Chapter 10

Hybrid Power Systems

10.1 Introduction

Electrical energy requirements for many remote applications are too large to allow the cost-effective use of stand-alone or autonomous PV systems. In these cases, it may prove more feasible to combine several different types of power sources to form what is known as a "hybrid" system. To date, PV has been effectively combined with other types of power generators such as wind, hydro, thermoelectric, petroleum-fueled and even hydrogen. The selection process for hybrid power source types at a given site can include a combination of many factors including site topography, seasonal availability of energy sources, cost of source implementation, cost of energy storage and delivery, total site energy requirements, etc.

10.2 Petroleum-fueled engine generators (Gensets)

Petroleum-fueled gensets (operating continuously in many cases) are presently the most common method of supplying power at sites remote from the utility grid such as villages, lodges, resorts, cottages and a variety of industrial sites including telecommunications, mining and logging camps, and military and other government-operated locations.

Although gensets are relatively inexpensive in initial cost, they are not inexpensive to operate. Costs for fuel and maintenance can increase exponentially when these needs must be met in a remote location. Environmental factors such as noise, carbon oxide emissions, transport and storage of fuel must also be considered.

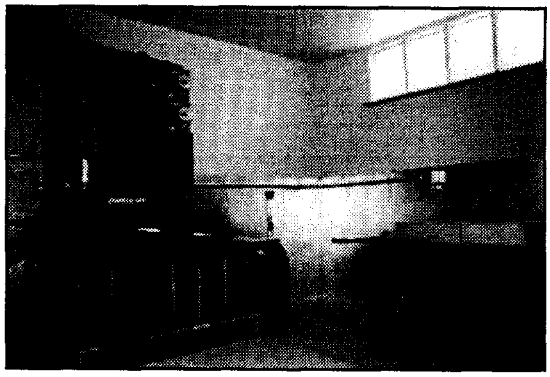


Figure 10.1 Hybrid PV/Generator System Example; Courtesy Photron Canada Inc., Location: Sheep Mountain Interpretive Centre, Parks Canada Kluone National Park, Yukon Territories, Canada, 63° North Latitude; Components shown include: generator (120/240 V), battery (deep cycle industrial rated @ ± 10 kWh capacity), DC to AC stand-alone inverter (2500 W @ 120 V output), miscellaneous safety + control equipment including PV array disconnect, PV control/regulator, automatic generator start/-stop control, DC/AC system metering etc.; -Components not shown: PV array (800 W peak).

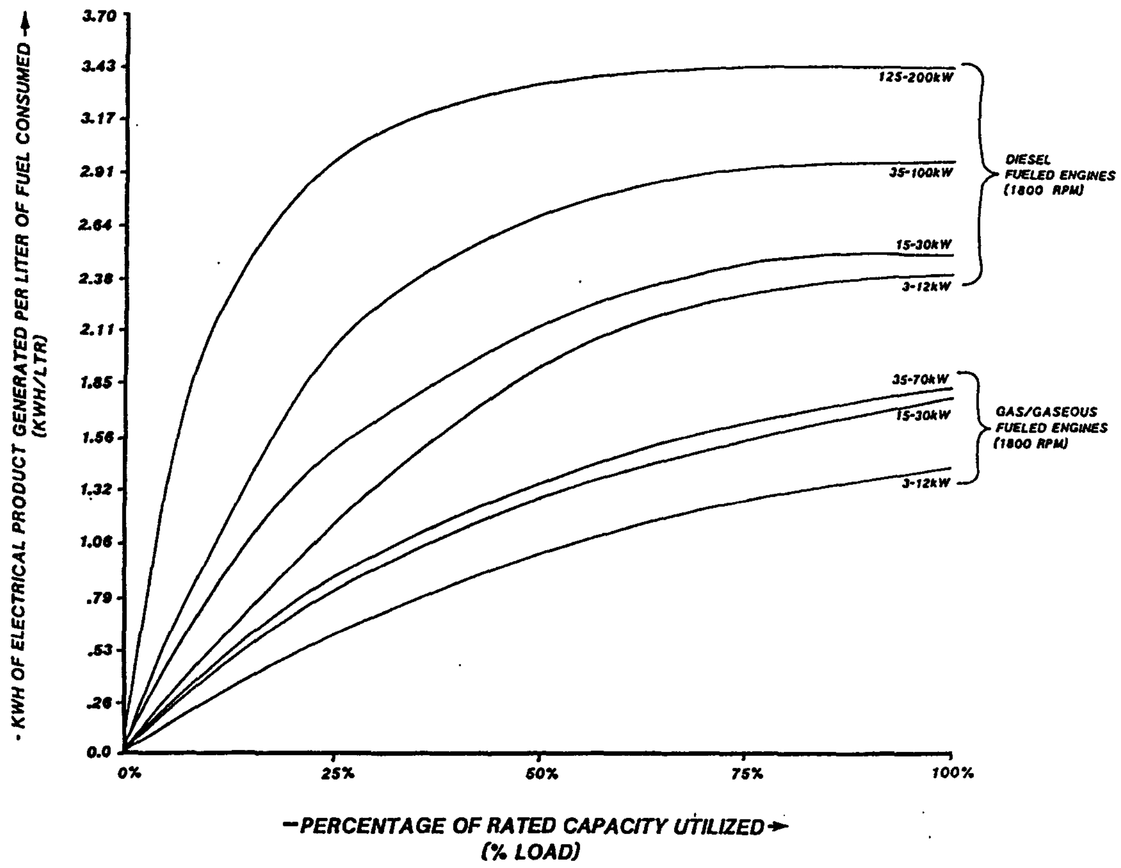


Figure 10.2 Genset fuel efficiency vs. capacity utilized.

Fuel to power conversion efficiencies may be as high as 25% (for a diesel fueled unit operating at rated capacity). Under part load conditions, however, efficiencies may decline to a few percent. Considerable waste heat is therefore available and may be utilized for other requirements such as space and/or water heating.

10.3 Why a PV/genset hybrid?

PV and genset systems do not have much in common. It is precisely for this reason that they can be mated to form a hybrid system that goes far in overcoming the drawbacks to each technology. Table 10.1 lists the respective advantages and disadvantages.

As the sun is a variable energy source, PV system designs are increased in size (and therefore cost) to allow for a degree of system autonomy. Autonomy is required to allow for provision of reliable power during "worst case" situations, which are usually periods of adverse weather, seasonally low solar insolation values or an unpredicted increased demand for power. The addition of autonomy to the system is accomplished by increasing the size of the PV array and its requisite energy storage system (the battery).

When a genset is added, additional battery charging and direct AC load supply capabilities are provided. The need to build in system autonomy is therefore greatly reduced. When energy demands cannot be met by the PV portion of the system for any reason, the genset is brought on line to provide the required backup power. Substantial cost savings can be achieved and overall system reliability is enhanced.

PV/genset hybrid systems have been utilized at sites with daily energy requirements ranging from as low as 1 kWh per day to as high as 1 MWh per day, which illustrates their extreme flexibility. They are a proven and reliable method for efficient and cost-effective power supply at remote sites.

10.4 PV/genset hybrid system description

The PV/genset hybrid utilizes two diverse energy sources to power a site's loads. The PV array is employed to generate DC energy that is consumed by any existing DC loads, with the balance (if any) being used to charge the system's DC energy storage battery. The PV array is automatically on line and feeding power into the system whenever solar insolation is available and continues to produce system power during daylight hours until its rate of production exceeds what all existing DC loads and the storage battery can absorb. Should this occur, the array is inhibited by the system controller from feeding any further energy into the loads or battery.

A genset is employed to generate AC energy that is consumed by any existing AC loads, with the balance (if any) being used by the battery charger to generate DC energy that is used in the identical fashion to that described for the PV array above.

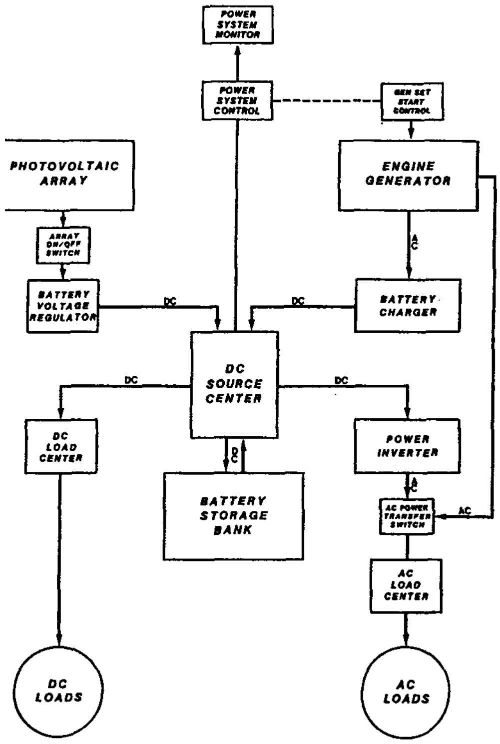


Figure 10.3 Block diagram of a hybrid PV-Genset system.

At times when the genset is not running, all site AC power is derived from the system's power conditioner or inverter, which automatically converts system DC energy into AC energy whenever AC loads are being operated.

The genset is operated cyclically in direct response to the need for maintaining a suitable state of charge level in the system's battery storage bank.

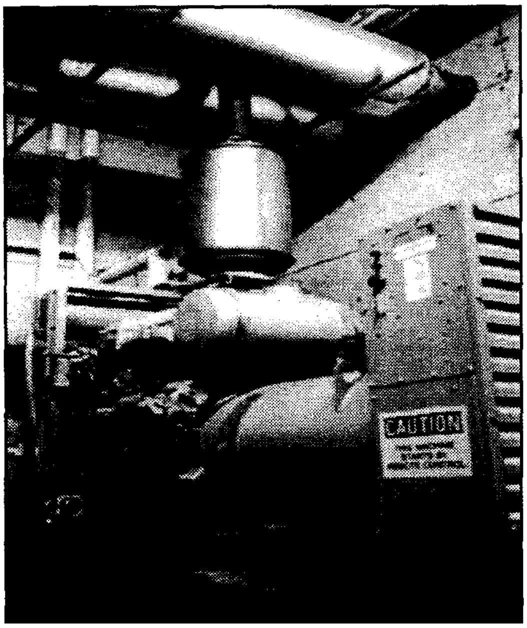


Figure 10.4 Hybrid PV/Generator System Example. Courtesy Photron Inc., Location: Caples Lake, California, USA; 65 kVA 3 0 @ 480 V generator which includes co-generation equipment (i.e. heat exchangers to utilize the thermal energy created by unit operation).

10.5 Other PV/hybrid types

Certain specific site locations may offer access to other forms of power generation. Access to flowing water presents the potential for hydro power. Access to consistent wind at sufficient velocity presents the potential for wind power. PV/hydro and PV/wind hybrid systems have been utilized at sites with daily energy requirement ranges similar to those described for PV/genset hybrids. Their use, however, is much more site dependent, as their energy source is a factor of that locations' topography.

PV/Thermoelectric generator hybrid systems have been used effectively at sites whose daily energy requirement is relatively low, ranging from 1 to 20 kWh per day. Propane is the fuel source for the thermoelectric process, and conversion efficiencies of up to 8% can be achieved. Considerable waste heat is therefore available which may be utilized for other requirements. In cold climates, this heat is often used to maintain the battery storage system at desired temperature levels.

	Advantages	**Disadvantages**
Genset	Low initial expense On-demand power High power density Widely known Highly portable	High operating cost High maintenance Non-renewable fuel Noise pollution Air pollution
PV	Renewable fuel Reliable/low maintenance Versatile/modular Non-polluter	Low power density High initial expense Sunshine dependent Not widely known

Table 10.1 Relative Advantages of Energy Sources: Genset vs. PV

Section C

Architectural Integration

Principal Contributors

Chapter 11: Introduction to Architecture and Photovoltaics

Ingo Hagemann
Steven Strong

Chapter 12: Photovoltaic Modules Suitable for Building Integration

Peter Toggweiler
Cinzia Abbate-Gardner

Chapter 13: Design Concepts

Cinzia Abbate-Gardner
Peter Toggweiler
Gregory Kiss
Tony Schoen
Heinz Hullmann

Chapter 14: Integration Techniques and Examples

Peter Toggweiler
Hermann Laukamp
Christian Roecker

Chapter 11

Introduction to Architecture and Photovoltaics

11.1 Motivation

The last two decades have brought significant changes to the design profession. In the wake of traumatic escalations in energy prices, shortages, embargoes and war along with heightened concerns over pollution, environmental degradation and resource depletion, awareness of the environmental impact of our work as design professionals has dramatically increased.

In the process, the shortcomings of yesterday's buildings have also become increasingly clear: inefficient electrical and climate conditioning systems squander great amounts of energy. Combustion of fossil fuels on-site and at power plants add greenhouse gases, acid rain and other pollutants to the environment. Inside, many building materials, furnishings and finishes give off toxic by-products contributing to indoor air pollution. Poorly designed lighting and ventilation systems can induce headaches and fatigue.

Architects with vision have come to understand it is no longer the goal of good design to simply create a building that is aesthetically pleasing - buildings of the future must be environmentally responsive as well. They have responded by specifying increased levels of thermal insulation, healthier interiors, higher-efficiency lighting, better glazing and HVAC (heating, ventilation and air conditioning) equipment, air-to-air heat exchangers and heat-recovery ventilation systems. Significant advances have been made and this progress is a very important first step in the right direction.

However, it is not enough. For the developed countries to continue to enjoy the comforts of the late twentieth century and for the developing world to ever hope to attain them, sustainability must become the cornerstone of our design philosophy. Rather than merely using less non-renewable fuels and creating less pollution, we must come to design sustainable buildings that rely on renewable resources to produce some or all of their own energy and create no pollution.

One of the most promising renewable energy technologies is photovoltaics. Photovoltaics (PV) is a truly elegant means of producing electricity on site, directly from the sun, without concern for energy supply or environmental harm. These solid-state devices simply make electricity out of sunlight, silently with no maintenance, no pollution and no depletion of materials. Photovoltaics are also exceedingly versatile - the same technology that can pump water, grind grain and provide communications and village electrification in the developing world can produce electricity for the buildings and distribution grids of the industrialized countries.

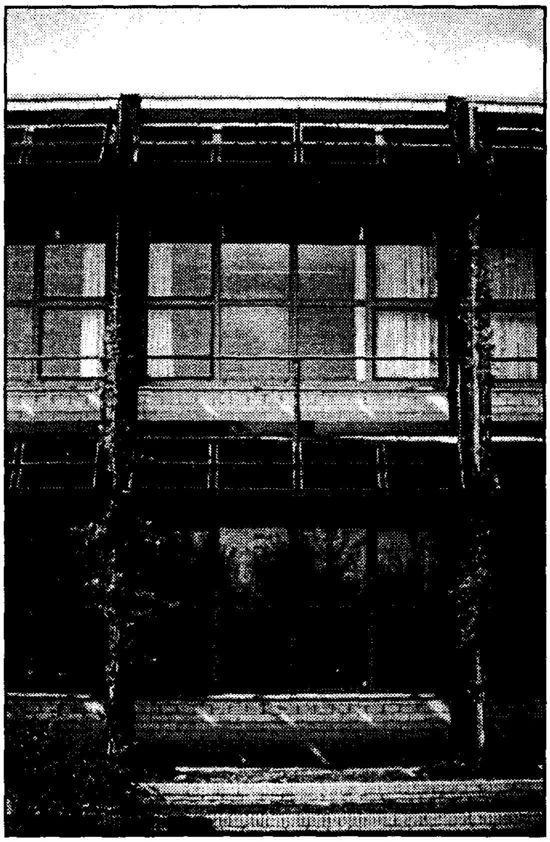


Figure 11.1 HEW, Hamburg, Germany: 16.8 kW_p facade-integrated PV system. The polycrystalline PV modules are installed as fixed shading devices.

There is a growing consensus that distributed photovoltaic systems which provide electricity at the point of use will be the first to reach widespread commercialization. Chief among these distributed applications are PV power systems for individual buildings.

Interest in the building integration of photovoltaics, where the PV elements actually become an integral part of the building, often serving as the exterior weathering skin, is growing world-wide. PV specialists from some 15 countries are working within the International Energy Agency's Task 16 on a 5-year effort to optimize these systems and architects are now beginning to explore innovative ways of incorporating solar electricity into their building designs.

This chapter presents the reasons behind building-integrated PV and some examples of this early work. View these PV-powered buildings as a first glimpse into the coming new era of energy-producing buildings where this elegant, life-affirming technology will become an integral part of the built environment.

11.2 Building envelope

More than any other building component, the roof and especially the facade, have to face changing and also often unpredictable demands. Facade materials, building components and construction techniques that are visible on the inside and outside of the building have to fulfill numerous requirements:

Figure 11.2 SOS Kinderdorf, Zwickau, Germany: 2.9 kW_p roof-integrated PV system. Frameless architectural laminated glass with amorphous silicon cells.

Weather condition requirements

- Protection against rain;
- Resistance to moisture;
- Protection against ice, hail and snow;
- Frost resistance;
- Be a heatshield;
- Be lightfastness;
- Allow heat adsorption and heat storage;
- Protection against sun;
- Allow admission of light and light conditioning;
- Control light diffusion;
- Sunlight reflexion, passage and control;
- Allow passage of wind for cooling in summer;
- Protection against cold winds in cold season;
- Avoid wind noises;
- Protection against glare.

Structural requirements

- Provide structural stability;
- Allow load-carrying capacity;
- Resist internal and external loads;
- Protection against risk of mechanical and chemical damage;
- Protection of building elements against coming-off;
- Avoid sweating;
- Easy maintenance or maintenance-free;
- Be durable;
- Be vandal-proof;
- Provide fire protection;
- Allow emergency exit.

Occupant requirements

- Allow incidence of light;
- Allow contact and communication with the outside;
- Protection against view inside the building (privacy);
- Allow spacial separation;
- Allow passage.

Town planning and design requirements

- Allow dialogue with urban surrounding;
- Give a spatial image;
- Appearance;
- Provide design possibilities;
- Choose appropriate materials, textures and forms;
- Be representative;
- Serve corporate identity.

Emissions requirements

- Keep heat emission to a minimum;
- Keep noise inside the building;
- Avoid passage of smell to outside.

Imissions requirements

- Protection against waste gas from the urban surrounding;
- Provide radiation shielding;
- Avoid odour nuisance;
- Keep out noises;
- Avoid insects and vermin infiltration;
- Keep out dust;
- Keep out pollen.

(© Ingo Hagemann)

Figure 11.3 Building envelope performance requirements.

11.3 Planning context of an energy conscious design project

The possibilities of an active and passive solar energy use in buildings is greatly influenced by the form, design, construction and manufacturing process of the building envelope. A promising possibility of active solar energy use is the production of electricity with photovoltaics. This technology can be adapted to existing buildings as well as to new buildings. It can be integrated into the roof, into the facade or into different building components, such as a photovoltaic rooftile.

Such an integration makes sense for various reasons:

- The solar irradiation is a distributed energy source; the energy demand is distributed as well.
- The building envelopes supply sufficient area for PV generators and therefore
- additional land use is avoided as well as costs for mounting structures and energy transport.

I. Heating Strategies for Buildings
- Collection of Solar Gains in Cold Climate
- Storage and Restorage of Solar Heat Gains
- Distribution of Solar Heat Gains
- Avoidance of Heat Losses
- Use Active Solar Systems like Hot Water Collectors or Photovoltaics
- Use Hybrid Systems

II. Cooling Strategies
- Control of Solar Radiation
- Reduction of External Solar Heat Gains
- Reduction of Internal Heat Gains
- Natural Cooling and Ventilation Techniques

III. Use of Daylighting Techniques to Reduce Cooling Loads and Energy Demands

Table 11.1 Active and Passive Solar Design Principles (© Ingo Hagemann).

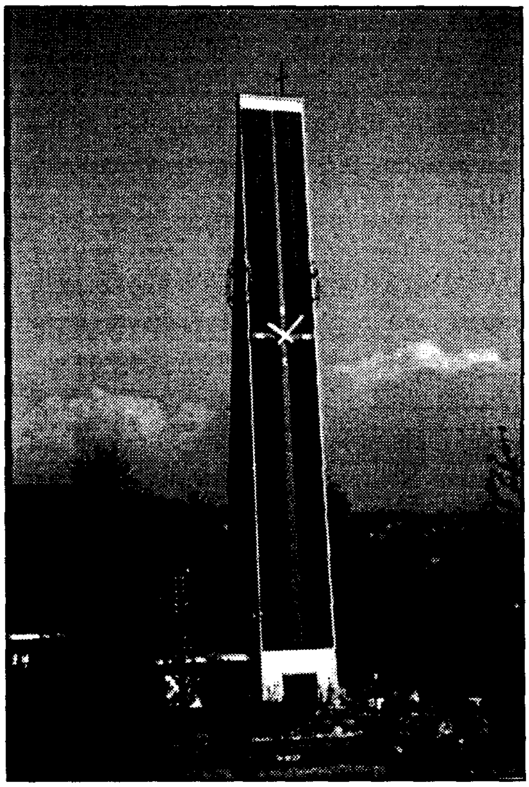


Figure 11.4 Laukaa autonomous house, Finland.

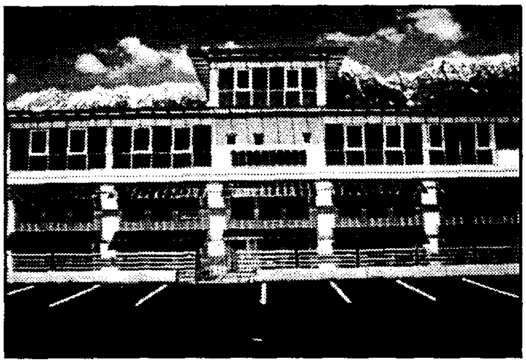


Figure 11.5 Commercial building (A. Wild) in Innsbruck, Austria.

In order to use PV together with other available techniques of active and passive solar energy, it must be considered that some techniques fit well together and others exclude each other. For example: As a kind of a "passive cooling system", creepers are used for covering the south facade of a building. The leaves evaporate water and provide shade on the facade. This helps to avoid penetration of direct sunlight and reduces the temperature in the rooms behind the facade. At the same time the leaves create shading on PV modules that may be mounted on the facade resulting in a far lower electricity production.

To avoid such design faults it is necessary to compare and evaluate the different techniques that are available for creating an energy conscious building. An overall energy concept for a building should be made at the beginning of the design process. Therefore, the architect and the other experts involved in the design and planning process need to work together right from the beginning of the design and planning process. All together they have to search right from the beginning for the best design for a building project.

11.4 Photovoltaics and Architecture

Photovoltaics and Architecture are a challenge for a new generation of buildings. Installations fulfilling a number of technical approaches do not automatically represent aesthetical solutions. A collaboration between engineers and architects is essential to create outstanding overall designs. This again will support the wide use of PV. These systems will acquire a new image, ceasing to be a toy or a solar module reserved for a mountain chalet but becoming a modern building unit, integrated into the design of roofs and facades. The architects, together with the engineers involved are asked to integrate PV at least on four levels during the planning and realisation of a building:

- Design of a building (shape, size, orientation, colour)
- Mechanical integration (multifunctionality of a PV element)
- Electrical integration (grid connection and/or direct use of the power)
- Maintenance and operation control of the PV system must be integrated into the usual building maintenance and control.

The photographs illustrate some examples of PV facades and PV house designs.

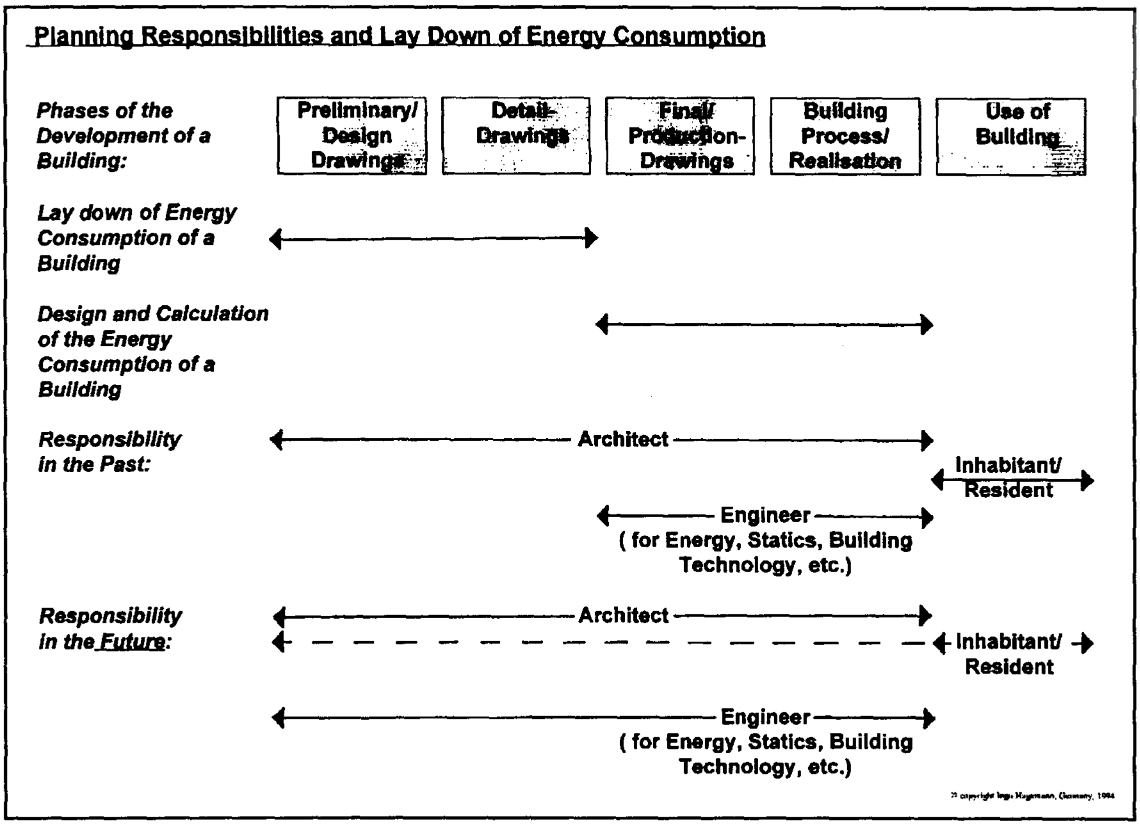


Figure 11.6 Planning Responsibilities and Lay Down of Energy Consumption.

Chapter 12

Photovoltaic Modules Suitable for Building Integration

12.1 Introduction

A PV module is basically designed and manufactured for outdoor use. All products available are suitable to be exposed to sun, rain and other climatic influences. These circumstances make possible the use of PV modules as part of the building skin. Many different types of module technologies are available. However, not all of them are useful for building integration. In the past, modules used to be specifically designed for energy generation and the building element function was neglected. Future considerations aim at designing building elements which also deliver electrical energy. The module configuration is described in Chapter 5. The various module types such as monocrystalline, polycrystalline and amorphous silicon have differing aesthetic considerations. The colour of monocrystalline cells varies from uniform black to a dark grey with a uniform surface structure. In contrast, the structure of polycrystalline cells shows irregular grey to blue coloured crystals. In both types, the current gathering grid lines are well visible as a silver or black metallic colour. This may change in the future, as the grid colour is better matched to the colour of the cells. Many types of modules and laminates are available with mono- or polycristalline cells. For semitransparent modules the space between the single cells is enlarged to let light pass through. Custom-designed modules allow an individual quality of the light transmission. In addition, the colour of the back sheet for non-transparent modules can be selected.

Amorphous silicon is deposited on metal, glass or plastic films, meaning different kinds of modules are available. These modules usually have a dark brown colour. For semi-transparent modules of amorphous silicon the cells themselves are pervious to light. Since the cells absorb a part of the spectrum, the colour of the passed light is changed.

Today's technology of module design has lead to several solutions for building-integrated PV systems. The following table shows the advantages and disadvantages of different types of PV modules.

	Module construction technique	Typical dimension [cm²]	Application suitability				
			Sloped roof	Flat roof	Wall	Window	Shading
12.1	Standard modules with plastic or metal frame (glass multi-layer non-transparent back sheet)	33 x 130 45 x 100 55 x 115	+	o	o	-	o
12.2	Standard laminates as above without frames	33 x 130 45 x 100 55 x 115	+	+	+	-	+
12.3	Glass-glass modules with predefined trans-parency	all dimensions between 15 and 200	o	o	+	+	+
12.4	Glass modules with transparent plastic back sheet (predefined transparency possible)	all dimensions between 15 and 200	o	o	+	+	+
12.5	Modules with metal back sheet and plastic cover	15 x 150	+	+	+	-	+
12.6	Roofing modules (tiles/slates)	to fit with stan-dard roofing systems	+	-	-	-	o
12.7	Custom-designed mo-dules	various di-mensions	+	+	+	+	+

+ = high suitability
o = low suitability
- = not suitable

Table 12.1 Suitability of different module types for building integration.

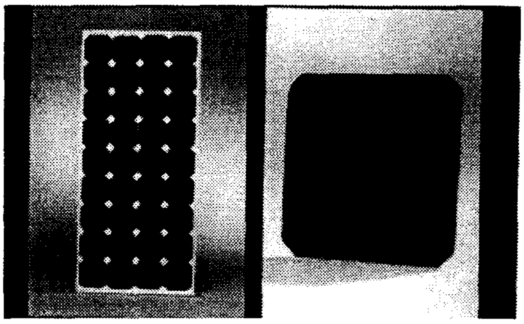


Figure 12.1 Standard module.

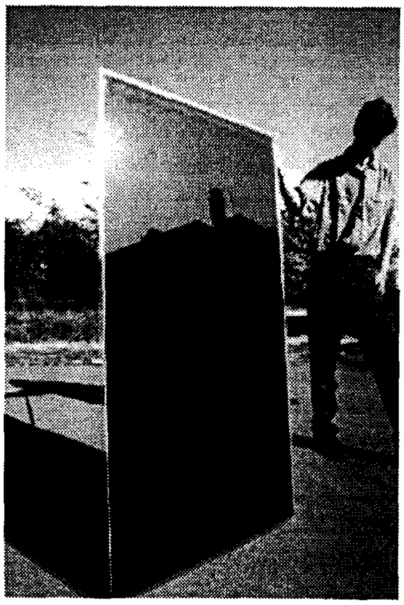


Figure 12.2 Standard laminate (APS).

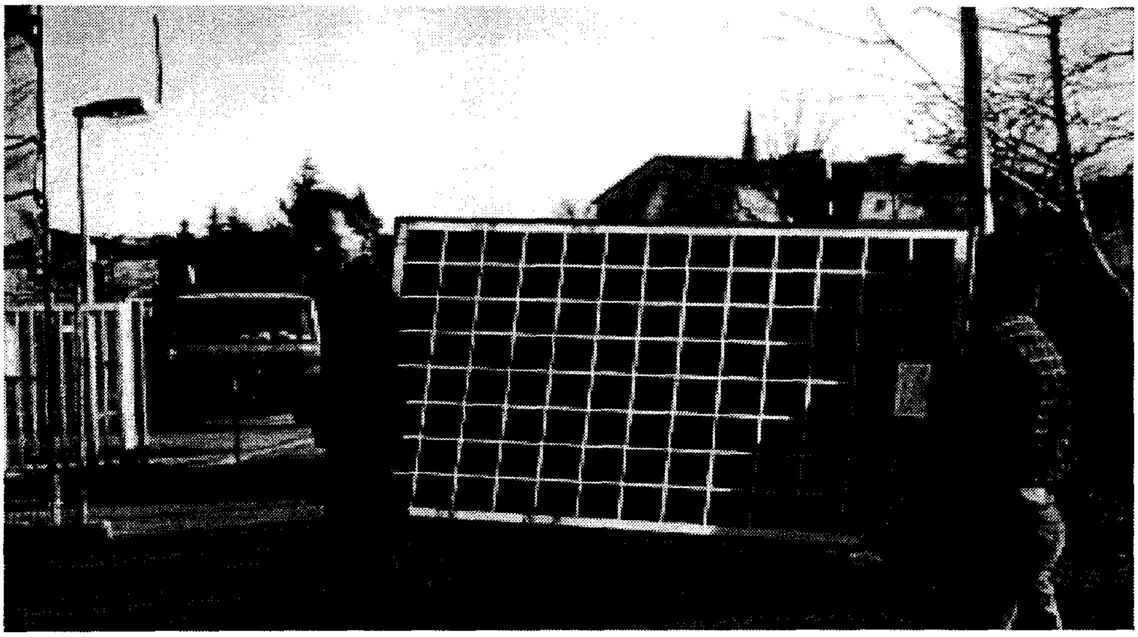


Figure 12.3 Large glass-glass module with predefined transparency (Flagsol).

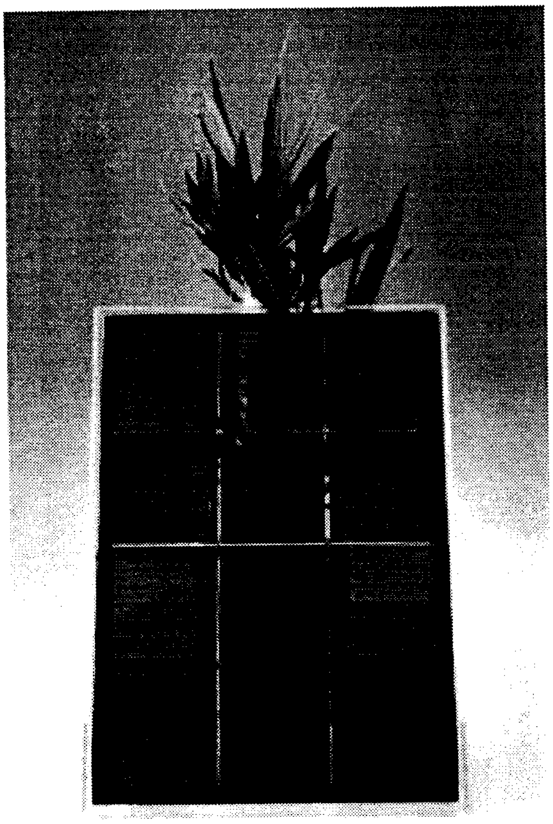


Figure 12.4 Glass module with predefined transparency.

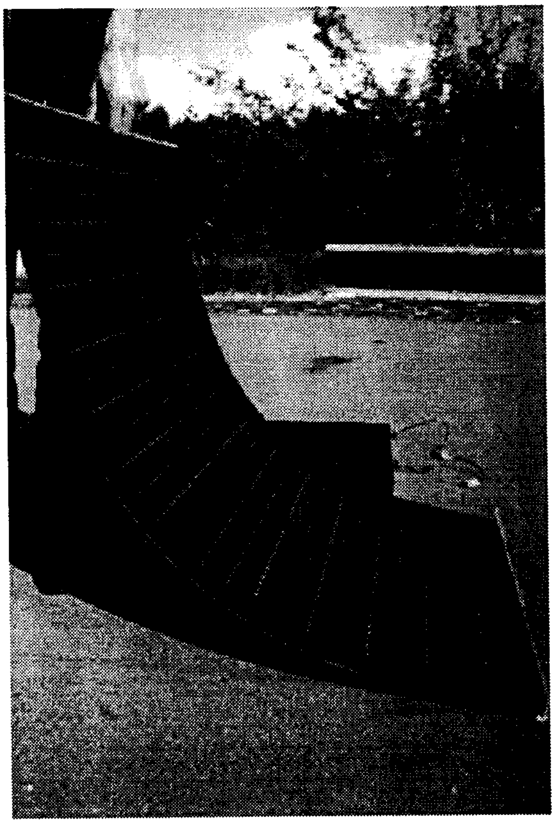


Figure 12.5 Module with metal back sheet and plastic cover (USSC).

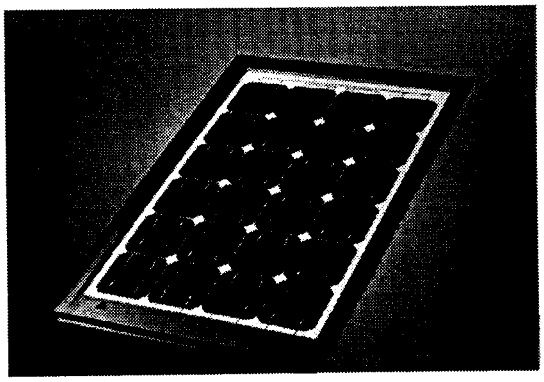


Figure 12.6 Swiss Solar Tile (Newtec).

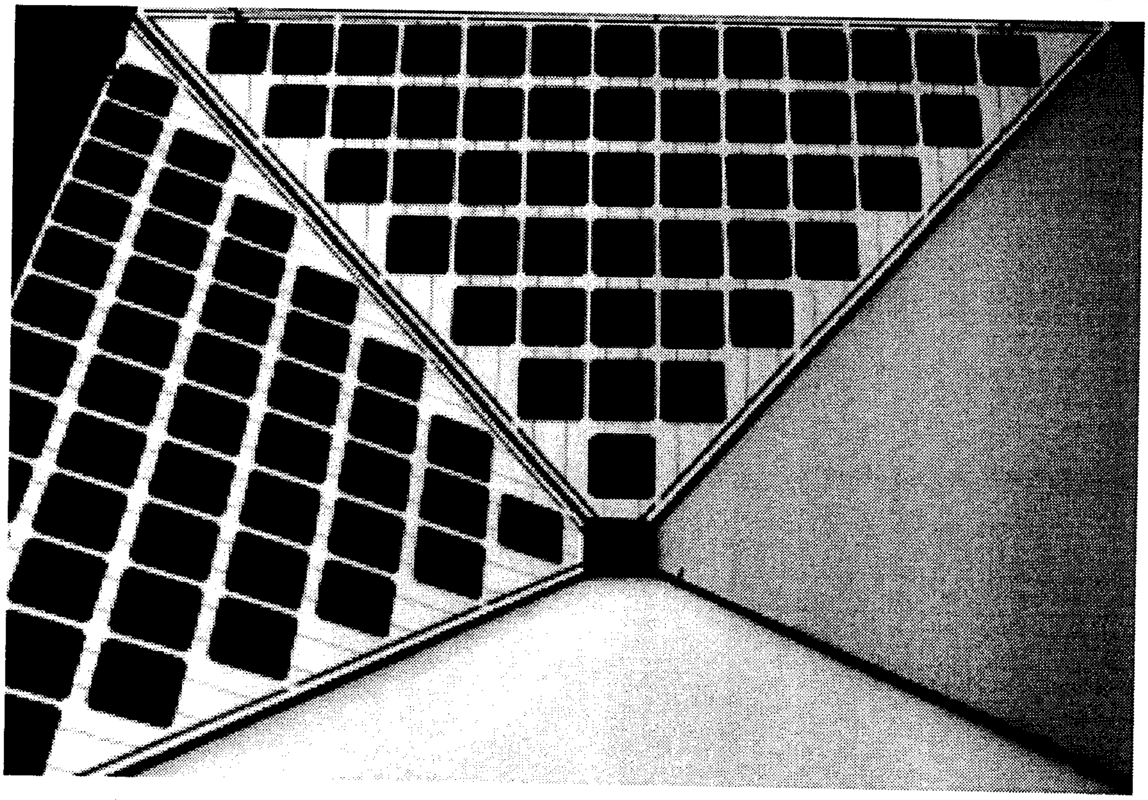


Figure 12.7 Custom-designed module (here: triangular shape) (Solution).

Chapter 13

Design Concepts

13.1 Design as multidisciplinary approach

The design and construction of buildings has shifted away from the creation of a "dwelling", moving towards the interpretation of the multi-functionality of the various construction typologies, as well as the components of architecture. The tendency to industrialize building construction has revealed the need to clarify the design process; which controls the growing complexity of the project, and the need to combine the technical-scientific role of the engineer with the technical and composite role of the architect, and with the new industrial technologies. The problem of architecturally integrating photovoltaic technology requires an interdisciplinary design approach. This not only imposes collaboration and the presence of highly specialized professionals on the project team, but also introduces a sensitivity to problems that go beyond the building itself. These inhabit a sphere that is even broader, including social, economic, environmental, energetic and ecological issues.

As an example, a building facade must not only keep out water and regulate heat loss, it must also regulate the entry of light, provide a sound barrier, offer ease of technical maintenance and also must be aesthetically and architecturally satisfying.

The study of the elements and components involved in photovoltaic application systems is of great importance in the final quality of the product. On this level, a PV building installation is a typical industrial design problem. Each project for the architectural integration of photovoltaics may require both the revision of the type and the dimensions of the photovoltaic panel, and the study of new framing and mounting systems. Individuals possessing the skills that are specific to this sector will be involved as well. These people range from the architects and engineers to photovoltaic cells manufacturers and to all the technicians and the producers of the materials employed in the construction.

13.2 The role of photovoltaics in building

It has been mentioned before that a building is a combination of many complex systems: structural mechanical, electrical, and others. Changes to the parameters of one system affect the others. An assessment of the performance of a building-integrated PV system as an element of a building skin therefore requires a multidisciplinary approach. A building- integrated PV system in fact adds another role to this program: power generation. A building surface can usually be classified as a roof or a wall, with significant differences in function, construction, and thermal and solar loading.

Architects are turning into industrial designers and project energy management consultants in order to address PV construction *as* more than just a building material. The value of PV can be significantly enhanced by collateral energy benefits. As PV cells capture sunlight and convert it to electricity, they also convert it to heat which can be used or discarded *as* necessary.

13.3 Considerations in designing building envelopes for PV

During the design stage, both the technical and aesthetic characteristics of the PV module must be considered in order to arrive at a satisfactory integration of PV into the building as a whole.

Central to the study of PV building design is the conflict between PV solar considerations and contemporary building conventions. The primary goal in the layout of PV power systems is to maximize the amount of power generated through optimum array orientation, but this goal is tempered in the case of building design by considerations of construction costs, optimum building floor area, daylight control, thermal performance, and aesthetics. In addition, building envelopes are often designed to deflect and minimize the amount of radiation falling on a building's surface, since cooling is often the largest consumer of energy in a building. By contrast, photovoltaics require the greatest possible radiation in order to maximize performance. Also, the envelope system must be designed to resist any water which may permeate the skin and infiltrate not only the framework, but also the photovoltaic panel interlayer. In addition, electrical connections which penetrate the weather seal must also be designed for reliable performance. In climates where clear/cold days bring substantial and immediate temperature changes to building surfaces, the PV envelope system needs to resist or eliminate the condensation.

Both mild and extreme climates require good insulating properties at the envelope. PV panels may be directly laminated with insulation or may be incorporated into multi-layer air or gas-filled insulating units. Electrical connection design will also need to take into account thermal bridging.

The impact of lightning on PV building envelopes is another important environmental issue. PV structures will need to be grounded and circuited to prevent a possible power surge which may result in damage to the panels or a hazard to their occupants.

The issues of building-integrated PV design are not exclusively technical. The balance between the issues of PV building design and construction will vary greatly according to the circumstances of each project (climate, budget, client priorities, aesthetics, etc.).

13.4 Outline for the design procedure

The following discussion attempts to identify a possible outline for the design procedure of a building-integrated PV system.

13.4.1 Climatic considerations and orientation

Locations, climates, latitude, average cloudiness, average temperatures, precipitation, humidity, dust/dirt, wind loads, and seismic conditions will all affect the economics of a PV-integrated building system by virtue of how they are addressed in the envelope design.

South-facing unobstructed PV panels are usually oriented at a tilt equivalent to the local latitude in order to receive maximum solar radiation, while building walls are generally vertical for reasons of economy, efficiency and traditional construction technology. East and West-facing facades perform relatively well at steep angles or vertical orientation due to the low angle of the sun at the beginning and end of the day. The building's electrical load profile and the utility time-of-use rate structure are important parameters in establishing optimum PV orientation.

The inherent flexibility of PV compared to other types of solar collectors (wiring is inherently easier to run than plumbing), combined with anticipated low material cost (thin-film PV on glass substrates are basically similar to coated architectural glass), raises the possibility of considering PV a building material first, and a PV device second. Thus, an architect desiring a monolithic appearance for a building may choose to clad all of a building's surfaces with PV, even those that will never see the sun. If the economics permit, PV can be used in any number of building component configurations and without an overriding demand for optimal orientation. If PV orientation is not perceived as a design restriction, architects will be much more open to their use.

13.4.2 The site

The characteristics of the site and its orientation will influence the design in order to determine where and how to integrate PV in the building.

Building floor area can be a precious commodity. In some cases, sloped PV panel configurations will reduce the amount of occupiable perimeter floor area because the wall effectively 'cuts back' on floor area as the building gets taller. Any reduction in usable floor area needs to be considered when evaluating the life-cycle costs of a PV system.

High rise structures are usually built in an urban environment where real estate costs are high and the surrounding landscape is dense. Shadows cast by other tall buildings reduce the performance of the panels. It may be that for certain high rise projects only the upper stories will be clad in PV with only some areas active during the course of a day. In such cases, the designer can chose to articulate or camouflage the active and inactive portions of the facade by using contrasting or matching cladding next to the PV.

13.4.3 Zoning regulations and building codes

Sometimes zoning regulations regarding colors, building shape, and building codes, will also have an impact on the selection of the different kind of photovoltaic material to use.

Another parameter is certainly the identification of technology, or which type of panels (single crystal or polycrystalline cells) should be used. This decision should be made in accordance with the dimension of the building, its possible overall configuration, the economical restraints (some technologies are more expensive than others) and the energy demand.

13.4.4 Type of panels

The selection of the PV panels, their aesthetic characteristics in terms of modular geometry, dimension, color, mounting system (with exposed frame or without frame), will influence the overall appearance of the building and the architectural character of the intervention. The modules are the most immediately recognizable and distinguishing components of the various PV systems. They are most visible from outside the building and will most probably be placed in a prominent position to avoid the shadow cones of nearby buildings that could reduce the efficiency of the system and the desired electric energy output. PV panels may provide energy benefits beyond the electricity they generate by providing passive solar heating or cooling load reduction.

The modular geometry, the colors and the texture of both the cells and the glass of the photovoltaic panels constitute the main aesthetic characteristics of the panels. The balance between the amount and quality of glass and the quantity and type of cells used in the panel is part of the design process and will be relevant to both the panel and the space. This device can be used to exploit a sort of decorative and functional texture formed by the natural light that filters through the cells. In fact, this transparent grid of light created by the glass space between the cells is a significant contribution to the enrichment of the architectural quality of the indoor spaces. Very different are those cases in which the panel is interpreted as real construction material. Here it acquires considerable functional and aesthetic validity, particularly when we analyze the very interesting dialectic taking place between PV and traditional construction materials.

The photovoltaic cell presents its most interesting aesthetic aspects on the exterior face which is exposed to the sun. By varying the selection and positioning of PV cells in the module, it is possible to obtain a wide variety of color, brilliance, reflectivity and transparency effects.

The cables, the junction box and the battery of a PV module might be visible, depending upon the type of installation and the type of module. This should be taken into consideration during the design stage, so that the overall spatial configuration is controlled.

13.4.5 Installation

For both new construction and retrofit, the method of installation is important to the cost effectiveness of the system. For example, glazing installation from the interior does not require exterior scaffolding. Interior glazing is a common method of contemporary curtain wall installation today, accomplished by splitting the mullion and muntin extrusions into separate elements which snap into place in the field.

Shop labor is usually cheaper and more precise than field labor. Whenever possible, panelized or prefabricated wall or roof sections will save money, especially in complex PV wall profiles. Prefabricated systems could also include some electrical balance of systems or PV-powered devices such as fans or lights.

It is important to recognize that the integrated nature of applied architectural PV installations (curtain wall framing, glazing systems, PV and electrical connections, etc.) will require the combined efforts of a number of different building trades and jurisdictions. Conventional construction sequences and responsibilities must be considered in the development of PV products if they are to fit present construction industry practice.

13.4.6 Structure, engineering and details

The mechanical and electrical systems required to maintain and operate a building of substantial scale are often complex and can require a tremendous amount of energy. Photovoltaics add both benefits and additional levels of complexity to the engineer's task. PV buildings will challenge architects and engineers to develop innovative solutions for integrating a building's support system with PV supplied power. Critical issues to consider for engineering systems integration will be, among others, safety, durability and economy.

13.5 Configurations for PV building integration

Before starting to design a PV building, it is very important to analyze each possible applicable solution of application to determine its overall impact on the building's energy balance and the energy efficiency performance of the overall system.

The following diagrams offer a panorama of configurations for PV integration, selected by three main architectural application typologies:

- walls and facades,
- roofs and large coverings,
- light filtration and screening elements.

13.5.1 Walls and facades (Figures 13.1 - 13 .7)

There are two basic curtain wall framing systems in common use: pressure plate and structural silicone glazing. In pressure plate systems, the glazing unit is mechanically held from the front by a plate with an extruded cover or 'cap'. Structural silicon glazing glues some or all of the glazing edges to the framing systems. In pressure plate systems, the mullion cap depth must be kept to a minimum to avoid adverse shadowing on PV cells. Alternatively, flush application of a structural silicon seal between PV glazing units eliminates shadowing effects but increases weather seal and durability problems for PV panel edges.

To minimize sealing problems, or to capture heat from the PV modules, it may make sense to fabricate a double wall envelope, where the PV glazing is the external, unsealed layer and the inner layer may be the weather tight enclosure.

Optimizing PV panel performance in building wall applications may require complex detailing and therefore higher construction costs in order to accommodate optimal orientations to the sun. For wall applications, these complex configurations may take on a sloped or "saw-tooth" profile (see Figures 13.3, 13.4, 13.13) or the PV may be applied independent of the building's skin as awnings or light-shelves (Figures 13.14, 13.15).

13.5.2 Roofs and large coverings (Figures 13.8 - 13.13)

For roof applications, installations generally require little compromise in solar orientation but may create structural or weather-proofing problems. Horizontal roof configurations must be structured to accommodate other types of loading such as snow and water. This issue requires different solutions depending upon the location of the building. In climates with considerable snow accumulation, skylights and roof systems incorporating PV may need to be designed with a slope sufficient to shed snow which may be steeper than the optimal slope for solar gain. Partial PV skylight enclosures will shade interior spaces from direct sunlight while simultaneously harnessing power from the sun's rays. PV roof monitors could also reduce or eliminate the need for daytime electric lighting by providing indirect daylight.

Flexible substrates such as sheet metal or fabric would open up large new markets. PV devices that mimic traditional building materials (such as clay roof tiles) may also increase their market.

13.5.3 Light-filtration and screening elements (Figures 13.14, 13.15)

Opaque PV panels installed as PV window awnings (Figure 13.14) or PV light shelves (Figure 13.15) can shield direct sun while providing diffuse, indirect light to interior spaces. The portion of these light shelves which are exposed to sunlight would be PV; the portion in shade could be any reflective material. The panels' surface would bounce light onto the ceiling inside.

Another PV device with some passive solar benefits is the semi-transparent photovoltaic panel, or PV window, designed to admit a specific amount of light and/or view to a space. Some thin-film PV devices are inherently semi-transparent, if produced with clear conductive coatings on glass substrates. Alternatively, opaque PV devices may be rendered effectively transparent by the creation of a pattern of clear areas where the opaque materials have been removed. It should be possible to incorporate semi-transparent PV into insulating or high-performance multi-pane glazing units. With less active PV area, the solar performance of these semi-transmissive panels will be less than with opaque PV. But the passive benefits and vision area produced in some cases will outweigh the reduction in efficiency.

A. Vertical Curtain Wall

Characteristics:
- Standard, economical, accepted construction

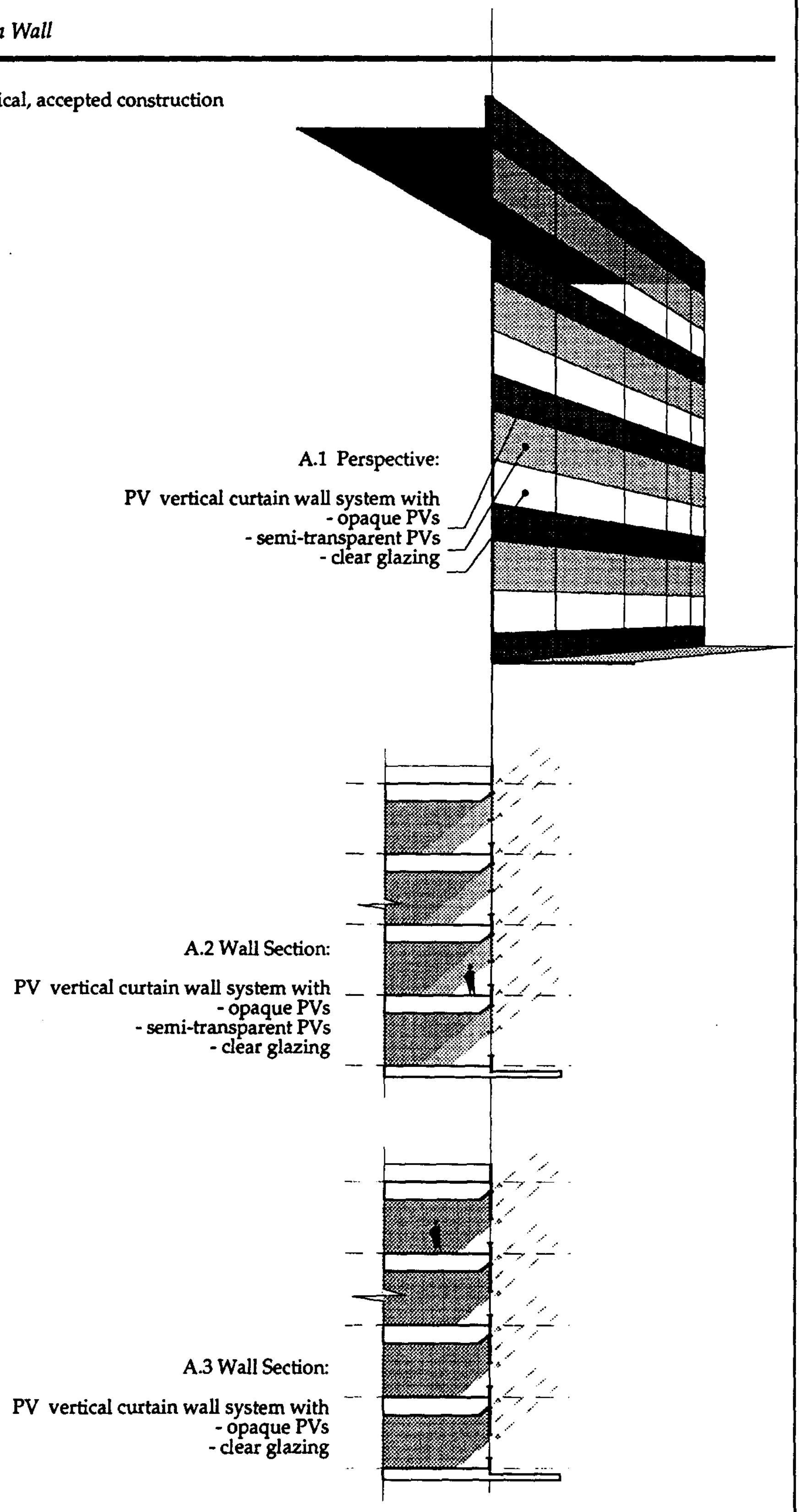
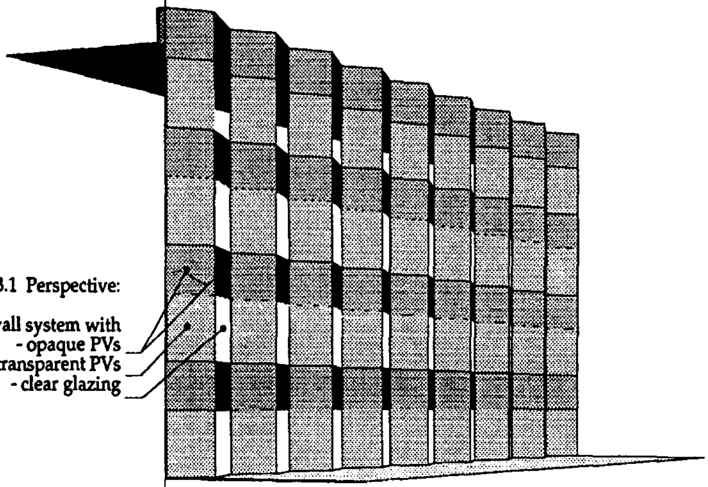


Figure 13.1 Diagram A: Vertical curtain wall.

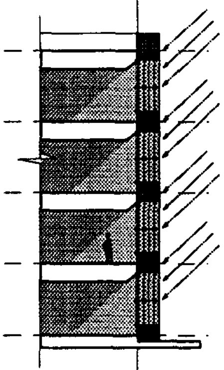
B. Sawtooth Vertical Curtain Wall

Characteristics:
- Minimal additional construction cost
- Good solar performance in certain orientations
- Creates multiple "corner" windows



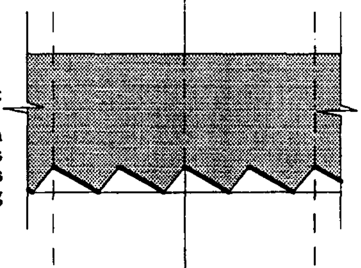
B.1 Perspective:

PV sawtooth vertical curtain wall system with
- opaque PVs
- semi-transparent PVs
- clear glazing



B.2 Wall Section:

PV sawtooth vertical curtain wall system with
- opaque PVs
- semi-transparent PVs
- clear glazing



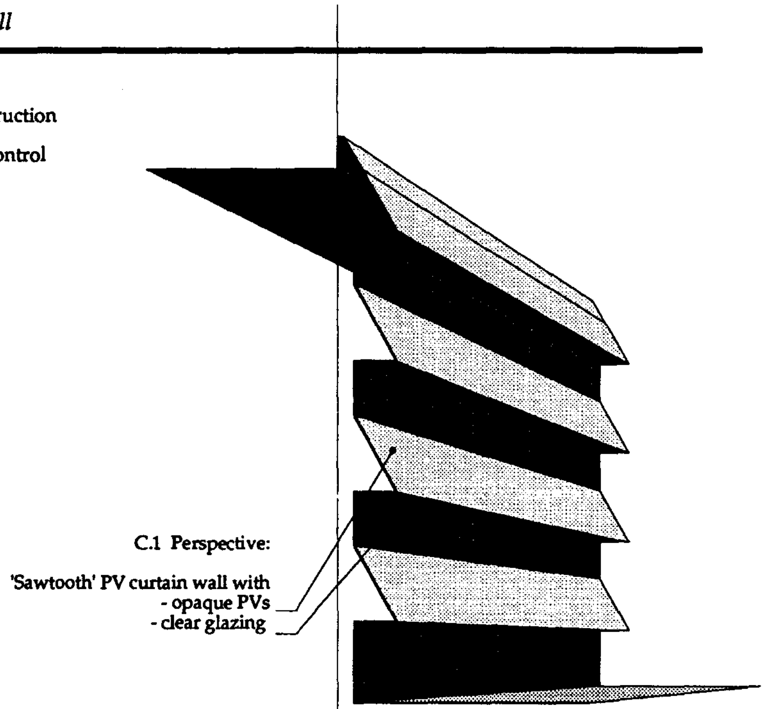
B.3 Floor Plan:

PV sawtooth vertical curtain wall system with
- opaque PVs
- semi-transparent PVs
- clear glazing

Figure 13.2 Diagram B: Sawtooth vertical curtain wall.

C. *PV Sawtooth Curtain Wall*

Characteristics:
- PVs as building skin
- Complex curtain wall construction
- Good PV efficiency
- Passive shading/daylight control
- Potential cleaning problems



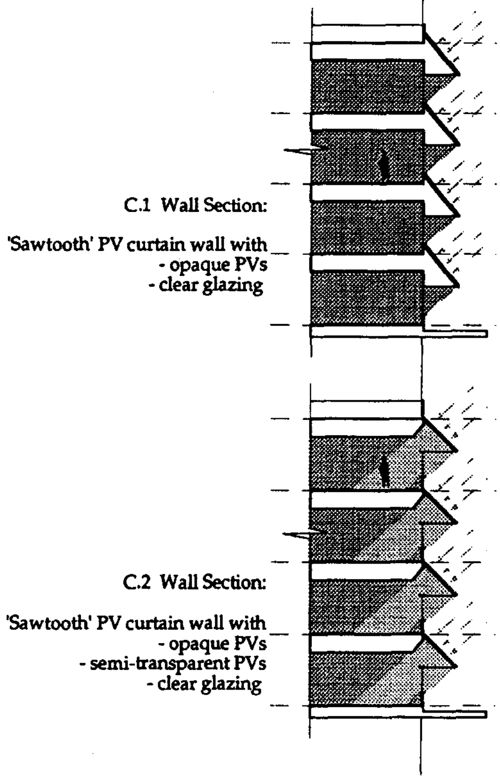


Figure 13.3 Diagram C: PV sawtooth curtain wall.

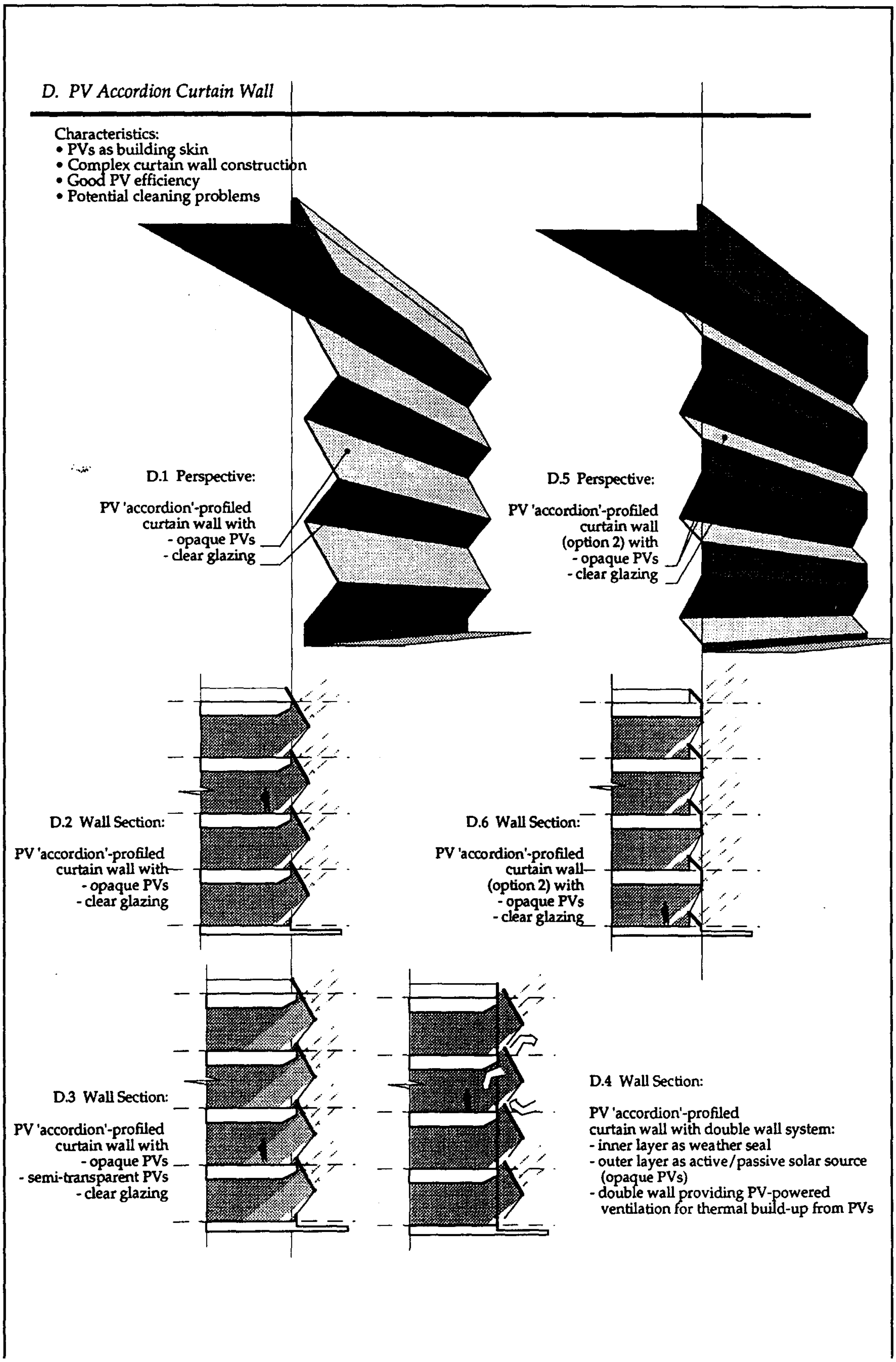


Figure 13.4 Diagram D: PV accordion curtain wall.

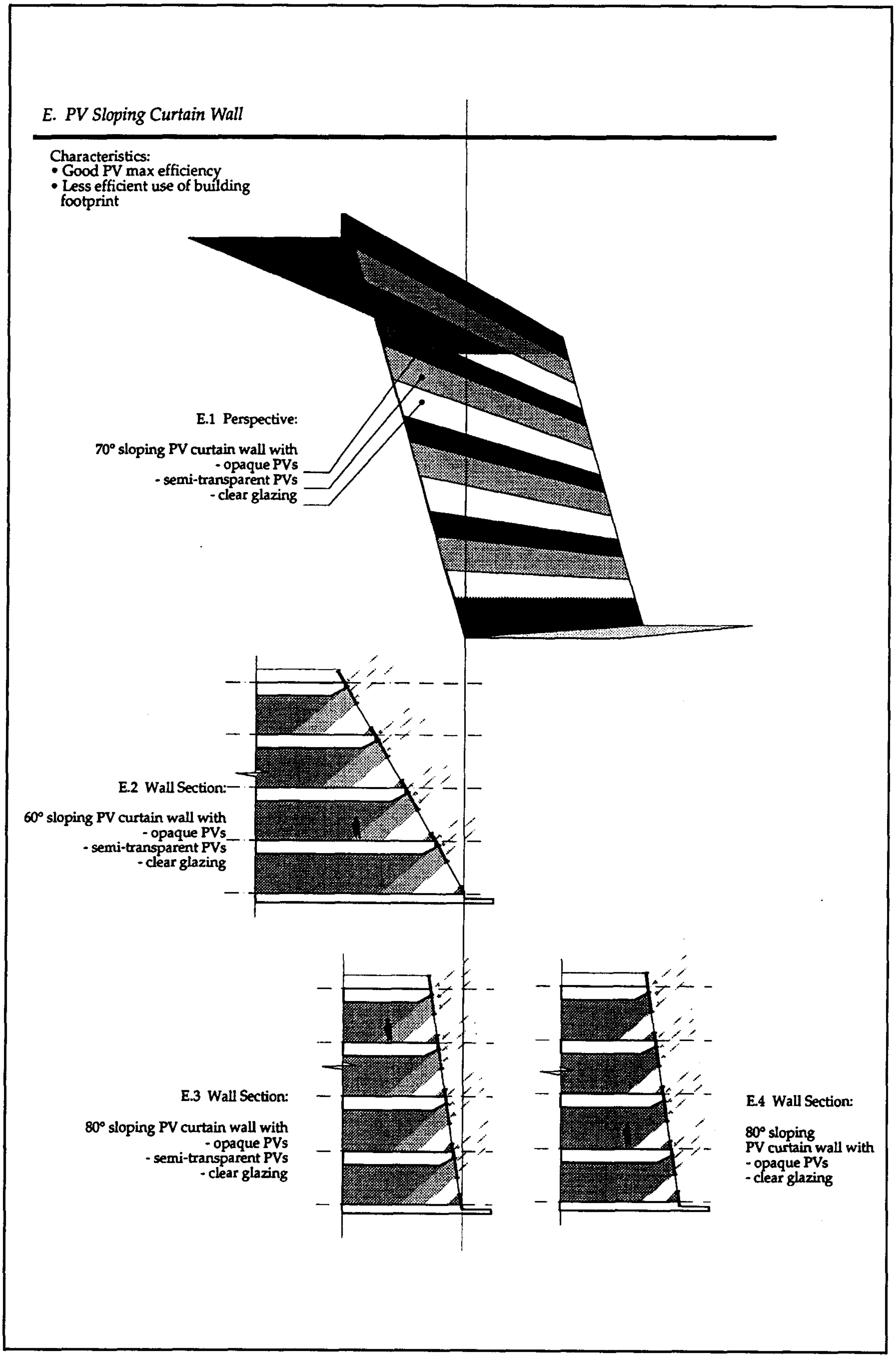


Figure 13.5 Diagram E: PV sloping curtain wall.

F. PV Sloping/Stepped Curtain Wall

Characteristics:
- Good PV max efficiency
- Less efficient use of building footprint
- Complex curtain wall construction

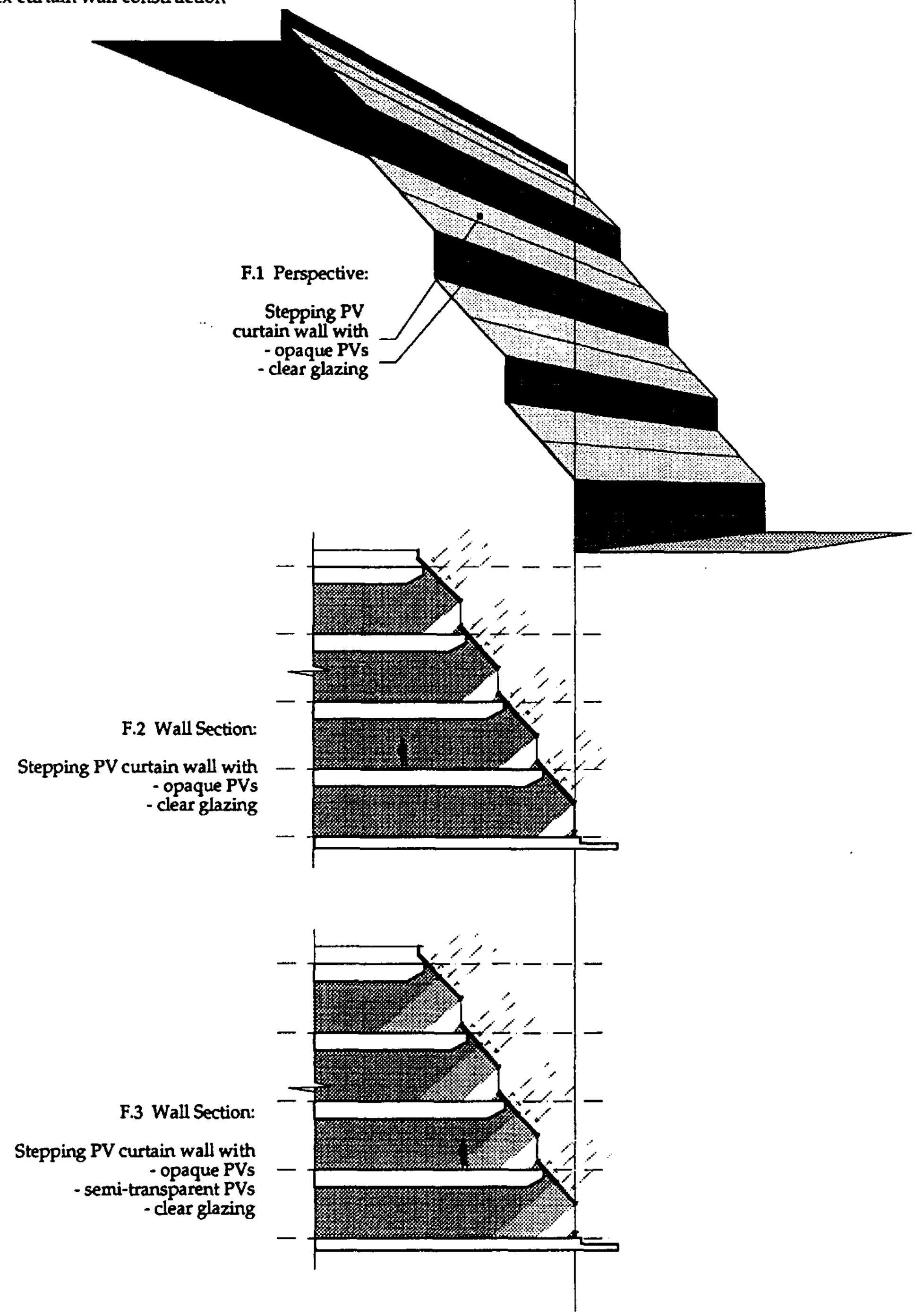
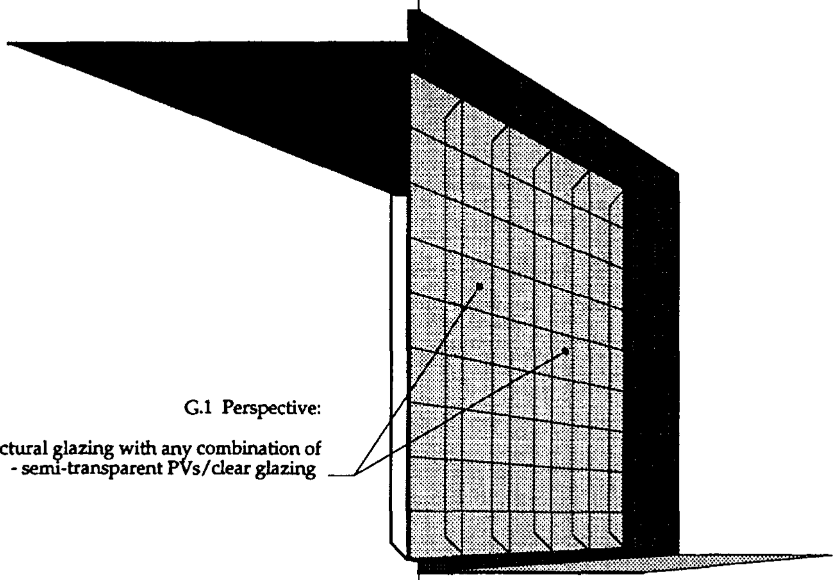


Figure 13.6 Diagram F: PV sloping/stepped curtain wall.

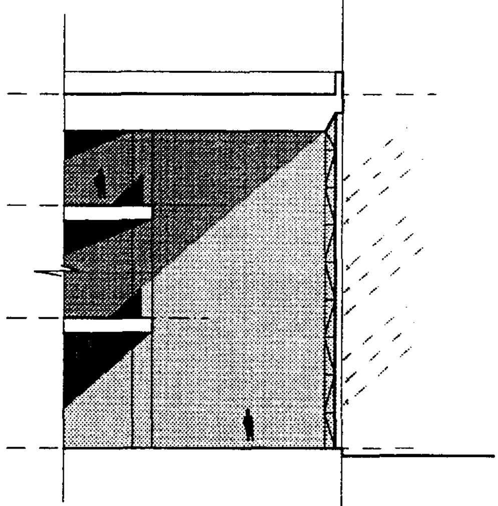
G. PV Structural Glazing

Characteristics:
- Standard, economical, accepted construction
- Difficult sealing problems for PV edges



G.1 Perspective:

Vertical PV structural glazing with any combination of
- semi-transparent PVs/clear glazing



G.2 Wall Section:

Vertical PV structural glazing with any combination of
- semi-transparent PVs/clear glazing

Figure 13.7 Diagram G: PV structural glazing.

H. PV Roof Panels

Characteristics:
- PVs as building skin
- Combined with rooftop structural system (panelized units with insulation, fastened directly to roof structure)
- Weatherproofing and structural issues must be carefully resolved
- Snow accumulation considerations

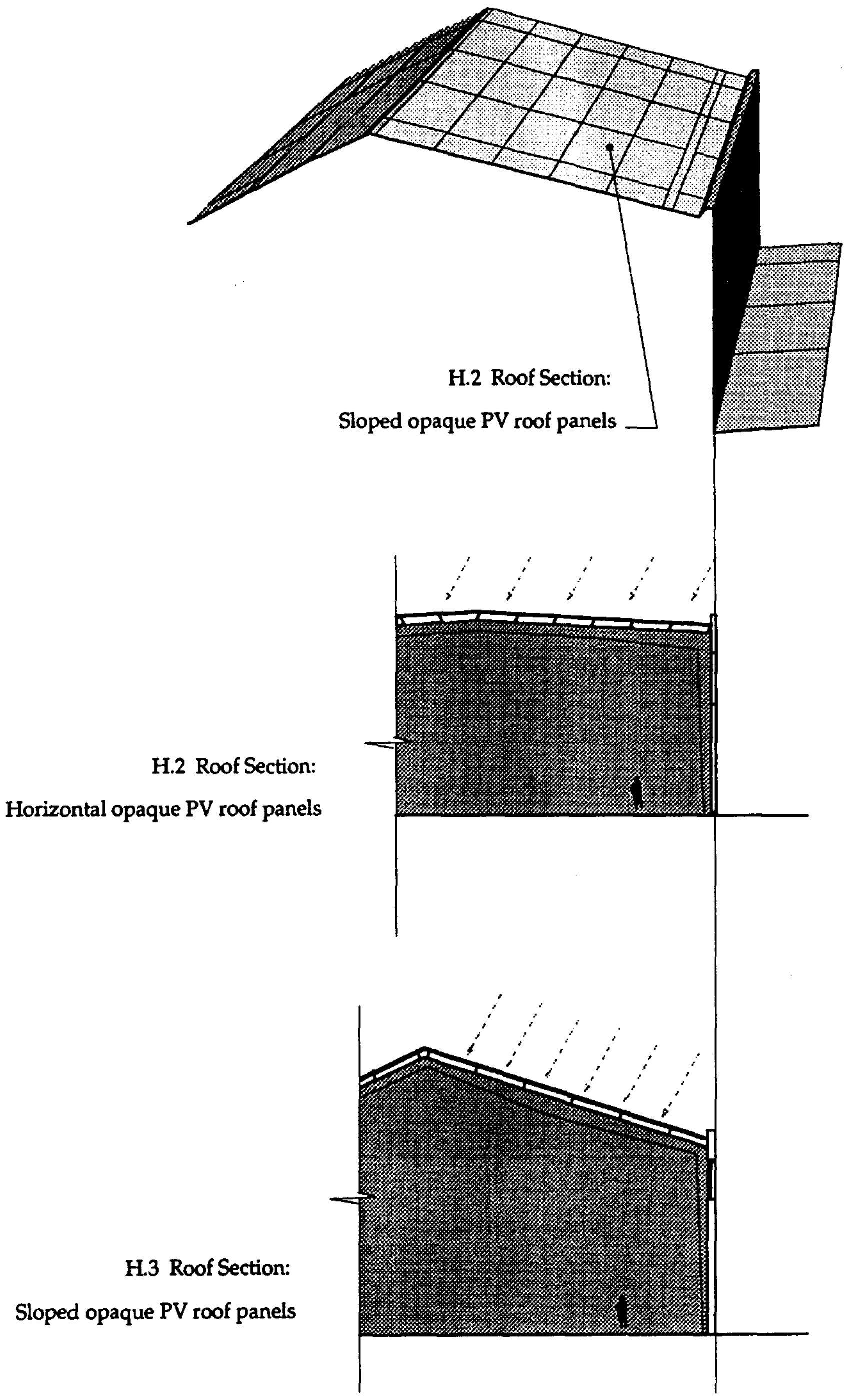


Figure 13.8 Diagram H: PV roof panels.

I. PV Atriums

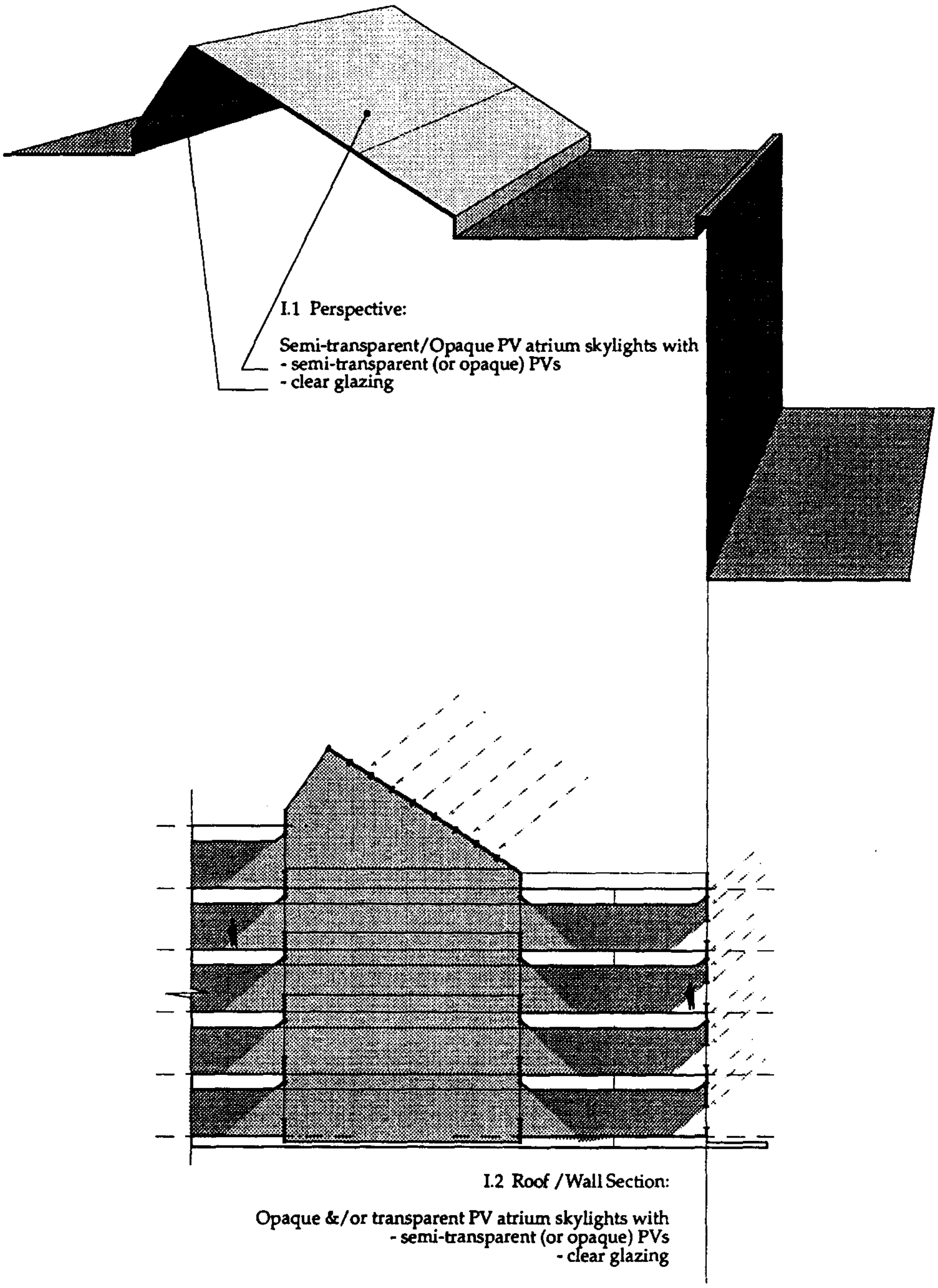
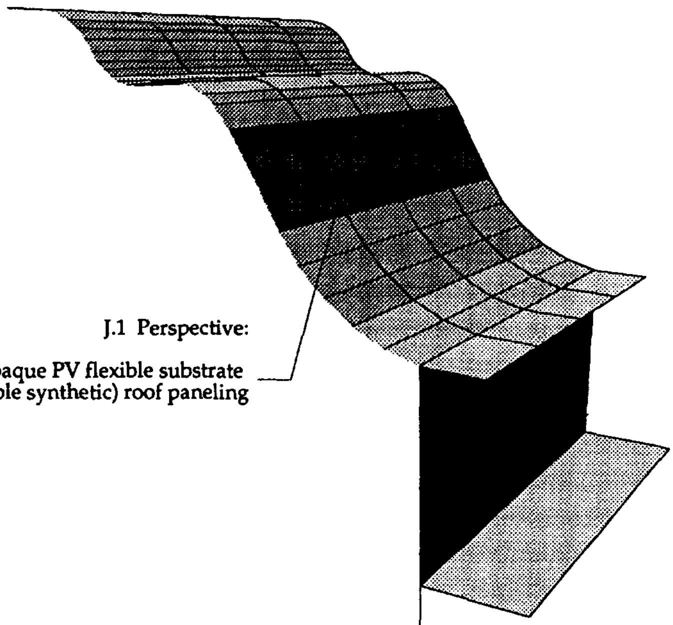


Figure 13.9 Diagram I. PV atriums.

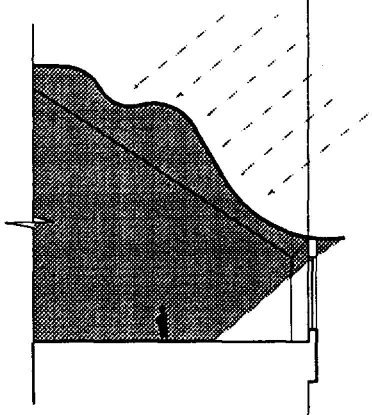
J. Flexible/ Metal PV Substrates

Characteristics:
- For roofs and/or wall applications
- Good design flexibility
- Light-weight
- Possible integral weather barrier



J.1 Perspective:

Opaque PV flexible substrate
(sheet metal or flexible synthetic) roof paneling



J.2 Wall Section:

Opaque PV flexible substrate
(sheet metal or flexible synthetic) roof paneling

Figure 13.10 Diagram J: Flexible/metal PV substrates.

K. PV Skylights

Characteristics:
- PV system as indiv. roof openings
- New construction or retrofit
- Tilted or horizontal orientation
- Numerous configurations possible
- Daylighting benefits
- Snow accumulation considerations

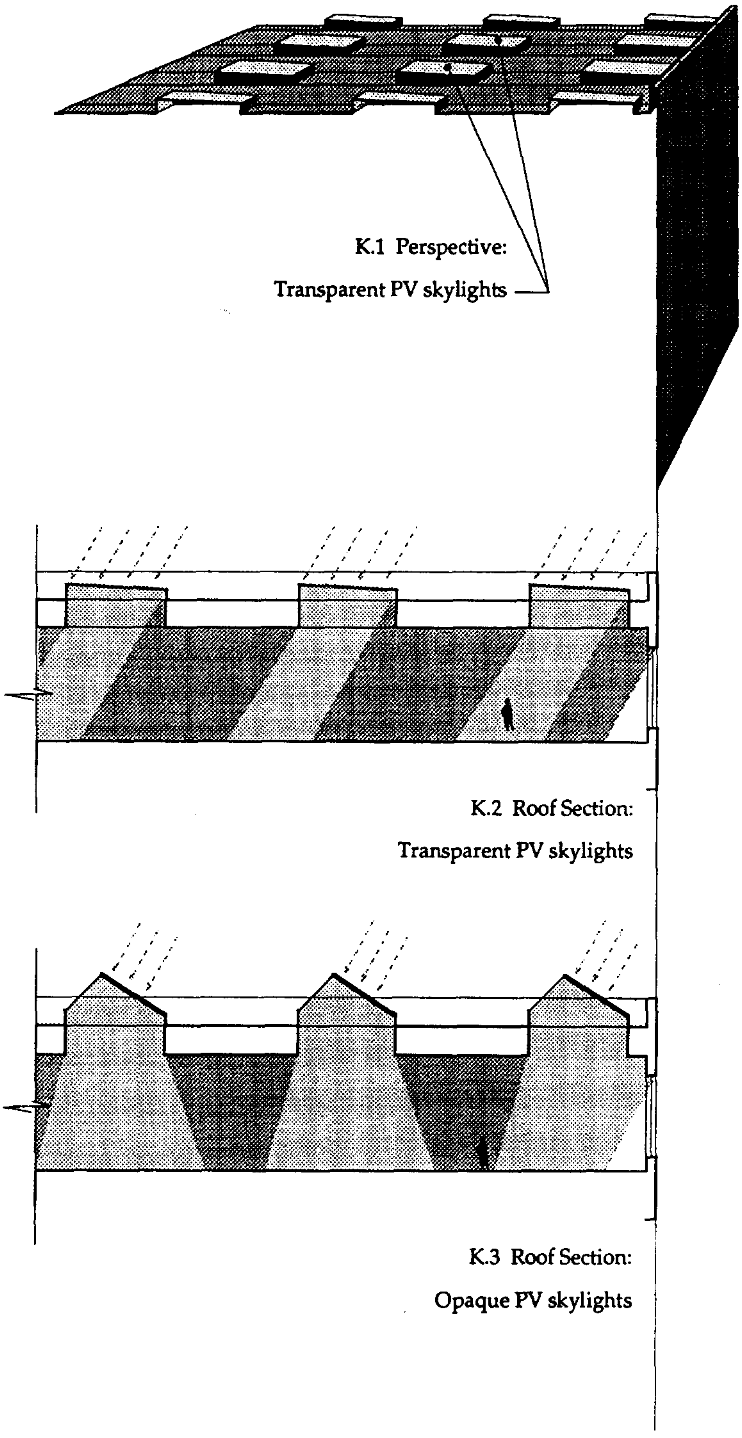


Figure 13.11 Diagram K: PV skylights.

L. Independent PV Rooftop Array

Characteristics:

- PV system independent of bldg skin.
- conventional array configuration installed on rooftop
- Maximal efficiency
- New construction or retrofit
- Potential passive benefit from reduced heat load
- Potential structural costs
- Water proofing issues at roof/structure

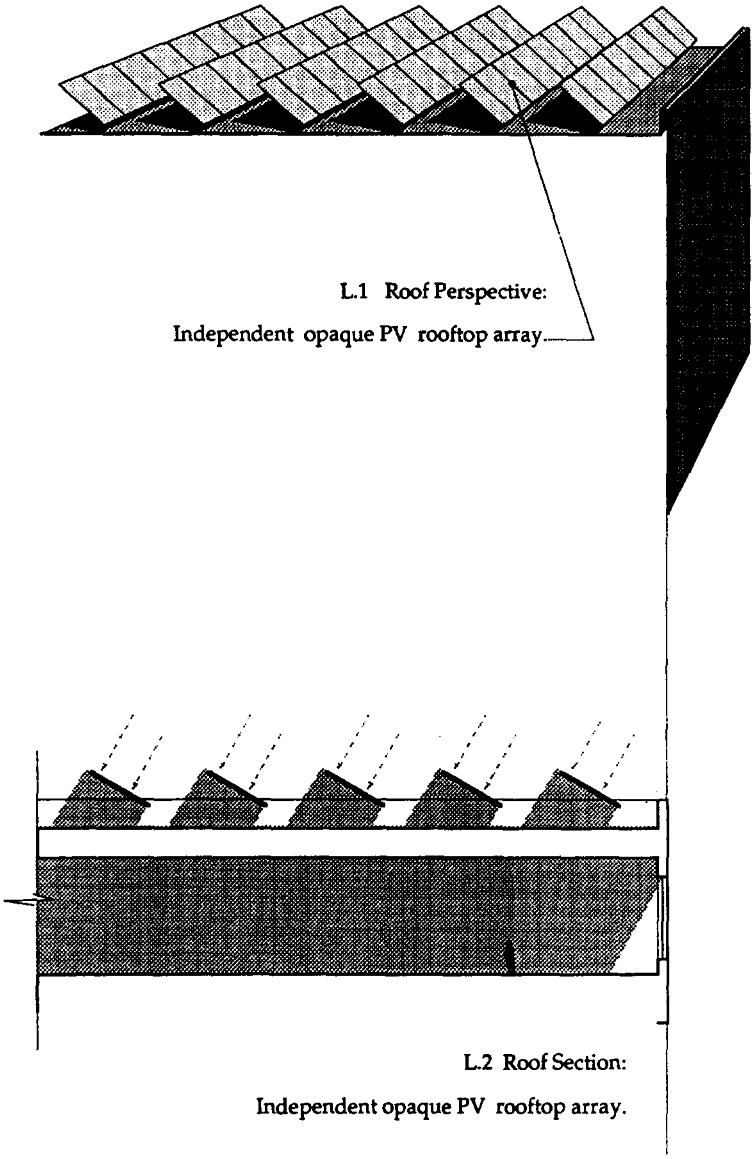


Figure 13.12 Diagram L: Independent PV rooftop array.

M. PV Sawtooth Roof Monitors

Characteristics:
- PV system as building skin
- Retrofit to exist. industrial buildings
- Good PV efficiency
- Good daylight benefits

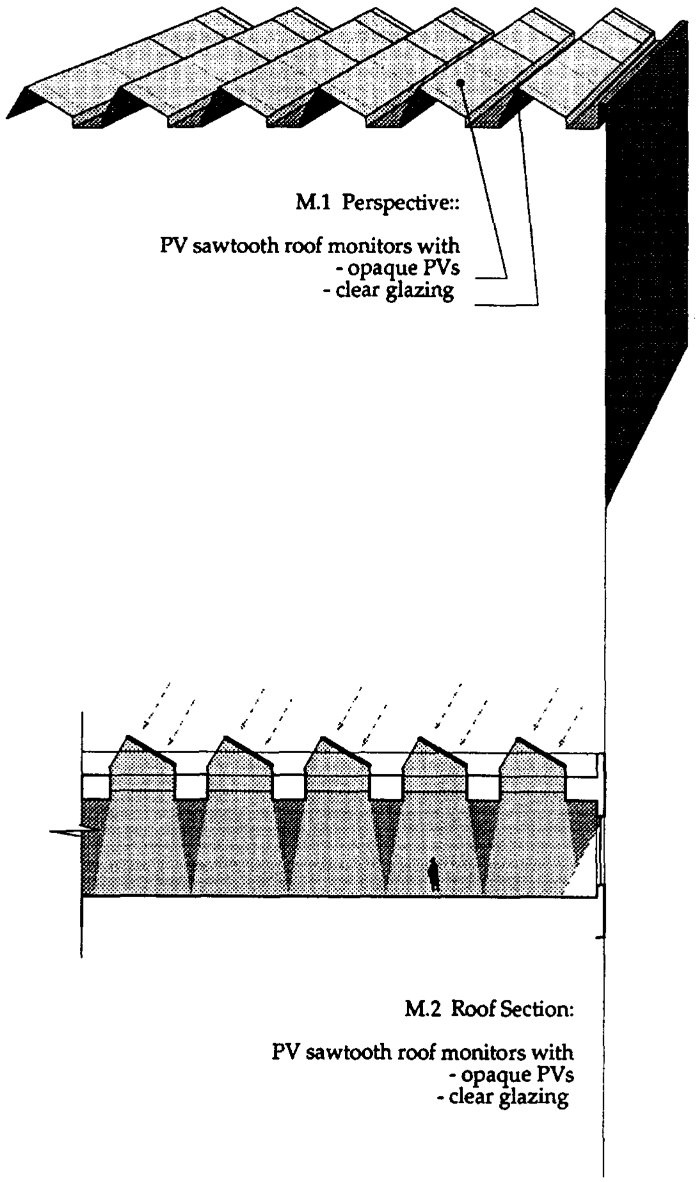


Figure 13. 13 Diagram M: PV sawtooth roof monitors.

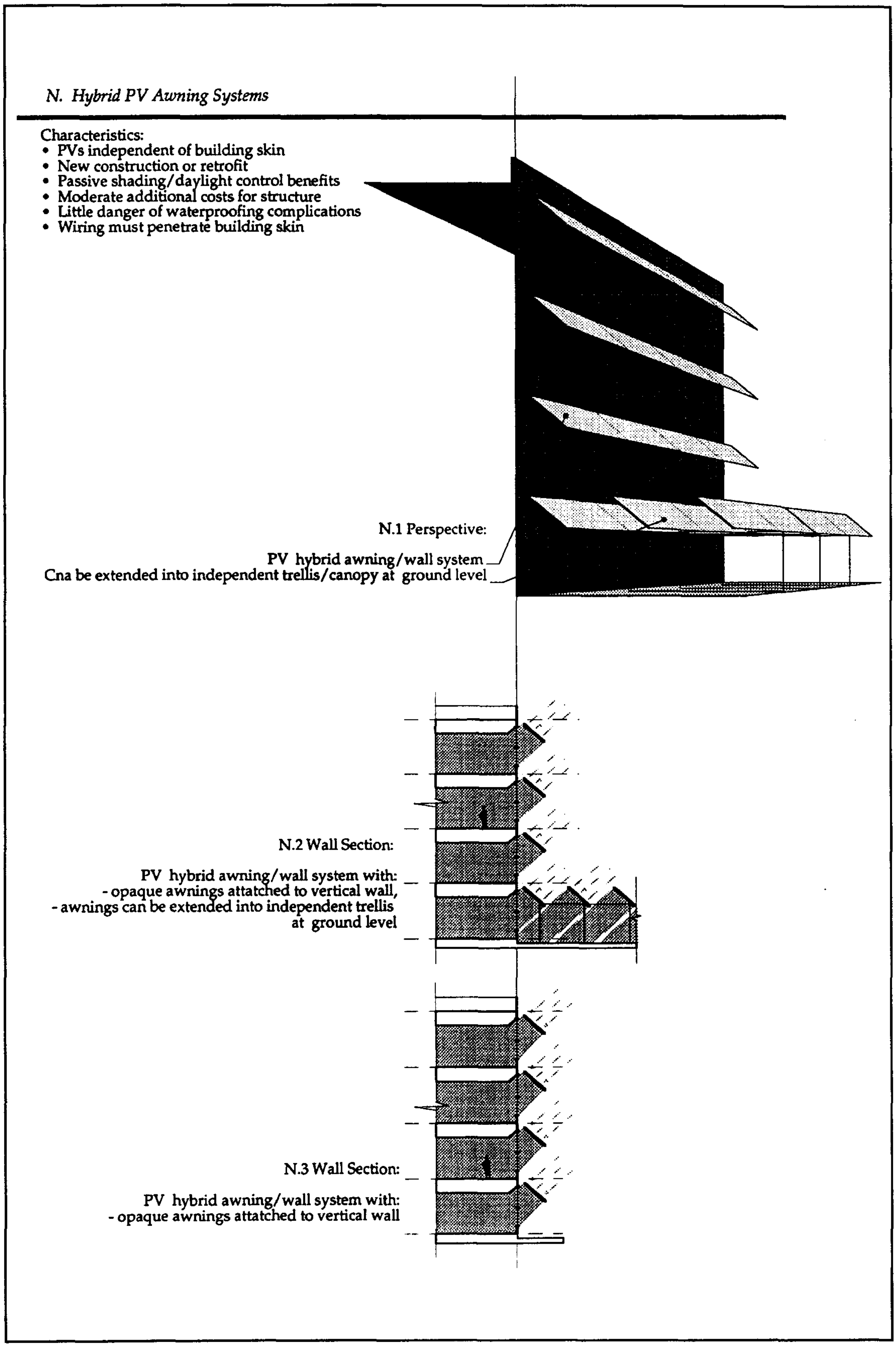


Figure 13.14 Diagram N: Hybrid PV awning systems.

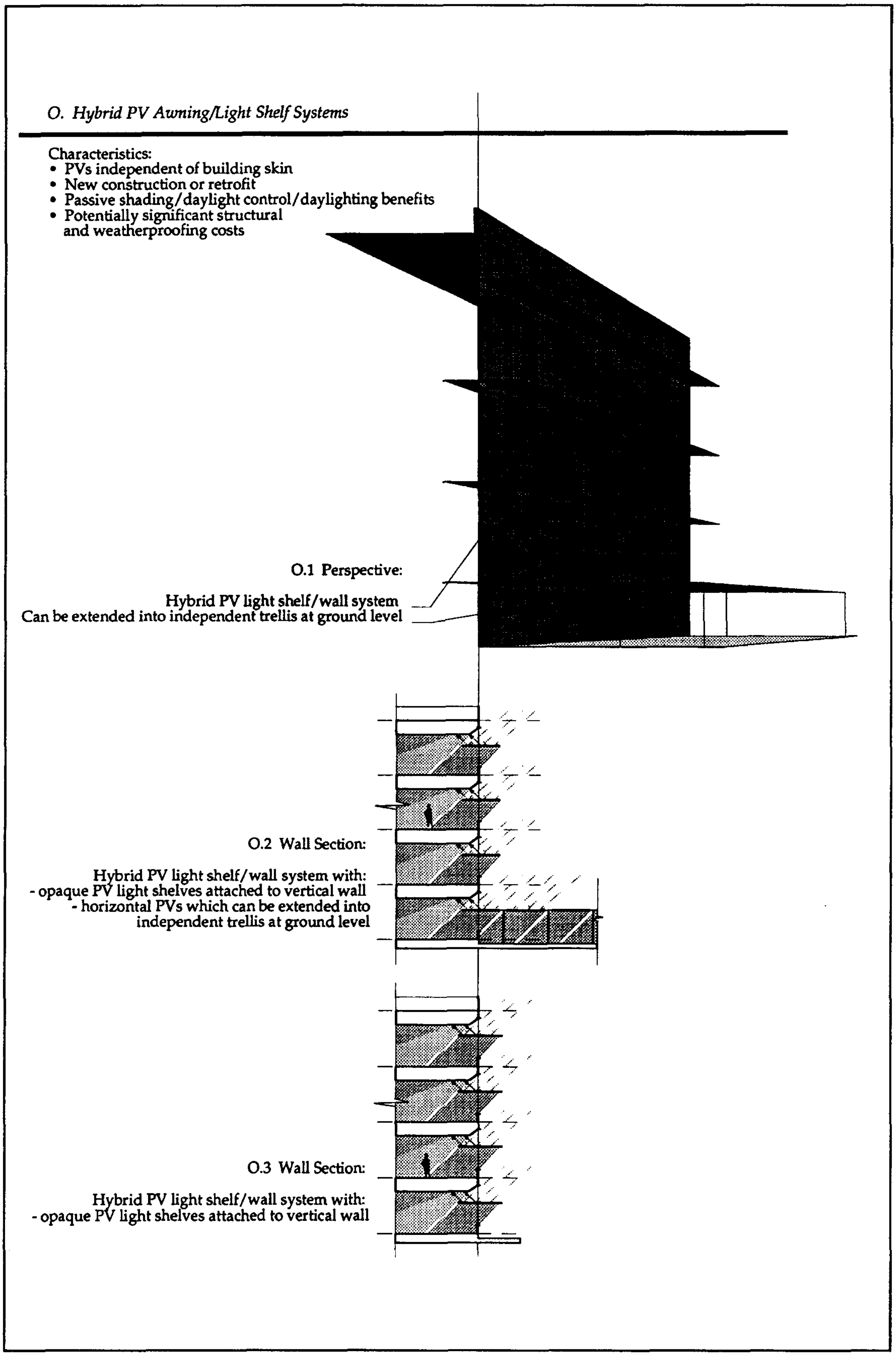


Figure 13.15 Diagram O: Hybrid PV awning/light shelf systems.

13.6 IEA Task 16 Architectural Ideas Competition

The following examples have been extracted from the IEA Architectural Ideas Competition "Photovoltaics in the Built Environment". The initiative for this competition, launched in 1993, lies with Task 16 of the IEA Solar Heating and Cooling Programme.

13.6.1 South East South South West
B.J. van den Brink,

The Netherlands

Environmental-friendly building means building as little as possible, and therefore as well building as compact as possible. A compact layout reduces the amount of needed building material. A compact building layout reduces as well the need for energy when the building is in use. Finally, a compact urban planning reduces need for transportation.

The detached houses have a compact layout (they approximate a sphere), but cannot match these principles completely because of a lack of urban compactness. To compensate this, the facades can absorb a lot of solar energy, and futuristic flaps on the roof can open during the day to collect solar energy and close during the night to insulate the building.

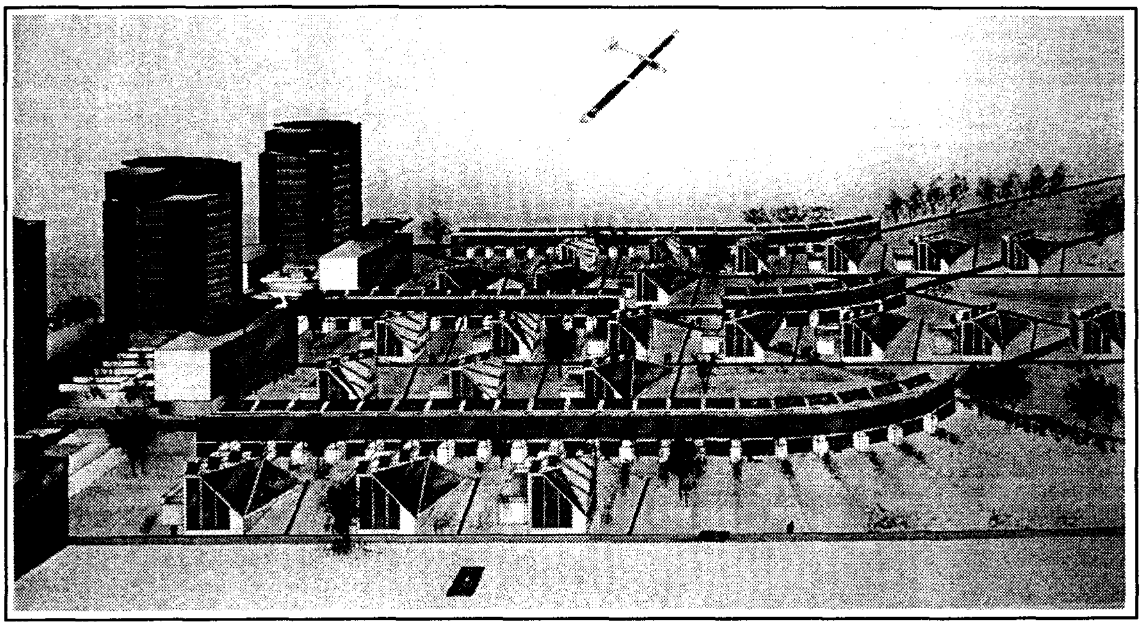


Figure 13.16 IEA competition entry by B.J. van den Brink, The Netherlands.

13.6.2 PV in single dwelling unit
D. Mizrahi, Switzerland

The design of a single dwelling unit using PV is a very delicate question which demands a higher grade of sensibility. The perceiving of the social implications of technological development and the responsibility for our environment are indispensable for that. To avoid 'architectural pollution' it is necessary to approach PV as self-defined design and construction element of architecture. In this way, PV becomes an obvious part of the building.

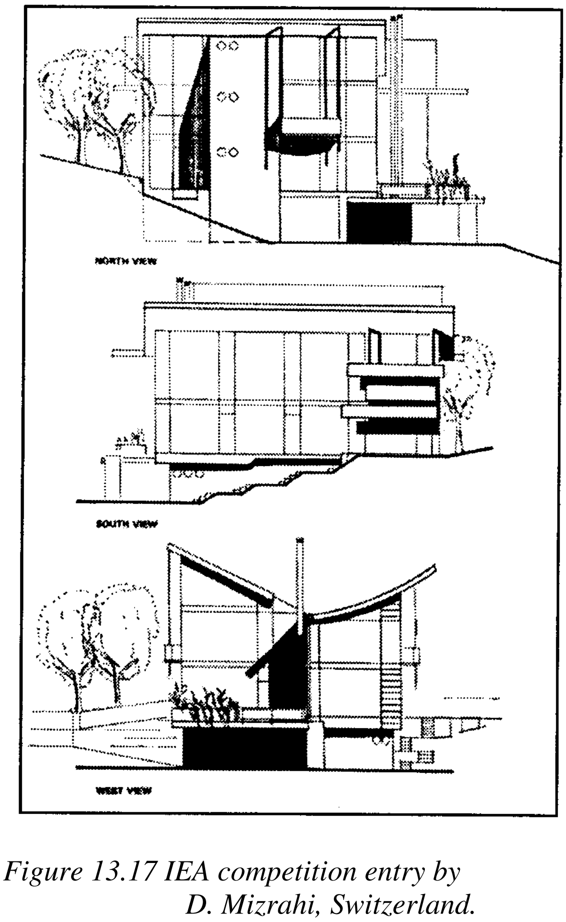


Figure 13.17 IEA competition entry by D. Mizrahi, Switzerland.

Figure 13.18 IEA competition entry by D. Mizrahi, Switzerland.

13.6.3 A conference and cultural centre
G. Kiss, USA

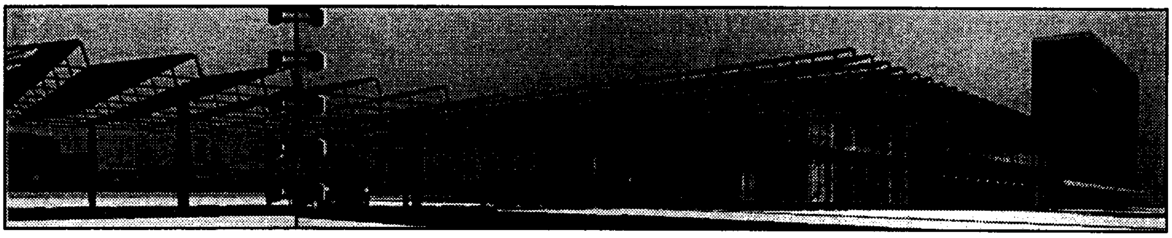


Figure 13.19 IEA competition entry by G. Kiss, USA.

Large-area, thin-film photovoltaics are used throughout. Uniform appearance, large size and low cost are the principle advantages of this type of PV. In each application in this design, collateral energy benefits (daylighting, thermal) are maximized while initial costs are minimized by multifunctional construction. The conference centre roof sawtooth is directly supported by box trusses tilted to support the photovoltaics while providing drainage sufficient to keep the modules clean, and providing clerestory area for full daylighting. Heat buildup (not needed for space heating in this climate) is circulated below the trusses and exhausted outside.

The hotel curtain wall is internally ventilated from floor to floor by convention dampers at the head and sill of each window. Hot air from the wall cavity is directed in or out according to demand. This avoids the costs of a full double wall system while providing the flexibility of operable windows.

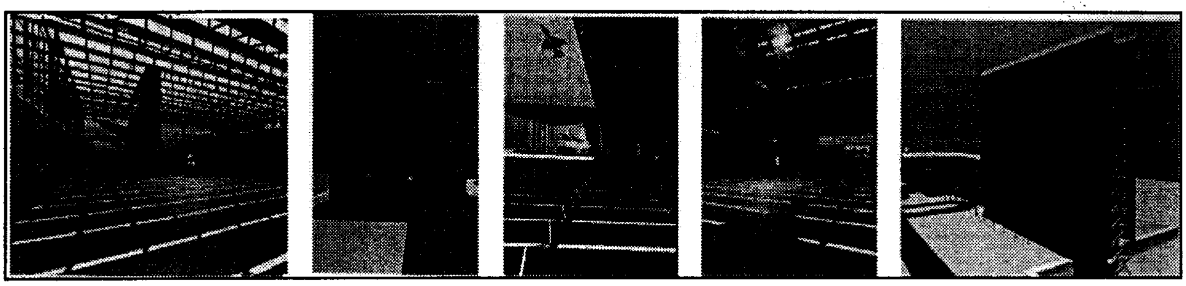


Figure 13.20 IEA competition entry by G. Kiss, USA.

13.6.4 An Energy-Conscious Office Building in Ankara C. Elmas, USA

There is no example of photovoltaics integration to buildings in Turkey. In order to make this technology acceptable, this project uses the PV modules as sunshades that are reminiscent of traditional mashrabiyas (wood lattice screens). PV modules are used with different configurations, transparencies and patterns at each facade in order to respond to the sun, views from the offices, character and scale of the particular facade.

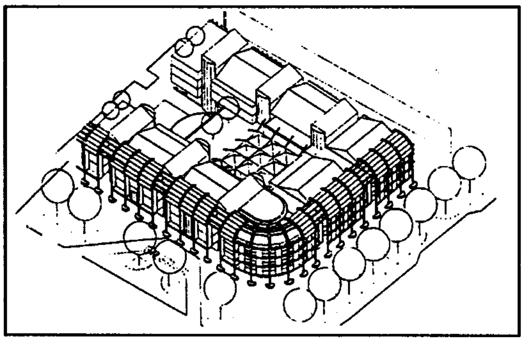


Figure 13.21 IEA competition entry by C.Elmas, USA.

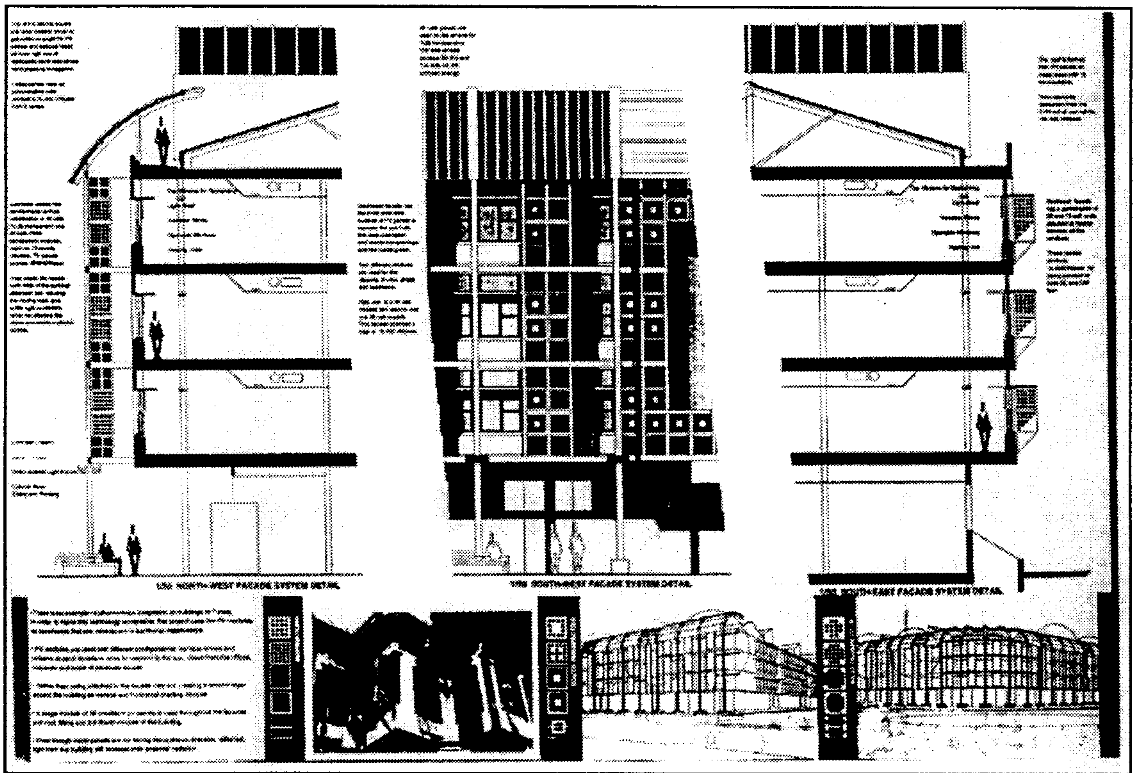


Figure 13.22 IEA competition entry by C. Elmas, USA.

13.7 German Architectural Ideas Competition 1994

The architectural ideas competition "Photovoltaics in Buildings" was initiated to encourage architects in cooperation with engineers to tackle the technically and aesthetically challenging problem of building integration of photovoltaic systems. It was supported by the Federal Ministry of Education, Science, Research and Technology under a grant to the Fraunhofer Institute for Solar Energy Systems (FhG-ISE) in Freiburg, Germany and organized by the Institute for Industrialization of Building Construction (Institut IB) in Hannover, Germany.

Using a building that was in planning and/or under construction anyway, possibilities for the integration of photovoltaic systems with high architectural quality were to be shown. The conditions for and the consequences of the integration were to get special attention with respect to the building. The buildings could be of any size and location within Germany, e.g. office and administration buildings, traffic facilities, sports facilities, convention halls, industrial buildings, schools or residential buildings.

The jury met in September 1994 to evaluate the 30 competition entries. The entries were judged in three rounds according to the following criteria:

- The overall architectonic concept,
- the overall energy concept,
- the integration of the photovoltaic elements,
- the transferability of the solution,
- the expense and the gain from the photovoltaic systems used.

Seven entries have been awarded and mentioned:

13.7.1 Zentrum für Kunst und Medientechnologie, Karlsruhe (Schweger + Partner, Hamburg)

An industrial area from the turn of the century will be modernized and prepared for the Center for Arts and Media Technology. The photovoltaic generators will be integrated in the transparent roof of the patios. This gives a multiple effect:

- Reduction of energy entry and air conditioning power by about 90 kW,
- a photovoltaic generator with a nominal power of about 100 kW,
- direct feeding of the electrical power into the overhead line of the Karlsruhe trolley cars (no batteries or current inverters).

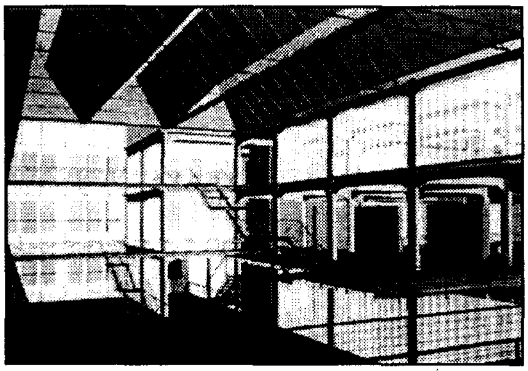


Figure 13.23 Visible photovoltaic panels above the entry hall.

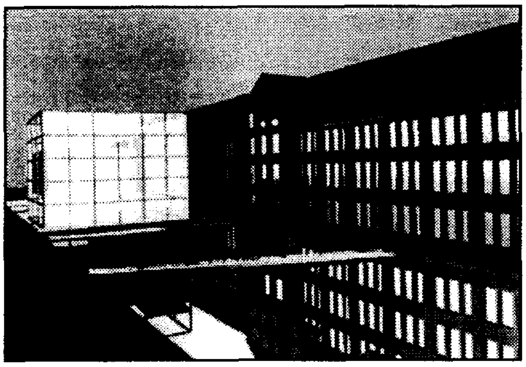


Figure 13.24 Cube of music studio outside the existing building.

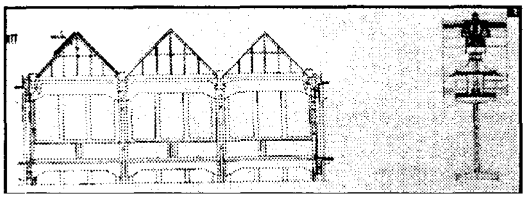


Figure 13.25 PV array on top of the music studio.

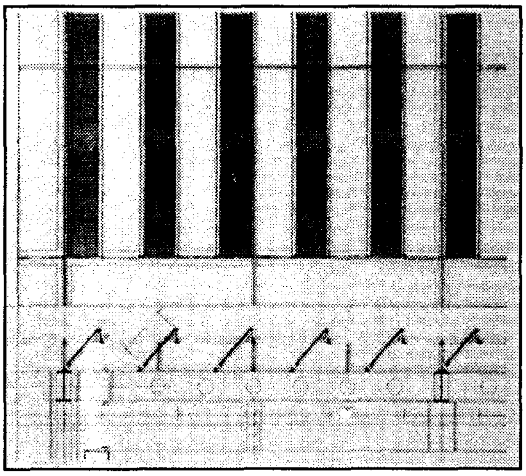


Figure 13.26 Section of the glass roof

13.7.2 Exhibition building "Haus des Waldes", Stuttgart (Dipl.-Ing. Michael Jockers, Stuttgart)

The pavilion contains an exhibition hall and supporting facilities. It is located in the Stuttgart city forest close to the television tower. The photovoltaic generator (14.5 kW) is used in addition to other energy saving measures (passive heat gains, daylighting, high insulation of opaque components, use of wood as load-bearing material, solar collectors for hot water supply).

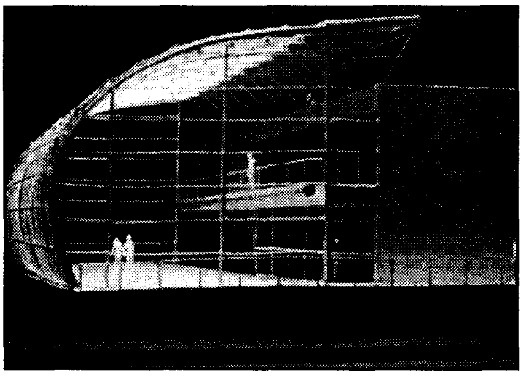


Figure 13.27 Model view of "Haus des Waldes".

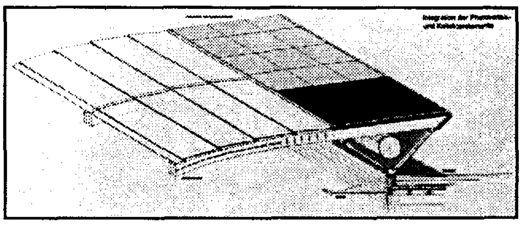


Figure 13.28 Detail of roof integration ("Haus des Waldes").

13.7.3 Housing project with nine apartments in Aalen (Kerler-Amesöder-Braun, Fellbach)

The terrace-shaped apartment building shows an interesting way of integration of the photovoltaic generator in combination with windows and loggias. The system is dimensioned to cover approximately two thirds of the yearly electrical energy consumption. Even during the summer months, almost all of the energy generated is thus consumed within the building. Excess energy is fed into the mains.

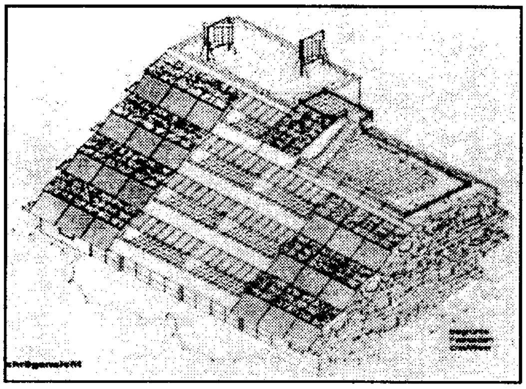


Figure 13.29 Section terrace.

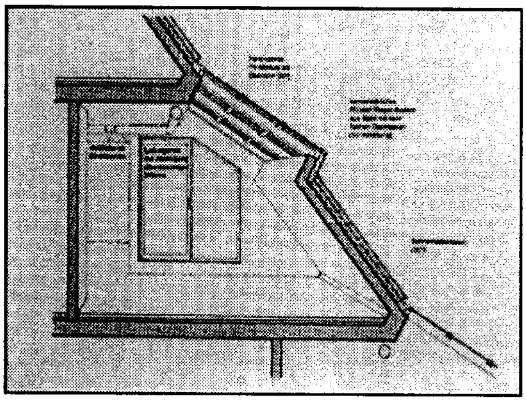


Figure 13.31 Section room.

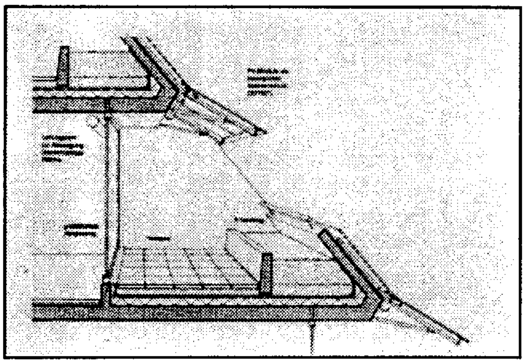


Figure 13.30 Bird's eye view.

13.7.4 Administration building for Nürnberger Versicherung, Nürnberg (P. Dirschinger, F. Bifang, Ammerndorf)

This is a large administration building (about 4500 employees) with photovoltaic generators integrated into different components (among others noise-absorbing walls, shading devices and an advertising sign). The total nominal electrical power is 366 kW. Other measures related to the energy consumption are transparent insulation, thermal collectors, daylighting, cold buffering, heat recovery and optimal insulation of all outer walls.

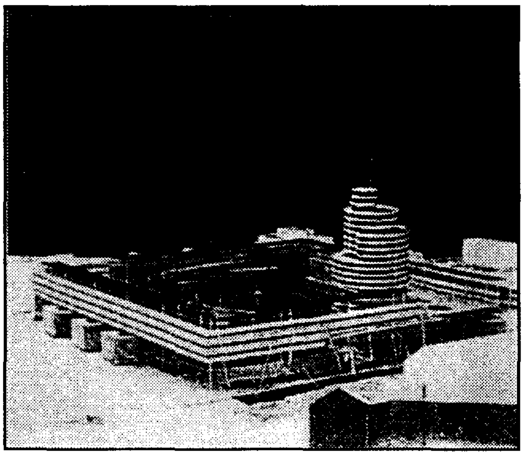


Figure 13.32 Model view.

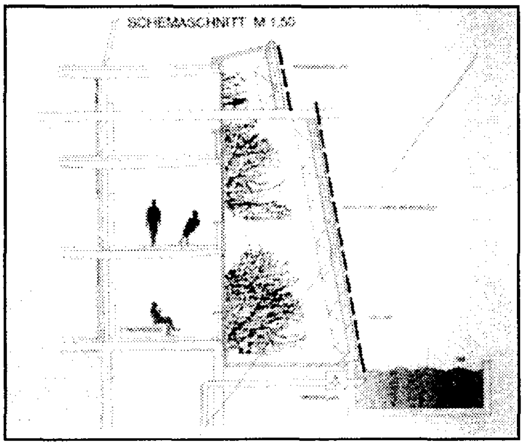


Figure 13.33 Section of sound protection wall with PV array.

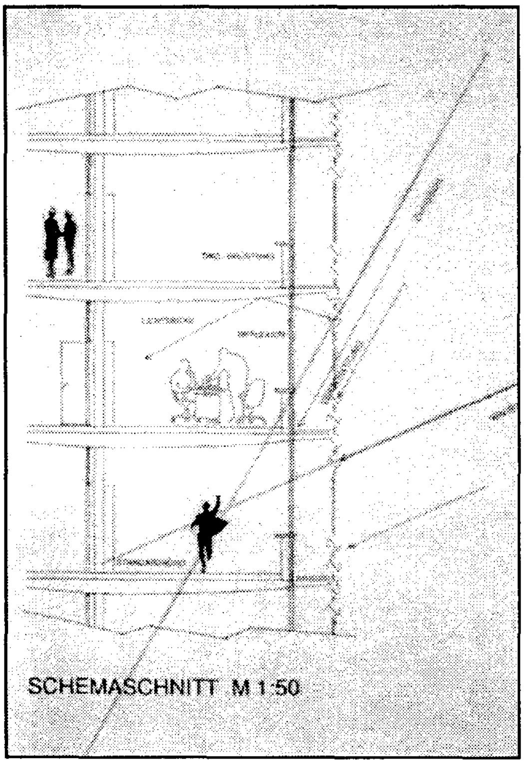


Figure 13.34 Section with shading PV elements.

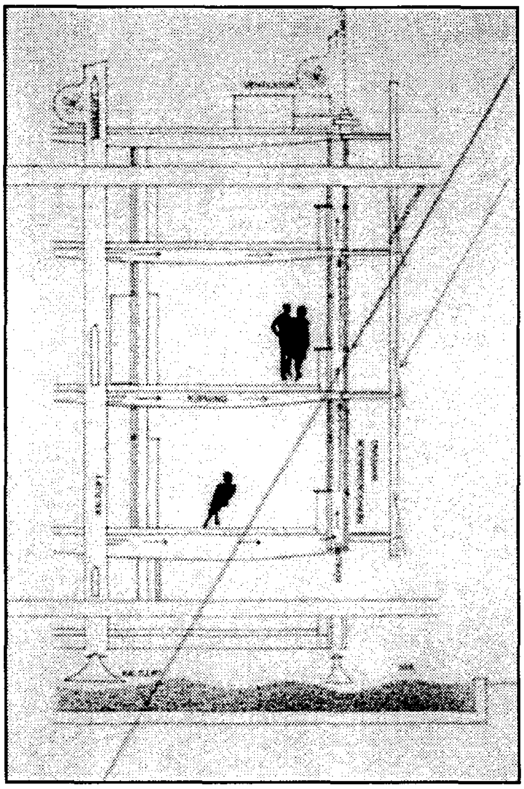


Figure 13.35 Section of ventilated facade.

13.7.5 Office building Luxemburger Stra-Be, Wirth (Elkin + Hövels, Cologne)

This building is planned for a private investor on the outskirts of Cologne on a corner site with good traffic connections. Several energy-relevant measures are planned:

- High-insulating glass facade,
- ventilation with heat recovery,
- integrated photovoltaic generators ("saddleback roof', "great sun shovel", "little sun shovel").

13.7.6 Ecological housing estate, Hamm-Heessen (H.F. Bültmann, Bielefeld)

This project, which will be built in two phases, will provide about 100 housing units of different types. The authors plan to approximately cover the yearly electrical energy consumption of the estate with a photovoltaic system of about 196 kW. Excess electrical energy will be fed into the mains.

Figure 13.36 View from east.

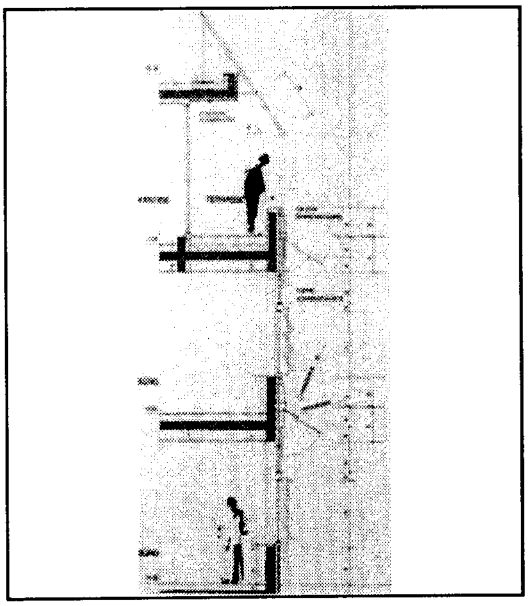


Figure 13.37 Facade section.

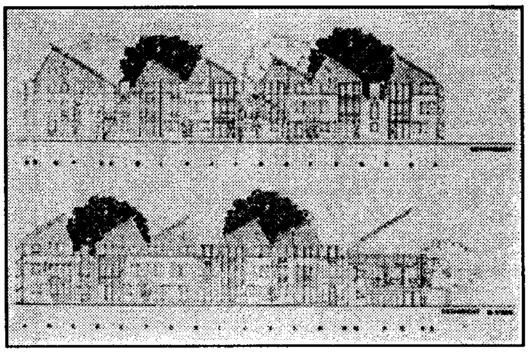


Figure 13.38 Integration details.

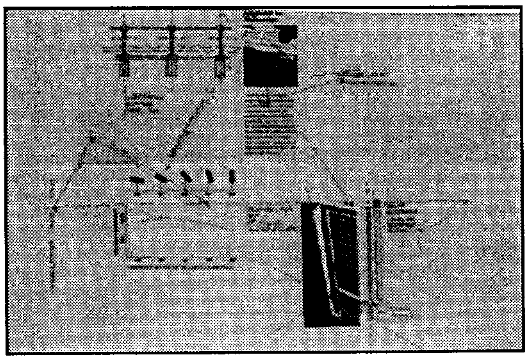


Figure 13.39 Western and eastern facade.

13.7.7 Radio relay station Tabarz I, Botterode/Thüringen (Streckebach Architekten, Kassel)

In this pilot project, a photovoltaic generator and batteries are used as backup to increase the reliability of the power supply. It is investigated as a possible way to replace diesel generators in environmentally sensitive areas. An architectonically interesting way of mounting the photovoltaic generator to the existing tower was found.

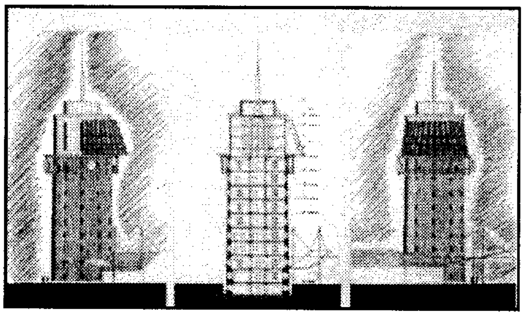


Figure 13.41 Tower with PV array.

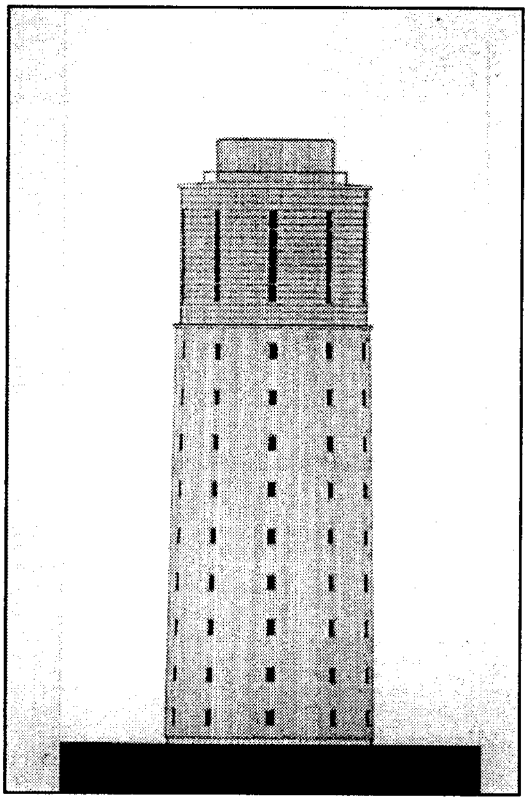


Figure 13.40 Existing tower.

Chapter 14

Integration Techniques and Examples

14.1 Introduction

The following selection of examples aims at presenting basically two key issues. One is the demonstration of a significant number of realised examples: facades, roofs and others show clearly that the architectural and technical integration of PV in buildings is feasible. And as a second message, the example descriptions show how the systems are mounted. Each mounting method is explained by a set of drawings. In addition to these example presentations, some general recommendations for module integration are given as follows.

Use of non-corrosive materials: On PV facades there are always small leakage currents around. In order to avoid corrosion caused by the leaking DC currents, it is essential to use non-corrosive construction materials. The joints and holding points require special concern.

Exchange of modules: The exchange of single modules should be possible without taking away a large part of the facade or roof.

Flat surfaces: To avoid shading, dust accumulation and to ease clearing by rain, protruding elements over the solar modules should be avoided. Fixation points for an unframed module may only little just out the module surface.

Easy cabling: Before the solar roof or facade elements are placed, the electrical connections have to be prepared. The use of reliable plug connectors makes a rapid and easy installation possible. During mounting of the modules no electricians should be required.

Minimum module handling on site: As most of the current solar modules consist of a glass surface, they require careful handling during transportation. Once being installed, the risk of damage is very low. This circumstance leads to the recommendation that module handling on the construction site should be reduced as far as possible. The module should go from the transportation container directly to a place along the roof or facade.

Module matching and string layout: Depending on the electrical layout and the module characteristics, they have to be assigned to a certain position in order to form groups or strings of modules with similar electrical characteristics. This can be done in the factory before shipping. The packing should then be accordingly in order to ease module handling on site.

Ventilation: As long as modules based on crystalline cells are used, it is an advantage when the modules' rear side is ventilated as with curtain walls. With amorphous modules the difference is negligible because the efficiency depends only little on temperature.

14.2 Stadtwerke Aachen, Aachen, Germany

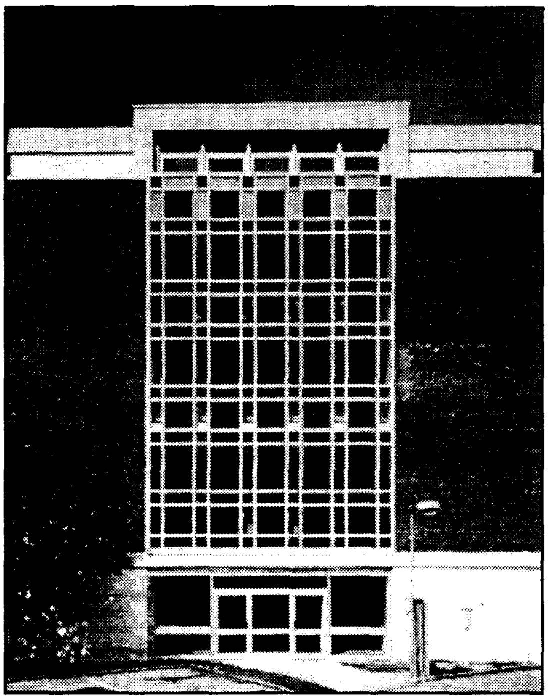


Figure 14.2.1 General view.

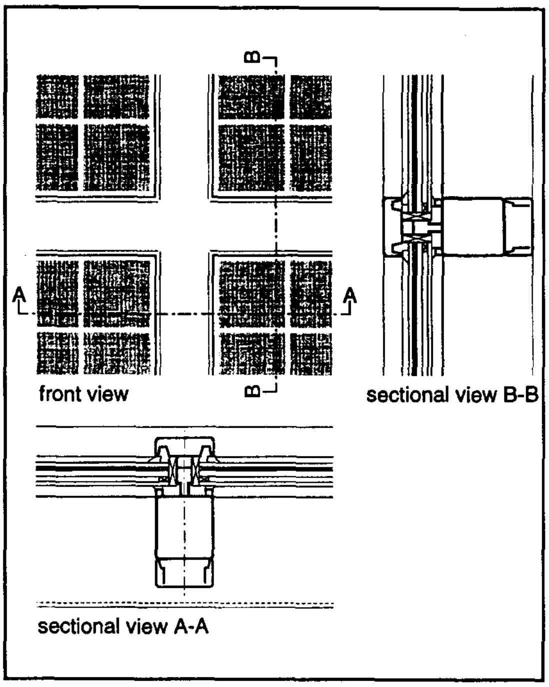


Figure 14.2.2 Detail of mounting structure.

Key data

Nominal power:	4.2 kW
Gross Area:	87 m2
Module manufacturer:	Flachglas Solartechnik
Inverter:	2 PVWR 1800
Start of operation:	1991
Owner:	Stadtwerke Aachen AG

Short description

The south-facing glass facade of the 20-year-old administration building of the Stadtwerke Aachen (Utility of Aachen) was replaced by a solar facade during the renovation of the heating services. Light-diffusing modules developed especially for this south-southeast front direct daylight into the staircase behind. The chessboard type combination of glass elements and the modules with dark-blue crystalline silicon cells between the compound glazing offers surprising patterns outside as well as inside.

This example was one of the first so-called multipurpose applications with PV modules. The PV modules act as semitransparent facade, as wall element including thermal insulation and as power production device. The wiring is integrated in the structure holding the modules.

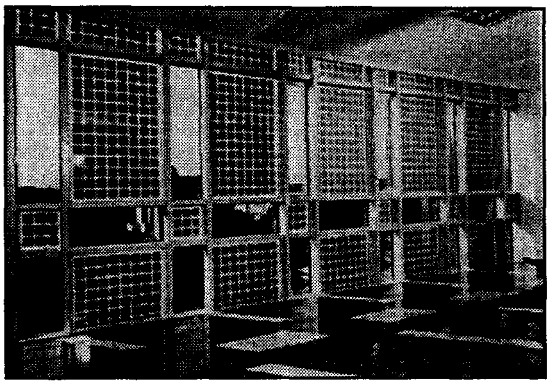


Figure 14.2.3 View of the facade from the inside.

14.3 Scheidegger Metallbau, Kirchberg, Switzerland

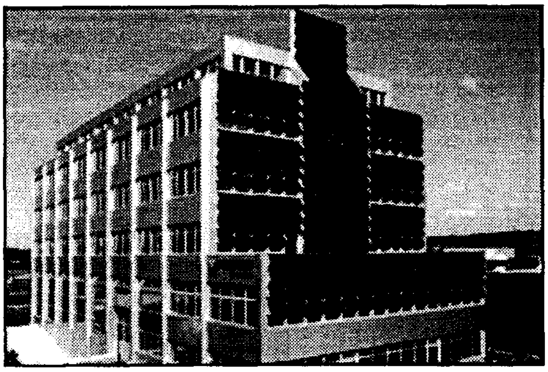


Figure 14.3.1 General view.

Figure 14.3.2 Detail of mounting structure.

Key data

Nominal power:	18 kW
Gross Area:	170 m2
Module manufacturer:	Solution
Inverter:	Solar Max
Start of operation:	1992
Owner:	Scheidegger Metallbau, AG

Short description

Just as important as the energy production was here the ability to gain knowledge about new architectural possibilities in facade design with PV modules. Besides the production of electricity and the aesthetic design, the weather protection of the building, the shading of workplaces near windows in summer and the combination of the production of electricity and hot air are other goals of this installation.

To make a better use of the PV modules, a part of the facade is built with reflecting elements. The whole installation is working properly, but there are high expenditures for attachment. Cheaper PV modules could be used effectively for the whole facade area.
The multifunctional design of the facade is sketched in Figure 14.3.3.

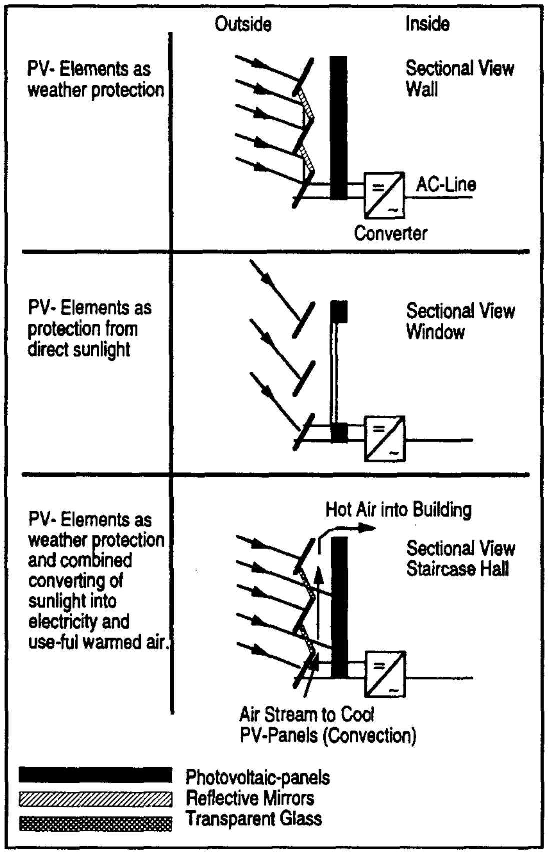


Figure 14.3.3 Multifunctional design of the PV facade.

14.4 ISET, Kassel, Germany

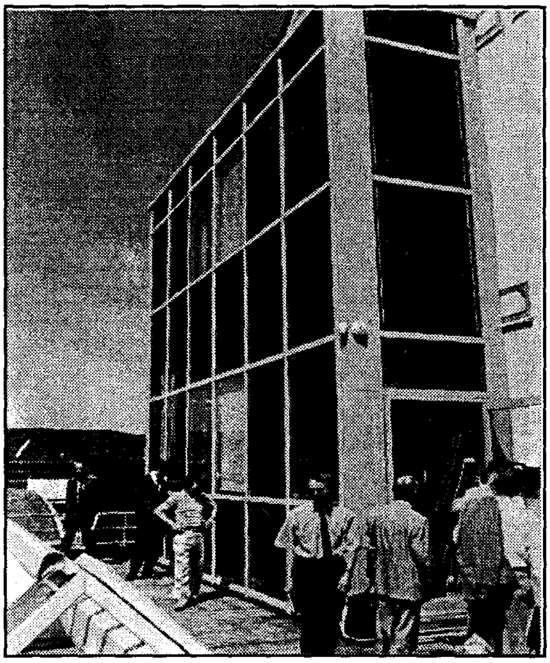


Figure 14.4.1 General view.

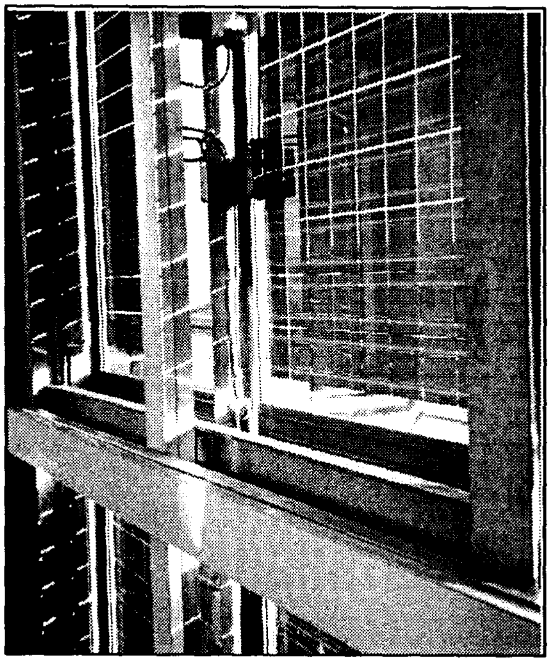


Figure 14.4.2 Detail view of the installation behind the facade.

Key data

Nominal power:	about 0.5 kW
Module manufacturer:	ASE GmbH
Inverter:	3 x NEG 1600
	3 x SLD 224
Start of operation:	1993
Owner:	ISET e.V., Kassel

Short description

The main idea of this project is the realisation of an experimental photovoltaic (PV) facade at an existing building at the University of Kassel. The facade consists of a PV array of 50 m^2 (75% south, 15% west and 10% east orientation) and is used for testing different components (modules or inverters) and concepts (mounting and electrical installation) in practice. Since July 1st, 1993, five different PV generators are in operation, their conditions are measured and recorded.

The project is funded by the Ministry of Environment of Hessia. The industrial project partners are ASE GmbH (DASA and NUKEM) and SCHÜCO International.

Detail of mounting structure

In this project existing industrial components are used for building up the PV facade. So a facade system was modified to integrate the PV modules. Three different sizes of modules are inserted: 1780 x 1180 mm, 1180 x 1180 mm and 580 x 1180 mm. The modules contain 160, 80 or 40 photovoltaic cells in order to be electrically connectable.

Main research aspects

The PV facade is exclusively designed for the following research aspects which enables answers to the questions and concerns of module manufacturers, facade builders, architects and energy industries. These are:

- edging quality of frameless PV modules,
- defect recognition to detect defects in the system,

- measuring technology, e.g. reference measuring,
- safety of persons and the system,
- energy processing, test of different types
- meteorology - recording of weather data
- installation - mechanical and electrical concepts,
- shadowing and the influence of HOT-SPOT-effect,
- mechanical tests - behaviour under extreme wind conditions,
- electrical tests - efficiency and isolation resistance.

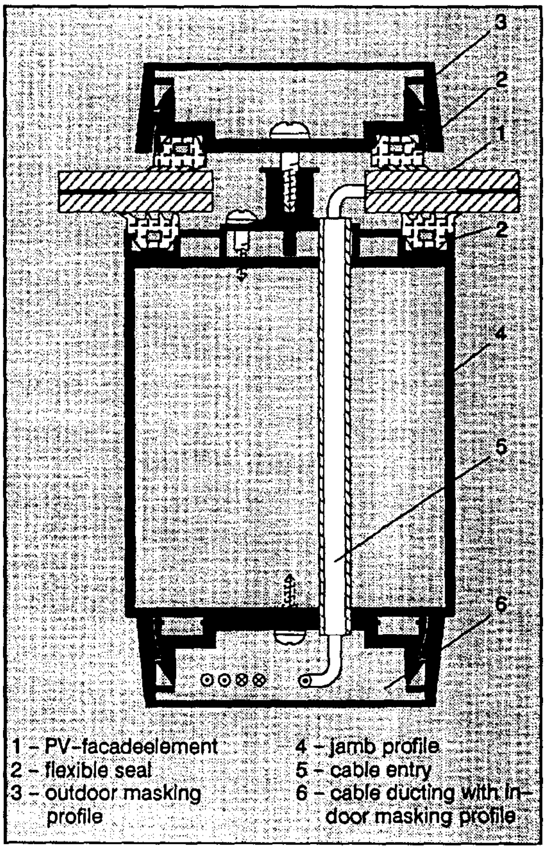


Figure 14.4.3 Detail view of the mechanical construction.

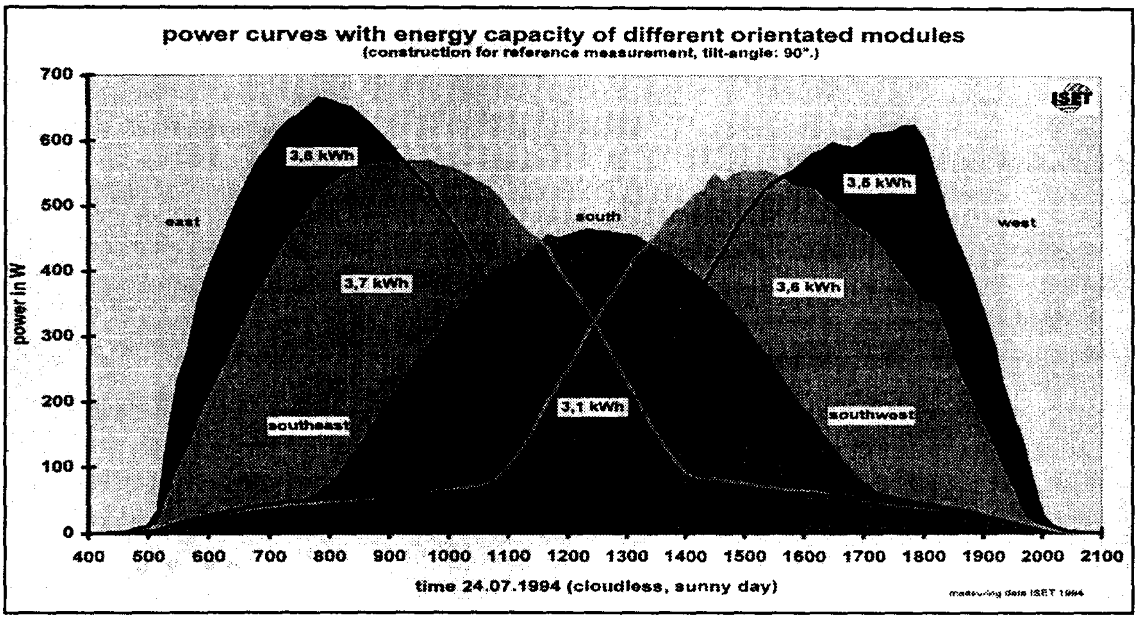


Figure 14.4.4 Energy input of reference PV module (refering to 1 kW).

14.5 Ökotec 3, Office building, Berlin

Figure 14.5.1 General view.

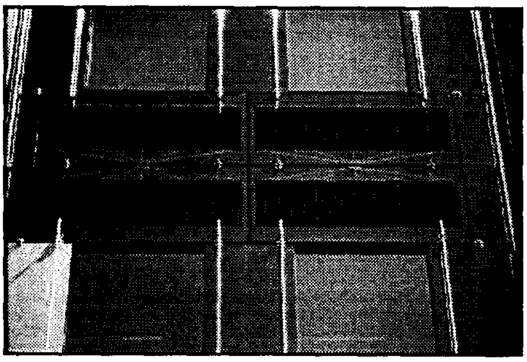


Figure 14.5.2 Detail of PV element.

Key data

Nominal Power:	4.2 kW
Gross area:	64 m2
Module manufacturer:	Flachglas Solartechnik GmbH
Inverter:	2 x PV-WR 1800 S
Start of operation:	1994
Owner:	Triangel Grund-stücksverwaltungs-gesellschaft

Short description
The goal to be achieved is to integrate a solar facade of the most progressive technical state into a new industrial building of the latest architecture. Special attention should be paid to obtain a good efficiency of the installation and to integrate the PV generator properly into the architecture.

The industrial building created by the architects Aicher, Jatzlau von Lennep and Schuler in Berlin-Kreuzberg, with a floor surface of 8100 m^2 was equipped with a grid-connected photovoltaic generator integrated in its south front. The 44 solar facade elements are integrated as cold facade elements into the framework system of a reflecting whole glass facade with interwork side ventilation.

The new "SJ" facade system used for the first time for a solar facade project stands out for its easy mounting system for glass panels. The solar facade modules are designed as blue glistening, partly reflecting double pane laminated glazing unit to harmonize best with the remaining reflecting "structural glazing" facade. The electrical connection is done by a standardized plug socket system.

With regard to the module configuration and production, the connection system - thought as a standard for future projects - as well as the aesthetic successful architectonic integration, this project sets an innovative example.

The facade system is particularly suitable for the integration of PV facade modules, as it holds frameless facade panes of any kind by a minimum of 4 fastening points through patented, star shaped stainless steel parts with elastic EPDM coating and is thus able to carry the frameless OPTISOL module assembly. Electrical connection: The collecting line is attached to the interior pane covered with solar control reflective insolating coating. The bypass cables coming from the panel board through standard sockets are connected with the modules. These modules are interconnected with a socket/plug system, the junction box being stuck to the glass back side of the module. The whole connection system makes the installation work easier and, if necessary, enables easy replacement of each individual module.

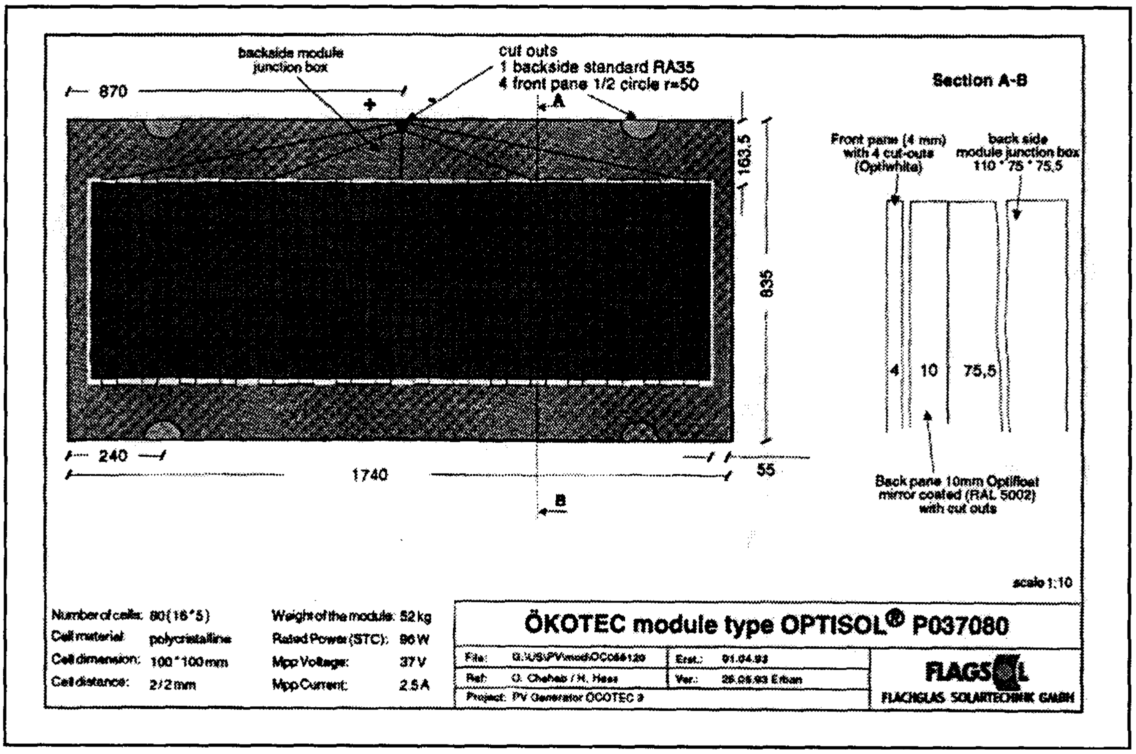


Figure 14.5.3 Module design drawing.

14.6 LRE building EPFL, Lausanne, Switzerland

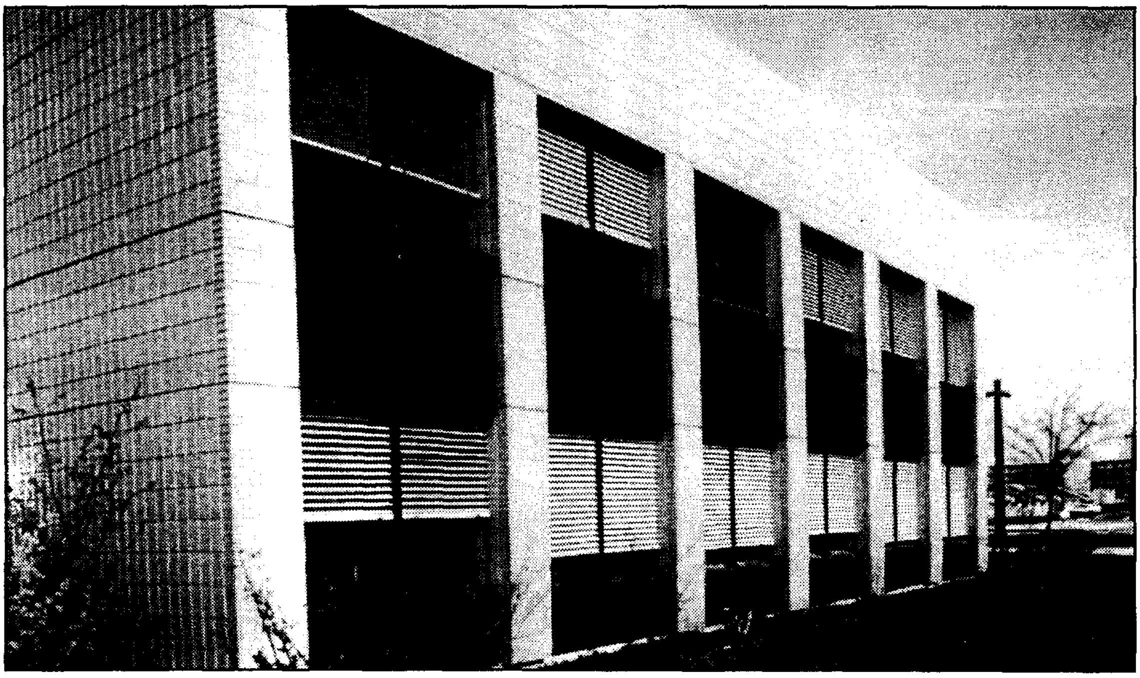


Figure 14.6.1 General view.

Key Data

Nominal power: 3 kW
Gross area: 28.5 m2
Module manufacturer: Flagsol AG
Inverter: Top Class 3000
Start of operation: 1993
Owner: EPFL Lausanne

Short description

On the outer wall of the Electric Power Systems Laboratory the metallic thermo-lacquered cladding was replaced by photovoltaic panels in sheeted glass.

As existing elements were replaced, particular attention was given to the following details:

- identical dimensions through made-to-measure photovoltaic modules;
- uniform color due to the use of polycristalline cells aligned edge to edge without visible electrical connections; within the panel itself a frame painted the same blue as the metallic structure to hide the main electric connections;
- minimum specularity due to acid treatment of the glass (reduced reflection) to produce an effect as similar as possible to that of the former cladding and differenciate the facade elements from the windows.

The panels were mounted in a traditional way by VEC-glueing and recessed fitting of the metal sections.

Mounting technique

As can be seen on the drawing of Figure 14.6.2 the mounting technique is quite traditional for glass panels:

- a metal frame is anchored into the wall, in this case using existing fixing points (Figure 14.6.3);
- two Z-shaped aluminium profiles are screwed onto the frame, over a protective sheet for the thermal insulation (Figure 14.6.4).

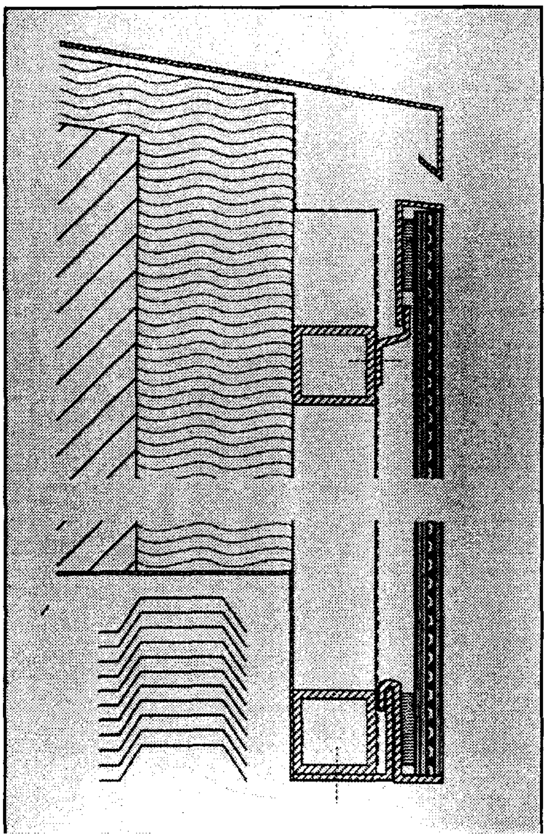


Figure 14.6.2 Cross-section of mounting design.

Figure 14.6.3 Detail: Metal frame.

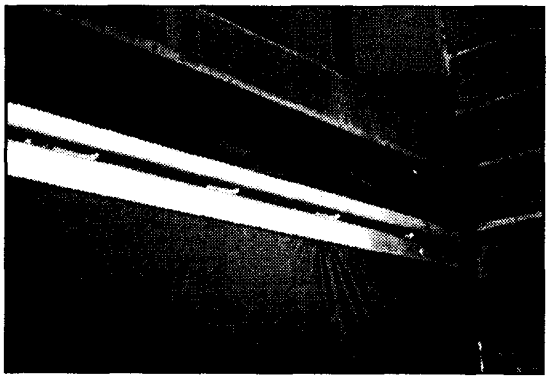
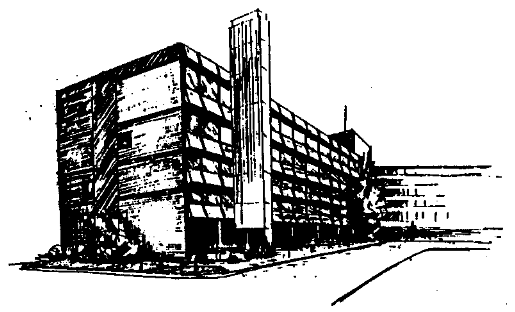


Figure 14.6.4 Detail: Z-shaped profile.

14.7 Northumberland Building, University of Northumbria, England



Artist's impression of the PV-clad facade of the Northumberland building, at the University of Northumbria.

Figure 14.7.1 General view.

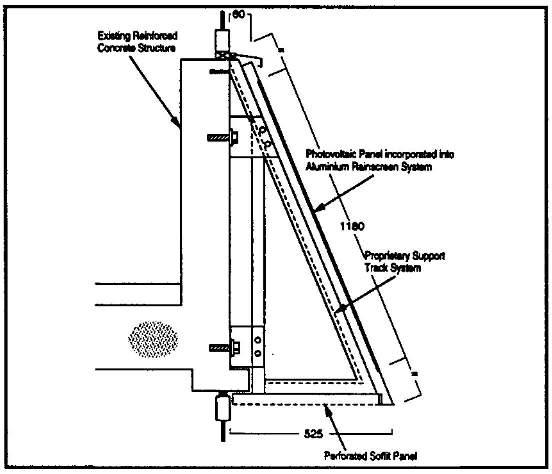


Figure 14.7.2 Sectional view of mounting structure.

Key data

Nominal power:	39.5 kW
Gross Area:	Laminate area 293m2 Clad area (covered) 442 m2
Module manufacture:	BP Solar
Inverter:	SMA PV-WR-T 40 kW
Start of operation:	December 1994
Owner:	University of Northumbria

Short description

The aim of this project is to provide a demonstration of an architecturally integrated photovoltaic (PV) facade on an existing building at the University of Northumbria in North-East England. The project will demonstrate the feasibility of PV cladding in a northern European climate and allow investigation of the installation details and supply profile of the electricity generated. This project will supply the first example of integrated PV cladding in the UK, in order to stimulate interest in this technology and to provide information for future integration into appropriate buildings.

The project partners are IT Power Ltd, Newcastle Photovoltaics Applications Centre, Estate Services Department of the University of Northumbria, Ove Amp & Partners and BP Solar.

The project is to fit rainscreen overcladding to the south facade of the Northumberland building. PV elements are integrated into this cladding system. This provides a total installed capacity of more than 39 kW. The cladding panels are approximately 3m x 1.4m, and each contains five PV laminates. There are 465 PV laminates used in the whole array, each rated at 85W.

The Northumberland building is a typical example of a 1960s construction for which the cladding has provided protection for over 20 years before refurbishment is required. Many similar buildings exist across Europe which will all require recladding within the next decade. The Northumberland building suffers from shading for some portions of the day and can therefore be used to study the effect of partial shading on such a system.

14.8 House Weiss, Gleisdorf, Austria

Figure 14.8.1 General view.

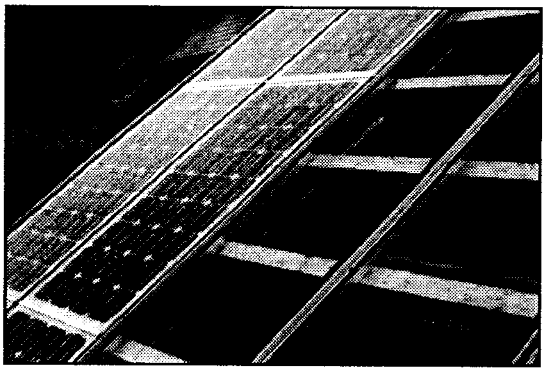


Figure 14.8.2 Detail of mounting structure.

Key Data

Nominal power:	2 kW
Gross Area:	18 m2
Module manufacture:	Siemens M50L
Inverter:	Siemens PV V 2500
Start of operation:	1992
Owner:	private owner

Short description

Within the framework of the Austrian "200 kW Rooftop Programme" Mr. Weiss installed a photovoltaic system on the roof of a building near his low energy house in 1992. The single family house has a living area of 150 It is located close to the small town of Gleisdorf in the Southern Austria. The heating load of the well insulated building was calculated to be 7 kW.

Mr. Weiss and his family already use very energy efficient household appliances. Data of the last years indicate, that only 2135 kWh of electric energy is annually consumed. This can only be achieved by using an 8m^2 solar thermal collector system providing hot water for the dish washer and the washing machine. An auxiliary electric heating element is used to supply domestic hot water in wintertime (it consumes 335 kWh annually). The house is heated by a wood stove and some passive solar gains are utilized.

For better integration of the solar modules in the wooden roof structure the house owner decided to use Siemens M50L laminates. The Solar generator consists of 4 strings with 10 modules each.

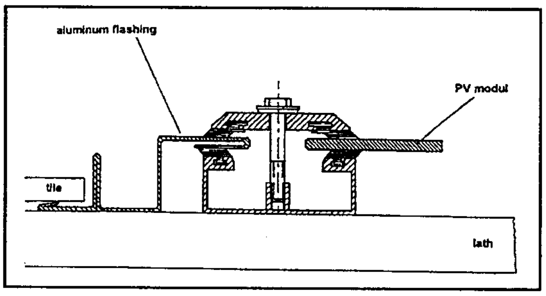


Figure 14.8.3 Sectional view of the horizontal structure.

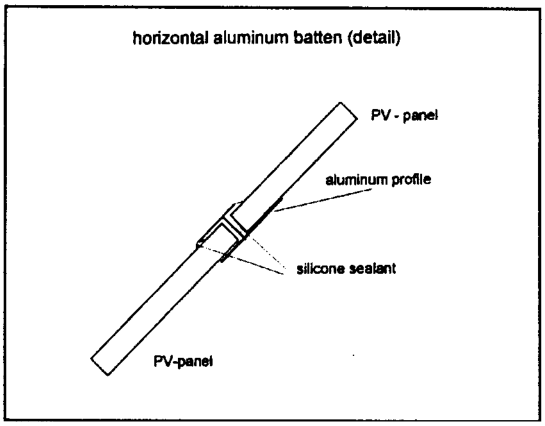


Figure 14.8.4 Sectional view of the vertical structure.

14.9 BOALsolar profile system for PV laminates

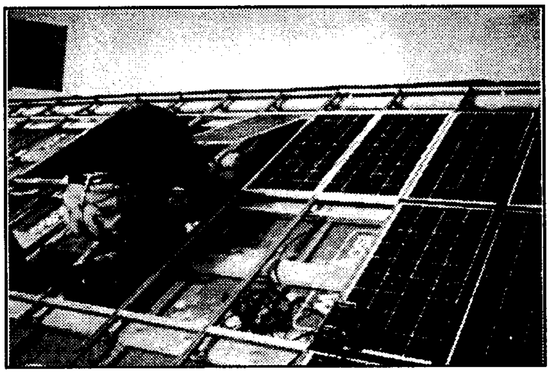


Figure 14.9.1 Detail of mounting structure.

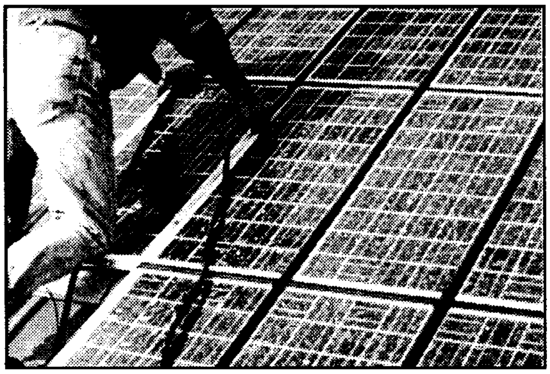


Figure 14.9.2 Detail.

Short description

This profile has been developed by R&S, Ecofys and Boal (a large manufacturer of profiles for greenhouse constructions). The main objective of the system is to provide a standard PV mounting system for slanted roofs.

The profile has been applied successfully in a number of projects, including the 250 kWp roof integrated PV system in Amsterdam and a 100 kWp roof integrated system in Amersfoort (both in cooperation with the local utility).

The mounting system has been tested in accordance to general Dutch standards for roofing materials (including water tightness, robustness and fire protection).

The system consists of vertical and horizontal aluminium profiles. The vertical profiles are screwed to the battens (which are slightly higher than standard battens, in order to provide enough ventilation). Horizontal profiles are glued to the PV laminate (prefab) and fitted into notches in the verticals. A plastic profile, placed over the vertical profiles, holds the laminates down and provides absolute water tightness.

Compared to mounting PV modules above the tiles, this system offers the following advantages:

- Avoidance of tile and tiling costs:
- High aesthetic value;
- Easy mounting technique;
- Well-proven construction system;
- Highly standardized, leading to lower costs;
- In-factory preparation of mounting (glueing of profiles).

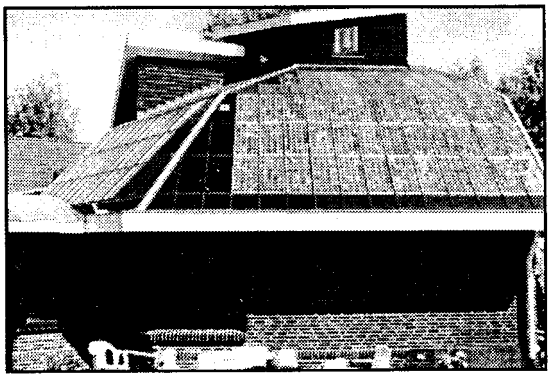


Figure 14.9.3 General view.

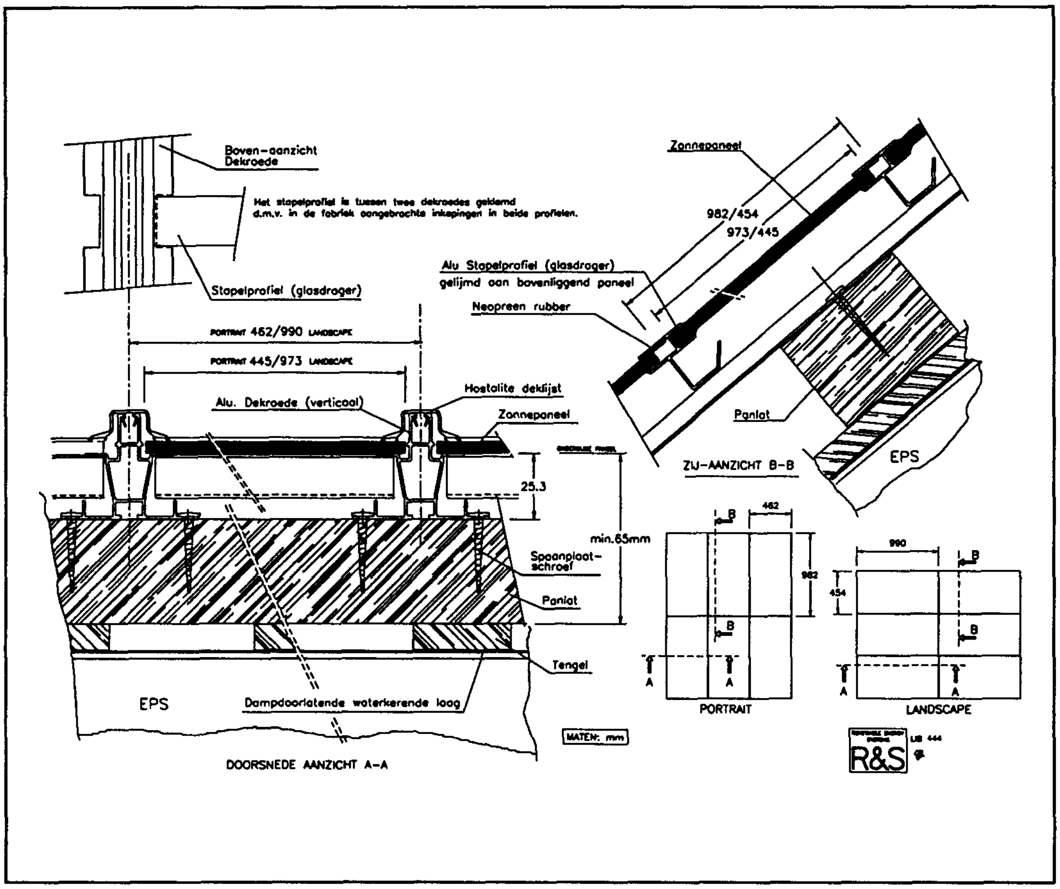


Figure 14.9.4 View, front view, side view.

14.10 Solar Tile, Mönchaltorf, Switzerland

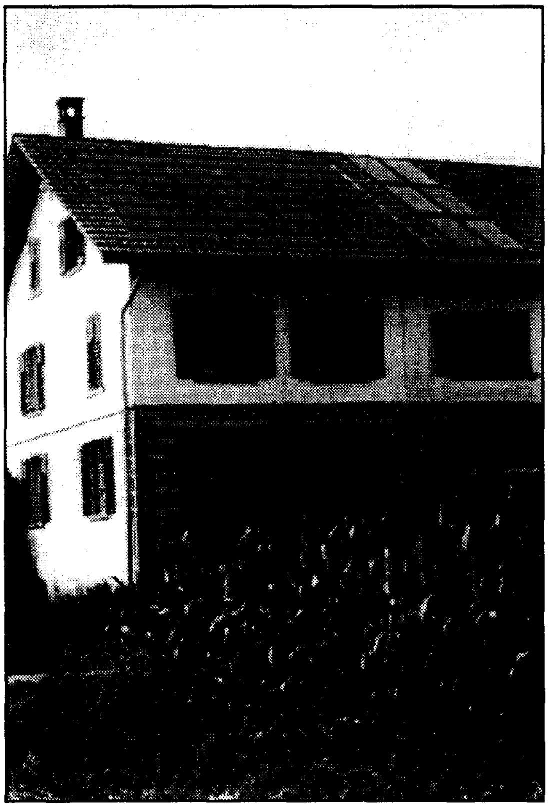


Figure 14.10.1 General view.

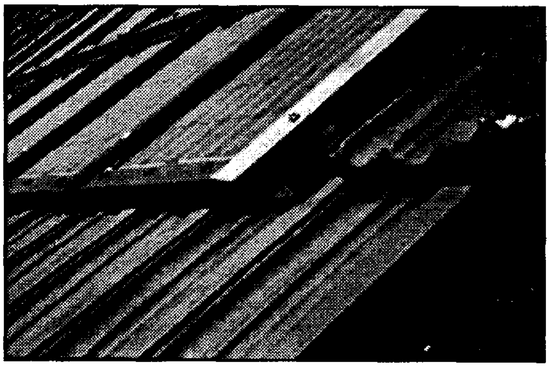


Figure 14.10.2 Detail of mounting structure.

Key **data**

Nominal power:	3 kW
Gross Area:	36 m2
Module manufacturer:	Plaston-Newtec
Inverter:	Solcon 3300
Start of operation:	1992
Owner:	PMS Energie AG

Short description

New solar roof tiles represent a real photovoltaic integration: the system is not installed on the roof, rather, the roof itself is the system. The roof elements installed on an old residential house in Mönchaltorf, made of glass, were developed and produced in Switzerland.

Each one of the 76.6 x 50.5 cm^2 lage, rain proof resin boards with integrated photovoltaic cells replaces five conventional tiles.

Under the guidance of Alpha Real AG, a group of three companies has developed a Solar Tile to cover inclined roofs in one step. The tile is based on a standard laminating technology equipped with a special frame and newly designed module interconnections. Particularly, this new solar tile design had to employ the following functions:

- easy mounting like ordinary clay tiles;
- the essential function of the clay tile (i.e. weatherproof building material) has to be substituted by the solar tile;
- the sealing of the roof has to employ age old roof sealing techniques, as they are functioning on clay tiles without silicon or rubber sealant;
- the interconnection among solar tiles and between solar tiles and clay tiles has to be simple, easy to install, and absolutely reliable;

- to speed up installation time, the electrical connection from module to module has to be made with plug connectors;
- roofmg professionals have to be able to do the installation and wiring work on the roof without extended training;
- every solar tile has to be easily exchange-able;
- the life assessment of the plastic frame has to be at least as long as the minimal expected life time of a solar module;
- it has to incorporate existing frameless solar modules of different thickness and to be able to adapt to future solar module development such as thin film technology or similar.

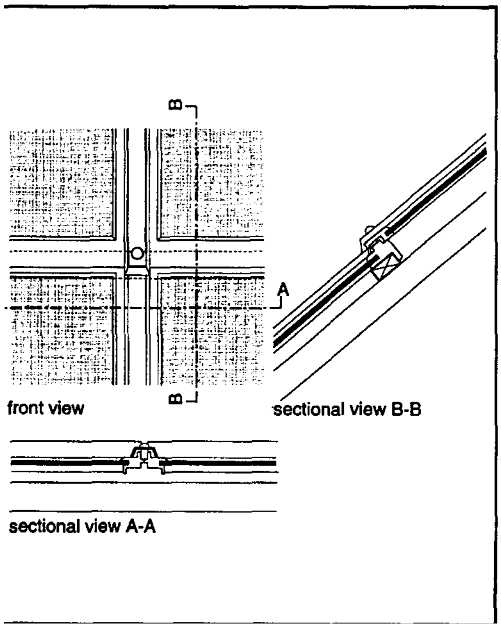


Figure 14.10.3 Front view, sectional views.

14.11 Pietarsaari Solar House, Finland

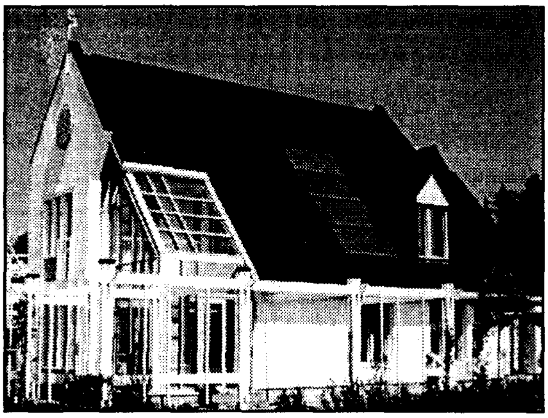


Figure 14.11.1 General view.

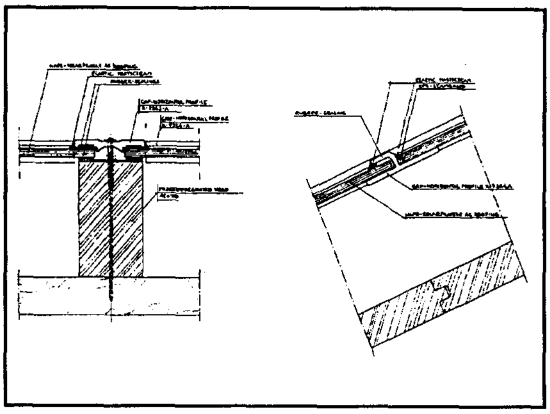


Figure 14.11.2 Detail of mounting structure.

Key data

Nominal power:	2.2 kW
Gross area:	55 m2
Module manufacturer:	APS
Inverter:	SMA 1800
System design:	NAPS
Start of operation:	1994
Owner:	private owner

The aim of the Pietarsaari Solar House, constructed in the Pietarsaari House Fair 94 area, is to demonstrate to a wide audience that with current commercial technology energy consumption of houses can be dramatically reduced. During the House Fair exhibition more than 100,000 people visited the Solar House. In contrast to a conventional average Finnish house, which needs purchased energy of 160-250 kWh/m^2 for space heating, water heating and electricity, the corresponding energy demand has been reduced to roughly 20-30 kWh/m^2 in the Pietarsaari low energy house. The low energy consumption has been achieved with a combination of improved insulation, heat recovery from ventilation, heat pump with ground pipes, super windows as well as by utilizing solar energy. The house has 10 m^2 solar thermal collectors and a 2.2 kW grid-connected PV system.

The aim of PV integration into this house was to develop and test a simple and inexpensive watertight photovoltaic roof structure and to test it. The system has been constructed by using frameless large area amorphous photovoltaic modules and glass fibre profiles.

Amorphous modules were chosen to be able to cover the whole roof with the chosen 2.2 kW array and thus to achieve a uniform appearance.

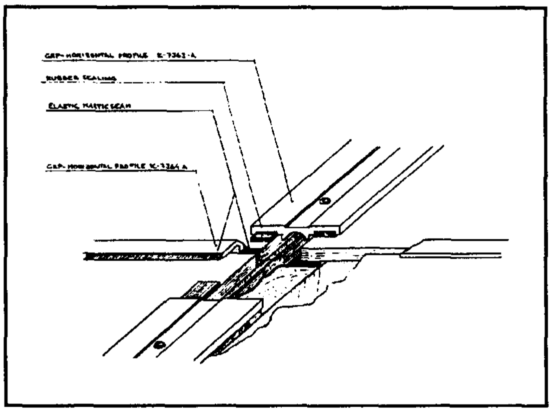


Figure 14.11.3 Construction detail.

By using large area modules the number of connections and mounting profiles could be minimized. Also the short energy payback time of amorphous technology was considered to be meaningful. The benefits of composite profiles are:

- similar thermal expansion to that of glass;
- good electrical and heat insulation characteristics;
- good corrosion resistance and
- good mechanical strength.

The watertight PV roof was achieved by mounting the frameless modules over the existing vertical wooden roof substructure with rubber seals and long vertical glass fibre profiles going from the top of the roof down to the bottom of the roof. The horizontal seam between the modules has been sealed with a fork-shaped profile and elastic silicon mass. This type of simple integration method was planned in order to reduce the cost of material as well as the installation time.

14.12 Office Building, Utility of Meilen, Switzerland

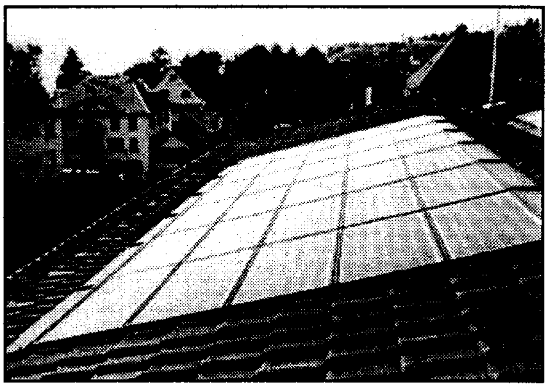


Figure 14.12.1 General view.

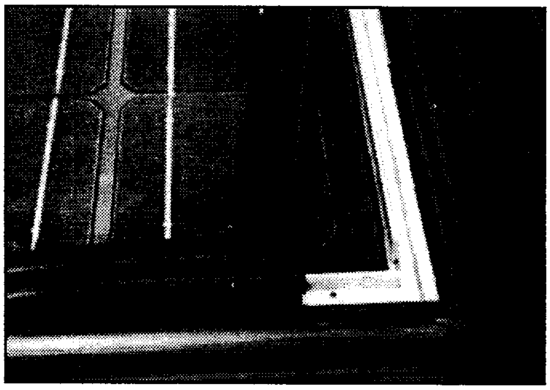


Figure 14.12.2 Detail of mounting structure

Key data

Nominal power: 3 kW
Gross Area: 30 m2
Module manufacturer: Helios
Inverter: Solcon
Start of operation: 1992
Owner: Utility Meilen

Short description

Schweizer Metallbau AG has developed a roof-integrated system that is able to carry PV modules or thermal collectors. The installation area is completely covered by the construction, conventional tiles are only necessary to cover the remaining area of the roof. A combination of photovoltaic and thermal use of solar energy is possible.

A relatively large space on the backside of the module allows a sufficient air circulation for module cooling and/or use of the low temperature heat. All current dimensions of PV modules or laminates are possible to apply, but there are some restrictions regarding the modules' edges. In order to not cover solar cells by rubber profiles, the distance between the edges and the first cells shall be at least 15 mm. The thickness of the module in the edge zone must be within 4 to 5 mm.

The laminate is completely kept by rubber profiles. There is no direct join to the aluminium profile. The top rubber profile is made of EPDM.

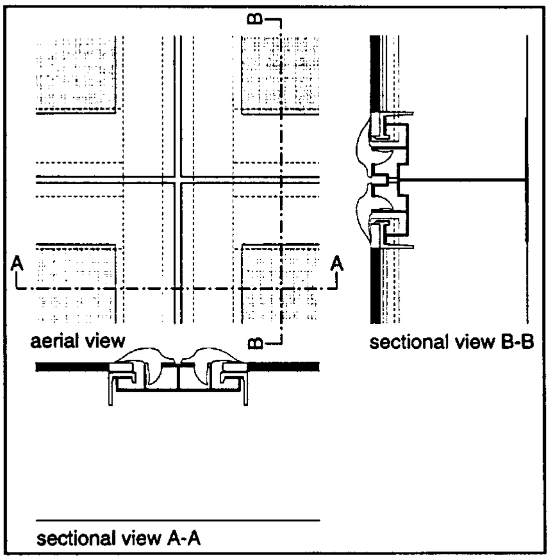


Figure 14.12.3 Aerial view, sectional views.

14.13 Integrated Solar Roof, Boston, USA

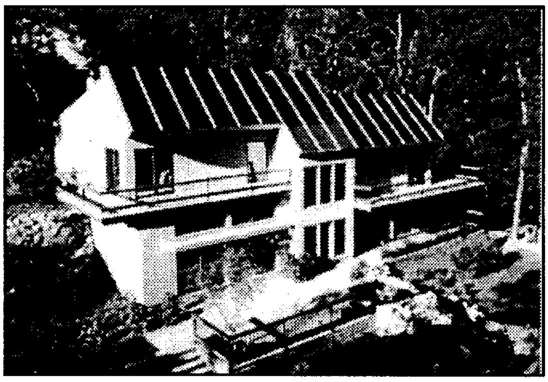


Figure 14.13.1 General view.

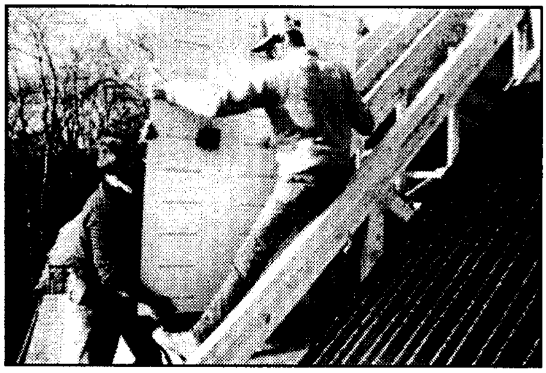


Figure 14.13.2 Detail of mounting.

Key data

Nominal power:	4.3 kW
Gross Area:	40 m2
Module manufacturer:	Mobil Solar
Inverter:	American Power Conversion
Start of operation:	1984
Owner:	private owner

Short description

In 1984, 10 million viewers watched a TV programme introducing the latest technology in the area of photovoltaics at that time; it presented this one-family house in the north east of the US. The roof facing south is tilted by 45 degrees and divided into three sections. Twelve photovoltaic modules are located in each of the left and right sections, while the middle section contains roof-integrated solar collectors.

The well-insulated house was designed as a model for a country-wide energy-saving programme. The private residence meets high demands in terms of both aesthetics and comfort. The frameless PV modules are the finished weathering skin and are mounted directly over the wooden roof trusses without structural roof sheating or additional weatherseal. Free air circulation behind the modules is encouraged with generous inlet and outlet vents designed to achieve maximum air flow. The PV laminates were designed specially for direct roof integration and the thermal collector uses the same glass cover. The result is a fully integrated appearance for both systems.

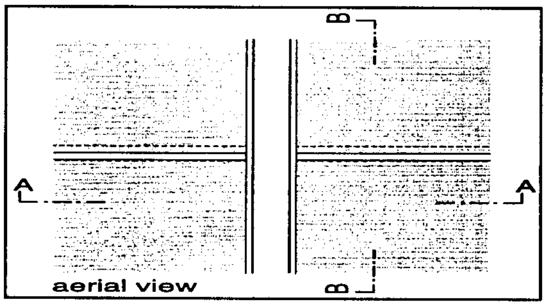


Figure 14.13.3: Aerial view

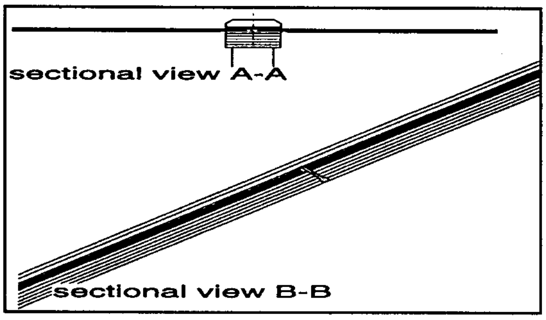


Figure 14.13.4: Sectional views

14.14 Norwegian Solar Low Energy Dwelling

Figure 14.14.1 General view.

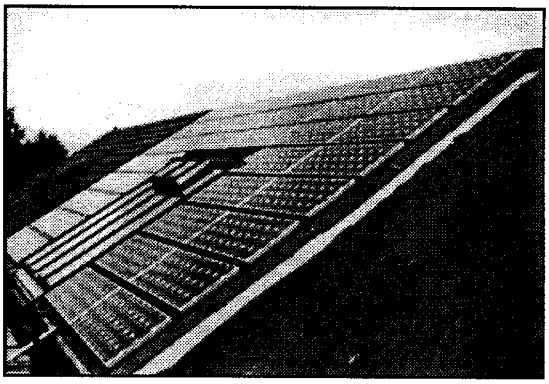


Figure 14.14.2 Detail of PV modules mounted on the roof.

Key data

Nominal power:	2.52 kW
Gross Area:	22.6 m2
Module manufacture:	BP Solar
Inverter:	SMA PV-WR 1800
Start of operation:	1994
Owner:	Hamar Building Society

Short description

As this was the first grid-connected, roof integrated PV system in Norway, there existed no ready-to-use mounting structures for PV modules on the market. Therefore, a safe and simple method of integration was adopted.

The PV panels were fitted on the south facing roof of the middle apartment of the 3-unit row house. Prior to being mounted on the roof, the PV modules were fixed onto aluminium profiles in units of two, as shown in the figure. In this way, a quick and simple mounting procedure was obtained.

Aluminium profiles were placed in between the PV modules to prevent the accumulation of snow. This solution is not watertight, and therefore requires a complete, finished roof underneath. An alternative solution (labelled A in the figure) is to let the PV panels replace the conventional roof tiles. Thus, one would simply need a conventional sub-roof construction.

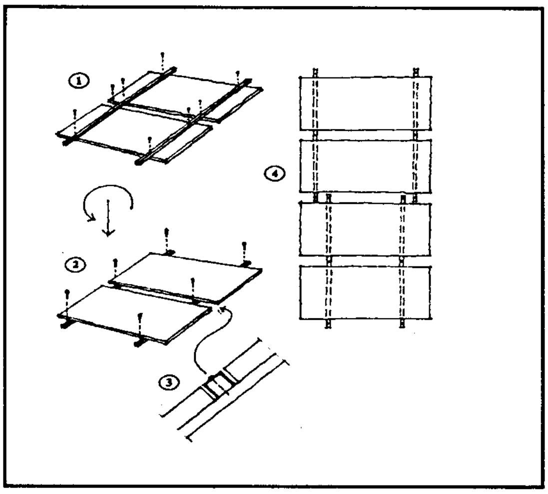


Figure 14.14.3 Mounting procedure.

14.15 Single Family House, Schauenbergstrasse, Zürich, Switzerland

Figure 14. 15. 1 General View.

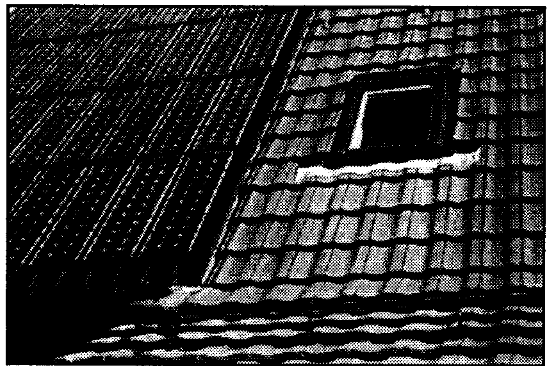


Figure 14.15.2 Detail of mounting structure.

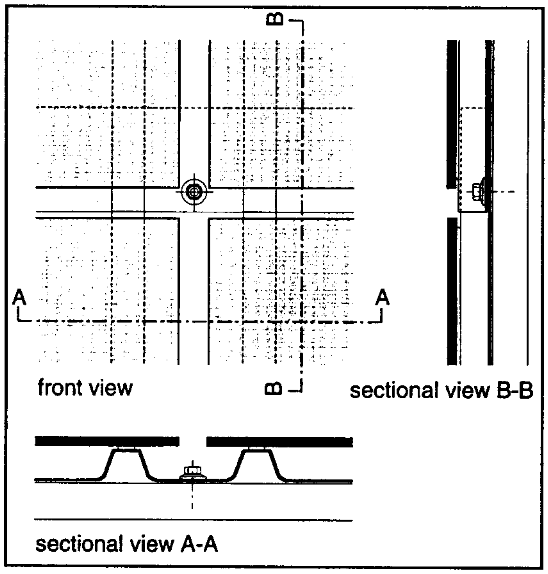


Figure 14.15.3 Front view, sectional views.

Key data

Nominal power:	3 kW
Gross Area:	25 m2
Module manufacturer:	Siemens
Inverter:	Solcon
Start of operation:	1990
Owner:	private owner

Short description

The applied mounting technology can be adapted for facades. The use of trapezoidal sheet metal with modules glued on leads to a low cost, safe and flexible installation.

Detail of mounting structure

As glueing technique, a special rubber tape (acrylic foam) is applied. Glueing is a competitive mounting technique compared to mechanical attachment. Glueing does not penetrate the material nor causes it corrosion.

14.16 Shopping Centre, Stockholm

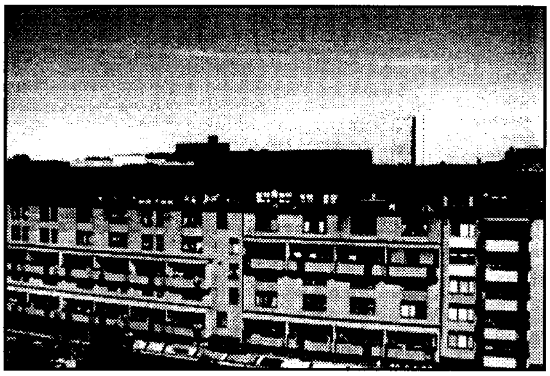


Figure 14.16.1 General view.

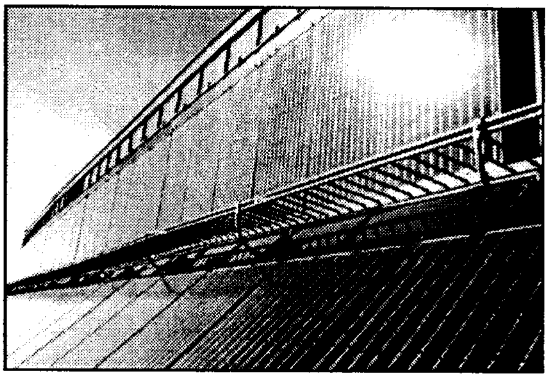


Figure 14.16.2 View of the PV generator.

Key data

Nominal power:	9.9 kW
Gross area:	76 m2
Module manufacturer:	GPV Sweden
System design:	NAPS
Inverter:	2 x Solcon 3400 HE 2 x PV-WR 1800
Start of operation:	1993
Owner:	Stockholm Energi AB

Short description

This photovoltaic project was the contribution from Stockholm Energi AB to the Swedish participation of Task 16. The system is also the Swedish "Demobuilding" and the largest PV installation in Sweden. The 90 modules are divided into three separate systems, each equipped with its own inverter. Two of the systems are mounted on the 45° tilted roof of a shopping centre in Stockholm City. The third part is installed on the vertical wall of a roof space on top of the building. The modules are standard GPV 110, framed modules, with black tedlar on the back side to make the array visually well integrated into the traditional black roofing sheet.

One of the tilted arrays and the vertical one are connected to Solcon inverters. The other tilted system is connected to two PV-WK1800 inverters operating in a master-slave configuration.

Detail of mounting structure

The modules are mounted in groups of three into a framework of black anodised aluminium U-profiles that are fixed to the roof or the wall in case of the vertical array. A cable duct is attached to one of the horizontal profiles. Each module is lifted up in the upper U-profile and then slid into the lower U-profile. By tightening screws on both the upper and the lower profile the modules are fixed into the structure. This method makes it very easy to remove any module for service. The cabling was laid out in the cable duct before installing the modules. The modules were delivered with cables and quick-coupling connectors which made the electrical installation work safe and relatively fast. The connectors were then sealed by shrinking tubing.

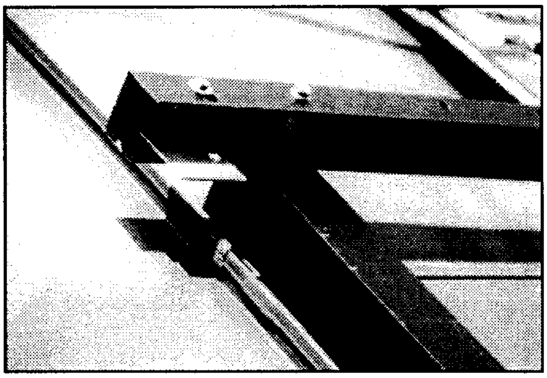


Figure 14.16.3 The upper part of the mounting frame.

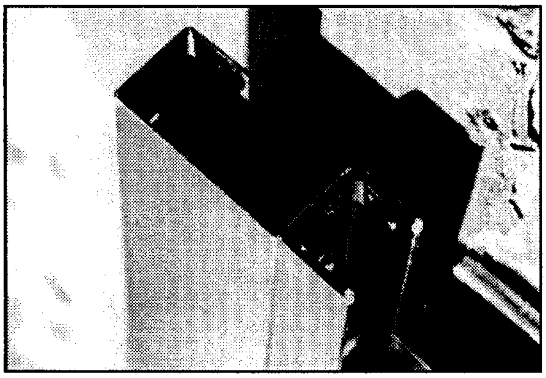


Figure 14.16.4 The lower part of the mounting frame with the cable duct attached below.

14.17 Fensterfabrik Aerni, Arisdorf, Switzerland

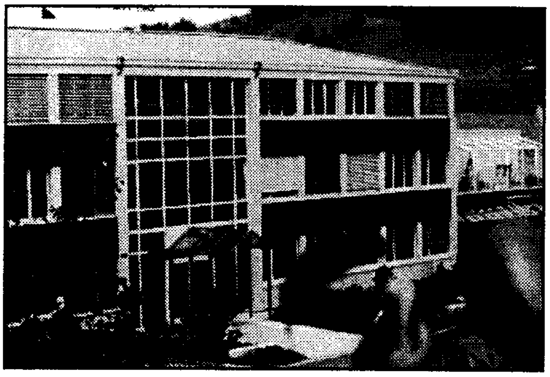


Figure 14.17.1 General view.

Figure 14.17.2 View of the facade.

Key data

Nominal power:	8 + 53 kW
Gross Area:	86 + 505 m2
Module manufacturer:	Solution
Inverter:	Solcon + Eco Power
Start of operation:	1991
Owner:	Fensterfabrik Aerni AG

Short description

Shed roof

Besides the production of electricity, the heat behind the sheds is used with an airstream on a low-temperature niveau. Goal of the combined solar system is to produce 70% of the total energy used.

The mounting into the shed with large area modules was done with a special mounting system. Two modules are fixed on a metal sub-structure with rubber profiles. The horizontal join is realised with silicon sealant. Behind the modules, an air channel allows to use the hot air for space heating. In summer time, the heat is stored in the ground.

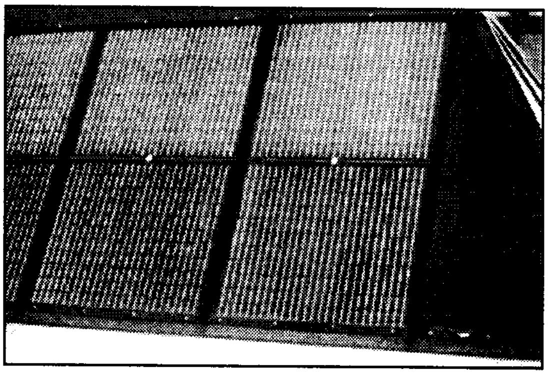


Figure 14.17.3 Partial view of shed roof

Facade

The drawings show the details of a standard facade cladding system. It is designed for the use with different materials such as glass, metal and composite panels including also PV modules. For large panels, the clip holding the modules has to be doubled. This depends also on the strength of the glass. Each single module can be exchanged.

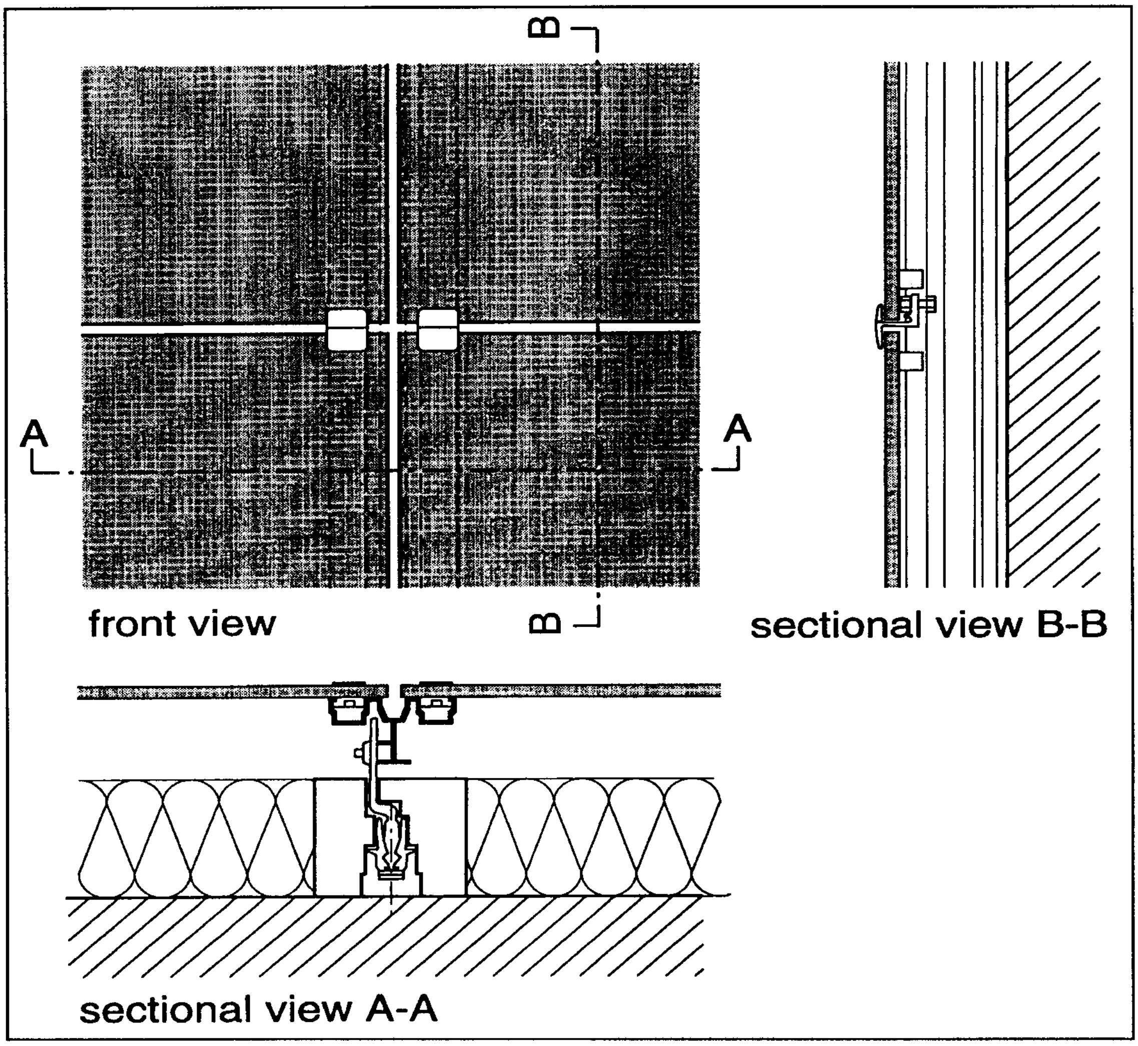


Figure 14.17.4 Detail drawing of ALUHIT®, a system to attach frameless PV modules on facades.

14.18 Solarzentrum Freiburg, Germany

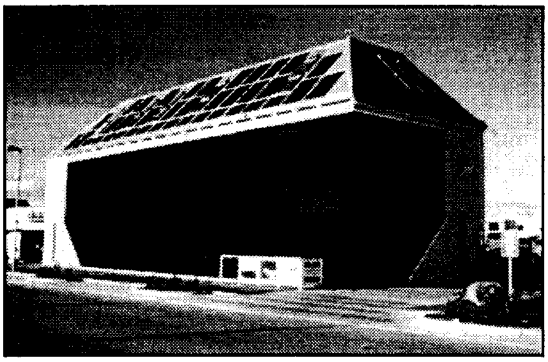


Figure 14.18.1 General view.

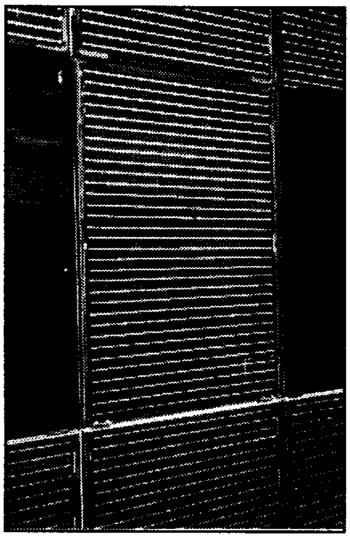


Figure 14.18.2 Facade detail.

Key data

Nominal Power:	18.5 kW
Gross area:	153 m2
Module manufacturer:	DASA
Inverter:	SKN402 /SKN 301
Start of operation:	1993
Owner:	SST GmbH

Short description

Four PV generators are integrated into the facade and roof of this office building. The facade is of special interest, since it is a structural glazing (SG) facade.

SG is a construction method using a special type of silicone adhesive to glue window and parapet elements, also made from glass, directly onto the statically bearing support structure. Additional fixtures, which are possibly visible from the outside are in many cases not necessary. The silicone adhesive performs sealing function and it takes all mounting forces as well as wind loads transferring these to the support structure. The support structure consists of thermally decoupled aluminium profiles, which are anchored to the building at the various storey ceilings.

Figures 14.18.3 and 14.18.4 show details of the sophisticated support structure, which have to fulfil very different functions: static support, thermal decoupling, accommodation of window elements, accomodation of parapet elements and accommodation of regular wall insulation.

A SG facade is turned into a PV facade by replacing the glazing material by customized frameless PV modules. The whole facade is divided into segments. Each segment, which may reach up to 8 m height, is completely factory-mounted including thermal insulation and a lining which eventually makes the inner wall cover. PV modules, regular wall elements as well as windows, all can be mounted in one segment.

Factory preconstruction of segments including PV modules offers a high production quality at very low tolerances. Thus cable glands etc. can be placed exactly in the area of installation channels or hollow ceilings. Preconstruction minimizes the risk of damaging the valuable PV modules in a harsh construction site environment.

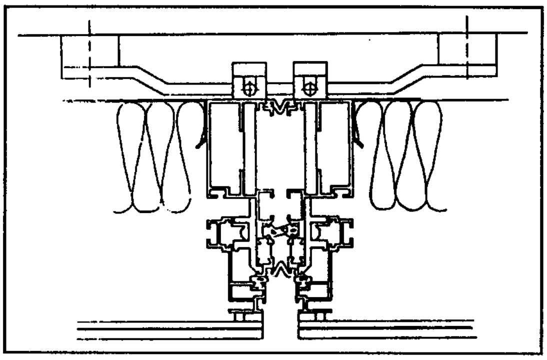


Figure 14.18.3 Horizontal cut through facade construction.

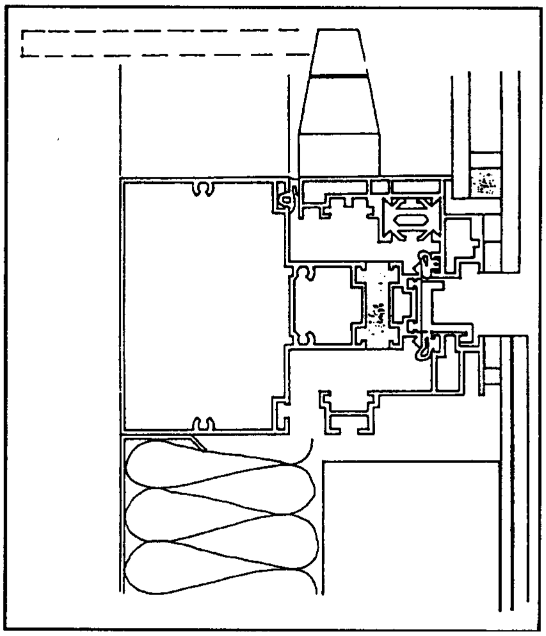


Figure 14.18.4 Vertical cut through facade construction.

14.19 SOFREL, Solar Flat Roof Element

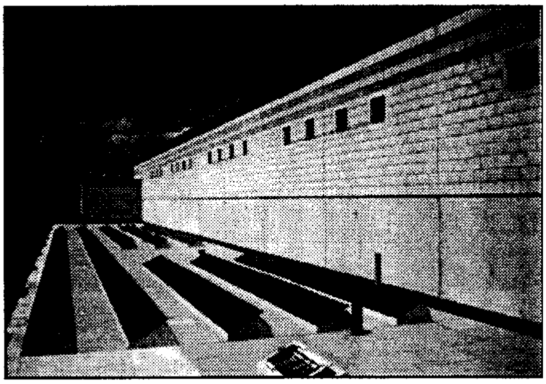


Figure 14.19. 1 General view.

Figure 14. 19.2 Detail of mounting structure.

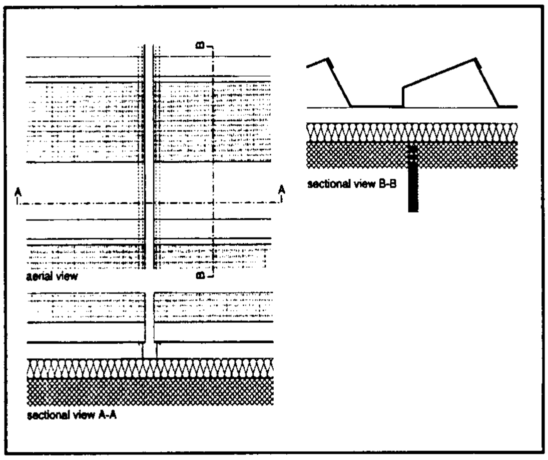


Figure 14.19.3 Aerial view, sectional views of a SOFREL with sheet metal or a composite material such as Alucobond.

Short description

SOFREL (Solar Flat Roof Elements) is a flat roof integrated PV system.

This new project has recently started in Switzerland which aims to develop a Solar Flat Roof Element (SOFREL). PMS Energy Ltd., Alpha Real Ltd., Swiss Institute of Technology in Lausanne (EPFL) and the Union Bank of Switzerland (SBG/UBS) are developing a flat roof integrated PV system. The main goal is to combine the function as building skin and PV element in one unit for flat or nearly flat roofs. As shown in Figure 14.19.3 the solar modules are integrated in composite materials such as Alucobond® which results in a watertight roof together with the drainage system. The difference between watertight and non-watertight SOFREL is explained Figures 14.19.5 and 14.19.6.

Non-watertight versions are made of steel reinforced concrete. In such a case, the flat roof is sealed with a conventional method.

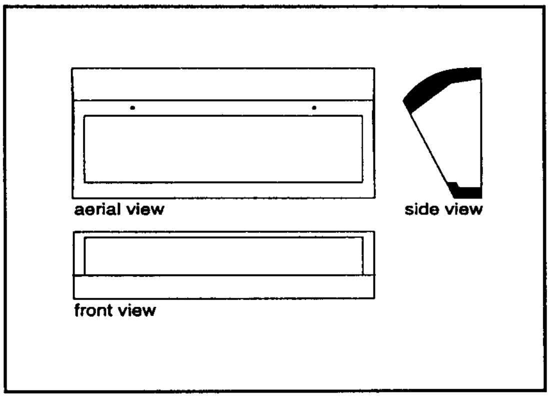


Figure 14. 19.4 Aerial view, front view, side view of a SOFREL element based on concrete.

The SOFREL system starts to enter the market during 1995. A patent is pending; production is not focused on a certain product, it can be realised by several companies.

Compared to a conventional PV structure with weight foundations the main advantages are:

- Improved flat roof design
- High aesthetic value
- Saving in material, therefore less disposal and improved energy and raw material balance
- Fewer planing costs
- Less installation effort
- Easy roof maintenance

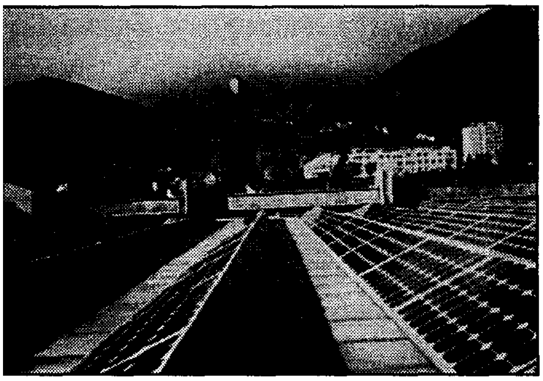


Figure 14. 19.7 PV array with concrete SOFREL on the building of the "Berufsschule Wattwil" in Wattwil, Switzerland.

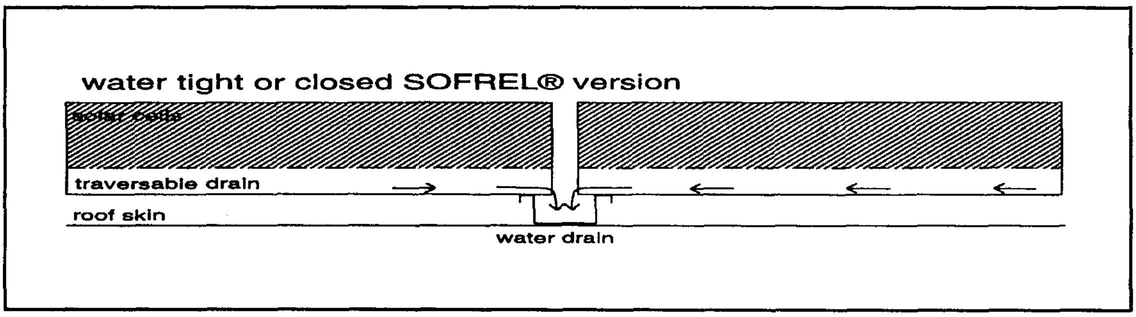


Figure 14.19.5 Watertight SOFREL. The water is drained on the SOFREL into a special drain channel. The SOFREL element serves as module substructure and as main part of the roof sealing. The main advantage is the longer life span to be expected and the possibility of checking the status of the roof sealing and the easy access for exchange of single elements.

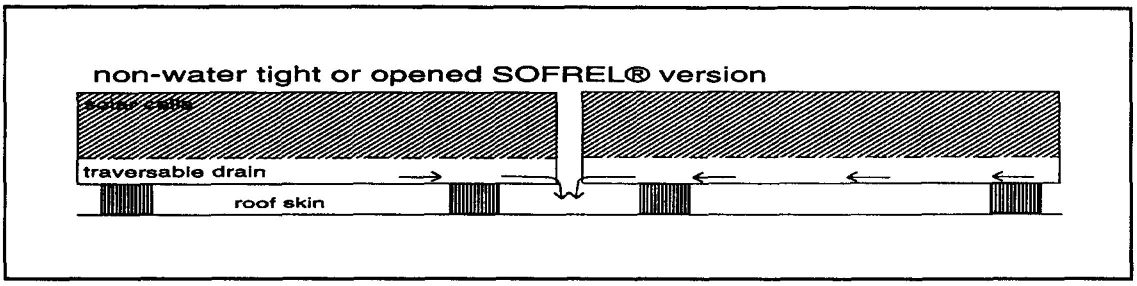


Figure 14.19.6 Non-watertight SOFREL. The water is drained beyond the module substructure by a standard flat roof sealing. The SOFREL element serves as module substructure and as weathering protection for the flat roof sealing.

14.20 Demosite, Lausanne, Switzerland

Figure 14.20.1 General view.

Key data
Nominal power: approximately 8 kW
Gross Area: 300 m2
Module manufacturer: several
Inverter: several
Start of operation: 1992
Owner: EPFL, Suppliers

Short description

DEMOSITE is an international exhibition and demonstration centre for photovoltaic building elements, located at the Ecole Polytechnique a Ecublens. The goal of this centre is to inform potential users (architects, project managers authorities...) of the various forms and functions photovoltaic elements can take it order to thus propagate their use in archi tecture.

In creating a link between manufacturers from various countries (at printing time: Swit zerland, Germany, USA, France, Japan, UK and users, DEMOSITE serves to promote the integration of photovoltaics on buildings and to stimulate demand for these new elements.

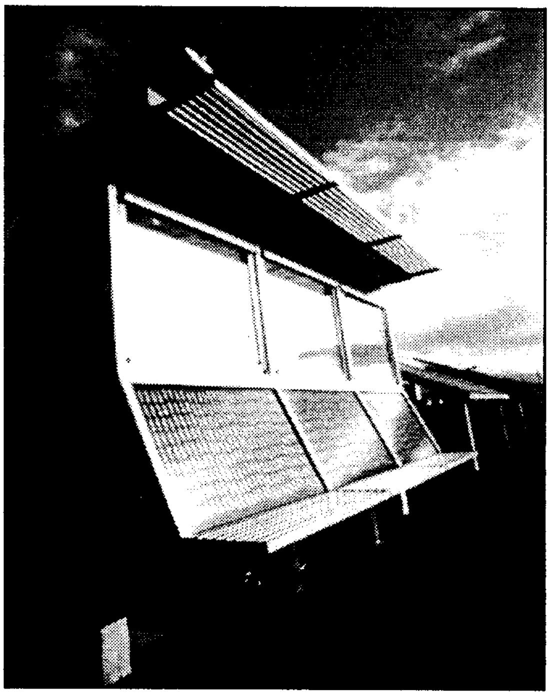


Figure 14.20.2 Facade element of Demosite.

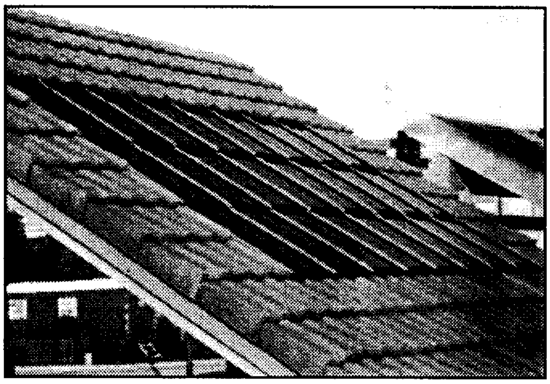


Figure 14.20.3 Marketed Solar Tile at Demosite.

Each pavilion is more than a simple display as it shows various solutions to problems of implementation and measures real on-site performance.

Objectives:

- to display construction elements that produce electricity from sunlight;
- to show different methods of implementation, including architectural and constructional details, at one location;
- to gather elements from different countries;
- to publicize these elements and to stimulate the development of new products and methods;
- to measure the energy produced by the various systems;
- to provide experimental data from energy measurements including climatic data;
- to stimulate architects to integrate photovoltaics into constructions;
- to offer public relations service, including guided tours with information panels on display and newsletters.

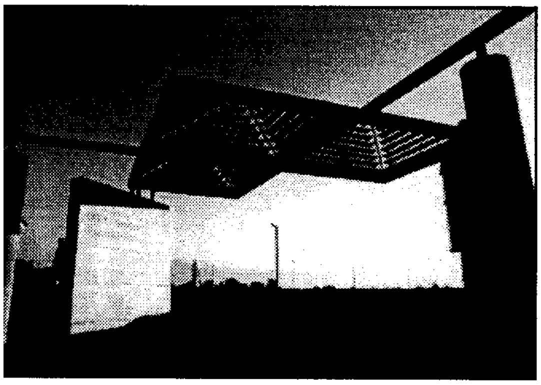


Figure 14.20.4 "Pyramides" at Demosite combining sun protection, natural lighting and electricity production.

14.21 Eurosolare photovoltaic roof system, Nettuno (Rome), Italy

Figure 14.21.1 General view.

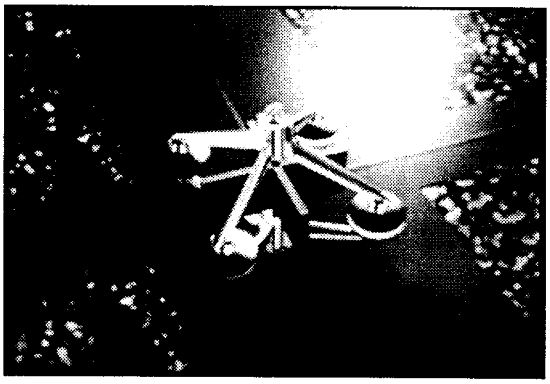


Figure 14.21.2 Detail.

Key data
Nominal power: 30 kW
Gross area: 300 m2
Module manufacturer: under negotiation
Inverter:
Start of operation: 1995
Owner: Eurosolare s.p.a.
Designers: Architects Cinzia Abbate and Corrado Terzi

Short description
The new roof will cover the central bay of the factory which is currently used for the assembly line of the photovoltaic cells, the office space and the conference room of the company. The project proposes a new roof made of two lenticular steel beams; two depressed arches, one counterpoised against the other, placed on both sides of the existing precast concrete beams of the factory.

Both the photovoltaic panels and the glass panels will be supported by the upper part of the lenticular steel beams as well as the tubular crossbeams. The shape of the tubular crossbeams has been studied so as to have a hollow circular section that not only functions as a secondary structural system but also provides a place to house the diodes and the wiring that connects to the power system.

From the structural point of view, the lenticular steel beams will be supported by the pre-existing beams, being attached to them by a triangular steel plate which is placed next to the pilaster .

Corresponding to the fascia of the pre-existing cement beams and pairs of steel beams connected to them, the roof is made of double glazing and low-emissive glass panels in which the aesthetic function is, on one hand, to underline the complexity of the structural design and, on the other hand, to define, through arcades of natural light, the rhythm of the individual bays covered by the photovoltaic panels.

An electrically operated brise-soleil system is proposed for this side of the roof in order to regulate the amount of daylight needed in the space below.

The system of joining both the photovoltaic and transparent glass panels is based on an impermeable extruded silicon seal and a special aluminium clamping joint able to connect two or four panels between them. This joint system tolerates a certain degree of movement thus allowing thermal expansion to be absorbed.

14.22 A photovoltaic and thermal co-generation facade system. Fondi (Latina), Italy

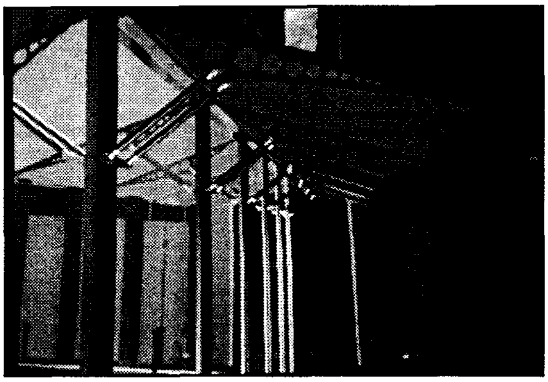


Figure 14.22.1 General view.

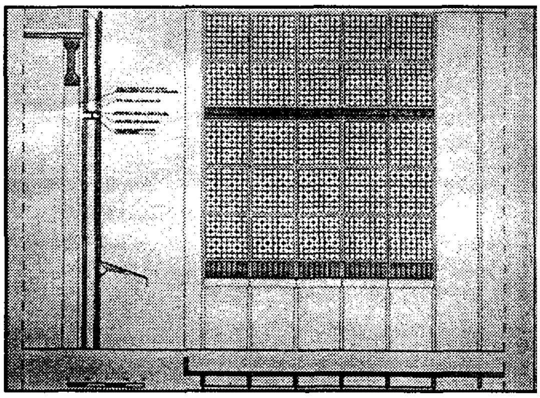


Figure 14.22.2 Detail.

Key data

Nominal power:	3 kW
Gross area:	30 m2
Module manufacturer:	under negotiation
Inverter:	
Start of operation:	summer 1995
Owner:	DI.CA and Eurosolare s.p.a.
Designers:	Architects Cinzia Abbate and Corrado Terzi

Short description

The prototype system will make use of an already existing southern exposed wall of the DI.CA company's factory at Fondi, Italy. The aim of this project is to create a prototype architectural modular system for the generation of thermal and photovoltaic (PV) energy.

The system is in fact made up of PV modules which form the outer wall of an air-gap in which the air is heated. The appropriate sizing of the air-gap will enable warm air to be directed into the interior of the building, by means of simple natural convection.

Preliminary calculations indicate that with an annual incoming solar radiation of 1.400 $K/Wh \bullet m^2$ the system will produce approximately 65 $K/Wh \bullet m^2$ annually. The system has been conceived of as modular elements for the construction industry; consisting of PV modules of 120 cm x 120 cm and of smaller modules of 120 cm x 60 cm.

The functioning of the "solar flue" created within the air-gap between the photovoltaic panels facing and the external wall, the system includes an exterior grill, 30 cm high and in line with the panels. There is also a 30 cm high grid allowing the warm air to be used for heating the interior or as an air in-take for the "solar flue".

The design will also provide a system of valves within the air-gap, that can be controlled within the building. These valves will regulate the flow of warm air into the building, thanks to a grid which will take the place of baseboards along the interior wall.

The project includes a PV canopy which will be able to supply electricity to those things such as illuminated signs, street lights, interior lighting that are not connected to the public grid. Steel rods and metal brackets make it possible to change the angle of the canopy by about 30°, in order to take better advantage of the incoming solar radiation.

An articulated coupling on the sign attached to the front portion of the canopy will have a flexible hook to keep it perpendicular, regardless of the inclination of the canopy.

Section D

System Design

Principal Contributors

Chapter 15: **Design Considerations**

Sandia National Laboratories [1)]
Jyrki Leppänen

Chapter 16: **Load Analysis**

Friedrich Sick

Chapter 17: **System Sizing**

Jyrki Leppänen
Jimmy Royer

Chapter 18: **Key Component Selection**

Jimmy Royer

1) Extracted from "The Design of Residential Photovoltaic Systems", volume 5 "Installation, Maintenance and Operation Volume", document number SAND 87-19515, edited by Dr. Gary Jones and Dr. Michael Thomas.
Contributors to this report were James Huning, John Otte, Elizabeth Rose, Russ Sugimura and Kent Volkmer of the Jet Propulsion Laboratory.

Chapter 15

Design Considerations

15.1 Overview of the design process

This section gives simple methods and tools on PV system design for a non-PV specialist. It is recommended, however, that the detailed final system design should be done by a specialist because of liability and responsibility matters, as well as technical familiarity.

The design process of a PV system is relatively straightforward. The design starts by screening the site and the building in question to evaluate the applicability of PV for electricity production in the specific case. This means that the solar availability must be evaluated for the region and building in question. Also, the energy efficiency of the loads should be considered. The trade-off questions between solar thermal and photovoltaics must be considered especially if there is lack of suitable building surface area. It should be noted that although solar thermal energy is cheaper, it is of little value, if the user needs electricity. In Appendix IV this topic is discussed in more detail.

After the decision of the suitability of PV has been made, the design starts with a detailed load analysis (Chapter 16) in order to improve the electricity utilization efficiency of the building and to get the basis for the PV system sizing. Following this, a rough system sizing can be performed (Chapter 17) giving the boundaries for the PV system component selection (Chapter 18). Then the house owner can turn to the PV system suppliers asking for a detailed offer for the system he needs. The design process described above is illustrated in Figure 15.1.

There are also several general institutional matters affecting the PV system, which should be considered at certain stages of the system design. These matters include: the utility interface and interconnection issues, land use and construction regulations, safety, financing, liability and insurance issues.

15.2 Screening the application site and the building

The general site aspects affecting the system design are: the actual location of the system, available array area, solar access to the considered PV array surface and the energy efficiency of the building.

The **location** of the system mainly affects the **amount and the value of the PV energy.** The value of the PV system is determined by the amount of energy produced annually and the value of that energy. The annual energy production depends proportionally on the incident radiation. The value of PV energy depends on the local utility's avoided costs and the utility's pricing policy concerning electricity buyback in grid-connected systems. In stand-alone systems this depends on the price and reliability of the alternative electricity production possibilities. Both insolation and PV energy value will vary from region to region. Also architectural, aesthetical and environmental matters can increase the value of a PV system.

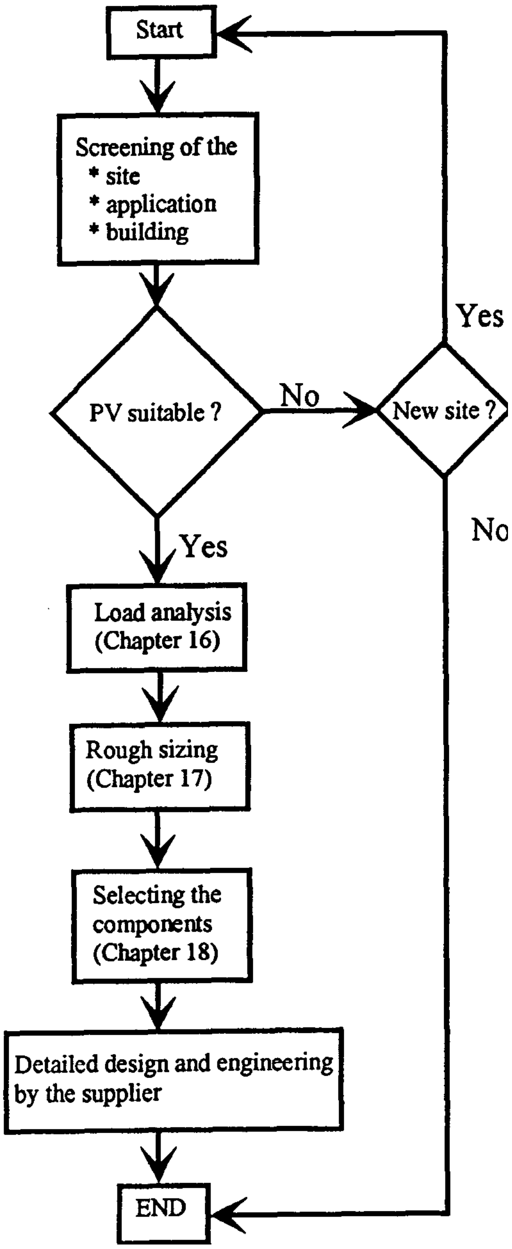


Figure 15.1 Design process.

The **available roof or facade area** facing approximately south (in the northern hemisphere), specifies the **maximum PV array size.** Today's commercial thin-film modules need 20-30 m^2 for a kW and crystalline modules need 8-15 m^2. In grid-connected systems the **minimum system size** is about 1 kW, because the price per kW increases rapidly below that range. This is due to a significant cost for size independent wiring, power conditioning and engineering. However, with the development of module-integrated inverters this minimum practically vanishes. In stand-alone systems there is no minimum size, because there is no grid electricity available and the minimum size is given by the load size.

System performance is mainly affected by solar access, which has to be guaranteed both at the time of system construction and also in the future. In general, no roof structure (chimneys, offsets, projections, antennas) or surrounding objects like trees and other buildings should shade the PV array at any time of the year. Shadowing - even on small parts of the array - cuts down the PV electricity produced and may also lead to PV array matching problems. Small soft shadows of distant objects are not a concern, but dark large shadows should be avoided. If solar access cannot be guaranteed now and in the future, the application site is not suitable for PV systems. Figure 15.2 illustrates solar access by two examples.

The energy generated by a PV system can have a high value in favourable applications. However, if the building has not been designed to be **energy-efficient,** it is a waste of valuable photovoltaic energy (and building owner's money) to power inefficient appliances. Therefore, before designing a PV system, the house loads should be decreased by using the best commercially available energy efficient appliances (Chapter 16).

15.3 Utility interconnection issues

Conventional energy production in industrialized countries is based on centralized power stations. Photovoltaic systems, and especially PV systems integrated into buildings, are very small compared to these. Utility companies in many countries are often not familiar with this kind of decentralized energy production form. Thus the utility interconnection, which is necessary for grid-connected systems, has been a barrier for the PV system implementation and still is in some countries. The problem has been addressed by many countries where the possibility of decentralized energy production is now guaranteed. There are, nevertheless, major differences between countries and also utilities based on the judgement of the utility management regarding the avoided costs, acceptable risk, possible equipment failure and the limited experience of the utility with PV system interconnection. Thus in case of grid-connected PV systems, the system designer should contact the local utility at the very beginning of the system design to establish the interconnection framework and the possibility of a contract between the utility and the PV system owner.

15.4 Land use, design and construction regulations

Land use requirements exist to define acceptable standards of community development in the interest of public health, safety and welfare. Several requirements exist, such as zoning ordinances, restrictive covenants and subdivision statutes.

Several key categories of land use issues that can affect the implementation of residential PV systems include:

- the guarantee of solar access for the PV system;
- compliance with building and site location regulations;
- compliance with conforming use regulations;
- compliance with design, style, materials or colour regulations.

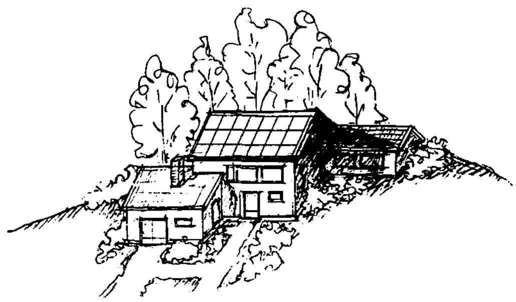


Figure 15.2a Solar access to the PV array hindered by different obstructions.

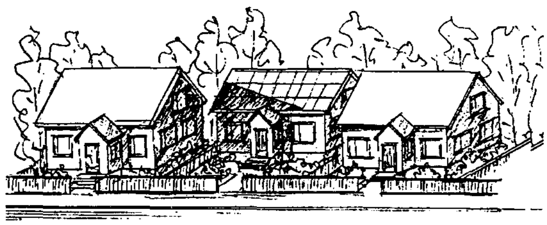


Figure 15. 2b Solar access to the PV array hindered by surrounding houses.

Of these issues, the guarantee of solar access for the PV system is the most critical, since legal precedent does not give the PV system owner any rights to the sunshine crossing adjacent property without a contract or ordinance.

Requirements such as standards of recommended design practice, testing standards and manufacturing standards establish a minimum level of quality and reliability in equipment, construction methods and materials. Because these standards are frequently referenced by construction codes, utility interconnection agreements, financing agreements or insurance agreements, they play a crucial role in PV system implementation.

15.5 Safety issues

Most safety concerns associated with residential PV systems can be addressed by careful attention to system design, i.e. good engineering practice. Major safety concerns arise from the fact that the sun cannot be turned off. Several less serious safety concerns are also associated with residential PV systems.

The following **checklist** serves as a reminder:

- PV-unique hazard potential understood by design team, installation crew and homeowner;
- Safety procedures, based on good engineering practice, followed;
- Safety devices employed;
- Risks to unauthorized persons minimized;
- Equipment stored in secure area;
- Emergency operating conditions addressed in system design;
- Service access that minimizes hazards provided;
- Rapid, efficient snow shedding addressed.

15.6 Financing issues

Financing issues for residential PV systems are not very different from those for conventional systems in residences. However, incentives are created from time to time by local and governmental offices to encourage the utilization of renewable energies like photovoltaics. The aim of these incentives is to reduce the solar energy cost for the consumer, either by decreasing the investment cost or by decreasing the system operation cost. These kind of incentives include tax credits, exemptions from sales/use tax, grants and loans.

15.7 Liability and insurance issues

Reasonable care is required in the design, manufacture, assembly and operation of the PV system in order to protect it, the residence and the utility system from damage as well as any operating personnel from injury. Product liability and owner liability must be considered. Product liability concerns the strict liability, warranties, negligence and misrepresentation. Owner liability concerns the degree of protection afforded to persons and property.

The types of insurance to be considered are product liability for the manufacturer, professional liability for the designer and casualty and liability for the homeowner. The potential hazards dealing with PV systems are:

- PV system damage from environmental degradation;
- Vandalism;
- Personal injury to installer, occupants and others;
- Property damage;
- Fire damage;
- Chemical damage (e.g. batteries);
- Communications interference (e.g. inverter).

Chapter 16

Load Analysis

16.1 Identifying loads

The very first step in designing a PV system must be a careful examination of the electrical loads. The reasons are twofold:

- Obviously, the sizing of the system components is dependent on the electricity and power demand. For stand-alone systems, this is crucial.
- Oversized systems resulting from a poor load analysis and the idea of staying on the "safe side" increase the system costs. This is particularly damaging in a field where poor economics are a major drawback, which still is the case for PV.

The second reason also leads to the important issue of minimizing loads without decreasing the user's comfort. This issue will be addressed in section 16.2.

The emphasis of this section is to give advice on how to estimate the actual loads. Past experience shows that often small power consumers are neglected or simply forgotten and add up to considerable loads in the end, e.g. the stand-by consumption of consumer electronics. A complete list of all possible electrical consumers would not fit into this design book. Table 16.1 should serve as a guide and reminder.

Both the rated power of the load and the energy demand are important for correct sizing. The energy is obtained by multiplying the power with the time of operation, called the duty cycle in Worksheet #2 (Appendix II).

- Lighting
- Clocks
- Pumps
- El. heaters
- Fans
- Air conditioners
- El. driven blinds
- El. driven doors (e.g. garage)
- Elevators
- Security systems
- Coffee machines
- Refrigerators
- Freezers
- Dishwashers
- Ovens
- Microwave ovens
- Toasters
- Grills
- Mixers, Blenders
- TV, VCR, Radio, Stereo
- Projectors
- Washing machines
- Irons
- Dryers
- Vacuum cleaners
- Hair dryers
- Shavers
- Sauna heaters
- PCs incl. Monitors
- Printers
- Copy machines
- Communication equipment (fax, phone)
- Other office equipment
- Battery chargers
- Monitoring equipment
- Tools
- Toys

Table 16.1 Examples for electrical consumers.

16.2 Improving the energy efficiency

One of the most cost-effective sources of energy is "saved energy". In PV systems the replacement of loads or appliances by more efficient ones is often economic because the investment costs for the new items are lower than those for the PV system components (modules, batteries, larger-rated power conditioning equipment) required to provide the difference in energy consumption of the old and the new loads or appliances. If, for instance, the installed nominal power of a residential system could be reduced by 1 kW (worth about 12 000 US$ in grid-connected and 25 000 US$ in stand-alone systems!) due to a number of more efficient household appliances, it would easily pay for them.

It is therefore not only cost-effective but crucial to perform a careful examination of the electrical consumers. There are two levels of reducing the energy demand: First, one should eliminate all electrical consumers that are not necessary at all or ecologically disadvantageous. Second, for the remaining consumers the most efficient ones should be selected.

The first category usually comprises thermal equipment. As long as electricity is produced centrally with an efficiency of 30 to 33% while generating mostly waste heat, it is not reasonable to use this valuable electricity for heating purposes. Electric space heating should be avoided in most cases. Exceptions, for practical reasons, might be radiators in the bathroom operated only for a very limited time per day or similar applications, where the total energy demand is very low.

Water should be heated using conventional burners, possibly in addition to solar thermal collectors. Washing machines and dish washers can be equipped with hot water inlets. The electric heating coil then only comes up for the temperature difference (if any) of the hot water and the set point.

Air-conditioning equipment is not always necessary. Especially in new buildings, with careful planning using expert knowledge and sophisticated computer simulation tools, it is often possible to avoid air-conditioning equipment. If there is still the need for air conditioning, intelligent controls and reasonable temperature set points can significantly reduce the loads. A fixed set point of 18°C to 20°C throughout the summer is a waste of energy. At outside temperatures of 35 °C one feels comfortable at, say, 28° C.

The cooling load could also be minimized through solar control, which is obtained by careful design of the building and different kinds of shading devices. Utilization of natural daylight through building design could both reduce the electricity demand for lighting and thereby also the cooling load.

The heating and ventilation loads of the building should also be minimized. This could be achieved through different means, e.g. by using a high degree of thermal insulation of the envelope, good air tightness and efficient heating and ventilation systems.

After eliminating electrical consumers that should not be there or not be electrically driven, the second stage is to improve the energy-efficiency and the right choice of electrical consumers has to be considered. For a selection of household appliances, Table 16.2 gives the range of annual energy consumption from very efficient over standard to poor.

16.3 Load management

The sizing of an energy supply system depends not only on the expected energy consumption over a given period but also on the peak power demand. This is true for the big utility grids as well as for the owner of a small stand-alone PV system. To ensure supply reliability, the system must be able to meet the maximum desired peak loads. If this happens at nighttime in a PV system, the battery and/or the back-up generator must do the entire job. It is obvious that a load profile following the supply curve of the incident radiation would be advantageous. This is where load management comes in. Along with the sensible selection and use of efficient home appliances, the practice of load management is a sound method of assuring that each kWh used is worth the money spent for it. At its simplest, load management consists of a series of conscious decisions concerning when to add certain appliances or power-consuming functions to the load. For instance, you may decide not to run the washing machine, vacuum cleaner and oven simultaneously. Equipment that does not have to be in operation at any given moment, as long as it runs for a certain amount of time over a given period, is well-suited for load management controllers. Air conditioning, refrigeration or well-water pumping equipment are examples. Load management microprocessors can be programmed to control loads according to user-specified strategies. These can be fixed-priority strategies, rotational strategies, where a number of loads are turned on and off in a sequential cycle, or combinations of both.

It will always be helpful to have the expected typical daily load curve at hand (see e.g. Figure 16.1). In existing households, it can be monitored. Otherwise it must be estimated. The next step is the analysis of sharp peaks. If they can be reduced or if parts of the load can easily be moved to periods with greater electricity production, a load management strategy should be applied.

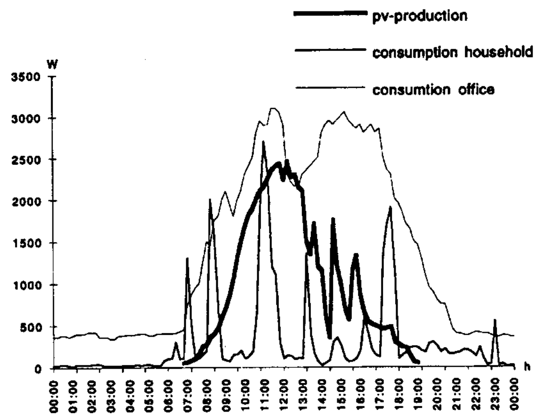


Figure 16.1 Daily load profile of a 5-person household and an office with 10 work places compared to the energy production of a 3 kW system in partly overcast conditions.

	low	std.	high
Refrigerator1)	87	230	270
Freezer2)	168	426	800
Refrigerator/-Freezer3)	267	343	625
Washing Machine4)	280	366	522
Washing Machine5)	202	--	--
Dish Washer6)	296	481	614
Lighting7)	87	--	438

1) 2001, no freezing compartment
2) 200 1
3) 200 1
4) without hot water inlet, 3 cycles per week
5) with 60 °C inlet, 3 cycles per week
6) without hot water inlet, 5 cycles per week
7) 4500 lm, 4 hours per day

Table 16.2 Electricity consumption ranges of typical electrical consumers [kWh/a].