TREES
Training for Renovated Energy Efficient Social housing

Intelligent Energy -Europe programme, contract n° EIE/05/110/SI2.420021

Intelligent Energy Europe

Section 1 Techniques
1.5 Photovoltaic systems

Annemie WYCKMANS
Sintef – NTNU

TREES

SINTEF

Main issues and definitions

- **Well-insulated houses have reduced energy need but still require electricity for lights, fans and other equipment**
- **Photovoltaic systems (PV) generate electricity from solar radiation, a renewable energy source, at the point of use.**
- **As the cost of fossil fuels steadily increases, PV becomes also economically attractive.**
- **Electricity produced by PV can be used on the spot, stored in batteries, or sold to the electricity distribution network.**
- **Mature technology with increasing demand worldwide.**
- **No noise, no moving parts, no emissions on-site.**

TREES

SINTEF

Main recommendations

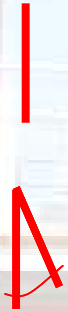
- **PV replacing a traditional building element, e.g. roof or facade cladding, reduces investment cost & provides « free » electricity**
- **Wide range of off-the-shelf PV products in various shapes, colours, costs and efficiencies to match the building project.**
- **Design guidelines for PV system:**
  - Access to solar radiation: horizontal orientation within due South +/- 45^0, vertical tilt within 90^0 minus site latitude +/- 45^0
  - Access to building surfaces on which to install PV: roof, facade, balconies, glazing, solar shading, ...
  - Avoid shading by surrounding vegetation or buildings
  - Sizing of PV according to electricity needs
  - Electricity storage by means of battery arrays or electricity distribution

TREES

SINTEF

Example : The Yellow House (Aalborg, DK)

- **4 storeys, 8 apartments**
- **Built in 1900, renovated in 1996, with focus on solar energy**
- **22,3 m² of PV panels:**
  - Some tilted vertically for optimal integration with building facade
  - Some with 30^0 tilt off vertical axis for maximised solar incidence



- **Electricity production:**
  - ~ 30 kWh / m² per year
  - ~ 25 % of the electricity sold to the electricity distribution network

Picture: Jørgensen & Nielsen

TREES

SINTEF

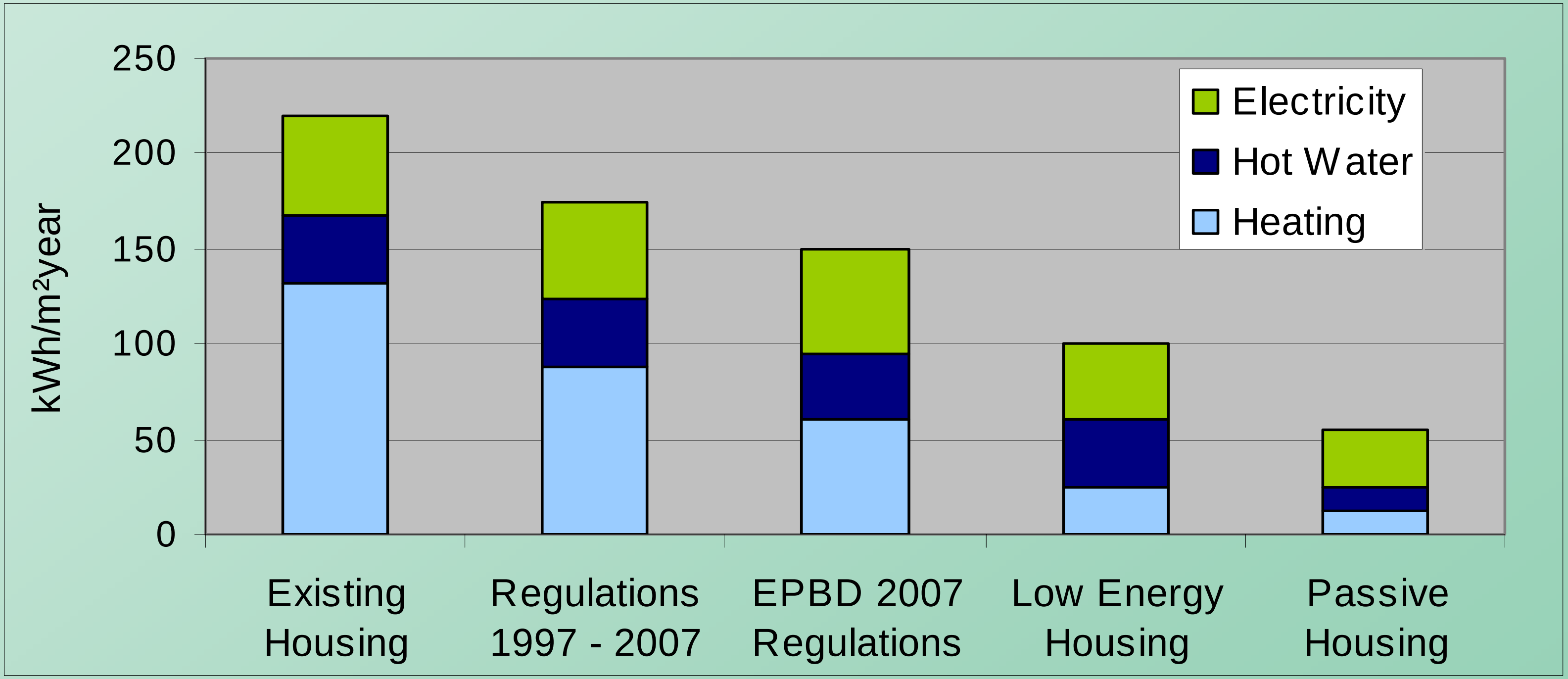
Content

- **PV application in housing**
- **PV cost – benefit analysis**
- **Commercially available products & applications**
- **Design guidelines**
- **Case studies:**
  - The Yellow House (DK)
  - Le Toit Bleu (F)
- **Summary**

PV application in housing

Trends in housing energy use

- Reduced energy use per m^2
- Changing energy use patterns



Energy use in Norwegian housing. Illustration: T.H. Dokka (SINTEF Byggforsk)
EPBD = European Energy Performance in Buildings Directive

TREES

SINTEF

PV application in housing

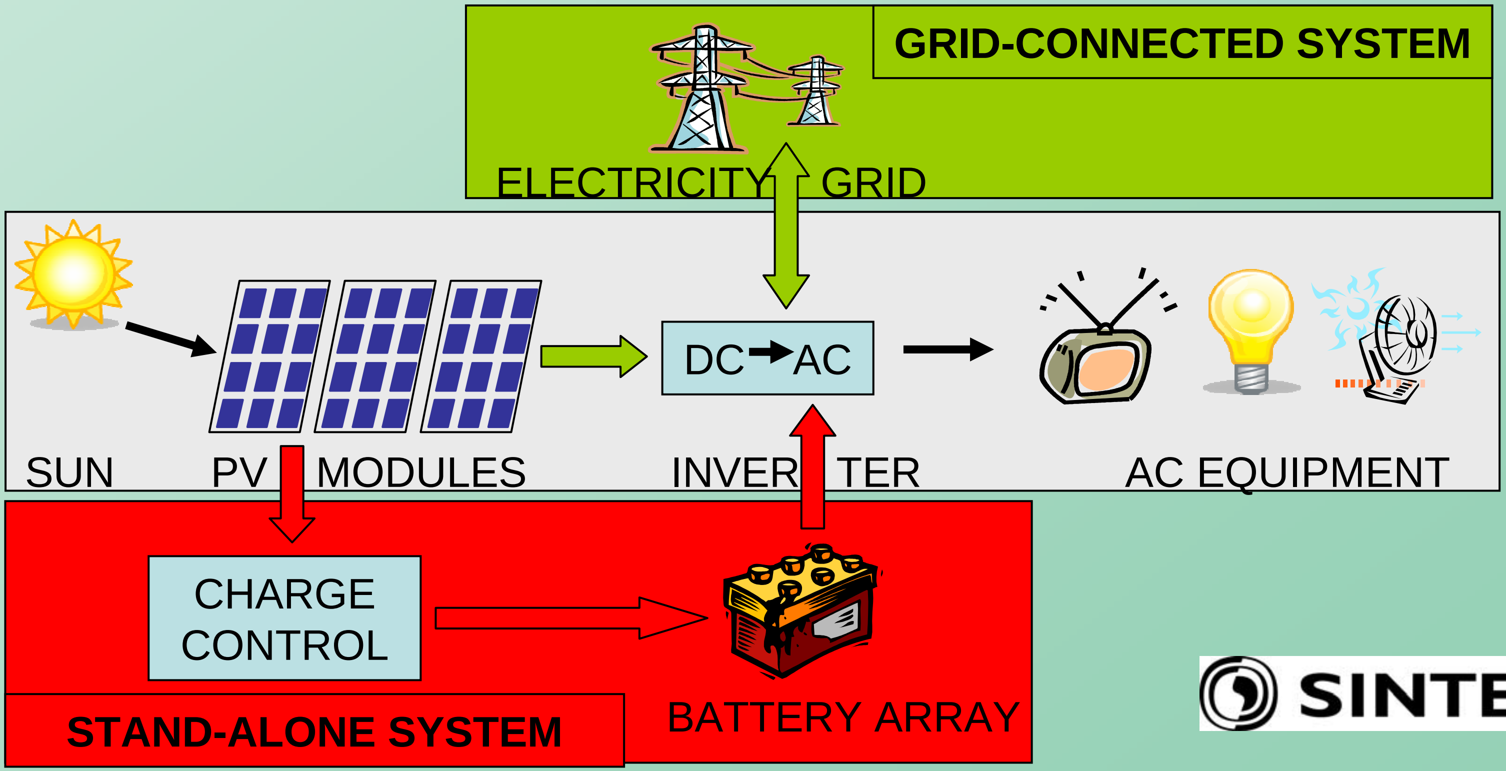
- **Reduced use of fossil fuels**
  - They become more expensive due to scarcity and increased environmental taxes.
- **Reduced use of electrical energy**
  - Energy efficient lighting and equipment
  - Low pressure drops in the ventilation system
  - Low specific fan power
  - Demand controlled heating, lighting, ventilation and cooling
- **Increased use of photovoltaics**
  - Using solar radiation, a renewable energy source
  - More attractive economically and environmentally

TREES

SINTEF

PV application in housing

- **On-site electricity production from renewable source**
- **PV can be used to produce electricity as a**
  - **stand-alone system** (not connected to public electricity grid)
  - **grid-connected system** (exchanging electricity with public grid)

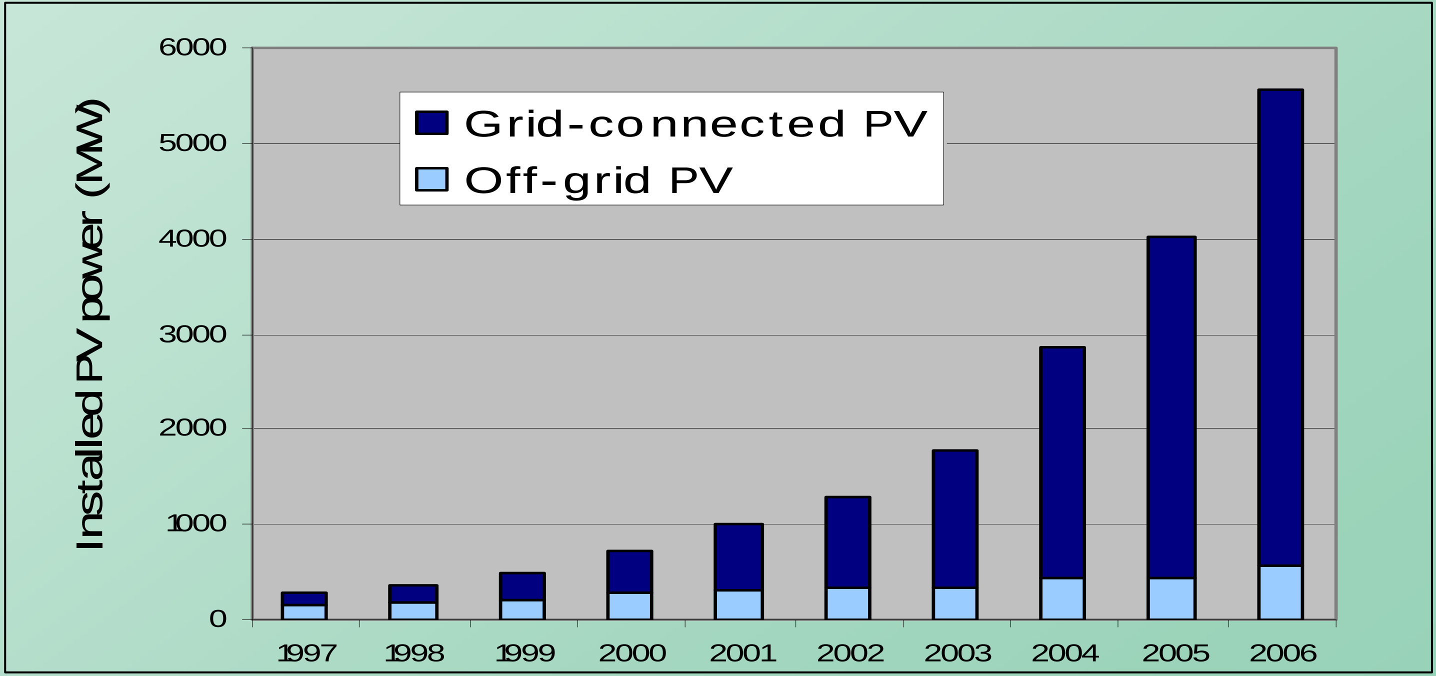


TREES

SINTEF

PV application in housing

- **Mature technology with off-the-shelf products**
- **Government support**
  - For national information regarding subsidies and other incentives, check http://www.iea-pvps.org
- **Expected growth 30% per year**



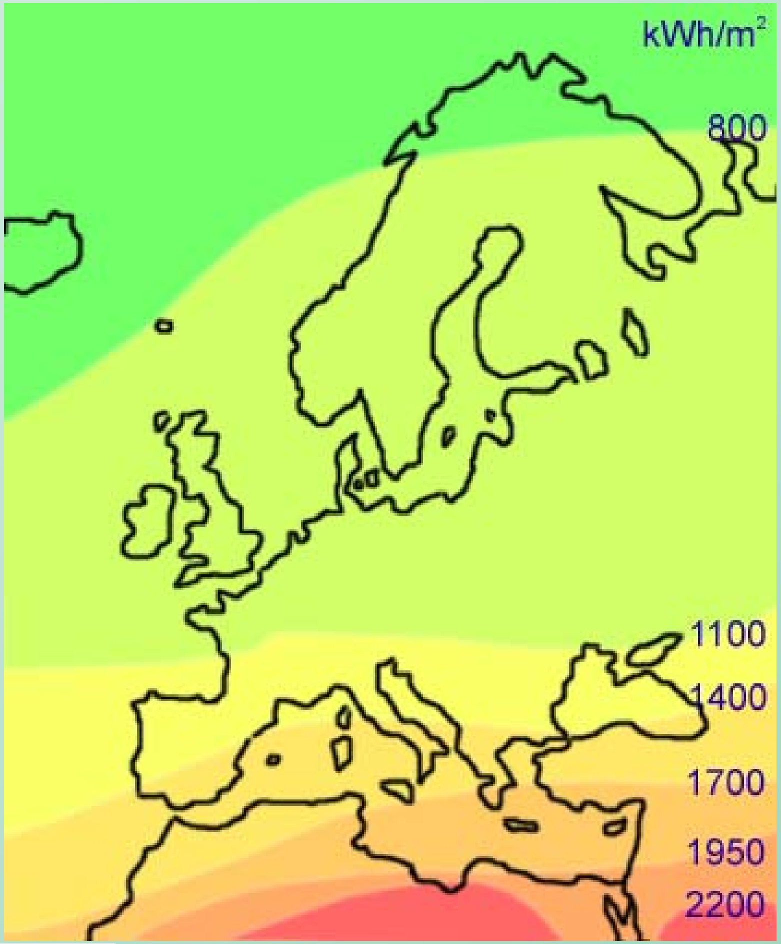
Data: http://www.iea-pvps.org

TREES

SINTEF

PV cost – benefit analysis

- **Output related to solar radiation availability**



Solar radiation availability according to latitude

- Sahara: 2,500 kWh/m^2 per year
- Norway: 700 – 1,000 kWh/m^2 per year
- PV efficiency of commercially available silicium cell: 15-20%

Example:

- PV area = 20 m^2
- PV output in Norway:
  = 1000 kWh/m^2 * 15% * 20m^2
  = <u>3000 kWh</u>

TREES

SINTEF

PV cost – benefit analysis

- **Investment costs**
  - System purchase & installation

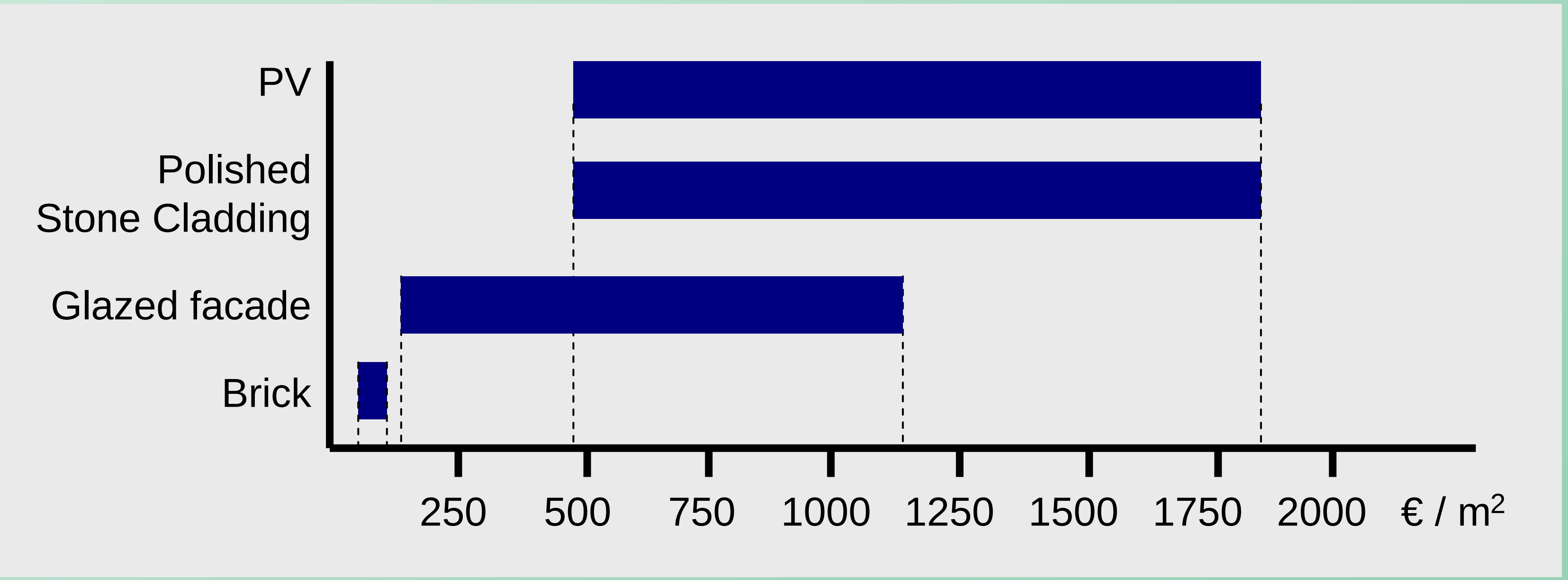
    Off-grid: 8-9 € / W; Grid-connected: 4-5 € / W
  - Incentives? Governmental programmes?
  - Building displacement costs?
  - Accessibility of components for maintenance & replacement?
- **Added value**
  - Local & environmentally friendly energy source
  - Less dependent on fluctuations in electricity market
  - Increased building value
  - Increased rental value
  - Modular
  - Non-intrusive: no noise, no moving parts, no on-site emissions

TREES

SINTEF

PV cost – benefit analysis

- **PV can be used as a multi-functional building material:**
  - As facade or roof element, and for daylighting and solar shading
  - Provides *free* electricity
  - May avoid upgrading of mechanical cooling systems



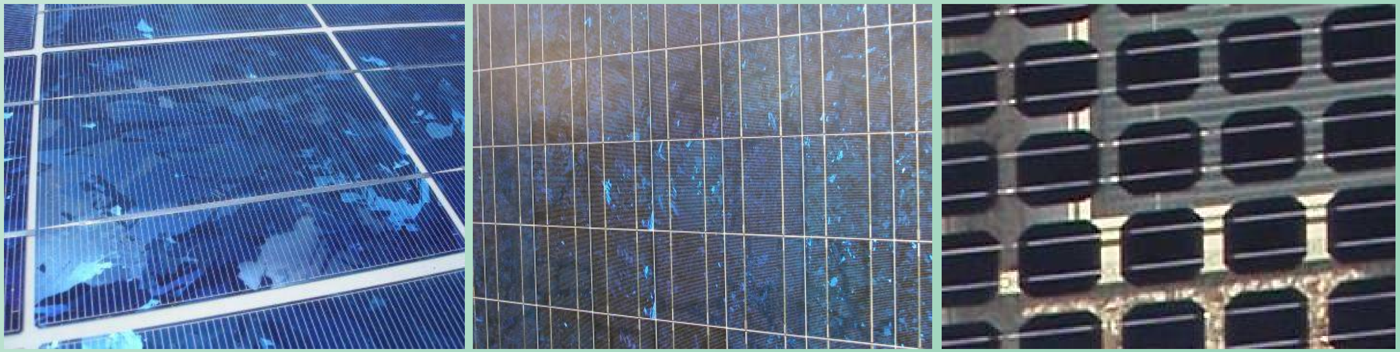
Comparison of capital cost for a range of building materials (illustration: Käthe Hermstad, SINTEF Byggforsk)

TREES

SINTEF

Commercially available products & applications

- **Types of commercially available PV cells**
  - Monocrystalline PV cells (~ 15% efficiency)
  - Polycrystalline PV cells (~ 13% efficiency)
  - Amorphous thin film PV (~ 7% efficiency)
- **Range of sizes, transparency & colour**



Photos: left © Marc Mossalgue / CLER; middle & right: Annemie Wyckmans

TREES

SINTEF

Commercially available products & applications

Type	Module efficiency (commercial) [%]	Module efficiency (laboratory) [%]	Embedded energy [MJ / m^2 PV]
Monocrystalline PV	13 – 18%	24%	5 600 – 24 000
Polycrystalline PV	12 – 17%	20%	2 700 – 8 300
Amorphous PV	6 – 9%	13%	1 010 – 2 750

A comparison of performance criteria for PV cells.

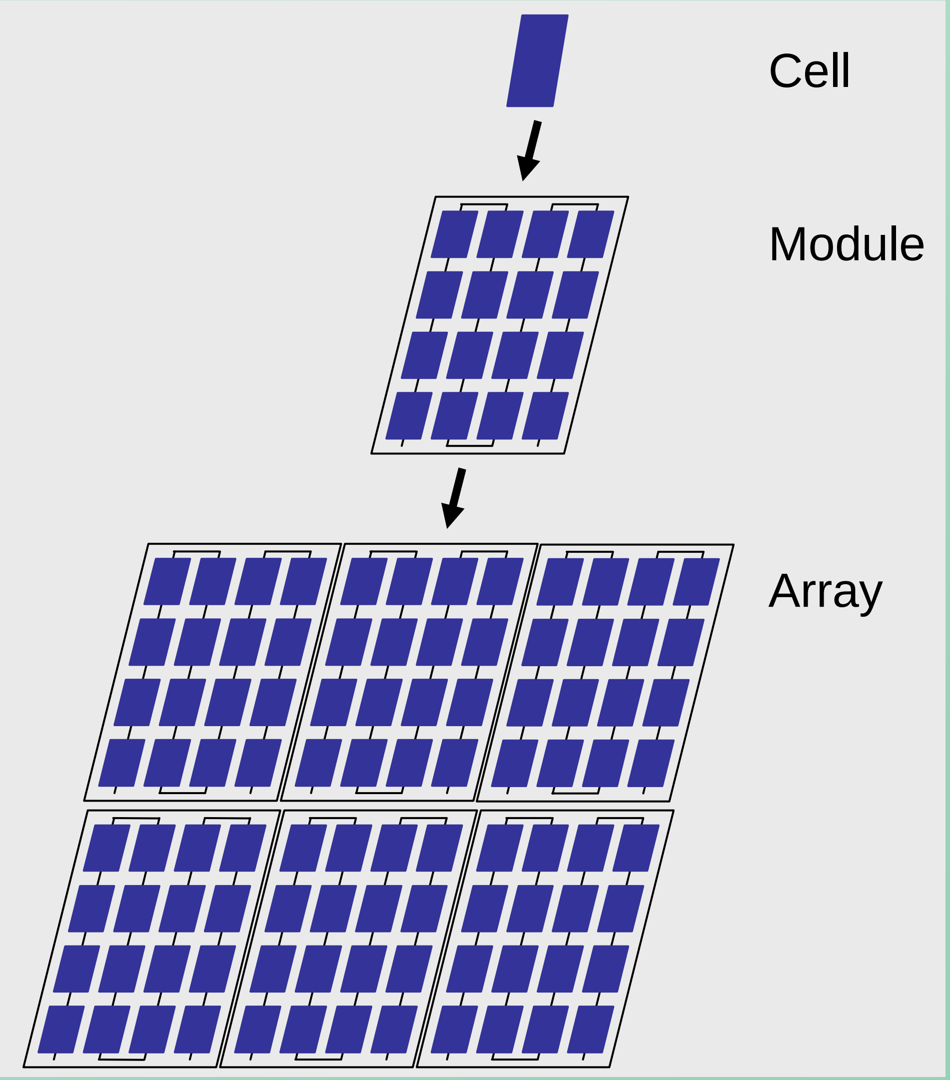
Data: Danish Technology Institute & BCSE (2004) ”The Australian Photovoltaic Industry Roadmap”

TREES

SINTEF

Commercially available products & applications

- **PV systems**
  - PV cells are connected in series (module) and parallel (array) to increase the voltage in the circuit
  - The PV cell with the lowest output determines the output of the entire PV module.



Commercially available products and applications

- **Design integration options:**
  - Roof & facade elements
  - Daylighting, solar shading & passive solar heating elements
  - Replacing building material, or mounted on top of existing envelope

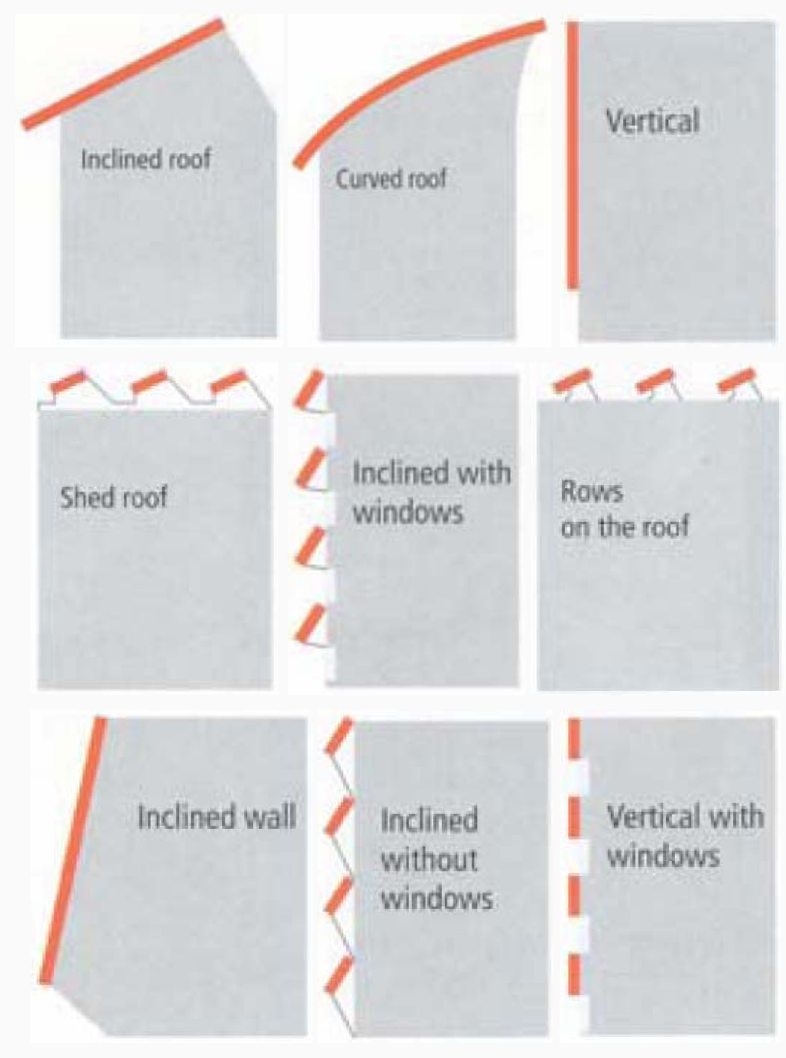


Illustration:

Käthe Hermstad

TREES

SINTEF

Design guidelines

Orientation of PV modules

Optimal angle with regard to solar irradiation:

- Vertical: 90º minus latitude (+/- 45º if better fit with building design)
- Horizontal: due South (+/- 45º if better fit with building design)

Example: the relative effect (%) of a PV system in Oslo

Vertical angle α	Orientation		
	South	East / West	North
90º	83	83	83
60º	96	66	31
30º	100	78	53
0º	73	49	22

TREES

SINTEF

Design guidelines

Shading effect

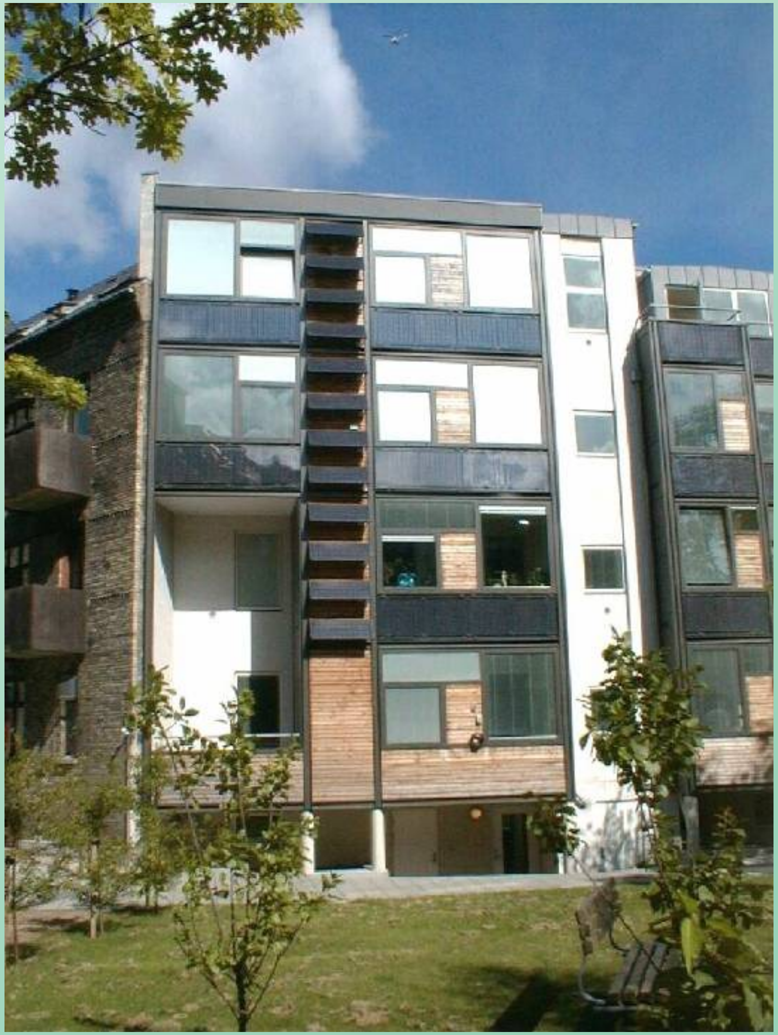
- PV cells are connected in series to increase the voltage in the circuit
- In a serially connected PV module, the cell with the lowest output determines the efficiency of the whole module
- Shading of single PV cells therefore reduces the efficiency of the entire module
- The shading effect can be reduced by connecting the cells in patterns with a similar shading problem

TREES

SINTEF

Case study: The Yellow House (DK)

- **Renovation project:**
  - a 4-storey high building
    with 8 apartments
    built in 1900
    in Aalborg, Denmark
- **Aim:**
  - to use solar energy to reduce
    the overall energy consumption
    for space heating, ventilation,
    hot water and electricity
    by up to 70%.



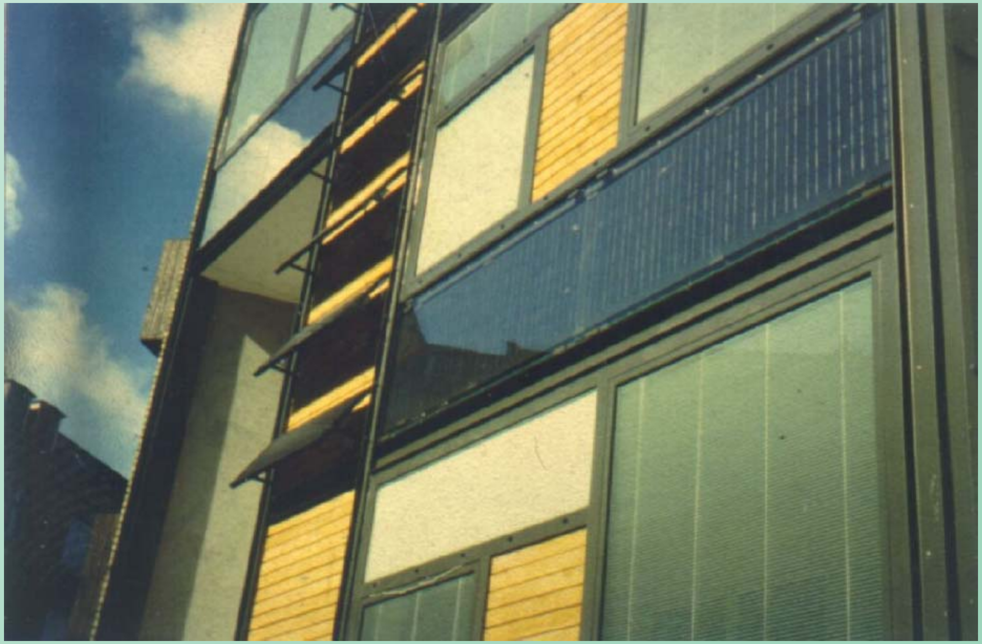
Picture: Jørgensen & Nielsen

TREES

SINTEF

Case study: The Yellow House (DK)

- **22,3 m² PV panels**
  - Integrated in south facade
- **Some 30º vertical tilt**
  - Optimal for solar irradiance
- **Some vertical panels**
  - Integrated in solar wall
  - Lower efficiency due to extra layer of glass & non-optimal tilt
- **PV output**
  - Used in the house
  - Sold to the grid when production > demand in the house



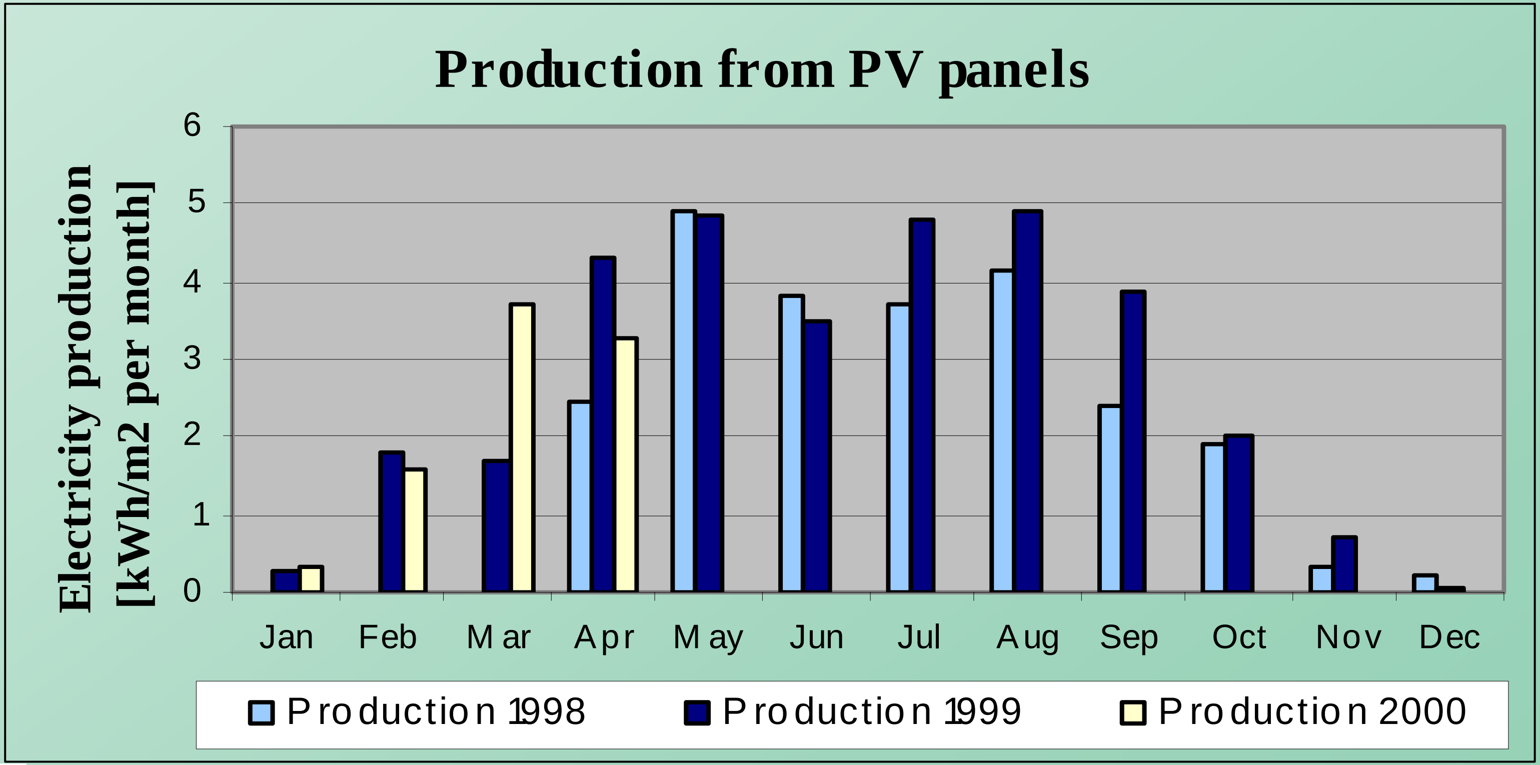
Picture: Jørgensen & Nielsen

TREES

SINTEF

Case study: The Yellow House (DK)

- **Electricity production**
  - ~ 30 kWh/m^2 per year
  - ~ 4,5% efficiency



TREES

SINTEF

Case study: The Yellow House (DK)

- **Electricity sale to grid**
  - ~ 20-30% of electricity produced

	Units	1997	1998	1999
Production	kWh	531,4	663,9	734,1
Production	kWh/m^2	23,8	29,8	32,9
Sale to grid	kWh	140,2	170,5	210,0
Sale / Prod.	-	26	26	29
Sun hours	Shr	1984	2025	1798

TREES

SINTEF

Case study: Le Toit Bleu (F)

- **Renovation project:**
  - Installation of PV panels on a building roof in a dense urban area
  - The largest rooftop integrated PV installation in France (2001)
- **Aim:**
  - Use of a local and renewable energy source
  - Integration in the building
  - Education of electricity consumers
  - Exemplary co-operation between decision-making organisations

Pictures: Christophe Noisette

TREES

SINTEF

Case study: Le Toit Blue (F)

- **PV layout:**
  - Area: 220 m^2
  - Number of PV modules: 200, polycrystalline
  - Orientation of PV: South
  - Vertical inclination of PV: 35º
- **PV output:**
  - Peak power: 22 kWp
  - Estimated output: 20,000 kWh per year
  - Measured output: 22,500 kWh per year (12,5% more than estimated)
- **Costs:**
  - 150,000 Euros
  - Grid-connected: selling excess electricity to the grid
  - Installation, assembly and erection time: 1 week

Pictures: Christophe Noisette

TREES

SINTEF

Summary

- **For each project, the appropriate type and size of PV system needs to be determined according to:**
  - Solar access
  - Building design
  - Building function
  - Electricity needs
  - Grid connection
  - Availability of incentives
- **More info:**
  - **The International Energy Agency PV Power Systems**
    http://www.iea-pvps.org
    http://www.pvdatabase.com
  - **The Australian Business Council for Sustainable Energy**
    http://www.bcse.org.au
  - **CLER – Comité de Liaison Energies Renouvelables**
    http://www.cler.org

TREES

SINTEF