TREES **Training for Renovated Energy Efficient Social housing**

Intelligent Energy Europe

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Section 1 Techniques

1.5 Photovoltaic systems

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Partners

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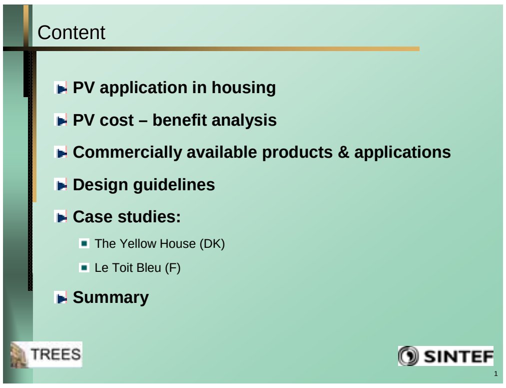
University of Kassel, Center for Environmental Systems Research (CESR), Germany

Slide 0: Introduction

This paper gives comments to each slide to help the lecturer in the issues that are presented. More detailed information can be collected from papers and reports included in the CD.

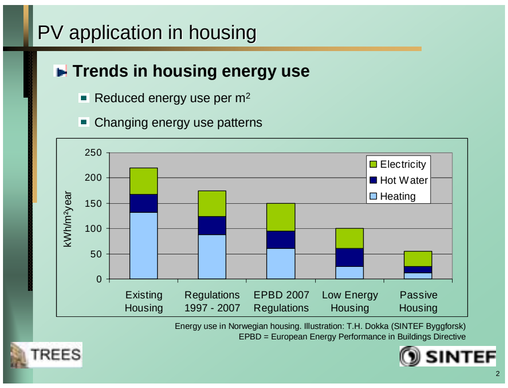
Slide 1

This lecture focuses on the use of photovoltaic systems in housing. It contains practical information and guidance with regard to the design, installation and operation of solar cells in housing.
Additionally, a range of slides shows the architectural potential of integrating PV into buildings. Two particular case studies are used to exemplify the design decisions that need to be made when applying photovoltaics in a housing project, regarding energy, technology and aesthetics.
In conclusion, a summary repeats the most important issues to be dealt with regarding PV, and shows several organisations from which to obtain more information if desirable.



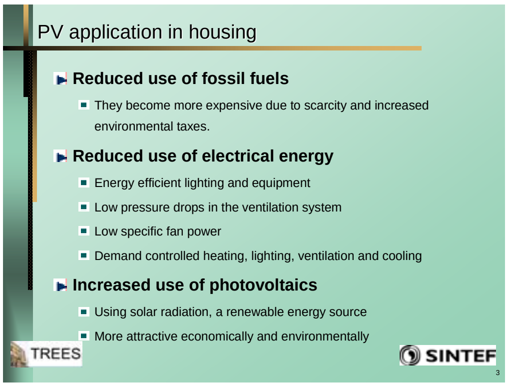
Slide 2

Future houses will have a reduced need for energy, as compared to the current standards. This is mainly due to better insulation and consequentially a lower heating need.
They will, however, still require a fair amount of electricity, for lights, fans, and other equipment.



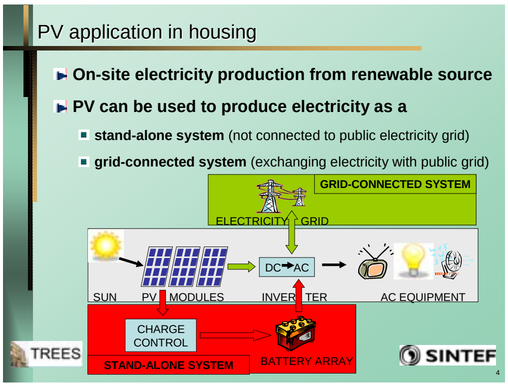
Slide 3

Electricity can be generated from a range of energy sources, among which fossil fuels and solar radiation. Fossil fuels are and have been used extensively during the past decades. Currently, however, fossil fuels are becoming increasingly more expensive due to scarcity, global politics, and environmental taxes. Apart from fossil fuels, electricity can be generated by means of a PV system.
Photovoltaic cells are semiconductors that generate electricity from sunlight. The electricity generated in this manner is environmentally attractive as solar radiation is a renewable source of energy. In addition, PV is becoming economically attractive, as the cost of fossil fuels steadily increases. PV also represents a locally generated source of energy.
As future houses require relatively less electricity due to better insulation and more efficient equipment, solar cells integrated in the building envelope will be able to provide up to 100% of the building's electricity needs.



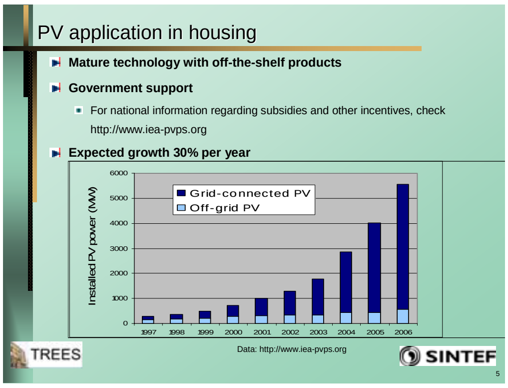
Slide 4

PV systems produce electricity from a renewable source, at the point of use: the electricity the PV system produces can be used immediately by the building occupants or stored for later use. Costs related to electricity transport, transmission and distribution are thus avoided.
In general, one can choose between a grid-connected and an off-grid system.
In an off-grid or stand-alone system, the electricity produced by the PV modules needs to be stored on-site if not used immediately. In that case, excess power can be stored in batteries.
In a grid-connected system, the PV modules are connected to an electricity distribution network. In principle, this grid functions as an electricity storage device, absorbing the excess electricity in case of excess, and providing electricity when the PV modules' production is insufficient. One can sell electricity to the power company in periods with a surplus, and buy when necessary. This eliminates the need for large battery arrays.
Either way, all of the components should be installed in a place accessible to maintenance.



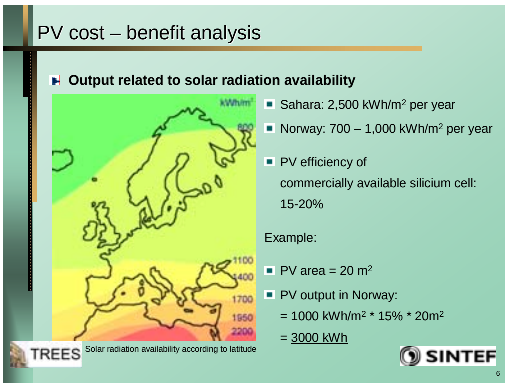
Slide 5

Since the 1990's, the PV market has been growing tremendously, in particular the grid-connected applications. This is partly due to the support of governmental programs and subsidies to promote this type of technology. Governmental support has led to the development and dispersion of a wide range of off-the-shelf PV products, in turn increasing the demand for PV applications worldwide.
In Europe, PV growth is expected to continue at a rate of 30% per year, leading to half a million solar roofs by 2010. In the US, the Government has launched the One Million Solar Roofs Initiative in 1997. This programme aims to install one million solar water heaters and PV systems on the rooftops of US buildings by 2010.



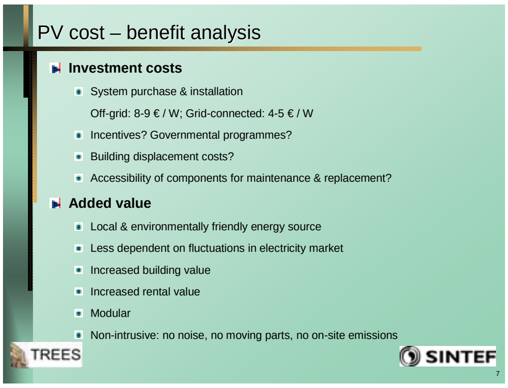
Slide 6

The design of a PV system is related to the building's access to solar radiation on the one hand, and the availability of building surfaces on which to install PV, on the other hand.
For example, the roof area qualified for PV installation in a particular project in Oslo is 20 m^2. The roof is exposed to 1000 kWh/m^2 per year. With a cell efficiency of 15%, the PV system would produce about 3000 kWh/m^2. If more output is needed, one needs to choose either a more efficient PV system, or extend the PV area on the roof or other building surfaces.



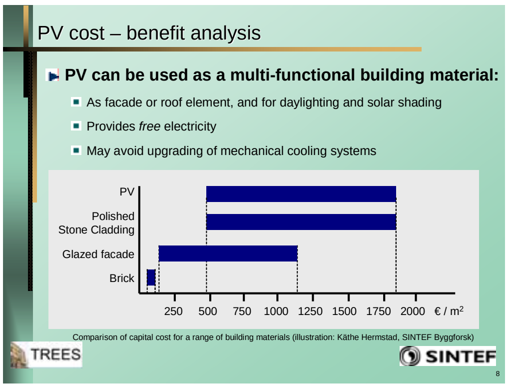
Slide 7

PV systems have low running costs. Investment costs, on the other hand, are relatively high. System purchase and installation cost about 8-9 Euros/Watt for off-grid systems, and 4-5 Euros/Watt for grid-connected systems, if no subsidies for market introduction are available. In general, off-grid connections cost about twice as much as grid-connected systems, as the former need storage batteries and associated equipment. Governmental incentives reduce the capital cost of PV. Having PV replace conventional building materials further reduces investment costs, as will be shown in the next slide. In addition, PV systems have a range of added values, the market price of which is difficult to establish. First of all, the installation of PV allows one to apply a local and environmentally friendly energy source. Producing electricity on-site will also make the building less dependent on fluctuations in the electricity market. This is likely to become of utter importance in the near future, with unstable fuel markets and a growing shortage of energy supply. The integration of PV in the building will most likely also have an effect on the value of the building in the real estate market. A building with integrated PV may become easier to let, and the corresponding market price may be higher. The building users may also get satisfaction from the fact that they are living in an energy conscious building. PV systems are modular. This allows for the installation and power output to be expanded or reduced over time if desirable. And, last but not least, PV generates electricity without generating noise, has no moving parts, and generates no emissions on-site.



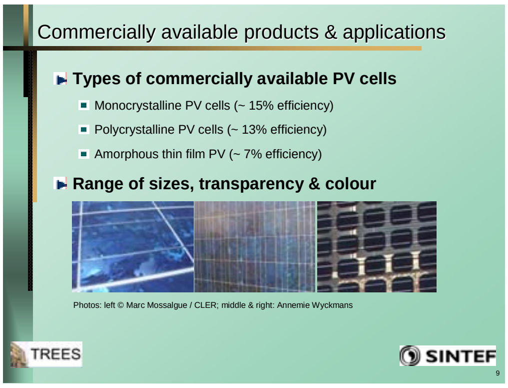
Slide 8

PV modules can be installed on the roof and the facade of a building. They can be used in addition to the existing building envelope, or, more favourably, to replace some of the original building materials and components. Regarding the PV system as a building element can reduce the investment costs of the installation. In addition, by integrating PV into the building envelope, electricity production can be combined with functions such as weather protection, solar shading, and daylighting. The cost savings achieved in this manner can be substantial. In calculating the investment cost of PV, one should therefore take into account the reduced cost in conventional material requirements and installation. The figure on the slide shows the relative cost of PV modules as compared to some other, more traditional building materials. The investment cost of PV modules is comparable to that of polished stone and marble. Hence, by replacing polished stone with PV modules in a renovation project, the PV modules will cost the same as the normal building material, but, in addition, they will generate ”free” electricity. Furthermore, using PV modules for solar shading and additional electricity generation produces power when the need for solar shading and cooling peaks. This may avoid the need for installing or upgrading existing mechanical systems in the building.



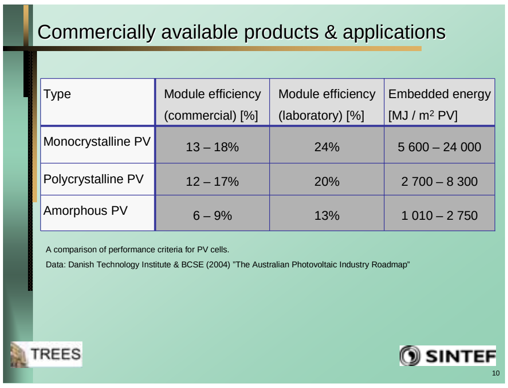
Slide 9

There exists a wide range of PV cells, and intensive research is steadily improving their efficiency, lifetime, and integration in building design. Commercially available PV cells can be divided into 3 main categories, according to their crystalline structure, cost and performance.
Monocrystalline PV cells are produced from one continuous crystal structure. They are the most efficient, but also more difficult and expensive to produce. Polycrystalline PV cells are a composition of smaller crystals. Hence, their production is less demanding, and their cost lower. Their efficiency, however, is lower than that of monocrystalline cells. Amorphous PV is the least efficient of the 3 types. It is composed of a thin film of silicon atoms deposited on a substrate, and has no crystal structure. This technique requires less material, and amorphous PV is thus cheaper to produce than crystalline PV. In return, amorphous PV is less efficient.
In addition to cost and efficiency, texture and colour are crucial characteristics for PV, particularly in a renovation project. Monocrystalline cells are typically dark blue, indicating a high level of solar absorption. Polycrystalline cells are typically available in bright blue, grey, magenta and cyan. Thin film PV typically has a reddish-black appearance. The clear advantage of amorphous PV is its flexibility. The film is bendable and very durable, making it highly appropriate for use in curved or moveable surfaces.
PV products can also be custom-designed to fit optimally in a building project. However, one should always keep in mind that custom designed products in general are more expensive than standardised products.



Slide 10

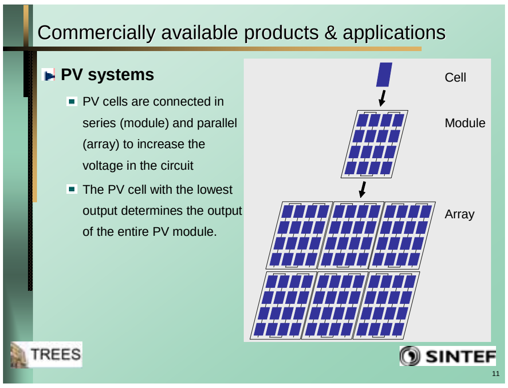
Different types of PV cells have different efficiencies. The choice of type of PV cell will therefore affect the sizing of the PV system.
For monocrystalline PV cells, for example, less PV area will be required to produce the same output than for amorphous PV, as the latter one is only half as efficient.
Higly-efficient, monocrystalline PV, therefore, fits well when little area for PV is available. For minimum costs, however, a larger surface area may be clad with thin-film PV to generate the desired power output.
Another important characteristic of PV cells is their energy neutralisation time. While neutral in operation, the fabrication of PV cells is quite energy-intensive. The energy embedded in the manufacturing of PV depends on the type of cells. Monocrystalline cells, for example, require 5 to 9 times as much energy to be produced as compared to thin film PV. This, however, is partially compensated for by their high efficiency.
In general, the energy neutralisation time for PV cells amounts to 3-4 years.



Type	Module efficiency (commercial) [%]	Module efficiency (laboratory) [%]	Embedded energy [MJ / m² 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

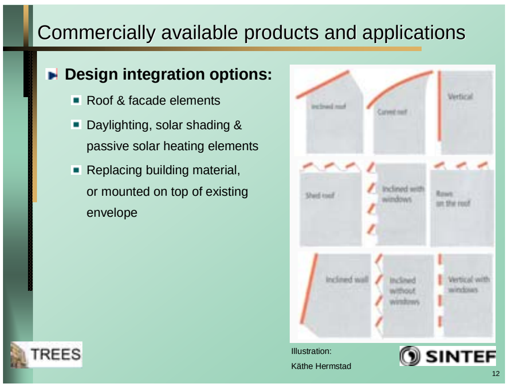
Slide 11

PV cells are connected in series (module) and in parallel (array) in order to increase the voltage in the circuit. The PV cell with the lowest output determines the output of the entire PV module. Therefore, it is vital to investigate the solar access and shading conditions before deciding on the location of the PV modules.



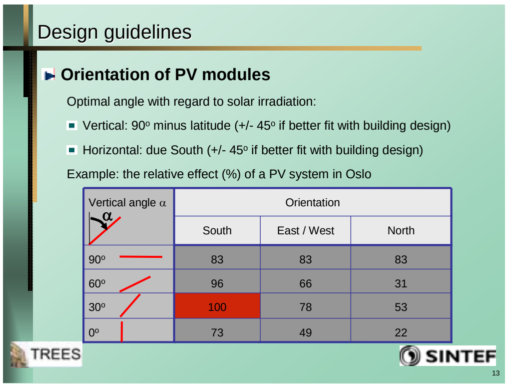
Slide 12

PV modules can be installed in the building envelope as two main types: (1) as facade or roof elements, or (2) as components for daylighting, solar shading and passive solar heating. In addition, a wide range of mounting systems has been developed to integrate PV into buildings, either installed on top of the existing building envelope, or as a replacement of the original building material.
As mentioned earlier, PV modules that replace conventional building materials may have a lower investment cost and are easier to integrate aesthetically in an existing building.
PV modules that are mounted on top of the existing building envelope, on the other hand, are easier to install, and can provide additional rain cover and insulation. However, they also impose additional weight to the existing building envelope.
A wide range of mounting systems is available to install PV systems on sloped, horizontal or vertical surfaces. In general, the output of PV on a vertical facade is lower than for a roof due to a less than optimal tilt, and a larger chance of being shaded by neighbouring buildings and other obstacles. However, if a sufficient area of the facade can be used for PV, and PV replaces the original facade cladding, a lower output is weighed up for by lower investment costs and a larger surface area.
The combination of electricity generation, solar shading and daylighting is likely to reduce the need for cooling and artificial lighting, and may decrease the required peak power of the mechanical systems in the building.



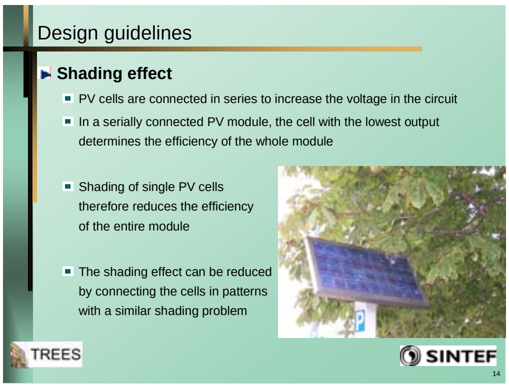
Slide 13

Choosing an appropriate location for the PV modules requires an understanding of the local climate and site. In particular, one needs to know the path of the sun in the course of the day and year in order to install the PV modules with the right orientation and vertical tilt so as to receive as much direct solar irradiation as possible.
In Europe, the building surfaces that are oriented towards the South are those that have a good exposure to solar radiation. In general, the optimal orientation for a PV module is due South. However, horizontal angles up to 45 degrees off South are still acceptable.
Concerning the vertical tilt of the PV module, the optimal angle is related to the latitude of the site. The optimal vertical angle of a PV module corresponds to 90 degrees minus the latitude.
The illustration on the slide shows the effect of orientation and vertical inclination of a PV module on its output, expressed as a percentage of the maximum output. The example is calculated for Oslo at 59 degrees latitude.
In Oslo, a PV module oriented towards the South, with a vertical inclination of 30 degrees, would achieve maximum annual solar exposure.
However, often it is more important to integrate the PV modules with the existing building design, than to achieve the optimal orientation for the PV modules.
For example, a PV module integrated in a roof with an angle of 45 degrees, oriented towards the West, would still generate about 70% of the optimal PV output.



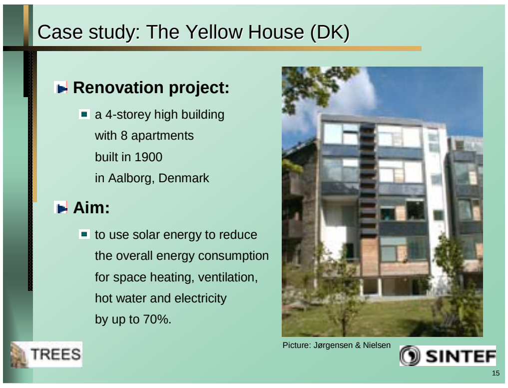
Slide 14

In addition to tilt and orientation, shading is a critical criterium for the output of PV modules.
Building surfaces that in theory are likely to receive a lot of solar radiation, may in practice be shaded by obstacles such as trees and neighbouring buildings certain portions of the day and year. In this manner, the PV cells' access to direct sun is reduced considerably, and their power output decreased accordingly.
The decrease in power output is not only affected by the size of the PV area that is shaded. Actually, it is the PV cell with the lowest output that determines the efficiency of the entire PV module. Hence, if one cell in a module is shaded, it is this cell that will determine the power output of the entire module.



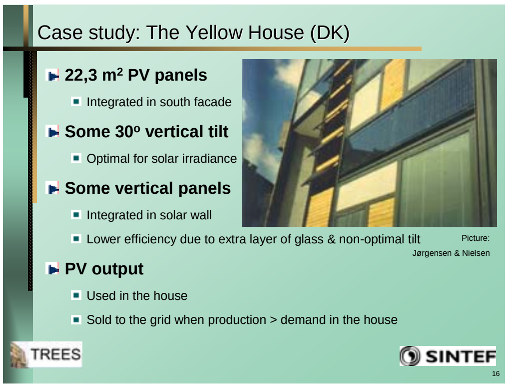
Slide 15

The Yellow House is a four-storey high building with eight apartments.
The house is situated in Aalborg in Denmark, and built in 1900.
In 1996, the house was renovated and the building envelope renewed with focus on solar energy.
The aim of the project was to use solar energy to reduce the overall energy consumption for space heating, ventilation, hot water and electricity by up to 70%.
After its renovation, the performance of the house has been monitored extensively.



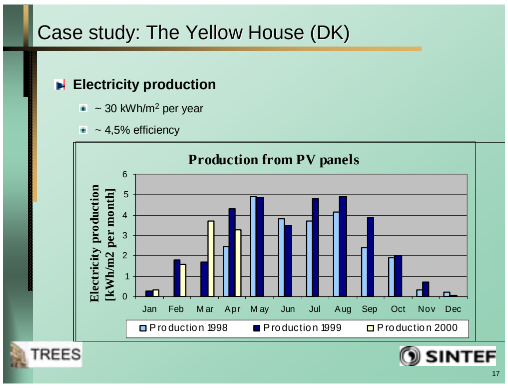
Slide 16

The house is connected to its neighbours by its East and West facades. The South facade of the house faces a back yard, which provides an opportunity for the use of solar energy.
The South wall is used as a solar wall that preheats ventilation air for the house. In addition, it features a range of PV panels, the total area of which amounts to 22,3 m^2.
Part of the PV panels are tilted 30^o vertically to optimise solar incidence. The other part of the PV panels are integrated in the vertical solar wall.
The output of these vertical panels is lower than that of the tilted ones, due to a less optimal solar incidence angle. In addition, an extra layer of glass in front of the PV panels is reducing their output even further.
Yet, this layout was chosen as the one most fit for this house. This is partly due to architectural reasons, and partly due to technical requirements. The PV panels integrated in the solar wall are used as absorbers to preheat the ventilation air.
All PV panels are grid-connected. The output of the PV panels is used directly in the house to service the electricity demands. When the demand in the house is lower than the amount of electricity produced, the excess electricity is sold to the power company.



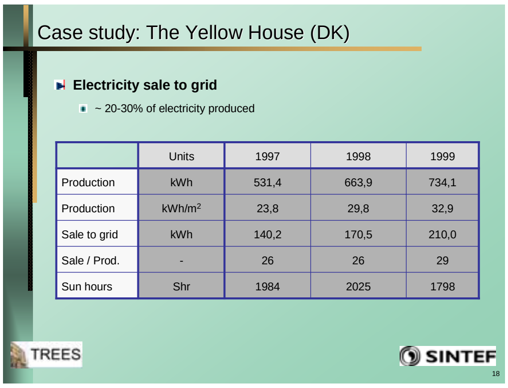
Slide 17

Ever since their installation in 1997, the PV panels have been functioning as expected. The panels produce about 30 kWh/m² per year. The graph shows the electricity production per month. The panels produce more electricity in summer than in winter, which is to be expected. Rather curiously, however, it also becomes clear that the electricity production in June and July is lower than in May and August. The relatively low production in June and July is due to the high incidence angle of the sun as compared to the tilt of the glazing. At an oblique incidence angle, most of the solar radiation is reflected off the glazing instead of being transmitted through, and thus never reaches the PV panels. In addition, the efficiency of the PV system is lower than expected. An electricity production of 30 kWh/m² per year corresponds to an efficiency of about 4,5%, while it should have been 10%.



Slide 18

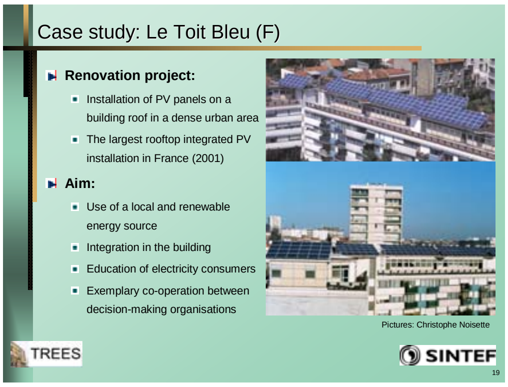
About 20-30% of the produced electricity can be sold to the grid. The table shows the output of the PV panels and the percentage of electricity sold to the grid for different years in which the system has been monitored.



	Units	1997	1998	1999
Production	kWh	531,4	663,9	734,1
Production	kWh/m²	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

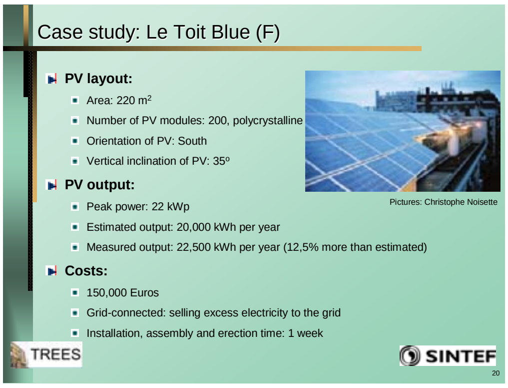
Slide 19

The project is situated at Montreuil-sous-Bois close to Paris, France.
The building is 4 storeys high, housing 11 apartments and 6 associations. The top storey is occupied by CLER, the French Committee for Renewable Energy, who also has taken the initiative for this project. The project is funded by several French governmental institutions. Due to this funding, the project was able to install the largest area of PV panels in social housing in France (in 2001).
There are various aims to this project. A first goal has been to produce electricity from a renewable source in a dense urban area, in immediate proximity of the consumer.
Furthermore, the project is to demonstrate the possibilities of integrating the use of solar energy into buildings, even in existing buildings in urban areas, and to educate and influence people in their everyday life.
In addition, the project has demonstrated the fruitfulness of co-operation and co-ordination among a number of public institutions on a governmental and local level.



Slide 20

The roof area is completely covered by PV panels, amounting to a total area of 220m². The panels are mounted on the roof of the building, oriented South, with an optimal inclination angle of 35º. In the project, polycrystalline PV cells were used, with a theoretic efficiency of 13%.
The expected output was 20,000 kWh per year. After having performed measurements for 1,5 year, the PV output turned out to be 22,500 kWh, which lies 12,5% above the expected performance.
The PV panels are grid-connected. Excess electricity is sold back to the power company. The association hopes to be able to invest in additional solar measures with the gains of the PV panels.



Slide 21: Summary