Building Integrated Solar Thermal Systems

Soteris A. Kalogirou
Cyprus University of Technology, Department of Mechanical Engineering and Materials Science and Engineering
soteris.kalogirou@cut.ac.cy

ABSTRACT: With buildings accounting for 40% of primary energy requirements in EU and the implementation of the Energy Performance of Buildings Directive, developing effective energy alternatives for buildings is imperative. The increasing role for renewables implies that solar thermal systems (STS) will have a main role as they contribute directly to the heating and cooling of buildings and domestic hot water. Meeting building thermal loads will be primarily achieved through an extensive use of renewables, following standard building energy saving measures. 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 STS integration on the building roofs and façades, applied so far. Through the presentation of the various examples, the advantages of integration are revealed.

Keywords: Solar energy, solar collectors, buildings, integration into facades.

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 (European Commission, 2005). Therefore, developing effective energy alternatives for buildings, used primarily for heating, cooling and the provision of hot water, is imperative. One way to reduce fossil fuel dependence is the use of renewable energy systems (RES) which are generally environmentally benign. In some countries, like Cyprus, 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 solar energy systems. 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 solar thermal systems (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 coming years. This is further augmented by the recast of EPBD, which specifies that by the year 2020 the buildings in EU should be of nearly zero energy consumption. Meeting building thermal loads will be primarily achieved through an extensive use of renewables, following standard building energy saving measures, such as good thermal insulation, advanced glazing systems, etc. STS are expected to take a leading role in providing the thermal energy needs, as they can contribute directly to the building heating, cooling and domestic hot water requirements.

2 BUILDING INTEGRATION OF SOLAR THERMAL SYSTEMS

Among the renewable energy resources, solar energy is the most essential and prerequisite resource of sustainable energy because of its ubiquity, abundance, and sustainability. Solar thermal systems can supply thermal energy for space heating, cooling and the provision of hot water for the needs of a house/building. The advantages of building integration of STS are that more space is available on the building for the installation of the required area of the STS systems and that the traditional building component is replaced by the STS 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 STS 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 to higher latitude countries.

The adoption of building integration of STS 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 STS 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 dismounted, dismounting includes or affects the adjacent building component, which will have to be replaced partly or totally by a conventional/appropriate building element. 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 solar thermal system (BISTS) 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 solar thermal systems can pose a number of problems that will need to be considered such as:

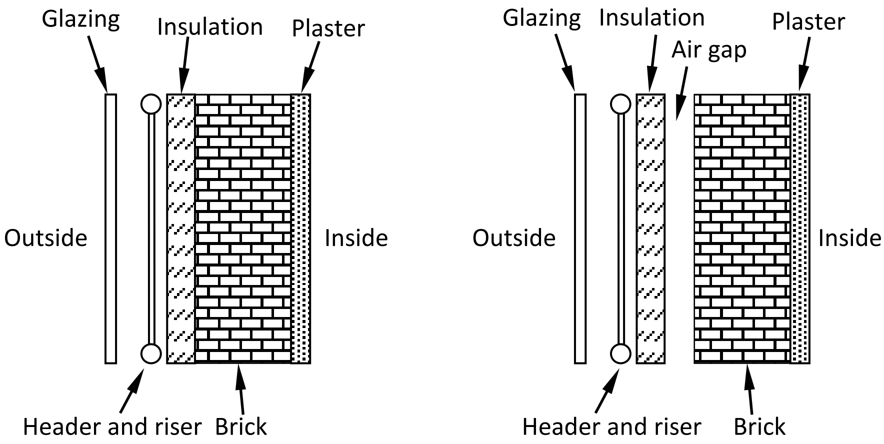
1. Amount of thermal energy collected and at what temperature range.
2. Resistance to wind-driven rain penetration.
3. If the underlying base layer is transparent, calculation of light and solar energy characteristics.
4. Calculation of thermal resistance and thermal transmittance characteristics of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

3 COLLECTOR SYSTEMS THAT CAN BE INTEGRATED

The solar collecting methodologies that can be applied in buildings are the simple thermo-siphonic units, forced circulation systems employing flat plate collectors, integrated collector storage units, evacuated tube collector systems and various low concentration compound parabolic units (Kalogirou, 2013). 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 (Maxoulis & Kalogirou, 2008).

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. 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 renewable energy systems due to this fact alone. The problem will be even more serious, when solar space heating and cooling systems are used, as they require 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.

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. 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 the rain out of the building structure.
Two solutions of building integrated flat-plate collectors are shown in Figure 1 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 brick-wall. The collector can be installed directly on the wall, as shown in Figure 1(a), or by leaving an air gap between the insulation and the brick, as shown in Figure 1(b), 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.

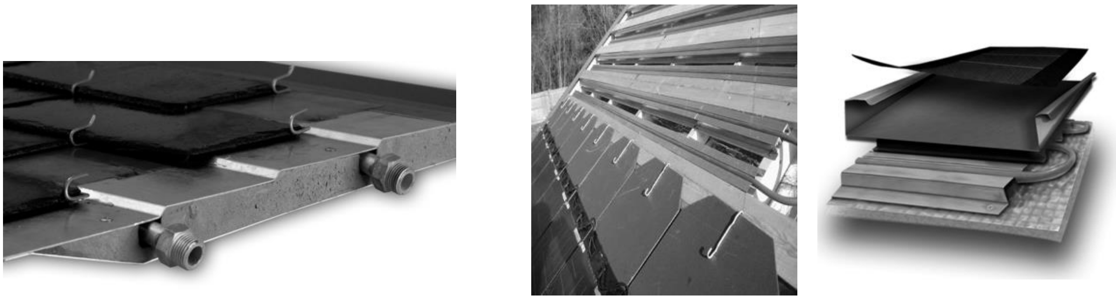


(a) STS adjacent to the brick

(b) STS with air gap

Figure 1 Two solutions of façade building integrated flat plate collectors.

In view of the EPBD, which requires also 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 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 1, but are extended to various other ones as shown subsequently. Additionally, many readymade products already appear on the market, like roof singles, façade coverings etc., all of which are also solar thermal collectors. Some typical examples are shown in Figure 2.



(a) Thermoslate (b) Englert Solar Sandwich

Figure 2. Commercial BISTS components

4 BISTS CLASSIFICATIONS/SYSTEMS

Building Integrated Solar Thermal Systems (BISTS) have been classified across a range of operating characteristics, system features and mounting configurations. The main classification criteria of all STS are based on the method of transferring collected solar energy to the application (active or passive), the energy carrier (air, water, water-glycol, oil, 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 in the integration has to fulfill in some cases many more specifications than the ordinary “add-on” collectors.

The majority of BISTS can be classified as being either passive or active, e.g. in the first case using thermal buoyancy for fluid transport (natural convection or circulation) or no transport at all, and in the second 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 however hybrids, 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 heating) if necessary. The BISTS delivers thermal energy to the building but additionally other forms of energy may contribute to the buildings energy balance. For instance daylight comes through a transparent window or façade collector, or PV/T systems will also deliver electrical power which may be used directly by any auxiliary electrical services. 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 cases.

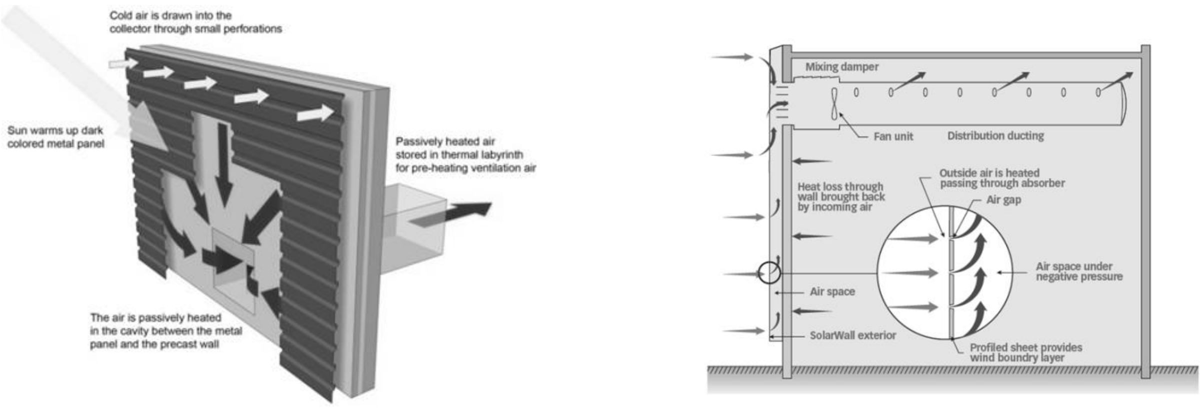
4.1 Space heating

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 as shown in Figure 3.

Figure 3. An indirect solar-comb construction BISTS.

4.2 Air heating & ventilation

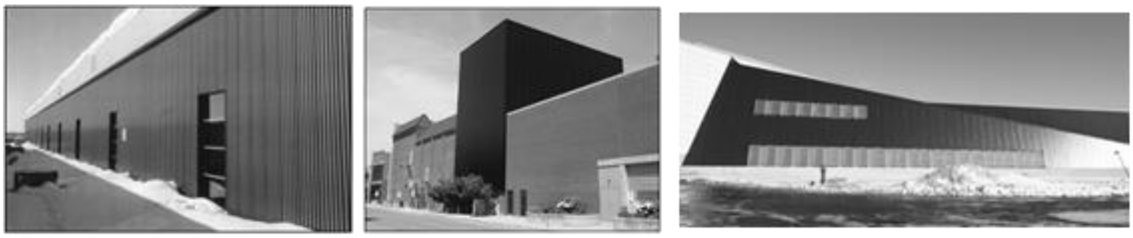
Thermal heat may be used also to preheat fresh air needed in the building. Air is heated di-rectly or indirectly (in a secondary circuit) and using forced flow or thermosiphonic action is used to provide space air heating and/or ventilation to the building as shown in Figure 4. In some instances, an auxiliary heating system is used to augment the heat input because of comfort reasons. This type of collector is called transpired air collector, shown in Figure 4(a). In this thousands of small holes are drilled on the building cladding, which is of dark colour. Air is drawn through these holes and by doing so it is heated and used directly in the space, as shown in Figure 4(b).



(a) Transpired collector (b) Principle of operation

Figure 4. Transpired air collector.

This is one of the mostly used systems and is applied in a large number of buildings mainly in Canada and USA. Notably the first application, which is also the largest solar air heating system in the world, is the Canadair Facility in Bombardier, Montreal, renovated in 1991. The solar installation was integrated on the extensive renovations that were needed to improve the indoor air quality and the appearance of the aged buildings of the complex. This is shown in Figure 5 together with other buildings where this system is installed.



(a) Canadair facility (b) Avon theatre, Canada (c) Torondo airport, Canada

Figure 5. Applications of transpired air collector in various buildings.

A variation of this collector is the Kingspan façade solar air heater shown in Figure 6, where instead of small wholes air passage is used as shown in the figure. Here the air enters on one side of the passage, as shown, and is withdrawn on the other side.

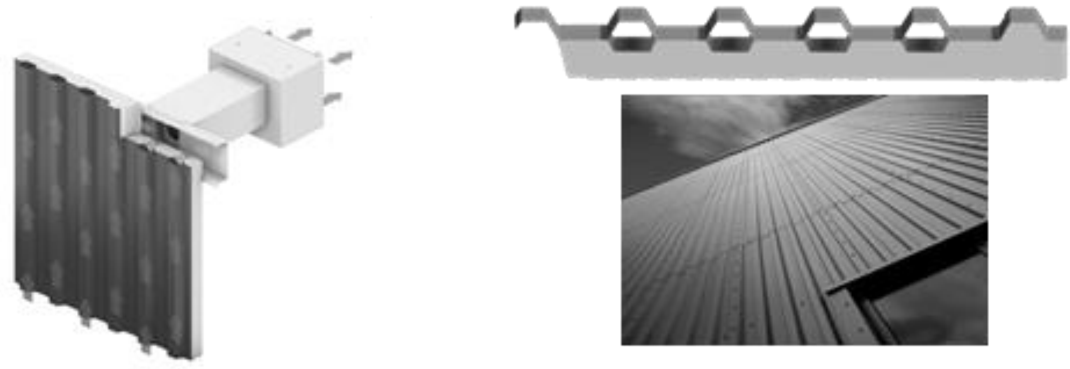
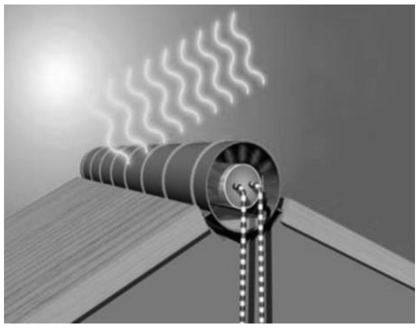


Figure 6. Solar air heating façade BISTS with auxiliary heating system.

4.3 Water heating

Covering hot water demand in the building is the most popular application. In the majority of water heating BISTS, a customized heat exchanger or integrated proprietary solar water heater 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 DHW application. In most instances, an auxiliary heating system is used to augment the heat input. Two examples are shown in Figure 7.

(a) Roof integrated flat plate collectors



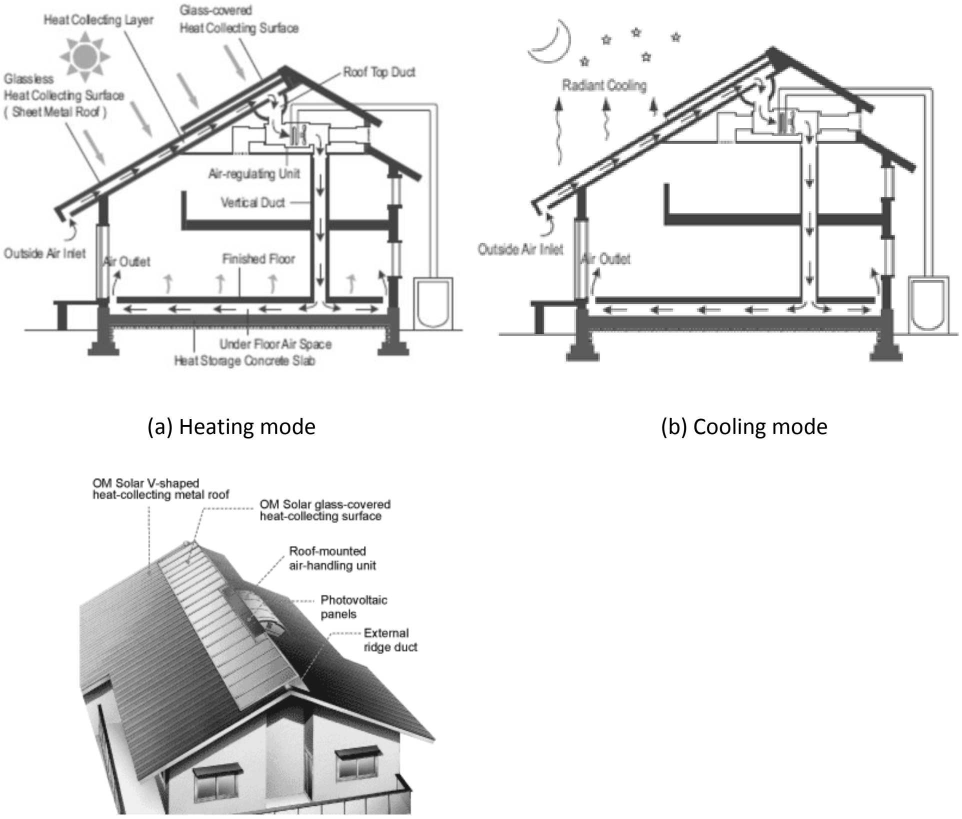
(b) Roof integrated integrated collector storage (ICS) unit

Figure 7. Roof integrated BISTS for Solar Water Heating.

4.4 Cooling & ventilation

In cooling dominated climates, buildings most of the time have an excess of thermal energy, and there BISTS can also be a technology to extract heat from a building. There are a number of methods providing a cooling (and/or ventilation) effect to a building; shading vital building elements, desiccant linings and supplying heat directly to 'sorption' equipment. An interesting idea is using induced ventilation through a stack effect and reverse operation of solar collecting elements for night-time radiation cooling as illustrated in Figure 8 (OM, 2014).

During the solar heating mode, shown in Figure 8(a), 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 improve collection) whereupon 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 the floor diffusers. In summer cooling mode, shown in Figure 8(b), outdoor air is directed through the roof channels at night-time, thus sub-cooled using radiant cooling, and as with the heating mode, directed into the space to be cooled via the underfloor channels (OM, 2014). An actual domestic example of this system is shown in Figure 8(c).



(a) Heating mode

(b) Cooling mode

(c) Actual application

Figure 8. Radiant cooling via a reversed BISTS (OM, 2014).

4.5 Other

The majority of BISTS documented are mounted on the façade or roofing structures, but a significant number can be classified as being 'other'. This embraces a multitude of mounting options, from shading devices to balcony balustrades such as the ones shown in Figure 9.

Figure. 9. BISTS balustrade/railing feature.

An additional classification can relate to the mode of installation; new build, refurbishment or retrofit which is often related to the form of the design or components utilized be 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 weather-proofing, acoustic attenuation or thermal insulation.

The work presented in this paper gives a brief summary of the activities carried out during the first year of the COST Action TU1250. The subsequent activities of the Action include the development of new products/systems, some of which will be demonstrated with actual pilot units, the creation of new models to help in the design of such systems, and the suggestion of new testing techniques to evaluate the performance of such systems. These include the following five systems:

1. Integrated PV/T/storage – modular façade unit.
2. Concentrating transpired collector.
3. Glazing integrated day-lighting/thermal collector.
4. Vacuum tube collectors on vertical facades.
5. Total construction integration of solar thermal.

The last one is the system described in section 3 but the purpose is to find solutions on fixing the absorber plate in front of the insulation, solutions on fixing large glass covers in front and ways to integrated hot water storage on the building structure, if possible.

5 CONCLUSIONS

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 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 of 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. STS are expected to take a leading role in providing the electrical and thermal energy needs, as they can contribute directly to the building 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.

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REFERENCES

European Commission. 2005. Doing more with less, Green Paper on energy efficiency, 22.06.2005 COM.

Kalogirou, S.A. 2013. Solar Energy Engineering: Processes and Systems, Elsevier, New York, Academic Press.

Maxoulis, C.N. & Kalogirou, S.A. 2008. Cyprus energy policy: the road to the 2006 World Renewable Energy Congress Trophy, Renewable Energy 33: 355–365.

OM. 2014. OM Solar Association. http://www.omsolar.net/en/omsolar2/roof.html (accessed 28/7/2014).