SECTION 3

NEW OPTIONS

CONTENTS

3.1 NEW ARCHITECTURAL DESIGN OPTIONS

Gerald Leindecker, Aleksandra Krstic-Furundzic

3.1.1 Introduction

The use of Solar Thermal System (STS) in new architectural design options is driven by evolution of material and system improvement combined with the challenge for integrated design solutions. The need for a search of the "ultimate form of environmental knowledge" (Banham, 1969) is a challenge for architects. It requires a solid understanding of the principles of physics and the various disciplines of building technology as well as an understanding that the new form has to deliver optimal performance criteria in coherence with high quality design (Leindecker, 2007).

3.1.2 Multifunctional requirements

In this comprehensive design task the issue of a full life cycle assessment becomes an important task. The Sunlight House by Jury Troy architects is an example of this new discipline (Figure 3.1.1 and Figure 3.1.2).

The house represents one of its first kinds in Austria of producing more energy in its whole life cycle than it uses and therefore the carbon footprint of this house becomes zero in the lifespan of thirty years (CO_2 neutral).

Figure 3.1.1. Sunlight House, 2010 (Photo: Jury Troy Architects by Adam Mørk).

It uses an integrated system of solarthermie as well as photovoltaics on a sculptural roof-wall element that provides an optimal angel for the systems and allowing also maximal daylight into the house. The ratio of windows to floor area is 42%. The element becomes a dominating feature of the house and is showing technology features detailed in close vicinity to traditional wood as material for the building envelope and inner walls.

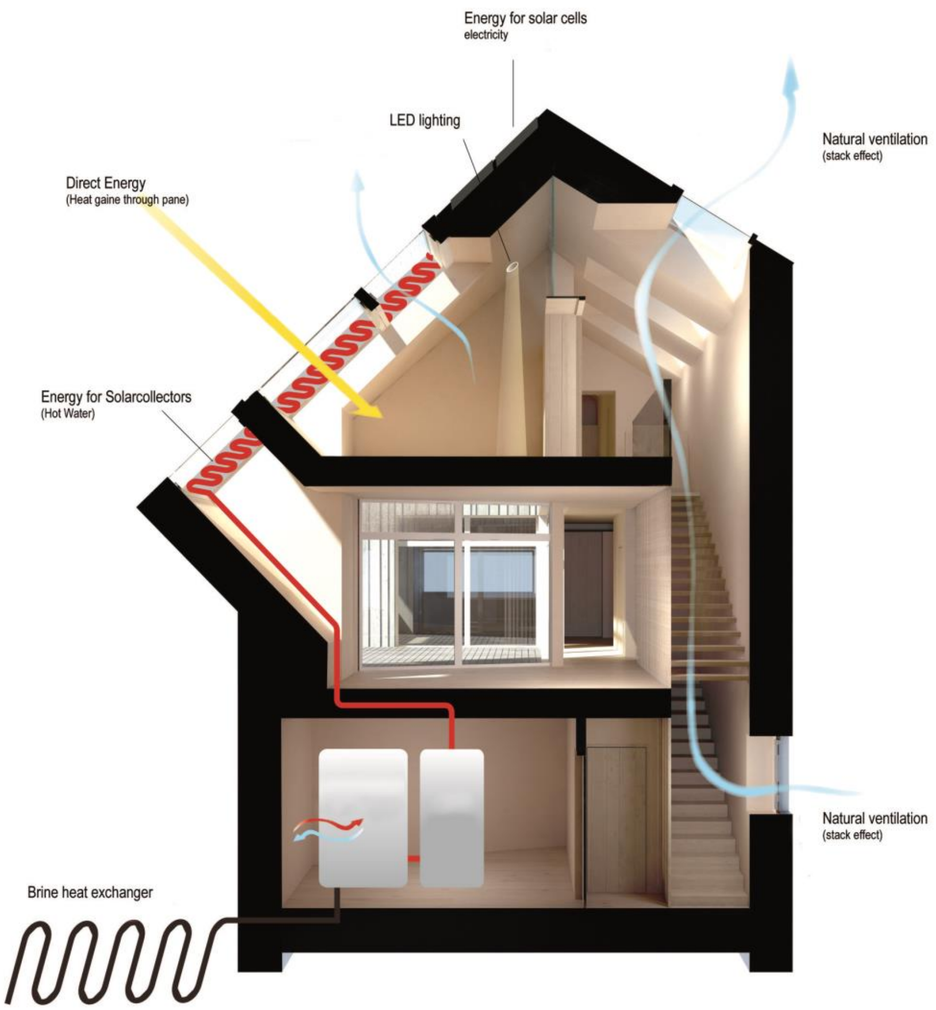


Figure 3.1.2. Sunlight House, Technical Section (Jury Troy Architects).

The house uses a combined hybrid system of a heat pump, 48 m^2 of mono crystalline photovoltaic panels and 9 m^2 of solar panels for hot water together with an air heat recovery system and windows, fulfilling near-zero-energy requirements.

The dimension of solar panels in the climate of Austria with freezing temperatures in the winter is very challenging. The system of solar-fluid circulation contains an additive of anti-freezing fluid. This fluid puts quit demanding physical features to the piping in respect to air blobs and the working temperature of the system. Shut off periods in summer due to high temperature can cause a problem to the pipes because the anti-freezing fluid can caramelize.

Therefore, an over-dimensioned system with too many solar panels compared to its actual use becomes a danger to the solar system and its functionality and lifetime.

Due to the fact that the solar panels and the photovoltaic panels are similar in size and framing material the mix of these principle different elements is not visible. This is one of the important further requirements to panel producers in both disciplines, solar thermal as well as photovoltaic environment.

On the side of manufacturers and producers the challenge of solar thermal modules is to fulfill functional, constructive and formal requirements of the building parts, that are replaced (Probst and Roecker, 2013).

Major producers are aiming at these parameters at present.

Figure 3.1.3. Hybrid Module, Photovoltaic Module, Solar Thermal Module - left to right (Photo: Leindecker G.).

The state-of-the-art panels combine features such as dimension, colour and facility for mounting with no visible difference (Figure 3.1.3). Current industrial development is looking towards hybrid modules combined in one panel.

The future development will provide direct access from planers and architects towards the production line for easy configuration of shape, colour and dimension of the panels and its parameters.

The issue of fully integrated comprehensive systems was accomplished in the Miba office building (Leindecker, 2009). The combination of photovoltaic and solar thermal panels on the elevation, along with a heat pump, was an early example of integration of systems and design. This feature is taken on by the house in Sulzenberg, Austria (Figure 3.1.4). One side of the traditional roof provides a fully integrated solar thermal system together with photovoltaic panels and roof windows. Here the geometry extends beyond the right angle and provides custom made panels for fully integration into the roof of the house. The envelope of the house is using traditional wood-shingles on the exterior wall, providing reference to traditional local building material.

Figure 3.1.4. House in Sulzberg, (Photo: Jury Troy Architects by Jury Troy).

To contrast the design aspect of integration, an example of adding pure elements on the elevation. The office building in St. Veit, Austria provides the typical elements by addition technical elements (Figure 3.1.5).

Figure 3.1.5. Office building, St. Veit (Photo: Leindecker G.).

3.1.3 New functional design options

Although the market of installed solar-thermal panels is decreasing by 15 % in 2015 compared to 2013 (Mauthner el al., 2016), new functional options are under development for wider applications.

One challenging application is tested in the Netherlands by integrating a solar thermal system into street-asphalt (Figure 3.1.6). It proves, that streets are potential options for gaining more surfaces to harvest solar thermal surplus.

Figure 3.1.6. Solar thermal system integrated into street asphalt (Road Energy systems).

This trend of functional use of public space is complemented by the project of implementing photovoltaic cells into a test tracks for bicycles in Krommenie, Netherlands[1], (Figure 3.1.7).

Figure 3.1.7. Existing test trial of a PV track for bicycles in Krommenie (Photo: Leindecker G.).

[1] Input is a result form a scientific exchange under the Cost TU 1205 framework to Wansdronk Architecture

Solar thermal systems for district heating are a new functional option (Figure 3.1.8). Although these do not require instant integration into buildings, it has an effect on the building envelope and the building design since it directs the challenge towards urban planning issues (Köhler et al., 2014).

Figure 3.1.8. New application of solar thermal solutions for district heating in Almere (Photo: Leindecker G.).

The level of efficiency makes these neighborhood solutions attractive and some large scale applications are under development. Especially with respect to new and big storage facilities these concepts are interesting and have wide acceptance.

3.1.4 Case studies

Building-integrated PV modules and solar thermal systems are building components that can be a substitute for conventional roof or facade cover materials (Krstic-Furundzic, 2007). A building envelope with such components becomes a multifunctional structure characterized by structural complexity. This multi-functionality can be recognized in combining already present facade technical solutions and systems resulting in a new architectural concept and appearance, as well attractiveness (Krstic-Furundzic, 2016). Taking this as a criterion, several samples-case studies of complex structures were selected, characterized by the following functional aspects:

- production of thermal and electrical energy (case study A., B., C.),
- heating and cooling potentials (case study A.),
- shading potential with light permeability and production of thermal and electrical energy (case study B and C).

Case study A: Double facade as hybrid BIPV/T system - Solar Building XXI (LNEG Office building, Lisbon)

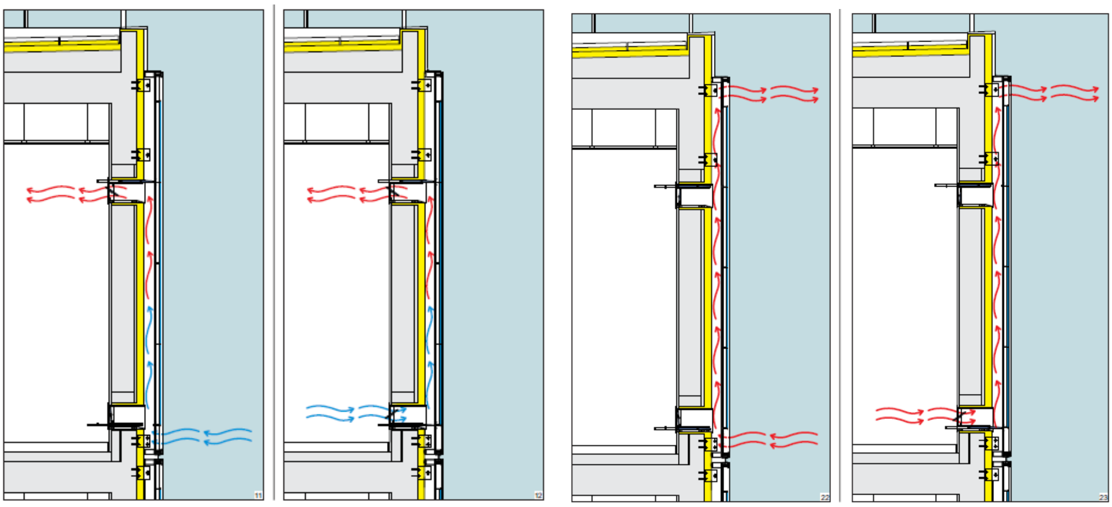
"Solar photovoltaic" alongside with "solar thermal" (active and passive) are an integral and fundamental part of the design of the facade of Solar Building XXI (LNEG office building in Lisbon). About 80% of energy consumption is from renewable sources, therefore, Solar Building XXI will fit in the context of the future, that is, of buildings that have a net zero energy consumption (“NZEB, Net Zero Energy Buildings").

Regarding design, Gonçalves and Cabrita (2010) point out that the project seeks the maximum continuity of detail between the different elements, both material and in its dimensioning, resulting in a design based on the concept of modularity and repetition.

Figure 3.1.9. Solar Building XXI, Lisbon (Photo: A. Krstic-Furundzic).

South oriented facade is characterized by vertical zones of windows and photovoltaic modules (Figure 3.1.9). Parts of the facade with photovoltaic modules are designed as a double facade with potential for heating and cooling, and also the ability to produce electricity (Figure 3.10). Air gap within the double facade (behind the PV module) is used for heating the air in the winter and in the mid-season months, but also for cooling the building in the summer.

Office rooms with permanent occupation are oriented to the south in order to take advantage of direct sunlight and thus achieve solar heat gains in winter, direct heat gain through windows and indirect heat gains through the double facade with PV modules.



a) **b)** **c)** **d)**

Figure 3.1.10. Double facade as hybrid PVBI/T system (Gonçalves and Cabrita, 2010).

Heating description - heat recovery on the inside face of photovoltaic modules:
The southern facade was designed with the integration of a solar photovoltaic system of about 100 m^2, in line with windows, allowing to meet the electricity demands needed to operate the building; this system was also designed to harness the heat generated inside of photovoltaic modules for winter heating demands, contributing to warm the air of offices and contiguous spaces (Gonçalves and Cabrita, 2010), as shown in Figure 3.1.10.a.

In the mid-season months, the system can function as a fresh air pre-heating system in which air is admitted from outside through the outer lower vents, which heats thereafter in the air gap before being inflated directly inside the room by natural convection through the vents located in the upper part of interior facade screen/layer (Figure 3.1.10).

Cooling description - photovoltaic facade ventilation:
During summer is important to extract the heat produced from the modules and released into the air gap of the facade. Therefore, the most used functional situation is the extraction of the heat to the environment using the two vents, in the top and bottom parts of the modules (Figure 3.1.10.c and Figure 3.1.11); in this situation the internal vents are fully closed (Gonçalves and Cabrita, 2010).

Another possible situation is the functional use of the double facade for obtaining chimney effect, in order to evacuate the hot air from the office through the lower internal vents and release it into the environment through the vents in the top parts of the modules (Figure 3.1.10.d).

Figure 3.1.11. Position of vents for air circulation through air gap of the double facade from the outside (left) and inside (right) of the double façade (Photos: A. Krstic-Furundzic).

Case study B: Solar Window, Lund, Sweden

The Solar Window combines all useable forms of solar energy into one system; active and passive heating, PV electricity and daylight. The concept also aims at visually exposing the system in a novel and attractive way; The key for this challenge was simply to use a window as the glazing for a solar collector; By using hybrid absorbers and pivoted reflectors behind the window, a multifunctional and responding building skin is achieved; A PV/T component on the inside of an antireflective insulation window with concentrating mobile reflector screens makes the system fully integrated into the building, even its interior (Fieber et al., 2003).

The Solar Window consists of three main components: the window, the hybrid absorber and the reflector, as shown in Figure 3.1.12. The backside facing the interior could be covered with any surface material suitable for the interior context (Figure 3.1.13).

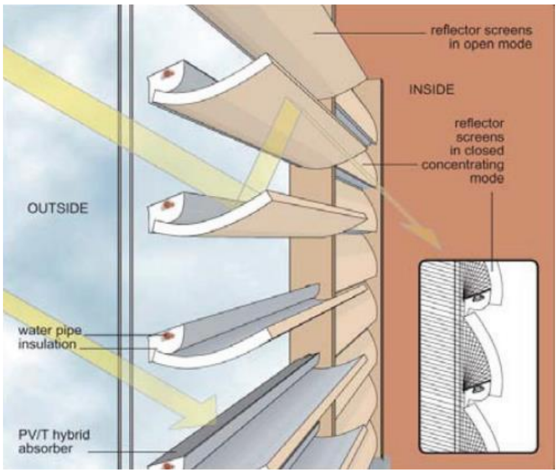


Figure 3.1.12. Solar window, shading potential with light permeability and production of thermal and electrical energy (Fieber et al., 2003).

Figure 3.1.13. Appearance of PV/T component in the interior (Fieber et al., 2003).

Fieber et al., (2003) note that the Solar Window provides PV electricity and warm water, besides passive space heating and day lighting, and that simultaneously, the reflector screens act as sunshades and added internal insulation for the window. The hybrid technology has synergetic effects such as cooling the PV cells for increased performance, and making use of heat generated in the cell. The authors of the solar window point out that its performance is directly connected to the user behaviour, due to the operation of the reflectors, which can be switched between a closed, concentrating mode or an open, transparent mode.

The modular nature of the reflectors, with no connection to the energy distribution, makes it possible to exchange them for alternative surface, thickness or reflecting geometry. The concave front facing the window will be highly visible from the exterior, and the mirror like surface might be the most critical aesthetical property for a wider acceptance. However, the curved mirror can generate interesting optical expressions in the facade. The overall impression of the facade will hence change when approaching it. The mobility of the reflectors also contributes to a dynamic facade expression. (Fieber et al., 2003)

Case study C: Solar hybrid shades, domestic building in Hollywood, USA

Figure 3.1.14. Shading potential with light permeability and production of thermal energy
http://inhabitat.com/b-i-o-tectures-hybrid-shades-double-as-solar-hot-water-collectors/

The domestic building with multi-tasking solar hybrid shades is built in Los Angeles next to the Hollywood sign (Figure 3.1.14). The design of the building is characterized by the integration of passive and active solar technology. The facade with BIST system combines three functions: water heating, shading and natural cooling.

Multi-tasking thermal shades in the southern side of the building provide solar hot water for domestic use and radiant floor heating. Installed on the south side of the building, the 250 sq. feet of vertical thermal shades protect the building from the sun and lower interior temperature. The shades are so effective that no air conditioning will be needed to keep the residence cool (Yoneda, 2016).

The thermal solar collector is invisible, fully integrated and does not distract from the clean architectural lines of the building.

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3.2 NEW SYSTEMS AND APPLICATION OPTIONS

Yiannis Tripanagnastopoulos, Dorota Chwieduk, Istvan Farkas

3.2.1 The Building as an Architectural Structure and an Energy System-Technical Aspects

The building sector is an important energy consumer for both heat and electricity. Existing buildings should be suitably renovated, following energy sustainability investigations and aiming to the reduction of energy consumption. New buildings should be constructed in the frame of the rules for Zero Energy Buildings. In addition, it's equally important to use new materials, special glazing and cladding structures, which aim to contribute to solar control of the building. In that case, there can be achieved an effective reduction of building thermal losses during winter and of energy consumption for cooling during summer. These materials are combined with solar thermal collectors and photovoltaics and are considered necessary for the improvement of energy behavior of buildings, giving at the same time a new visage to them.

Towards zero energy consumption concept for the new buildings, there are steps to solar thermal collector and PV module design and operation improvements, considering building integration requirements. In order to reach these targets of high solar fraction, new type of solar energy systems for domestic hot water production, space heating, cooling and lighting of the buildings, are required. All building types have to be included (single and multifamily houses, public buildings, office buildings, hotels, hospitals, etc). Roof and façade integrated collectors are fundamental elements and a combination of solar thermal collectors and photovoltaics will help to achieve the objectives, considering the requirement of very low heating and cooling demand of the building.

Building integration with Solar Thermal Systems gives a background for the further development of integration of a building structure with other energy systems, mainly based on renewable energies. This integration could be done through incorporating the energy systems or their elements into building envelope (walls, windows, roofs, basement piles and partitions) and/or internal elements of a building structure, i.e. internal walls (internal partitions), floors, ceilings, etc. It may be expected that in future every building will be an architectural and civil engineering form as well as an energy system.

In addition to solar thermal collectors, photovoltaics have been installed on buildings and in a large variety. Most of the applied photovoltaic panels are of silicon type, followed by the CIGS, CdTe, Organic, Dye sensitized and other new technologies. Further improvement in efficiency and durability is needed for these technologies in order to be widely applied next years. PV module temperature increases by the absorbed solar radiation that is not converted into electricity, causing a decrease in their efficiency. This undesirable effect can be partially avoided by heat extraction with a fluid circulation and this is achieved by the hybrid photovoltaic/thermal (PV/T) collectors (Tripanagnostopoulos et al., 2002). These solar energy systems can provide electrical and thermal energy, thus achieving a higher energy conversion rate of the absorbed solar radiation. Building Integrated PV/T systems (BIPVT) consist of PV modules coupled to heat extraction devices, in which air or water of lower temperature than that of PV modules is heated whilst at the same time the PV module temperature is reduced. In case of air, the contact with PV panels is direct, while for liquids the contact is through a heat exchanger. The PV/T systems can provide electrical and thermal energy, thus achieving a higher energy conversion rate of the absorbed solar radiation.

Apart from solar energy systems integrated to buildings, geothermal heat pumps (GHP) and biomass boilers can contribute to the thermal energy demand of buildings. From these systems a significant part of building energy requirements can be covered, contributing therefore to conventional energy savings and protection of the environment by reducing CO_2 emission. Regarding geothermal energy, many buildings have available land surface area in their surrounding site to install horizontal ground heat exchangers (to extract heat out of the ground and supply it the heat pump evaporator). In the case of vertical ground heat exchangers (located in bore holes – ducts) little surface area is needed, sometimes it can correspond to the diameter of one drilled hole. GHP systems can provide space heating during winter and space cooling during the summer and domestic water heating through the whole year. The required electricity for the operation of a heat pump can be obtained from the PV modules on a building roof and façade. The GHP can also be boosted by the solar thermal system increasing the total SCOP and the SPF of the system (Chwieduk, 2012). In countries with a good forestry industry, biomass systems offer a large potential in combination with solar heating systems for domestic hot water production and space heating.

Incorporation of BISTS, including active and passive solar energy systems will enable a rapid decrease of energy consumption in buildings. Improved technologies for collecting solar energy and converting it into useful heat (thermal systems) and electrical energy (photovoltaic systems), and combined PVT (photovoltaic/thermal systems) with appropriate energy storage solutions can promise providing the total energy needs (heating and cooling energy and electricity) of buildings in low latitude countries. Such systems can be called "stand-alone" BISTS/BIPVSTS and will be applied to energy self-sufficient buildings. These systems will be able to operate in monovalent mode using only one energy source – solar energy. However, in high latitude countries, and often in low latitudes, too, such solar systems will need coupling to other renewable energy systems, to realize the nearly zero-energy buildings in practice.

When solar energy cannot provide all energy needs of a building it is necessary to apply multi-energy sources (hybrid energy systems), that could be called "complimentary multi-energy sources systems". In case of integration buildings with renewable energy systems, the best name seems to be BIRES – Building Integration with Renewable Energy Systems. Perhaps only in the summer will these systems will be able to operate in monovalent mode using only solar energy for hot water heating, and in such case they can be called the BISTS. If, additionally to water heating the electricity is to be supplied by the solar PV system, then BIPVSTS – Building Integrated Photovoltaic Solar Thermal Systems can be applied. During other seasons and for most time of the year, more complicated multivalent modes of operation will be required, and then energy loads of a building will be provided by the BIRES.

Thus, classification of energy systems integrated with buildings and used mainly in low or nearly zero energy buildings can be as following:

- single-energy source systems, when only one energy source is used and system operates in monovalent mode (using only this source), the most typical examples can be BISTS and BIPVSTS;

- bi-energy (double) source systems, when two energy sources are used and system operates in monovalent mode (using only one energy source) or in bivalent mode (using two energy sources), e.g. BISTS or BIPVSTS is supported by the auxiliary energy source, usually electricity from the grid is used;

- multi-energy sources systems, when a few energy sources are applied, they are complimentary to each other's, the system can operate in monovalent or multivalent modes; when different renewable energy sources are utilized then the BIRES is used, it can be supported by the auxiliary energy source, e.g. electricity from the grid or other conventional energy from fossil fuels.

In moderate climate and in high latitude countries in winter, solar irradiation is not high and it is not possible to apply the solar thermal system as the only one system which provides all heating loads (for the hot water and space heating), especially when the ambient air temperature is low and the space heating load is high. In such situation BISTS can be coupled to other energy systems in a building. Using different energy sources, the system can operate in a monovalent bivalent or in multivalent modes. Standard solar heating systems are equipped with conventional auxiliary heater (usually electrical one). Here more sophisticated solutions of thermal energy systems are considered. First some or all elements of the thermal system are integrated with a building structure and focus is put on application of renewable energy. Thus solar heating system is coupled with other renewable energy systems, which elements are integrated with a building.

In the case of BIRES – Building Integration with Renewable Energy Systems, i.e. when multi-energy sources systems are applied different types of their configuration and modes of operation can be applied. It is possible to connect different systems in series, parallel or in more complex systems in a combination of series and parallel configuration. Connecting different systems in series means that the first system in series is a system for preliminary heating and the next one in series is the supplementary heat source that provides the rest of the heat required. When energy supplied by the first energy source is sufficient to cover the heating demand then the second energy source is not used, so the monovalent mode of operation is possible.

Connecting different systems in parallel, different options of the system operation can be used. The most typical is the standard parallel mode of operation, when systems supply heat to the end user in independent way, but at the same time. It means that the sum of energy supplied by both systems provides the total energy needs. Thus both systems are complimentary to each other. For example, solar heating system supplies heat to the underfloor heating system and a heat pump supplies heat to the air space heating systems, or visa versa. The total energy supplied by both systems is equal to the total space heating loads. Another option for operation is the alternative mode. In this mode the energy systems work separately, i.e. one or the other, but not both at the same time. One energy source is usually applied as the main basic energy source. When this energy source cannot meet total energy needs, then another energy source is applied as a peak energy source, and it covers the total energy demand.

It is also possible to have one system which can use two energy sources, e.g. a double source heat pump. The double source system can operate in different bivalent modes, which are combination of series, parallel and alternative ones. Usually the combined modes of operation (combination of series, parallel, alternative, and other modes) are used, when a system is more complex. Taking into account the consideration presented above the following classification of the BISTS/BIRES operation modes can be given:

- monovalent mode, when only one energy source is used (e.g. solar energy) and operation of the system is based on this energy source;

- bivalent mode, when two energy sources are used, both energy sources can co-operate in different following way:

    - series – one energy source is used; e.g. solar energy is used as the main or preliminary energy source (depending on solar irradiation) then the other energy source is used as auxiliary (supplementary) energy source;

    - parallel – both energy systems are providing heating loads, they supply heat (to the end user) in independent way, but at the same time, being complimentary to each other;

    - alternative - energy systems work independently and not at the same time; one energy source operates as the main basic energy source, another one as a peak energy source;

    - double source - one energy system uses two different energy sources, energy sources can be utilized in series, parallel or in alternative way;

- multivalent mode when a few energy sources is used, usually these energy sources are complimentary to each other and different modes of operation are possible even at the same time. It means that the system operates combining series, parallel and alternative modes of operation at the same time.

A very good solution is to couple the solar energy systems with other systems based on renewable energies. Renewable energies can be complimentary to each other. For example, such complementarity can be expected in case of the solar energy and the wind energy. Depending on the time of a day and the season of a year, one of the energy sources can be treated as the base source and the other as the peak source. For example, in a summer's day – the solar energy will be the base and at night time the wind energy is the base. However, during any day both forms of energy can be used in parallel.

Figure 3.2.1. Integration of solar energy systems and wind energy systems.

Surplus of electric energy produced by the wind turbine, which cannot be consumed or to be charged in batteries (to avoid overcharging), can be supplied to an electric resistance heater in a water storage tank. Thus auxiliary energy will be in a form of renewable energy. In this case the building structure will be integrated not only with the solar thermal system or with batteries for electricity, but with the wind turbine, too. Such a wind turbine can be attached to the building, or it can form part of the external construction element of the building. Such a construction belongs to the structure of a building and improves its architecture or can be adapted to traditional architecture (Figure 3.2.1 (Tripanagnostopoulos, 2015)). The best potential solution is the BIRES that couples the solar system with a heat pump as the heat pump can use the solar energy as a heat source. However, other forms of energy from environment: ambient air, ground and ground water can be used as heat sources, too.

In the case of solar energy, apart from the traditional BISTS coupled with a heat pump, when solar collectors are integrated with roofs or the façade of a building and the heat gained is transferred to the heat pump evaporator, more unconventional solutions can be used. For example, solar collectors integrated within a roof can be the actual heat pump evaporator. In such a case the solar collector (glazed or unglazed - bare solar collector) and heat pump evaporator constitute one integral unit. The working fluid of the heat pump, i.e. a refrigerant, flows through integrated solar collector/evaporator. Under solar radiation the refrigerant is directly evaporated and then expanded, commonly called a direct expansion (DX) solar assisted heat pump system (DXSAHP), (Chwieduk, 2012; Gorozabel et al., 2005; Kuang and Wang, 2006; Hawlader et al., 2008). Such solar evaporators could be incorporated into external walls or windows, or glazed façade.

Heat pumps can also use ambient air as a heat source. In the case of a compact heat pump design the air can be transported through ducts from the outside to the inside of a building to the heat pump evaporator. These ducts and their inlets can be located at specific sites in a building envelope and a building’s interior layout. In the case of a split heat pump design, the evaporator is separate from the rest of a heat pump (compressor, expansion valve and condenser). Usually it is located outside the building, but in a BIRES solution it could be incorporated into the building envelope (external wall, roof, etc.). It should be known from the beginning of any building architectural concept, that the heating energy will be supplied to the building via an air heat pump, and a part of this device will be included into (integrated with) the building structure. The specific location of the heat pump evaporator should be planned at the conceptual phase of architecture of a building. An architect must be aware of technical aspects/energy system concept, since this is the first phase in designing the building envelope and structure. It is especially important for an air heat pump with its evaporator (or inlet air ducts) situated in the envelope structure of the building that it is planned. The external walls and roofs can be made as prefabricated elements with evaporator pipes incorporated directly into their structure.

Apart from air source heat pumps, ground (geothermal) heat pumps can also be recognized as BIRES solutions. In this case the building construction piles or basement can contain the heat transfer elements of a heat pump. Heat exchangers that extract heat from the ground (direct or indirect) can be incorporated into the building support. Of course, this requires a conceptual design approach so that such elements will be included in the initial structure of a building. The heat transfer fluid will flow through the constructional elements of a building structure representing a big challenge for architects, civil engineers and developers of buildings.

The building structure of the future will generate energy for its own needs. If there is a surplus of energy it will be transferred to the external grid, being sold or balanced with the consumption. If the grid cannot accept (for example) electricity, it can charge batteries inside the building to be used later. Buildings will be independent from conventional energy supplies perhaps even becoming energy exporters. A building will not just be a structure anymore, it will be also an energy system which will link behaviour of its structure and materials to the energy systems and related equipment. Energy management in a building no longer will be based on power from external networks, it will be dependent only on the building's own energy sources. The energy management system will be responsible for the management of the energy source used. Depending on the energy performance of the energy source in a given time the control system will decide upon which energy source is the most efficient and should be given priority. We can expect the future buildings to be designed on the basis of complementarity energy sources, mainly renewable energies, used in a planned and controlled manner.

Building integration with solar thermal systems, BISTS, or BIPVSTS is a new technology, but building integration with renewable energy systems, BIRES, is an emerging technology. There is much to be invented, developed, validated and implemented. It can therefore be expected that BIRES is the future for micro and small scale renewable energy technologies in the building construction sector.

3.2.2 New systems for building integration

The integration of advanced solar thermal flat plate collectors into a building leads to improvements of the collector performance and to a reduction in heat loss from the building, due to improved envelope insulation. Another new concept is the so called multifunctional plug and play facade, which is a combination of PV and solar thermal for electricity and heat, ventilation and air conditioning (HVAC), prefabricated in one module. The approach of active envelope systems of unglazed and glazed flat plate systems has been introduced to meet the needs of energy production of the buildings. 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.

Polymer collectors have been suggested as an alternative option. They are manufactured more cheaply and flexibly, with dimensions adapted to integration needs and of all shapes and sizes (Figure 3.2.2). They are lighter in transportation and easier in installation and can be in a variety of attractive views of different colours. Advanced plastic materials such as polycarbonate sustains itself at high temperatures and retains excellent properties under humid conditions and twin wall absorber sheets contain a large number of channels filled with ceramic particles.

Figure 3.2.2. Polymer solar thermal collectors for building integration.

3.2.2.1 Hybrid photovoltaic/thermal collectors

In BIPVT systems the production of electricity is of priority, therefore it is necessary to operate the PV modules at low temperature in order to keep PV cell electrical efficiency at a sufficient level. This requirement limits the effective operation range of the PV/T thermal unit (Figure 3.2.3) to low temperatures, thus, the extracted heat can be used mainly for low temperature applications as space heating and natural ventilation of buildings, air or water preheating, etc. (Tripanagnostopoulos et al., 2002).

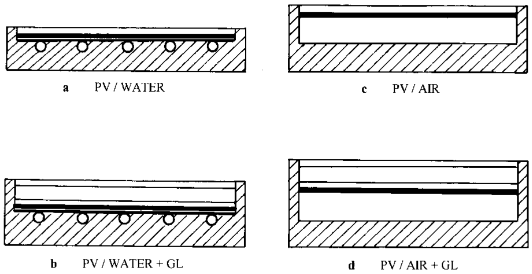


Figure 3.2.3. Cross section of PV/T collectors for water and air heating.

Air-cooled BIPVT systems have been recently applied on building inclined roofs or façades. By these systems building space heating needs during winter can be covered and also building overheating during summer is avoided. Natural or forced air circulation is a simple and low cost mode to remove heat from PV modules, but it is less effective at low latitudes where ambient air temperature is over 20^{o}C for many months during the year. In some cases, PV modules are combined with perforated metallic plates, which consist the building skin and PV cooling is obtained by the air circulation through the thousands of holes at the rear side of PV module (Figure 3.2.4). Water-cooled BIPVT systems are addressed for water heating and are mainly effective from spring to autumn.

In BIPVT systems the thermal unit for air or water heat extraction, the necessary fan or pump and the external ducts or pipes for fluid circulation constitute the complete system. To increase the system operating temperature, an additional glazing is used, but this results in a decrease of the PV module electrical output because an amount of solar radiation is reflected away, depending on the angle of incidence. BIPVT systems can produce electricity and heat and are suitable for applications under high values of solar radiation and ambient temperature.

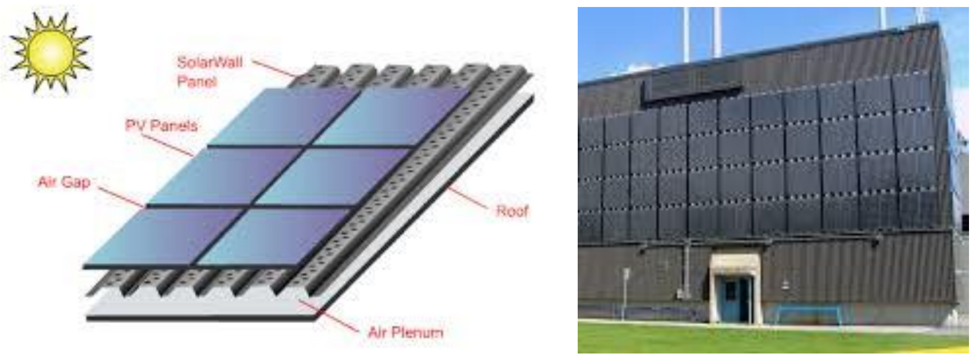


Figure 3.2.4. BIPVT systems with PV modules on perforated metallic roofs and facades.

3.2.2.2 New water heating BISTS

Integrated Collector Storage (ICS) systems

Integrated Collector Storage (ICS) systems can be applied by open or closed water circulation. In forced circulation systems the heat from the collectors is transferred from the collectors to the hot water storage tank, by using a temperature balance control system. In these systems a heat exchanger is usually applied to improve system durability. In closed solar water heating systems the collector circuit is pressurized and therefore the boiling temperature of the fluid is raised and allows higher operational temperatures.

In ICS systems a cylindrical storage tank, or a mechanically reinforced storage vessel of rectangular shape, is coated with a solar radiation absorbing surface. The storage per collector aperture of 50-100 l/m^2 is incorporated into the collector which may be optimized for façade or roof integration. Water is directly heated without the need for a pump and control system. Improved ICS solar water heaters have been developed (Tripanagnostopoulos et al., 2002) using cylindrical collector-water storage tank inside compound parabolic concentrating (CPC) reflectors, presenting efficient water heating during day time and satisfactory heat preservation during night. These ICS systems can be integrated to building roofs and balconies because of their low height. The absorbers of the cylindrical tank ICS systems could be painted with other than black colour to adapt aesthetically the architecture of modern and traditional buildings (Figure 3.2.5).

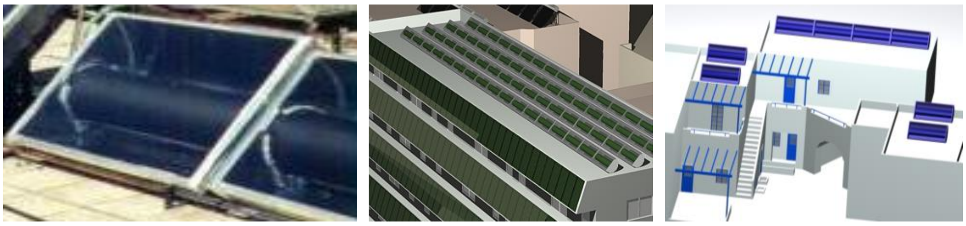


Figure 3.2.5. ICS solar water heaters that can be effectively integrated to buildings.

As auxiliary water heating system to ICS systems, a fast and powerful electrical or a gas heater, may be connected to the outlet. Cold water from mains replaces the preheated water in the collector storage vessel. ICS units should be designed to optimize collection during collection periods and reduce unwanted heat loss during non-collection periods. The use of selective coatings, insulation, thermal diodes, or transparent insulation materials, has been investigated, while special attention must also be given to issues related to freezing and negative energy balances.

Air collector systems

Air can be used as heat removal fluid to transfer the heat from solar collectors directly to space heating (Figure 3.2.6). In case of preheating operation, the outlet air from the solar collectors can be supplemented by auxiliary (heating) air handling units. Alternatively, the collector outlet air can be used to provide heat to other building heating systems (e.g. heat pump, etc.), increasing therefore their operational energy efficiency. Warm air delivered from the solar collectors can be stored by appropriate techniques (greenhouses using thermal storage materials, phase change media, thermal mass in the form of rock storage or building envelope, etc.).

Figure 3.2.6. Solar air heaters for buildings.

Energy efficient wall

Transparent Insulation Materials (TIM) can cover the outside of a building massive wall. Solar energy is converted to heat at the absorber and conducted with a time delay of some hours through the massive wall into the interior space, depending on thickness and building material. For these reasons the windows and the solar wall heating with transparent insulation fit very well together. The direct solar gains are used during day time, while the heated wall operates later during night time, extending the passive solar heating period considerably. Suitable wall materials have a high density which is correlated with good conductivity and high thermal capacity. Examples are concrete, limestone and low porosity bricks. The wall should be coated with a dark colour (black, blue, green, dark red) and this influences the performance of the system. Solar gains are transferred over an air gap (necessary because of building tolerances, to the wall by radiation and convection. The absorber colour cannot be selected freely by the customer for this type. Another case is the absorbed solar energy by the wall to raise the temperature of the outer surface to a value closer to the interior temperature, thus lowering the temperature gradient over the heating season to nearly zero. There will be no solar heating, but the insulation level will be increased without using excessive material thickness. Figure 3.2.7 presents the ISES (International Solar Energy Society) Headquarters in Freiburg. This is an old Villa refurbished using modern energy efficient technologies, including TIM incorporated into west façade.

Figure 3.2.7. Application of TIM integrated to the west façade of the ISES Headquarters in Freiburg.

Ventilation and cooling

Buildings need a ventilation system in order to provide fresh air for the occupants. This air may be preheated by a solar thermal system in order to reduce the building heating load. Uncovered façade collectors are an interesting option and the systems may be combined with heat recovery heat exchangers to provide additional heat to the fresh air supply stream from the building exhaust air stream. In cooling dominated climates the incoming air must be cooled down in order to achieve comfortable supply conditions. Solar thermal cooling using adsorption or absorption chillers in a closed circulation net may cool down the incoming air via an air-fluid heat exchanger. Alternatively, desiccant (and evaporative) cooling, can use the heat from solar collectors to provide regeneration of the sorption components.

Colour and surface texture

The colour of the BISTS collector depends primarily on the absorber colour, but also to some extent on the cover material. Flat plate solar collectors are of black appearance because of the colour of the absorber, which is employed to maximize the absorption of solar spectrum. By this way it is aimed to avoid the monotony of the black colour collectors by using absorbers of blue, red–brown, green or other colour. These collectors are of lower thermal efficiency than that of the usual black type collectors, because of the lower collector absorbance, but they are of more interest to architects for applications on traditional or modern buildings. The application of solar collectors with coloured absorbers is a new concept and regarding the total solar system, it is noticed that the increase in cost (by using larger area of collectors to overcome the lower efficiency of the coloured absorber) is balanced by the achieved aesthetic harmony with the building architecture. The difference in energy output is at an acceptable level considering the improvement in aesthetics and this implies the use of proportionate larger collector aperture areas to have the same energy output as that of typical black coloured collectors (Figure 3.2.8) (Tripanagnostopoulos, 2000).

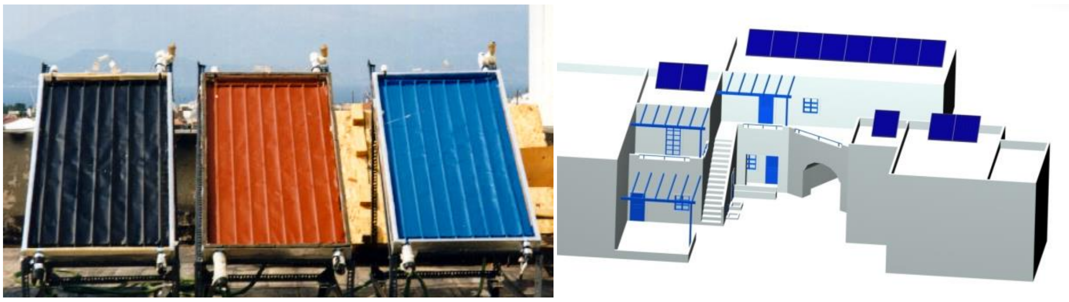


Figure 3.2.8. Coloured solar thermal collectors which can give new views to buildings.

Although most of the architects would like to make use of coloured collectors, even with a slightly reduced efficiency, the integrated black collectors are still in the majority. This of course does not mean that coloured collectors are not being integrated, but it demonstrates that integration issues are much more complex than just choosing an appropriate collector colour. Polymer thermal collectors can potentially offer greater choice with acceptable performances. An optimistic perspective is the use of unglazed coloured absorbers, which are suitable for large building facades, where the perforated type is an interesting case (Figure 3.2.9).

Figure 3.2.9. Perforated solar building facades.

3.2.3 Roof integrated solar tile collectors

3.2.3.1 Basic aspects for tile type solar thermal collectors

Significant research and development activities for the capture and utilization of renewable forms of energy has led to the birth of new applications and equipment, and the design of systems over the past decades to commercially viable technologies. Literature confirms that solar collectors are appreciated not only by their usefulness, but also according to their aesthetic consideration. In addition to understanding traditional solar collection performance it is also necessary to study how effective the building structural elements are when they are used to capture solar energy. The above concept is to consider new, non-standard solutions for BIST such as building integrated tile collector systems.

These new type of collectors along with their thermal behaviour have been theoretically and experimentally studied (Fekete, 2015, Fekete and Farkas, 2012). Economic calculations and other aspects can give a defined idea about energy performance of tile type solar thermal collectors. In summary, it can be stated that optimizing the collector body shape and the selection of appropriate materials to meet structural element requirements, it is still technically possible to achieve a maximum thermal efficiency.

3.2.3.2 Materials for tile type collector

In tile type solar thermal collectors, the absorbed radiation energy is partially lost by heat conduction to another part of the collector and through convection to the environment. The useful heat is transported by the collector fluid through the entire system. The level of radiation emissions, the environment and radioactive material depends on the temperature difference (Kendrick, 2009). A desired temperature value of the absorber surface can be reached when the heat formed by the incoming global radiation, and it is equal to the sum of heat loss and the conveyed heat energy. The proportionality factor depends not only on the heat transfer factors, but also on the absorbing surface material and its design and quality. Furthermore, it is influenced by temperature and distance from surrounding objects and wind speed. If the absorbing surface is covered with a transparent layer, the heat loss is reduced and the body temperature is increased under the same incoming radiation conditions (Fekete 2015, Fekete and Farkas, 2012). The resulting energy can be conveyed by liquid or air according to the type of collector working medium. Based on above, it can be stated that the uncovered surfaces behave more dynamically, while covered surfaces show a slower warming or cooling.

3.2.3.3 Construction of the shell-structured collector system

Positioning the solar collectors is usually on a roof surface. In this application, the main goal is to replace the traditional collectors for aesthetic reasons, so concrete tile forms are considered. The converted corresponding load elements had a painted surface. The concrete tile shape and sizing constraints were part of the heat exchanger construction and its positioning. The pipe distance should follow the formal characteristics and dimensions of the original concrete tiles. Due to the better heat transfer processes the heat exchanger has to be located close to the absorber layer. However, this design, where the pipe system is positioned in contact with the tile surface is not adequate due to strength requirements (Figure 3.2.10).

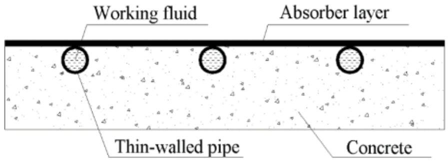


Figure 3.2.10. Structure of tile element with touched absorber and the pipe.

Consequently, another type of layer-planning design structure of the solar tile collector system can be used, where the thin-walled pipe system is installed inside the concrete made layer (Figure 3.2.11).

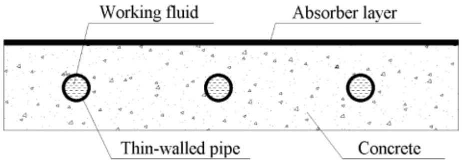


Figure 3.2.11. Structure of tile element without touched absorber and the pipe.

The produced tile element has the same size as a commercially available roof tile (Figure 3.2.12a). For better illustration purposes, the internal heat exchanger is placed on the interface. The entire collector surface design of about 2 m^2 is shown in Figure (3.2.12b).

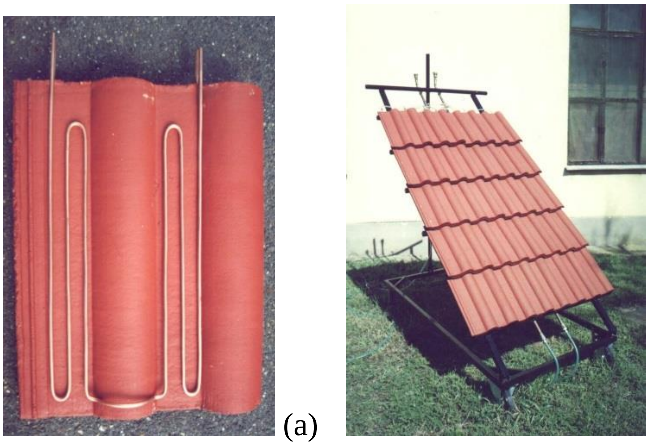
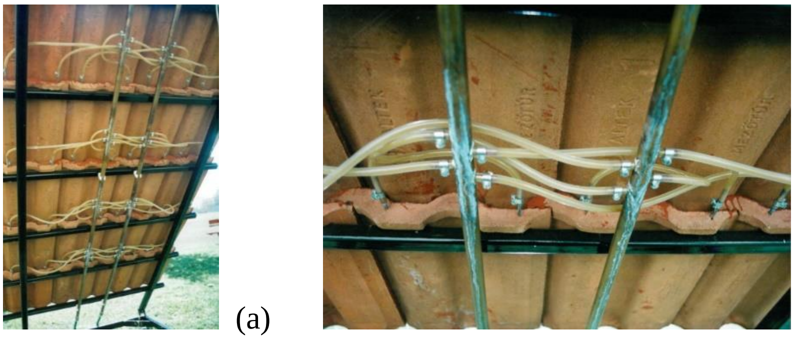

(a) (b)

Figure 3.2.12. (a) The tile element design and (b) Surface of the tile collector.



(a) (b)

Figure 3.2.13. Rear surface of the tile collector. (a) pipe junction system (b) fitting arrangements.

Based on modeling and simulation results, a prototype system was constructed. The system was used to allow comparative measurements with the modeled simulation. The rear surface of the tile collector, showing the pipe junction system and the fitting arrangements, are shown in Figure 3.2.13.

To illustrate the influence of heat flow (Figure 3.2.14) an infrared camera image shows the temperature distribution across the tile surface. At the bottom of the tile, it can be seen that the outlet fluid is still cold. At the top of the tile a constant, controlled state can be observed, where the temperature of the outlet fluid and the surface are nearly the same.

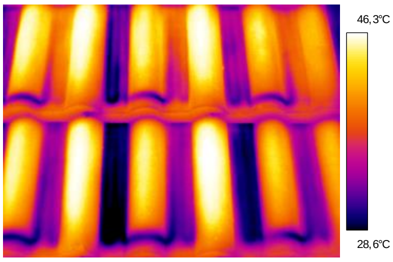


Figure 3.2.14. Visualization of temperature distribution across the tile collector surface.

3.2.3.4 Efficiency range of the tile collector

To determine the performance of tile type solar thermal collector, comparative tests with a typical solar thermal collector and Cu-based solar absorber were conducted. Orientation measurements were also carried out in advance and efficiency results were obtained. The test efficiency parameters cannot be measured directly, therefore the estimated parameters were determined using extrapolation. The fluctuations in the actual operating conditions differ by only a few percentage points in the worst case, compared to the test values of the typical collector. The measured data of the tile collector, converge according to the calculations as expected. Based on the data (Farkas, 2011), the efficiency calculations were performed across several operating conditions which show that the values are appropriate compared to traditional solar collectors (Figure 3.2.15).

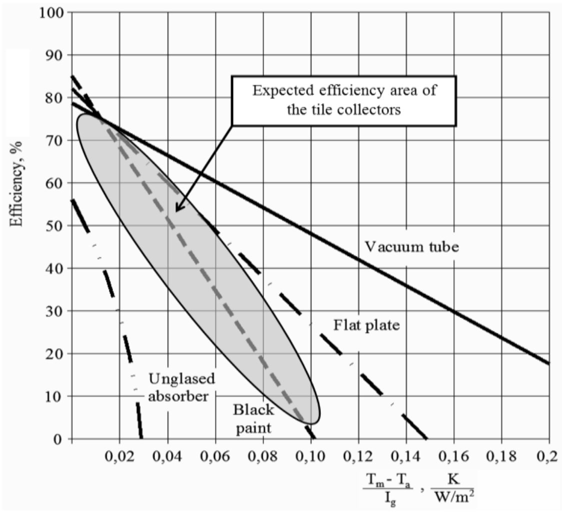


Figure 3.2.15. Efficiency range of the solar tile collector system.

3.2.3.5 Economic issues

There are several calculation methods used to estimate the economics of solar thermal systems, for instance the multiple calculation method (Varian, 2005).

The improvements and efficiency of production processes are constantly evolving, so they can be observed to decrease in price. In addition, installation costs need to also be considered (Strategic research and innovation agenda for renewable heating & cooling, 2013). As more attention is given to system integration, it is expected that installation costs will also decline. The design of tile type solar thermal collectors is simple and easy to assemble. The suggested building-integrated solar collector elements formed on the basis of the experimental and modeling results are estimated efficient in an energy context, but also in reference to aesthetic reasons. This approach may also help to reduce the urban heat-island effect. Another aspect is their use in architectural sensitive (protected) elements or the renovation of historic buildings, but still increasing the active utilization of solar energy in order to meet the increasingly stringent building energy standards.

3.2.4 Building Integrated Concentrating Solar Energy Systems

Concentrating solar energy systems (thermal, PV and PV/T) is a new concept for building integration of solar energy systems. Cylinder parabolic reflector systems, 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 building spaces covered with transparent materials (atria). In hybrid building integrated photovoltaic/thermal (BIPVT) collectors the preheated fluid from PV/T system can circulate through high efficiency thermal collector to increase the temperature further. Due to their visibility, specific architectural requirements for the integration of solar energy systems are needed to ensure that these systems are accepted for application.

Some new designs of concentrating solar energy systems have been developed, which are addressed to building integration. Among several studies, IEA Task 41 has focused its work on high architectural quality and high energy performance of building integrated solar energy systems with overall benefit the increased use of solar energy in buildings. This Task includes studies for residential and non-residential buildings, both new and existing buildings, for several climatic zones, keeping large the potential impact of it, while a number of publications give a figure of integration, information, requirements and perspectives, of building integration of solar energy systems.

3.2.4.1 Building integration of CPC collectors

Apart from the typical forms of TC units (flat plate, vacuum tube, etc) and PV modules (c-Si, pc-Si, a-Si CIS, etc), new designs of solar energy systems have been developed to address building integration, as of ICS collectors, CPC collectors and other types. In addition, new solar concentrating systems are examples that show the potential for a wider application of novel solar energy systems to buildings (Figure 3.2.16).

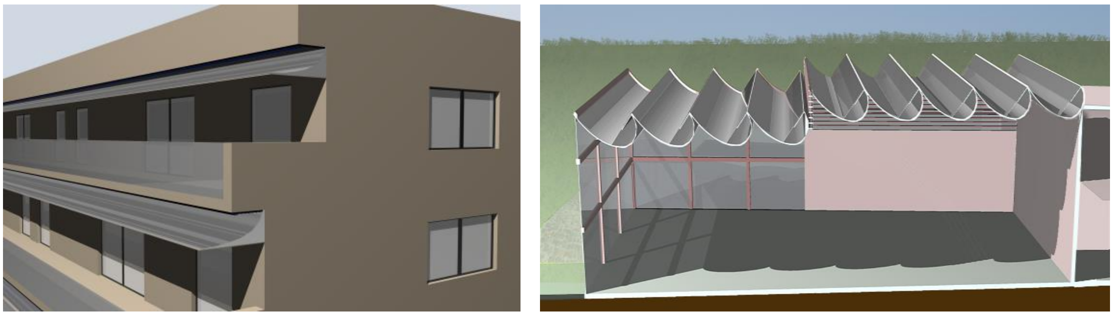


Figure 3.2.16. Building integration of CPC reflector solar energy systems.

In new building designs or retrofitting the emphasis is to passive and active solar energy systems, to partially or entirely cover natural lighting, space heating and cooling, air ventilating, domestic hot water and electricity. The works on building integrated concentrating solar energy systems are not many and among them some specific architectural designs (Tripanagnostopoulos, 2014) is a characteristic example of the variety of possible applications. Flat booster reflectors can be used between the parallel rows of the collectors on building roof to improve thermal output or achieve higher operating temperature (Figure 3.2.17).

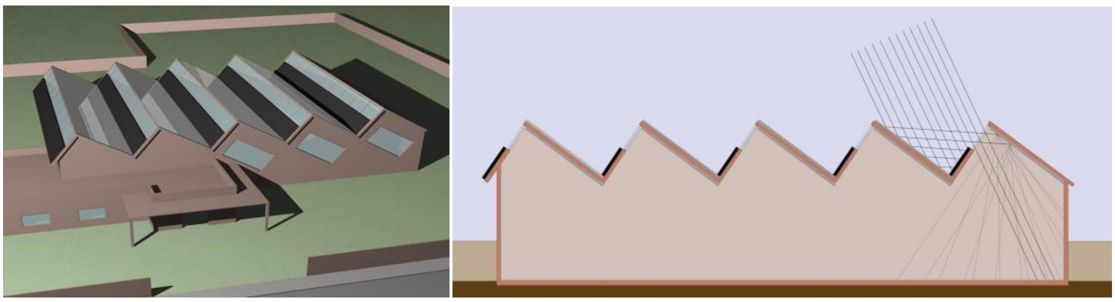


Figure 3.2.17. Building integration of solar energy systems.

3.2.4.2 Systems for solar control of buildings

Solar control of building atria can be performed by flat or curved Fresnel lenses combined with multifunctional absorbers. Concentrating solar devices using reflectors or lenses combined with thermal or/and PV absorbers have been suggested for buildings (Figure 3.2.18). Linear Fresnel lenses can achieve illumination and temperature control of buildings and are suitable to extract the surplus solar radiation from the interior space in the form of electricity and heat, by using PV/T absorbers. The Fresnel lens concept is considered for solar control of building interior spaces, to keep the illumination and the temperature at the comfort level. Last years, the installation rate of thermal collectors and photovoltaics has been increased and aiming to realize energy targets of 2020, BIPVT collectors, will play an important role (Tripanagnostopoulos et al., 2007).

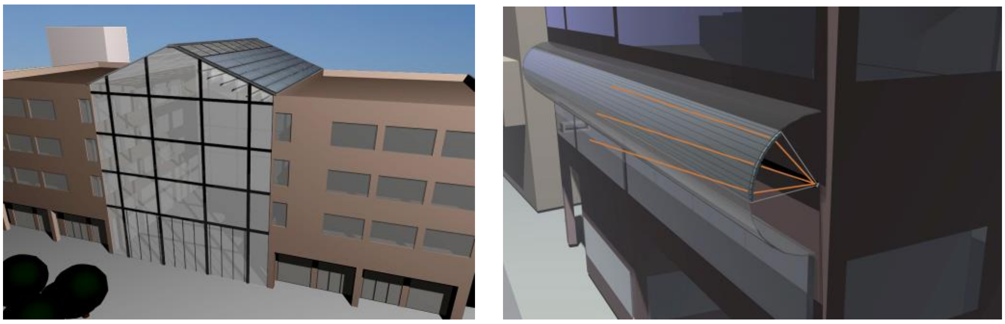


Figure 3.2.18. Building integration of Fresnel lens concentrating solar energy systems.

3.2.4.3 Operational and architectural aspects for BICPVT systems

Considering building integrated concentrating PV/T systems (BICPV), there are some operational and architectural aspects. Hybrid PV/T systems can be used during the whole year for the pre-heating of water, since the temperature of water in the water supply network is no more than 20º C, even during summer months. Considering the integration of solar energy systems on building roof or façade, the combination of PV/T collectors with thermal systems have some aesthetic problems due to the different size and appearance. The problem can be overcome if there is a harmony in size and if solar thermal collectors have absorbers with same or similar colour to the colour of PV cells.

Based on the investigated CPV and CPVT systems some new architectural designs have been performed, giving a better idea about the aesthetic integration of them on building structure. The building balconies can be used to put the reflectors, which can have the parabolic form and the reflected radiation to be focused on the back of the front building. This design is a suggestion for buildings that are built in groups and where the orientation of the buildings is adapted to the South (Figure 3.2.19). In the cross section, the ray trace gives a figure of the reflector operation. It should be noticed that the reflectors can be mounted on building balconies and as alternative they could be moving using in this case stationary absorber, possibly mounted on the top of the front placed building (Tripanagnostopoulos, 2014).

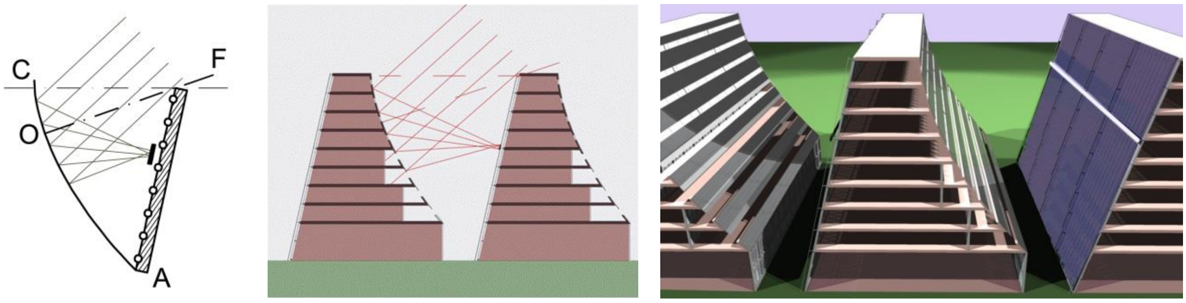


Figure 3.2 19. Suggestion for building integrated solar energy systems.

3.2.5 Conclusions

In this chapter designing, operating and aesthetic aspects, for the building integration of solar energy systems, are presented. New systems and application options are analyzed and technical aspects are included. Apart of solar thermal collectors, photovoltaics and hybrid PV/T systems, other energy systems as geothermal heat pumps, biomass boilers and wind turbines, can be used to cover the energy demand of buildings. In this case the BIRES – Building Integration with Renewable Energy Systems are considered, where BISTS – Building Integration with Solar Thermal systems is a standard rule of designing and method of construction. In addition to flat type non concentrating solar thermal collectors and photovoltaics, new concentrating systems have been developed, which can be integrated to buildings for solar control and energy conversion of the incoming solar radiation. The roof and the façade of buildings are available building elements for mounting of suitable design, construction, operation and performance, solar energy systems. Regarding the suggested new systems, ICS solar water heaters, solar collectors with coloured absorbers, Hybrid PV/T systems, CPC thermal, PV and PV/T collectors, solar tiles and concentrating solar energy systems with flat or curved reflectors and Fresnel lenses can be applied to buildings, adapting requirements of operation, performance and aesthetics.

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3.3 NEW MATERIALS

Jasna Radulovic, Danijela Nikolic

3.3.1 Introduction

Standard BISTSs use solar collectors, which are built in a wide variety of designs and from many different materials. Solar collector absorbers are usually black painted metal (mostly copper because of the corrosion resistance, rarely aluminium and steel) or plastic plates. Low-iron glass has been widely used for solar collector glazing. Also, BIPV systems are based on different technologies. The material most commonly used is silicon (Si). Silicon is a leading material in PV cells technology, due to its high efficiency.

With the great development of technology in the last decades of the twentieth century, there has been an appearance of numerous new materials suitable for use in BISTS. Phase change materials (PCMs), nanomaterials and nanofluids have shown many interesting properties which have been reported in the past decades. The distinctive feature of these materials offer unprecedented potential for many applications, including application in Building Integrated Solar Thermal Systems.

3.3.2 Phase Change Materials

Over the last decade PCMs are very attractive for research as they represent an innovative solution that can contribute to the improvement of the energy performance of buildings. A trend towards integrating PCMs into transparent envelope components is observed recently (Fokaides et al., 2015). Thus integration of these materials into buildings is their significant application, and it enables more dynamic use of energy. A large number of PCMs are available in any required temperature range. PCMs utilize the latent heat of phase change to control temperatures within a specific range. Sharma et al. (2009) review summarizes the investigation and analysis of the available thermal energy storage systems incorporating PCM for use in different applications.

Three general categories of PCMs are organic, inorganic and eutectics, and they can be further classified according to various components of the PCMs, (Sharma et al., 2009; Kalnæs and Jelle, 2015). One classification is given in Fig. 3.3.1.

Another classification, where difference in melting enthalpy and melting temperature for some of the most common materials used as PCMs was suggested by Cabeza et al. (2011).

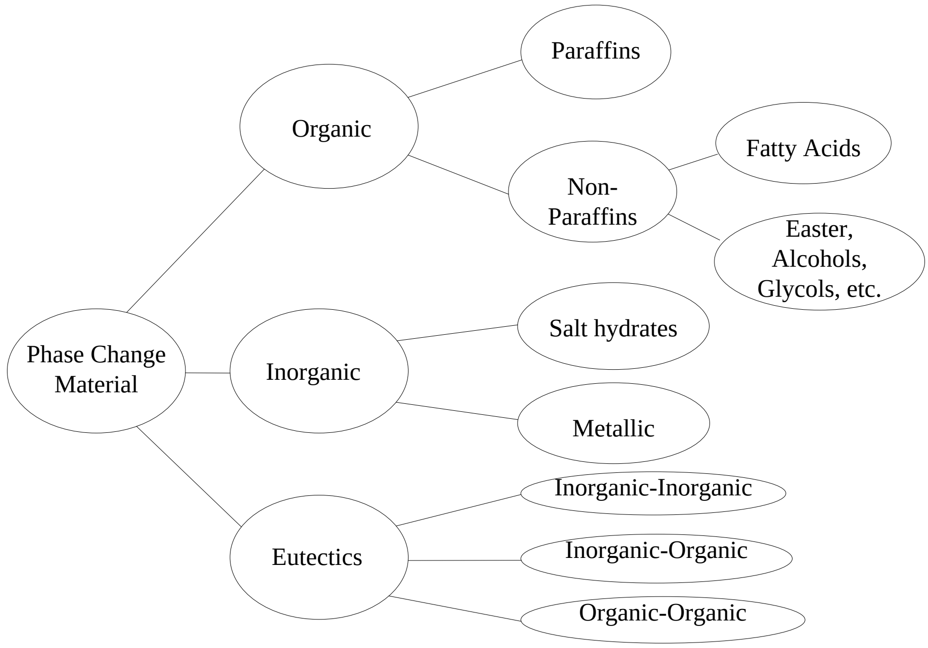

Figure 3.3.1. General categorization of PCMs.

Organic PCMs

Organic PCMs are divided into paraffin and non-paraffin. Organic materials include congruent melting, self-nucleation and usually non-corrosiveness to the container material (Tyagi and Buddhi, 2007; Sharma et al., 2009).

Paraffins are available in a large temperature range, which make them suitable for use in various other areas besides building related applications. Non-paraffins used as PCMs include fatty acids and their fatty acid esters and alcohols, glycols, etc. Fatty acids have received the most attention for use as PCMs in buildings and the most interesting ones include lauric acid, myristic acid, palmiticacid and stearic acid. Organic PCMs have many qualities which make them suited for building applications, but the fact that many organic PCMs are considered flammable is a crucial drawback for which impacts the safety aspect of organic PCMs considerably when aimed at building applications (Kalnæs and Jelle, 2015).

Inorganic PCMs

Inorganic materials are classified as either salt hydrate and metallic. These phase change materials do not supercool appreciably and their heats of fusion do not degrade with cycling (Sharma et al., 2009). Inorganic compounds have a high latent heat per unit mass and volumes are low in cost in comparison to organic compounds and are non-flammable.

For building applications however, metallic materials are not within the desired temperature range and have severe weight penalties making them unsuitable. Hydrated salts consist of an alloy of inorganic salts and water and provide a cost-effective PCM due to easy availability and low cost. The phase change transformation involves hydration or dehydration of the salts in a process that resembles typical melting and freezing. The salt hydrate may either melt to a salt hydrate containing less water or to an anhydrous form where salt and water is completely separated (Sharma et al., 2009).

Eutestic mixtures

An eutectic is a minimum-melting composition of two or more components, each of which melts and freeze congruently, forming a mixture of the component crystals during crystallization (Tyagi and Buddhi, 2007). Eutectics can be made as combinations of organic–organic, inorganic–inorganic or organic–inorganic mixtures. This gives options for a wide variety of combinations that can be appropriate for specific applications.

The most commonly studied organic eutectic mixtures consist of fatty acids. Karaipekli and Sari (2008) have investigated organic eutectic which consist of capric acid and myristic acid, Sari et al. (2004) have studied some organic eutectics: lauric acid and stearic acid, myristic acid and palmitic acid and palmitic acid and stearic acid and Shilei et al. (2006) have analysed organic eutectic consist of capric acid and lauric acid. The most common inorganic eutectics that have been investigated consist of different salt hydrates. Capability to obtain more desired properties such as a specific melting point or a higher heat storage capacity per unit volume is one of advantages of eutectic mixtures. The thermo-physical properties are to be tested and proved in the future, which makes them adequate for further investigations (Kalnæs and Jelle, 2015).

Comparison summary

PCMs can be found in a wide variety of temperature ranges. The PCMs in number of studies have been limited to PCMs with phase change temperatures in the appropriate range to be efficient in buildings.

Cabeza et al. (2011) have listed several tables of PCM properties where the potential areas of use have been divided by the PCMs' phase change temperature. For use in buildings, three temperature ranges were suggested: (1) up to 21 °C for cooling applications, (2) 22–28 °C for human comfort applications, and (3) 29–60 °C for hot water applications.

Many substances have been studied as potential PCMs, but only a few of them are commercialised. Detailed review of the different substances (organic, inorganic and eutectic) that have been studied by different researchers for their potential use as PCMs is given by Zalba et al. (2003). Some of their thermo-physical properties are included (melting point, heat of fusion, thermal conductivity and density), although some authors give further information (congruent/incongruent melting, volume change, specific heat, etc.). Zalba et al. (2003) also shows a list of the commercial PCMs available in the market with their thermo-physical properties as given by the companies (melting point, heat of fusion and density).

Fokaides et al. (2015) summarized the employed testing facilities, equipment and measurements for the investigation of the thermal performance of PCMs for transparent building elements from literature. Also, this study presented the main solutions proposed in the literature for applications in the past few years for PCMs integrated into transparent buildings elements.

Kalnæs and Jelle (2015) have compared and summarized the advantages and drawbacks of organic, inorganic and eutectic PCMs, shown in Table 3.3.1.

Table 3.3.1. Overview of advantages and drawbacks for PCMs.

Organic		Inorganic		Eutectics	
Advantages	**Drawbacks**	**Advantages**	**Drawbacks**	**Advantages**	**Drawbacks**
- No supercooling - No phase segregation - Low vapour pressure - Large temperature range - Self-nucleating - Compatible with conventional construction materials - Chemically stable - Recyclable - High heat of fusion	- Flammable - Low thermal conductivity - Low volumetric latent heat storage capacity	- High volumetric latent heat storage capacity - Higher thermal conductivity than organic PCMs - Low cost - Non-flammable - Sharp phase change	- Corrosive to metals - Supercooling - Phase segregation - Congruent melting - High volume change	- Sharp melting points - Properties can be tailored to match specific requirements	- Limited data on thermophysical properties for many combinations - High cost

3.3.3 Nanomaterials

New opportunities for the development of nanoelectronic devices for solar cell applications were brought by nanotechnology as new technology in processing PV solar cell. Characteristics of bulk materials are substantially different than semiconductor particles with dimensions in nanometer range. Due to quantum confinement effects in nanocrystalline semiconductors an effective increase in bandgap is achieved. As energy band-gap can be controlled by nanoscale components, nanotechnology referred as “third generation PV” is used to help increasing conversion efficiency of solar cell (Tyagi et al., 2013). There are three devices used in nanotechnology for PV cell production: carbon nanotubes (CNT), quantum dots (QDs) and “hot carrier” (HC). The advantages of nanotechnology are:

- Enhance material mechanical characteristic,
- Low cost,
- Lightweight and
- Good electrical performances.

Carbon nanotubes (CNT)

Carbon nanotubes (CNT) are constructed of a hexagonal lattice carbon with excellent mechanical and electronic properties (El Chaar et al., 2011). With n lines and m columns the nanotube structure is a vector which defines how the graphene (an individual graphite layer) sheet is rolled up. Carbon nanotubes can be metallic or semiconducting. CNTs provide the highest spectral absorptivity (particularly on a per unit mass basis) over the entire solar range and they are present in different forms: single-walled carbon nanotubes (SWCNTs), double-walled carbon nanotubes (DWCNTs) and multi-walled carbon nanotubes (MWCNTs) (Chaar et al., 2011). SWCNTs are formed by wrapping a one-atom-thick layer of graphene into a seamless cylinder while DWCNTs and MWCNT are formed by concentrically wrapping two and multiple layers of graphite, respectively (Mesgari et al., 2016).

A p-n junction which generate electrical current is formed of PV nanometer-scale tubes coated by special p and n type semiconductor materials and this methodology improves and increases the surface area available for electricity production. CNTs can be used as reasonably efficient photosensitive materials as well as other PV materials.

Nanotubes are currently used as the transparent electrode for efficient, flexible polymer solar cells. Naphthalocyanine (NaPc) dye-sensitized nanotubes have been developed. These resulted in higher short circuit current, while the open circuit voltage is reduced. Totally inorganic based nanoparticle solar cells, based on nanoparticles of CdSe, CdTe, CNTs and nanorods made out of the same material are studied by number of research groups. The efficiencies are still in the 3–4% range but much research is being conducted in this field.

Quantum dots (QD)

Nanometer-sized crystallite semiconductors produced by a number of methods are quantum dots (QDs) (Razykov et al., 2011). Their ability to tune the absorption threshold simply by choosing the dot diameter is the main advantage. QDs can be described as a material that is built with many forms of materials thus makes it a special semiconductor system with an ability to control the band-gap of energy. If band-gap energy size increases voltage output can also be increased. On the other hand, smaller band-gap can also increase current output. QDs are found as appropriate solution since they can vary light absorption and emission spectra of light (Tyagi et al., 2013).

According to opportunity to control the energy of carrier states by adjusting the confinements in all three spatial dimensions QDs are known as “artificial atoms”. With QDs closely packed, the confined levels overlap to form minibands in QD superlattices, which extends the range of electronic and optical properties that can be provided by semiconductor materials. QD superlattices have interesting possible applications in “third-generation” PV with the control of miniband energy level and bandwidth, especially for tandem solar cells. The basic principle behind the efficiency increases offered by QD intermediate-band solar cells is that the discrete states that result from the inclusion of the dots allow for absorption of sub-bandgap energies. When the current is extracted, it is limited by the host bandgap and not by the individual photon energies, and that is the reason why this approach can exceed the efficiency of an ordinary dual-junction cell.

Aroutiounian et al. (2005) developed a mathematical model to calculate photo current for the solar cell that is QD based. Two assumptions are made: (1) QDs are located in subsequent layers, (2) periodically stacked M times together at a distance of d, d>>0, where a0 is typical size of QDs are contained in this model. Efficiency of solar cells based on QD are easily influenced by the defects on them (Gorji, 2012).

Hot Carrier solar cells (HC)

This technique utilizes selective energy contacts to extract light generated by “hot carriers” (HC) (electrons and holes) from semiconductor regions without transforming their extra energies to heat. That is why it is the most challenging method compared to CNT and QD (El Chaar et al., 2011). HCs have to be collected from the absorber over a very small energy range, with selective energy contacts, which is the most novel approach for PV cell production and it allows the use of one absorber material that yields high efficiency under concentration.

The efficiency of HC reaches 66% which is three times higher than existing cell made from silicon (Ross, 1982), but this technology will never fully develop until solutions to the main material challenges are found. Furthermore, away from incorporating multiple absorption path devices into a shorter time realization since most of these devices are more suitable for the high energy portion of the spectrum (Hosenberg et al., 2007), meaning to date that HC solar cells are just an experimented technology. The schematic of HC solar cell is presented in Fig. 3.3.2., adapted from Tyagi et al. (2013).

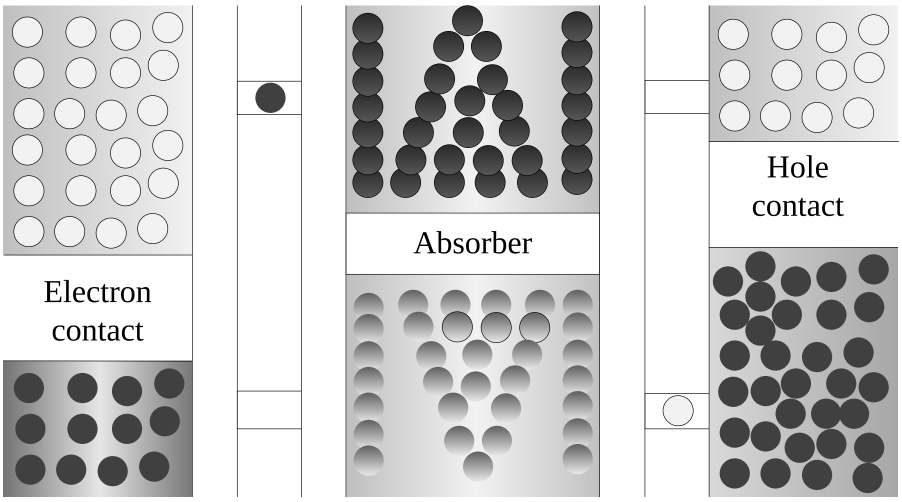

Figure 3.3.2. HC schematic (Adapted from Tyagi et al., 2013).

3.3.4 Nanofluids

Nanofluids can be tailored to provide superior optical and thermo-physical properties and thus have increasingly attracted attention for use in solar thermal applications. Up to a 10% increase in the efficiency has been reported through the use of nanofluids compared to conventional collectors (Mesgari et al., 2016).

As a colloidal mixture made of a base fluid and a nanoparticle, nanofluid is a new generation of heat transfer fluids becoming a high potential fluid in heat transfer applications due to enhanced thermal conductivity (Devendiran, 2016). Nanofluids have great potential in a wide range of fields, and their concept is extended by use of PCMs, going well beyond simply increasing the thermal conductivity of a fluid.

Unlike micron-sized suspensions, nanofluids, known as the suspension of nano-sized solid particles in a liquid, were found to form stable systems with next to no settling under static conditions (Arthur et al., 2016). Even at small concentrations of nanoparticles (~ 1% mass fraction) these stable suspensions anomalously increase the thermal conductivity compared to that of the base fluid. In some cases, increases in specific heat capacity have been observed (Shin et al., 2013).

Taylor et al. (2013) gave the nanofluid possible advantages over the traditional heat transfer fluids:

1. Due to the incredibly small size of the particles they are essentially fluidized. Allowing them to pass through pumps, micro-channels and piping without any adverse effects.

2. Nanoparticles act as the absorption medium allowing the nanofluid to directly absorb solar energy.

3. Optically selective, allowing for high absorption in the solar range while obtaining low emittance in the infrared. Allowing for a volumetric receiver instead of a selective surface system, which is favorable as selective surfaces have a poorer temperature profile resulting in higher emissive losses.

4. Enhancement of efficiency and uniformity of receiver tem perature is possible by tuning nanoparticle size and concentration.

5. Enhanced heat transfer may result in improved receiver performance.

6. Absorption efficiency can be altered by tuning the size, shape and concentration to suit conditions.

The main step in experimental studies with nanofluids is their preparation (Devendiran, 2016). Nanofluids are produced by dispersing nanometer-scale solid particles into base liquids such as water, ethylene glycol (EG), oils, etc. The major problem in synthesis of nanofluids is agglomeration. The delicate preparation of a nanofluid is important because nanofluids need special requirements such as an even suspension, stable suspension, low agglomeration of particles, and no chemical change of the fluid.

Classification of nanofluids

Nanofluids can be normally classified into two categories: metallic and non-metallic nanofluids. The third category is hybrid nanofluids (Nagarajan et al., 204).

Metallic nanofluids refer to those containing metallic nanoparticles (Cu, Al, Zn, Ni, Si, Fe, Ti, Au and Ag), while nanofluids containing non-metallic nanoparticles such as aluminium oxide (Al2O3), copper oxide (CuO) and silicon carbide (SiC, ZnO, TiO2) are considered as non-metallic nanofluids, semiconductors (TiO2), Carbon Nanotubes and composites materials such as nanoparticles core polymer shell composites.

A single material does not possess all the favourable characteristics required for a particular purpose. It may have either good thermal properties or good rheological properties. In many practical applications it is required to trade-off between several properties, and that is where hybrid nanofluids come, exhibiting remarkable physicochemical properties that do not exist in the individual components.

In addition, new materials and structure are attractive for use in nanofluids where the particle liquid interface is doped with various molecules.

Types of nanofluids

Two techniques are mainly used to produce nanofluids, the one-step and the two-step method. One-step technique combines the production of nanoparticles and dispersion of nanoparticles in the base fluid into a single step, and this technique have some variations. The two-step method is extensively used in the synthesis of nanofluids considering the available commercial nanopowders supplied by several companies. In this method, nanoparticles are first produced and then dispersed in the base fluids. Based upon the preparation methods, there are different types of nanofluids:

- Alumina nanofluids;
- Aluminum nitride nanofluids;
- Zinc oxide nanofluids;
- Titanium dioxide nanofluids;
- Silicon dioxide nanofluids;
- Iron oxide nanofluids;
- Copper nanofluids;
- Carbon nanofluids;
- Gold and silver nanofluids;
- Graphene nanofluids;
- Hybrid nanofluids.

Characterization of nanofluids

The nanofluids are characterized by the following techniques: SEM, TEM, XRD, FT-IR, DLS, TGA and zeta potential analysis (Devendiran, 2016).

SEM analysis is carried out to study the microstructure and morphology of nanoparticles or nanostructured materials. TEM is like SEM, but with much higher resolution. XRD images are taken to identify and study the crystal structure of nanoparticles. FT-IR spectroscopy is done to study the surface chemistry of solid particles and solid or liquid particles. DLS analysis is performed to estimate the average disperse size of nanoparticles in the base liquid media and TGA is performed to study the influence of heating and melting on the thermal stabilities of nanoparticles. Zeta potential value is related to the stability of nanoparticle dispersion in base fluid.

Review of characterization studies reveals that the important information like nanoparticle size, shape, chemical bonds, distribution and stability are found from characterization techniques.

Nanofluids properties

The properties of nanofluids are mainly based on five parameters: thermo fluids, heat transfer, particles, colloid and lubrication.

- Thermo fluid property includes temperature, viscosity, density, specific heat and enthalpy.
- Based on the heat transfer are thermal conductivity, heat capacity, Prandtl number and pressure drop.
- The parameters based on particles are size, shape, BET (surface area analysis) and crystalline phase.
- Based on the colloidal properties are suspension stability, Zeta potential and pH.
- The final properties based on lubrication are viscosity, viscosity index, friction coefficient, wear rate and extreme pressure.

The physical properties of nanofluids are quite different from the base fluid, and density, specific heat and viscosity are also changed which enhance the heat transfer coefficient exceeding the thermal conductivity enhancement results as reported in some experimental studies.

3.3.5 PCM, nanomaterial and nanofluid applications in BISTS

PCM can be used in thermal energy storage applications. The ideal PCM to be used for any thermal storage system must meet the following requirements: high sensitive heat capacity and heat of fusion; stable composition; high density and heat conductivity; chemical inert; non-toxic and non-inflammable; reasonable and inexpensive. The salt hydrates, paraffin and paraffin waxes, fatty acids and some other compounds in the nature have high latent heat of fusion in the temperature range from 30 °C to 80 °C that is interesting for solar applications. PCMs are chemical substances that undergo a solid-liquid transition at temperatures within the desired range for heating purposes and during the transition process, the material absorbs energy as it goes from a solid to a liquid and releases energy as it goes back to a solid. Most organic PCMs are non-corrosive and chemically stable. They exhibit little or no subcooling, and are compatible with most building materials and have a high latent heat per unit weight and low vapour pressure.

The integrated PCM solar collector storage concept is economically promising in low temperature solar water heating systems for domestic, agricultural and industrial applications. A system of this type combines collection and storage of thermal energy into a single unit. This integrated solar collector storage water heater approach was developed from early systems and comprised simply a simple black vessel placed in the solar collector. Integrated PCM solar collector for a low-temperature SDHW system using salt hydrate eutectic mixture (48% $CaCl_2$, 4.5% KCl, 0.4% NaCl and 47.1% H_2O) where the PCM is held inside the collector and thermally discharged to cold water flowing through a heat exchanger is developed by Rabin et al. (1996). Integrated system is shown in Fig. 3.3.3.

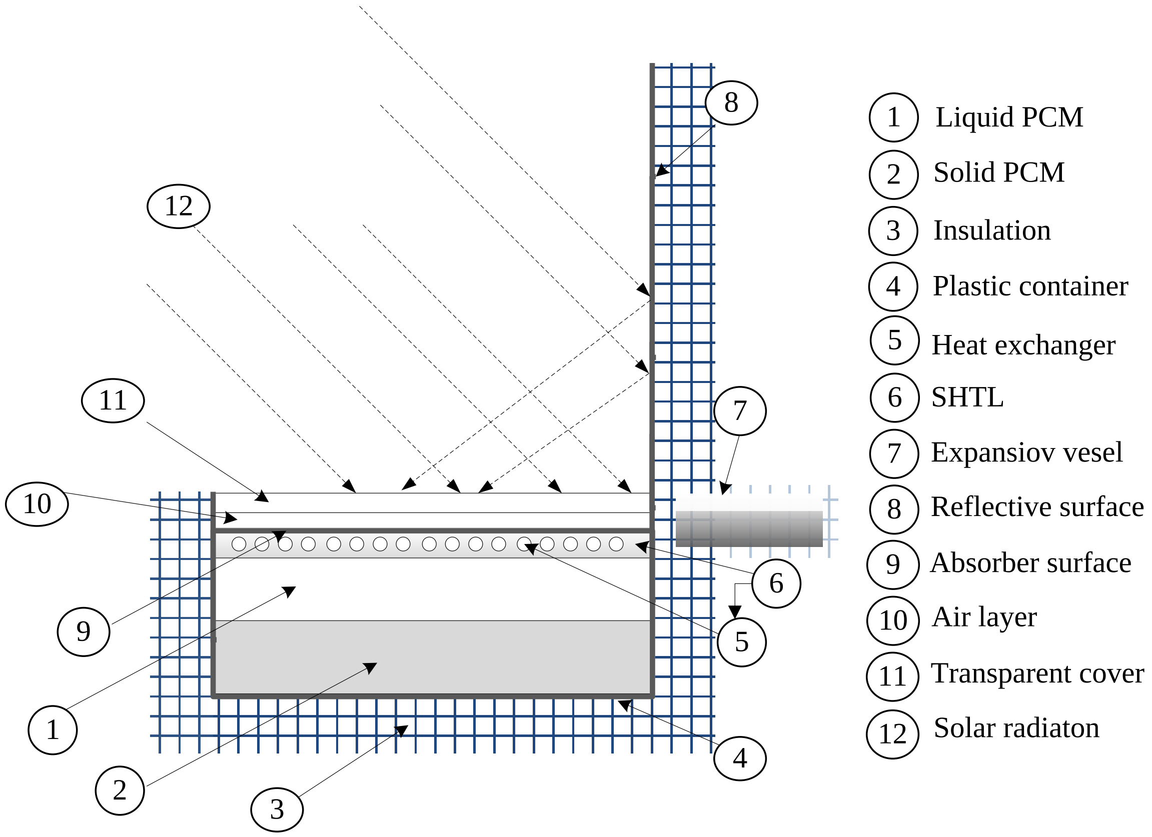

Fig. 3.3.3. Integrated PCM solar collector storage system designed.

A type of water-PCM solar collector consisting of two adjoining sections is developed by Kürklü et al. (2002). One section is filled with water and the other with paraffin wax, where melting temperature is in range 45–50 °C, as shown Fig. 3.3.4. The experimental results indicated that the water temperature could exceed 55 °C during a typical day of high solar radiation and remain over 30 °C during the whole night.

The key component in the solar domestic hot water system using phase change materials is the latent heat storage unit. Many researchers focused on improving the heat transfer inside the latent heat storage unit, in order to improve the energy storage and thermal performance of solar hot water systems. Two main fields of interest are configuration of the latent heat storage unit to improve heat transfer inside the unit, and the heat transfer mechanism in the PCM (Seddegh et al., 2015).

Recently, the incorporation of PCM in different applications has grown interest to the researcher. A large number of solid–liquid PCMs have been investigated for heating and cooling applications (Sharma et al., 2009).

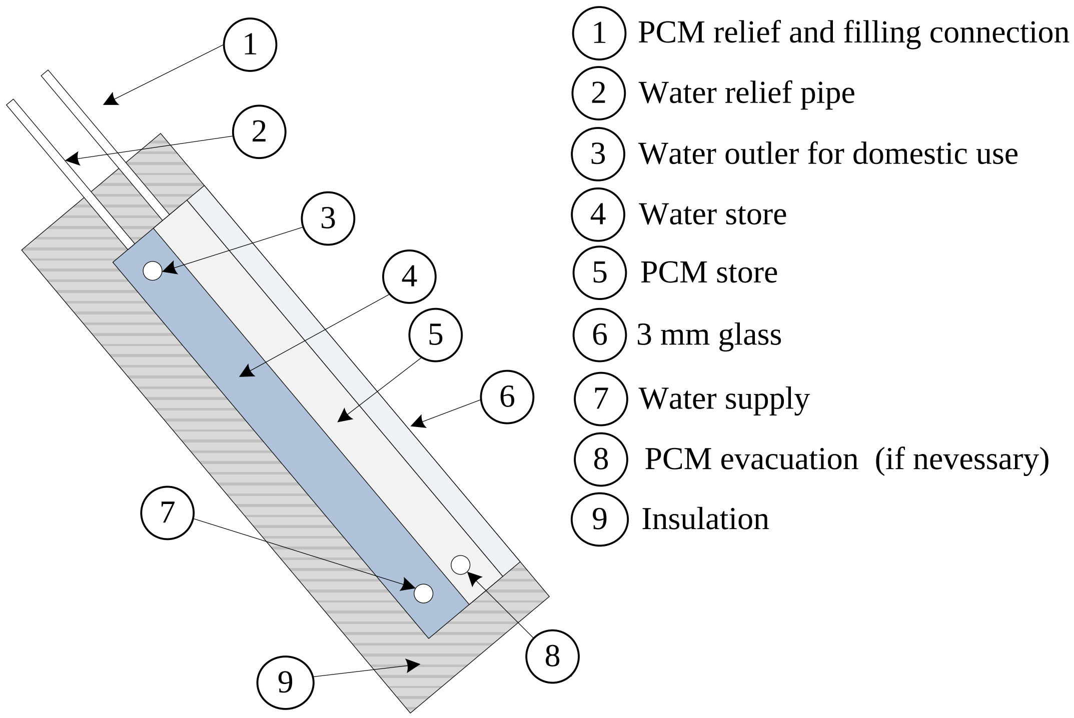

Figure 3.3.4. Schematic view of solar collector construction with PCM.

Nanotubes can potentially replace indium tin-oxide in solar cells as a transparent conductive film in solar cells to allow light to pass to the active layers and generate photocurrent (Kaushik and Majumder, 2015). CNTs in organic solar cells help reduce energy loss and increase resistance to photooxidation. Germanium CNT diode can be fabricated and it exploits the photovoltaic effect. Photovoltaic technologies may incorporate CNT-Silicon hetero junctions to leverage efficient multiple-exaction generation at p-n junctions formed within individual CNTs.

The inclusion of nanoscale components in PV cells (BIPV or PV/T) is a way to reduce some limitations. First, the ability to control the energy bandgap provides flexibility and inter-changeability. Second, nanostructured materials enhance the effective optical path and significantly decrease the probability of charge recombination.

The use of nanocrystal quantum dots, which are nanoparticles usually made of direct bandgap semiconductors, lead to thin film solar cells based on a silicon or conductive transparent oxide (CTO), like indium-tin-oxide (ITO), substrate with a coating of nanocrystals (Razykov et al., 2011). Quantum dots are efficient light emitters because they emit multiple electrons per solar photon, with different absorption and emission spectra depending on the particle size, thus notably raising the theoretical efficiency limit by adapting to the incoming light spectrum.

Initially, the nanofluid applications in solar collectors and water heaters are investigated from the efficiency, economic and environmental points of view. The experimental analysis of thermal conductivity done by some authors, and optical properties of nanofluids are also reviewed. The reason is that these parameters show the capability of the nanofluid to work as an enhanced HTF under high temperature. Reddy et al. (2016) reported the optical characterization of single-wall carbon nanohorn (SWCNH) nanoparticles for solar energy application. The result shows that carbon nanohorn-based nanofluids can be useful for increasing the efficiency and compactness of thermal solar devices.

Some authors carried out the investigation of nanofluids in the flat-plate collector for low-temperature applications and they found that a nanofluid-based solar collector is more efficient than a conventional solar collector (Reddy et al., 2016). Low-temperature solar collectors mainly include flat-plate collectors where the operational temperature is below 100 °C. In this section, the review of flat-plate solar collectors using a nanofluid as the heat transfer medium has been carried out. It is found that different nanofluids significantly increase the collector's efficiency under non concentrated radiation.

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3.4 RETROFITTING BUILDING INTEGRATED SOLAR THERMAL SYSTEMS

Donal Keys, Andy Ford

3.4.1 Integration with existing building fabric

Building facades have evolved considerably in recent decades and can no longer be considered as merely a barrier to provide protection against the external environment. They have a significant role to play in the conservation of energy and the subsequent limiting building carbon emissions and are also required to provide a comfortable thermal environment for building occupants whilst providing acceptable levels of daylighting and glare control. Recent developments have seen their function extended from being a passive element to an active element through the development and integration of renewable energy technologies into the building façade.

3.4.2 The Retrofit Challenges

For a new construction project where BISTS (Building Integrated Solar Thermal Systems) are to be incorporated, the integration considerations may be accounted for at the design stage of the project and will influence to some extent the design of the building structure, the facade and the services installation. However, where BISTS are to be retrofitted to the facades of existing buildings there are inherent difficulties with both the physical/architectural integration of the system and the connection with existing services for space heating or cooling and water heating.

The challenges of retrofitting BISTS are compounded by the varied and complex nature of building geometries and their distribution. Retrofitting buildings for energy efficiency improvement is generally characterised by non-uniformity and hence careful consideration of the BISTS system, which are usually based around modularity, is required. Retrofitting existing buildings tends to lead to a more fragmented approach for BISTS to fit in with existing restrictions and as a consequence many individual system designs are required. This has led in part to a non-standard approach of both fully integrated systems which displace existing building fabric and also hybrid systems where an additional superficial frame mounting arrangement is provided in which to integrate the system. The fully integrated systems are generally glazed collector systems providing a weatherproof barrier while the hybrid systems are usually unglazed systems which may form part of a secondary skin.

3.4.3 Building Integration considerations

Using the building facade to harness solar energy has significant potential to further minimise the energy requirements of buildings however the integration of solar thermal systems into the façade requires careful consideration, design and planning. The system design and integration will have to meet specific building codes in line with the construction of new buildings. The focus must remain primarily on the safety of building occupants and the general public in the vicinity of the building. The functional requirements should therefore consider:

- The additional load the collector will impose on the structure taking into consideration further imposed loads which may result from collector geometry such as the effects of wind and snow etc.
- The level of water tightness, air and moisture permeability and general impact from the weather
- The ability of withstanding the effects of fire attack
- The mechanical fixing and anchoring of the collector to the structural frame of the building
- The impact of the system on the thermal performance of the façade and the requirement for additional cooling if required
- Jointing and connection with the existing structure and components/materials considering thermal movements
- Resistance to applied external impacts from weather or directed damage

3.4.4 Architectural Integration considerations

In addition to the technical challenges the impact of retrofitting BISTS on the building appearance must be considered and the architectural integration with existing systems must not be to the detriment of the aesthetical value of the building and its surroundings if these systems are to be widely accepted and adopted. This can be of particular importance for historic conservation type buildings or where the architectural merit of the building must be maintained.

Integration may be described as building integration or architectural integration. The former has less consideration for the appearance or impact on the aesthetics but is concerned with the technical challenges. The architectural integration considerations will include the appearance (largely dependent on colour and texture of absorber or the aperture glass cover), collector and non-collector areas, panel size and interconnection with other components.

Traditionally solar absorbers have been coloured black to maximise absorption and efficiency. Now there is a range of colour options and finishes available which may be used to an advantage when retrofitting to blend in with the existing building structure and indeed its surroundings.

In retrofitting for building integration to existing buildings it is necessary to consider both the design requirements and construction of the collector system and the specific construction characteristics of the structure to which the collector will be attached. The level of flexibility for integration also depends to the extent of retrofitting/refurbishment planned for the building. For concrete and steel framed buildings which are common construction techniques in most countries retrofitting can involve the complete removal of the existing fabric, for example an inefficient lightweight cladding system. In this instance the level of flexibility is high and architectural integration can be achieved with greater ease in addition to building integration. For buildings where existing glazed or spandrel elements are to be replaced then the opening dimensions and shape will largely dictate the collector design specification.

The architectural challenges are not to be underestimated as these can have the most significant influence on the acceptance of a particular technology even to the detriment of the performance characteristics. Solar collectors are designed primarily with their maximum efficiency in mind by optimisation of the size, geometry etc. New collector designs need to be architecturally inclusive and there might exits certain 'trade-offs' as some functionality gives way to design aesthetics.

3.4.5 Building Services

Systems Integration

Integration of a BISTS into an existing building services system requires

- Suitable uses for heat
- Appropriate temperatures
- Suitable interface
- Suitable size of collector
- Service link to the building skin roof or wall
- Storage
- Integration with the façade design and during construction
- BMS control connection with remaining existing services

Retrofitting solar thermal into either domestic or non-domestic situations generally means looking at the uses of heat and identifying when and at what temperature they will be required.

The most common retrofit use of solar thermal has been for hot water generation. This has only requirements for effective heat collection and transfer into a store in the form of an insulated hot water tank. The use of the water is not instantaneous and energy collection can be spread over time provided the required temperature differences are achieved in the store to allow heat transfer. This is typically through effective stratification in the cylinder. This hot water only approach also requires a relatively small collector and simple flow and return link to the store. The integration with existing hot water generation systems is straightforward through the use of cylinders with several primary coils taking heat from more than one source.

By far the majority of retrofit measures in domestic schemes are unintegrated. More recently there has been an expansion of bolt on roof panels some of which might now be reasonably described as integrated being designed to replace roof tiles rather than sit above them.

The expansion of the domestic PV market has led to increased exploration of the possibilities of integrating PV and Solar Thermal collectors making use of the larger array sizes which are normal for PV and collecting excess solar thermal energy and exploration of the possibility of utilising the surplus for heating examples is seen in Figure 3.4.1.

Figure 3.4.1. PVT Panel integrated into the tiled roof system.

The expansion of building integrated solar thermal into the area of heating with the intention of providing a significant solar fraction over a year requires development of suitable thermal storage solutions as interfaces and significant increase in collector area.

The scale of thermal storage required for heating an individual dwelling over a season utilising hot water tanks makes this an extremely difficult solution to retrofit as illustrated by the steel tank being fitted to a new dwelling in Figure 3.4.2. This has occasionally been resolved by converting a basement area into a thermal store with an on-site constructed solution utilising insulated panels.

Figure 3.4.2. Steel prefabricated seasonal store and Insitue constructed Polymeric tank.

The requirement for large collector areas for BISTS Heating solutions has led to solutions which utilise the entire roof replacing roof tiles with glazing such as illustrated in Figure 3.4.3 from the UK. The need for size also drives the use of larger collectors integrated across multiple roofs of multi tenanted buildings. Other approaches to resolving the large collector sizes required for solar heating in refurbishment move off the building into the adjacent parking areas and utilise tarmac surfaces as large low temperature collectors such as the example in Figure 3.4.4 Garth Prison, UK. The exercise yard has been utilised as the solar collector by laying pipework within the tarmac surface. Thermal storage solutions are separated and either integrated as tanks within the buildings, where suitable spaces can be found, or the buildings connected to the collector by underground pipework. In such cases they typically utilise either ground thermal energy storage borehole fields or large insulated underground water reservoirs.

Figure 3.4.3. Garth Prison, ICAX ltd, Uk.

Figure 3.4.4. Glass Tiles.

How building integrated such an approach is can be debated being more site integrated than building integrated but they work well in retrofit situations. In Denmark retrofit is now being dealt with to a large extent by integrating solar with district heating and just between 2010 and 2011 around 65,000 m² of solar district heating was installed and at the end of 2011 at least 140,000 m² were connected.

Retrofitting solar facades

Whilst the solutions discussed above are largely roof collectors the non - domestic area has seen many collectors integrated into the walls of commercial and industrial buildings utilising both air and water as the heat transfer medium.

Perhaps the most successful solution to date has been the use of perforated metal wall cladding integrated with the ventilation system. This system SolarWall was initially developed in Canada but there are now many examples around the world both domestic and non-domestic.

Figure 3.4.5. Community housing scheme in Windsor, Ontario, Canada.

The example in Figure 3.4.5 is a community housing scheme in Windsor Ontario southern Canada. A 1,000 m^2 black SolarWall system was installed on the two south-facing walls. An Exterior Insulated Finish System (EIFS) was specified for the building façade and a SolarWall® Flat Panel system was specified for the southeast and southwest-facing stairwell walls. Costs of the installed collector walls were less than the costs of the insulation system applied to the other walls. The system is a solar air heating technology that also acts as a second skin for a building. As such the design needs to be developed with the architecture at a relatively early stage and as is the case with all these solutions this requires early involvement of environmental engineers to ensure the systems are sized correctly at planning stage.

The ventilated façade draws in outside air through tiny micro-perforations in the surface of the wall collector and heats that air before it is ducted into the building's HVAC system (Figure 3.4.6). This reduces the conventional daytime heating load on the building. The advantage of such a technology in retrofit is that air can be extracted adjacent to the locations typically occupied by ventilation plant on the roof and this simplifies integration into existing systems.

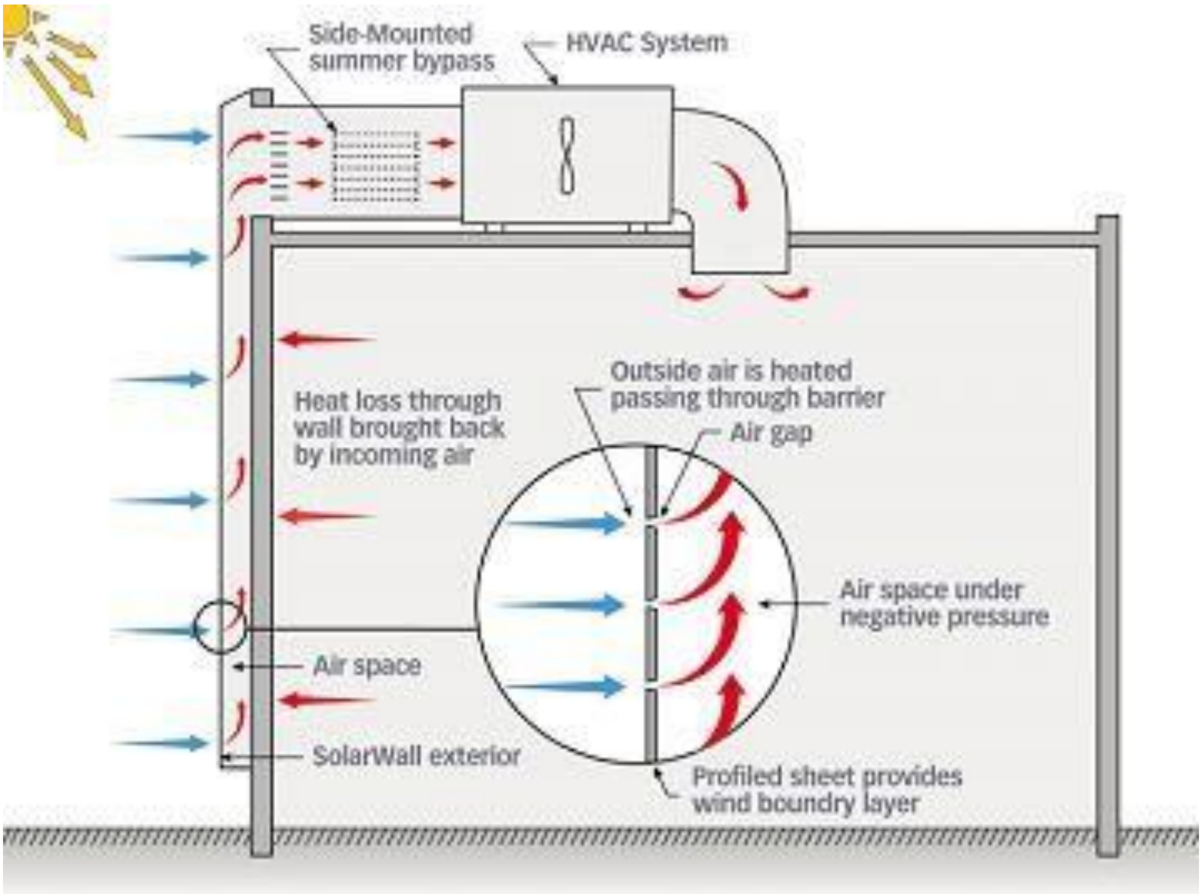

Figure 3.4.6. SolarWall.

Figure 3.4.7. Jaguar Land Rover Academy transpired solar wall.

A non-domestic demonstration was installed during the retrofit of the building for the Jaguar Land Rover Academy, Gaydon, Warwickshire UK (Figure 3.4.7). The use of large solar collectors such as this has wide applications in the many steel clad industrial and commercial sheds around the world. The collectors are now being more commonly linked with seasonal storage systems again either borehole fields, underground reservoirs or more recently and still at non-commercial level with thermochemical storage such as is being developed at SPECIFIC on Port Talbot, Wales http://www.specific.eu.com/technologies and Merits http://www.merits.eu/project in the Netherlands. The retrofitting of Solar Collection integrated with the storage system must be developed not just at the physical level but concurrently considered in the development of appropriate control algorithms in the BMS system for the building.

3.5 BUILDING INTEGRATED THERMAL STORAGE SYSTEMS

Luisa F. Cabeza, Lidia Navarro[2]

3.5.1 Thermal energy storage

Energy demand in residential, commercial or industrial sectors experience daily, weekly or seasonal variations. Thus, these demands can be matched with the energy supply through the help of thermal energy storage (TES) systems. The developed TES techniques have large potential to make use of the thermal equipment more efficiently and to increase the energy storage capacity. Moreover, the use of TES in energy systems lead to a better economic feasibility, reducing investment and running costs, and less pollution of the environment and less CO_2 emissions (Dinçer and Rosen, 2002; Mehling and Cabeza, 2008).

Solar systems (installed in buildings) require storage of thermal energy for different periods of time depending on the applications, from short duration periods (minutes or hours) to seasonal storage. The main advantage of using TES in solar systems for buildings is the success of converting an intermittent energy source in meeting the demand, which may be intermittent and/or have a time shift (Cabeza, 2012; Heier et al., 2015).

Different thermal storage methods can be found depending on the process that is affecting the material or storage medium: sensible heat, latent heat and thermochemical energy storage (Cabeza, 2012; Kakaç et al., 1989). Sensible heat storage is carried out when changing the temperature of a storage medium, without having a change in its phase in the storage process. The amount of heat that a sensible TES system can store depends on the temperature difference between the initial and final conditions, the mass of the storage medium, and its heat capacity (Dinçer and Rosen, 2002). On the other hand, latent heat is the energy absorbed or released by a substance when it changes from one phase to another. The latent heat change usually is much higher than the sensible heat change. During the phase changing process the temperature remains constant at its so-called phase change temperature (Mehling and Cabeza, 2008). Thermochemical energy storage is based on reversible physical and chemical processes or reactions involving two substances named thermochemical materials (TCM).

Sensible and latent heat storage are the methods used in building applications so far. Thermochemical energy storage still has some limitations on material development, reactor configuration and costs that should be addressed to be competitive with the other technologies (Solé et al., 2015; Tatsidjodoung et al., 2016).

The use of latent heat storage materials in buildings is of large interest because of the narrow temperature range where the PCM can store heat or cold with high storage density. Many studies of PCM materials characterization and compatibility with building materials (Cabeza et al., 2011) have been carried out to provide wide information to building engineers and final users (de Gracia and Cabeza, 2015; Parameshwaran et al., 2012). TES in buildings can be applied in passive systems acting as a delay of the peak heating or cooling demand, or working as an active storage unit reducing directly the energy consumed by the heating ventilating and air conditioning (HVAC) systems or domestic hot water (DHW) facilities (Heier et al., 2015).

[2] Non-COST Action member.

3.5.2 Building integration

Energy efficiency requirements have been included in many building codes and energy standards. Low energy buildings and net zero energy buildings are becoming a target in the research field, through the incorporation of solar energy systems and thermal energy storage among others. Mostly, more than one technology is needed to achieve low energy rates hence, architects and engineers have to deal with their integration during the building design. Building integration can be defined by the idea of a functional or constructive incorporation of the technology in the building structure (IEA SHC Task 41, 2012). Within this definition, passive systems or technologies such as seasonal shadings, blinds, thermal mass increase or thermal insulation, which are focused on reducing the energy demand, are widely incorporated in the building design process.

Active systems such as renewable energy facilities or energy efficiency HVAC systems require more effort on integration. Many studies have been focused on improving the efficiency of these technologies by incorporating thermal energy storage systems that implies an additional storage volume (Basecq et al., 2013). Therefore, a means of integration of these technologies inside the building to promote them as an alternative to the conventional systems is needed. So far this issue has been not widely considered although some studies applied the constructive incorporation of their thermal storage systems.

Nevertheless, some of these systems may cause additional problems to the building physics such as thermal bridges, air tightness or humidity issues. So, architects and engineers should pay special attention to the integration of these systems in order to achieve their maximum efficiency. On the other hand, important barriers could be found in the building sector when introducing the idea of active TES systems integration. The building sector is a quite hermetic area where new systems are difficult to be introduced mainly because a lack of knowledge of the constructors, architects and customers (IEA SHC Task 41, 2012).

3.5.3 Passive TES systems

Thermal energy storage has been applied in building envelopes for many years, using sensible heat storage in traditional building materials such as stone, earth, brick and concrete. Many studies have compared thermal inertia construction systems against lightweight systems such as wooden frame having better thermal performance due to the higher thermal mass (Zhu et al., 2009). However, depending on the climate conditions, thermal mass has a low influence on the heating and cooling demands of a building.

In spite of this, solar walls were designed to increase the potential of the high thermal mass envelopes by covering them with a glass a leaving an air channel between both components (Saadatian et al., 2012). Even though, the standard solar wall registered energetic benefits, many researchers have modified the original operation adding mechanical or natural ventilation (Stazi et al., 2012; Briga-Sá et al., 2014).

On the other hand, latent heat storage materials are known as a potential technology to reduce energy demand in buildings. Phase change materials (PCM) have been incorporated in buildings envelope as a passive system inside building materials (concrete, plaster), as a new layer in the construction system or in windows or sun protections. In general terms, the incorporation of phase change materials into the construction elements of a building is demonstrated to improve the stability of the internal temperatures by the thermal inertia effect. However, the potential of these passive PCM systems is to reduce the energy demand of the building, but the studies showed limited potential on achieving significant energy savings in HVAC systems. Moreover, results obtained from the different passive PCM applications are quite disperse and not comparable between them, since different boundary conditions (phase change temperature, type of study, weather conditions, among others) (Navarro et al., 2016a).

3.5.4 Active TES systems

Active TES systems are becoming more popular in building applications for space heating and cooling purposes, because of their potential on achieving higher energy benefits than the passive PCM applications. As mentioned in section 3.6.2, the integration of these storage units is still a target to achieve, however some applications can be found in the literature that solve the integration issue.

A classification of active TES systems in buildings was done depending on the components where the storage unit is included (Navarro et al., 2016b). Figure 3.6.1 presents different ways to integrate the thermal energy storage active system; in the core of the building structure (ceiling, floor, walls), in external solar facades, as a suspended ceiling, in the ventilation system, or for thermal management of building integrated photovoltaic systems. This review also considers building integration of heat storage water tanks as well as ground integrated for seasonal storage.

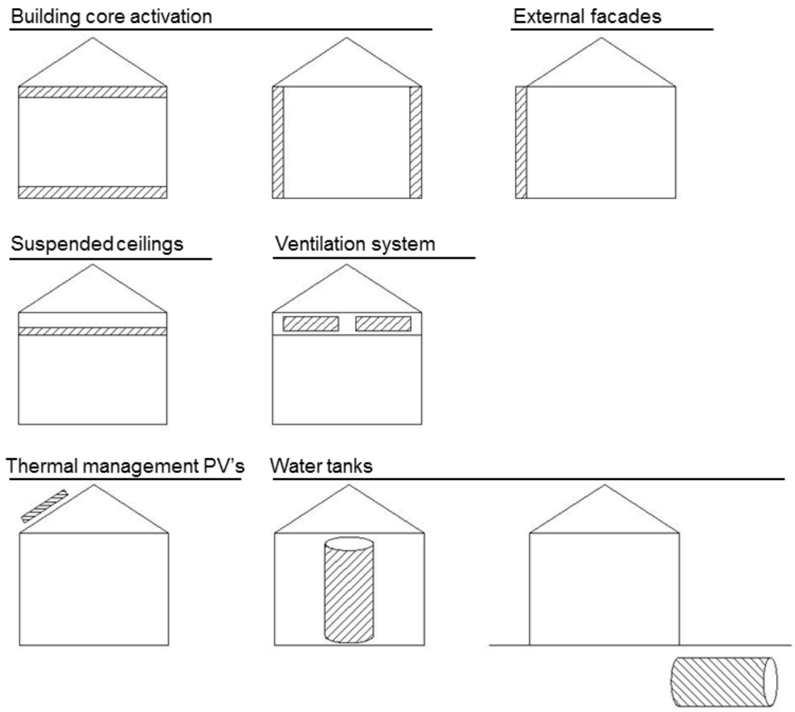

Figure 3.6.1. Active thermal energy storage systems integration in buildings (Navarro et al., 2016b).

The common parameter between these systems is the charge process actively done, by means of a mechanical input. However, the discharge process of the storage unit of the technologies found in the literature is done through passive or active means.

3.5.4.1 Building core activation

Building thermal inertia is commonly incorporated as a methodology to enhance the thermal performance of the construction systems using materials of high thermal mass such as bricks or concrete, which increases the thermal storage capacity of the envelope and hence attenuate thermal oscillations passively. Nowadays, the concept called thermal mass activation (TMA) is mostly used for building components with heat storage enhancement by the addition of latent heat storage materials or by the controlled management of the heat storage. In this section, building structure components such as walls, ceiling or floors used as a storage unit have been considered. In the studies done so far the activation occurs inside the building component by the use of pipes or ducts. Nevertheless, most of the systems are air based (Yuxiang et al., 2010; Navarro et al., 2015) which means that the air is the heat transfer fluid used to charge the storage unit and to provide heating or cooling (Figure 3.6.2).

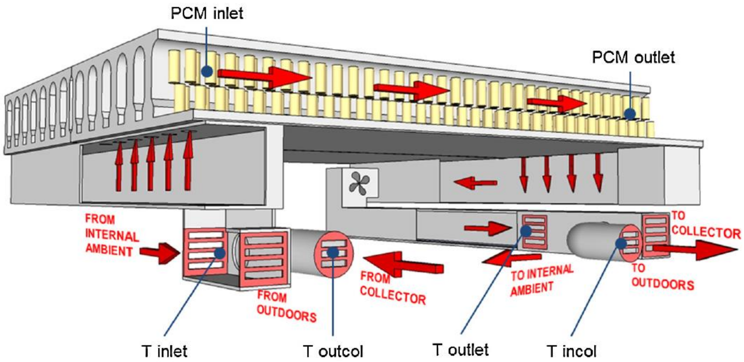

Figure 3.6.2. Active slab with phase change materials for heating and cooling purposes (Navarro et al., 2015).

Building core activation is demonstrated to be an interesting technology for new constructions domestic, public or office buildings. However, ceiling and floor activation components are considered better than wall activation as they are usually exposed and wall surfaces are usually used for shelving, cupboards, or other furniture. Moreover, few commercial products have been developed as prefabricated components with the implementation of water pipes in a concrete slab or air ducts system inside a hollow concrete slab.

3.5.4.2 Suspended ceilings

Some active applications can be found in suspended ceiling panels (Koschenz and Lehmann, 2004) that are actively charged through water pipes. These systems are designed to absorb internal thermal loads of the building during summer periods. However, due to the panel material (usually gypsum) and the thickness, presented low storage capacities (Figure 3.6.3).

Nowadays, a significant amount of old buildings need an energetic retrofitting in order to accomplish the standards defined by the European building directives. For this reason, the implementation of thermal energy storage components in the suspended ceiling such as actively charged water panels are good options as cooling or heating systems.

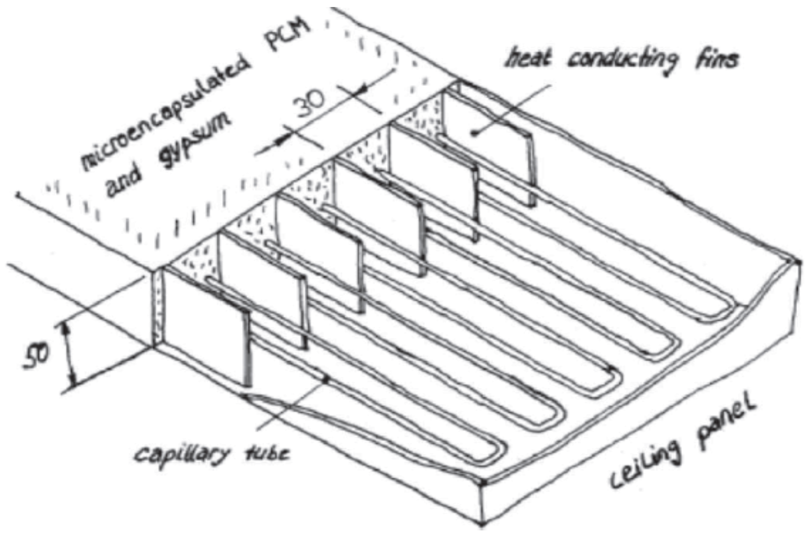

Figure 3.6.3. Thermal activated gypsum ceiling panel (Koschenz and Lehmann, 2004).

Since energetic regulations in building sector are becoming stricter, old buildings need retrofitting to accomplish the new energy efficiency standards so implementation of energy saving actions must be undertaken. Suspended ceiling products such as radiant panels or thermal activated gypsum panels, which were experimentally tested with successful results, may be possible solutions for building energetic refurbishment.

3.5.4.3 Ventilation system

Thermal storage units could be also placed in the ventilation duct systems behind the suspended ceiling, in the heat recovery unit or the air handling unit, as a thermal battery taking advantage of the night ventilation. Most of these systems are designed for cooling purposes, and since they are related to the ventilation systems are air based.

The implementation of PCM in these systems has been done by macro-encapsulation in aluminium panels or fins to achieve better heat transfer with the air flow (Stritih and Butala, 2010). The operational principle is based on taking advantage of the night temperatures to solidify the PCM, while the air is pumped through the storage unit during the daytime when a cooling supply is needed (Figure 3.6.4).

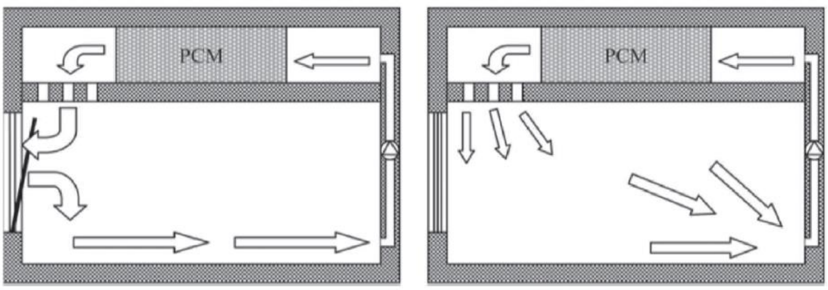

Figure 3.6.4. Operational principle of PCM free-cooling system (Stritih and Butala, 2010).

The addition of thermal storage units in ventilations systems either air ducts or air handling units are interesting locations for office or public building retrofitting, since the space heating and cooling systems, are mostly done through air systems. Also, some commercial systems which incorporate phase change materials in the AHU are currently marketed for use in buildings.

3.5.4.4 External solar facade

Double skin facades (DSF) have become a characteristic of modern buildings mainly because of the aesthetic value and the daylight contribution. Moreover, double skin facades if well designed are able to improve the thermal energy performance of the building (Shameri et al., 2011). DSF have high potential in reducing energy consumption of the HVAC systems, nevertheless some problems need to be overcome such as the overheating in summer. The incorporation of thermal energy storage system in DSF has been studied using both sensible and latent methods.

The integration of the concrete thermal mass has been studied in DSF systems in order to reduce the risk of overheating, by combining mechanical and natural ventilation alternatives (Fallahi et al., 2010). On the other hand, the integration of latent heat storage materials has been studied in the air channel of double skin facades system as a heat storage unit and heating supply (Figure 3.6.5). High potential of energy savings was demonstrated of this combination either with mechanical or natural ventilation strategy (de Gracia et al., 2013).

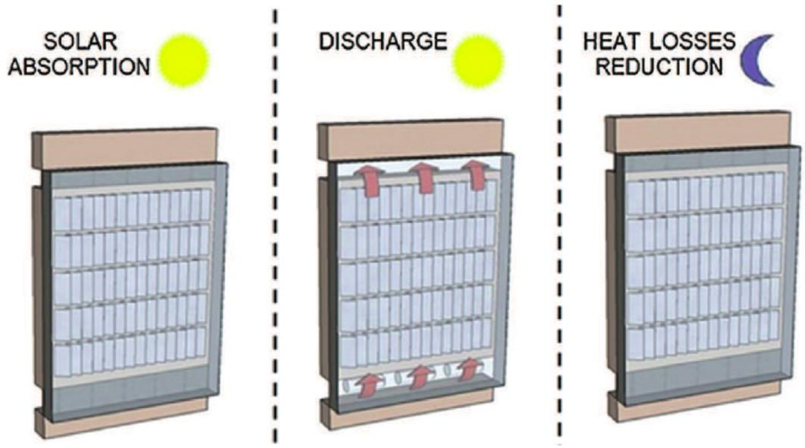

Figure 3.6.5. Operational mode of the double skin facade with PCM for heating purposes (de Gracia et al., 2013).

The double skin facade system is widely used in office and public buildings where the implementation of PCM could take profit of the solar energy to store and provide space heating to the building.

3.5.4.5 TES coupled to building integrated photovoltaics

The temperature increase of the PV cells causes a decrease on the electrical performance, hence the excess heat needs to be managed through cooling strategies. Thermal energy storage has been also implemented in building integrated photovoltaics (BIPV), in fact (Norton et al., 2011) stated that storage, PCM in this case, can be used for thermal management of these systems.

Many studies demonstrated that the incorporation of PCM in BIPV panels increase the PV performance due to thermal management functionality of the PCM through the excess heat storage (Huang et al., 2006). Moreover, new combinations of trombe wall system with PV cells are presented with an interesting heating potential (Jie et al., 2007). PV glass panel located in front of a blackened wall with an air chamber between them and two openings at the top and bottom of the wall provide heating to the adjacent room. Although the heating potential is significant in these systems, the electrical efficiency of the PV cells needs to be enhanced.

3.5.4.6 Seasonal water tanks

Thermal storage water tanks have an important role on the final efficiency of the solar systems or the domestic hot water systems. However, when implementing solar thermal systems in buildings the volume of the solar water tank needs to be taken into account.

Some projects are found on building integration water tanks mainly used as seasonal storage systems for covering both heating and domestic hot water demands. The integration inside the building architecture of huge seasonal water tanks have been installed in some projects (Simon and Firth, 2011). The main issue to highlight is the integration effort done making the water tanks a feature of stairwells in single houses and small apartments building (Figure 3.6.6). Moreover, underground integration of seasonal thermal storage water tanks is studied in existing buildings by the EINSTEIN project (The European project EINSTEIN, 2014) funded by the European Union.

Seasonal thermal water tanks coupled to solar systems started to be popular within the last decade in central Europe countries to cover domestic hot water and heating supply. However, their integration requires a lot of space, so in many cases these systems have limited potential.

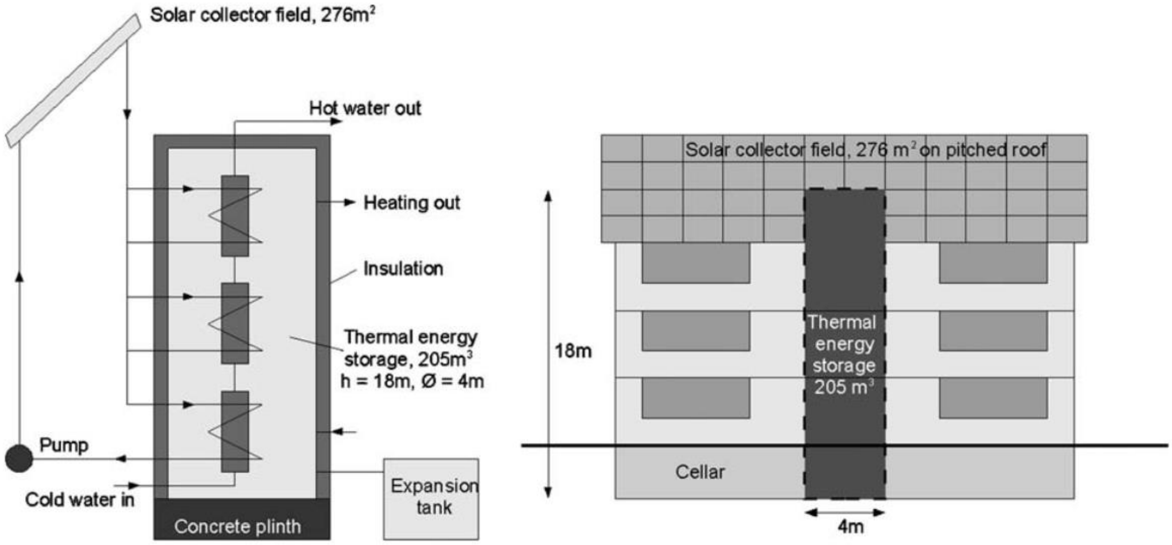

Figure 3.6.6. Thermal energy storage of a solar thermal system in an apartment building (Simon and Firth, 2011).

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