

Building integrated solar thermal systems – a new era of renewables in buildings

Soteris A. Kalogirou

*Cyprus University of Technology, Department of Mechanical Engineering and Materials Sciences and Engineering,
P.O. Box 50320, 3603 Limassol, Cyprus*

Buildings' in EU consume 40% of the primary energy requirements. This is the main reason the Energy Performance of Buildings Directive was implemented whereas the recast of the Directive, specifies that the buildings erected after 2020 should be of nearly zero energy consumption, a requirement that assumes extensive use of renewables. This new role of renewables implies that in addition to photovoltaics, solar thermal systems (STS) will also have a main role to play. The primary use of STS is to meet the building thermal loads, after the traditional standard building energy saving measures are applied, like thermal insulation, double glazing, etc. STS are typically mounted on building roofs as add-on components with no attempt to incorporate them into the building envelope. In this way aesthetic challenges, space availability issues and envelope integrity problems need to be considered. The purpose of this paper is to give a survey of possible applications of STS integration on the building roofs and façades. Details of some projects already under development are also presented.

Keywords: building integration, building performance, solar thermal systems, flat-plate collectors

INTRODUCTION

Buildings energy consumption, account for 40% of the total primary energy requirements in the EU [1]. For this reason, the Renewable Energy Framework Directive, known as the 20-20-20 Directive, is developed which sets a 20% target for renewables by 2020. It is therefore imperative to develop effective energy alternatives suitable to be applied in buildings. An effective and environmental friendly way to reduce fossil fuel dependence in buildings is the use of renewable energy systems (RES). These can be used mainly for heating, cooling and the provision of sanitary hot water. For example, in Cyprus RES, and more specifically solar water heating, are used extensively for the sanitary hot water preparation to more than 93% of the dwellings. Usually these are mounted on building roofs not in a very aesthetic way and sometimes are seen as a foreign element on the roof. For this fact alone and irrespective of the significant economic benefits obtained, some architects do not like this use of solar water heaters or tried to hide them, which usually creates operational problem mainly due to shading. There is therefore a need to find ways to integrate solar systems on the building envelope (walls and roof), which should be done in an aesthetic pleasing way. This is usually done in a win-win situation, i.e., by replacing a part of the building construction the solar system becomes more economically viable and at the same time the building structure provides thermal energy for use in the building.

Energy Performance of Buildings Directive (EPBD) from its inception, and especially its recast published a few years ago, requires that RES are actively employed to offset conventional fossil fuel consumption in buildings. Such a use of RES reduces the overall building energy consumption and thus a better building category is achieved. Solar thermal systems (STS) integration will directly support this Directive, leading to an increased use of renewables in buildings, which is expected to rise drastically in the coming years. Moreover, the recast of EPBD, specifies that by the year 2020 the buildings in EU should be of nearly zero energy consumption, meaning that after applying various measures to reduce building consumption the rest of the load is covered by RES to achieve nearly zero consumption on a yearly estimation basis. This mean that the building thermal loads will be primarily covered through an extensive use of renewables, which is done after standard building energy saving measures, such as the use of good thermal insulation, advanced glazing systems, etc. are applied. Therefore, STS are expected to take a leading role in covering the building energy needs, and they can contribute directly to the building heating and cooling loads and the provision of domestic hot water for the needs of the occupants.

BUILDING INTEGRATION OF SOLAR THERMAL SYSTEMS

Among the various renewable energy resources, solar energy is considered as the most effective that

* To whom all correspondence should be sent:
soteris.kalogirou@cut.ac.cy

can be applied to buildings to achieve sustainable development mainly because of its abundance and the relatively easy way that this can be used. In particular, solar thermal systems can supply thermal energy for space heating/cooling and the provision of hot water for the needs of a building. An effective building integration of STS, can also create aesthetic improvement, and there would be more space on the building for the installation of the required area of collectors. This is also cost beneficial as the traditional building component is replaced by the STS one, which increases the economic viability of the systems, both of the building and the solar system.

The adoption of building integrated solar collectors, in addition to the architectural and aesthetic benefits that this integration will bring, it creates also some practical issues which need to be addressed; such as rainwater sealing and protection from overheating (avoiding increased cooling loads during summer). As façade installed STS are latitude dependent with respect to solar incidence angle effects, this needs to be considered in detail as countries close to the equator have high solar incidence angles, especially during summer, but more energy is available year round, compared to the high-latitude countries where the sun is much lower, thus smaller incidence angles are evident but the sky is usually cloud covered.

The adoption of building integration of STS, abbreviated to BISTS, can fundamentally change the accepted way solar installations are implemented. These could affect residential and commercial buildings throughout the world. This will surely create a new era of the use of renewables 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 STS is dismantled, dismantling includes or affects the adjacent building component, which will have to be replaced partly or totally by a conventional building component.

The scope of this paper is to present a review of current building integrated STS state of the art technological developments and the most suitable options to achieve this objective. This will enable an understanding of how this integration is applied so far in various buildings worldwide, which will help to identify new ways to achieve better integration. For architects, the application of STS on buildings must form part of a holistic approach. A high-quality solar system can provide a

substantial part of the building's energy needs if the building has been designed in the right way. Through a holistic approach, integrating these systems does not only mean replacing a conventional building material, but also aesthetically integrating it into the building design. The integration then takes over other functions of the building's skin. For example, mounted on a sloped roof, profiled systems mean that the STS modules can be part of the watertight skin. A distinction can be made between integration of these systems in the building skin as cladding elements or integrated into the roof or as building components like awnings, shading devices etc. The aim of architectural and building integration of these systems into buildings is to reduce the requirement for land and additional costs, in addition to aesthetics that is generated by the process. This could be the cost of a support structure and the cost of building elements, such as tiles and cladding elements. It is evident that STS integrated into buildings give a more elegant look, and it is more efficient to integrate these systems when constructing the building, rather than mounting them afterwards. Additionally, the integration can bring other added benefits, as for example they may provide a high degree of solar shading for the building itself, which is particularly important in warm climates.

Usually there are three zones for integrating the systems into buildings. These are the roofs, façades and building components like balcony railings, sunshades and sunscreens [2]. STS can be incorporated into buildings by either superimposition - where the system is attached over the existing building envelope, or integration where the system forms a part of the building envelope [3].

COLLECTOR SYSTEMS THAT CAN BE BUILDING INTEGRATED

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 [4].

In some countries, such as Cyprus, renewable energy systems and in particular solar water heating are used extensively, with 93% of all domestic dwellings currently equipped with such a system [5]. Most solar collecting components are mounted on building roofs with no attempt to incorporate them into the building envelope. In many instances,

these are actually seen as a foreign element on the building roof. Many architects, irrespective of the substantial benefits that these systems offer, object to this use of renewable energy 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 collector area. 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.

Classification

BISTS have been classified across a range of operating characteristics, system features and

mounting configurations. The main classification criteria of any solar thermal system is based on the method of transferring collected solar energy to the application (active or passive), the energy carrier (air, water, water-glycol, oil, electricity etc.) and the final application for the energy collected (hot water and/or space heating, cooling, process heat or mixed applications). Additionally, for BISTS the architectural integration quality based on structural, functional and aesthetical variations have to be classified. The collector as a central element of integration has to fulfil in some cases many more specifications than ordinary, add-on collectors. Fig.1 illustrates a simple BISTS classification.

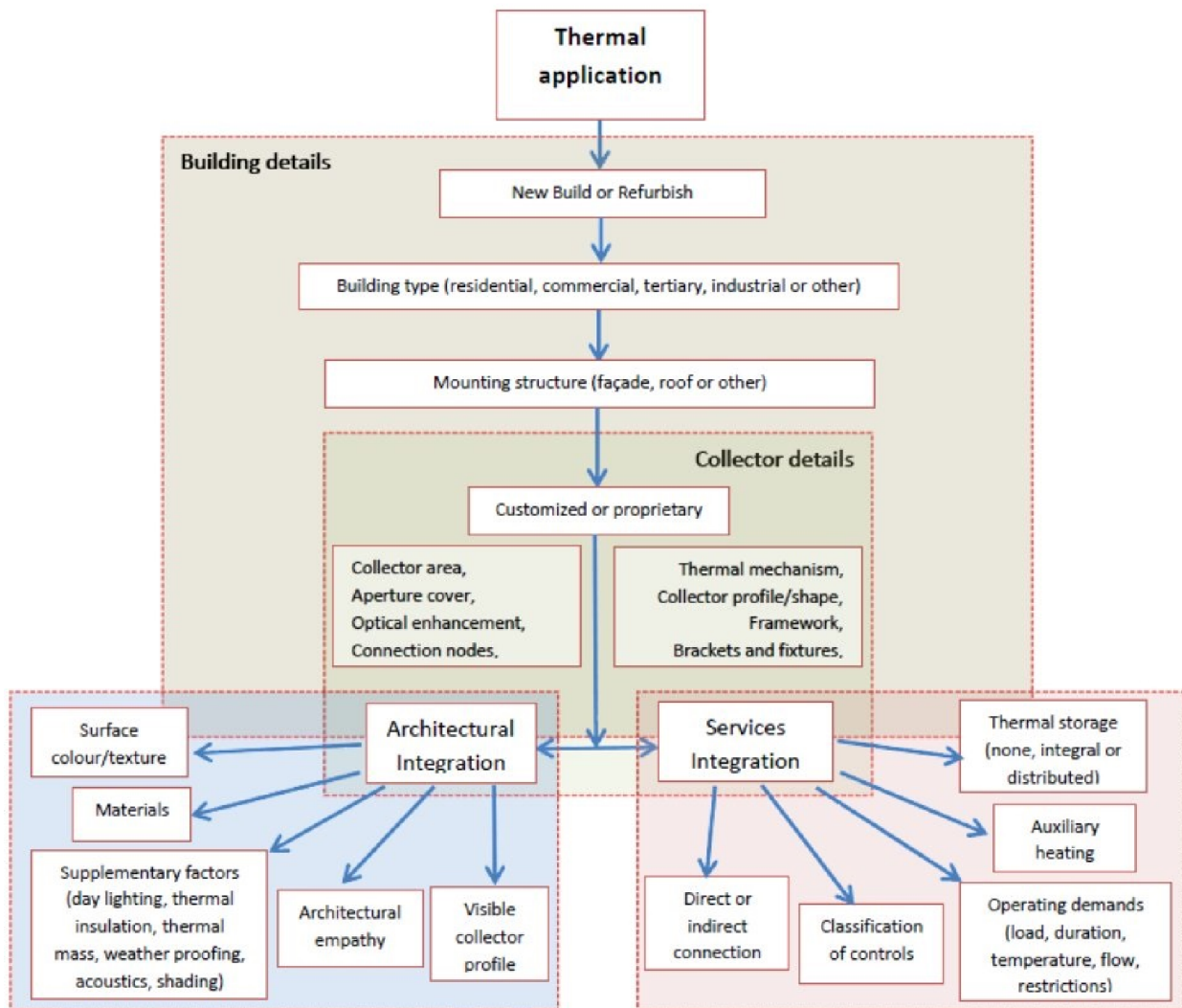


Fig.1. BISTS classification

The majority of BISTS can be classified as being either passive or active, e.g. in the former case using thermal buoyancy for fluid transport (natural convection or circulation) or no transport at

all, and in the latter case utilizing pumps or fans to circulate the thermal transfer fluid to a point of demand or storage (forced convection or circulation). A number of systems are hybrids, i.e.,

operating in part through a combination of natural and forced transport methods. Many façade solar air heaters use thermal buoyancy to induce an air flow through the vertical cavities that can be further augmented with in-line fans (and auxiliary heating) as necessary.

BISTS deliver thermal energy to the building but other forms of energy may contribute additionally to the buildings energy balance. For instance, daylight comes through a transparent window or façade collector. Heated air or water can be stored or delivered directly to the point of use. Although the range of applications for thermal energy is extensive, all of the evaluated studies demonstrate that the energy is used to provide one or a combination of the following [6]:

1. Space heating: Thermal energy produced by a BISTS may reduce the space heating load of a building by adding solar gains directly (e.g. by a passive window) or indirectly (e.g. by transferring heat from the collector via a storage to a heating element) into the building. An example is shown in Fig.2.

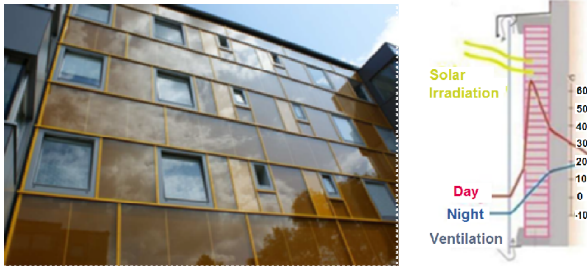


Fig.2. An indirect solar construction BISTS

2. Air heating and ventilation: Thermal heat can be used to preheat fresh air supply to the building. Air is heated directly or indirectly (in a secondary circuit), using forced flow or thermosiphonic flow (natural circulation) to provide

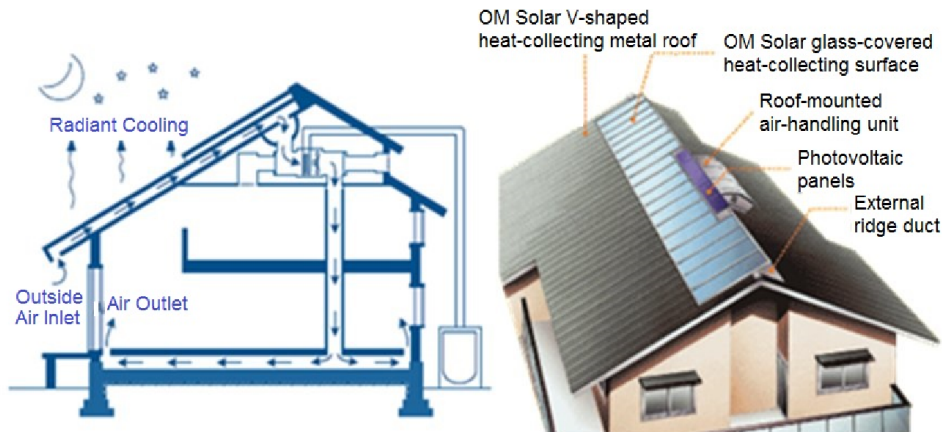


Fig.5. Radiant cooling via a reversed BISTS [7]

space air heating and/or ventilation to the building as shown in Fig.3. In some instances, an auxiliary heating system is used to augment the heat input because of comfort reasons. A variation of this system is the transpired collector in which the sheet metal in front of the building has thousands of small holes to draw the air which gets warm by flowing over the hot sheet.

3. Water heating: Hot water demand in the building is the most popular application. In the majority of water heating BISTS, a customized heat exchanger is used to transfer collected heat to a (forced) heat transfer fluid circuit and on to an intermediate thermal store and/or directly to a domestic hot water application. Usually, an auxiliary heating system is used to augment the heat input. An example is shown in Fig.4.

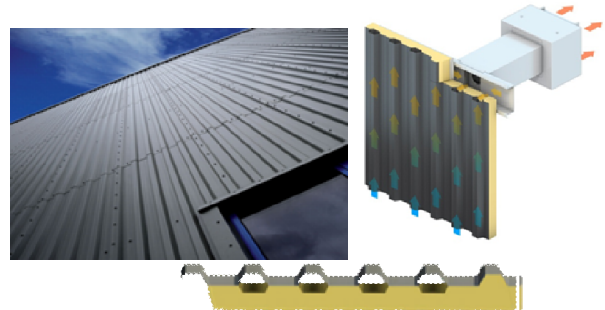


Fig.3. Solar air heating façade BISTS with auxiliary heating system



Fig.4. Roof integrated flat plate BISTS for Solar Water Heating

4. Cooling and ventilation: In cooling-dominated climates, buildings most of the time have an excess of thermal energy, and therefore there is a requirement to remove this heat in order to create a comfortable environment. In this view BISTS can also be a technology to extract heat from a building. A number of methods can be used to provide cooling (and/or ventilation) like; shading vital building elements, desiccant linings, supplying heat directly to ‘sorption’ equipment, or induced ventilation through a stack effect and reverse operation of solar collecting elements for night-time radiation cooling as illustrated in Fig.5 [7].

With reference to Fig.5, during the solar heating mode, fresh outdoor air enters a channel under the roof and flows upward. The air is heated on contact with the metal roof sheet, passing through an upper glazed section (to reduce heat losses) so the heated air enters roof top duct and is mechanically forced through the air-regulating unit. The temperature controlled air is directed down into the space to be heated via underfloor channels between the floor and the concrete slab before finally being diffused into the room through floor diffusers. In cooling mode during summer, outdoor air is drawn through the roof channels at night-time, sub-cooled using radiant cooling, and as with the heating mode, directed into the space to be cooled via the underfloor channels [7].

5. Other applications: The majority of BISTS presented so far are mounted on the façade or roofing structures, but a significant number can be classified as being other applications. This includes

a number of mounting options, from shading devices or protective barriers to balcony balustrades such as those shown in Fig.6.



Fig.6. BISTS balustrade/railing feature

Taxonomy

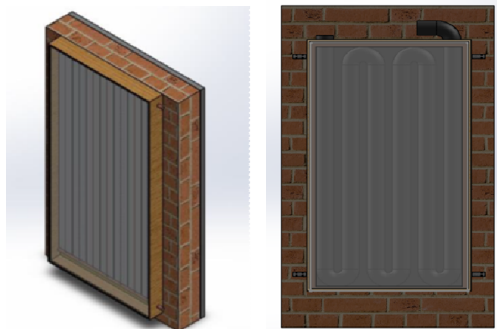
A different classification can relate systems to the mode of installation, i.e., new build, refurbishment or retrofit which is often related to the form of the design or components utilized such as proprietary/pre-fabricated or customized. Further sub-section classification can be related to features such as optical enhancements or indirect benefits associated with the BISTS, such as weatherproofing, acoustic attenuation or thermal insulation. A pictorial taxonomy of the wider BISTS family is shown in Fig.7 [6].

				Installed element					
				Façade		Roof		Other	
				New	Retrofit	New	Retrofit	New	Retrofit
OUTPUT	AIR	Air heating & ventilation	Active						
			Passive						
		Space heating	Active						
			Passive						
		Combined air and water heating	Active						
			Passive						
	WATER	Water heating	Active						
			Passive						
		Cooling & ventilation	Active						
			Passive						
ELECTRICITY	PVT	Active							
		Passive							

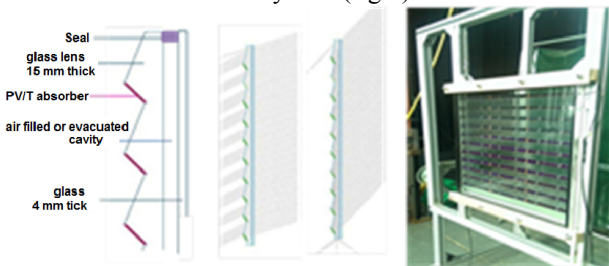
Fig.7. Taxonomy of BISTS

NEW SOLUTIONS

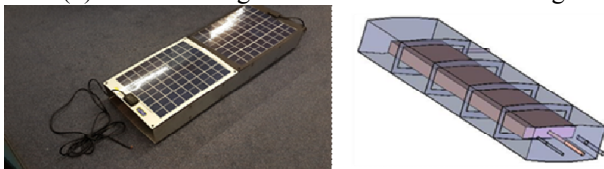
A COST Action is currently investigating the building integration of solar thermal systems (BISTS). The COST identification number of the Action is TU1205 and the Action belongs to the Transport and Urban Development (TUD) Domain. More details can be obtained from COST web page (www.cost.eu/domains_actions/tud/Actions/TU1205) or the project web page (<http://www.tu1205-bists.eu/>).



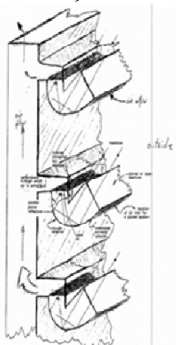
(a) Flat-plate collector water system (left) and air system (right)



(b) Concentrating PV/Thermal Double Glazing



(c) Hybrid Photovoltaic/Solar Thermal (HyPV/T) Façade Module



(d) Solar plenum



(e) Façade mounted evacuated tube collectors

Fig.8. New solutions of façade building integrated solar collectors

As part of this Action, a number of new solutions of building integrated solar thermal systems are currently under development as shown in Fig.8. The first one is a flat-plate collector, which 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 brick-wall. The system can use water or air as heat transfer medium.

The concentrating PV/Thermal Double Glazing, shown in Fig.8(b) is a façade technology that integrates glazing based solar concentrating elements, coupled with PV/Thermal absorbers [8]. As a multifunctional building component based on conventional double glazing, the system is compatible with traditional façade structures and fenestration, facilitating direct integration into new and retrofit building applications. It can provide solar electricity and heat while insulating the building thermally by using inert gases to suppress convective heat loss inside the glazing cavity. Further thermal insulation levels can be achieved by evacuation of the glazing cavity [8].

The innovative modular HyPV/T façade concept shown in Fig.8(c) integrates a novel cascade thermal diode solar water heater technology with PV cells into a single multi-functional facade element [9]. Two flattened structural vessels (outer absorbing vessel and inner storage vessel) are arranged to create a cavity between the walls of respective vessels. The cavity (maintained at a sub-atmospheric pressure) contains a liquid/vapour phase change material which is the working Heat Transfer Fluid (HTF). The HTF using an absorption/evaporation/condensation processes, the diode concept promotes solar collection and thus thermal storage during collection periods but reduces thermal losses at non-collection periods. The system can produce useful amounts of hot water and electricity [9].

The “solar plenum” shown in Fig.8(d) is an air heating solar collector in which the inclusion of an asymmetric compound parabolic concentrator with a tertiary reflector sector that reflects solar radiation into a downward facing absorber surface. Being downward-facing convection heat loss from the absorber surface is inhibited. The concentration of insolation to an absorber leads to it being at a much higher temperature than ambient. Air enters the solar plenum via a grille beneath its glazed aperture. Heat is removed by the air passing through pin holes in the transpired absorber. The flow rate is maintained at a rate that allows air plumes to pass through the thermally stratified air

layers beneath the absorber without significantly diminishing the thermal insulation of the absorber provided by the stratification.

Finally, the evacuated tube collector integration shown in Fig.8(e) is already tried in Porter school of environmental studies in Israel. A number of facade and roof applications are demonstrated and the idea is to find additional ways to incorporate this type of collector of the building envelope.

Additionally, many readymade products already appear on the market, like roof singles, façade coverings etc. Some typical examples are shown in Fig.9.

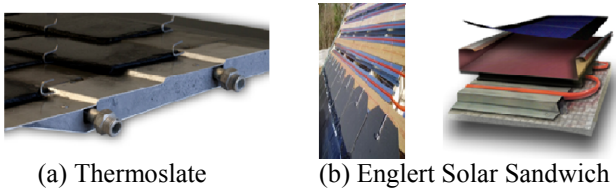


Fig.9. Commercial BISTS products

CONCLUSION

A number of building integrated solar thermal systems are presented in this paper. The implementation of EPBD and its recast which demands nearly zero energy consumption, requires that RES are actively promoted in offsetting conventional fossil fuel use in buildings. Therefore, this uptake in RES in buildings is expected to rise dramatically in the next few years. Meeting building thermal loads will be primarily achieved through an extensive use of renewables, following standard building energy saving measures. STS are expected to take a leading role in providing the thermal energy needs, as they can contribute to the building heating, cooling and domestic hot water requirements. Most of the solutions presented can be applied both to domestic and commercial buildings.

The various systems that can be integrated are classified as presented in this paper. Additionally, the taxonomy is presented according to the working fluid, application component and new or retrofit application. A number of new systems that are currently under development are also presented. 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.

ACKNOWLEDGEMENT

The author is grateful to the EU COST Action TU1205: “Building integration of solar thermal systems (BISTS)” for its sponsorship.

REFERENCES

- 1 European Commission, Doing more with less, Green Paper on energy efficiency, 22.06.2005 COM, 2005.
- 2 T. H. Reijenga, H. F. Kaan, PV in Architecture. In Antonio Luque, Steven Hegedus (Eds.): Handbook of Photovoltaic Science and Engineering: John Wiley & Sons, 2011.
- 3 M. Fuentes, Integration of PV into the built environment. Available online at http://www.brita-inpubs.eu/bit/uk/03viewer/retrofit_measures/pdf/FINAL_12_Integration_of_PV_red_kth_rev1.pdf, (2007).
- 4 S.A. Kalogirou, *Solar Energy Engineering: Processes and Systems*, Academic Press, Elsevier, New York, (2009).
- 5 C.N. Maxoulis, S.A. Kalogirou, Cyprus energy policy: the road to the 2006 World Renewable Energy Congress Trophy, *Renewable Energy*, 33, 355, (2008).
- 6 COST TU1205: Overview of BISTS state of the art, models and applications, ISBN: 978-9963-697-16-8, (2015).
- 7 OM Solar Association. <http://www.omsolar.net/en/omsolar2/roof.html>.
- 8 A. Zacharopoulos, C. McAnearney, T.J. Hyde, J.D. Mondol, M. Smyth, I. Lytvyn, Experimental evaluation of a Concentrating PV/Thermal Glazing Façade Technology, Proceedings of COST Action TU1205 Symposium, Guimaraes, Portugal, pp 128-137, ISBN: 978-9963-697-17-5, (2015).
- 9 M. Smyth, A. Besheer, A. Zacharopoulos, J.D. Mondol, A. Pugsley, M. Novaes. Experimental evaluation of a Hybrid PV/Solar Thermal (HyPVT) Façade Module Technology, Proceedings of COST Action TU1205 Symposium, Guimaraes, Portugal, pp 68-77, ISBN: 978-9963-697-17-5, (2015).