

# Building integration of solar renewable energy systems towards zero or nearly zero energy buildings

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## Abstract

With buildings accounting for 40% of primary energy requirements in EU and the implementation of the Energy Performance of Buildings Directive (EPBD), developing effective energy alternatives for buildings is imperative. The increasing role for renewables implies that solar thermal systems (STSs) and photovoltaics (PVs) will have a main role as they contribute directly to the heating and cooling of buildings and the provision of electricity and domestic hot water. Meeting building electrical and thermal loads will be primarily achieved through an extensive use of renewables, following standard building energy saving measures, such as good insulation or advanced glazing systems. These systems are typically mounted on building roofs with no attempt to incorporate them into the building envelope creating aesthetic challenges, space availability issues and envelope integrity problems. This paper aims to give a survey of possible solutions of PV and STS integration on the building roofs and façades. The advantages of integration are quantified and suggestions are given to address the possible problems created.

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## 1 INTRODUCTION

The Renewable Energy Framework Directive sets a 20% target for renewables by 2020. Buildings account for 40% of the total primary energy requirements in the EU [1]. Therefore, developing effective energy alternatives for buildings, used primarily for electricity, heating, cooling and the provision of hot water, is imperative. One way to reduce fossil fuel dependence is the use of renewable energy systems (RESs) which are generally environmentally benign. In some countries, RES and, in particular, solar water heating are used extensively. The benefits of such systems are well known, but one area of concern has been their integration. Most solar components are mounted on building roofs and they are frequently seen as a foreign element on the building structure. Due to this fact alone and irrespective of the potential benefits, some architects object to this use of RESs. It is therefore necessary to find ways to better integrate solar systems within the building envelope, which should be done in a

way that blends into the aesthetic appearance and form of the building architecture in the most cost-effective way.

The Energy Performance of Buildings Directive (EPBD) requires that RES are actively promoted in offsetting conventional fossil fuel use in buildings. A better appreciation of photovoltaic (PV) and solar thermal system (STS) integration will directly support this objective, leading to an increased uptake in the application of renewables in buildings, which is expected to rise dramatically in the next few years. This is further augmented by the recast of EPBD, which specifies that by the year 2020 the buildings in EU should be nearly zero energy consumption. Meeting building electrical and thermal loads will be primarily achieved through an extensive use of renewables, following standard building energy saving measures. Both PV and STS are expected to take a leading role in providing the electrical and thermal energy needs, respectively, as they can contribute directly to the building electricity, heating, cooling and domestic hot water requirements. There

are many discussions about the advantages and disadvantages of adopting RES towards achieving zero or nearly zero energy buildings. The advantages are:

- (1) Offer local generation of heat and electricity so transmission losses are minimized.
- (2) Usually the generation is done by RESs, which are friendly to the environment.
- (3) The building owner can install a high-tech system by taking advantage of the various subsidies that exists.
- (4) The energy consumption expenditure for the building is minimized or it is not existent (for 100% coverage).
- (5) The overall value of a property increases tremendously.
- (6) The building can be of a higher class concerning energy performance certificate.
- (7) As the energy performance certificate and the class of the building are related to the amount of rent requested, a higher income can result for the owner.
- (8) There may be substantial income to the building owner by selling the electricity produced (for grid-connected systems).

The disadvantages are also important and are as follows:

- (1) The initial expenditure for the building is higher.
- (2) The owner usually has to pay the expenditure for the RES and then apply to get the money back from subsidies.
- (3) Problems to install the RES on the building structure.
- (4) Problems with respect to the space availability to install the RES systems required.
- (5) Most RES systems will require periodic maintenance, which creates extra worries and costs for the building owner.
- (6) On existing buildings, there may be disruption of existing services.
- (7) Building integration may require specialist training for the installers.

## 2 BUILDING INTEGRATION OF SOLAR RES

Among the renewable energy resources, solar energy is the most essential and prerequisite resource of sustainable energy because of its ubiquity, abundance and sustainability.

The systems that are usually employed in buildings are PVs and solar thermal collectors. PVs can supply the electricity required to the building or the generated electricity can be fed/sold to the grid. The latter is usually preferred as the system does not require batteries for energy storage and take advantage of higher electricity rates that can be obtained by selling the electricity produced to the grid. STS can supply thermal energy for space heating, cooling and the provision of hot water for the needs of a house/building. These systems are examined separately in the following sections.

The advantages of building integration of RES are that more space is available on the building for the installation of the required area of the RES systems and that the traditional

building component is replaced by the RES one, which increases the economic viability of the systems.

In the case that this concept is employed, coupled with aesthetic and architectural challenges of building integration, many practical issues need to be resolved, such as rainwater sealing and protection from overheating (avoiding increased cooling loads during summer). The extra thermal energy can also be used for the heating of the building in winter. As RES are latitude dependant, with respect to façade application and solar incidence angle effects, these needs to be considered as countries near the equator have high incidence angles (the sun is higher on the sky) but more energy is available compared with higher latitude countries.

The adoption of building integration of RES can fundamentally change the accepted solar installation methodologies that affect residential and commercial buildings throughout the world. Maybe the single most important benefit originating from this idea is the increased adoption of RES in buildings.

A solar energy system is considered to be building integrated, if for a building component this is a prerequisite for the integrity of the building's functionality. If the building integrated PV or STS is dismantled, dismantling includes or affects the adjacent building component, which will have to be replaced partly or totally by a conventional/appropriate building component. This applies mostly to the case of structurally bonded modules but applies as well to other cases, like in the case of replacing with building-integrated STSs (BISTS) or building-integrated PVs (BIPV) a wall-leaf in a double wall façade. Therefore, building integration must provide a combination of the following:

- (1) Mechanical rigidity and structural integrity
- (2) Weather impact protection from rain, snow, wind and hail
- (3) Energy economy, such as useful thermal energy, but also shading and thermal insulation
- (4) Fire protection
- (5) Noise protection

The building integration of RESs can pose a number of problems that will need to be considered such as:

- (1) Amount of thermal energy collected and at what temperature range
- (2) Resistance to wind-driven rain penetration
- (3) If the underlying base layer is transparent, calculation of light and solar energy characteristics
- (4) Calculation of thermal resistance and thermal transmittance characteristics of the construction (overall heat transfer coefficient)
- (5) Fire protection classification and fire protection from hot components in contact with flammable materials
- (6) Noise attenuation

### 2.1 PV systems

The usual way to install a PV system on a building is to install it with brackets on a flat roof or on top of a sloping roof.

The former is more pleasing aesthetically, but the idea of building integration systems is to be able to replace a building element with the PV system and thus increase the prospects of the RES system. Originally, one of the best typical applications considered to integrate PV on buildings was as a shading device as shown in Figure 1. These are installed over equator facing (south in north hemisphere and north for the south hemisphere) windows of buildings, replacing the traditional overhangs and provide shade on the transparent elements (e.g. windows) and electricity from the PVs, which are located at the optimal direction and angle to provide the maximum shading but also the maximum radiation capture.

Integration improves the cost-effectiveness by having the PV panels provide additional functions, which involve active solar heating and daylighting. The following are some recognized methods of beneficial integration:

- (A) **Integrating the PV panels into the building envelope—building integrated PV (BIPV).** This strategy involves the replacement of roof shingles or wall cladding with PV panels. It has significant advantages over the more usual ‘add-on’ strategy. Not only does it eliminate an extra component (e.g. shingles), but it also eliminates penetrations of a pre-existing envelope that are required in order to attach the panel to the building. Architectural and aesthetic integration is a major requirement in this type of BIPV system. Not only can this strategy lead to much higher levels of overall performance, it can also provide enhanced durability. This kind of system provides only electricity either to the building or the grid.
- (B) **Integrating heat collection functions into the PV panel – building integrated PV/thermal (BIPV/T).** PV panels typically convert from ~6 to 18% of the incident solar energy to electrical energy, and the remaining solar energy is available to be captured as useful heat. This is normally lost as heat to the outdoor environment. In this strategy, a coolant fluid, such as water or air, is circulated behind the panel, extracting useful heat. The coolant also serves to lower the temperature of the panel; this is beneficial, because the panel efficiency decreases with higher panel temperature. This strategy can be adopted in either in an open-loop or closed-loop configuration. In one open-loop configuration, outdoor air is passed under PV panels and the recovered heat can be used for space heating, preheating of ventilation air or heating

domestic hot water—either by direct means or through a heat pump. Therefore, this kind of system provides both electricity either to the building or to the grid and thermal energy, which is used to satisfy part of the thermal load of the building.

Two applications which fall into the above two categories; one using the PV as a roof (PV roof) and one as a façade (PV façade) of the building are shown in Figure 2a and b, respectively. It should be noted that in this case the appropriate building component (roof or wall or their finish) is replaced by the PV. This is advantageous for the economic viability of the PV system but creates a number of problems that need to be resolved. These are the problems of rain penetration or protection and the increase of temperature of the building component and consequent thermal load of the building during summertime. For this purpose, an air gap is created at the back of the PV and the basic building component through which usually fresh air is blown. This air can be directed into the building during winter time, in which case recirculated air from the building is used, or thrown away to the environment during summer time.

- (C) **Integrating light transmission functions into the PV panel – building integrated PV/light (BIPV/L).** This strategy uses special PV panels (semitransparent PV windows) that transmit sunlight. As was the case for the previous approach, this strategy draws on the fact that only a fraction of the incident solar energy goes into electricity, and the remainder can be used for other purposes—in this case for useful light, thereby saving on the energy that electrical lights would otherwise



Figure 1. Typical applications of PV shading on buildings.

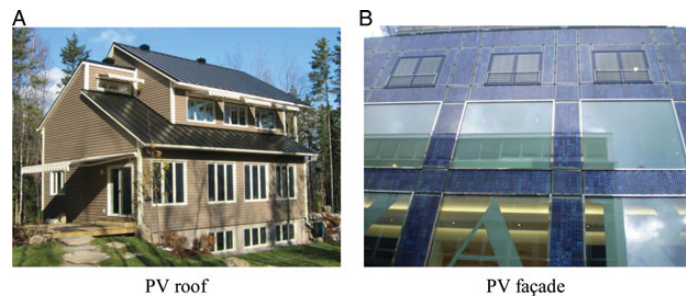


Figure 2. Building integration of PV. (a) PV roof. (b) PV façade.

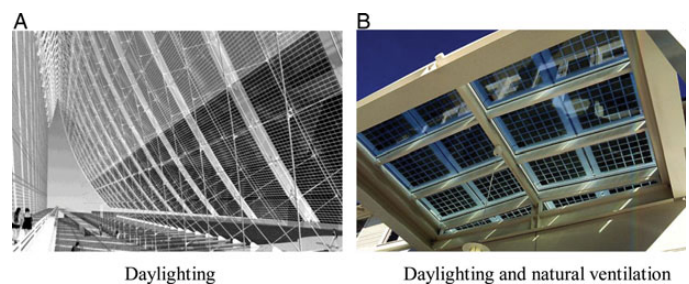
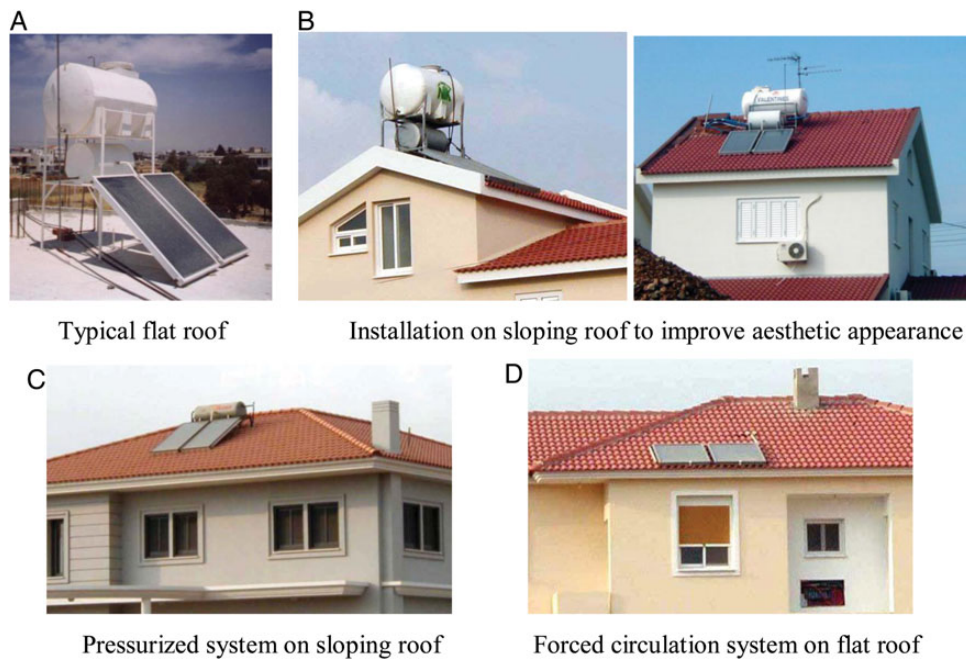


Figure 3. Combination of building integrated PV with daylighting and natural ventilation. (a) Daylighting (b) Daylighting and natural ventilation.



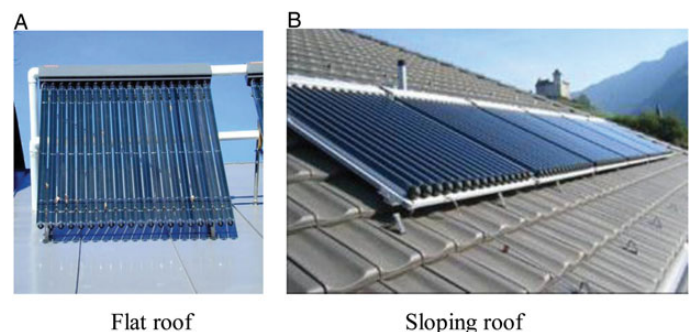
**Figure 4.** Various flat-plate solar water heating systems in Cyprus. (a) Typical flat roof. (b) Installation on sloping roof to improve aesthetic appearance. (c) Pressurized system on sloping roof. (d) Forced circulation system on flat roof.

draw. Thin-film PV cells that let some sunlight through are commercially available for this purpose. A major challenge is limiting the temperature rise of the windows, and controlling the impact of the associated heat gains, during times when building cooling is required. Compared with normal windows, these windows have a reduced light transmission and can therefore function as shading devices. Therefore, this kind of system provides both electricity either to the building or the grid and daylight, which is used to satisfy part of the lighting requirements of the building.

Photographs of actual applications of PV with daylighting and/or natural ventilation are shown in Figure 3. As can be seen, a transparent PV system is used which allows daylighting to pass into the building and if this is combined with opening mechanisms as in Figure 3b the system can be combined also with natural ventilation of the space below the PV system.

## 2.2 Solar thermal systems

The solar collecting methodologies that can be applied in buildings are the simple thermosiphonic units, forced circulation systems employing flat plate collectors, integrated collector storage units, evacuated tube collector systems and various low concentration compound parabolic units [2]. In some countries, such as Cyprus, RESs and, in particular, solar water heating are used extensively, with 93% of all domestic dwellings currently equipped with such a system [3]. Figure 4 shows a number of these systems as applied in various situations. Figure 4a shows the typical flat roof installation of a thermosiphon solar water



**Figure 5.** Evacuated tube solar collector on building roofs. (a) Flat roof. (b) Sloping roof.

heating system, which is the mostly used system. Cyprus suffers for many years from a water shortage problem, which leads to frequent water supply interruption. For this reason, a cold-water tank is installed (top big white circular tank) above the collector and hot water horizontal cylinder to supply both the solar system and the building with water. As can be seen this creates an even more serious aesthetic problem to the building. Some other designs try to blend the system on the building roof, as shown in Figure 4b.

A better way is to use a pressurized water supply system, in which case the cold-water tank can be installed at a lower level but this is more expensive. Such a system on a sloping roof is shown in Figure 4c and the aesthetic improvement is obvious. An even better solution is the use of a force circulation system, in which case even the hot water storage tank is also removed

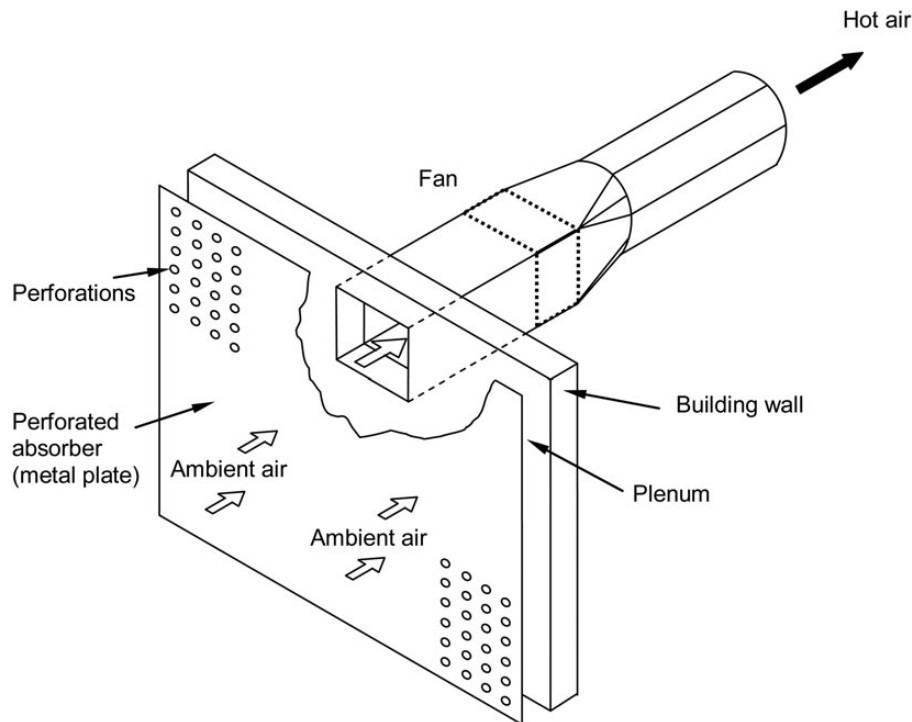


Figure 6. Transpired air solar collector.

from the roof, located indoors and although this system is even more expensive, the aesthetic appearance of the building is further improved. The solar flat-plate collectors are now the only part of the system installed on the roof but are not usually integrated to it as shown in Figure 4d. A similar situation occurs for other solar water heating system as the ones using evacuated tube collectors, shown in Figure 5.

The benefits of solar water heating systems are well known, but one area of concern has been their integration. Most solar collecting components are mounted on building roofs with no attempt to incorporate them into the building envelope, as shown in Figures 4 and 5. In many instances, they are actually seen as a foreign element on the building roof. Many architects, irrespective of the potential benefits, object to this use of RESs due to this fact alone. The problem will be even more serious, when solar space heating and cooling systems are used, as they required much more solar collectors. It is therefore necessary to find ways to better integrate solar collectors within the building envelope and/or structures, which should be done in a way that blends into the aesthetic appearance and form of the building architecture in the most cost-effective way.

Another example of a collector system, which is really building integrated, is called the transpired solar air collector. Transpired air collectors are quite simple structures used for heating purposes in buildings. This collector consists of a perforated blackened metal sheet, which is placed at a close distance in front of an equator facing building wall. A fan forces ambient air to pass through the perforation holes, which is thus heated and distributed inside the building, as shown in Figure 6. So,

this kind of system is used to satisfy directly the heating needs of a building.

As was seen above, various solar heating systems can be installed in buildings and each one of them has to be considered by itself when building integration is considered. For example, it is not yet investigated if a thermosiphon system installed vertical on the façade of a building can work effectively. Maybe the easier solution is to have an active system with a pump to transfer the thermal energy collected. Evacuated tube collectors can lead to serious rain penetration problems when integrated in buildings unless a special construction is done behind the collector to keep rain out of the building structure. Two solutions of building integrated flat-plate collectors are shown in Figure 7 as examples of this application. The collector consists of the usual parts found in stand-alone systems without the casing and the whole construction is set up in front of the brick of the normal wall. The collector can be installed by leaving an air gap between the insulation and the brick according to the prevailing conditions that exist in the area of installation and the necessity to avoid migration of moisture into the building. In both cases, good insulation is used to avoid transferring unwanted heat into the building, especially during the summer months. The same construction can be used for sloping roof applications in which case the brick is replaced by concrete slab.

In view of the EPBD, which also requires the extensive use of thermal insulation, the above solutions can be viewed, especially for retrofitting applications, as external insulation applied to the external wall surface, protected with glazing. So, the only extra

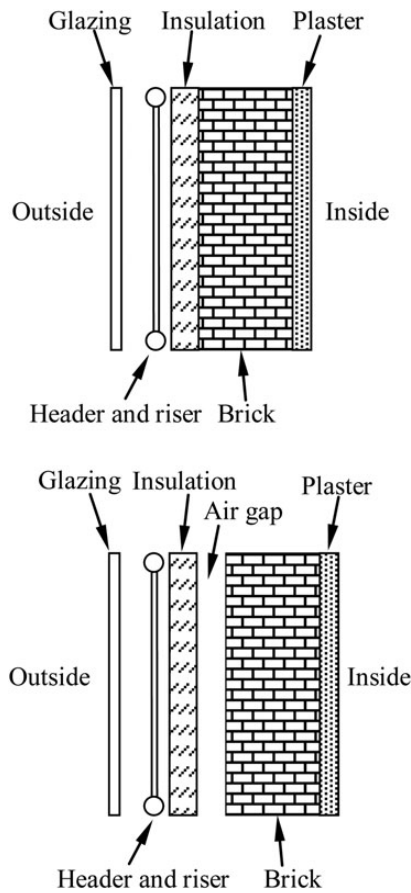


Figure 7. Two solutions of façade building integrated flat plate collectors.

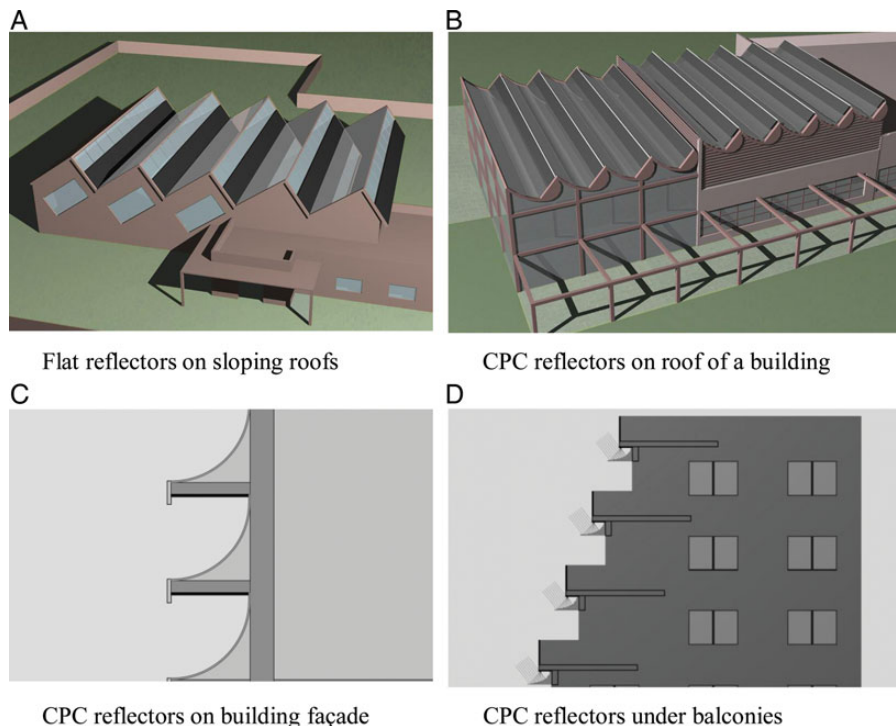


Figure 8. Building integration to flat and CPC type of reflectors. (a) Flat reflectors on sloping roofs. (b) CPC reflectors on roof of a building. (c) CPC reflectors on building façade. (d) CPC reflectors under balconies.

element required is the header and riser assembly, storage tank and piping (not shown) and glazing in order to convert the system into a thermal energy collection system. Of course, the ideas and systems to be used are not limited to the ones shown in Figure 7, but can include relatively simple solutions, like, for example, in the form of a Trombe wall with pipes running into the concrete wall, which is painted black, to collect and transfer the thermal energy collected.

Integrated collector storage and compound parabolic collector (CPC) designs can be used in a variety of applications. Various solutions to integrate these collectors on the building structure are proposed by Tripanagnostopoulos [4, 5]. These concern flat reflectors to increase the solar radiation falling on solar receiving surfaces, CPC-type designs and Fresnel-type reflectors. All of them can be used for solar thermal applications and/or PV systems and some of the proposed solutions are shown in Figure 8. The designs which show building integration of CPC solar systems concern static concentrators with linear absorbers on building roofs, facades or under the balconies. CPC systems can also be used effectively in central and northern Europe where the Sun is at low altitude angle for many months of the year.

Recently a new COST Action is approved to investigate the building integration of STSs (BISTS). The COST identification number of the Action is TU1205 and the Action belongs to the Transport and Urban Development (TUD) Domain. More details can be obtained from COST web page ([www.cost.eu/domains\\_actions/tud/Actions/TU1205](http://www.cost.eu/domains_actions/tud/Actions/TU1205)) or the project web page (<http://www.tu1205-bists.eu/>).

### 3 CONCLUSIONS

The EPBD requires that RES are actively promoted in offsetting conventional fossil fuel use in buildings. A better appreciation of PV and STS integration will directly support this objective, leading to an increased uptake in the application of renewables in buildings. This uptake in RES in buildings is expected to rise dramatically in the next few years. This is further augmented by a recast of the Directive, which specifies that the buildings in EU should be nearly zero energy consumption (residential and commercial buildings by the year 2020 and public buildings by 2018). Meeting building thermal loads will be primarily achieved through an extensive use of renewables, following standard building energy saving measures, such as good insulation or advanced glazing systems. Both PV and STS are expected to take a leading role in providing the electrical and thermal energy needs, as they can contribute directly to the building electricity, heating, cooling and domestic hot water requirements.

As can be seen from the solutions presented in this paper a number of ideas have been tried and others are just at the concept stage and generally more R&D effort is needed. It is believed that, in the coming years, more and more of these

solutions/ideas will find their way in the market in view of the implementation of the directives imposed by the EU.

### ACKNOWLEDGEMENTS

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