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Comparison of Different Solar Thermal Energy Collectors and Their Integration Possibilities in Architecture

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Abstract

Solar energy is becoming an alternative for the limited fossil fuel resources. One of the simplest and most direct applications of this energy is the conversion of solar radiation into heat, which can be used in water heating systems. A commonly used solar collector is the flat-plate. A lot of research has been conducted in order to analyze the flat-plate operation and improve its efficiency.

The solar panel can be used either as a stand-alone system or as a large solar system that is connected to the electricity grids. The earth receives 84 Terawatts of power and our world consumes about 12 Terawatts of power per day. We are trying to consume more energy from the sun using solar panel. In order to maximize the conversion from solar to electrical energy, the solar panels have to be positioned perpendicular to the sun. Thus the tracking of the sun's location and positioning of the solar panel are important.

The main goal of this article is explaining all the solar thermal systems available and the integration possibilities with comparisons for better usages and integration process into design.

Keywords

architectural integration, photovoltaics, active solar systems, solar architecture, building integration, solar thermal energy, solar thermal system

1. Introduction

The building sector is responsible for about a third of the total energy consumption of western countries. The use of solar energy in buildings is becoming of critical importance if we are to prepare for fossil fuel energy shortages and reduce our exposure to global warming impacts and associated environmental costs.

In this regard, there is a pressing need for architects to complete competencies in this field. The present manual, conceived for architects and intended to be as clear and practical as possible, summarizes the knowledge needed to integrate active solar technologies into buildings, handling at the document in the first part it talk in general and focuses on the definition of architectural integration quality and related criteria. It outlines possible practical ways that lead to high quality outcomes. Solar thermal and Photovoltaics are treated separately, since one technology is designed to transform the solar radiation into heat, while the other is designed to transform it into electricity: two different energies, with very different transportation, storage, and safety issues. This brings different formal and operating constraints, leading to different integration possibilities.

Solar Energy in Architecture

In recent times, the world has fortunately become increasingly constant of the significant potential of solar energy as a replacement for non-renewable fossil fuel energy. The sun is a clean, unlimited and almost infinite energy source, providing each hour on earth as much energy as the whole world needs in a year. Proven technologies are able to transform its radiation into heat, electricity and even cold, and are now largely available at affordable prices.

Building Energy Needs and Available Solar Technologies

Solar energy, in its active or passive forms, is able to deliver the entire set of building energy needs space heating and lighting, Domestic Hot Water (DHW), electricity, and recently also space cooling (Figure 1).

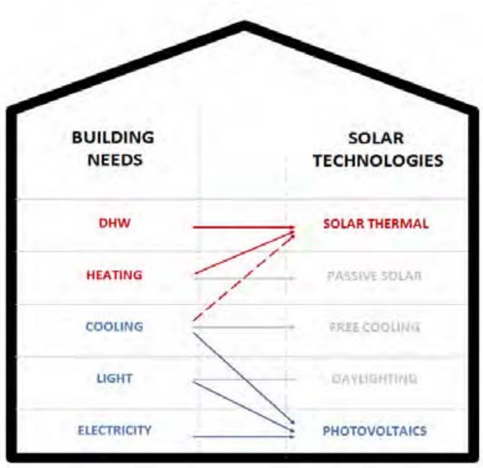


Figure 1. Different Solar Technologies Covering Different Building Energy Needs

2. Architectural Integration Quality

Architectural integration quality is defined as the result of a controlled and coherent integration of the solar collectors simultaneously from all points of view, functional, constructive, and formal (aesthetic), When the solar system is integrated in the building envelope (as roof covering, façade cladding, sun shading, balcony fence…), it must properly take over the functions and associated constraints of the envelope elements it is replacing (constructive/functional quality), while preserving the global design quality of the building (formal quality). If the design quality is not preserved (i.e., the system is only constructively/functionally integrated into the building skin without a formal control), we can only call it a building integrated system.

2.1 Functional and Constructive Aspects

The building envelope has to fulfill a wide and complex set of protection and regulation functions, requiring the use of different structures and components (opaque/transparent elements, monolithic/multilayer structures, composed of fixed/mobile parts…).

The integration of solar modules in the envelope system should then be studied very carefully, to preserve/ensure the standard envelope functions and the durability of the whole.

The multifunctional use of solar elements taking over one or more envelope functions may require an extra effort to building designers, calling for instance for some modifications in the original design of the collector, in the way it is mounted or by restraining its use in some parts of the building. On the other hand, it brings the major advantages of a global cost reduction and an enhanced architectural quality of the integration.

In addition to the functional compatibility, it is important to ensure that the new multifunctional envelope system meets all building construction standards:

- The collector load should be correctly transferred to the load bearing structure through appropriate fixing;
- The collector should withstand fire and weather wear and tear;
- It should resist wind load and impact, and should be safe in case of damage;
- Risks of theft and/or damage related to vandalism should be evaluated and appropriate measures taken;
- The fixing should avoid thermal bridges and the global U value of the wall should not be negatively affected;
- Vapour transfer through the wall should avoid condensation layers, and allow the wall to dry correctly.

Besides these standard building construction constraints, the integration of solar systems implies other issues resulting from specific solar technology attributes, i.e., the presence of a hydraulic system (for ST) or electric cabling (for PV) and the high temperatures of some modules. Integrating the new function "solar collection" into the building envelope requires an understanding of where (opaque parts, transparent parts, fixed/mobile elements), how, and which collectors can be made compatible with the other envelope elements, materials and functions.

2.2 Formal Aspects & Aesthetics

All the system characteristics affecting building appearance (i.e., system formal characteristics) should be coherent with the overall building design):

- The position and dimension of collector field(s) have to be coherent with the architectural composition of the whole building (not just within the related façade);
- Collector visible material(s) surface texture(s) and color(s) should be compatible with the other building skin materials, colors and textures they are interacting with;
- Module size and shape have to be compatible with the building composition grid and with the various

dimensions of the other façade elements;

- Jointing types must be carefully considered while choosing the product, as different jointing types underline differently the modular grid of the system in relation to the building.

Clearly, mastering all characteristics of an integrated solar thermal system in both perspectives of energy production and building design is not an easy task for the architect.

The formal characteristics of the system are strongly dependent on the specific solar technology, which imposes the core components of the solar modules, with their specific shapes and materials.

The more flexibility that can be offered within these imposed forms and materials, the more chances for a successful integration.

The actual flexibility of solar modules is presently very different in the two fields of ST and PV, making the integration design work either more or less challenging.

3. Solar Thermal Technologies

Solar thermal energy can be used for different building applications: direct or indirect space heating, Domestic Hot Water production (DHW), and very soon for building cooling. It can be collected in different ways, using different technologies.

- passively, through the transparent parts of the building envelope, storing the gains in the building mass itself. These systems can only be used for space heating.

- actively on surfaces optimized for heat collection (solar absorbers) placed on the outside of the building envelope, and transported by a medium either directly to the place of use or to a storage.

Among active systems, two main families can be identified according to the medium used for the heat transport: air collector’s systems and hydraulic collector’s systems.

- Air systems are characterized by lower costs, but also lower efficiency than hydraulic ones, mainly due to air low thermal capacity. Solar thermal gains are generally used immediately and without storage, for pre-heating the fresh air needed for building ventilation. The heat can also be stored by forcing the air to circulate in a stones bed underneath the ground, or by using the solar air as cold source in a heat pump air/water such applications can be quite expensive, and are therefore rare. Like passive systems, air systems can only be used for space heating and will not be further considered here Figure 2.

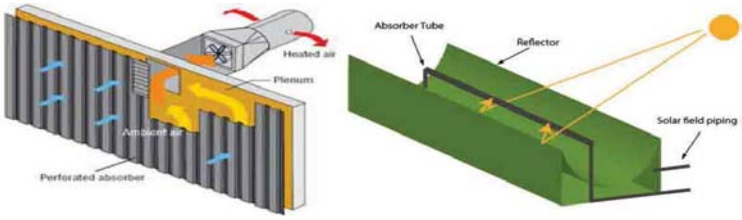


Figure 2. Concentrated Solar Collector System (Left). Air Collector System Working Principle (Right). Based on Animage Made by the US Department of Energy, National Renewable Energy Laboratory

3.1 Glazed Flat Plate Collectors (Figure 3)

They are the most diffused in the EU and typical applications are DHW production and space heating. They usually consist of 10 cm thick rectangular boxes of about 2 m2, containing several layers:

- a metal plate with a selective treatment, working as solar absorber;
- a hydraulic circuit connected to the absorber;
- a back insulation;
- a covering glazing, insulating the absorber by greenhouse effect.

Usual working temperatures are between 50°C and 100°C, but they can rise up to more than 150°C in summer (mid latitude climates). Therefore, measures should be taken to avoid overheating risks which can damage sensible parts (rubber jointing for instance).

Figure 3. Glazed Flat Plate Collectors Applied on a Tilted Roof

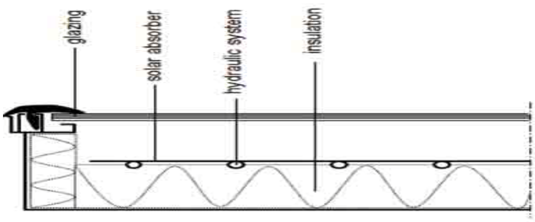


Figure 4. Section of Glazed Flat Plate Collectors

Figure 5. Façade Integration of Glazed Flat Plate Collectors as Façade Cladding, Detail and Picture

3.2 Unglazed Flat Plate Collectors (Figure 6)

They are adequate for swimming pools, low temperature space heating systems and DHW pre-heating. They are composed of a selective metal plate (the absorber) and a hydraulic circuit connected to this absorber. When used for DHW or space heating they also need a back insulation, but differently from glazed collectors, the front part of the absorber is not insulated by a covering glass. Consequently, working temperatures are lower, reaching 50°C-65°C. When used for swimming pool water heating, the back insulation is not needed. For this specific application, polymeric absorbers can also be used to replace the more performing—and more expensive selective metal plates (most often black polymeric pipes systems).

Figure 6. Unglazed Flat Plate Collectors Applied on a Roof

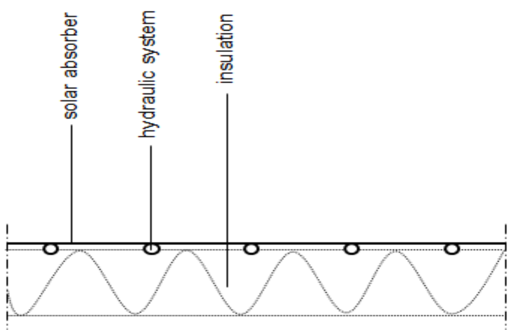


Figure 7. Section of Unglazed Flat Plate Collectors

Figure 8. Roof Integration of Unglazed Flat Plate Collectors Used as Roof Covering

Figure 9. Façade Integration of Unglazed Flat Plate Collectors Used as Façade Cladding

3.3 Evacuated-Tube Collectors (Figure 10)

Evacuated tubes are especially recommended for applications requiring high working temperatures such as industrial applications and solar cooling, but are also used for Domestic Hot Water (DHW) production and space heating, particularly in cold climates. They are composed of several individual glass tubes, each containing an absorber tube or an absorber plate bound to a heat pipe, surrounded by a vacuum. The very high insulation power of the vacuum allows reaching very high temperatures (120°C-180°C) while keeping losses to a minimum even in cold climates.

Figure 10. Vacuum Tubes Collectors Mounted on a Tilted

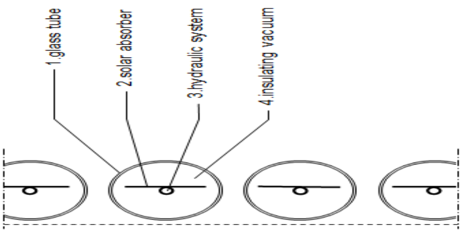


Figure 11. Section of Unglazed Flat Plate Collectors

Figure 12. Evacuated Tubes Collectors Used as Balcony Eaves, Arch. Beat Kaempfen

Figure 13. Used as Deck Sun

3.4 System Sizing and Positioning

Several major factors must be considered when choosing, sizing and positioning a solar thermal system:

· Area availability on the different envelope parts;

· Seasonal solar radiation on these surfaces;

· Desired solar fraction (i.e., the portion of the building's energy covered by the solar system), and available storage possibilities.

As the solar radiation varies with the orientation, systems with lower exposure (Figure at the top) will need a larger collector area than well exposed ones to achieve the same solar fraction. This also holds true for technology efficiency: the higher the collector efficiency the smaller the needed collector area (Figure 14, previous section). Understanding the crossed impact of orientation and technology on system size is fundamental for a proper system choice.

To limit investment costs, solar thermal systems are usually oriented where the yearly solar radiation is maximized (45° tilted, facing south for EU mid latitudes), thus minimizing the needed collector area. This is a valid approach as long as the total energy produced by the system can be used by the building. But because of the summer peak production (Figure 14) this leads to solar fractions up to 50%−60% only, in mid-latitude.

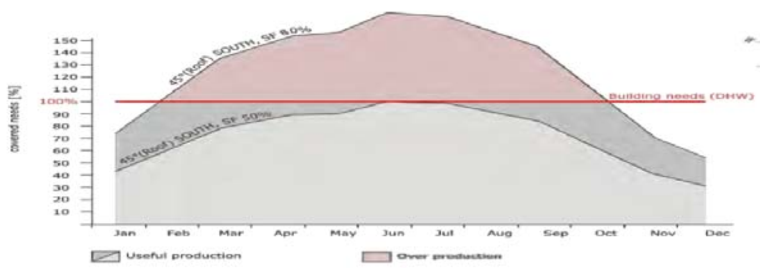


Figure 14. Comparison of the Different Annual Production Profiles of 2 Systems (both South Oriented, 45° Tilted—Midlatitudes, North Hemisphere) Covering Respectively 50% and 80% of DHW needs. No Overproduction Occurs Insummer in the Smaller System (50% of DHW) so that all the Produced Energy is Used. The Second System is Dimensioned to Cover 80% of the Annual Needs, but This Implies an Important Overproduction in Summer (Red Area)

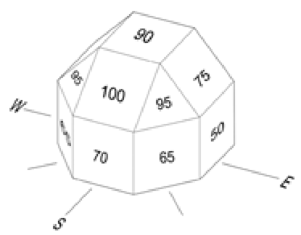


Figure 15. Yearly Solar Radiation in Relation to Orientation and Surface Inclination (Mid Latitudes, Northern Hemisphere)

This limitation is specific to solar thermal and is due to heat transportation and storage issues. Whereas the electricity produced by PV can be injected for storage in the electricity grid and transported with negligible losses, the heat produced by ST is subject to transport losses, and heating grids are very rare. Then, unless a district heating grid is available, or a big seasonal storage for a cluster of buildings can be considered 2, the heat produced by the system has to be stored within the limited volume of the storage tank, in the building itself. The useful solar heat is then only the part that can be directly used or stored.

3.5 Methods Used in Comparison between Available Systems

In comparison to a similar investigation of solar systems carried out five years ago it is remarkable that the solar systems technology has moved towards a higher level of integration the results of all the types above were compared and test through these methods:

3.5.1 Thermal Performance

For the assessment of the thermal performance, the fractional energy savings, the system efficiency, the usable hot water volume, and for comb systems additionally the space heating buffer volume, are taken into consideration.

The assessment concept was intentionally designed in a way that the typical design parameters such as collector area, store volume, usable hot water volume and, if existing, the space heating buffer volume did not affect the results as long as they are varied within sensible limits. Due to this approach the thermal performance of the system is primarily affected by the performance of the different components and their interaction within the complete system.

3.5.2 Behavior during Operation, Durability and Reliability

The behavior of the whole thermal solar system or its subsystems, respectively, was observed during different operating conditions In order to assess the durability and reliability, the quality and the suitability of the materials used as well as the way how they were processed was considered. Additionally the period of warranty for the most important components (collector, store and controller) was assessed.

3.5.3 Environmental Aspects

The energy payback time was determined and the used materials as well as the packaging and environmental aspects were assessed.

3.5.4 Safety Aspects

The most important components as well as the whole system was investigated with respect to electrical safety and the risk of injury due to sharp edges, burning and scald. The documentation was checked with regard to notes dealing with safety aspects during the installation of the system. For systems with an integrated gas burner safety aspects related to gas and fire were considered additionally.

3.5.5 Handling

The way how the system has to be mounted, maintained and operated was assessed. Criteria of this assessment were, e.g., the time required for the system installation as well as ergonomic aspects. Additionally it was examined if the corresponding work steps were described understandably, detailed and correctly in the documentation supplied with the system.

3.6 Comparisons between Systems

Table 1. Characteristics of Different Solar Systems with Energy Production Integration Possibilities and General Pricing

	Glazed Flat Plates	Unglazed Flat Plates	Evacuated Tubes
Working temperatures	50-100°C	25-50°C	120°C
Main applications	DHW, space heating	Swimming pools, space heating, DHW pre-heating	DHW, space heating, solar cooling, industry
Energy production (Switzerland, 6m^2 field)	400-600 kwh/m^2	300-350 kwh/m^2	480-650kwh/m^2
Average cost (Switzerland. 2010, 6 m^2 filed)	370/m^2 ($^($Price variation 320-480/m$^{2)}$)	220/m^2 (Price variation 200-260/m^2)	800/m^2 (Price variation 500-1100/m^2)

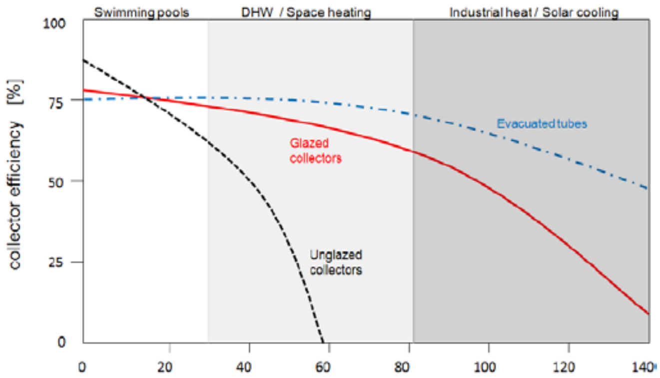


Figure 16. Comparison of the Different Solar Thermal Technologies Relevant for DHW and Space Heating Production in Relation to Their Efficiency, Cost, Specific Working Temperatures, Suitable Applications

4. Case Studies Unglazed Flat Plate Collectors

Figure 17. The Facads of the CeRN Building Shading

Note. CeRN buildings, Bursins, Switzerland, 2004-2007, arch. Niv-0, Lausanne Building facts. Climate type: continental; Building size: 8’600 m²/46’800 m³; Energetic standard: Minergie Eco label; Application: Unglazed metal collectors used as multifunctional façade; Claddings on the south façade. Non exposed façades are covered by nonnative elements having the same appearance.

The south-facing facade of the building is covered with thermal solar collectors. The vertical position of the collectors provides a good compromise between solar gains and architectural integration. The result gives an optimum yield during the cooler months of the year when heating is required. The collectors produce maximum energy in the winter season, which is used to heat the floor of the building. During summer the system still produces enough energy for the hot water needs of the building. By using the facade element, the building owner openly demonstrates their commitment to solar heating and renewable energy.

The solar collectors operate as both solar radiation absorbers and as a multifunctional facade-cladding material. They are not just an additional element on the building. The collectors help to meet the economic and sustainability criteria of the project. The solar facade is made-up of stainless steel absorbers. The absorbers contain heat exchangers through which the heat transfer fluid circulates. Its degree of efficiency, allowing great flexibility in building integration. Inclined planes with slight slopes, curved roofs or vertical solar walls on facades are all possible.

Tests and experience have shown that the absorber concept is outstandingly efficient at relatively low temperatures or in mild climates. Under these conditions, the installations give results equal or even superior to those of glazed collectors. Unlike glazed solar collectors, they do not overheat.

The north facade has been completed with stainless steel elements of the same geometry. The elements have the same appearance as those on the south side, but they are made from a single sheet of stainless steel and are not thermally active.

Figure 18. The Stainless Steel Elements are Visible below the Windows of the Upper Floor

Figure 19. Partial View of a Non-Active Façade

The solar collectors are multifunctional. They gain energy from solar radiation as well as forming an excellent corrosion-resistant building element. The collectors withstand the impact of aggressive climates without sustaining any damage and they are fully recyclable. Panels are modular in length, so they fit the modular demands of the building. The panels weigh about 10kg/m2, an important consideration for easy assembly.

Figure 20. Details of the Interconnection of the Stainless Steel Collectors and Connection to the Upper Tube for the Heat Transfer Fluid

Figure 21. Materials Used in the Construction of the Building Have Been Selected According to the Criteria of Ecology, Low Energy Content and Economy

The main materials used in the building are:

• Timber for the load-bearing structure;

• Concrete recycled from demolition material;

• Stainless steel for the facades and solar energy gains;

• Timber and metal for the window frames.

The selection of materials is a major component of the sustainable architectural design. It also influences the form and arrangement of the buildings. A green roof adds to their eco-friendly profile. The water supply comes from two sources. Valuable and expensive drinking water is used only for the kitchen, showers and bathrooms. Grey water (used to clean vehicles, irrigate the site and for lavatory flushing) is pumped from nearby Lake Geneva. A system to pump water from the lake is already used to irrigate the neighboring vineyards. Sealed surfaces are reduced to a minimum, allowing rainwater to seep away into the ground.

A combined heating system is used for low-temperature floor heating and hot water production. The solar facade, with an area of 590 m^2 facing south-east, provides about 40% of the annual heat requirements. The rest is provided through a 240kw woodchip boiler which burns waste wood from highway maintenance. The heat protection incorporated into the building means that annual heat requirements are only 30 kWh/m^2.

The use of a domed roof-light and windows enable the use of daylight and natural ventilation in the offices and garages. This contributes further to the operation of the building in an energy-conscious way. Around 97% of the energy consumed in the building is either gained or produced on site. A 190 m2 photovoltaic array provides electricity that is used in the building.

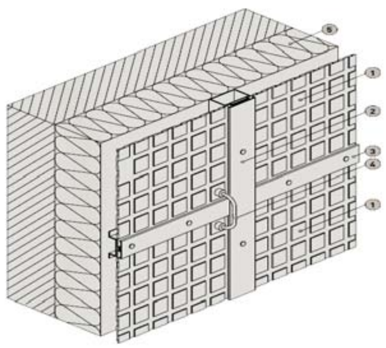


Figure 22. Detailed View of Joint of Four Solar Collectors

Note. 1 Stainless steel solar collector;

2 Vertical aluminum profile;

3 Horizontal aluminum profiles;

4 Tube connection between lower and upper collector;

5 Heat insulation.

Collector panels are fixed using aluminum profiles with EPDM1 joints. The profiles are used to fix conventional metal cladding. Once mounted, the facade is watertight and durable.

Energy Data			
Heat protection office section			
Facades			U = 0.3 W/(m²K)
Roof			U = 0.11 W/(m²K)
Energy demand			
Floor heating office	24.1 kWh/(m²a)	67.0%	150,600 kWh/a
Hot water	5.45 kWh/(m²a)	15.6%	35,000 kWh/a
Electricity	6.28 kWh/(m²a)	17.4%	39,100 kWh/a
Total office section	35.8 kWh/(m²a)	100.0%	224,700 kWh/a
Total garages included			448,000 kWh/a
Energy production in place			
Photovoltaic array	191 m²		23,875 kWh_{el}/a
Thermal solar collectors	576 m²		288,000 kWh_{th}/a
Waste wood			120,000 kWh_{th}/a
Total production in place			431,875 kWh/a
External energy			
Floor heating and hot water			0 kWh/a
Electricity			16,000 kWh/a

Figure 23. Energy Data for the CeRN Building

4.1 Evacuated Tubes Collectors Case Study Sunny Wood, Multiple Family House, Zurich 2002, Arch Beat Kämpfen

Figure 24. Elevations of the Sunny Wood House Building

Note. Project information.

The project is based on passive solar design combined with the following technical features:—Highly insulated, airtight building envelope:

- Minimized thermal bridges;
- Energy efficient windows;
- Efficient ventilation with heat recovery and ground preheating;
- PV-roof, grid connected thin film solar cells;
- Vacuum collectors for DHW and heating;
- Efficient appliances;

Total heated area: 1,387 m^2.

4.1.1 Solar Thermal System: Evacuated Tubes

6m^2 vacuum collectors serve as the balcony railing, the storage tank contains 1400,l (combined domestic hot water and space heating).

Heating:

Heat is distributed by the fresh air supply, heated with a water-air heat exchanger supplied by the solar collectors or heat pump. There are radiators in the bathrooms.

4.1.2 Solar Collector Type

Vacuum collectors: B. Schweizer Energie AG, Chnübrächi 36, CH-8197 Rafz ECONOMY everything considered, the pure construction costs exceeded the costs of a conventional building by around 5%. The energy consumption is only 10% of the consumption of a traditional building. The remaining demand will be provided by the building itself.

4.1.3 Energy Performance

Space and ventilation heating 14.7kWh/m^{2}a;

Energy source: solar thermal system, electricity-calculated-Domestic hot water 8.4 kWh/m^{2}a;

Energy source: solar thermal system, electricity;

5. Photovoltaic Technologies

Photovoltaics (PV) is a way of generating electrical power by converting solar radiation into Direct Current (DC) electricity through the use of semiconductor technologies through the photovoltaic effect. Materials presently used for Photovoltaics, discussed thoroughly in the following sections, include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide/sulphide. All these technologies differ both in terms of employed material and structure and they consequently influence the efficiency of the energy conversion. The cell types can be grouped in three categories: the traditional crystalline silicon cells (wafer based), the thin-film cell (made from different semiconductors materials) and the nanotechnology based solar cells. This third group is now appearing in the market. PV cells must be interconnected to form a PV module. PV modules combined with a set of additional application-dependent system components (e.g., inverters, batteries, electrical components, and mounting systems), form a PV system.

5.1 Available Technologies

- Wafer based crystalline silicon cells: Monocrystalline cells (sc-Si), Multicrystalline cells (mc-Si) Solar cells made from crystalline silicon continue to account for about 85% of the cells used worldwide. Crystalline silicon cells (C-Si) are subdivided in two main categories: single crystalline (sc-Si) multi-crystalline (mc-Si).

Crystalline silicon cells are typically produced in a complex manufacturing process. In the following sections/paragraphs a strong simplification in describing the production process will be made, to make clear what the main features of this technology are. Monocrystalline cells are produced from silicon wafers; these wafers are extracted from a square block of single crystal silicon, by cutting slices of approximately 0.2 mm thick. This produces square cells of 100 to 150 mm sides with a homogeneous structure and a dark blue/blackish color appearance.

For multicrystalline cells, the melted silicon is cast into square ingots where it solidifies into a multitude of crystals with different orientations (frost-like structure), which gives the cells their spotted and shiny surface (Figure 25).

Figure 25. Mono and Poly Crystalline Silicon Cells

To collect the electricity, very thin silver contacts are applied on the front of the cells, while a back contact is applied at the rear. Finally, an anti-reflection coating is applied to enhance the light capture properties (Figure 26).

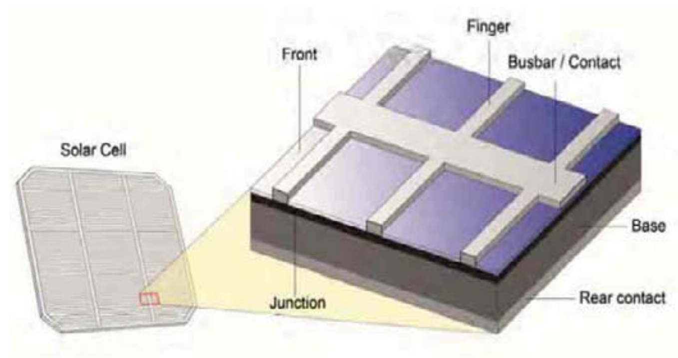


Figure 26. Crystalline Cell Structure

The efficiency of monocrystalline cells is currently the highest available on the market, ranging approximately from 17% to 22%, while multicrystalline cells are around 11% to 17%. To become a usable product, crystalline cells are electrically wired together and encapsulated into a substrate and a front covering material to create a solar module. The module can be provided with a frame, in order to improve its mechanical resistance. If it is kept unframed, the module is also called a “solar laminate” (Figure 27).

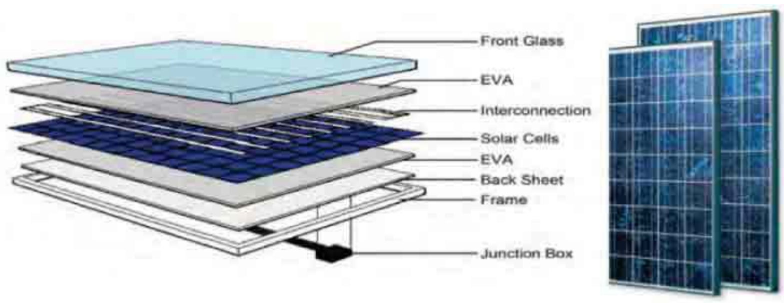


Figure 27. Left: Module Structure for Crystalline Cells, Right: Polycrystalline

5.2 Emerging Pv Technologies (Third Generation)

The category "Emerging" is used for those technologies which have passed the "proof-of concept" phase, or could be considered as mid-term options compared with the two main established solar cell technologies (crystalline Si and thin-film solar cells). The category "Novel" will be used for developments and ideas which can lead to potentially disruptive technologies, but where there is not yet clarity on practically achievable conversion efficiencies or structure cost. Sometimes they are called also "third generation" (cells Figure 28).

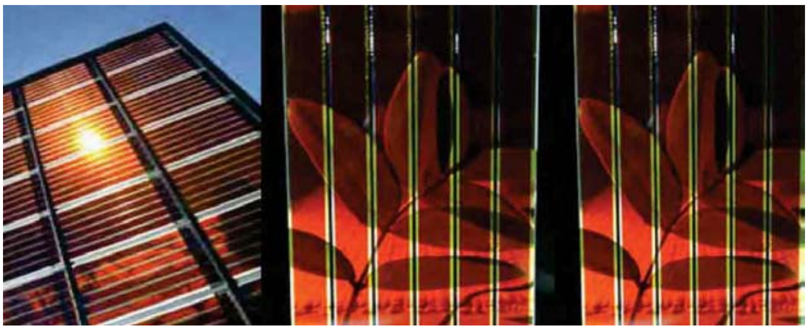


Figure 28. Dye-Sensitized Solar Cell and Module Modules

Novel PV-technologies are characterized as high-efficiency approaches. Within this category, a distinction is made between approaches that tailor the properties of the active layer to match better the solar spectrum, and approaches that modify the incoming solar spectrum and function at the periphery of the active device, without fundamentally modifying the active layer properties.

PV System

As the voltage and power of individual solar cells is inadequate for most applications, they are connected in series. As a consequence, the individual voltages of each cell are added together. The result is the formation of a PV module, the main element of a PV system.

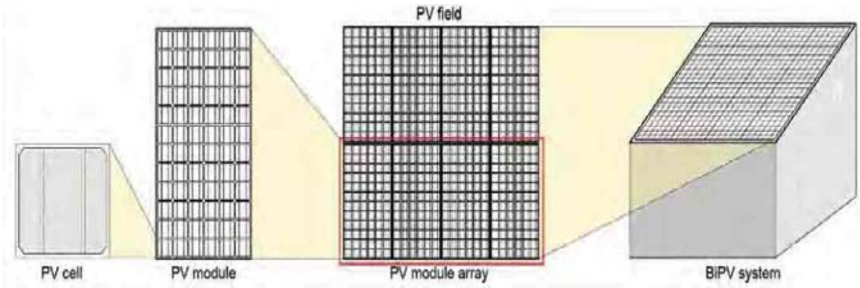


Figure 29. From the Solar Cell to the BiPV System

The energy output from a single PV module is typically in the range of 180-250 Watts (also if small modules are available) in bright sunshine. A photovoltaic system is normally built up from a number of panels (an array), linked together to produce a more significant energy output. Before starting the discussion on the infrastructure and the components needed in order to use the produced electricity, we have to distinguish between stand alone and grid-connected systems.

5.3 Integration Possibilities—Roofs

Figure 30. Crystalline Roof Systems: Solar Tile from © Ideassolar, Solar Slate from © Megaslate

Tilted Roof: Building added PV systems have been very common on tilted roofs, especially in case of integration into existing buildings. Using this solution, there is a need for an additional mounting system and in most cases the reinforcement of the roof structure due to the additional loads.

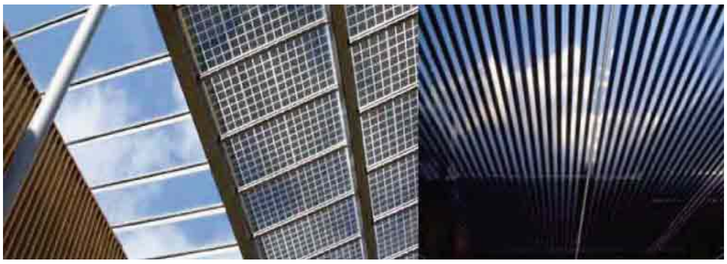
The system mentioned above have been highly criticized for its aesthetics that urged the market to provide building integrated products replacing all types of traditional roof claddings. There are products both with crystalline and thin film technologies for roof tiles, shingles and slates that formally match with common roof products (Figure 30). Several metal roof system manufacturers (standing seam, click-roll-cap, corrugated sheets) developed their own PV products with the integration of thin film solar laminates (Figure 31). Moreover, there are also prefabricated roofing systems (insulated panels) with integrated thin film laminates available.

Depending on the insulating features, these PV "sandwiches" can be suitable for any kind of building (i.e., industrial or residential). It is somewhat surprising that many so called "first generation" BIPV products (i.e., roof tiles) proved to be unsustainable due to many reasons (especially cost-effectiveness).

Figure 31. Crystalline Modules for Flat Roof. On the Left: Standard Module on Rack Mounting System, from © Prosolar on the Right: Special Rack System for Flexible Laminate on Stainless Steel Substrate

Flat Roof: We can distinguish among PV systems with different tilt angles and PV systems on the same plane of the roof. The most common are added systems with rack supporting standard glass-Tedlar modules or to use specific tilted rack system for thin film (Figure 32).

Figure 32. Integration of Thin Film Laminates on Flexible Substrate in Flat Roof. On the Left: Powerply Monocrystalline Module with Plastic Substrate



Figrue 33. Semi-Transparent Sky Lights. Community Center Ludesch, Austria, Herman Kaufmann: Semitransparent Modules with Crystalline Cells

The PV system can also become the complete roof covering, fulfilling all its functions. Most commonly semi-transparent crystalline or translucent thin film panels are used in skylights. These solutions provide controlled day lighting for the interior, while simultaneously generating electricity. In the selection of the product it is important to consider the thermal (such as U-value and g-value) and day lighting features. Semi-transparent crystalline modules are sometimes custom-made. In this case it could happen that the architect has no technical information and data about the performance of the component from the manufacturer. A simulation or a special test or measurement should then be asked for. Standard translucent thin film modules, however, have more detailed datasheets with this information (Figure 34).

A PV component can substitute the external layer of the facade (i.e., PV as a cladding of a cold facade), or it can substitute the whole façade system (i.e., curtain walls—opaque or translucent) Depending on the layer(s) the PV component substitutes, it has to meet different requirements that influence the choice of the most suitable PV component. In the following, a general overview of the way PV can be used in facades is presented (Figure 34).

Figure 34. Semi-Transparent Sky Lights. Ospedale Meyer, Florence

Figure 35. On the Left Facade Cladding Solutions, on the Right Detail of Ventilation Principle

Photovoltaic modules can be used in all types of façade structures. In opaque cold facades, the PV panel is used as a cladding element, mounted on an insulated load-bearing wall. In this case, the PV is usually back ventilated, to avoid lowering the efficiency of the cells. As the cooling air is heated by the panels, some systems make use of it for building heating (PVT).

Several fastening systems have been developed for façade cladding, both with framed panels and laminates (unframed modules) and for all PV technologies (Figures 36, 37, 38).

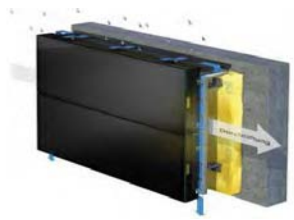


Figure 36. On the Left Facade Cladding Detail of Ventilation Principle

Figure 37. Green Pix Media Wall, Beijing, China, and the upper Figure is Zara Fashion Store

Figure 38. Frameless Modules with Spider Glazing System

Photovoltaic modules can be used as shading devices. Quite common these are semi-transparent glass-glass components integrated as canopies or louvers, but there are also movable shutters with semi-transparent crystalline or thin film (Figures 39, 40, 41).

Figure 39. Spandrels and Parapet Solutions

Figure 40. SBL Offices Linz, Austria, Helmut Schimek, Shading Louvres with Integrated Photovoltaics and Sun Tracking Dystem

Figure 41. Solar Shading Solution, Colt Ellisse PV Sliding Shades at Company HQ, Bitterfeld-Wolfen, Germany, © Colt, Right: Keuringsdienst, Eindhoven

6. Photovoltaics Vs Solar Thermal

The ever increasing interest for renewable energies results in a constantly growing market demand for active solar systems, both for electricity (photovoltaics) and for heat production (solar thermal). This trend, added to the new promotion policies recently set up by the EU, let foresee an increased interest for all the sun exposed building surfaces, resulting in a new debate on how to optimize their use for the production of solar electricity and/or solar heat.

Although similarities in the integration on the building envelope of solar thermal and photovoltaic systems do exist, there are also major differences that need to be considered. Both technologies deal with the same building skin frame, and have similar surfaces and orientations needs. On the other hand, they have different intrinsic formal characteristics, different energy transportation and storage issues, different insulation needs, shadow influence, etc.

The impact these technology peculiarities have on the building implementation possibilities are described here to support making the best use of the available exposed building surfaces.

6.1 Significant Collectors Formal Characteristics

Both fields of solar thermal and PV count several technologies interesting for building integration: monocrystalline, polycrystalline and thin films in the field of PV; glazed flat plates, unglazed flat plates and vacuum tubes collectors in the field of solar thermal. Unless differently specified, the following considerations refer to the most diffused ones in EU, i.e., crystalline-mono and poly-cells for PV and glazed flat plate collectors for solar thermal. To keep the message clear and short, distinctions will be made only when considered important.

Shape, Size, Flexibility

The basics shape, size and dimensional flexibility of the PV modules are fundamentally different from the ones of thermal collectors. The size and shape of PV modules are very flexible since they result mainly from the juxtaposition of single squared silicon cells (mono or polycrystalline) of approximately 12 to 15cm side. Modules can come in the size of less than 0.1m2 (few cells) up to 2m^2 (more than 60 cells). Thanks to the flexibility of the internal connections and the small cells' size, made to measure module can be provided in almost any shape (at a higher price in this case). Moreover, the possibility of partial transparency is offered through glass-glass modules. Thin films modules can also offer a new level of freedom when using flexible metal or plastic sheets. Solar thermal collectors are much bigger (1.5 to 3m^2) and their shape definitely less flexible. This derives mainly from the need of a non-flexible hydraulic circuit fixed to the solar absorber to collect the heat: the freedom in module shape and size would require reconsidering every time the hydraulic system pattern, which is generally difficult and expensive. The lack of market demand for architectural integration is also a cause of this poor offer up to recently. The case of evacuated tubes is different: the panel size and shape result from the addition of evacuated tubes: length from 1 to 2m, diameter from 6 to 10cm. In most cases though, only standard modules are available (Figure 42).

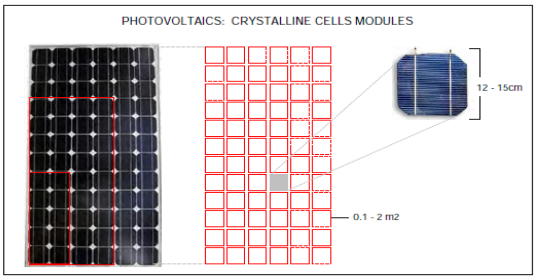


Figure 42. Shape and Size Flexibility of Crystalline Photovoltaic Modules

6.2 Module Structure, Thickness, Weight

The thickness and weight of PV and solar thermal modules are also totally different. PV modules are thin (0.4 to 1cm) and relatively light (9-18kg/m2), while solar thermal ones are much thicker (4 to 10 cm) and heavier (around 20 kg/m2). PV mainly consists in thin laminated modules encapsulating the very thin silicon cells layer between an extra white glass sheet (on top) and a composite material (Tedlar/Mylar) or a second sheet of glass.

Solar thermal collectors are composed by multiple layers in a sandwich structure: glass sheet/air cavity/metal absorber/hydraulic system/insulation. Evacuated tubes have a different structure: an absorber core protected and insulated by a glass tube. Impact on building integration (Figures 41, 42).

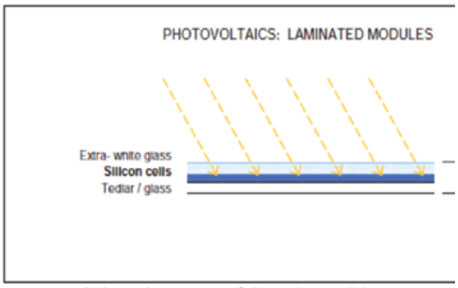


Figure 43. Low Thickness Characterizing of Photovoltaic Modules

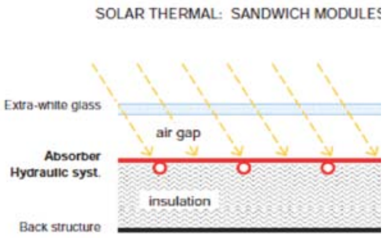


Figure 44. Thickness Standard Glazed Flat Plate Collectors

6.3 The Visible Materials, Surface Textures, Colors

The glass surface can be smooth, textured or acid etched, but always let's see the internal layer: the silicon cells in PV, the metal absorber in solar thermal.

The structure, the geometry and the appearance of these layers are very different: the metal absorber of solar thermal collectors is generally continuous and covers the whole module area, while for PV the cells can be arranged in different patterns, also playing with their spacing.

PV crystalline cells have a flat surface, mainly blue or black, with a squarish shape Figure 45. The absorbers of thermal collectors are characterized by a more or less corrugated metallic surface, coated in black or dark blue. Evacuated tubes are different, as described in the previous chapter.

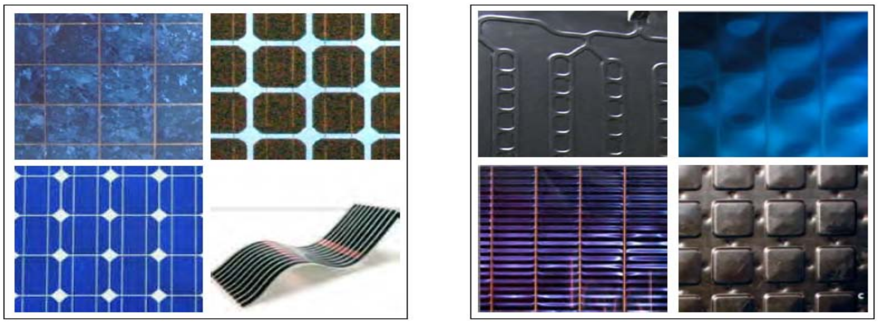


Figure 45. Visible Surface Colours and Textures of PV Modules (Left) and ST Collectors (Right)

6.4 Energy Transport and Storage

As PV modules produce electricity and solar thermal produces heat, they have to deal with different energy transportation, storage and safety issues. 4.4.1 Energy medium and transport Electricity can be transported easily and with very small losses through thin (0.8-1.5cm diameter), flexible electric cabling. It can then be easily transported over long distances, so that the energy production doesn't need to be close to the consumption place.

Heat is transported by water (charged with glycol to avoid winter freezing) through the rigid piping of the hydraulic system. Heat transportation is very sensitive to losses, meaning on one hand that the piping system has to be very well insulated (resulting diameter: 3 to 8cm), on the other hand that the heat should be used near the production place.

Energy storage

Because of the different ways these energies can be transported, their storage issues are radically different, affecting strongly the implementation possibilities. The electricity produced by the PV modules can be injected practically without limits into the grid. As a result, the sizing of the system is totally independent from the local consumption and the energy produced can exceed by far the building electricity needs. On the contrary, the heat produced by thermal collectors has to be stored close to the consumption place, usually in the building storage tank. In practice, the storage capacity of the water tank is limited, usually offering no more than a few days' autonomy. Furthermore, solar thermal collectors are sensitive to damages resulting from overheating, so that ideally the heat production should not exceed the storage capacity.

6.5 Operating Constraints, Temperatures and Related Insulation Needs

Suitable operating temperatures are again different between the two technologies: for PV, especially for crystalline cells, the lower the operating temperature, the better; for solar thermal, the higher the better (still avoiding overheating) Impact on building integration. This difference affects once more the integration possibilities in the building envelope: PV modules should be back ventilated for a higher efficiency; solar thermal absorbers require back insulation to minimize heat losses. Integrating the collectors directly in the building envelope layers, possibly without air gap, is ideal in this sense for solar thermal, while freestanding or ventilated applications would be preferable for PV.

6.5.1 Shadows

Impact on building integration for solar thermal, the heat losses resulting from partial shadowing are just proportional to the shadow size and don't cause any particular production or safety problem. Photovoltaics on the other hand can be very sensitive to partial shadowing: the electricity production may be greatly affected by partial shadows if special care is not given to the modules placement and string cabling. The energy losses are generally higher than the shadow ratio, with possible risks of modules damage if its impact is not well considered during the system design phase.

6.5.2 Conclusions

As shown above, there are clear differences in the characteristics of solar thermal and photovoltaics systems, leading to different approaches when integrating them in the building envelope. A synthetic overview is presented in the table below (Figure 46).

Figure 46. Different Usages of the Technologies in Buildings

		PHOTOVOLTAICS *	SOLAR THERMAL**
FORMAL CHARACTERISTICS	MODULE SIZE	0.1 to 2m^2	1.5 to 3m^2
	SHAPE / SIZE FLEXIBILITY	High flexibility	Low flexibility
	THICKNESS	0.4 cm to 1 cm	4 to 10 cm
	WEIGHT	9-18 kg/m^2	20kg/m^2
	MODULE STRUCTURE	laminated modules	sandwich modules
	MATERIALS	Glass / silicon cells / Tedlar -Mylar or glass	Glass / air / metal absorber / hydr.system / insulation
	SURFACE TEXTURES	External glass: smooth / acid etched / structured. Silicon cells: variable patterns, possible transparency	External glass: smooth / acid etched / structured. Absorber: slightly corrugated, opaque metal sheet
	COLOURS	Black / blue mainly.	Black / dark blue mainly
TECH. CHARACTERISTICS	ENERGY MEDIUM	Electricity	Hot water
	ENERGY TRANSPORT	Flexible cabling (0.8-1.5 cm diameter). Low energy losses.	Rigid insulated piping system (3-8 cm diameter). High energy losses.
	ENERGY STORAGE	Presently unlimited, into the grid	Limited to building needs / storage capacity of the building tank.
	WORKING TEMP.	The lower the better (back VENTILATION required)	The higher the better (back INSULATION required)
	SHADOWS IMPACT	Reduction in performances higher than shadow ratio; risks of permanent damage to the panel.	Reduction of performances proportional to shadow size, no damage to the panel.
	ENERGY PRODUCTION	80- 120 kWh/m^2 per year	450-650 kWh/m^2 per year
	COST (CH – 2009)	300.- to 450.- €/m^2	300.- to 450.- €/m^2

Figure 47. Formal and Technical Characteristics of Photovoltaics and Solar Thermal

Note. Please remember that the two technologies are not interchangeable, hence are not competing against each other: both are equally needed as they cover different building needs.

It is important to underline one major outcome that concerns the positioning options induced by the different storage constraints: As there are presently no limitations in the storage of the energy produced by PV, its annual energy production should be optimized by locating and orienting the PV where its sun exposure is maximized (tilted or flat roofs mounting in most cases). This brings one interesting option for solar thermal integration. In EU mid latitudes, where the solar radiation varies dramatically during the year, the maximum summer production can be twice the winter one. To avoid summer overheating, tilted solar thermal systems are usually undersized (solar fractions around 50%). A good way to increase the whole year solar fraction while limiting overheating risks is to mount the collectors vertically, using the facade areas. The heat production would then be almost constant during the year, making it possible to dimension the system according to the real needs. This allows solar fraction of up to 90%, while opening the way to building facades use.

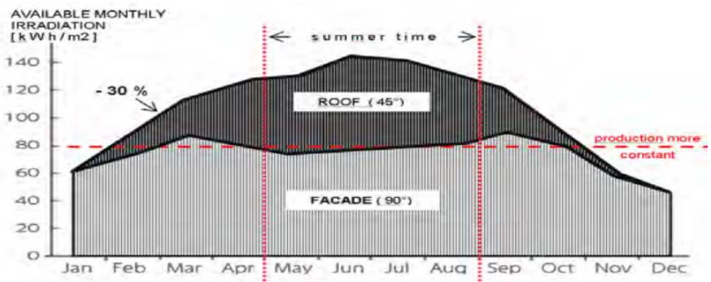


Figure 48. Comparison of the Monthly Sun Radiation Available on a 45° South Oriented Tilted Surface vs. a Vertical South Oriented Surface in Graz, Austria (47° Latitude). Data from W.Weiss

However, if for photovoltaics there is a large offer of products suitable/conceived for building integration, exploiting the flexibility of the technology, the situation is different for solar thermal. The big size of most collectors now available, their lack of dimensional flexibility as well as the dark irregular appearance of their absorber makes it difficult to integrate solar thermal, particularly on facades. This is an issue that should be solved urgently, especially in the light of the previous considerations: New solar thermal products conceived for building integration should be developed, matching the offer available in the PV field, to help answer to the booming demand for architectural integration of solar in buildings. This is even more important considering the high efficiency and cost effectiveness of this technology.

7. Discussion

Solar technology made one more step towards professionalism. Most of the investigated products convinced due to good quality and performance. And between the variety of systems, in the case studies provided it shows the improvements and many integration methods and possibilities. Statistics indicate that the production, conversion and consumption of different types of energy are the main factors for destruction and pollution of the environment among the man-made factors.

However, not only the world's energy consumption will remain constant, but forecasts indicate that consumption will continue growing due to increasing population, the desire for prosperity and increasing per capita GDP (Gross Domestic Product) in the world. (The World Bank) Consequences of energy consumption are increasing the amount of carbon dioxide emissions and also SOX and NOX emissions. Studies show that there are two main solutions to mitigate this issue:

- Increasing energy efficiency;
- Increase the share of renewable energy in the global energy mix.

8. Conclusion:

As seen in the previous chapters, good knowledge in three key topics is needed to properly integrate photovoltaics and solar thermal systems into architecture:

- Knowing the different energetic specifications of solar thermal and photovoltaic technologies;
- Understanding the respective system dimensioning principles, with their cross dependences from technology, orientation, building needs and storage possibilities;
- Knowing the formal properties of existing products, with their features and limitations, to best use their characteristics in a project.

Upcoming improvements in both the dimensioning and the products integrality domains should help more and more professionals access this knowledge: On one hand, new smart software tools for architects simplify the study of solar systems variants in the early design stage of projects, when a smooth integration process is easiest as freedom is maximized.

On the other hand, thanks to the growing interest of architects for solar use, manufacturers are becoming much more aware of the need for new products specially adapted to architectural integration, or at least for an increased flexibility in their existing products, leading to novel development activities also in the less developed field of solar thermal integration.

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