Solar Energy and the Building Holistic Energy Concept

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Abstract

Solar thermal collectors (STC) and photovoltaics (PV) can be effectively combined with other Renewable Energy Sources (RES) to adapt energy demand of buildings. Buildings should be designed according to bioclimatic architecture, to reduce energy needs and minimize CO_2 emissions to the atmosphere. Therefore, the application of solar energy systems is actually useful regarding their contribution to the total energy consumption. Solar thermal collectors and photovoltaics can be grouped into façade and roof integrated systems and should be installed properly to adapt building architecture, improving also its thermal insulation. In addition, small wind energy generators, heat pumps operating with geothermal energy and biomass boilers, can also be applied, being effectively combined with the solar energy system, to achieve the holistic energy saving concept of buildings. In the present work some innovative systems are briefly described and aspects regarding aesthetics and other application issues are discussed. The wide use of RES combined with passive heating and cooling, natural lighting, air ventilation, infrared heat protection and other building energy saving improvements can replace a great amount of conventional energy sources in heating, cooling and electricity, contributing to a significant CO_2 reduction in global scale.

1. Introduction

The energy demand of buildings for electricity and heat corresponds to more than a third of total energy consumption in many countries. Renewable energy sources (RES) can be used to cover a significant part of the energy requirements in building sector contributing to conventional energy savings and the protection of the environment. Solar thermal collectors (STC) and photovoltaics (PV) are installed on buildings to cover hot water and space heating/cooling needs and provide electricity [1,2]. Facades and horizontal or inclined roofs of buildings are appropriate surfaces for the application of solar thermal collectors and photovoltaic panels, for heat demand and electricity, contributing also to the reduction of the heat transmission through building external walls [3, 4].

Wind energy is a very promising renewable energy source, estimating to cover 20% of the global electrical energy demand by 2020. Wind turbines (WT), especially of small size (SWT), can be mounted on the roofs of buildings mainly at locations with satisfactory wind potential, to both stand-alone and grid connected applications. Regarding integration aspects, solar and wind energy systems appear to be the most interesting among RES for the built environment. Due to their visibility, specific architectural requirements will need to be met to ensure that they are accepted by the community. Several types and forms of STC and PV comprise new and interesting materials, which can be easily integrated into buildings, creating new shapes and symbolizing the ecological concept. These collectors also appear as a new material in the architect's hands, ready to be shaped to create alternative buildings. Apart from the typical forms of STC (flat plate, vacuum tube, etc) and PV (c-Si, pc-Si, a-Si CIS, etc) modules, new designs of solar energy systems have been developed to address building integration, as of ICS collectors, CPC collectors and other types [5-10].

New concentrating systems are already commercially available. Cylinder parabolic reflector systems with thermal or PV absorbers, Fresnel reflectors and Fresnel lenses and other concentrating geometries can effectively be applied not only to provide electricity and heat but also to control the light and the temperature of internal spaces with transparent covers. Apart of separate STC and PV systems, the hybrid PV/T collectors can be applied, in effective combination with solar thermal collectors, to use the preheated fluid from PV/T system and to increase the temperature further [11]. The thermal part of the solar system can also be combined with a wind turbine, as buffer energy storage in the form of heat, using the surplus of electricity from the SWT that cannot be transferred to batteries or to the electricity grid [12].

In addition to solar and wind energy systems, geothermal heat pumps (GHP) and biomass boilers, can contribute to the energy demand of buildings. By these systems a significant part of the energy requirements can be covered, contributing to conventional energy savings and protection of the environment by reducing CO_2 emission. Regarding geothermal energy, many buildings have available ground in their surrounding and GHP systems can provide space heating during winter and space cooling during summer. The required electricity for the operation of the heat pump can be obtained from an installed PV array. The GHP can also be boosted by the solar thermal system increasing the total COP. In countries with a good share of forestry industry, biomass systems offer a large potential especially in combination with solar heating systems for domestic hot water preparation and space heating [14]. A brief description of the contribution of RES to building holistic energy concept is presented and some aspects on system energy, operation and aesthetics are discussed.

2. Building Integration of Solar Energy Systems

2.1. General aspects

Regarding integration aspects, solar and wind energy systems are directly visible and specific architectural requirements should be met to ensure their aesthetic integration. The European Solar Thermal Technology Platform (ESTTP) aims towards buildings where heating and cooling demand is covered to 100 % by solar thermal energy [3]. For existing buildings the heating and cooling demand of an actively solar renovated house should be covered to at least 50 % by solar thermal energy [4]. In order to reach these targets of high solar fraction, solar systems for domestic hot water production, space heating and cooling of the buildings are required. All building types have to be included (single and multifamily houses and office buildings), roof and façade integrated collectors are fundamental and a combination of solar thermal collectors and photovoltaics will help to achieve the objectives [1], considering the requirement of very low heating and cooling demand [1,2,4].

Another aspect is the full integration of collectors in roofs and façades under the consideration of architectural and economical aspects. For higher acceptance and a higher market introduction of solar systems, architectural aspects have to be taken into consideration. Solar collectors have to become an integral part of the building, ideally becoming standard construction elements. Higher levels of building integration require new research and development efforts, in close interaction with architects, construction companies and manufacturers of building envelopes. To achieve the goal of an energy efficient building, technologies should be combined and possible synergy effects be used. System integration concerns issues on how to include the solar technology into the energy supply system of the building with regard to optimization of energy gains and solar fraction. A high quality of architectural integration of solar collectors is regarded as key issue to open the way to successful perception of collectors by designers and larger public acceptance of both, solar thermal and electrical systems. Solar collectors are not only part of the architecture but the main influence to define the future architecture [15]. Some architects and researchers [15-21] underline the need for higher architectural quality, such as size, color or shape of the collectors.

The constructional building integration of solar thermal collectors aims towards the replacement of the building envelope by the solar collector. The integration of solar collectors into the building envelope, instead of separate installation, represents a transition from the concept of the envelope considered as an energy loss to the envelope being an energy source (energy active envelope) which actually means a step further to solar energy active buildings. Therefore it is important to create an interdisciplinary project and installation cooperation between the architect, builder, solar engineer, plumber etc. to guarantee a working multi-functional building element. For an aesthetic building integration of both solar energy systems, STC and PV, it is important to think about the form and the available surface areas on façade and roof of the building and to pay attention to their type, performance and color. The integrated solar energy system should be of high aesthetics because they are directly visible, as they constitute a large part of the external building surface. In an extended use of solar energy, the majority of the exterior surfaces of buildings will be covered with absorbing surfaces of solar thermal collectors and photovoltaics and their form and color should be taken under consideration, especially in the case of buildings with traditional architecture.

2.2. Solar Energy Systems

Flat plate collectors are the most widespread collectors but also efficient evacuated tubular collectors and Compound Parabolic Concentrating (CPC) collectors are used. The well known Flat Plate Thermosiphonic Units (FPTU) and the less widely applied Integrated Collector Storage (ICS) systems [5] are solar water heaters, aiming to cover domestic needs of 100–200 l of hot water per day and are mainly suitable for locations with favorable weather conditions. The unglazed solar collectors are cheaper than typical glazed collectors, but the increased absorber thermal losses limit their effective use in low temperature applications.

Photovoltaic systems have been installed on many types of buildings in a large variety. Office blocks, residential buildings and commercial or industrial buildings offer a field of significant interest for the installation of PV systems. Photovoltaics can also be used as elements for building ventilation (solar chimney effect) heated by the solar radiation that is not converted to electricity. Thus, BIPVs may be of triple operation, as building construction material, contributing to building cooling by natural ventilation and of course to provide electricity. Photovoltaics convert a small percentage (5%-15%) of the incoming solar radiation into electricity, depending on the type of PV, with the greater percentage converted into heat. The solar radiation increases the temperature of PV modules, resulting in a drop of their electrical efficiency, but their installation on horizontal roofs of buildings (parallel rows of PV tilted panels) permits their natural cooling. This undesirable effect can be partially avoided by heat extraction with a fluid circulation which is obtained by hybrid PV/T solar systems [8]. These systems can provide electrical and thermal energy, thus achieving a higher energy conversion rate of the absorbed solar radiation. Apart from the typical forms of solar thermal collectors (flat plate, vacuum tube, etc) and photovoltaic modules (c-Si, pc-Si, a-Si CIS, etc), some new designs of solar energy systems have recently been developed to address building integration [10].

In addition, new solar concentrating systems are already commercially available. These systems are examples that show the potential for a wider application of novel solar energy systems to the buildings. In addition to STC and PV systems it is equally important to use new heat-insulating materials, roof and façade infrared protection and special glasses, which reduce thermal losses of buildings during winter and energy consumption for cooling during summer. These products are already considered necessary structural materials for the improvement of energy behavior of buildings, giving at the same time a new visage to them. In new building designs or retrofitting the emphasis is addressed to the effective use of passive and active solar energy systems to partially or entirely cover the demand in natural lighting, space heating and cooling, air ventilating, domestic hot water and electricity.

The integration of advanced solar thermal flat-plate collectors leads to improvements of the collector performance and to a reduction of the heat loss of the building, due to improved envelope insulation [22,23]. Another new concept is the so called multifunctional plug and play facade, which is a combination of PV, solar thermal and heating, ventilation and air conditioning (HVAC) prefabricated in one module [24]. The approach of active envelope systems developing unglazed and glazed flat-plate systems has been introduced to meet the needs of energy production and building. The emerging concerns for environmental protection and global energy saving have introduced new architectural design rules for buildings, aiming at buildings of reduced energy consumption with effective integration of solar energy systems in combination with satisfactory aesthetics as well. PVs are used as construction materials, which allow innovative architectural designs since there is variety of colors, sizes and shapes of them. Furthermore, they may offer different light transparency, depending on design demands.

3. Contribution of other RES to Buildings

3.1. Wind Energy

The integration of medium or high power wind turbines (WT) in buildings is not practical and small size wind turbines are recommended. Small wind turbines can be mounted on building roofs, mainly at locations with satisfactory wind velocity potential and are effective to both stand-alone and grid connected applications. Regarding building integrated wind turbines (BIWT), their weight and dimensions are two important factors that must be taken into consideration. Small wind turbines, designed for urban use, offer another very important aspect of wind energy applications and change the idea of energy production in the cities, make energy consumers less dependent on the grid and can be financially accepted. Vertical axis wind turbines (VAWT) seem to be the best choice for urban use as they are less sensitive to turbulence and wind changes than the Horizontal axis wind turbines (HAWT) and also they have low weight relative to the power output. In addition, their motor is at low position, below the rotor, and it is a very important issue when we are interested in roof mounting and service access. Besides, VAWTs are more visually attractive than HAWTs. Generally, three basic types of WT integration in the urban environment have been proposed: (i) between buildings constructed in a form of wind energy concentrator (ii) in a duct through a building and (iii) on top of or alongside a building.

3.2 Geothermal Energy

Medium and high-enthalpy resources, such as dry steam and hot fluids can be gainfully utilized to generate electricity using modern technologies and binary cycle plants. On the other hand, moderate-to-low temperature resources such as warm-to-hot waters that are found extensively in most continental areas are best suited for direct heating and cooling (non-electrical) purposes. A geothermal heat pump (GHP) is a central heating and/or cooling system that pumps heat to or from the ground. It uses the earth as a heat source (in the winter) or as a heat sink (in the summer). This design takes advantage of the moderate temperatures in the ground to boost efficiency and reduce the operational costs of heating and cooling systems, and may be combined with solar heating to form a geo-solar system with even greater efficiency. Ground source heat pumps harvest a combination of geothermal power and heat from the sun when heating, but work against these heat sources when used for air conditioning. Shallow horizontal heat exchangers experience seasonal temperature cycles due to solar gains and transmission losses to ambient air at ground level. Ground source heat pumps must have a heat exchanger in contact with the ground or groundwater to extract or dissipate heat. Another issue regarding geothermal heat pumps is that the needed electricity for their operation can be supplied from a PV installation on building roof or façade. This concept is an interesting combination of geothermal energy with solar energy and can be applied if a suitable surface area for the installation of PV panels is available. Thus, solar energy can contribute to boost the heat transfer from the ground by the solar thermal collectors and to operate heat pumps by photovoltaics. Hybrid PV/T solar collectors can contribute to both above energy demand modes and total system performance is increased, therefore decreasing the pay back period. Small wind turbines would be also installed on buildings to provide the necessary electricity for the heat pumps and thus, renewable energy sources can be effectively combined and buildings with low to zero CO_2 emission will be achieved.

3.3 Biomass

A wide range of technologies have been developed for processing various forms of biomass. However, the effective technology is solid fuel combustion, the Compound Heat and Power unit (CHP) for both heat and electricity generation. Solid fuel units use either wood chippings or wood pellets. Wood pellets are formed from compressed sawdust and as a result they have a lower moisture content than wood chippings and consistent dimensions, so are easier to handle but are about twice as expensive. Biomass heat output can be controlled but not instantaneously, so systems cannot respond to rapid load changes. Solutions to provide more flexibility include provision of peak capacity from gas-fired systems, or the use of thermal stores that capture excess heat energy during off-peak periods, enabling extended operation of the biomass system itself. Compared with solar or wind power installations, the initial costs of biomass systems are low, the technology is well established and energy output is dependable. As a result, the real challenge for successful operation of a biomass system is associated with the reliable sourcing of feedstock. An interesting combination is the hybrid solar-biomass system [14] to cover domestic hot water and space heating loads. The effective operation of such system can be achieved if solar thermal collectors preheat a water storage tank and the biomass boiler provides the final water temperature by the main heating process. This system can be used in urban buildings of high built density, as they cannot have the necessary available surface area and suitable orientation to absorb the necessary amount of solar radiation that adapts the building energy needs.

4. Other aspects for RES

The building sector is an important energy consumer for both electricity and heat and is the major in the urban environment. A basic requirement to adapt cost effectively the holistic energy saving of buildings and minimize the environmental impact is to construct or retrofit them applying bioclimatic architecture. Solar lighting, passive heating and cooling, natural ventilation, shading, thermal mass and other energy saving improvements as cool paints, smart windows, solar chimney installations, etc, constitute the new concept for sustainable buildings they present low energy demand, definitely less than the required energy in most typical buildings. The aim of low energy consumption is the first step, with target the zero energy building (zero CO_2 emissions from conventional energy sources). Apart from the building design, it's equally important to use new heat-insulating materials and special glasses, which reduce heat transmission, resulting to lower heating and cooling load. As far as new buildings are concerned, their design must provide passive and active energy system combination, for the avoidance of augmented cost and wrong integration of systems in building's architecture.

The issue of aesthetic integration of solar collectors in building architecture and the environment is important and constitutes a reason for the application of these devices in the built environment. In an extended use of solar energy, the majority of the exterior surfaces of buildings will be covered with absorbing surfaces of solar thermal collectors and photovltaics and their form and color is a basic factor that has to be taken under consideration, especially in the case of buildings with traditional architecture. Regarding solar water heaters, for locations with favorable weather conditions, ICS systems have simpler construction and lower cost than FPTU systems, as they consist of solar collector and water storage tank mounted together in the same device [5].

Solar thermal collectors as vacuum tube, CPC (Compound Parabolic Concentrator), PTC (Parabolic Trough Concentrator) and linear Fresnel reflectors or lenses, can be also applied to buildings, to adapt efficiently higher temperature level (80 ^{o}C – 180 ^{o}C), as of solar cooling and combining heat and electricity. Hybrid PV/T collectors can be effectively used for preheating and main heating be obtained by typical and high performance solar thermal collectors [11]. In case that the building roof or façade has no suitable surface area for the installation of solar energy systems then biomass boilers are the main alternative RES that can be applied. If there is sufficient wind potential, small wind turbines (of horizontal, or better of vertical axis), could meet the electricity demand. Solar, wind, biomass and geothermal energy systems should be suitably applied all together and supplementing each other, to achieve system cost effectiveness with optimal energy contribution, operation and aesthetics, but first of all energy saving by using bioclimatic building design and construction, should be considered.

5. New solar systems for integration to buildings

In the Physics Department at the University of Patras, solar energy devices with innovative design have been developed and prototypes have been studied, aiming to be aesthetically integrated in buildings. Flat plate solar collectors with colored absorber have been studied to avoid the black monotony of the facades and the roofs of buildings [7]. The lower efficiency of collectors with colored absorbers requires an increase of about 20% of the needed collector area for the same amount of thermal output that corresponds to black collectors. The additional cost from the extended aperture surface area is balanced by the improvement of the aesthetic view. These collectors can have selective or non-selective colored absorber and also spectral selective glazing. To improve thermal output or achieve higher operating temperature, flat booster reflectors (Fig. 1.a, 1.b) can be used between the parallel rows of the collectors on building roof [13]. The light and the temperature inside building atria, can be controlled by mounting linear Fresnel lenses combined with multifunctional absorbers (Fig. 1.c) converting the solar radiation in useful energy form [9]. In addition, new concentrating solar devices using reflectors (Fig. 1.d) or lenses combined with thermal or/and photovoltaic absorbers with application to buildings have been recently suggested [10].

In the combined solar and wind energy systems for building application, the hot water storage tank of a PV/T system can be the energy storage for the surplus of energy from PV and WT subsystems. Experimental results from the operation of a small WT, a PV array and a thermosiphonic water heater show the effectiveness of this system [12]. In case that the surplus of electricity from PV or WT sub-systems is not used or stored in batteries, it can increase the temperature of the thermal storage tank of solar thermal unit. In PV/T/WT systems the output from the solar part depends on the sunshine time and the output of the wind turbine part depends on the wind speed and it is obtained any time of day or night. Thus, PV and WT subsystems can supplement each other to cover building electrical load.

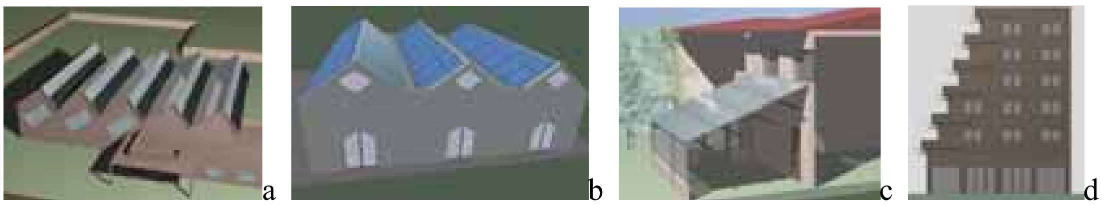

Fig. 1. Architectural designs of building integrated concentrating solar energy systems

5. Conclusions

Application aspects for the design, operation and aesthetics of building integration of solar thermal collectors, photovoltaics, small wind turbines, biomass boilers and geothermal heat pumps are briefly given. The suggested systems aim to cost effective solutions for the reduction of the used conventional energy in buildings and show that new ideas should be applied for a wide application of RES to buildings. Bioclimatic building construction or retrofitting and synergy effects between all RES can result in a building holistic energy consumption and contribute to the protection of the environment.

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