wind hits any obstruction, it creates a separation zone arching out from the top of its vertical face. Above this point, the air remains smooth, but below, it becomes quite turbulent. This behavior must be considered in every rooftop-wind project to figure out how much higher the turbine must be mounted to capture energy from the smooth airflow.

To improve the performance of Building Integrated Wind Turbines (BIWT), local roughness, blocking, turbulence, and roof dynamics, should be considered. With better data, installers and customers can make better decisions, which will lead to better performance of BIWT. This opens up the urban wind energy market for explosive growth in the coming years. Recent developments in building integrated wind turbine technologies involve improving reliability, improving efficiency at low wind speeds and lowering capital cost. Wind turbine blades are now designed with lightweight materials and aerodynamic principles, so that they are sensitive to small air movements. Furthermore, the use of permanent magnet generators, based on rare earth permanent magnets, results in lightweight and compact systems that allow low cut-in wind speeds. In this way, electricity can be generated with wind speeds as low as a few meters per second. In addition, prior to installation on an existing building rooftop, it is important to ensure the roof structure is strong enough to hold the additional loads. These include the weight of wind turbines and vibration from wind turbine operation. Vibration absorbent technology should be applied in order to prevent damage to building structure and to reduce interior noise in the building.

To be more attractive for integrating into buildings, small wind turbines are also being designed to be more visually attractive, without compromising their performance. Another objective is to reduce or eliminate noise associated with blade rotation and gearbox and also generator noise. This can be achieved by using low-noise blade designs, vibration isolators to reduce sound and sound absorbing materials around the gearbox and generator. Furthermore, simplifying wind turbine components and systems adds to the attractiveness of wind turbine application and reduces maintenance costs. In addition, to lower the product costs, advanced blade manufacturing methods, such as injection compression and reaction injection moulding are being applied to reduce labor and increase manufacturing quality. A typical wind home system comprises a small wind turbine, a battery, and various DC electrical appliances.

Another important factor for large-scale implementation of BIWT is the technical knowledge to compute, simulate and deploy appropriate types of wind turbines at appropriate locations and to maximize their performance and aesthetic integration with buildings and urban landscape. Other requirements are the installation skills and techniques for local workforce and the maintenance and management. In this way, the small wind turbines are locally available and the local green economy is supported with new jobs creation and income sources. Financial requirements for the implementation of BIWT include investment and maintenance costs. Investment cost covers not only the turbines and their installation, but also feasibility studies and system design related activities. One of the most critical activities is to analyze (for existing buildings) and predict (for new buildings during design stage) the wind conditions on and around the building to determine the feasibility and location for installation. The cost components of wind turbines vary in a wide range, depending on the type, capacity rating, and local availability. Return on investment depends greatly on the actual wind conditions and performance onsite, and partially on the incentive level of feed-in tariff and local electricity pricing.

4.1 Combined solar and wind energy systems

Apart of the building integration of solar energy systems only, there has been suggested also the combined building integration of solar energy and wind energy systems, as presented in the works of Tripanagnostopoulos in 2015. A special case has been studied, the case of buildings in Cycladic islands and an optimized system has been suggested (Fig. 10). In this design the PV panels could be also PV/T panels or blue colored thermal collectors (to adapt the blue doors and windows of the building). These solar energy systems can increase their energy output by the additional radiation that is due to the reflectance by the white painted roof surface. The small wind turbines can be integrated to the curved forms of the building roof, which adapt the Cycladic architecture.

Fig 10 Combined solar and wind energy systems

5. Conclusions

The use of heat-insulating materials and effective glazing to buildings can achieve a considerable reduction of energy demand and following it, the integration of active and passive solar energy systems can adapt their energy demand. The design, operation and aesthetic aspects of solar energy systems that are investigated at the University of Patras and aim to be integrated to buildings, are briefly presented. Among the investigated solar energy systems, ICS solar water heaters, solar collectors with colored absorbers and static concentrating devices, as of booster reflectors, CPC reflectors and Fresnel lenses are suggested, aiming to provide new solutions for building integration. The installation of solar energy systems should be effectively harmonized with building architecture and environmental requirements. Solar thermal systems, photovoltaics and hybrid Photovoltaic/Thermal systems can cover the energy needs of the building and if it is necessary they could be combined with geothermal heat pumps, biomass boilers and small wind turbines.

6. References

Probst, M. C. M., Schueler, A. & Roecker, C. Bringing colours to solar collectors: a contribution to an increased building "integrability". Colour & Light in Architectecture. Venice, Italy, 2010.

Probst, M. C. M. & Roecker, C. Architectural Integration and Design of Solar Thermal Systems, Oxford, UK, Routledge Taylor and Francis Group; 2011.

Tripanagnostopoulos Y. and Yianoulis P. CPC solar collectors with multichannell absorber. Solar Energy, 1996; 58 (1-3): 49-61.

Tripanagnostopoulos, Y., Souliotis, M. & Nousia, T. Solar collectors with colored absorbers. Solar Energy, 2000; 68: 343-356.

Tripanagnostopoulos Y., Nousia Th., Souliotis M., Yianoulis P. Hybrid photovoltaic/ thermal solar systems, Solar Energy, 2002; 72: 217–234.

Tripanagnostopoulos Y., Souliotis M. ICS solar systems with horizontal (E–W) and vertical (N–S) cylindrical water storage tank. Renewable Energy, 2004; 29: 73–96.

Tripanagnostopoulos Y. and Souliotis M. Booster Reflector Contribution to Performance Improvement of Solar Collectors. Proc. in CD, Int. Conf. WREC 2005, pp. 63–68, Aberdeen, Scotland, UK, 22–27 May 2005.

Tripanagnostopoulos Y., Siabekou Ch. and Tonui J. K. The Fresnel lens concept for solar control of buildings. Solar Energy, 2007; 81: 661-675.

Tripanagnostopoulos Y. New designs of building integrated solar energy systems. Energy Procedia, 2014; 57: 2186-2194.

Tripanagnostopoulos Y. Operational and aesthetical aspects of solar energy systems for building integration. Int Conf EuroElecs 2015, COST Action TU1205 Symposium, July 2015, Guimaraes, Portugal.