SOLAR SYSTEMS FOR PASSIVE BUILDINGS – GENERAL APPROACH AND EXAMPLES



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Summary

Paper deals with the integration of solar systems into the energy optimized buildings, like passive houses. The energy concept, the physical integration into the building envelope and the visual aspects are presented here. The passive house development in Koberovy will be shown in detail. All houses with unified wooden skeleton structure are equipped with the roof integrated solar thermal collectors as a standard solution. Furthermore, one of these houses is equipped with PV-roof (8.45 kWp). In this case the close-to-zero energy house level should be reached, taken into account the delivered energy over the year. Another house here is equipped with smaller PV-system extended by accumulators and electronic control unit to guarantee the 24 hour grid-independence for basic operation in the house. After completing in summer 2007 a long-time monitoring has started. Finally, the information about experimental studies on photovoltaic sun blind systems is presented.

Keywords: Solar system, photovoltaics, building integrated photovoltaics (BIPV), passive building, overall energy performance, sun shading, solar protection

1 Introduction

Basically, solar systems have a real chance to be a part of newly designed or substantially refurbished buildings on a larger scale only if the stakeholders (developers, building owners, architects and building designers, facility managers, etc.) are familiar with this technology. The solar system should be designed very consequently considering the energy targets and the overall sustainability parameters, like primary energy, embodied carbon dioxide values, etc. [1].

From the point of view of architecture and building science, the term **solar system integration** is a real key word that can be understood in different ways:

- Integration of a solar unit produced energy into the **energy** balance of the building,
- Integration as an **architectural design** (visual) problem,
- Integration from a **building-physics** point of view,
- Integration into building **construction** and **operation costs** (project cash-flow), etc.

Considering the ecological consequences and overall sustainability approach, the appropriate use of solar systems is a logical further step in the development of passive houses: The substantially reduced space heat demand here represents about 1/3 of total energy need of the household only, considering also hot water preparation and household electricity.

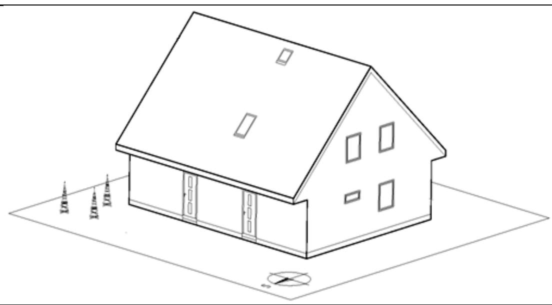
The sizing of solar thermal system for hot water is limited usually by 60-70 % covering of the energy demand in the year. Another approach can be used by photovoltaics: Larger systems can be connected to public grid, the smaller PV-installations can serve as supporting systems for the house. In any case, an extra attention should be given to the attractive visual form of installation, together with correct solution from building physics point of view.

2 Solar systems in residential area in Koberovy

The concept of sustainable building was consequently followed by designing a new residential area in Koberovy (a village in the northern part of the Czech Republic, in a protected landscape area, also declared a UNESCO geo-park, **Fig. 1**) [2]. Several limits concerning the form of buildings are given here in order to reflect local tradition. The location is at 430 m above sea level, with long periods of snow in winter. The houses have a wooden framed load bearing structure completed by extensively insulated envelope.

Tab. 1 Typical basic characteristics of the house in Koberovy [3]

Characteristic	Unit	Value
Built-up area	m^2	82.1
Net floor area	m^2	147.7
Air volume	m^3	355.0
Total envelope area	m^2	393.1
Window area	m^2	21.1
Occupancy	person	4



2.1 Energy system

The energy system of each house consists of thermal accumulator with an integrated hot water preparation system and mechanical ventilation unit with a highly efficient heat recovery. Energy from solar thermal circuit, wooden stove circuit and from electrical heating rods – if needed – is used in the thermal accumulator. The doubled earth heat exchanger with a closed loop was developed to have higher efficiency in summer to avoid possible overheating.

2.2 Solar thermal collectors

At all houses hot water is from approx. 60 % provided by three solar-thermal collectors (ca.6 m^2). The collectors are roof-integrated with a smart design in detailing (**Fig. 2**).

Fig. 1 Part of new residential area in Koberovy – July 2007. All passive houses are equipped with solar thermal collectors, integrated in pitched roofs

Fig. 2 Roof integrated solar thermal system with carefully designed and performed details

2.3 Roof-integrated photovoltaic system

As an experimental solution in one of these houses, the large photovoltaic system (PV) was utilized as an active and instantaneous source of electricity. Sizing of the PV system was based on a simple assumption: The annual energy production of the PV system should be equivalent to the amount of energy supplied to the house from external sources (delivered energy - electricity, wood, see **Tab. 2**). This would lead to a **zero-energy house** over the year. However, it should be noted that the house is not energy independent since the production and consumption curves are not even. Moreover, in this case it was decided to sell all the produced energy back to the local distributor to avoid losses resulting from the inequality between the production and consumption curves.

An approach to fully integrate the PV system into the south-facing pitched roof (45°) was adopted. The required PV capacity and annual energy production of the PV system was calculated in PVGIS PV Estimation Utility [4]. The necessary installed peak PV power of 8.67 kW_p was determined in order to produce the desired 7 680 kWh of energy annually. However, the demand for a compact layout of the roof-integrated PV array (see

Fig. 6) led to the final solution embodying 65 polycrystalline PV modules with 8.45 kW_p of total installed PV power. The PV system is equipped with all necessary protection devices and conversion from DC to AC power is provided by two string inverters. The following table shows in detail a prediction scheme of annual energy production of the system.

Tab. 2 Expected yearly delivered energy [3]

Category	**Energy demand in MWh/a**
Heating and ventilation	3,1
DHW preparation (solar supply substracted)	1,3
Electric appliances (fridge, stove, lights, PC,…)	2,4
Household technologies (pumps, fans, …)	0,9
TOTAL	**7,7**

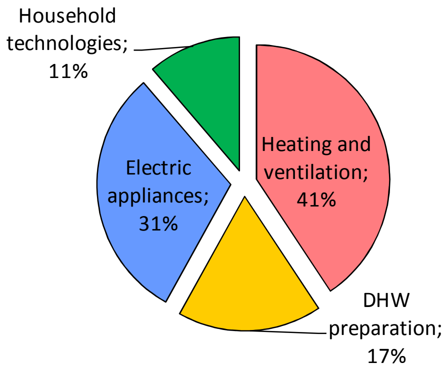


Fig. 3 Household yearly delivered energy breakdown

Tab. 3 Annual energy production calculated in PVGIS PV Estimation Utility [4]

Parameter	**Units**	**Value**
Latitude of the site	-	50°37’29” N
Longitude of the site	-	15°13’42” E
Module inclination	-	45°
Module orientation	-	South
PV technology	-	Crystalline silicon
PV modules	-	Kyocera 130GHT-2
Installed peak PV power	kW_p	8.45
Total area of PV array	m^2	62.9
PV modules nominal conversion efficiency	%	14.0
Irradiation at inclination 45° at the site	$kWh/(m^2.a)$	1 012
Losses due to temperature	%	6.4
Losses due to angular reflectance effect	%	2.9
Other system losses (cabling, inverter, …)	%	14.0
TOTAL ANNUAL ENERGY PRODUCTION	**kWh/a**	**7 486**

Full structural integration of the PV modules into the roof was one of the important requirements. Properly chosen supporting structure [5] made it possible to replace a traditional roof tiling by the PV modules. The fact that crystalline silicon PV modules operate best when their temperature is kept low has led to the design of a 100 mm high ventilated air gap at the back of the modules – between the modules and double-layer weather proof sheathing membrane (opened for water vapor diffusion). The air gap is opened to the exterior at the eaves and at the ridge ensuring that all the excessive heat is effectively removed (see **Fig. 5**). The PV panels are otherwise properly sealed to fulfill the function of a rainscreen. An additional ventilated air gap is placed between the sheathing membrane and a thermal insulation layer to safely take off all the water vapor diffusing from the interior heated space. The thermal insulation is also protected by a sheathing membrane.

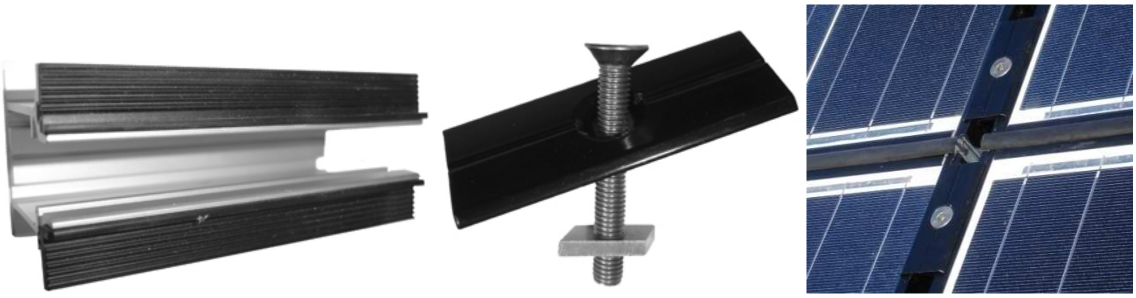


Fig. 4 Supporting aluminum rails that are vertically attached to the battens (left), fastening clamp (centre) and a detail of modules junction where the horizontal dilatation spacing of 5 mm is sealed by EPDM rubber profiles (right).

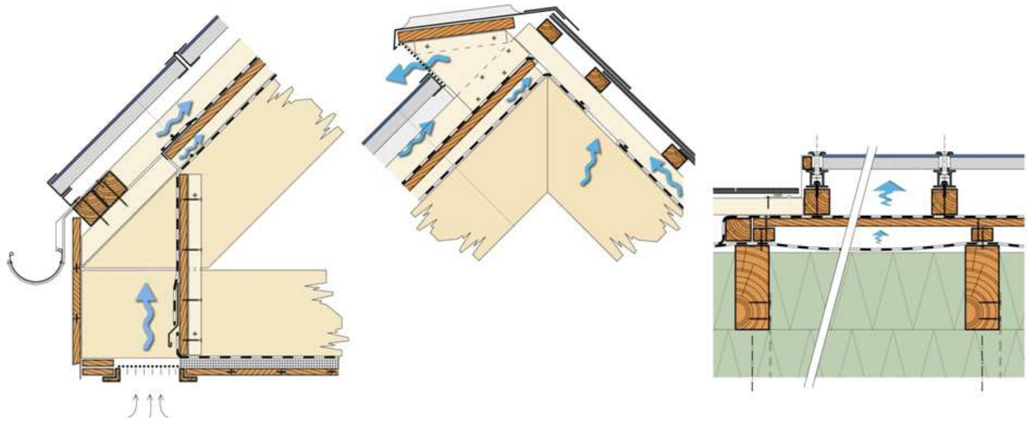


Fig. 5 Sections of the roof structure: detail at the eaves with the air inlet (left), detail at the ridge with the air outlet (centre) and horizontal section at the transition between the PV array and traditional roof tiling (right).

Fig. 6 The pitched roof with 62.9 m^2 large PV array during construction works (left) and completed roof (right)

2.4 Passive house with PV for more independence

Another passive house in Koberovy development is equipped with smaller PV-system extended by accumulators and electronic control unit to guarantee the grid-independence for basic operation in the house in the case of black-out. All technological equipment, like fans of mechanical ventilation, pumps of heating and solar system together with lighting can be in use at least for 24 hours of energy delivery break.

3 Experimental studies of sun shading systems using PV

The importance of protection against the unwanted overheating of interiors comes up with its relevance to the costs of energy for cooling and high demands for a better comfort in the interior as an interesting challenge to be dealt with. Problems of overheating due to the lack of sun shading, and an overall deficient thermal behaviour needs to be tackled as soon as a project is arising in the energetic feasibility study. An integrated design approach should be introduced to explore the possibilities of building integrated photovoltaics (BIPV) within a complex building concept.

An invention of PV sun blind shading system is disclosed that shades a building from solar energy gain while simultaneously channeling intercepted energy in the form of electricity (hybrid systems also make use of heat) for useful purposes. It is mounted optimally on exterior building surfaces having some direct exposure to the sun. The installation includes modular units, each having several louvers that may track the movement of the sun to provide optimal shading. Each louver contains photovoltaic cells and heat dissipating substrate to which the cells are mounted.

There is a live discussion which of the systems is most efficient in the terms of energy production and shading, cost, variability, maintenance etc. The easiest to install is a stationary system - a simple PV module mounted above a window conveniently tilted [6]. It works well in the summer when the sun goes high on the sky, but it does not help to stop glares in the winter. Another stationery solution could be using of semitransparent phovotoltaics straight in the building envelope as subsidy for windows. It is important what kind of room is intended to be behind the semitransparent PV installation, since there are various possibilities the light penetrating through can be formed. When using classical crystalline silicon waffles laminated in glass and just set a bit farther apart, it will give a sharp border of light and shadow in the interior. This might be a very interesting and eye-catching element in an atrium, but a very disturbing pattern in an office room or on your monitor. Thin film silicon technology may be an alternative for interiors which require a diffuse light source as it is possible to treat it as printing technology. It is not a problem to create a dense mesh which will solve the problem. Moveable and tracking systems are believed to produce more electrical power (by 20-40 %) and are more efficient in shading, but they are counterbalanced by it their price, need for operating system and maintenance.

A potential problem for all shading systems is a level of daylight available in the interior when there is cloudy outside. This is one of the important design parameters. Of course, the users of the building will not suffer that much and switch the artificial light on, but won't they waste due to the inappropriate design of shading system the energy produced on the photovoltaic cells? In my opinion this is a topic to be closer examined.

The project is aimed at searching for optimal geometries of the photovoltaic sun blind shading system with regard to the daylight factor, the heat load from passive solar gains, minimization of the need for cooling the interior and also with regard to the electricity production. The goal is to use as much solar energy as possible and decrease the overall energy consumption of the building/room in the course of the whole year. It is supposed to be solved as a part of the whole integrated design of "intelligent buildings" which should be tested and evaluated in the climatic conditions of the Czech Republic.

As a base for further studies and numerical simulations a physical model of a middle-size office room with PV louver was constructed (represented by a wooden insulated case in a scale 1:3 – see **Fig. 7**). Data like the daylight factor, temperatures on various spots inside and outside the case, sun irradiance, electrical output of the PV panel and air flow exchange are measured there. After processing the data on the computer a thermal dynamic simulation will be done. As a result, parametric studies predicting the interior's behaviour in relation to external conditions will be done and basic recommendations for optimal solutions will be made.

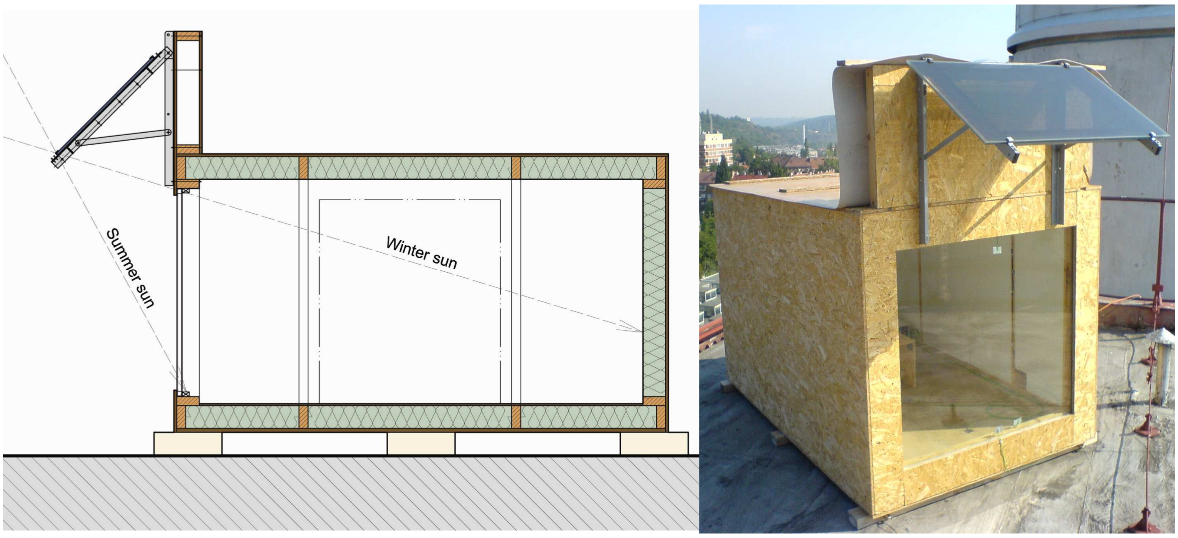


Fig. 7 Experimental set-up with PV sun blind. Roof of the CTU-campus building

4 Concluding remarks

The methodologies of optimized solar energy use in relation to buildings, especially to low-energy and passive buildings are subjects of further research studies at CTU in Prague. Only a deeper understanding of all relevant phenomena could lead to a significant change in the practice. The close-to-zero energy house in Koberovy will serve temporary as an information and education centre for promoting of new technologies. Long time monitoring of energy and comfort related data at together 5 houses in Koberovy development is under preparation now.

Results of experimental studies concerning total performance of PV-sun shading components will be hopefully used in a future design of an experimental house.

PV Building Integration needs innovative products, concepts and technologies, developed in an interdisciplinary "networking" collaboration and be realized within a "whole building approach". Only if technical and esthetical needs are met at the same time, PV will have a great future in our built environment.

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