Building integrated photovoltaics (BIPV)
Tools for Implementation and Design Approaches

Part 1: Tools for Implementation
Part 2: Thesis Report (Tools for Implementation and Design Approaches)

Thesis in the Master Degree Program: Design for Sustainable Development

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Report No. 465

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PART 1: Tools for Implementation

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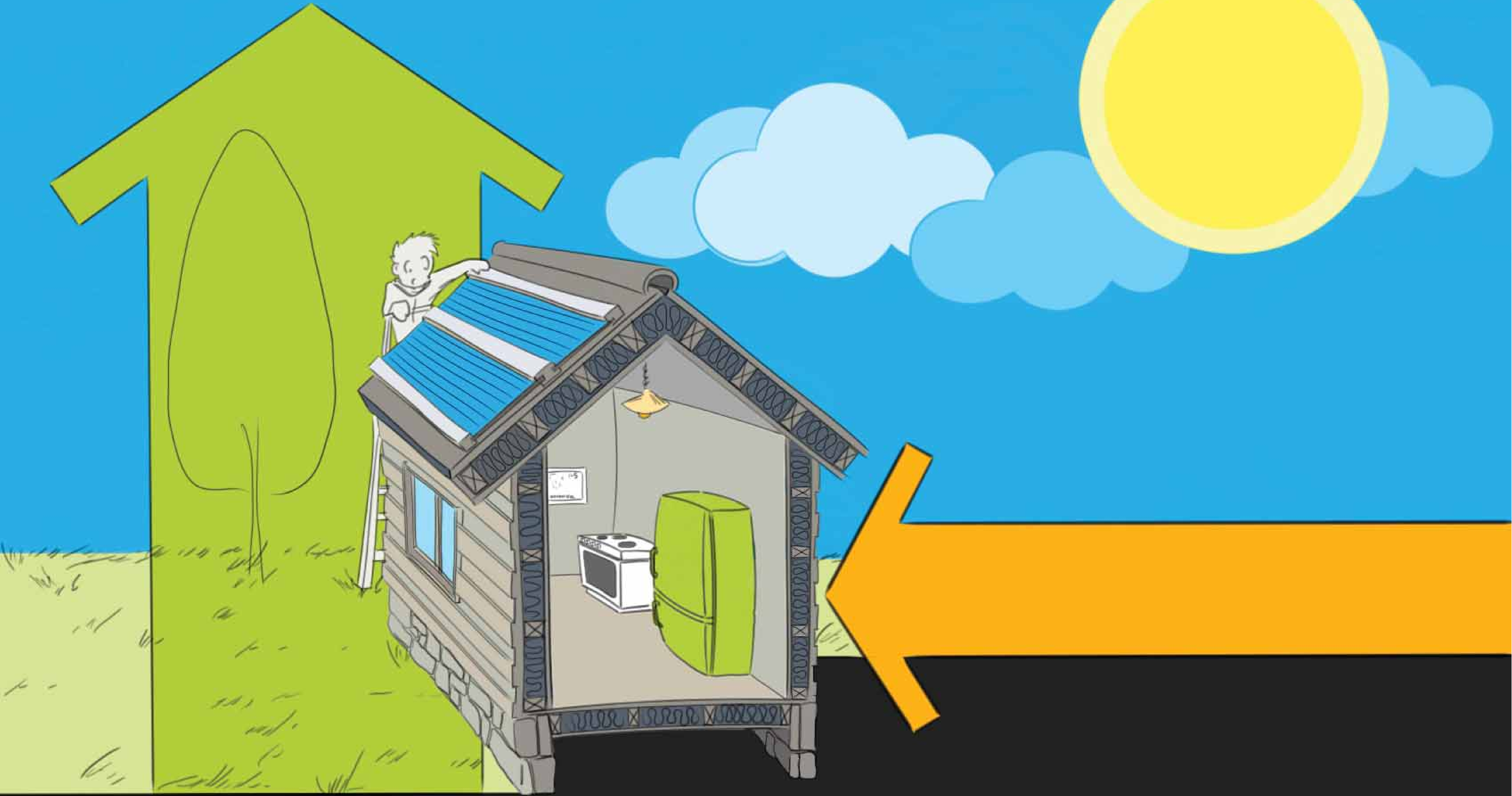
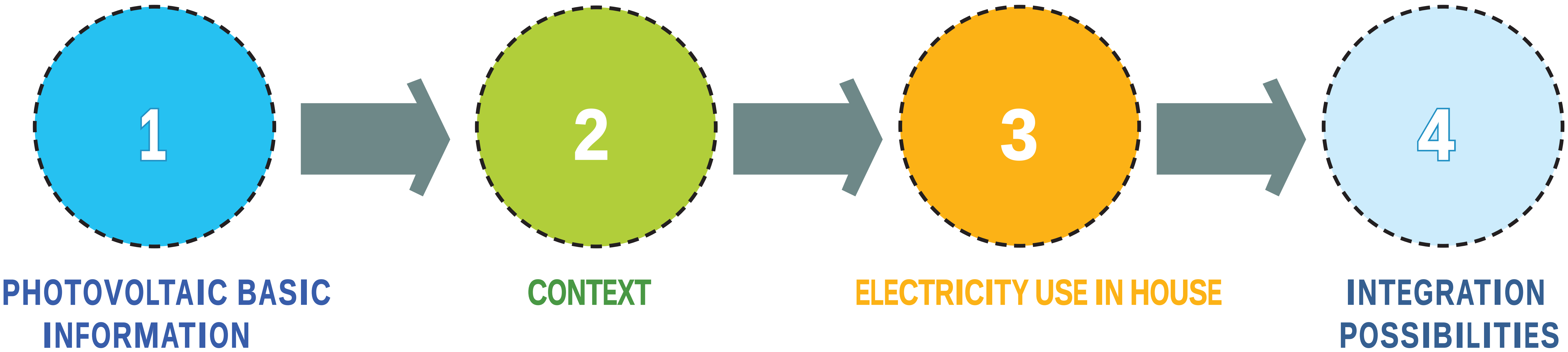


BIPV: TOOLS FOR IMPLEMENTATION

WHAT SHOULD WE KNOW?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INTRODUCTION

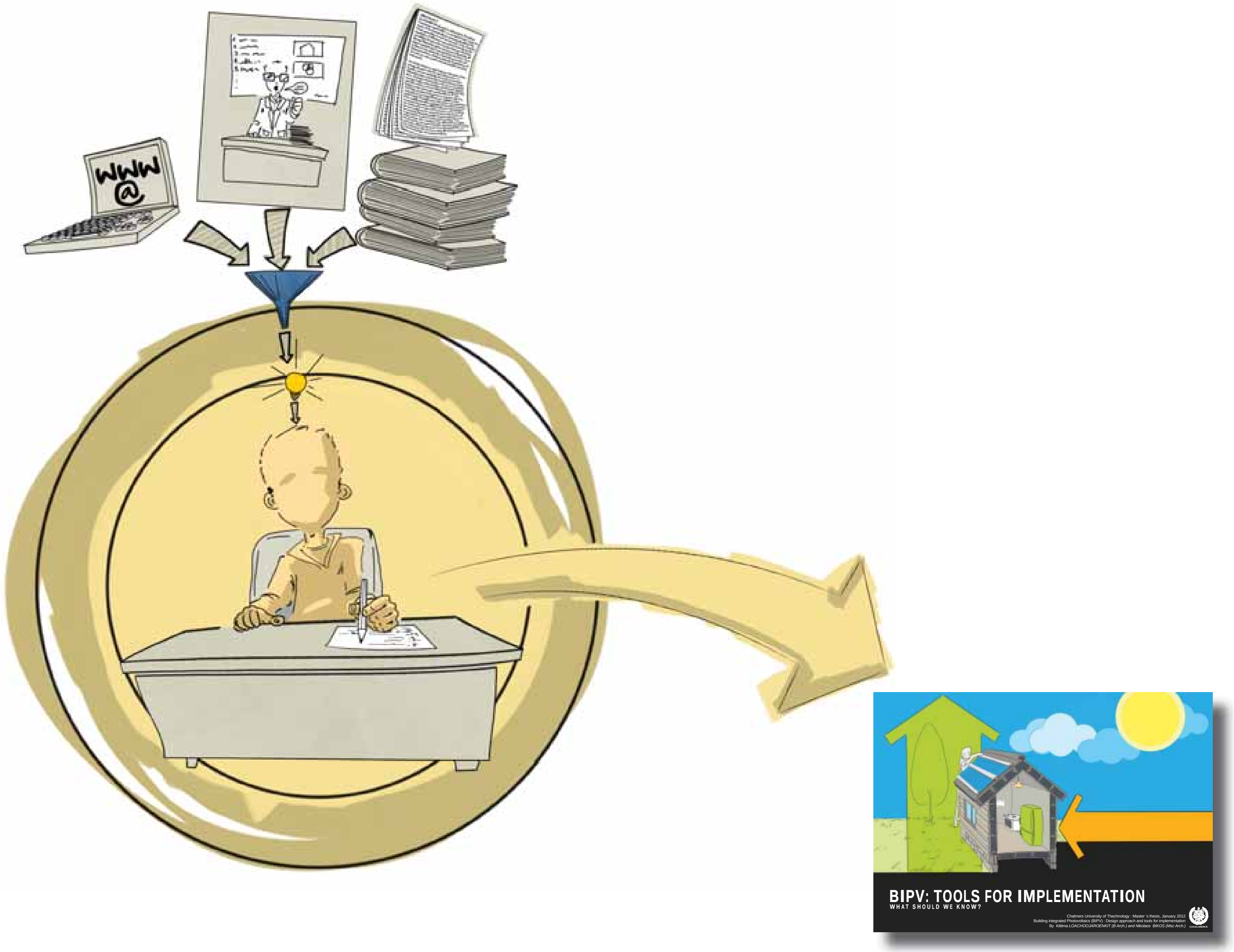
WHY?

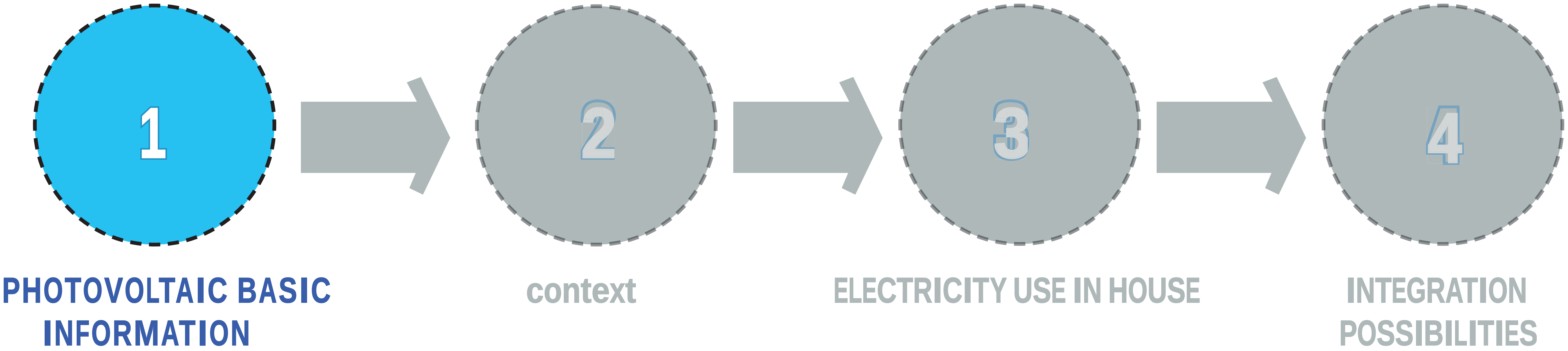
The subject of sustainable buildings is being widely discussed by the actors involved in the field of education, architecture, engineering, construction, and politics, with the issue of energy being commonly in the foreground. Energy in terms of efficiency as well as renewable resources, with the importance of the integration of the latter into the building design being stressed many times. In order for one to be able to follow these discussions and contribute as an actor, the need of a background knowledge on the issue is becoming evident.

The field of renewable technologies - and more specifically photovoltaics - is continuously developing. This, in conjunction with the vastness of information available on the issue, makes it difficult for one to navigate through and mine the essential information for forming the necessary background and thus having a springboard for tackling the subject of integration.

In the present booklet, information collected, analyzed and categorized regarding PVs and their integration to buildings is presented, in steps that can be easily understood. The subjects covered are: PV types and technologies, PV systems and their components with a more in-depth presentation of batteries and sizing calculations, calculation examples for the user related electricity consumed within a building, context related factors that affect the design, integration possibilities and examples, PV data sheet analysis accompanied by a calculation method of PV electricity production and relative example.

The information presented is aiming to provide a solid background and be used as a set of tools for further research and application of PV technologies during the design process. The booklet is a tool for architects who are interested on the field of BIPV (Building Integrated Photovoltaics), as well as others who are also interested in the topic.

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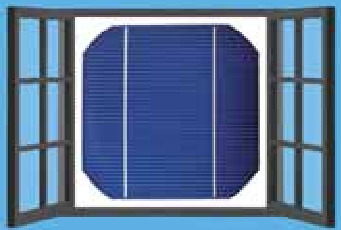
TRUE MATCH
WHICH TYPE IS YOU?

PV TYPES

Hit is a hybrid construction, being a combination of crystalline and thin-film cells. They are the most efficient type of cells, have less degradation of efficiency with increase in operating temperatures, and the thin-film component allows them to use the diffused light more efficiently. They are the most expensive type of cells. Cell efficeiency: 30-42% , Module efficiency: ~25%

HETEROJUNCTION WITH INTRINSIC THIN-LAYER HIT CELLS

CRYSTALLINE CELLS (c-Si)



MONOCRYSTALLINE: the cell comes from a single crystal ingot of high purity, with typical dimensions of 12,5 or 15cm. Because the ingot has to be cut in thin slices, a large portion of the material is wasted. They tend to be expensive but are the most commonly used.Cell efficeiency: 16-20%
Module efficiency: 13-19%
Area need per KW per modules: ~7 sqm

POLYCRYSTALLINE: They are more simple and less expensive to produce than monocrystalline silicon cells, due to the fewer material losses during the production, and they have a high number of sales. The drawback is that they are less efficient, due to the grain boundries, and so require larger cels (21x21 cm) in order to reach the same efficiences.
Cell efficeiency: 14-18%
Module efficiency: 11-15%
Are need per KW per modules: ~8sqm

THIN FILM

The reduced amount of material and the lower temperatures required for the creation of the cell, decrease the modules' embodied energy. They are more efficient at overcast conditions and high temperatures and are popular due to their cost, flexibility, light weight and ease of integration levels, but their reduced efficiency leads to larger installation areas for reaching the same efficiency levels as the c-Si modules.

Cell efficeiency: 12-20%
Module efficiency: 7-13%
Area need per KW per modules:
~10-15 sqm

DYE SENTITIZED CELLS (DYSC)

Dye Sensitized: They are a type of thin film, made from titanium dioxide nanoparticles and dye, not by silicon.They are low cost cells that require no protection from minor events like hail or tree strikes. The conversion efficiency is less than the best thin-film cells and they are not commonly used. The tecnology is still developing and appears to be very promising. Cell efficeiency: ~ 11%

SILICON INGOT

AMORPHOUS SILICON

SILICON

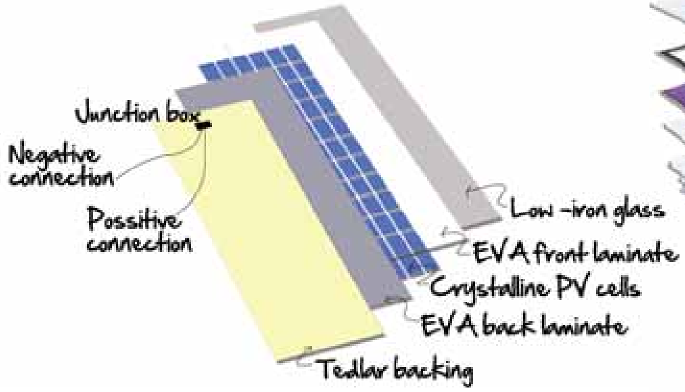
TITANIUM DIOXIDE AND DYE

PV PRODUCTION & MATERIALS

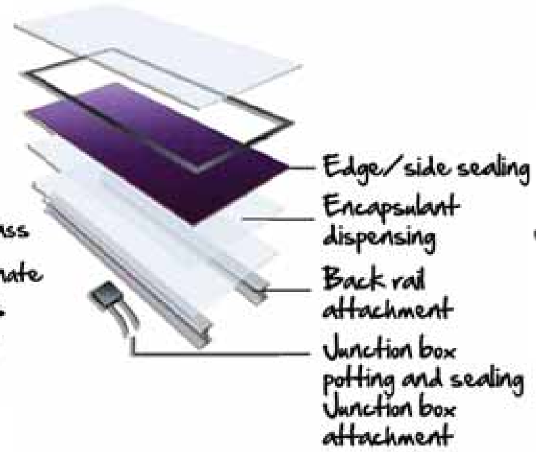
Solar cell technology is a constantly developing sector, one of the fastest growing ones of the renewable energy industry. During the last years, the installations of PV's has increased greatly, making the PV market a very competitive sector. PV cells are using different materials, and so display differences when it comes to efficiencies and costs.

Silicon cystal ingot

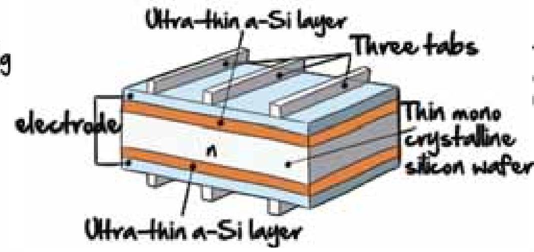
Silicon wafer



C-Si Typical Module



Thin film Module



HIT cell strcture

DYSC Cell structure

CRYSTALLINE CELLS are divided into two categories:

1.MONOCRYSTALLINE (also known as single crystal) silicon cells

2.POLYCRYSTALLINE SILICON CELLS (also known as multicrystalline silicon).

Both types are manufactured from silicon.

MONOCRYSTALLINE: The cell comes from a single crystal ingot, that has to be cut into wafers. Other methods are edge-defined film-fed growth (EFG) and string ribbon processes, resulting in minimization or even elimination of the losses from the slicing processes. In order for increasing light absorption and so resulting in higher currents, an anti-reflection coating is applied, giving the dark blue color to the cell.

POLYCRYSTALLINE: the material is melded and cast in a cuboid form. Large crystals start forming while the material solidifies. The ingot is cut into bars and sliced into thin wafers (a thin sheet of semiconductor material), which in turn are used to create the cells. Polycrystalline silicon differs from monocrystalline in terms of cost (due to the reduction of losses) and efficiency (lower due to the grain boundaries).

THIN-FILM: These cells are constructed through the deposition of thin layers of PV materials (cadmium telluride, copper indium selenide/sulfide, amorphous silicon) onto a superstrate (covering on the sun side/front side of a PV module, providing protection for the PV materials from impact and environmental degradation while allowing maximum transmission of the appropriate wavelengths of the solar spectrum) or onto a substrate (the physical material upon which a photovoltaic cell is made/back side).

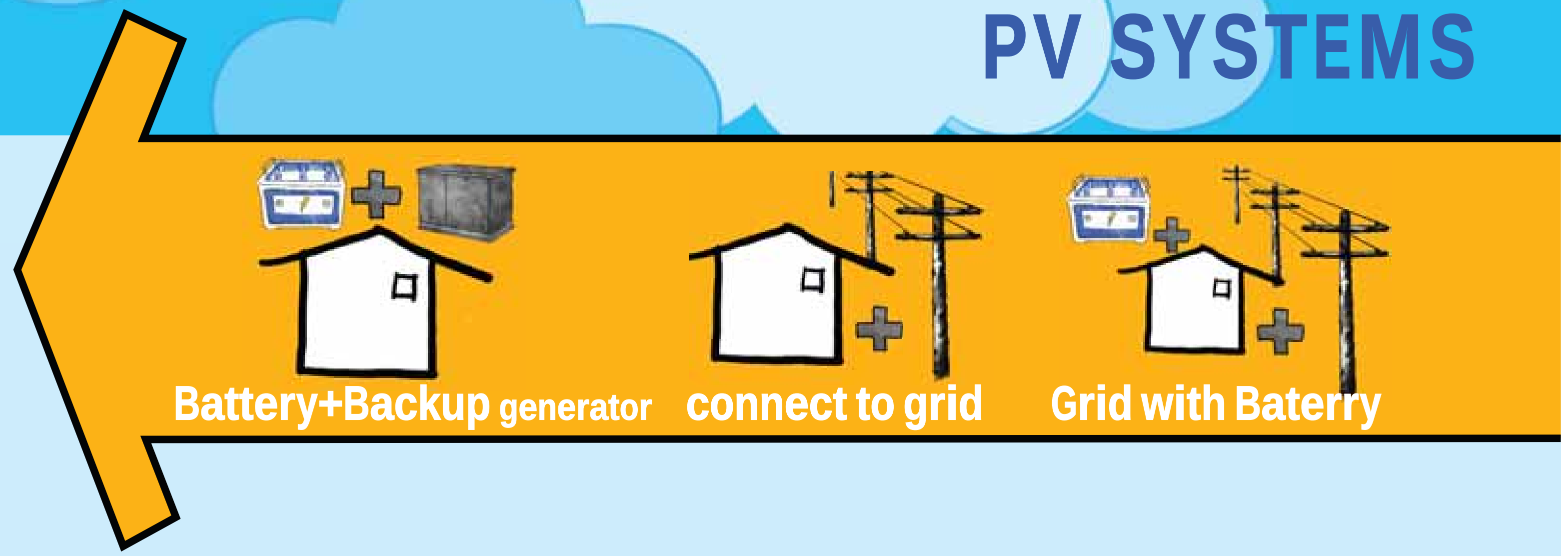
Connections between cells are an integral part of the cell, meaning that the module is made at the same time. The difference in thickness and thus in the materials needed, along with the lower temperatures needed for the production of the cell (less energy consumption) leads to considerable cost savings.

The downside is the drop in efficiency, leading to larger installation areas for reaching the desired power. Thin-film technologies are developing, and efficiency levels are increasing. The interest of the market is driven by the flexibility of the module and hence its better integration to buildings, along with the cost savings.

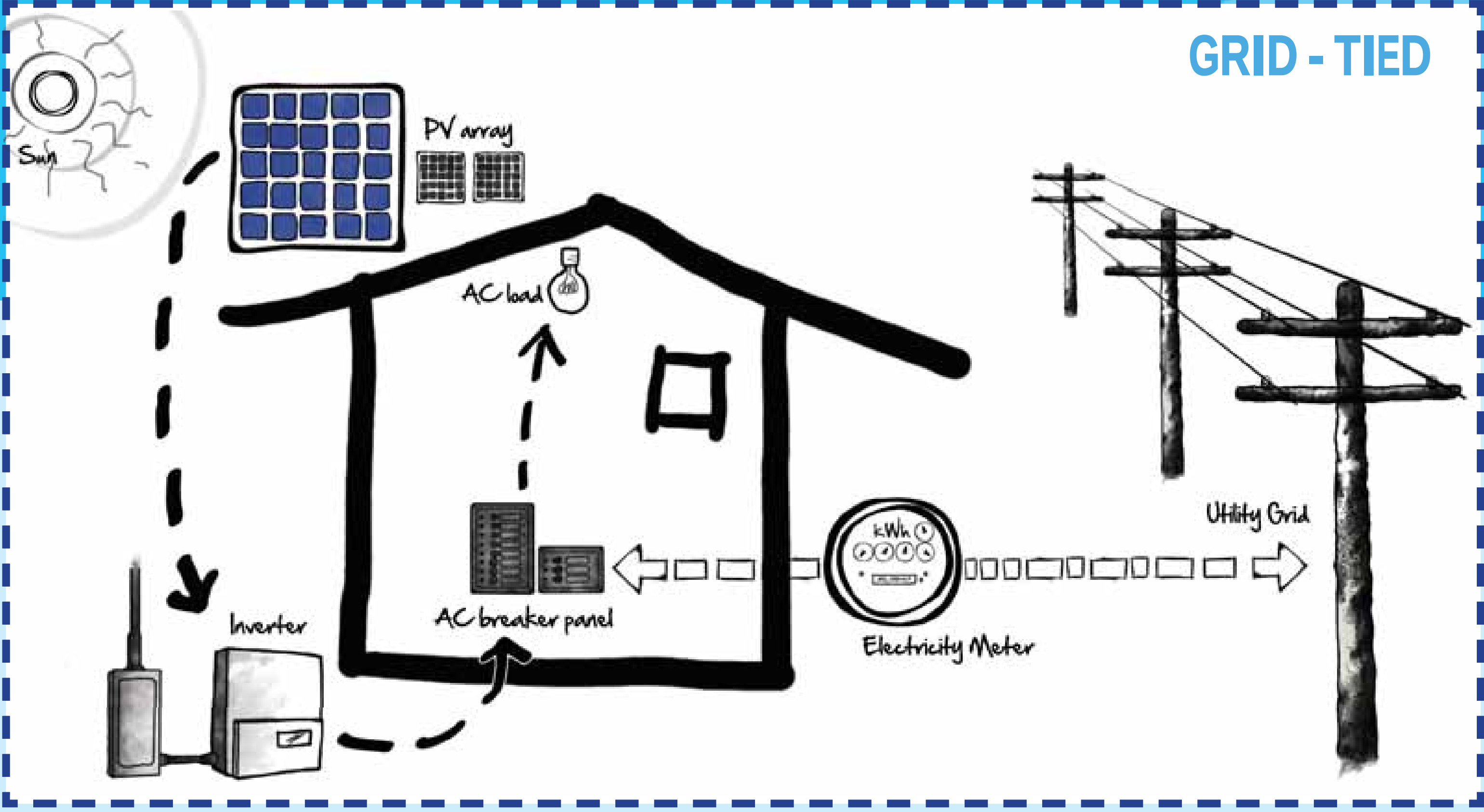
HIGH-PERFORMANCE OR MULTIJUNCTION: They are comprised by structurally different semiconductors (thin-film and crystalline silicon). GaAs (Gallium arsenide) based multijunction devices are the most efficient solar cells to date. These PV cells are more efficient and have less degradation of efficiency with increase in operating temperatures. An alternative are the bifacial cells. They are sensitive both at the front and rear (rear side can benefit from ambient and reflected light when applied in buildings) allowing it to generate at least 10% more electricity. Bifacial transmit more infrared than mono-facial cells so benefit from a lower operating temperature.

DYE SENSITIZED SOLAR CELLS (DSSC, DSC OR DYSC) are low cost thin-film solar cells, based on a semiconductor formed between a photo-sensitized anode and an electrolyte; a photoelectrochemical system. The low cost materials used in the production combined with the fact that they do not require elaborate apparatus to manufacture (less expensive) makes them technically attractive. A porous layer of titanium dioxide (TiO_2) nanoparticles is covered with a molecular dye that absorbs sunlight, like the chlorophyll in green leaves.

MAKE IT WORK
PV SYSTEMS



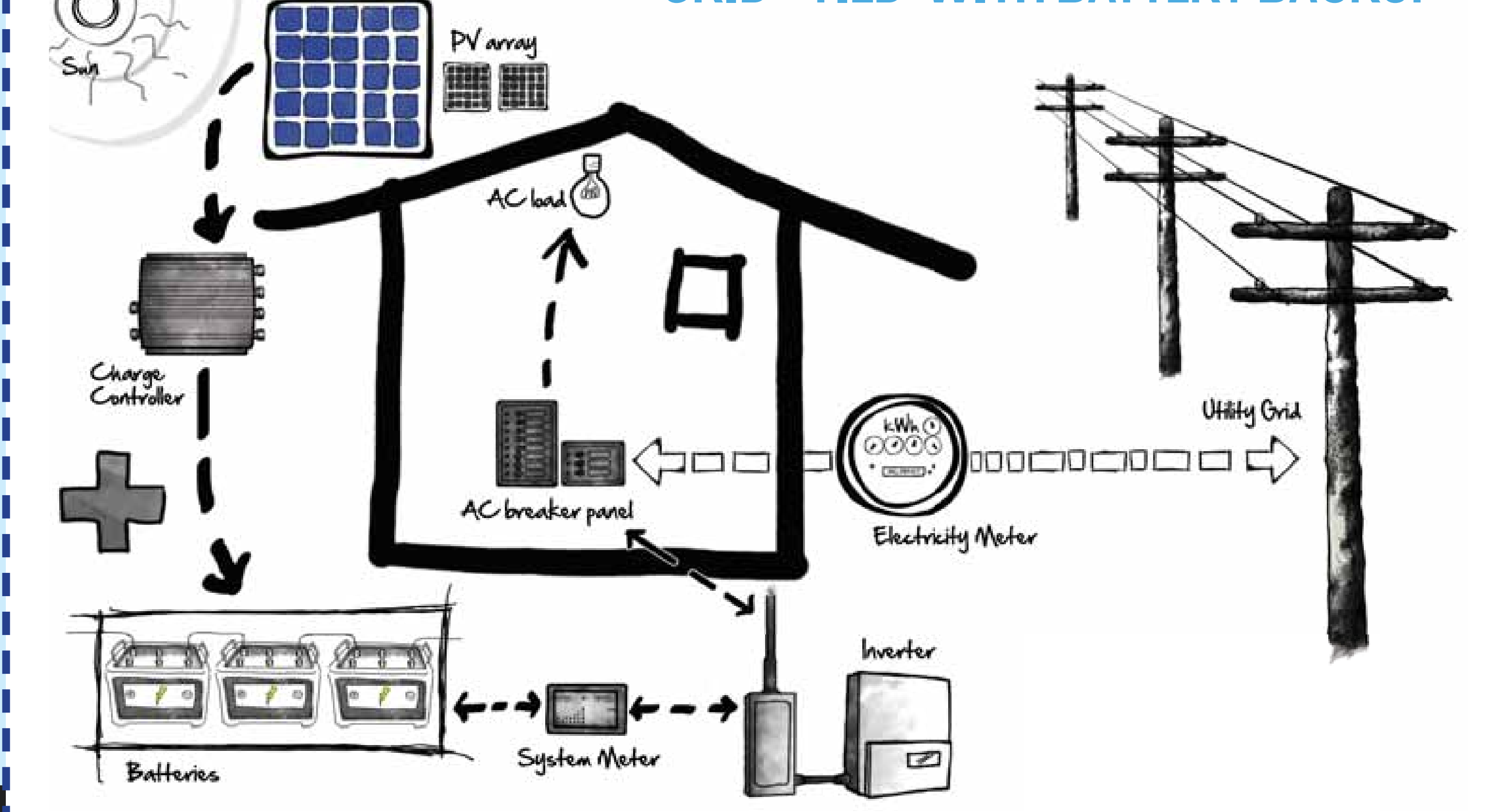
GRID - TIED



This system allows the use of electricity generated by the PV system as well as electricity from the grid. When the PV system is producing electricity, the home is powered by solar electricity.

During the times when the PV system is not producing electricity, such as at night, the home will receive power from the grid.

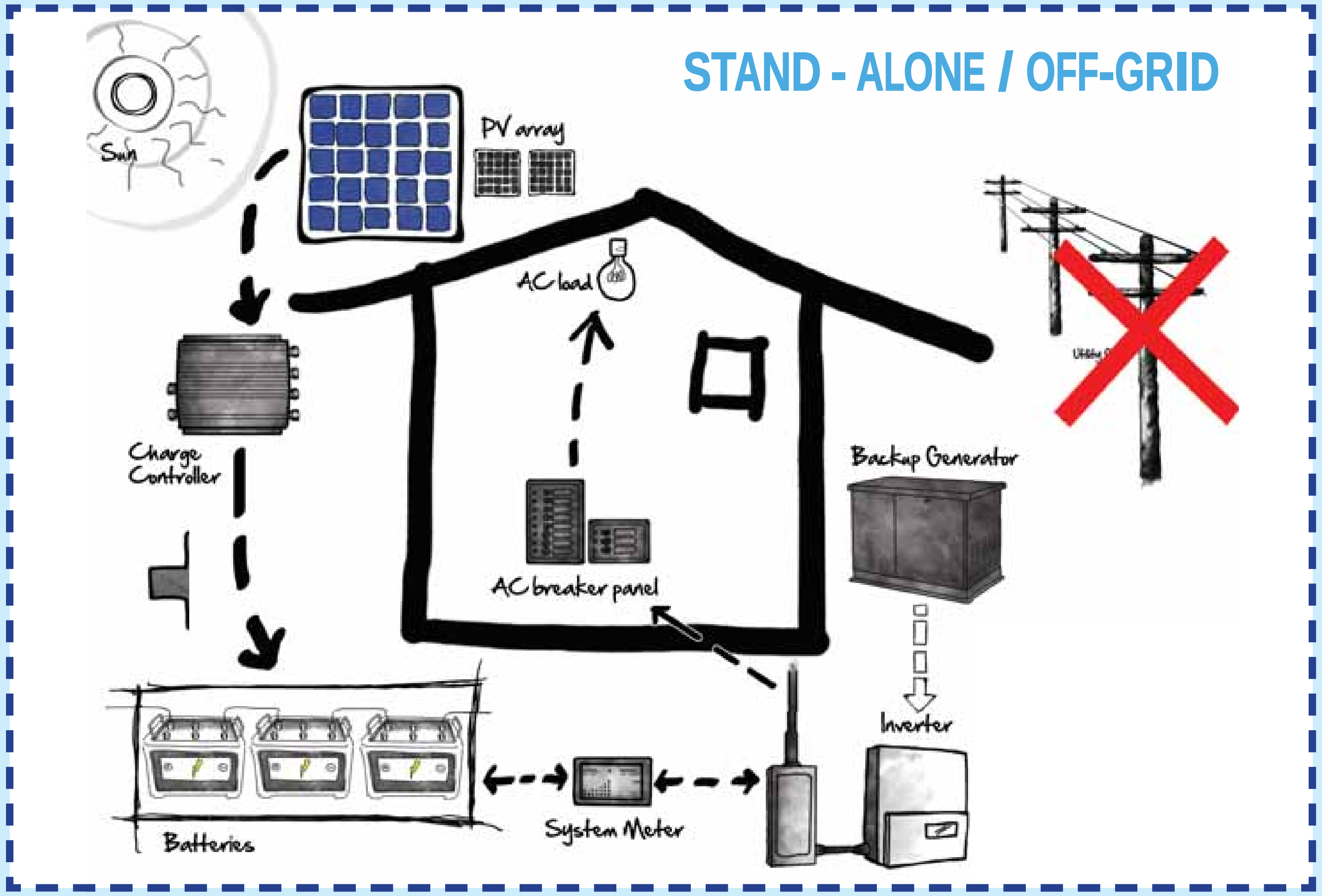
GRID - TIED WITH BATTERY BACKUP



Including a battery bank into the system allows utilization of energy produced from the PV system and stored in the batteries during a power outage.

A grid-tied PV system with battery backup is ideal when living in areas with unreliable power from the grid or that experience power outages due to natural disasters.

STAND - ALONE / OFF-GRID



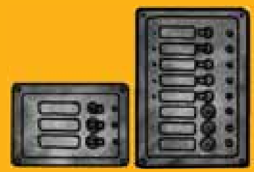
Stand-alone PV systems are designed to operate independently from the grid and to provide all of the electricity you need for your home.

Ideal for homes in remote areas that don't have utility grid service or where it would be very costly to have power lines run to the home.

Offers possibilities for going completely green regarding the source of electricity.

PV SYSTEM COMPONENTS

Systems meter

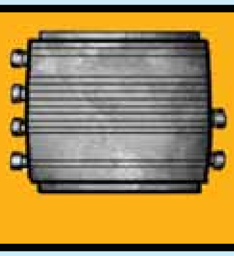


AC Breaker

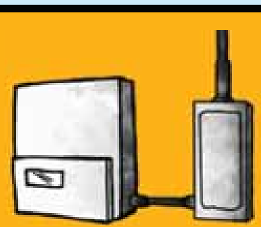
System meters measure and display the charge of the battery bank, production of electricity from solar panels, and ammount of electricty in use.

The Ac breaker panel contains circuit breakers that route electricity throughout the house. When service is recuired, the breakers disconnect the electricty.

They are also designed to protect wiring against electrical fires, due to overloads or short circuits.



Charge controller



Inverter

A charge controller regulates batteries charge/discharge, preventing overcharging, which can reduce battery performance/lifespan and may pose a safety risk.

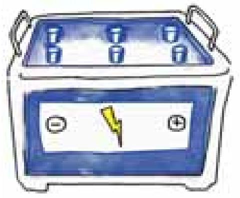
It may also prevent deep discharge, or perform controlled discharges, depending on battery technology, protecting battery life.

MPPT charge controllers (Maximum Power Point Tracking) match the output of solar panels to the battery voltage, insuring maximum charge.

An electrical device that converts direct current (DC) electricity (from batteries or solar arrays) into alternating current (AC) electricity as required for domestic use.

Inverters work either for standalone systems when not connected to the grid, or for utility-interactive systems.

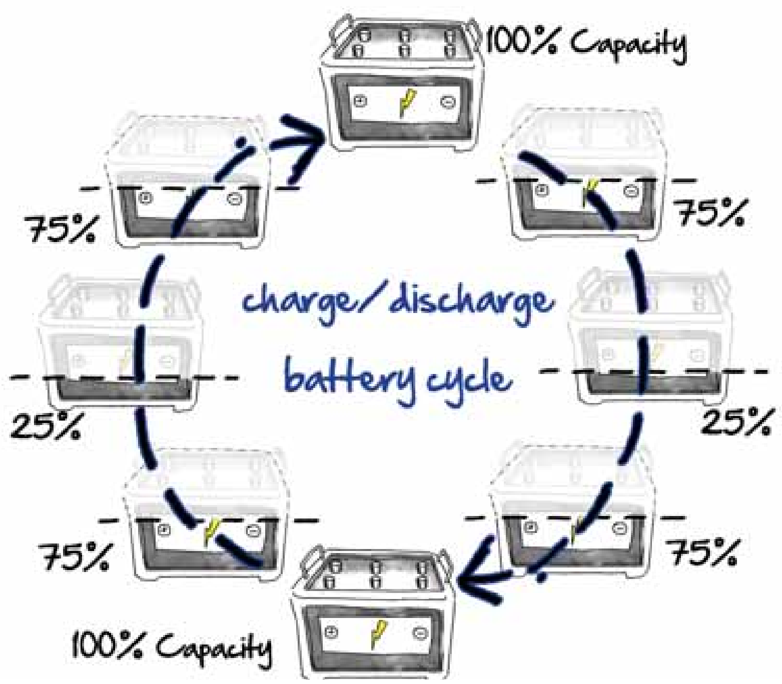
When PV inverters are connected to the grid, they are designed to shut-down automatically upon loss of grid supply, for safety reasons.



BATTERY

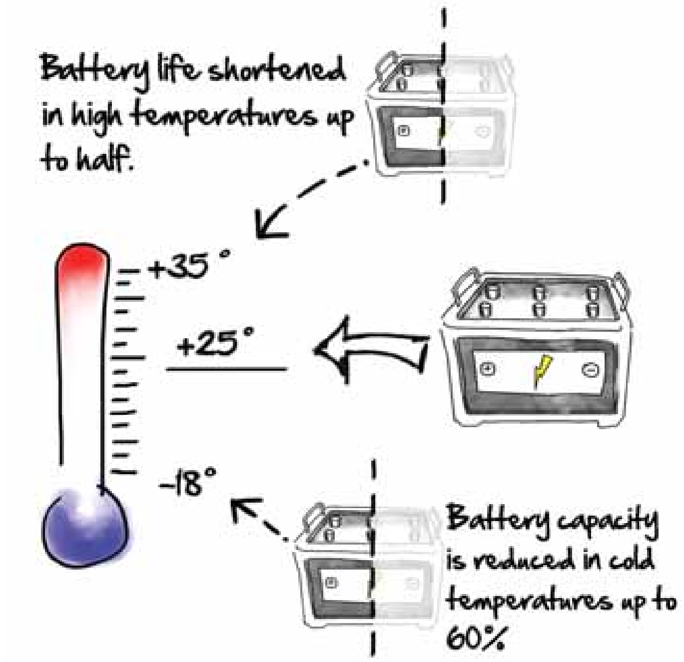
The batteries in a Photovoltaic system should be designed to be shallowed cycled. for a 10-20% discharge.This means discharged only by about 20% of their of their capacity for a given day.

All batteries will last substantially longer if they are shallow cycled. Deep cycling should be saved for occasional duty, like several cloudy days in a row



BATTERY CYCLE

Battery systems should be designed for 10-20% daily discharge for a couple of reasons.
1. Cover the need for capacity for a few days to cover cloudy days.
2. Batteries are expensive and so should last as long as possible. The deeper the discharge, the fewer the cycles.



BATTERY TEMPERATURE

The temperature of the battery is a major factor in a PV system. Battery capacity is reduced in cold temperatures and the battery life is shortened in high temperatures.

BATTERY SIZING FOR
PV STAND ALONE OR OFF-GRID SYSTEM

BATTERY LIFE SPAN

The lifespan can vary considerably depending on use, maintainance and charge, temperature, and other factors.
Life span spans from 2 to 5 or 7 years.
In bad condintions, batteries may not even last a year.

BATTERY SIZING

The recommended type of battery for a PV system installation is the Deep cycle battery. This is due to the fact that they are designed to be discharged at low energy levels as well as for rapid charges and discharges.

Sizing of the battery bank is related directly to the days of autonomy. The latter is used as a multiplier factor to ensure availability of energy, enough for covering the energy loads for a specified time period of low energy gains (i.e. cloudy days and night hours). This time period varies from three to five days.

BATTERY CAPACITY INITIAL CALCULATION

The battery bank size is determined through the following steps:

1. Determine the total Watt-hours per day used by the households electrical appliances.

2. Devide the Watt-hours by the nominal battery voltage to get the required Amp-hour capacity of the battery. Battery Voltages vary from 12V to 24V

3. Multiply the unadjusted Amp-hours from step 2 with the days of autonomy.

4. Devide the Amp-hours from step 3 by the depth of discharge (0.2 for 20% discharge is recommended)

5. Add a design margin adjustment of 10% to 25% for uncertainties in the load determination, e.g., less-than-optimum load-operating conditions and load growth.

6. If Battery efficiency has not been a factor when determining the PV system power generation, devide the Amp-hours from step 6 by 0.85 (85%) for battery losses.

CALCULATION EXAMPLE

Battery capacity (Amp-hour, Ah)

$$= \left[\frac{\text{Total energy use per day x Day of autonomy}}{\text{Nominal battery voltage x Dept of discharge x Battery efficiency}}\right] + \text{Design margin}$$

Total energy use per day	= 1000 Wh/day
Days of autonomy	= 3 days (3-5 days recommended)
Nominal battery voltage	= 12 Volt
Dept of discharge	= 20% or 0.2
Battery efficiency	= 85% Or 0.85
Design margin	= 10%

$$\text{Batter capacity (Ah)} = \left[\frac{\text{1000(Wh/day) x 3 (days)}}{\text{12 (V) x 0.2 x 0.85}}\right] + 10\%$$

$$= \left[\frac{3000}{2.04}\right] + 10\%$$

$$= 1470.6 + (\,1470.6 \times 10\%\,)$$

$$= 1470.6 + 147.06$$

$$= 1617.66 \text{ Ah}$$

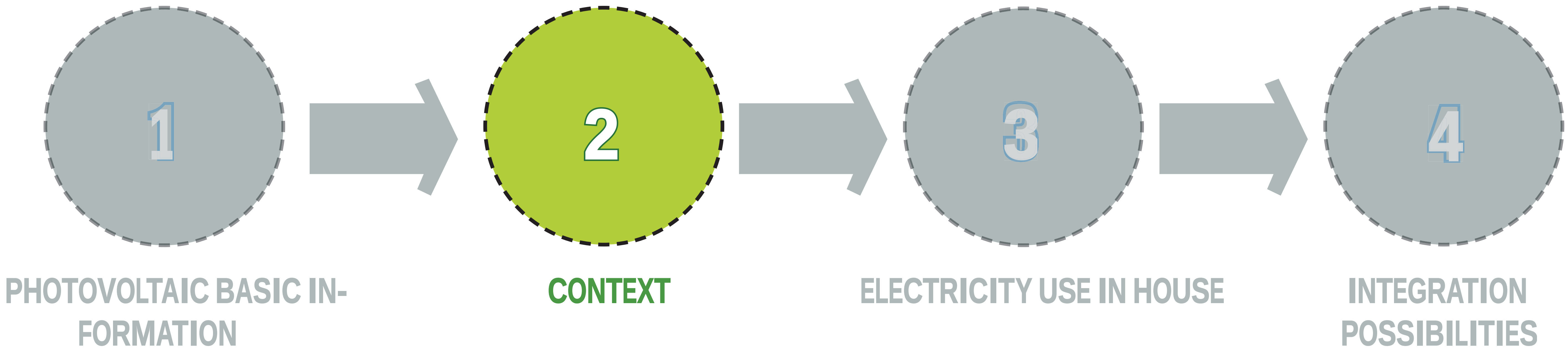
Product Example	Dimension
Brand: Rolls	Total height: 224 mm
Model: S12-290AGM	Height x Length x Width :
Nominal voltage: 12V	220 x 521 x 269 mm
Rated Capacity: 260Ah	Weight: Approx. 78.2 kg.

Using the specifications from the example battery product, we can determine how many batteries are required.

$$\text{Batteries required} = \frac{\text{1617.66 (Ah)}}{\text{260 (Ah)}}$$

$$= 6.22 \sim 7$$

From the energy load set in this example, 7 batteries are needed to be installed in order to provide the necessary capacity for covering the loads for the specified days of autonomy.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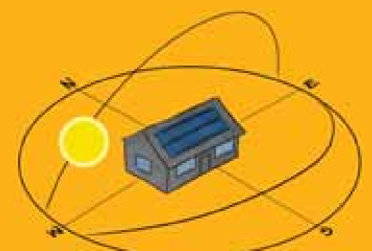
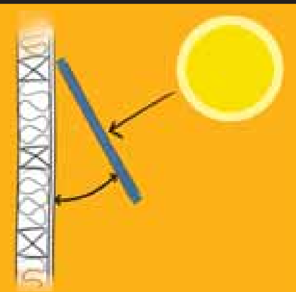
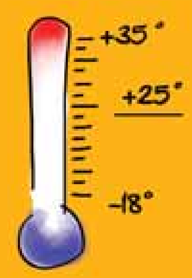


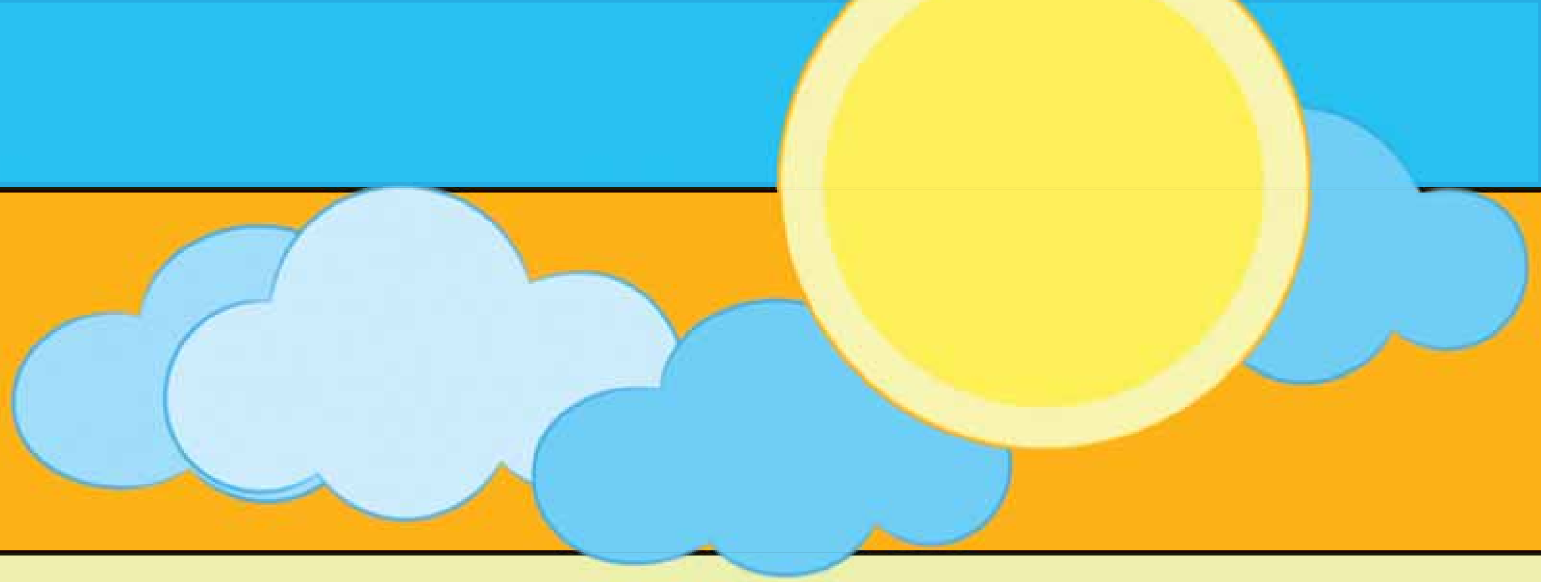
SUN ANGLE & ORIENTATION ANGLE



INCLINATION ANGLE



TEMPERATURE



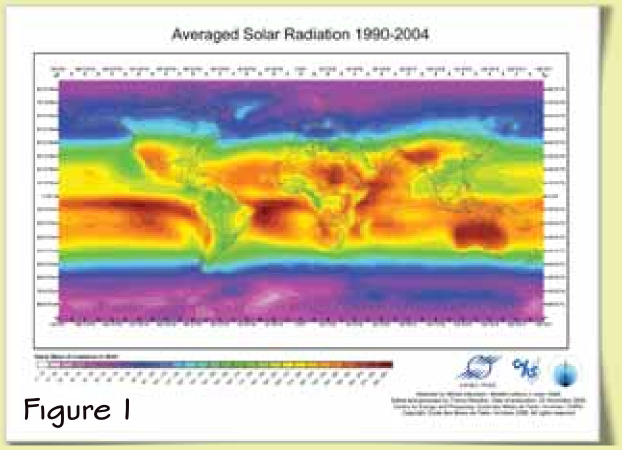


Figure 1

ELECTRICITY GENERATION RELATING FACTORS & LOCATION VARIABLES

The Sun effects different regions of the world in different ways as it can be seen in the solar radiation map (figure 1). The specific solar radiation of a location is a key figure in designing a PV system.

SUN ANGLE: The angle which the sun rays reach the earths' surface varies according to latitude and longitude. This means that different locations have a different optimum installation angle for the PV modules.

PEAK SUN HOUR: The sunlight energy received expressed as the equivalent number of hours of 1kW/m^2 irradiance. If a location receives 7 kWh/m^2 over the course of a day, this would be expressed as 7 peak sun hours

INCLINATION ANGLE: The angle of the PV modules from the horizontal plane, for a fixed (non-tracking) mounting. Affects PSH.

ORIENTATION ANGLE: The angle of the PV modules relative to the direction due South (-90° is East, 0° is South and 90°. is West). Different locations have different optimal values for inclination and orientation.

SOLAR IRRADIANCE: It is a measure of how much solar power you are getting at your location. It varies throughout the year depending on the seasons. It also varies throughout the day, depending on the position of the sun in the sky, and the weather. Solar insolation is a measure of solar irradiance over of period of time - typically over the period of a single day.

TEMPERATURE: Ambient (air) temperature is used during the PV System design stage and power generation calculations.

The operating temperature of the PV modules differs from the ambient temperature.

If the PV modules are integrated in such a manner that free flow of air at their back side is restricted, module temperatures will rise. Output of the PV array can drastically drop when temperature rises.(P.23)

Standard Test Conditions (STC), of 25°C, and this may not be the case at the site.(P.21)

SUN

Photovoltaic modules rely on the sun for producing electricity. Thus, the sun is a key factor in the design of a PV system.

When designing a PV system, location is the starting point, from which the following information, necessary for the design, derive from.

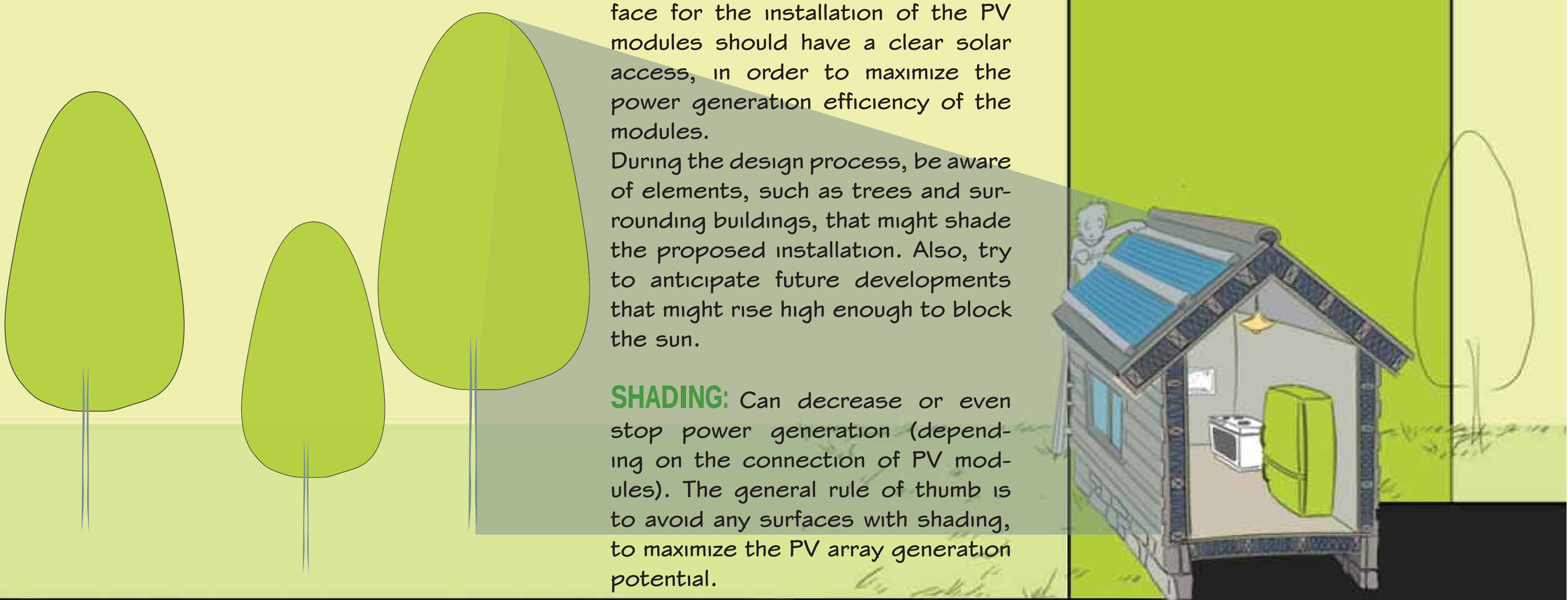
BE METHODICAL

BUILDING INTEGRATION LIMITATIONS

BUILDING CHARACTER: One of the challenges of integration is the preservation of the buildings character. The difficulty level varies between different buildings. The design of the original architect should not be completely disregarded, since a considerable amount of energy has been devoted for each project. The highest level of difficulty is posed by historical buildings and settlements. The cultural and historical values of a buildings morphology must not be altered or downgraded by any integration.

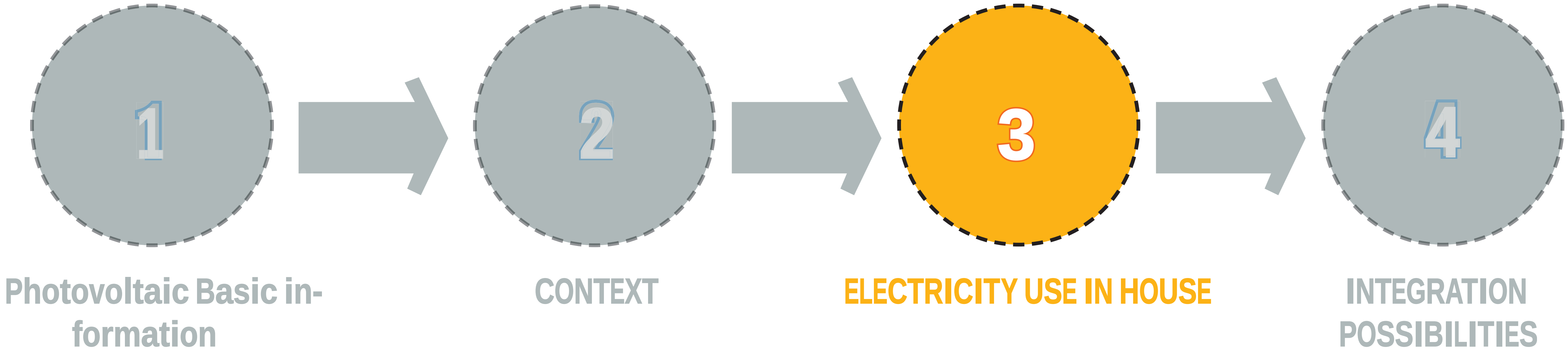
STRUCTURE AND MATERIALS: The integration of PV modules may require the construction of new support structures. The latter may not be possible, due to increases of structural loads that can damage the existing buildings' structure and materials, and pose risks for the users.

BUILDING REGULATIONS: Possible restrictions from building codes and regulations may exist, not allowing the alteration of the buildings envelope.



SOLAR ACCESS: The selected surface for the installation of the PV modules should have a clear solar access, in order to maximize the power generation efficiency of the modules.
During the design process, be aware of elements, such as trees and surrounding buildings, that might shade the proposed installation. Also, try to anticipate future developments that might rise high enough to block the sun.

SHADING: Can decrease or even stop power generation (depending on the connection of PV modules). The general rule of thumb is to avoid any surfaces with shading, to maximize the PV array generation potential.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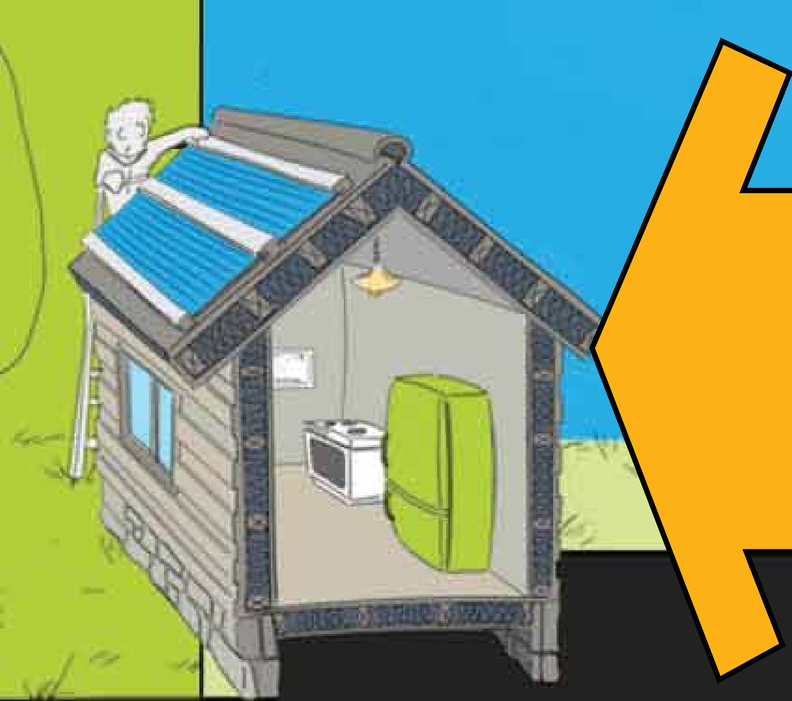
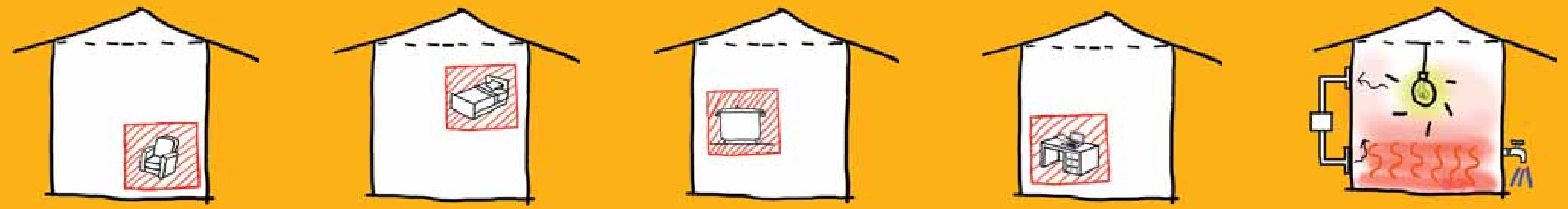




LIVING ROOM | BEDROOM | KITCHEN | OFFICE SPACE | LIGHTING+UTILITIES

MAKE A LIST

ELECTRICITY USE IN HOUSE

Calculating the electricity loads in the house is essential for sizing up the PV system. Knowing the annual electricity consumption of the household appliances makes obvious which ones are the most energy demanding and therefore the most responsible for increasing the electricity bills.

Area	Appliances	Brand/Model	NO.	Electricity use (kW)	Usage	Usage Hour/year	Electricity use (kWh/year)
Kitchen	Refrigerator	Electrolux (A+) Inspire, ERE38400	1	-	24 hr/day	8760	144
	Toaster	Philips Brödrost HD4816	1	0.8	1 hr/month	12	9.6
ETC.							

OR Ask for electricity bills and monitored consumption

The total Electricity use in the housing sector is 60%. 40% of the electricity is related to domestic purposes other than heating.

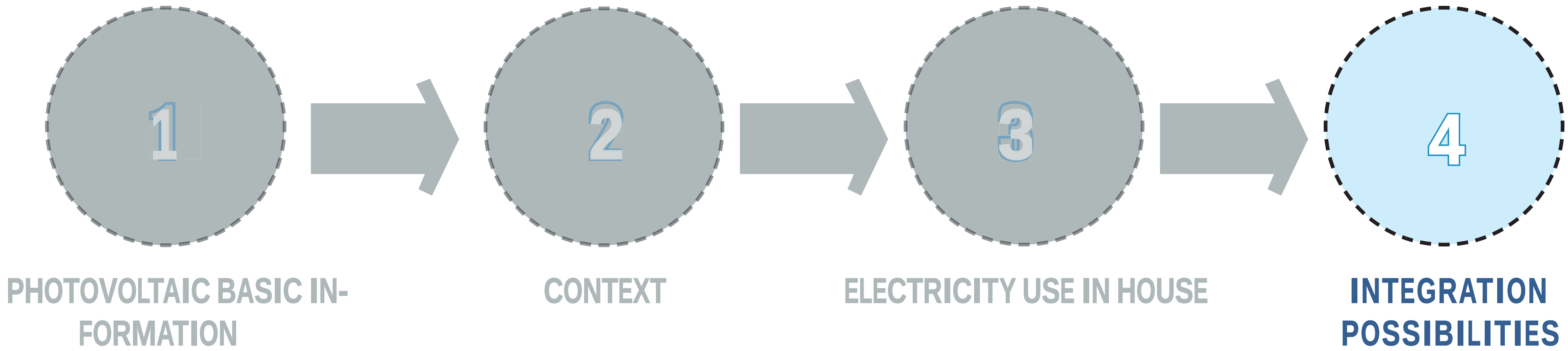
The increase in the number of households, combined with the increase in electrical appliances found in them and changes in the behavioral patterns of the appliances use can be seen as factors leading to the increase in electricity use.

APPLIANCES

HOURS OF USE

The electricity consumption of electrical appliances can be calculated from the power rating and the usage time.
For example:
Toaster: Philips HD4816
power rating=80 Watts
Time usage = 1 hr/month
therefore, the electricity use per year is equal to:
80 x 1 (hr) x 12 (months) =960 Wh = 9.6 kWh/year

TIPS
Some manufacturers may provide the annual energy consumption of appliances in the tecnical specification or user manuals, such as refrigerators, some kitchen appliances and washing machines.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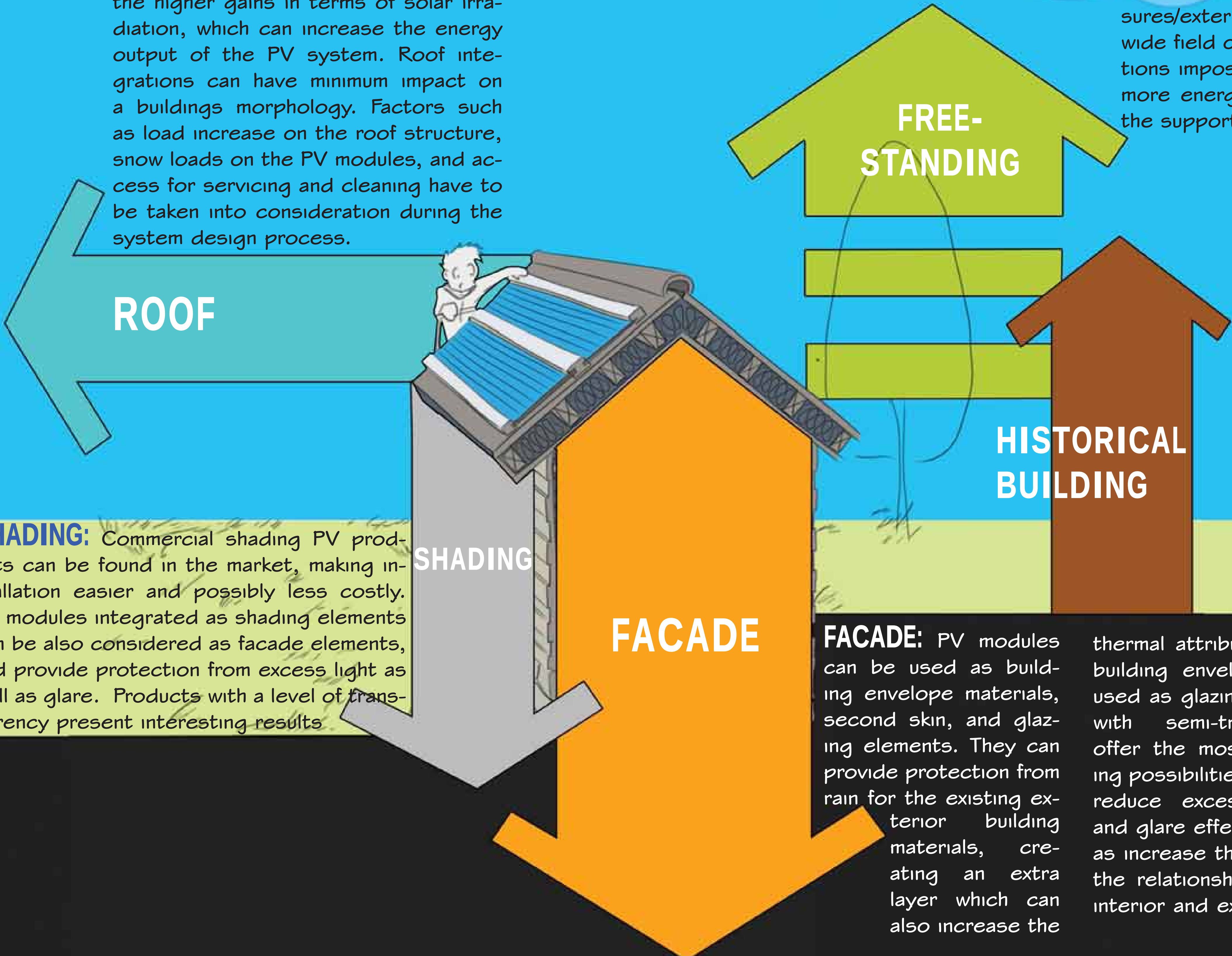
INTEGRATION POSSIBILITIES

LOCATE ME

INTEGRATION POSSIBILITIES

ROOF: The most common and "traditional" integration surface on a building of any type, since it is usually the most available surface for the PV array. Use of high efficiency PV modules, such as crystalline (CIS) and HIT, is probably the best practice. This is because of the higher gains in terms of solar irradiation, which can increase the energy output of the PV system. Roof integrations can have minimum impact on a buildings morphology. Factors such as load increase on the roof structure, snow loads on the PV modules, and access for servicing and cleaning have to be taken into consideration during the system design process.

FREE STANDING: A free standing installation can perhaps offer the most flexible possibilities in terms of design morphology and function, like green houses, enclosures/exterior skins, power plants, or even pieces of art. The wide field of integration options is due to the lack of restrictions imposed by an existing structure. This also means that more energy is consumed in the installation process, since the supporting structure has to be new.



HISTORICAL BUILDINGS:

The most challenging of all integration approaches, due to the cultural and historical values of the buildings morphology, as well as possible restrictions from building codes and regulations. Special care has to be given, in order to leave the buildings character intact. Integrations of this short can be more pedagogical and informative than others, since these buildings are usually carriers of collective memories, and therefore can be seen as examples of building and society standards.

SHADING: Commercial shading PV products can be found in the market, making installation easier and possibly less costly. PV modules integrated as shading elements can be also considered as facade elements, and provide protection from excess light as well as glare. Products with a level of transparency present interesting results

FACADE: PV modules can be used as building envelope materials, second skin, and glazing elements. They can provide protection from rain for the existing exterior building materials, creating an extra layer which can also increase the thermal attributes of the building envelope. When used as glazing, modules with semi-transparency offer the most interesting possibilities. They can reduce excess sunlight and glare effects, as well as increase the variety in the relationship between interior and exterior. Thin film products are usually preferred over crystalline ones, due to their better performance with diffused light.

EXAMPLE OF BIPV

ROOF

Bob & Helen Hughes residence
England
Example

Monocrystalline silicon cells

House in UK
: single family house
: Replacement of existing roof tiles

ROOF

Monocystalline combine with-Polycrystalline silicon cells

Mont-Cenis Academy – Herne Sodingen, Germany
: Education centre and public buildings.

: Main Materials: timber, glass and concrete, all locally produced.

ROOF

Example
Bifacial PV, Solar Decathlon

Bifacial PV: Sanyo HIT Double 195
Solar Decathlon project from University of Minessota in 2009.
: Building designed according to Minnesota climate conditions.

FREE STANDING

Monocrystalline silicon cells

(Left)Solar-power charging stations for electric cars

(Right)Street light

FREE STANDING

HIT cell

Vauxhall Cross bus station in London

FACADE

Thin Film

Technium OpTIC (Opto-electronics Technology and Incubation Centre)

St Asaph, North Wales, UK

: Office building

HISTORICAL BUILDINGS

Thin film

Solar Information Board, La Spezia, Italy

: Information banner

FACADE

Polycrystalline silicon cells

Manchester College of Arts and Technology (MANCAT)

: Education and public buildings.

HISTORICAL BUILDINGS

Monocrystalline silicon cell

Academy Building "Alter Klosterhof", Meißen, Germany

Mounted on glass structure over new stair tower.

SHADING

source: Green handbook ,Pv in building

Polycrystalline silicon cells

Bayerische Landesbank, Munich, Germany

:Commercial building

SHADING

Product: 1600 PowerShade®
http://www.kawneer.com

Monocrystalline silicon cells

Commercial product

SANYO - HIT Double SOLARMODULE

HIT - 205 DNKHE1
HIP - 200 DNKHE1

To maximize the yield

1. Installation surface with high reflection rate material (more than 60% recommended)
2. No shadow cast on the rear side by mounting structure
3. Space between roof and the bottom of the array (50 cm recommended)

HIT Double
Photovoltaic Module

Models HIT-205DNKHE1 / HIT-200DNKHE1

Electrical data	205DNKHE1	200DNKHE1
Maximum power (Pmax) [W]	205	200
Max. power voltage (Vpm) [V]	41,3	40,7
Max. power current (Ipm) [A]	4,97	4,92
Open circuit voltage (Voc) [V]	50,9	50,3
Short circuit current (Isc) [A]	5,43	5,40
Warranted min. power (Pmin) [W]	194,8	190,0
Maximum over current rating [A]	15	15
Output power tolerance [%]	+10/-5	+10/-5
Max. system voltage [Vdc]	1000	1000
Temperature coeff. of Pmax [%/°C]	-0,30	-0,30
Temperature coeff. of Voc [V/°C]	-0,127	-0,126
Temperature coeff. of Isc [mA/°C]	1,63	1,62
NOCT [°C]	48,0	48,0

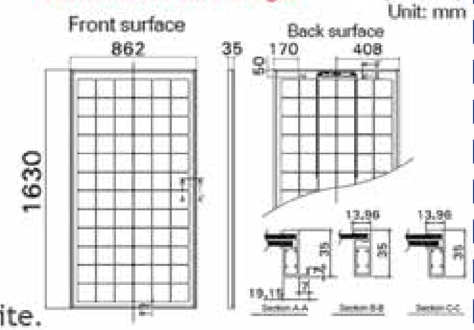
Note 1: Standard test conditions: Air mass 1.5, Irradiance = 1000 W/m2,
Cell temperature = 25°C.
Note 2: The values in the above table are nominal.

Guarantee

Product: 10 years
Power output: 10 years (90% of Pmin),
25 years (80% of Pmin)
Full conditions are available on SANYO website.

Dimensions and weight

Weight: 26 kg
Unit: mm



STANDARD TEST CONDITIONS

PV modules are tested and rated under Standard Test Conditions (STC), in order for making different modules/types comparison possible. STC are at solar irradiance of 1000 W/m² and cell temperature of 25°C. One site conditions can and will vary from STC in terms of irradiance and temperature, affecting the PV module power generation.

PV DATA SHEET EXAMPLE

MAXIMUM POWER (P MAX)

The module power rated under STC conditions.

MAXIMUM POWER VOLTAGE (VPM)

The maximum voltage that the PV module is generating when exposed to sunlight and connected to a load, such as an inverter or a charge controller and a battery. It is determined under STC and it directly affected by the PV module temperature. Vmp is important for correctly sizing an array to an inverter or controller.

MAXIMUM POWER CURRENT (IPM)

The maximum amperage where a panel outputs the maximum power when exposed to sunlight and connected to a load. Maximum power current is used in array and charge controller sizing calculations for

OPEN-CIRCUIT VOLTAGE (VOC)

The maximum voltage that the PV module is generating when exposed to sunlight, without being connected to a load. It is dependent to air temperature (the lower the temperature the higher the voltage) and must be shown on the PV disconnect label.
Voc is used to calculate the highest maximum system voltage.

SHORT-CIRCUIT CURRENT (ISC)

It is the amperage generated by a PV module or array when exposed to sunlight and with the output terminals shorted. It must be listed on the PV systems disconnect panel. Calculations of the PV circuit's wire size and overcurrent protection (fuses and circuit breakers) are based on the module/array short-circuit current.

OUTPUT POWER TOLERANCE

Rated Power Tolerance refers to the potential range of under-performance or over-performance under STC. For Example: Product X has a rated power 100W and a tolerance of +-5%. The actual power rating can be 95W or 105W.

MAXIMUM POWER TEMPERATURE COEFFICIENT (%/°C)

The panel output power change for temperatures other than 25°C (STC conditions), in percent of change per degree Celsius, used for calculating module power changes (gains or losses) due to temperature changes. Lower power temperature coefficients mean better performances in higher-temperature conditions.

NOMINAL OPERATING CELL TEMPERATURE CELL [NOCT]

NOCT is the module temperature, given at an irradiance of 800W/m² and an ambient (air) temperature of 20°C. It is used in conjunction with the maximum power temperature coefficient to get a better real-world estimate of temperature related power loss.

Differences between cell and ambient temperature are dependent to sunlight intensity in W/m². Real condition differ from STC. The standard of 800W/m² is used for this reason, instead of 1000W/m², which is considered full sun.

HOW MANY PANELS DO WE NEED?

CALCULATION : PV Electricity production

ELECTRICITY WHICH PV CAN PRODUCE (1 panel / 1 day)

= PV'S POWER RATING(W) x PV'S EFFICIENCY(%) x BATTERIES EFFICIENCY(%) x WIRE EFFICIENCY(%) x INVERTER EFFICIENCY(%) x PSH
= PMAX (WATTS) x PV'S EFFICIENCY(%) x 85(%) x 97(%) x 95(%) x PSH

- PV POWER RATING(PMAX) = Given by manufacturer data sheet
- PV'S EFFICIENCY(%) = 100(%) x Tolerance/Dust/Mismatches efficiency factor(%)[1] x (PV module) Heat Losses efficiency factor(%)[2]

1. Efficiency factor for module tolerance, mismatches and dust degradation = 90%

2.Heat Losses efficiency factor(%) =
100% - Heat Losses from Temp. Degradation(%)
2.1 Heat Losses from Temperature Degradation =
(Tc-25) x Temperature coefficient (%)

* Tc = TA(°C) + [(NOCT-20/800) x G] ,G (irradiance) is given in W/m^2, and NOCT in °C
Tc = PV Cell Temperature in TA condition (°C)
TA= Ambient temperature (°C)

- BATTERIES EFFICIENCY(%) = 85% (loss 15%) (Most efficient products: The hightest efficiency)
(do not take in an account incase of Grid-tied system)
- WIRE EFFICIENCY(%) = The wiring losses in the best situation ≤ 3% ,Efficiency factor=97%
- INVERTER EFFICIENCY(%) = Inverter efficiency = 85-95%, Most efficient products= 95%
- PSH = PEAK SUN HOUR (Page.9)

EXAMPLE

FIND IN PV DATA SHEET

PRODUCT DETAIL	Type of PV: HIT Double cell Name of Product: Sanyo HIT-205DNKHEI Double NOCT: 48°C Pmax (Front surface):205W Pmax (Back surface): 143W Temperature coefficient [%/ °C]= 0.3%/ °C

DEPEND ON SPECIFIC LOCATION

LOCAL CLIMATE SPECIFICATIONS	Summer (June-August) 92 days Ambient temperature(TA) =20°c Location: Gothenburg Sweden Installation: East facade Orientation 90° PSH 2.9 G=350W/m² (*see techinal report for all calculation information)

CALCULATIONS - 5 STEPS

1
Tc = TA(°C) + [(NOCT-20/800) x G]
= 20°C + [(48-20/800) x 350]
Tc = 32.38 °C

2
Heat losses from temperarture degradation
= (Tc-25) x Temperature coefficient(%)
= (32.38-25) °C X 0.3%/ °C
= 0.022%

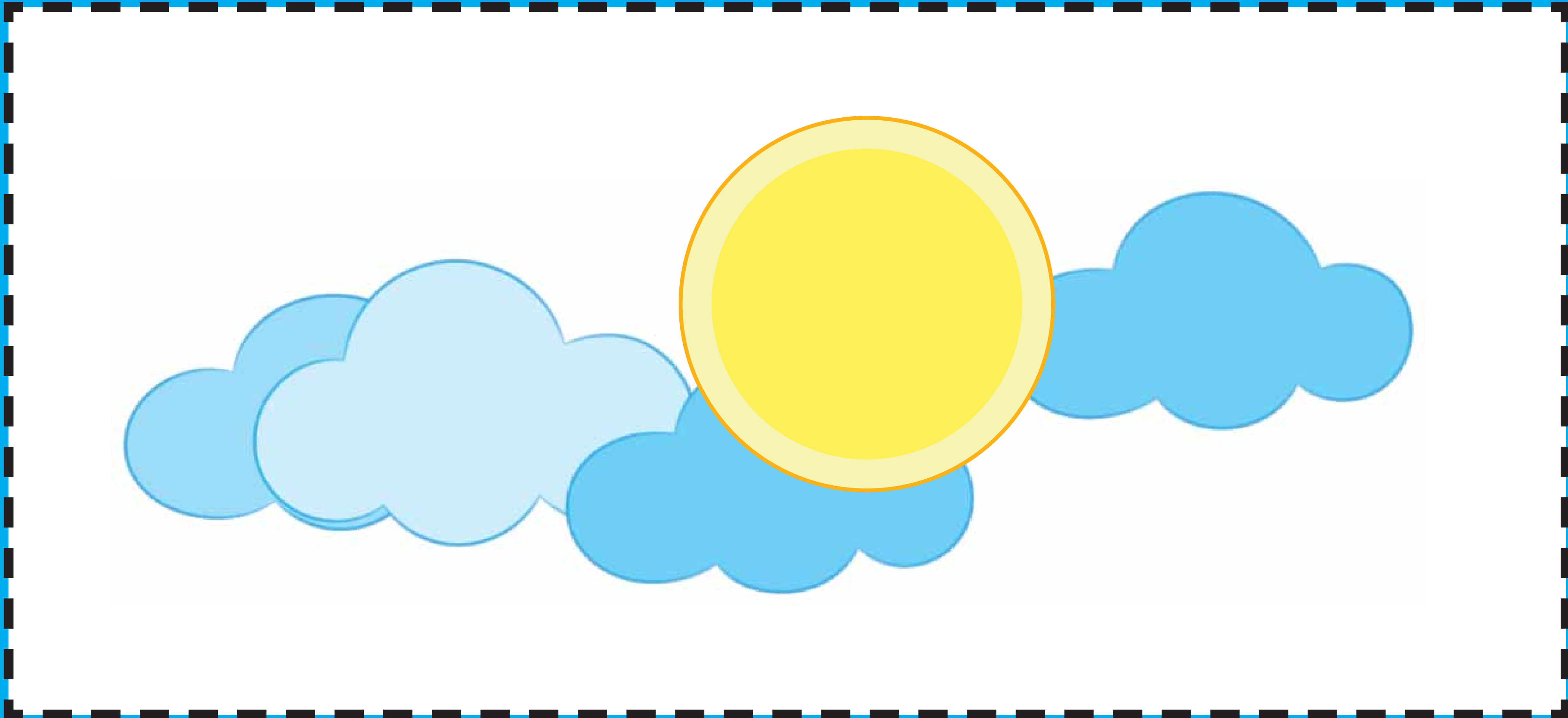
3
Heat losses efficiency factor(%)
= 100% -Heat Losses from Temp. Degradation(%)
= 100% - 0.022%
= 97.8%

4
PV's efficiency(%) = 100(%) x Tolerance/Dust/Mismatches efficiency factor(%) x (PV module) Heat Losses efficiency factor(%)
= 100% x 90% x 97.8% = 88%

5
= PV's Power rating(W) x Pv's efficiency(%) x Batteries efficienCY(%) x Wire efficiency(%) x Inverter efficiency(%) xPSH
= 205(W) x 88% x 85% x 97.8% x 95% x 2.9
= 409.78 Wh/day ~ 0.41 kWh/day
In summer produce = 0.41 x92(day)
= 37.72 kWh

PV ELECTRICITY PRODUCTION

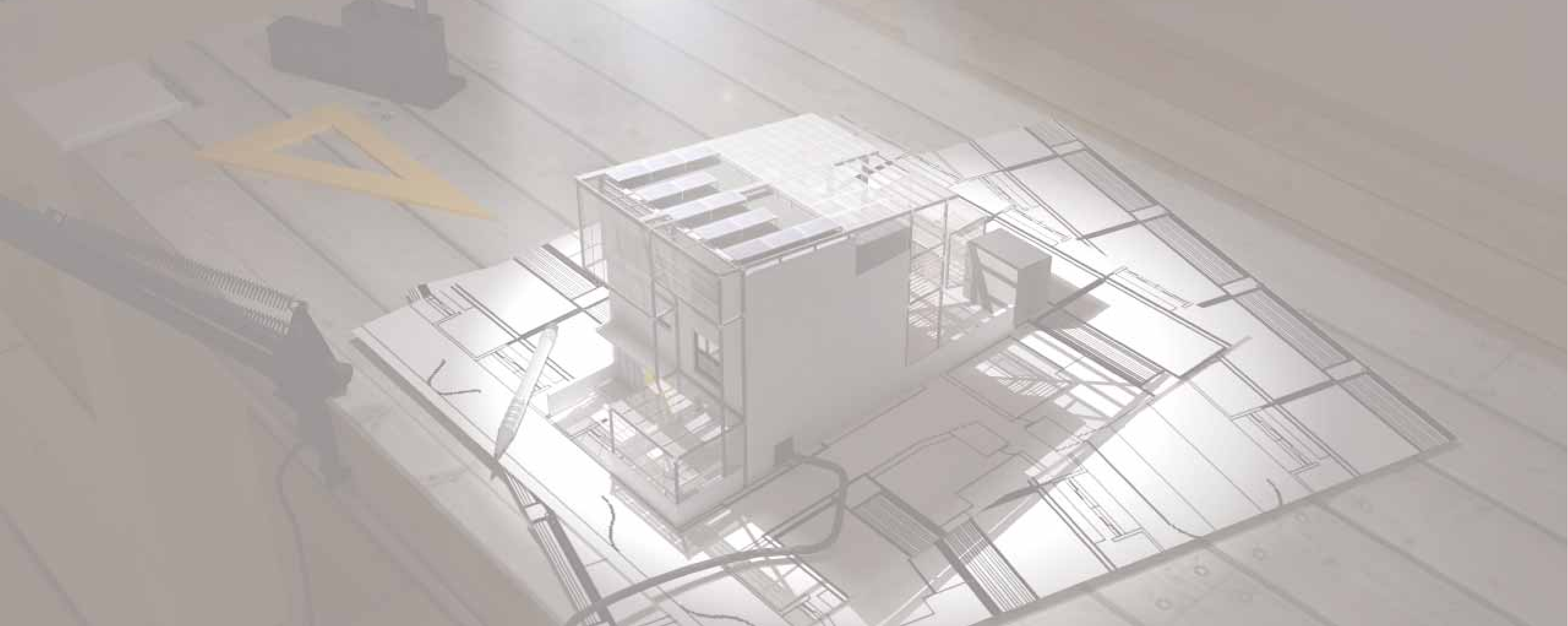
If our consumption is 1000 kWh, it means we need (1000/37.72=26.5)
~27 panels of installed on the East facade.
= 37.94 m² installation area needed



TOOLS FOR IMPLEMENTAION

BUILDING INTEGRATED PHOTOVOLTAIC

PART 2: Thesis Report (Tools for Implementation and Design Approaches)



CHALMERS

Acknowledgements

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Finally, our families and friends, for their continuous support and belief in us and our work throughout time, even though we could not have been near them during the past years. Without you we would have not been the same people or reached where we are now.

CHALMERS

BIPV: TOOLS FOR IMPLEMENTATION AND DESIGN APPROACHES

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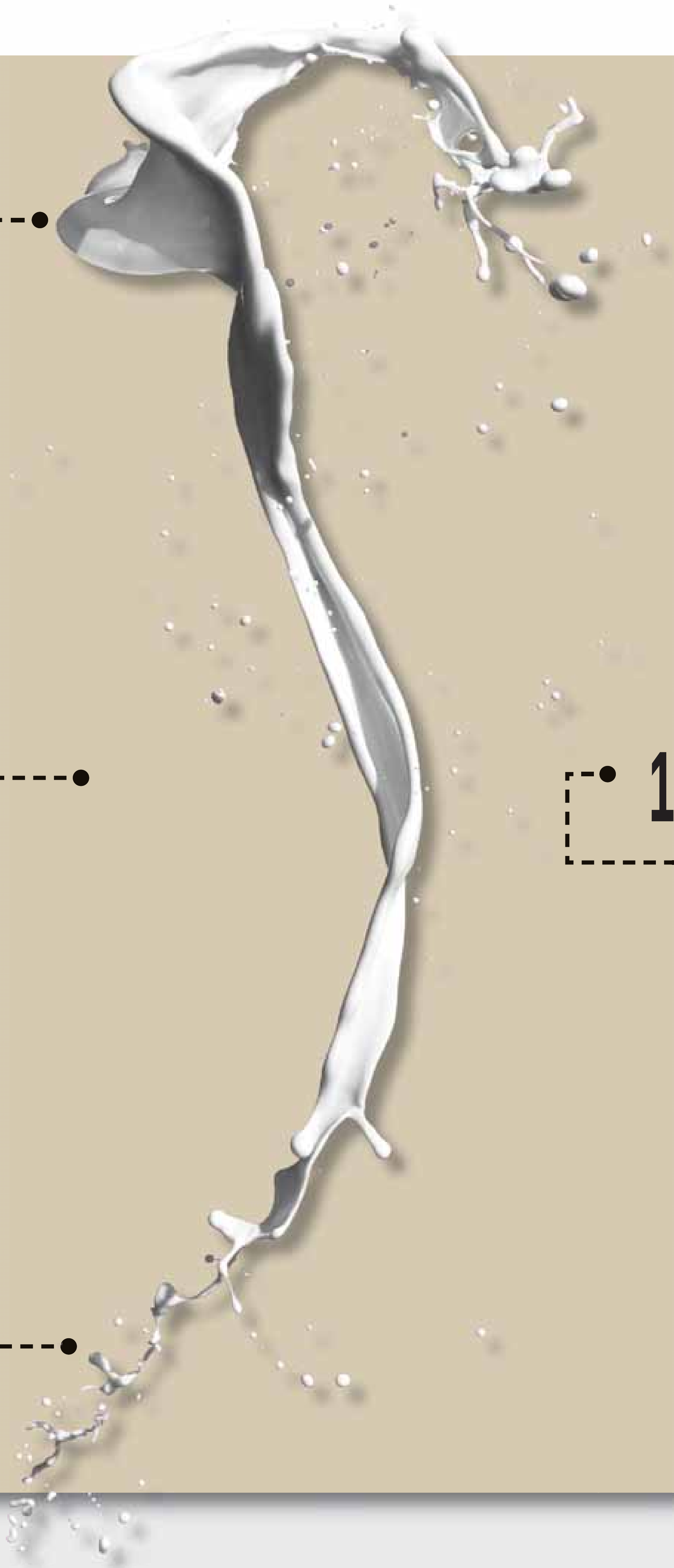
CHALMERS



1. INTRODUCTION

1.1 BACKGROUND

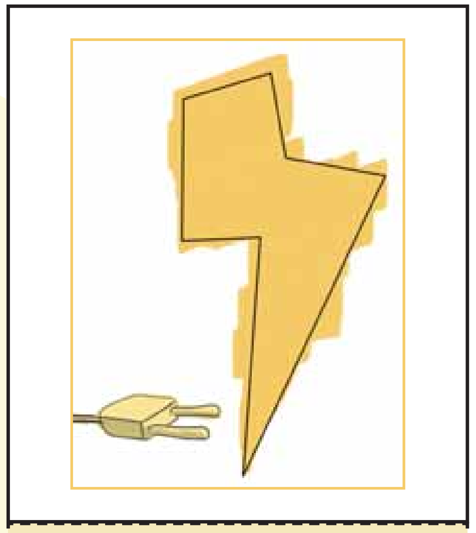
During the process of determining the focus of this thesis, the idea of identifying a common ground on which sustainability can be promoted was formed. Although the background of the authors has not been the same, in terms of study or working experiences, there was a realization of the differences of how people relate to the design of a house, and the scarcity of sustainable buildings constructed. The latter either due to the lack of knowledge from the stakeholders (clients, architects and engineers) or due to the fact that other primary goals where set, with the most prominent one being cost reduction during the construction. The necessity of motivating others by establishing a direct and personal relation that can act as a motivational catalyst for acting towards sustainability was set as the initial goal.

If relationships can be formed on a personal level, making a choice that can have a positive effect on the environment can become easier. The authors determined that energy can be the key. It is a concept that can be directly recognized by most, since it affects all aspects of life and relates directly to the three spheres of sustainability. Presenting the possibilities of energy independence, economical gains, and reduction of our footprint on the environment can prove a strong motivational catalyst for people to relate and act. If these concepts can be presented through physical examples, such as the use of Photovoltaic modules, then the desired relationship can be formed and action can be taken by the stakeholders.

The issue of energy efficiency has been stressed many times throughout the education within the Masters program, as has the importance of integrating renewable technologies, and in specific Photovoltaic Systems, into the building design. The same issue is being widely discussed by all actors who are involved with the build environment. In order for one to be able to contribute as an actor, it is necessary to have a background knowledge on the issue. The basic introduction to the use of photovoltaics (PVs) during the course of our education has been extremely stimulus and a springboard for the selection of the topic of this thesis, but did not provide us with the tools for tackling the subject of integration.

The field of photovoltaics is continuously developing. This, in conjunction with the vastness of information available on the issue, makes it difficult for one to navigate through and mine the essential information for working with BIPV (Building Integrated Photovoltaics). This "gap" needs to be filled, so we can be better equipped for our professional careers, and be able to meet the demands set from the goal of sustainable development.

People relate differently to the design of a house. Some are aware of sustainability issues, and others are not.



ENERGY related issues can be strong motivational catalysts for people.

So how can people be motivated to act towards sustainability?

The integration of renewable energy technologies, such as **BIPV** can be a means of promotion.

1.2 METHOD, CONTENTS & PROJECT STRUCTURE

METHOD

The study is based on a single family home. Information of the energy consumption within the various building sectors in Sweden, and more specifically in the housing is presented, followed by information relating the latter to consumption behavioural patterns. Research continues on renewable energy technologies and integration possibilities in the form of a presentation of the available photovoltaic technologies in the market today, accompanied by examples on BIPV's. An analysis of electricity use in the chosen household (washing/drying, cooking and eating, entertainment, lighting and office area) is carried out, followed by an analysis of the effects of solar irradiation on the building functions and envelope. Calculations which are carried out for a number of PV products are conducted in order to find the most suitable ones for covering the electricity needs of the household, in close relation to design proposals on integrating PV's as part of the households envelope.

The study continues with a discussion regarding system payback times along with the importance of planning strategies regarding the integration of Photovoltaic Systems and a justification of the necessity of all the steps taken. The conclusion is based on the authors personal impressions on the impact of integrating PV's on the architectural values of a house and the lessons learned regarding the nature of PVs.

The sun and shadow studies along with the solar irradiation surface study where performed initially within the Vasari Project of the Revit Architecture software. The latter software was used for creating the model of the residence under study, and the authors, having no previous contact with the aforementioned software, had to become adept on their use. For the completion of the pre-mentioned studies, a daylight system setting within 3D Studio Max, in conjunction with a Gothenburg Climate data file where used. Solar Irradiance data where provided by the Photovoltaic Geographical Information System (PVGIS) of the European Commission, found on http://re.jrc.ec.europa.eu/pvgis/. Orientation angle information were obtained from http://solarelectricityhandbook.com/solar-irradiance.html.

The electricity consumption calculations, as well as the PV module power generation calculations where performed using formulas that will be explained in the relevant chapters.

PROJECT STRUCTURE

As seen on diagram 1 (page 12), the structure of the current project has not been a linear one. After the determination of the thesis focus, a first level of research and analysis was conducted, followed by a project study on an already existing building, as a testing and application of the information collected up until that point. At that stage, more questions formulated, leading at a second level of research and analysis, which in turn led back to the project study, for the application of the new information, and the finalising of the design process, At that stage, the authors reflected on the lessons learned through the whole process and concluded the current thesis.

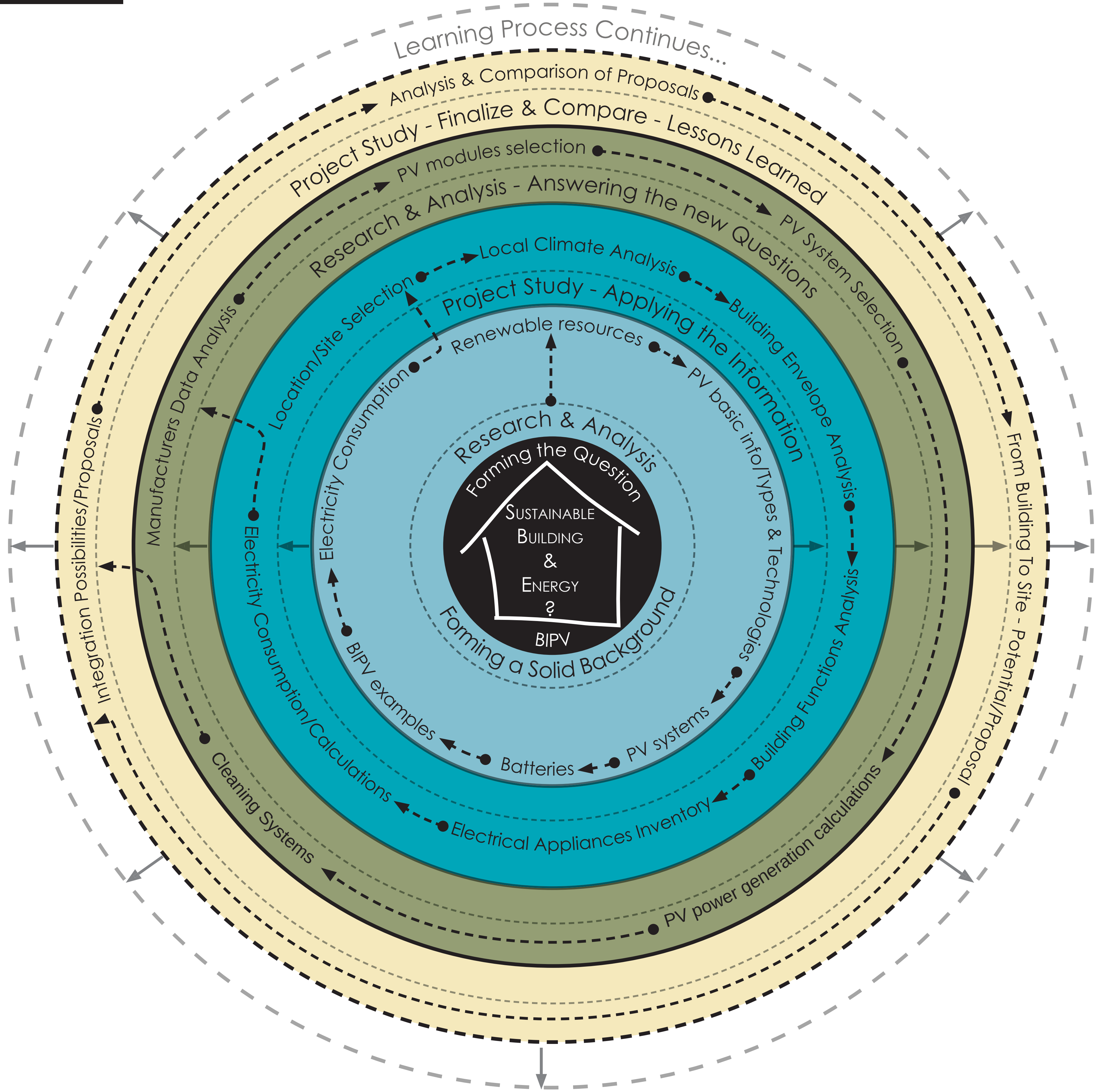
CONTENTS

The resulting project is comprised by two parts:

1. The ***BIPV: Tools for Implementation*** guideline booklet, containing summarized basic information on PV technologies and systems, context related considerations, integration examples, a calculation method for the consumption of electricity for household purposes, information regarding PV manufacturers data sheets and finally a calculation method for estimating the power generation of the selected PV modules and system.

2. The present thesis report, which includes all the steps described in the Method section, the information included in the ***BIPV: Tools for Implementation*** guideline booklet in an extended form, the design approaches and the authors conclusions and personal opinions regarding PVs, and the solar irradiation data collected for the site.

PROJECT STRUCTURE



1.3 ENERGY & CONSUMPTION

The analysis of the current state in Sweden is an extremely important step towards becoming more proficient on the issue of energy. It offers an insight and a connection with the local context. This connection is necessary for the development of any type of project.

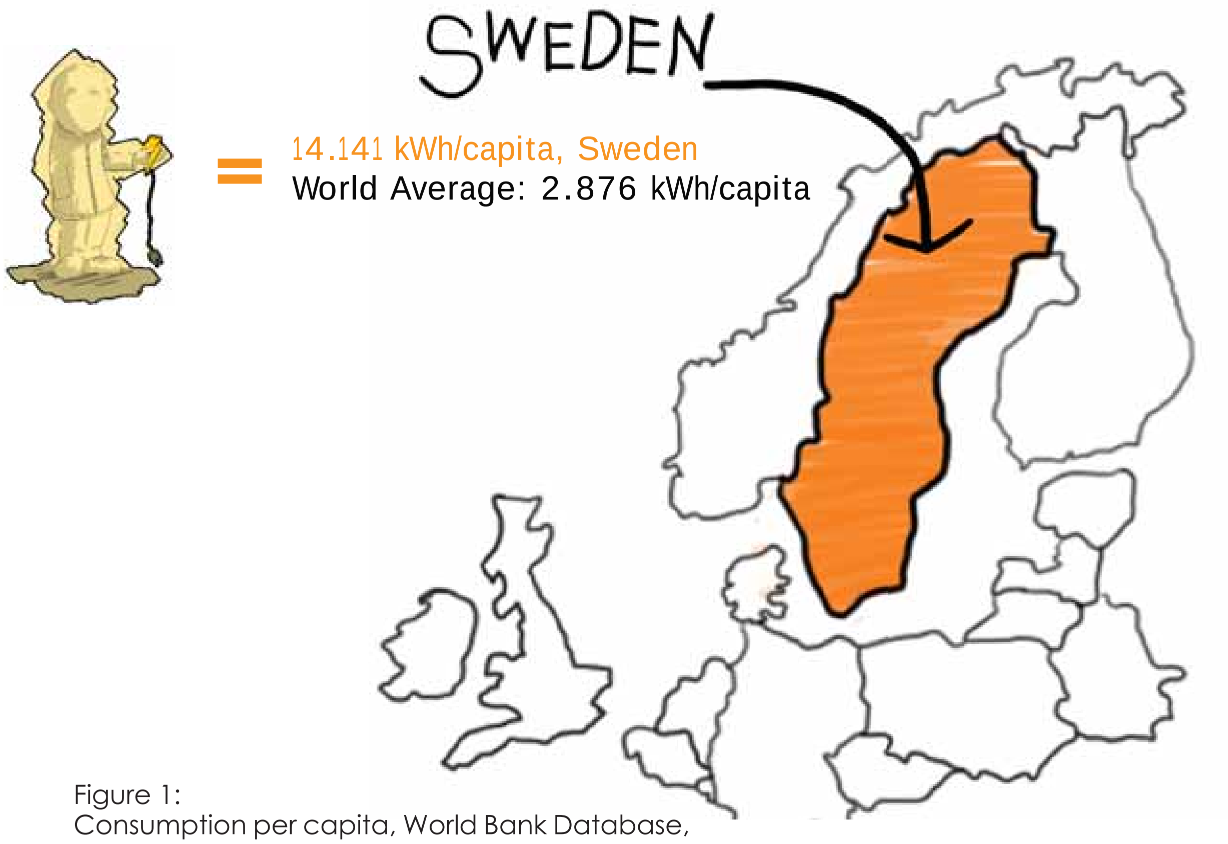


Figure 1:
Consumption per capita, World Bank Database, World Development Indicators

When the discussion comes to energy efficiency and households, the tendency is to focus on the construction technology and structural details in order to improve the insulation of the envelope, decrease the heat bridges created by critical junctions of the envelopes' structure, and implement technological features, such as heat exchangers, with higher energy efficiency than their predecessors.

Although the electricity consumed for heating takes up a large portion of the total final energy use, electricity use related to household purposes is equally important. Considering the fact that electricity is an integral part of our consuming habits leads to the conclusion that these habits are as important as the structure of the envelope we live in. The problem lies in the invisibility of the product (electricity). Being unable to see what we consume makes it easy for us to overlook its importance and affect on our lives.

Figure 2*:
Total final use per energy carrier, 376 TWh

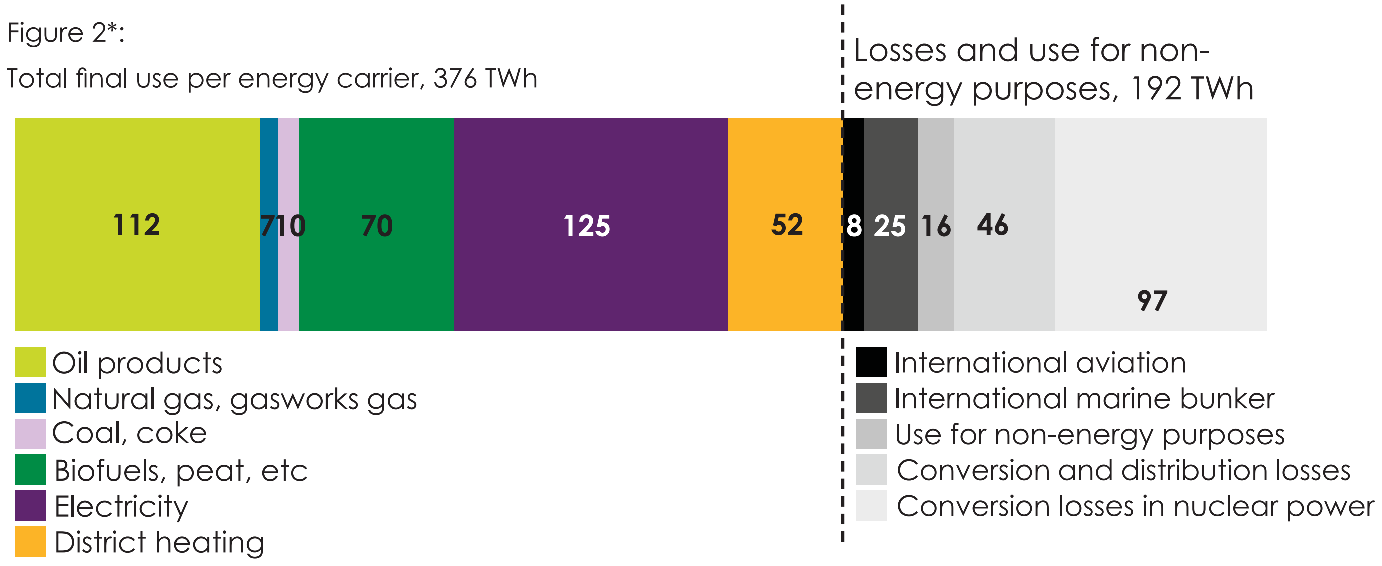
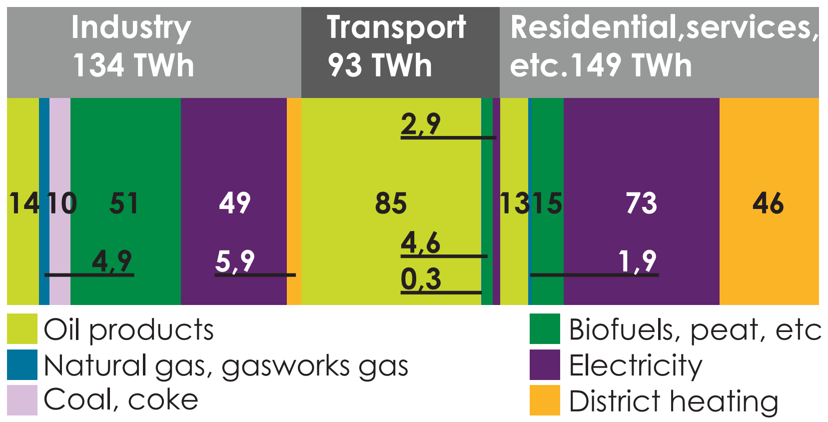


Figure 3*: Total final use per sector, 376 TWh



*SOURCE: Statistics Sweden, Additional Processing by the Swedish Energy Agency

In order to get a firmer understanding of the energy issues in relation with the local context within Sweden, a study of the relative facts and figures was conducted. Statistically the housing and service sectors are grouped together and are responsible for the 58% of the final use of electricity during 2009 (73 TWh out of 125 TWh total)[1] (Figure 1 & 2, page 14). District heating for the same sectors amounted to about 46 TWh, almost 90% of the total quantities for the same time period (total energy use for district heating was 52 TWh)[2]. In 2007 they used 143 TWh, of which the Swedish housing sector represented 124 TWh, roughly corresponding to 30 percent of our country's energy consumption[3].

It is also interesting to note that according to the 2010 World Bank Database and the World Development Indicators, the electricity consumption in Sweden equals to 14.141 kWh/capita, while at the same time the figures for Norway, Finland, Denmark and the World average are 23.549 kWh/capita, 15.241 kWh/capita, 6.246 kWh/capita and 2.876 kWh/capita respectively[4] (Figure 1, page 14).

[1] Swedish Energy Agency 2010
[2] Swedish Energy Agency 2010
[3] Prospects for Swedish technology contributing to reduced climate impact, A report produced under the auspices of Future Climate – Engineering Solutions, Sveriges Ingenjörer / The Swedish Association of Graduate Engineers, 2009
[4] 2010 World Bank Database - World Development Indicators

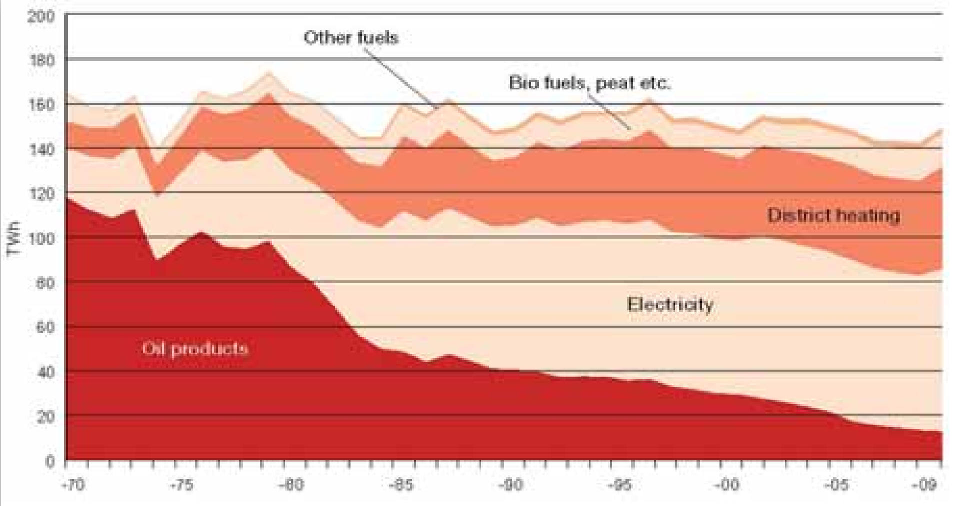


Figure 4: Final energy use in residential sector 1970-2009*

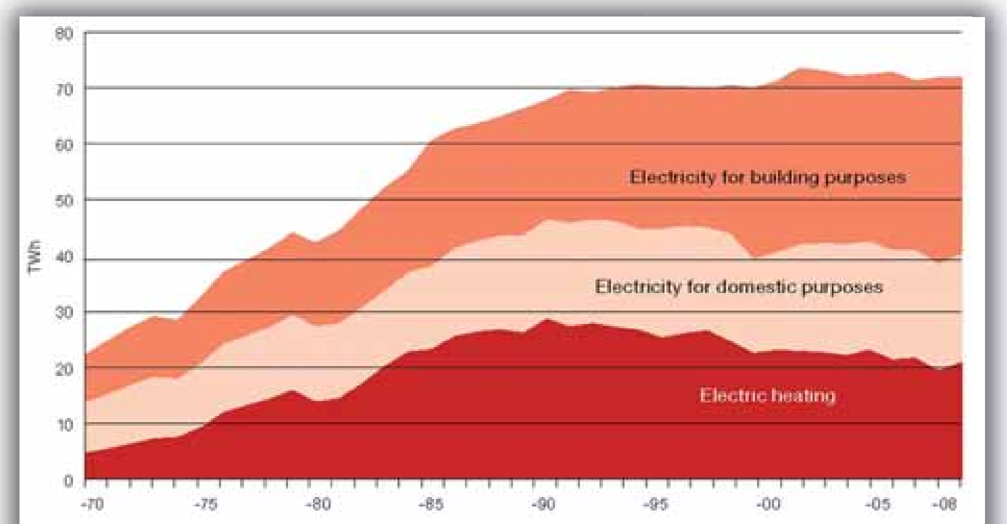


Figure 5: Electricity use in residential and service sectors 1970-2008*

According to Energimyndigheten, half of the electricity use within the residential and services sectors is consumed for domestic purposes (lighting, white goods, domestic appliances and other electrical equipment), with the percentage related to it exhibiting considerable raise since the 1970s[5] (figure 4 and 5, page 15).

The increase in the number of households during the last decades, combined with the greater ownership of electrical and electronic equipment (table 1, page 15) and changes in the behavioural patterns related to their use are factors leading to the recorded increase in electricity use.

The actual figures of electricity consumption for domestic purposes reveal an increase from 9.2 TWh in 1970 to 19.5 in 2008, while the average consumption for the same purposes of a four member family house is at the level of 6000 kWh/year[6].

The increase in consumption of electricity and appliances is accompanied by the increase in electricity prices, with the numbers revealing almost a doubling of prices for Sweden in a period of 13 years, as it is shown in table 2 (page 15)[7].

The aforementioned facts make obvious the importance of our consumption patterns. Our pressure on the environment is increasing and so is the cost of our living. Integrating a sustainable, local and personal way of generating electricity should become the norm if we want to maintain our current way of living and reduce our footprint on the environment.

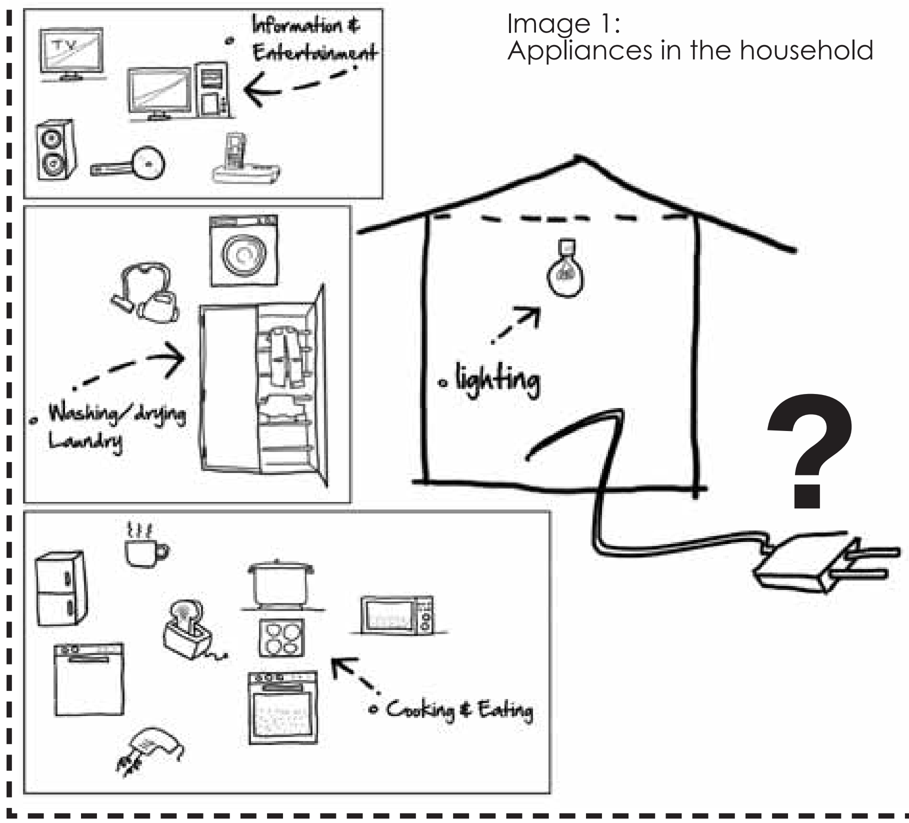


Image 1:
Appliances in the household

Table 1. Average number of appliances in three functional areas owned by households, 1950 and 2000 (mean values for year)[7].

Functional Area	1950	2000
Washing/drying Laundry	1	3
Cooking and Eating	2	10
Information and Entertainment	2	18

Table 2. Comparison of Electricity Prices, (1991-2010) for medium sized households [8]

Electricity Prices (€ /kWh)				
Geographical location	1997	2002	2005	2010
European Union (27 countries)	-	-	0.1013	0.1223
Sweden	0.0675	0.0701	0.0846	0.1195

[5] *First European Conference, Energy Efficiency and Behaviour, Energy efficiency in every-day household life, Three scenarios, Maastricht, Anna-Lisa Lindén, Department of Sociology, Lund University, 18-20 October 2009*
[6] *Benchmarking table-KanEnergi Sweden AB*
[7] *First European Conference, Energy Efficiency and Behaviour, Energy efficiency in every-day household life, Three scenarios, Maastricht, Anna-Lisa Lindén, Department of Sociology, Lund University, 18-20 October 2009*
[8] *Eurostat, updated: 27.04.2011*

14 TRENDS & PROBLEM AREA

As mentioned earlier, during our studies within the Master program it became obvious that the subject of sustainable buildings is being widely discussed by the actors involved in the build environment, and there appears to be a trend towards the design and construction of more sustainable buildings. Having a look at the current trends in architecture gave us the opportunity to become familiar with the objectives set out by the EU, and at the same time obtain information of the tendencies within the construction market.

According to the European Parliament's Industry Committee (ITRE), "from 2019, all newly constructed buildings must produce as much energy as they consume on-site. The Committee also wants Member States to set intermediate national targets for existing buildings, i.e. to fix minimum percentages of buildings that should be zero energy by 2015 and by 2020 respectively"[9]. Many argue that this goal is over-optimistic, and the lack of a common comprehensive approach with clear guidelines supported by necessary legislation for all Member States is a barrier that should be overcome in order for the goal to be met.

This common guideline should also specify which definition regarding "Zero Energy Building" (Site, Source, Costs, Emissions) should be followed. National deviation across Europe regarding very low energy buildings make cross-country comparisons of the calculated energy performance difficult. Currently only seven countries have an existing official definition (Austria, Czech Republic, Denmark, UK, Finland, France and Germany). Sweden has no definition for Low Energy Buildings currently, although there is an existing legislation regarding very low energy buildings and the planned tightening of the national Building Regulations. The Swedish National Energy Efficiency Action Plan (NEEAP) is under development, and classification of low energy buildings is proposed.

Even though these obstacles are real, the fact that the EU Member States have decided to move towards this common goal is of great importance. We as architects and therefore actors responsible for the build environment must expand our field of expertise and become familiar and fluent with the technical aspects of making a "Zero Energy Building". Integration of new technological features such as renewable energy sources into the design of a new building or as part of a renovation/adaptation/transformation of an existing one has to become a part of our design process.

A quick search on the subject of renewable energy technologies, and more specifically of PVs which is continuously developing, reveals a vastness of information available on them, making it difficult for one to navigate through and mine the essential information for working with BIPV (Building Integrated Photovoltaics). It is very easy for one to get lost within all this information, and consequently lose interest on the subject.

To contribute as actors, we realised that background knowledge on the issue is necessary. This information should cover all basic aspects of PV technology and what that relates to it (systems, components, limitations etc), and act as a set of tools for our approach in tackling the subject of integration.

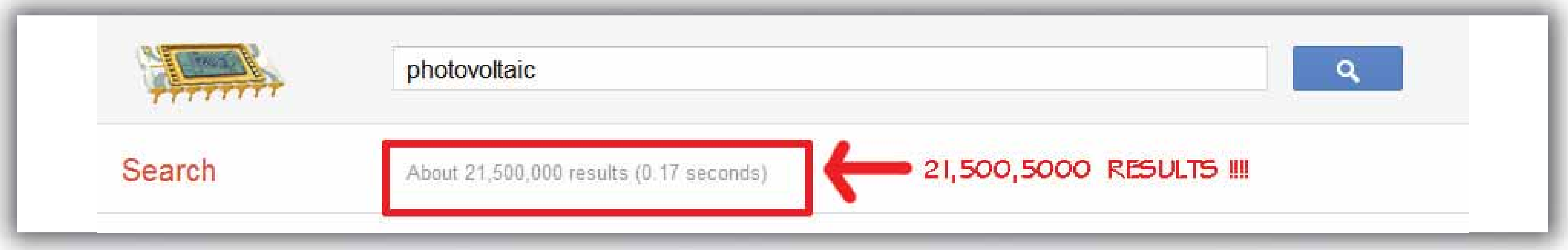


Image 2:
Results from Google for the term "photovoltaic". Source: Google search engine.

Image 3: A quick search on the internet reveals a growing amount of firms and projects focusing on Sustainable development and renewable energy sources
Source: Google search engine.

[9] *Net zero energy buildings: definitions, issues and experience, second paper of eceee guides to issues related to the recast of the EPBD. Updated September 2, 2009*
[2] *Swedish Energy Agency 2010*
[4] *2010 World Bank Database - World Development Indicators*

1.5 SUSTAINABILITY & OUR ROLE

Households will play an important role in saving electricity in the future, by becoming more self sufficient and leave a smaller footprint on the environment. Taking into account the fact that a large portion of the build environment needed to cover our needs is already available, we realize that renovation, transformation, restoration and adaptation projects will take up a large portion of an architects' work. Consequently, being able to design new buildings with a high degree of quality will not be enough. One should be able to work on existing structures reaching the same level of result.

Adapting the design of buildings to meet our needs means making design choices that will allow the building itself to provide the necessary electricity in order to cover the loads that derive from our consumption patterns. Buildings that are more self sufficient and leave a smaller footprint on the environment. BIPV has this potential. But in order to work with the issue of energy and PV integration, a better understanding of the subject is required.

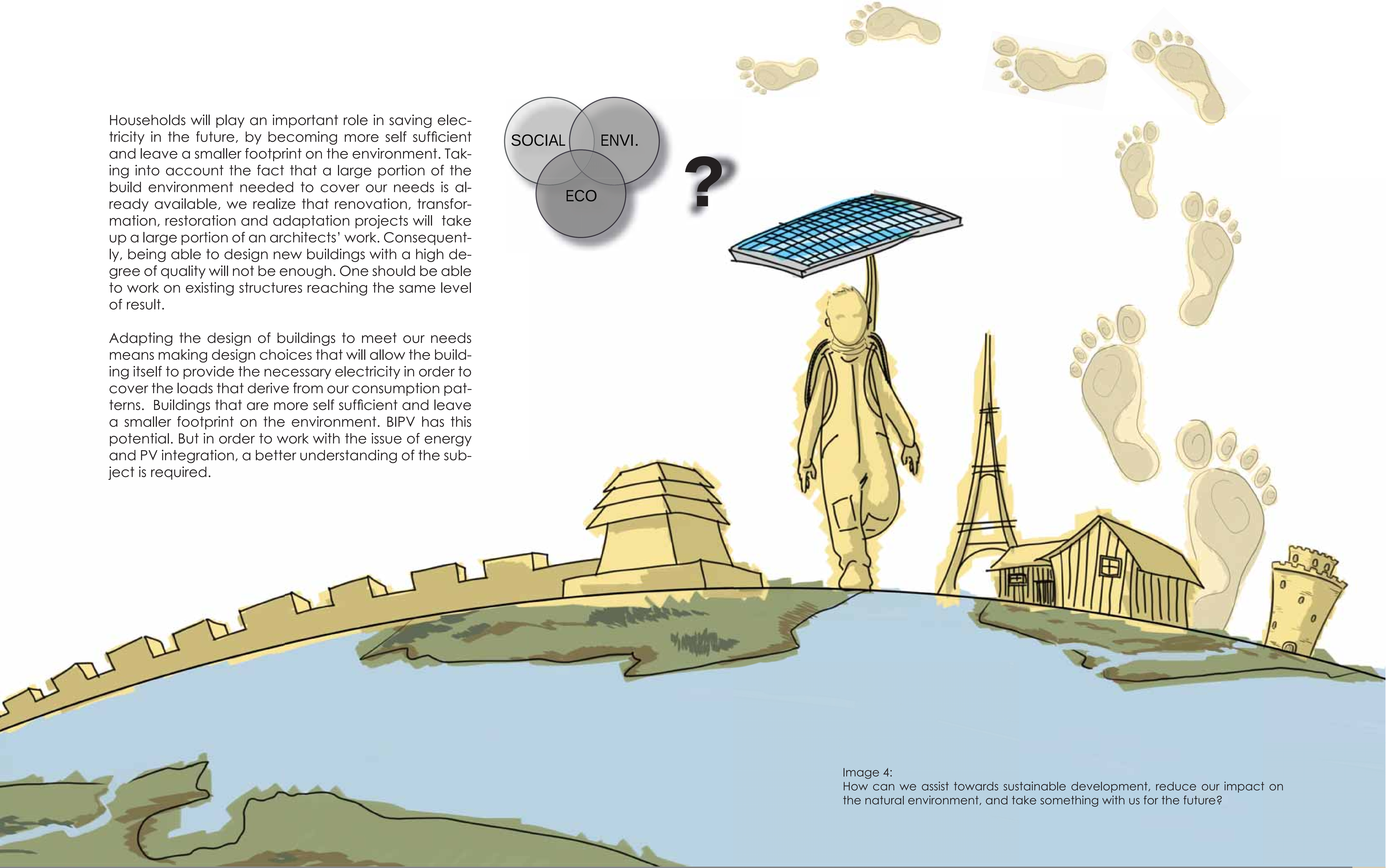


Image 4:
How can we assist towards sustainable development, reduce our impact on the natural environment, and take something with us for the future?

1.6 PROJECT IDEA & AIMS

As architects, in order to be able to contribute towards the goal of sustainability, we decide to explore the possibilities of **BIPV**. By integrating a PV system to a building, we could cover a portion or even the total of the electricity load for household purposes, decrease our environmental impact, and perhaps be an example for others to follow. But which are the main characteristics of PVs?

Photovoltaics are:

+

- Easily recognisable as power sources.
- They offer payback of investment.
- They can be used as building materials.
- They can increase character and value of the building.
- Their use leads to a decrease of our environmental impact.
- They can offer various integration possibilities.

-

- Even though they have been in the market for a long time they are still expensive.
- We architects still consider them to be a new technology.
- There is a lack of information which can be easily accessed and understood
- People depend on subsidies for the installation of such systems.

Through this thesis we aim to:

EDUCATE OURSELVES by:

- Gaining a solid background on the issue of integration of PVs

- Learning how to adapt our designs

- Making them more self sufficient, able to cover our needs

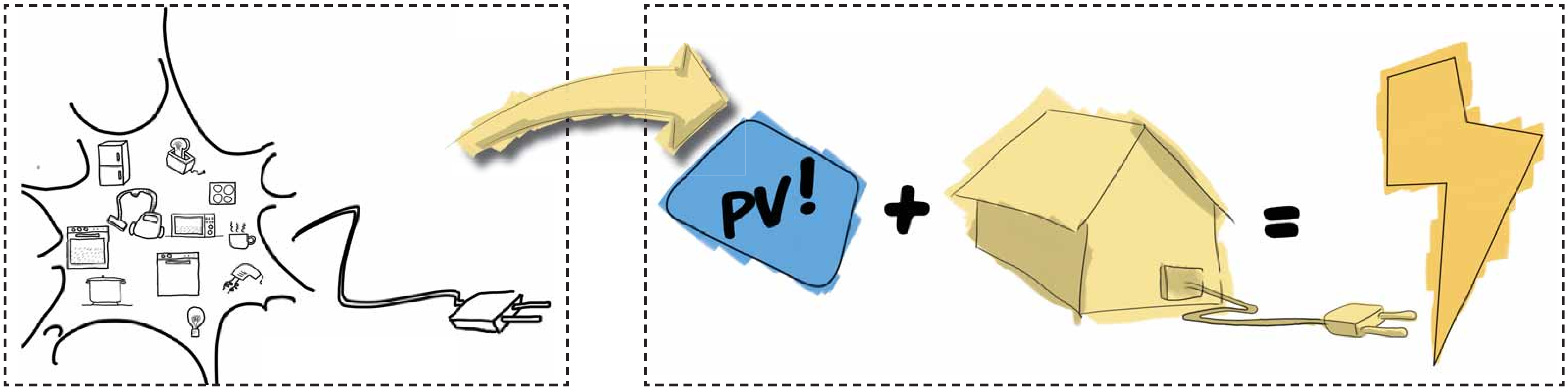
- Reducing our footprint on the environment

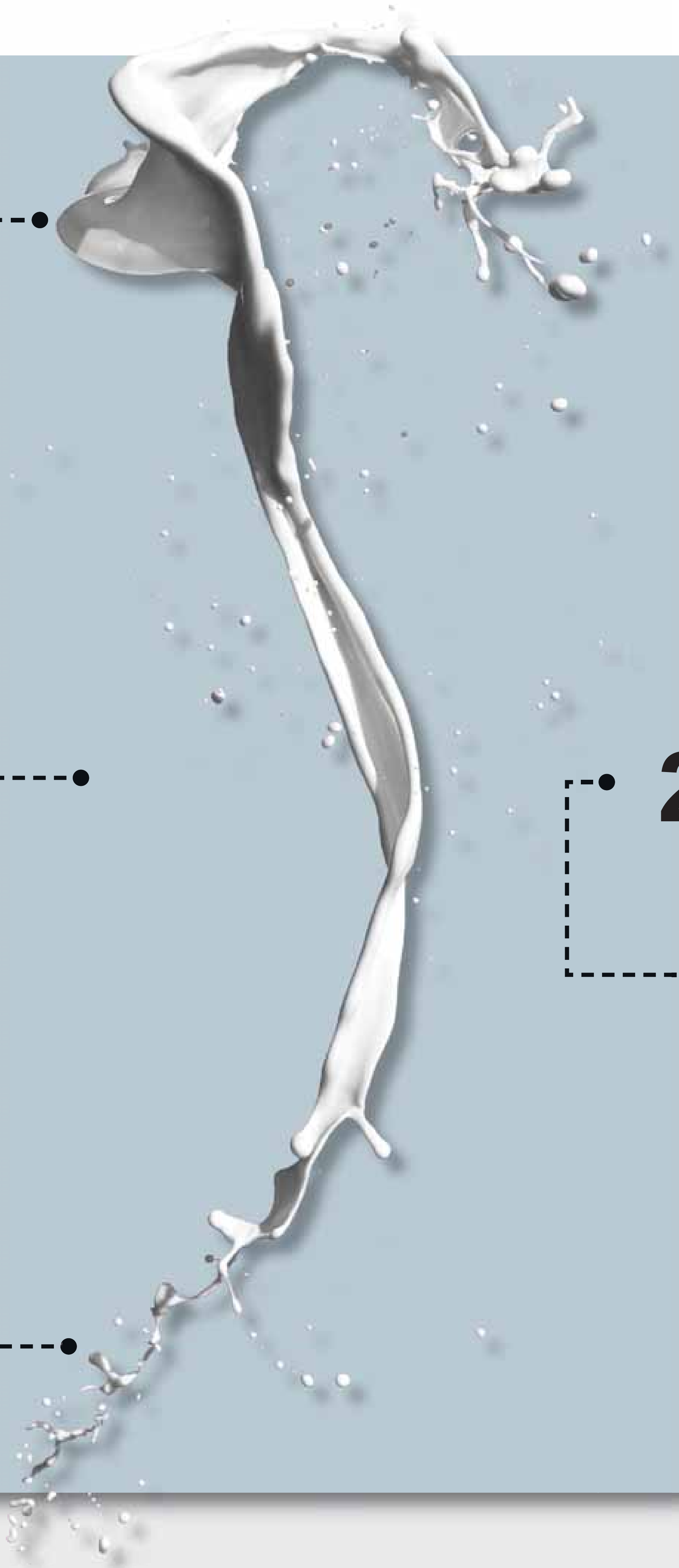
- Expanding our horizons

CREATE A GUIDELINE FOR US & OTHERS by:

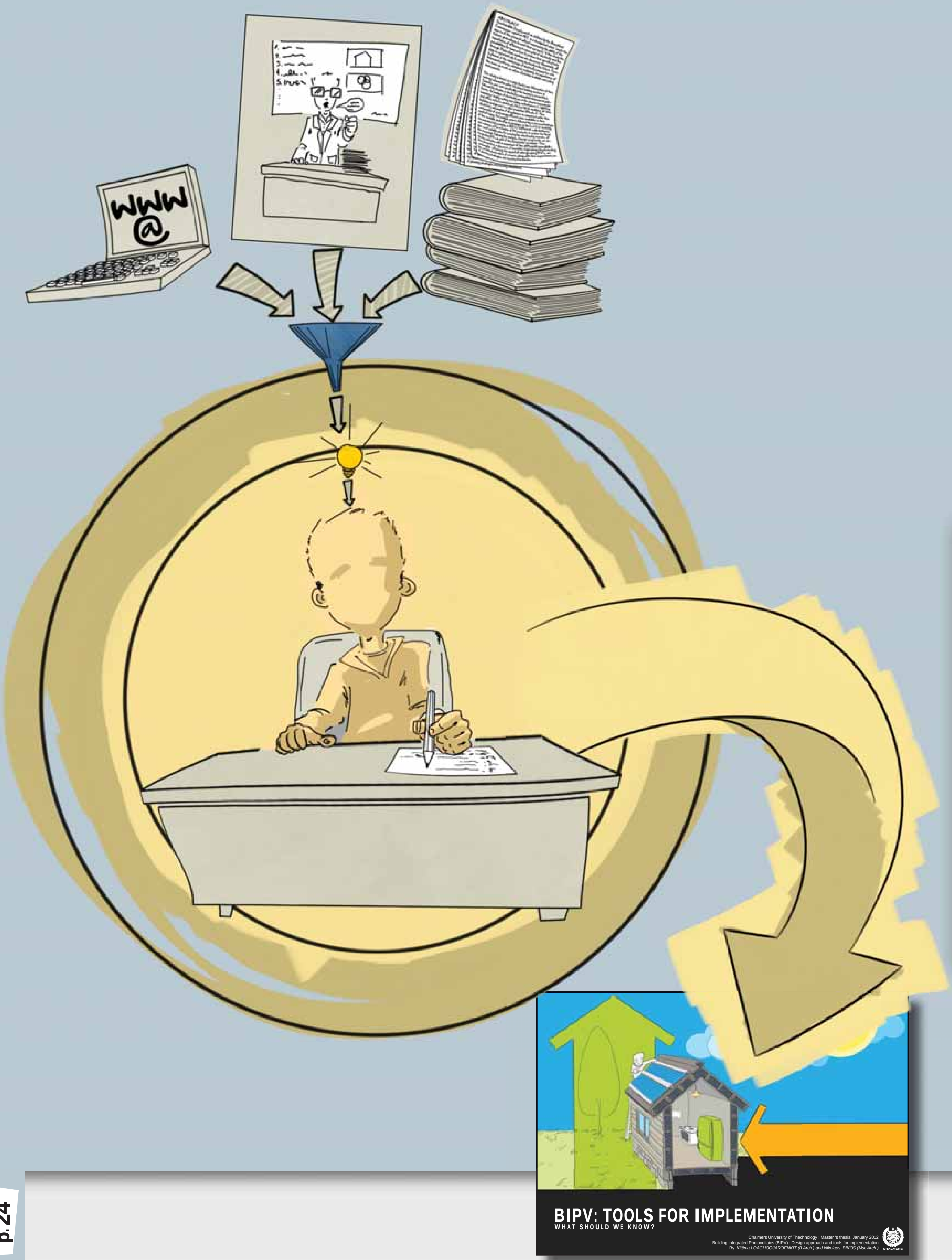
- Producing a work which we can take with us in our future careers, and others can benefit from it.

Image 5: Graphic representation of the projects' idea.





2. BIPV: TOOLS FOR IMPLEMENTATION



In "BIPV: Tools for Implementation", information collected, analysed and categorized regarding PVs and their integration to buildings is presented, in steps that can be easily understood. The subjects covered are: PV types and technologies, PV systems and their components with a more in-depth presentation of batteries and sizing calculations, calculation examples for the user related electricity consumed within a building, context related factors that affect the design, integration possibilities and examples, PV data sheet analysis accompanied by a calculation method of PV electricity production and relative example.

The information presented is aiming to provide a solid background and be used as a set of tools for further research and application of PV technologies during the design process. The booklet is a tool for architects who are interested on the field of BIPV (Building Integrated Photovoltaics), as well as others who are also interested in the topic.

2.1 PHOTOVOLTAIC BASIC INFORMATION

TERMINOLOGY

The process of direct conversion of light into electricity, discovered by the French physicist Alexandre-Edmond Becquerel in 1839, is expressed by the term Photovoltaic. The word is consisted by two parts, the first one being Photo from the Greek word φώς (phōs) which means "light", and the second one being Voltaic, from the name of the Italian physicist Volta, after whom a unit of electromotive force, the volt, is named[10]. The first solar cell was built in 1883 by Charles Fritts, an American inventor, with the use of selenium with a thin film of gold as semiconductor.

THE PHOTOVOLTAIC EFFECT

During the Photovoltaic (PV) effect (the physical process where electricity is generated from the conversion of sunlight by the solar cell), a portion of the photons - the "particles" in a beam of sunlight - that strike the cell is absorbed by the semiconductor material (a material with electrical conductivity due to electron flow), knocking electrons loose from the atoms they strike. The light absorption frees electrons, from the in-build electric field in the PV cells, to flow as current in a certain direction across a junction which sets up a voltage, making electrical power available. The electric field is created through the controlled introduction of impurities to the intrinsic (extremely pure) semiconductor, creating n-type (negative electron charge) or p-type (positive electron charge) zones[11],[12].

MATERIALS AND CELLS

Solar cell technology is a constantly developing sector, one of the fastest growing ones of the renewable energy industry. Concerns such as environmental awareness, climate change, air quality, national and individual energy security issues, along with the rising cost of fossil fuels, are the driving forces of the market. During the last years, the installations of PV's has increased greatly, making the PV market a very competitive sector. A quick look on available products and on-going research leaves no room for arguments.
PV cells are using different materials, and so display differences when it comes to efficiencies and costs. Materials for efficient solar cells must have characteristics matched to the spectrum of available light. Some cells are designed to efficiently convert wavelengths of solar light that reach the Earth surface. However, some solar cells are optimized for light absorption beyond Earth's atmosphere as well. Light absorbing materials can often be used in multiple physical configurations to take advantage of different light absorption and charge separation mechanisms.

Most commonly, the materials used for the production of PV cells are monocrystalline silicon, polycrystalline silicon, amorphous silicon (a-Si), cadmium telluride (CdTe), and copper indium selenide/sulfide (CIGS), although new research is introducing new materials and methods, such as quantum dot solar cells[13], light bending polymer film/stickers[14], and carbon nanotubes, which promise a further improvement of the cells efficiency in the future. PV cells can be classified as:

- Crystalline Si Cells
- Thin-film technologies
- High-performance or Multijunction PV cells
- Dye sensitized cells
- Photovoltaic Thermal Hybrid Solar Collectors

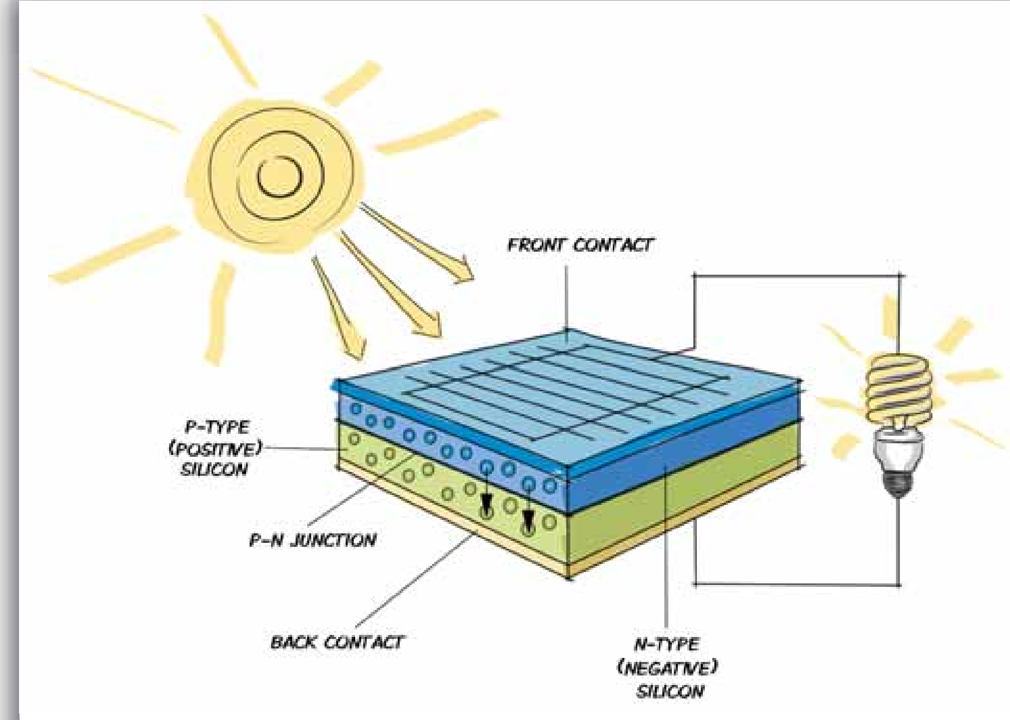


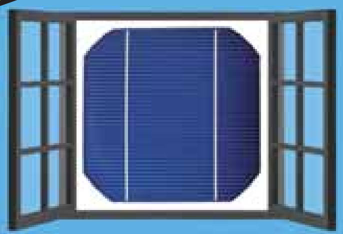
Figure 6: The photovoltaic effect.

[10] http://en.wikipedia.org/wiki/Solar_cell
[11] Building Integrated Photovoltaics: A Handbook by Simon Roberts & Nicolò Guariento, p.16
[12] http://www1.eere.energy.gov/solar/solar_glossary.html#P
[13] http://inhabitat.com/new-quantum-dot-solar-cells-could-double-efficiency/
[14] http://www.soloptics.com/fusion

PV TYPES AND THEIR MAIN CHARACTERISTICS

HETEROJUNCTION WITH INTRINSIC THIN-LAYER HIT CELLS

HIT:
Hybrid construction, combination of c-Si and thin-film cells.
The most efficient type of cells.
Less degradation of efficiency with increase in operating temperatures.
Thin-film component allows them to use the diffused light more efficiently.
The most expensive type of cells.
Cell efficiency: 30-42%
Module efficiency: ~25%



CRYSTALLINE CELLS (c-Si)

MONOCRYSTALLINE (mono-c-Si):
Material: single crystal silicon ingot of high purity
Typical cell dimensions: 12,5 or 15 cm.
A large portion of the material is wasted during the cutting process.
Tend to be expensive but are the most commonly used.
Cell efficiency: 16-20%
Module efficiency: 13-19%
Area need per KW per modules: ~7 m^2

POLYCRYSTALLINE (poly-c-Si):
Material: single crystal silicon ingot of high purity
Typical cell dimensions: 21 x 21 cm.
More simple and less expensive to produce than mono-c-Si
Fewer material losses during the production
Have a high number of sales.
Less efficient, due to the grain boundaries
Require larger cells to reach the same efficiencies.
Cell efficiency: 14-18%
Module efficiency: 11-15%
Are need per KW per modules: ~8 m^2

THIN FILM

THIN FILM (a-SI):
Material: amorphous silicon
Decreased embodied energy due to reduced amount of material and lower temperatures required for the creation of the cell
More efficient at overcast conditions and high temperatures
Popular due to their cost, flexibility, light weight and ease of integration levels
Reduced efficiency leads to larger installation areas for reaching the same efficiency levels as the c-Si modules.
Cell efficiency: 12-20%
Module efficiency: 7-13%
Area need per KW per modules: ~10-15 m^2

DYE SENSITIZED CELLS (DYSC)

Dye Sensitized (DSSC, DSC, DYSC) or Grätzel cells:
A type of thin film
Material: Titanium dioxide nanoparticles and dye, not by silicon.
Low cost cells that require no protection from minor events like hail or tree strikes.
Conversion efficiency is less than the best thin-film cells
They are not commonly used.
The technology is still developing and appears to be very promising.
Cell efficiency: ~ 11%

SILICON INGOT

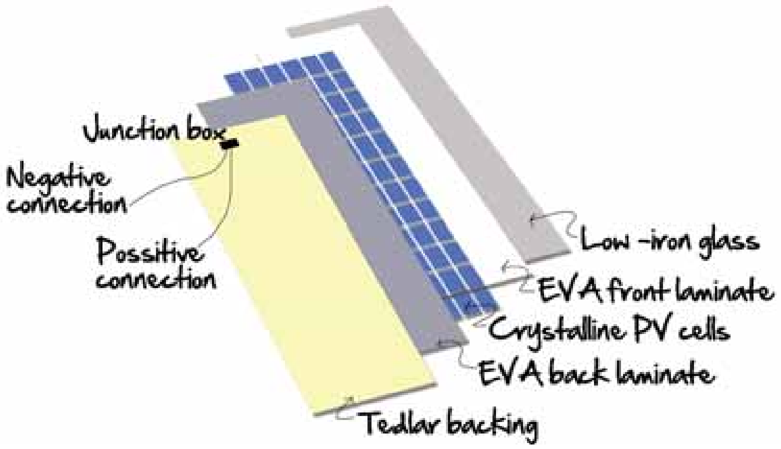
AMORPHOUS SILICON

SILICON

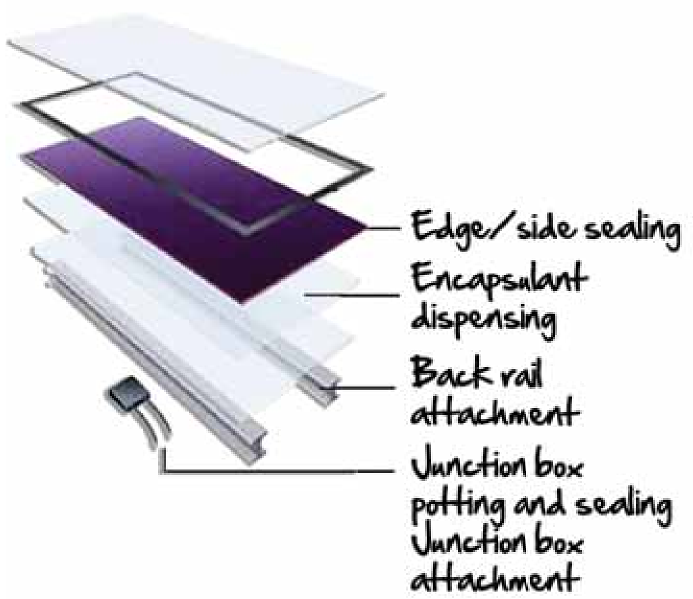
TITANIUM DIOXIDE AND DYE

SILICON CRYSTAL INGOT

SILICON WAFER



C-SI TYPICAL MODULE



THIN FILM MODULE

Figure 7: C-si and a-Si Materials and structures of cells.

CRYSTALLINE CELLS

Crystalline cells are divided into two categories, the monocrystalline (also known as single crystal) silicon cells, and the polycrystalline silicon cells (also known as multicrystalline silicon). Both types are manufactured from silicon.

In the case of the former, the cell comes from a single crystal ingot of high purity, with typical dimensions of 12,5 or 15 cm. The ingot when grown by the Gzochralski method (crucible drawing process) has a cylindrical shape, and therefore needs to be cut into better packing shapes (varying from round, semi-round or square) after it has been cut into thin slices. Other methods for making monocrystalline silicon are edge-defined film-fed growth (EFG) and string ribbon processes. Through these the cells can be grown into the desirable thickness as well as cut square with right-angle corners, resulting in minimization or even elimination of the losses from the slicing processes. In order for increasing light absorption and so resulting in higher currents, an anti-reflection coating is applied, giving the dark blue colour to the cell. For aesthetic reasons (variations in colour) the coating step can be skipped. This though leads to a drop in efficiency of 3% to 30%[15]. Cell efficiencies (in research) range up to 27.6%[16], while commercial module efficiencies range around 13-20%.

In the case of polycrystalline silicon, the material is melded and cast in a cuboid form. Large crystals start forming while the material solidifies. The grain sizes of these are between a few millimetres to a few centimetres. The ingot is cut into bars and sliced into thin wafers (a thin sheet of semiconductor material), which in turn are used to create the cells. Polycrystalline silicon differs from monocrystalline in terms of cost (due to the reduction of losses) and efficiency (due to the grain boundaries). The difference is small, but still leads to the need for larger cells (21x21cm) in order to reach the same efficiency levels[17].Cell efficiencies (in research) range up to 20.4%[18],while commercial module efficiencies range around 14-18%.

THIN FILM CELLS

Thin-film[19],[20],[21] cells are constructed through the deposition of thin layers of PV materials (cadmium telluride, copper indium selenide/sulfide, amorphous silicon) onto a superstrate (covering on the sun side/ front side of a PV module, providing protection for the PV materials from impact and environmental degradation while allowing maximum transmission of the appropriate wavelengths of the solar spectrum) or onto a substrate (the physical material upon which a photovoltaic cell is made/back side).

Connections between cells are an integral part of the cell, meaning that the module is made at the same time. The difference in thickness and thus in the materials needed, along with the lower temperatures needed for the production of the cell (less energy consumption) leads to considerable cost savings. The downside is the drop in efficiency, leading to larger installation areas for reaching the desired power.

Thin-film technologies are developing, and efficiency levels are increasing. The interest of the market is driven by the flexibility of the module and hence its better integration to buildings, along with the cost savings. Cell efficiencies (in research) range around 12-20%[22] while commercial module efficiencies range around 7-13%.

[15] *Building Integrated Photovoltaics: A Handbook by Simon Roberts & Nicolò Guariento, p.18*
[16] *NREL, Best Research-Cell Efficiencies*
[17] *Building Integrated Photovoltaics: A Handbook by Simon Roberts & Nicolò Guariento, p.19*
[18] *NREL, Best Research-Cell Efficiencies*
[19] *http://www.gosolarpowerforhomes.com/*
[20] *http://www.daviddarling.info/encyclopedia/T/AE_thin_film_cell.html*
[21] *Building Integrated Photovoltaics: A Handbook by Simon Roberts & Nicolò Guariento, p.20*
[22] *NREL, Best Research-Cell Efficiencies*

HIT CELLS

High-performance or Multijunction. A multijunction cell is comprised by structurally different semiconductors (thin-film and crystalline silicon). The choice of the semiconductors is carefully based on their band gap energy characteristics. This means that each one will have a better efficiency level in absorbing light (electromagnetic radiation to be precise) over a portion of the spectrum. Absorption of different parts of the solar spectrum (nearly all of the solar spectrum), leads to the generation of electricity from as much of the solar energy as possible. GaAs (Gallium arsenide) based multijunction devices are the most efficient solar cells to date. In October 2010, triple junction metamorphic cell reached a record high of 42.4%[23],[24].

Another high performance cell type is the HIT PV cell, where HIT stands for "heterojunction with intrinsic thin-layer". These PV cells are constructed with a combination of crystalline and thin-film silicon cells. Amorphous silicon is coated onto both front and rear faces of a monocrystalline silicon wafer. The interface is made by intrinsic (meaning undoped) silicon layer. Whereas a change in doping creates the necessary junction in a standard crystalline cell, here the junction is created between two structurally different semiconductors, hence the name heterojunction. When compared to monocrystalline silicon, these PV cells are more efficient and have less degradation of efficiency with increase in operating temperatures[25].

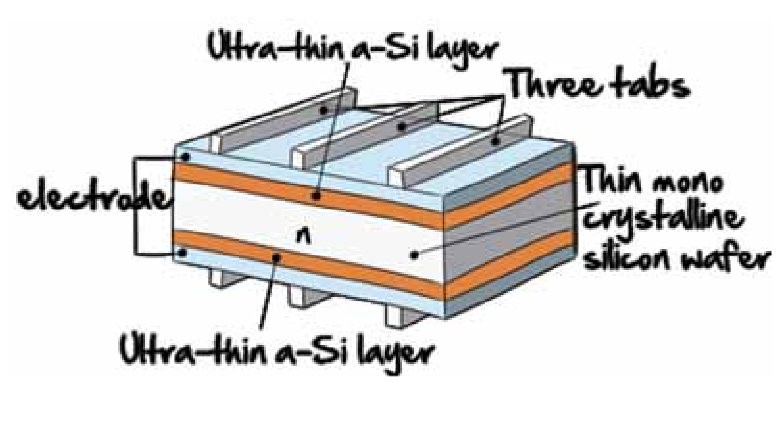
Another alternative to the conventional mono-facial PV cells, are the bifacial ones. In these cells, the electrical doping along with the contacts, that where located at the front or back face of the wafer, are at the edges. The cell thus becomes sensitive both at the front and rear (rear side can benefit from ambient and reflected light when applied in buildings) allowing it to generate at least 10% more electricity. Bifacial transmit more infrared than mono-facial cells so benefit from a lower operating temperature[26].

DYE SENSITIZED CELLS (DSSC, DSC, DYSC) OR GRÄTZEL CELLS

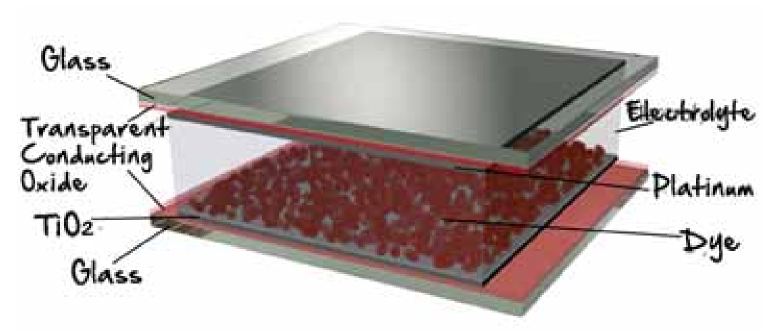
Dye sensitized solar cells (DSSC, DSC or DYSC) are low cost thin-film solar cells. They are based on a semiconductor formed between a photo-sensitized anode and an electrolyte; a photoelectrochemical system. The low cost materials used in the production combined with the fact that they do not require elaborate apparatus to manufacture (less expensive) makes them technically attractive. They can be engineered into flexible sheets and require no protection from minor events like hail or tree strikes.

A porous layer of titanium dioxide (TiO_2) nanoparticles is covered with a molecular dye that absorbs sunlight, like the chlorophyll in green leaves. The TiO_2 is immersed under an electrolyte solution, above which is a platinum-based catalyst. As in a conventional alkaline battery, an anode (TiO_2) and a cathode (platinum) are placed on either side of a liquid conductor (electrolyte). DSSC's degrade when exposed to ultraviolet radiation. The barrier layer may include UV stabilizers and/or UV absorbing luminescent chromophores (which emit at longer wavelengths) and antioxidants to protect and improve the efficiency of the cell[27].

A practical advantage, one DSSC's share with most thin-film technologies, is that the cell's mechanical robustness indirectly leads to higher efficiencies in higher temperatures. The major disadvantage to the DSSC design is the use of the liquid electrolyte, which has temperature stability problems. At low temperatures the electrolyte can freeze, ending power production and potentially leading to physical damage. Higher temperatures cause the liquid to expand, making sealing the panels a serious problem. Another major drawback is the electrolyte solution, which contains volatile organic solvents and must be carefully sealed. This, along with the fact that the solvents permeate plastics, has precluded large-scale outdoor application and integration into flexible structure[28]. Cell efficiencies (in research) range up to 11.1%[29].



HIT CELL STRUCTURE



DYSC CELL STRUCTURE

Figure 8 & 9: HIT and DYSC structures of cells.

[23] *http://en.wikipedia.org/wiki/Solar_cell*
[24] *NREL National Renewable Energy Laboratories, Best Research-Cell Efficiencies*
[25] *Building Integrated Photovoltaics: A Handbook by Simon Roberts & Nicolò Guariento, p.21*
[26] *http://en.wikipedia.org/wiki/Solar_cell_research*
[27] *"Photovoltaic cell, European patent WO/2004/006292". http://www.wipo.int/pctdb/en/wo.jsp?IA=US2002018922&DISPLAY=DESC*
[28] *Ecole Polytechnique Fédérale de Lausanne, "New Efficiency Benchmark For Dye-sensitized Solar Cells", ScienceDaily, 3 November 2008*
[29] *NREL National Renewable Energy Laboratories, Best Research-Cell Efficiencies*

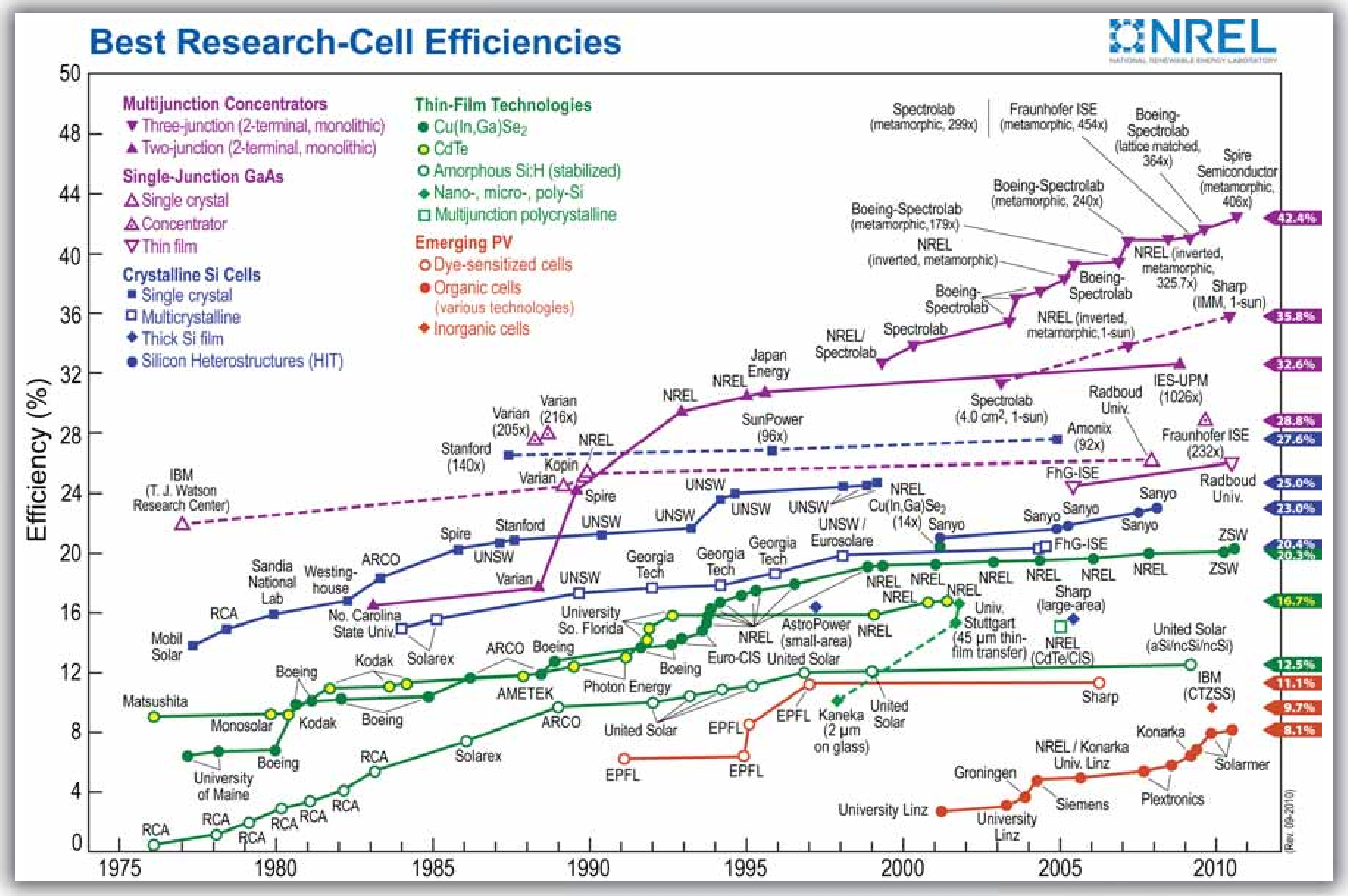
2.1.1 COMPARISON BETWEEN PV TECHNOLOGIES

The following table lists comparisons of technologies that have already been established (Table 3, page 30) and technologies in research (Table 4, page 30).

Table 3. Comparison of Commercial Module Efficiencies [27]

Commercial Module Efficiency								
Technology	Thin-Film					Crystalline Silicon		CPV (concentrated photovoltaics)
	a-si	CdTe	CI(G)S	a-Si/µc-Si	Dye s. cells	Mono	Poly	III-V Multijunction
Cell efficiency	4-8%	10-11%	7-12%	7-9%	2-4%	16-22%	14-18%	30-38%
Module efficiency						13-19%	11-15%	~25%
Area needed per KW (for modules)	~15m²	~10m²	~10m²	~12m²		~7m²	~8m²	

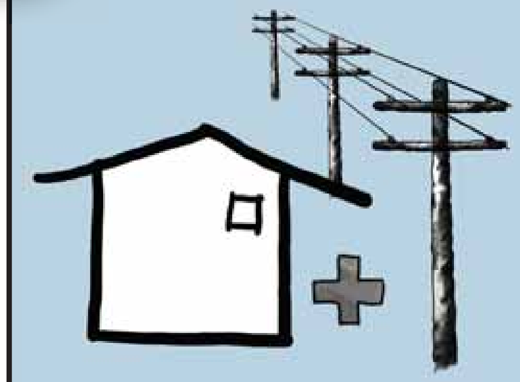
Table 4. Best Reseach-Cell Efficiencies [28]



[27] EPIA 2010. Photon international, March 2010, EPIA analysis. Efficiency based on Standard Test conditions
[28] NREL 2010. National Renewable Energy Laboratories. Best Research-Cell Efficiencies

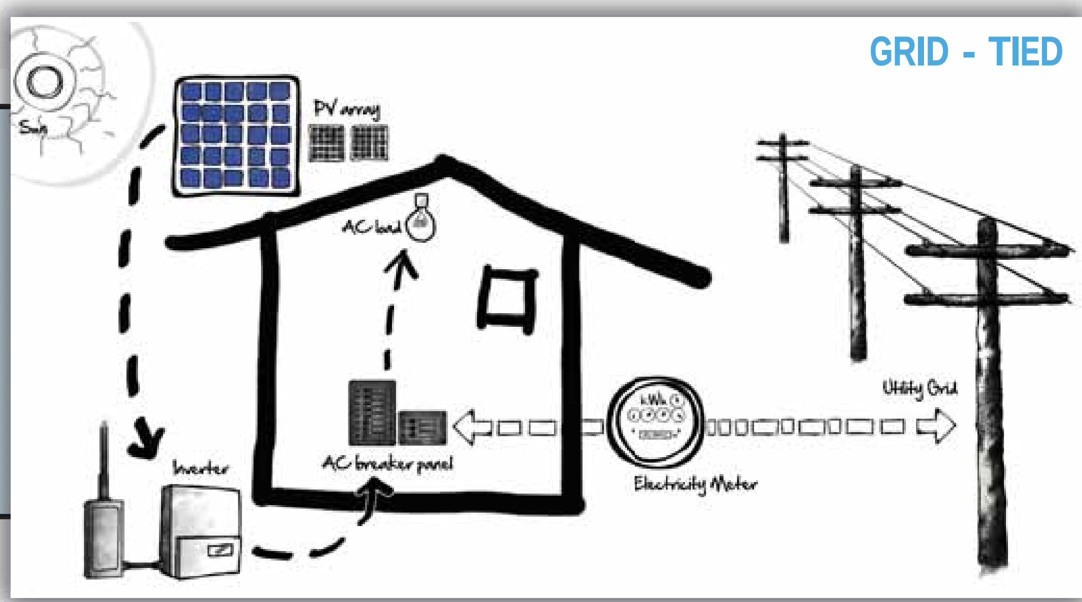
2.1.2 PV SYSTEM TYPES

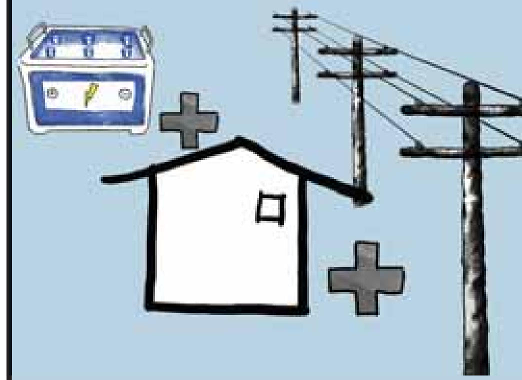
PV Systems are generally divided into three categories:



GRID-TIED SYSTEM

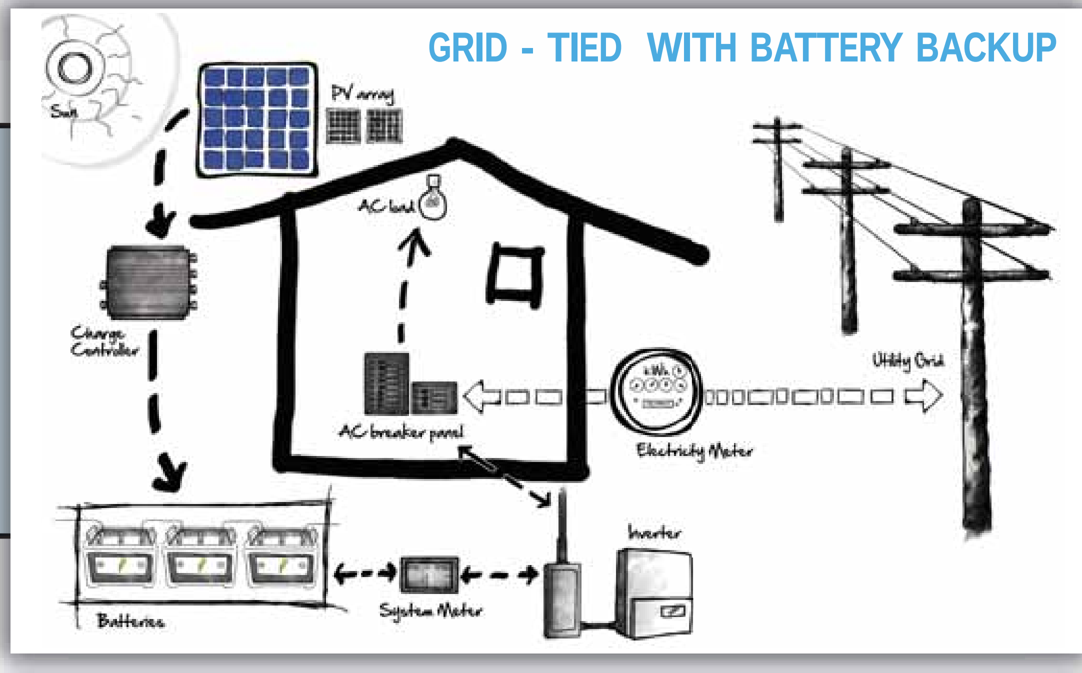
This system allows use of the electricity generated by the PV system as well as electricity from the grid. When the PV system is producing electricity, the home is powered by solar electricity. During the times when the PV system isn't producing electricity, such as at night, the home will receive power from the grid. If there is an outage of the grid, the inverter shuts down the whole system automatically.

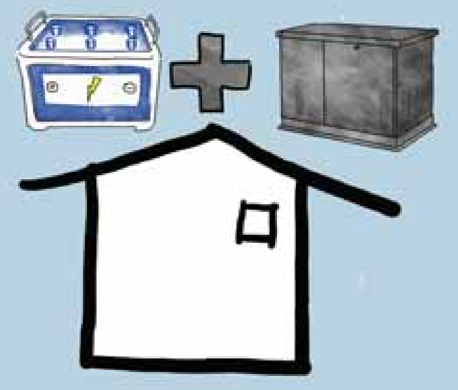




GRID-TIED WITH BATTERY BACKUP SYSTEM

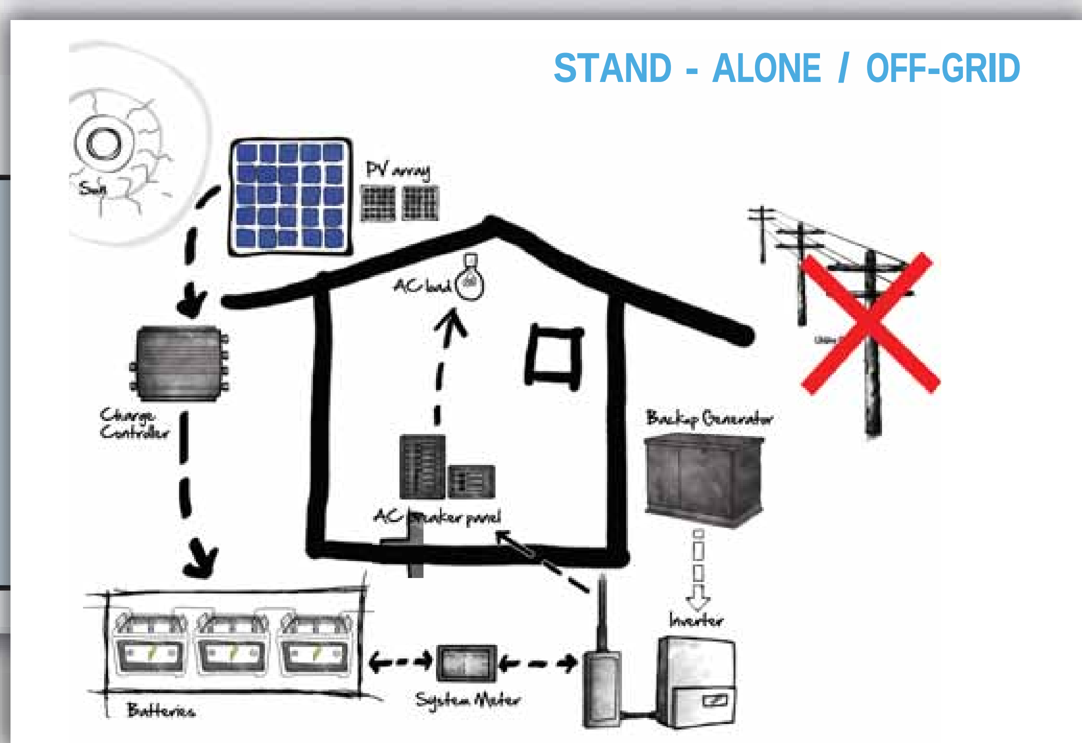
Including a battery bank into the system allows utilization of energy produced from the PV system and stored in the batteries during a power outage. A grid-tied PV system with battery backup is ideal when living in areas with unreliable power from the grid or that experience power outages due to natural disasters.





STAND ALONE OR OFF-GRID SYSTEM

Stand-alone PV systems are designed to operate independently from the grid and to provide all of the electricity you need for your home. They are ideal for homes in remote areas that don't have utility grid service or where it would be very costly to have power lines run to the home, and offer possibilities for going completely green regarding the source of electricity.



2.1.3 PV SYSTEM ANALYSIS

Image 6: PV cell

Image 7: PV module or panel

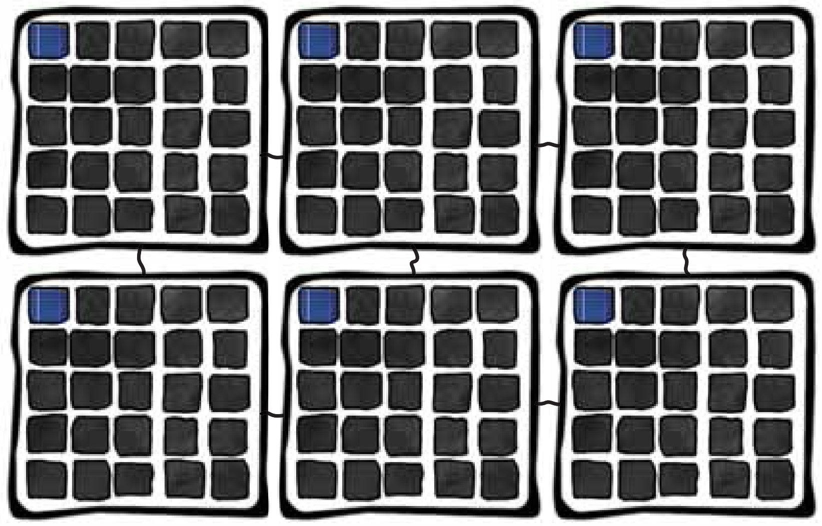


Image 8: PV array

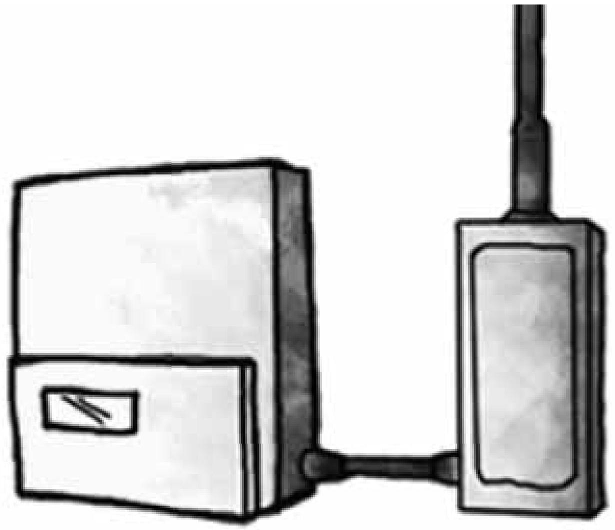


Image 9: PV inverter

A Photovoltaic system is comprised of various parts needed for the conversion of light into electricity. The system includes the array and the balance-of-system components. Each part of the system is briefly explained in the following section.

1. ARRAY COMPONENTS

1.1. PHOTOVOLTAIC (PV) CELL: The basic smallest semiconductor element within a PV module unit that collects energy from the sun. The cells convert light into electrical energy (dc voltage and current)[29].

1.2. PHOTOVOLTAIC (PV) MODULE: The assembly of solar cells and ancillary parts, interconnections, terminals, (and protective devices such as diodes), also referred as PV panel, that are protected from the environment by their layers of glass, plastic and metal frame. They are designed to generate dc electrical power from sunlight[30].

1.3. PHOTOVOLTAIC (PV) PANEL: Also known as a PV module, this is a physically connected collection of modules or a laminate string of modules used to achieve a pre-stated level of voltage or current[31].

1.4. PHOTOVOLTAIC (PV) ARRAY: An interconnected system of photovoltaic modules that are all linked together, functioning as a single electricity-producing unit. In smaller systems, a PV array may consist of just one single module[32]. PV arrays are designed for outdoor use and need to be durable, although new systems are being developed for indoor use (systems in enclosures i.e. Integrated Concentrating (IC) Dynamic Solar Facade from CASE).

2. BALANCE-OF-SYSTEM OR BOS:

The term refers to all of the system components except the PV modules. These components frequently account for half of the system cost and most of the system maintenance. The components consist of structures, enclosures, wiring, switch gear, fuses, ground fault detectors, charge controllers, batteries, and inverters[33].

2.1. PV INVERTER: A solar inverter or PV inverter is a type of electrical inverter that converts direct current (DC) electricity (from batteries or solar arrays) into alternating current (AC) electricity as required for domestic use. Inverters work either for stand-alone systems when not connected to the grid, or for utility-interactive systems. When PV inverters are connected to the grid, they are designed to shut-down automatically upon loss of grid supply, for safety reasons[34]. Solar inverters use special procedures to deal with the PV array, including maximum power point tracking and anti-islanding protection, and may be classified into three broad types[35]:

- **STAND-ALONE INVERTERS**, used in isolated systems where the inverter draws its DC energy from batteries charged by photovoltaic arrays and/or other sources, such as wind turbines, hydro turbines, or engine generators. Many stand-alone inverters also incorporate integral battery chargers to replenish the battery from an AC source, when available. Normally these do not interface in any way with the utility grid, and as such, are not required to have anti-islanding protection[36].

- **GRID TIE INVERTERS**, which match phase with a utility-supplied sine wave. Grid-tie inverters are designed to shut down automatically upon loss of utility supply, for safety reasons. They do not provide backup power during utility outages[37].

- **BATTERY BACKUP INVERTERS**. These are special inverters which are designed to draw energy from a battery, manage the battery charge via an onboard charger, and export excess energy to the utility grid. These inverters are capable of supplying AC energy to selected loads during a utility outage, and are required to have anti-islanding protection. - Multifunction inverters are not the most efficient intertie inverters because the system must have a battery, but they allow system flexibility that intertie inverters do not[38].

[29] *http://en.wikipedia.org/wiki/Solar_cell*
[30] *http://www.standardsolar.com/Residential-Solar-Panels/Maryland/Learning-Center/Glossary*
[31] *Photovoltaics: design and installation manual : renewable energy education for a sustainable future, By Solar Energy International, p.195*
[32] *http://colorado-clean-energy.com/id36.html*
[33] *http://photovoltaics.sandia.gov/docs/BOS.htm*
[34] *http://en.wikipedia.org/wiki/Grid-tie_inverter*
[35] *http://en.wikipedia.org/wiki/Solar_inverter#Classification*
[36] *http://en.wikipedia.org/wiki/Solar_inverter#Classification*
[37] *http://en.wikipedia.org/wiki/Solar_inverter#Classification*
[38] *http://en.wikipedia.org/wiki/Solar_inverter#Classification*

2.1.a. MAXIMUM POWER POINT TRACKING (MPPT): The major principle of MPPT is to extract the maximum available power from the PV module or array, by making them operate at the most efficient voltage (maximum power point). This voltage is matched to the battery voltage, in order to insure maximum charge(amps). The PV module or string of modules maximum power point defines the current that should be drawn from the PV in order to get the most possible power (power is equal to voltage times current) [39],[40].

2.2. DISTRIBUTION BOARD - AC BREAKER & INVERTER AC DISCONNECT PANEL: A component of the electricity supply system, where all of the electrical wiring of the house meet with the provider of the electricity, whether that's the grid or a solar-electric system. It divides the electrical power feed into subsidiary circuits for various rooms in the house, while providing a protective fuse or circuit breaker for each circuit, protecting the building's wiring against electrical fires and safeguarding the circuit's electrical wiring. These breakers also allow electricity to be disconnected for servicing[41].

2.3. CHARGE CONTROLLER: The Charge Controller is installed between the Solar Panel array and the Batteries. It regulates the rate at which electric current is added to, or drawn from the battery bank, preventing overcharging and overvoltage. This changes in voltage can reduce the battery performance or lifespan, and may pose a safety risk. Additionally it may also prevent deep discharging (completely draining) of batteries, or perform controlled discharges, depending on the battery technology, to protect battery life[42].

2.4. PV BATTERIES: Batteries accumulate excess energy created by the PV system and store it to be used at night or when there is no other energy input. Rechargeable batteries are the most effective storage mechanism available. Remaining capacity can be used up by the electrochemical conversion process of the battery. Battery storage capacity is rated in ampere hours, which is the current delivered by the battery over a set number of hours, at a normal voltage, and at a temperature of 25°C. Most PV systems use lead acid batteries or conventional flooded batteries. Nickel cadmium batteries are usually the best option when very high reliability is required[43].

2.5. SYSTEM METER: System meters measure and display the charge of the battery bank, production of electricity from solar panels, and amount of electricity in use[44].

3. OTHER SYSTEM COMPONENTS:

3.1. IMPORT/EXPORT UTILITY METER: A meter that measures electricity exported to the grid (when the energy generation is exceeding the needs) or imported from the grid (when the energy generation does not meet the energy demands). Switch from import to export and vise verse takes place automatically without any human intervention.

3.2. UTILITY CABLE

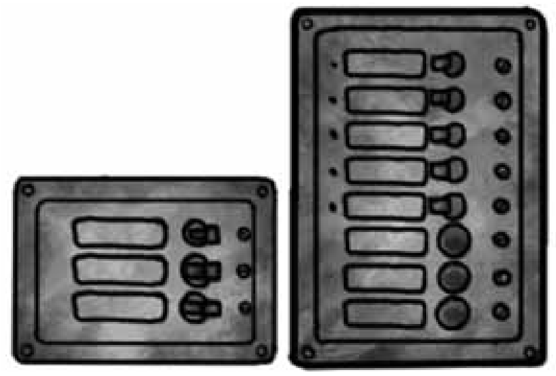


Image 10: Distribution board - AC breaker & Inverter AC Disconnect panel

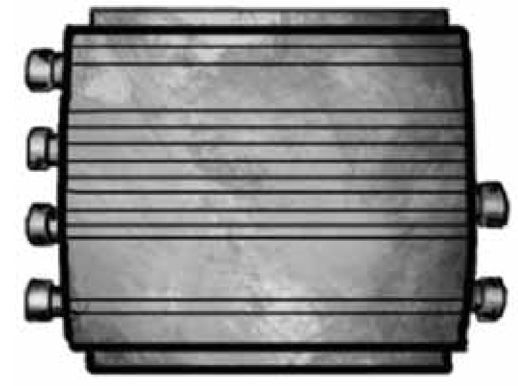


Image 11: Charge Controller

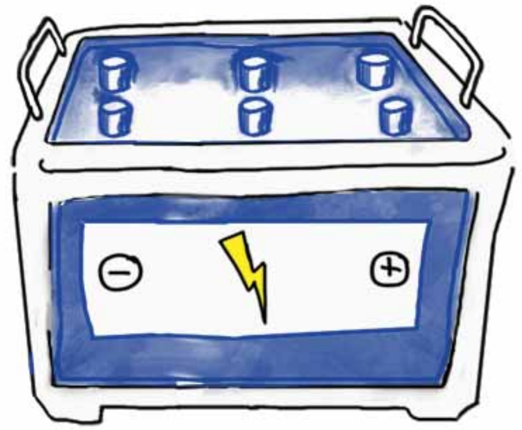


Image 12: PV Battery

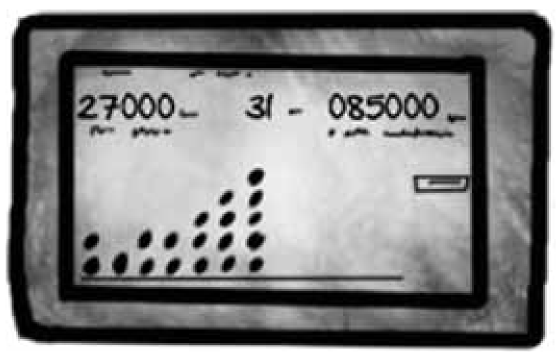


Image 13: System Meter

[39] http://www.freesunpower.com/chargecontrollers.php
[40] http://en.wikipedia.org/wiki/PV_module
[41] http://homepower.com/basics/solar/
[42] http://homepower.com/basics/solar/
[43] http://www.solardirect.com/pv/batteries/batteries.htm
[44] http://homepower.com/basics/solar/

2.14 PV SYSTEMS TYPES COMPARISON

Table 5. Comparison between different PV systems.

●●● High ●● Medium ● Low

Type	Stand Alone/ Off-Grid	Grid-Tied	Grid-Tied with Battery Backup
Complexity	Introduction of Batteries and backup generator increases complexity ●●	Less components in the system ●●●	Introduction of Batteries and backup generator increases complexity. Requires different inverter. ●
Maintenance	Batteries increase maintenance need. More than Grid-Tied but less than Grid-Tied with battery back-up. ●●	Less than the other systems. ●●●	Depending on batteries. More than other systems. ●
Life Span	Decreased due to batteries. ●●	Longer than other systems due to decreased complexity. ●●●	Decreased due to batteries. ●●
Energy/Economy	No utility bills. Increased cost of system. ●●●	Net metering allows financial gains from the energy utility if feed-in tariffs are possible. ●●●	Net metering allows financial gains from the energy utility if feed-in tariffs are possible. Increased cost of system. ●●
Autonomy	Autonomous System. If power from PV modules cannot produce enough power, batteries and backup generator cover the critical loads. ●●●	Relies upon grid. If grid fails, the system shuts down and energy produced is wasted. ●	Larger autonomy. If grid fails, backup power from batteries is used to cover critical loads. ●●●

2.1.5 BATTERY DESIGN CONSIDERATIONS & SIZING METHOD

1. BATTERY LIFE SPAN

Batteries are a very important component for the *Stand Alone/Off-Grid* and *Grid-Tied with Battery Backup System*, since they are the most effective method of storing the electricity generated by the PVs. The recommended type of battery for a PV system installation is the Deep cycle battery. This is due to the fact that they are designed to be discharged at low energy levels as well as for rapid charges and discharges. Factors such as charging methods, regulation voltage and temperature variations, affect the batteries performance and life span, and should be taken into consideration when designing the battery bank.

1.1 BATTERY CYCLE

The batteries in a Photovoltaic system should be designed to be shallow cycled, meaning a 10-20% discharge. This means that only this percentage should be drown from the batteries in a daily basis. This is done for 2 reasons:

1. In order to have enough capacity in them for covering the electricity load needs for a number of cloudy days.

2. To increase their lifespan. Batteries are an expensive component of the system and they should last as long as possible. The deeper the discharge of a battery, the fewer the cycles.

1.2 BATTERY TEMPERATURE

The temperature of the battery is a major factor in a PV system. Batteries general optimum operation temperature ranges close to 25°C. Their capacity is reduced in cold temperatures, and batteries can even be subjected to freezing when a temperature reaches a certain level. The battery life is also shortened in high temperatures. At higher temperatures, a battery will deliver more than its specified capacity by the manufacturer, but the rate of discharge is increased, and thus the battery' life is shortened. Batteries should be located in an insulated or other temperature-regulated enclosure to minimize battery temperature variations. This enclosure should be separated from controls or other PV system components for safety reasons. Adequate ventilation these enclosures is required, for the removal of toxic and explosive mixtures of gasses that may be produced by the batteries.

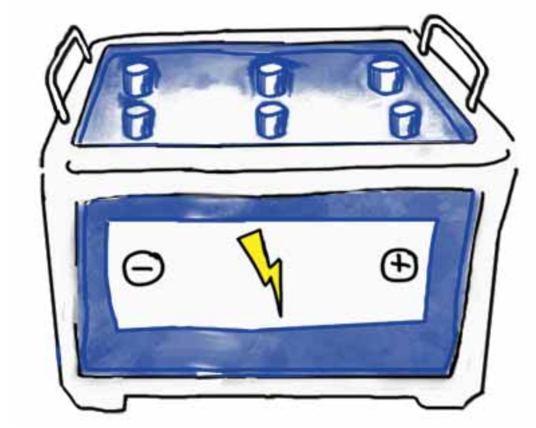


Image 14: Battery

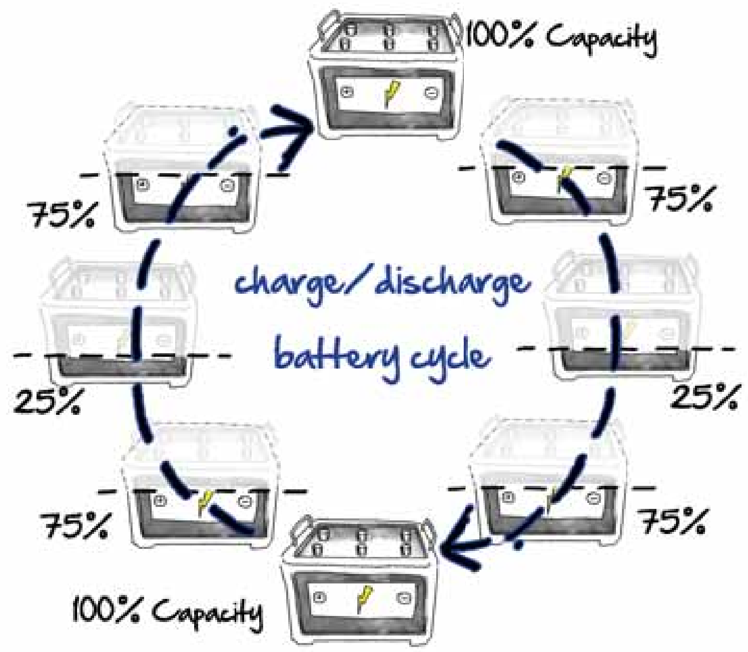


Image 15: Battery Charge/Discharge Cycle

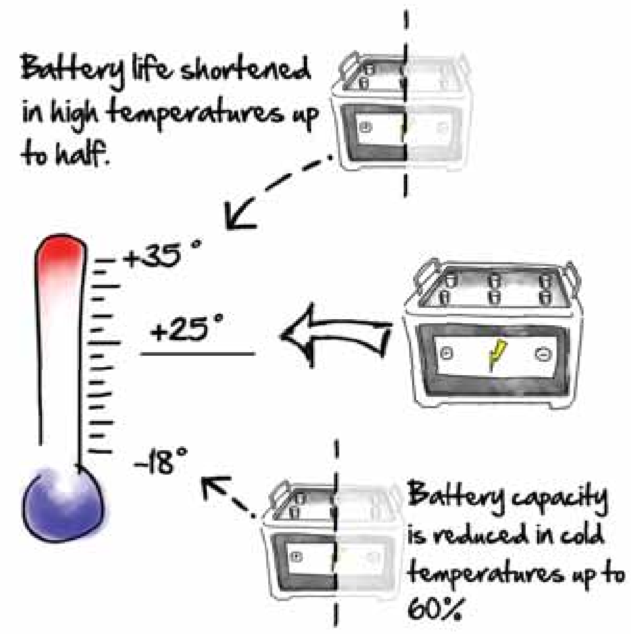


Image 16: Effects of temperature on batteries

2. BATTERY SIZING

Sizing the battery bank for the worst case is not only important for ensure that the PV system can cover the loads of the building under all conditions,but also because to increase the chances of minimizing the seasonal battery depth of discharge[45]. In terms of solar irradiation, the worst time period is December and January, when its value is at the lowest point. It is possible that in some instances, the worst case for the load is for the summer and the worst case for the resource is at the winter. In this case, two designs have to be performed and then the one that will carry the load during both summer and winter will be selected.

2.1 BATTERY CAPACITY INITIAL CALCULATION

The battery bank size is determined through the following steps:

1. Determine the total Watt-hours per day used by the households electrical appliances.

2. Divide the Watt-hours by the nominal battery voltage to get the required Amp-hour capacity of the battery. Battery Voltages vary from 12V to 24V

3. Multiply the unadjusted Amp-hours from step 2 with the days of autonomy.

4. Divide the Amp-hours from step 3 by the depth of discharge (0.2 for 20% discharge is recommended)

5. Add a design margin adjustment of 10% to 25% for uncertainties in the load determination, e.g., less-than-optimum load-operating conditions and load growth.

6. If Battery efficiency has not been a factor when determining the PV system power generation, divide the Amp-hours from step 6 by 0.85 (85%) for battery losses.

2.2 BATTERY SIZING CALCULATION EXAMPLE

Battery capacity (Amp-hour, Ah) [46]

$$= \left[\frac{\textbf{Total energy use per day x Day of autonomy}}{\textbf{Nominal battery voltage x Depth of discharge x Battery efficiency}}\right] + \textbf{Design margin}$$

Total energy use per day	= 1000 Wh/day
Days of autonomy	= 3 days (3-5 days recommended)
Nominal battery voltage	= 12 Volt
Depth of discharge	= 20% or 0.2
Battery efficiency	= 85% or 0.85
Design margin	= 10%

$$\text{Battery capacity (Ah)} = \left[\frac{1000(\text{Wh/day}) \times 3\ (\text{days})}{12\ (\text{V}) \times 0.2 \times 0.85}\right] + 10\%$$

$$= \left[\frac{3000}{2.04}\right] + 10\%$$

$$= 1470.6 + (\,1470.6 \times 10\%\,)$$

$$= 1470.6 + 147.06$$

$$= 1617.66\ \text{Ah}$$

Image 17: Rolls S12-290AGM Battery [47]

Product Example

Brand: Rolls
Model: S12-290AGM
Nominal voltage: 12V
Rated Capacity: 260Ah

Dimension

Total height: 224 mm
Height x Length x Width : 220 x 521 x 269 mm
Weight: Approx. 78.2 kg.

Using the specifications from the example battery product, we can determine how many batteries are required.

$$\text{Batteries required} = \frac{1617.66\ (\text{Ah})}{260\ (\text{Ah})}$$

$$= 6.22 \sim 7$$

[45] *Batteries and Charge Control in Stand-Alone Photovoltaic Systems Fundamentals and Application, Sandia National Laboratories 1997, p.18*
[46] *Sun Xtender Batteries Application Guide, http://www.sunxtender.com/*
[47] *http://www.rolls-battery.com*

2.2 CONTEXT

2.2.1 ELECTRICITY GENERATION RELATING FACTORS & LOCATION VARIABLES

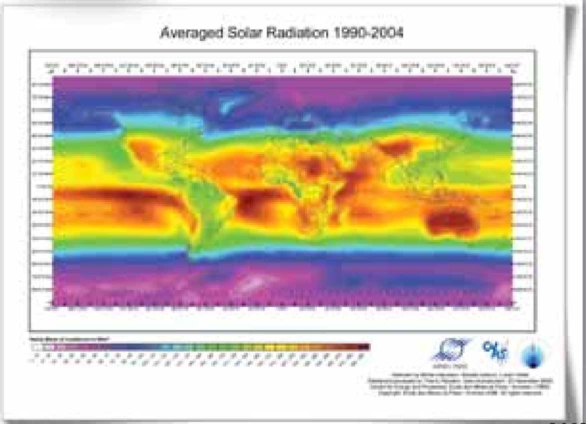


Image 18: Average Global Solar Radiation[49]

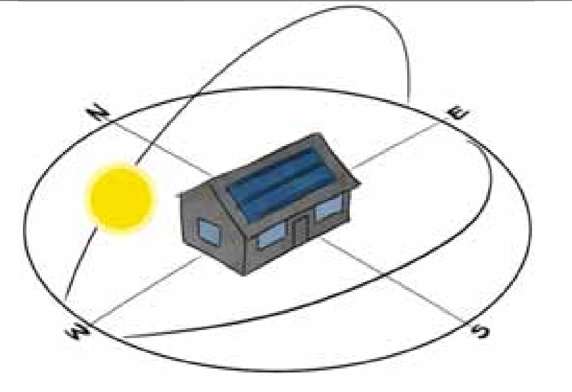


Image 19: Sun Angle and Orientation Angle

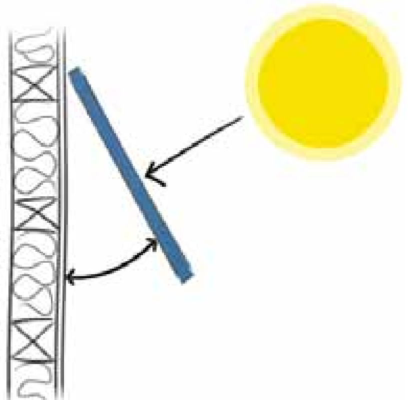


Image 20: Inclination Angle

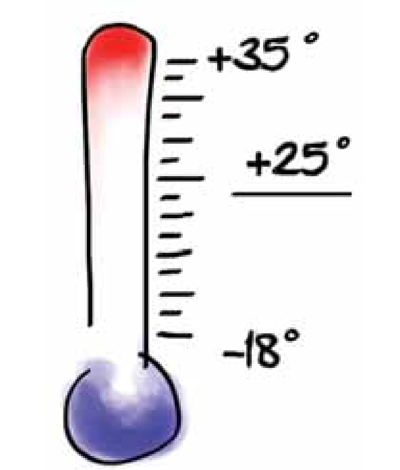


Image 21: Temperature

LOCATION

When designing a PV system, location is the key starting point. Climate information (sun angle, duration of day, ambient temperature), and site information and limitations/restrictions (shadow, site and building character, structure) derive from each specific location. These information are required for the integration and the calculations of the system.

Clear access to solar radiation is important for maximizing the PV systems' power generation potential. The surfaces selected for the PV modules integration should be unobstructed by other elements (trees, buildings, etc) due to the fact that shade can reduce, or even halt the power generation. Solar irradiation and surfaces-shadow studies have to be carried out, in order to get necessary figures for later calculations, as well as avoid selection of surfaces with low power generation potential, that would result only in the increase of the investment cost. The seasonal ambient temperature has to be researched as well, since it affects the efficiency of the PV modules. If the PV modules are overheated, their output potential can drop drastically. The operating temperature of the PV modules differs from the ambient temperature. The latter will be used for determining the temperature of the PV cells, a necessary step in the calculations stage. Standard Test Condition (STC) are used for the module power rating, and the temperature of 25°C that is specified for them may differ from the one on site.

PEAK SUN HOUR

The sunlight energy received expressed as the equivalent number of hours of 1kW/m^2 irradiance. If a location receives 7 kWh/m^2 over the course of a day, this would be expressed as 7 peak sun hours[48].

SOLAR IRRADIANCE

It is a measure of how much solar power you are getting at your location. It varies throughout the year depending on the seasons. It also varies throughout the day, depending on the position of the sun in the sky, and the weather.

Solar insolation is a measure of solar irradiance over of period of time - typically over the period of a single day.

SUN ANGLE

The angle which the sun rays reach the earths' surface varies according to latitude and longitude. This means that different locations have a different optimum installation angle for the PV modules.

ORIENTATION ANGLE

The angle of the PV modules relative to the direction due South (-90° is East, 0° is South and 90° is West). Different locations have different optimal values for inclination and orientation.

INCLINATION ANGLE

The angle of the PV modules from the horizontal plane, for a fixed (non-tracking) mounting. Affects PSH.

TEMPERATURE

Ambient (air) temperature is used during the PV System design stage and power generation calculations.

The operating temperature of the PV modules differs from the ambient temperature.

If the PV modules are integrated in such a manner that free flow of air at their back side is restricted, module temperatures will rise. Output of the PV array can drastically drop when temperature rises.

Standard Test Conditions (STC), of 25°C, and this may not be the case at the site.

[48] http://www.dkasolarcentre.com.au/go/how-pv-works/glossary
[49] http://www.soda-is.com/eng/map/maps_for_free.html

2.2.2 BUILDING INTEGRATION LIMITATIONS

BUILDING CHARACTER

One of the challenges of integration is the preservation of the buildings character. The difficulty level varies between different buildings. The design of the original architect should not be completely disregarded, since a considerable amount of energy has been devoted for each project. The highest level of difficulty is posed by historical buildings and settlements. The cultural and historical values of a buildings morphology must not be altered or downgraded by any integration.

STRUCTURE AND MATERIALS

The integration of PV modules will probably require the construction of new support structures. The latter may not be possible, due to increases of structural loads that can damage the existing buildings' structure and materials, and pose risks for the users. Furthermore, new materials proposed for an integration into an already existing structure should be in a harmonic relationship with the existing ones, increasing the architectural values in each case. The new structures should also have a character that can be easily identified as a new addition, without compromising the buildings unity.

BUILDING REGULATIONS

Possible restrictions from building codes and regulations may exist, not allowing the alteration of the buildings envelope. It is wise to contact the relevant buildings authorities and check if permission for this type of interventions can be given.

SOLAR ACCESS

The selected surface for the installation of the PV modules should have a clear solar access, in order to maximize the power generation efficiency of the modules. During the design process, be aware of elements, such as trees and surrounding buildings, that might shade the proposed installation. Also, try to anticipate future developments that might rise high enough to block the sun.

SHADING

Shading can decrease or even stop power generation (depending on the connection of PV modules). The general rule of thumb is to avoid any surfaces with shading, to maximize the PV array generation potential.

Image 18: Monument castle of San Giorgio, 2nd half of the 14th century, La Spezia, Italy [50].

Image 18 to 20: The varying building characters, structure and materials, and building regulations can set boundaries to what a PV integration may be like.

Image 20: Early 21st century house at Carmencitas Gata 13, Gothenburg, Sweden

Image 19: Early 20th century house at Skjutbanegatan 39A, Gothenburg, Sweden

[50] *Solar Design, Photovoltaics for Old Buildings, Urban Space, Landscapes, Ingrid Hermannsdorfer & Christine Rub, p92.*

2.3 ELECTRICITY USE IN THE HOUSE - CALCULATION

Calculating the electricity loads in the house is essential for sizing up the PV system. Knowing the annual electricity consumption of the household appliances makes obvious which ones are the most energy demanding and therefore the most responsible for increasing the electricity bills.

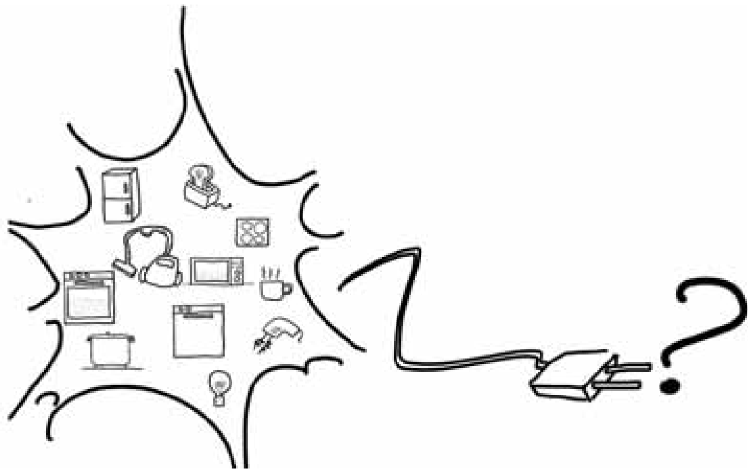


Table 6. Calculation example for electricity consumption

Area	Appliances	Brand/Model	No.	Electricity use (kW)	Usage	Usage Hour/year	Electricity use (kWh/year)
Kitchen	Refrigerator	Electrolux (A+) Inspire ERE38400	1	-	24 hr/day	8760	144
	Toaster	Philips Brödrost HD4816	1	0.8	1 hr/month	12	9.6
ETC.							

OR Ask for electricity bills and monitored consumption

The electricity consumption of electrical appliances can be calculated from the power rating and the usage time.
For example:

Toaster:	Philips HD4816
power rating=	80 Watts
Time usage =	1 hr/month

therefore, the electricity use per year is equal to:
80 x 1 (hr) x 12 (months) =960 Wh = 9.6 kWh/year

TIPS
Some manufacturers may provide the annual energy consumption of appliances in the technical specification or user manuals, such as refrigerators, some kitchen appliances and washing machines.

2.4 INTEGRATION POSSIBILITIES

2.4.1 INTEGRATION POSSIBILITIES

The study of various examples of BIPV projects process is used as a form of precedent studies. This step provides us with visual stimulants and allows us to identify a set number of potential integration approaches.

ROOF

The most common and "traditional" integration surface on a building of any type, since it is usually the most available surface for the PV array. Use of high efficiency PV modules, such as crystalline (CIS) and HIT, is probably the best practice. This is because of the higher gains in terms of solar irradiation, which can increase the energy output of the PV system. Roof integrations can have minimum impact on a buildings morphology. Factors such as load increase on the roof structure, snow loads on the PV modules, and access for servicing and cleaning have to be taken into consideration during the system design process.

examples:

- **Mont-Cenis Academy Herne Sodingen, Germany, Mono + Poly-crystalline silicon cells**
- **Solar Subway Station Hails, Eco-Transportation, New York, Thin-film**

examples:

Image 21: Exterior view of the Academy. Main Entrance

Roof integrated PV Mono + Polycrystalline silicon cells[51] [52]

- Mont-Cenis Academy – Herne Sodingen, Germany
- Location: Herne Sodingen, Ruhr, Germany.
- Feature: IBA-Emscherpark project.
- Purpose: Education centre and public buildings.
- Main Materials: timber, glass and concrete, all locally produced. The Mont Cenis academy building is a huge glass greenhouse structure that includes accommodation, classrooms, a cafeteria, and a library. Glass-glass Photovoltaic panels with crystalline panels makes up the whole envelope and overhang.
- Balance between day-lighting and incoming solar heat is maintained by the choice of different cell densities in the panels. Roof Cleaning System: automatic, employs recycled rainwater.
- 10.000 m2 PV modules providing 1MW Solar Power Generation. PV modules (mono & polycrystalline) provide shading and protect from glare and direct solar radiation.
- Density of PV cells/panel vary from 58 to 86% (energy production from 192-416 Wp/panel.
- Solar panels are also incorporated into the west facade of the envelope.
- 600 inverters transform DC current to AC which can be fed back to the general grid.
- Energy generated exceeds the required by the building itself (750,000 Kwh).
- PV system power: 1000 kWp
- Yield: 700 kWh / kWp

Image 22: Timber structure supporting the pv roof

Image 23: Interior view of the Academy. Interior courtyard

Roof integrated PV Thin-film[53]

- Solar Subway Station Hails,
  Eco-Transportation, New York
- The newly reconstructed Stillwell Avenue subway station in Brooklyn has become the city's very first solar-powered train terminal.
- The 76,000-square foot state-of-the-art PV roofing, produced by RWE SCHOTT Solar, is expected to contribute approximately 250,000 kWh/a. 12 months to the station's non-traction power needs.
- The solar panels produced by RWE SCHOTT Solar are the biggest thin- film panels within the world, requiring less framing to reduce set up costs. The partially transparent 5'x 20'glass laminate panels used in the station are created of transparent glass and strips of thin-film amorphous silicon material.
- The PV shed roofing enables 20-25% light transmission, helping to fulfil these requirements while reducing expenses for daytime lighting.

Image 24: Aerial view of the solar roof [53]

[51] http://www.akademie-mont-cenis.de/EN/index.html
[52] Green handbook for Photovoltaic (PV) System in Buildings, Building & Construction Authority, Singapore Government, 2006
[53] http://www.renewableenergyworld.com/rea/news/article/2005/06/solar-bipv-pulls-into-brooklyn-train-station-33583

FACADE

PV modules can be used as building envelope materials, second skin, and glazing elements. They can provide protection from rain for the existing exterior building materials, creating an extra layer which can also increase the thermal attributes of the building envelope. When used as glazing, modules with semi-transparency offer the most interesting possibilities. They can reduce excess sunlight and glare effects, as well as increase the variety in the relationship between interior and exterior. Thin film products are usually preferred over crystalline ones, due to their better performance with diffused light.

examples:

- **Solar-Fabrik AG, Germany, Monocrystalline silicon cells**
- **Tobias Grau GmbH head office building, Polycrystalline silicon cells**
- **Manchester College of Arts and Technology (MANCAT), Polycrystalline silicon cells**
- **Polycrystalline silicon cells**
- **Technium OpTIC St Asaph, North Wales, UK, Thin-film**

examples:

Facade integrated PV Monocrystalline silicon cells[54]

- Solar-Fabrik AG, Germany
- Twenty percent of the building's electrical power is supplied by solar modules.
- Photovoltaic has multiple functions. It is used to shade and prevent the glass-clad factory from overheating whilst generating electricity.
- It serves as a major architectural design element of the building as well as a showcase of the latest PV technologies of that time.
- PV area: 575 m2 PV system power: 56.5 kWp
- Estimated energy output:45,000.0 kWh / yr
- Yield:800 kWh / kWp

Image 25: The facade of Solar-Fabrik AG building in Germany [54]

Facade integrated PV ,Polycrystalline silicon cells[55]

- The lighting company,Tobias Grau GmbH head office building is closed towards to North with fully glazed, un-shaded, inward-sloped façade and towards the South with PV façade.
- The east and west elevations present curved glazed facades which are protected from the solar radiation by external, movable louvers, spanning 2.5m each.
- The vertical south façades of the two building together present an overall area of 179 m2 for PV integration.
- The cells have a 10 mm spacing so that the module let some natural daylight trough the façade with the cell acting as solar shading device.

Image 26: Manchester College of Arts and Technology [55]

[54] *Green handbook for Photovoltaic (PV) System in Buildings, Building & Construction Authority, Singapore Government, 2006*
[55] *http://www.brt.de/en/projects/nav/search/details/1/project/tobias-grau-lighting-hq-1/sword/tobias.html*

Facade integrated PV, Polycrystalline silicon cells[56]

- Manchester College of Arts and Technology (MANCAT)
- MANCAT demonstrates the potential of solar technology as a truly building integrated material and how it can help to “ reduce a building’s year-round energy demand.”
- The solar cladding also “reduces solar gain ” to the development helping to keep the building cool during summer months.
- Generates total electricity for 14 average three-bed houses each year.
- Generates enough electricity each year to light an average three-bed house for over 73 years.
- Generates enough electricity to make 1.6 million pieces of toast/2.3 million cups of tea every year.

Image 27: Manchester College of Arts and Technology [57]

Facade integrated PV, Thin-film[58] [59] [60] [61]

- Technium OpTIC (Opto-electronics Technology and Incubation Centre) St Asaph, North Wales, UK. The architects, Percy Thomas Partnership, used the PV to create a massive ‘solar wall’, curving from the roof line into an ornamental pool, which also collects rainwater run-off for use in the building and external irrigation systems. The Technium OpTIC building also features a Photovoltaic Wall which is the largest Copper Indium Diselenide (CIS) photovoltaic wall in Europe & the first of its kind in the UK.
- Capacity : 85 kWp
- Installed area : 1176 m^2
- Inverters: Siemens Sitop inverters
- cost of system: 360,000 €
- year of installation : 2003
- The 2400 panels are each 140 cm x 35 cm in size and were mounted in sub-arrays in the factory. These 400 sub-arrays were then transported to site and craned into position to create over 1000 m2 of solar facade on the southerly wall and roof of the building.

Image 28: Technium OpTIC solar facade[58] [61]

[56] http://www.solarcentury.co.uk/schools-public-sector/public-sector/manchester-college-of-arts-and-technology/
[57] http://www.design-buildsolar.com/projects/manchester_college_of_arts_and_technology/
[58] http://www.theplan.it/J/index.php?option=com_content&view=article&id=738:technium-optic-centre&Itemid=229&lang=en
[59] http://www.technium.co.uk/en/optic_technium.htm
[60] http://www.pvdatabase.org/projects_view_detailsmore.php?ID=213
[61] http://www.technium.co.uk/en/optic_pictures.htm

SHADING

Commercial shading PV products can be found in the market, making installation easier and possibly less costly. PV modules integrated as shading elements can be also considered as facade elements, and provide protection from excess light as well as glare. Products with a level of transparency can be a solution to the afore-mentioned issues, without cutting of the visual connection between interior and exterior.

examples:

- **Bayerische Landesbank, Munich, Germany, Polycrystalline silicon cells**
- **1600 PowerShade®, Monocrystalline silicon cells**
- **Clinical Molecular Biology Research Centre: Universit tsbauamt Erlangen, Erlangen, Germany, Polycrystalline silicon cells**

examples:

PV shading device, Polycrystalline silicon cells[62]

- Bayerische Landesbank, Munich, Germany (Commercial building)
- PV integration: Facade, canopy and shading device
- Type of PV cell technology: Poly-crystalline Silicon
- PV area: 538 m2
- PV system power:73.5 kWp
- The semi-transparent PV modules are integrated in different areas of the building; Canopy, facade and Sunshades


Image 29: Facade, canopy and shading device in Bayerische Landesbank, Munich, Germany [63]

PV shading device, Monocrystalline silicon cells[63]

- A pivot point allows the PV panels to be optimally positioned to maximize the generation of energy from the sun – 75 watts per day at peak performance.
- 1600 PowerShade® reduces solar heat gain on the glazing thus lowering building cooling costs.
- A function of the horizontal projection and height of the window, takes into account the shading effect thereby reducing the dependence on the glass coatings alone to manage.


Image 30: 1600 PowerShade® [62]

PV shading device, Polycrystalline silicon cells[64]

- Clinical Molecular Biology Research Centre : Universitätsbauamt Erlangen , Erlangen, Germany
- Building type: Institutional
- Type of PV integration: Shading device
- Type of PV cell technology: Poly-crystalline Silicon
- PV system power: 29.8 kWp
- SOLON AG für Solartechnik Fixed solar blind and Sun-tracking solar lamella were solutions to the challenge to combine improvedaesthetic solar building integration and a high power output.
- A total of 120 photovoltaic modules form a shady and translucent solar blind covering the glass facade, protect the southern areas of the building from direct sunlight.
- Linear motors move the 140 glass-glass modules, adapting them to the exterior lighting conditions.


Image 31: Shading device [64]

[62] *Green handbook for Photovoltaic (PV) System in Buildings, Building & Construction Authority, Singapore Government, 2006*
[63] *http://www.kawneer.com/kawneer/north_america/en/product.asp?prod_id=1850*
[64] *Green handbook for Photovoltaic (PV) System in Buildings, Building & Construction Authority, Singapore Government, 2006*

FREE STANDING

A free standing installation can perhaps offer the most flexible possibilities in terms of design morphology and function, like green houses, conservatories, exterior skins, power plants, or even pieces of art. The wide field of integration options is due to the lack of restrictions imposed by an existing structure. This also means that more energy is consumed in the installation process, since the supporting structure has to be new.

examples:

- **Streetlight tree outside Museum für Angewandte Kunst, Vienna (Austria), Monocrystalline silicon cells**
- **solar-power charging stations for electric cars, Monocrystalline silicon cells**
- **power generation system, Mindanao Island, in the Philippines, Monocrystalline silicon cells**
- **Vauxhall Cross bus station in London, UK, HIT cells**

examples:

PV free standing, Monocrystalline silicon cells

- Streetlight tree outside Museum für Angewandte Kunst, Vienna (Austria) [65] [66], image 32.

Image 32

- Reno Contracting and Envision Solar team up for solar-power charging stations for electric cars [67], image 33.

Image 33

- 1-MW PV power generation system commissioned for the Cagayan de Oro Electric Power and Light Company, Mindanao Island, in the Philippines[68], image 34.

Image 34

- street light[66], image 35.
- system requirements
  a) solar PV module
  b) boxed battery
  c) change controller c/w inverter
  d) lamp fixture installed on
  e) support post.
- The system is designed so as to allow electricity produced by the PV panel
- Lit the lamp for a maximum period of 12 hours/day.
- Controlled by an automatic ON/OFF

Image 35

[65] http://www.elren.net/Technologies/Solarenergy/SolarPV/tabid/254/Default.aspx
[66] http://hg.hu/cikk/epiteszet/2976-lovegrove-s-solar-tree-in-vienna
[67] http://www.pv-tech.org
[68] http://www.irradiance.com/philippine.html

PV free standing, HIT cells[69]

- Vauxhall Cross bus station in London
- The interchange has a photovoltaic array incorporated into a canopy which provides shelter to the bus station. The canopy takes the form of a sculptural ribbon running the length of the bus station, with PV installed on the upper surface of the cantilevered ends.
- Total area of PV 198 m2
- Peak output: 30.24 kWp
- Type of PV: Sanyo HIP-H54B Hybrid silicon modules
- Annual energy production: 23.76 MWh
- 68 photovoltaic modules are fitted to the top of the cantilevered arms of the roof. Generating around 23,000 kWh of energy per year, they provide around 30% of the bus station's annual electricity requirement.
- The PV system provides up to 30 % of the energy required to power the bus station area over the course of the year.


Image 36: Vauxhall Cross bus station in London [70]

Image 37: Vauxhall Cross bus station PV installation by Solarcentury.co.uk [71]

[69] PV42p © Energy Saving Trust November 2006. E&OE
[70] The Arup Journal 3/2005
[71] http://www.solarcentury.co.uk/media/picture-library/solar-projects/solar-generator-london-vauxhall-cross/

HISTORICAL BUILDINGS

The most challenging of all integration approaches, due to the cultural and historical values of the buildings morphology, as well as possible restrictions from building codes and regulations. Special care has to be given, in order to leave the buildings character intact. Integrations of this short can be more pedagogical and informative than others, since these buildings are usually carriers of collective memories, and therefore can be seen as examples of building and society standards.

examples:

- **Academy Building Alter Klosterhof , Meißen, Germany, Monocrystalline silicon cells**
- **Solar Information Board, La Spezia, Italy, Thin-film**

examples:

Integration in Historical Buildings, Monocrystalline silicon cells[72] [73]

- Academy Building “Alter Klosterhof”, Meißen, Germany
- Location: Meißen, Germany
- 13th century Augustian monastery of St. Afra
- Renovation project, currently conference & meeting place for the Lutheran Academy with accommodations & catering facilities.
- Particular interest due to historical value
- Grid-connected PV system.
- Mounted on glass structure over new stair tower.
- Modules: 24 semitransparent.
- Module Size: 0.68m x 1.30m.
- Black monocrystalline silicon cells, 10cm x 10cm
- Incline: 8o for both light and shade.
- Energy output: 2.76kWp
- Area: 21m2


Image 38: PV installation above the Alter Klosterhof staircase [73]


Image 39: PV installation above the Alter Klosterhof staircase [72]

Image 41: Screen-printing Solar Information Board [75]

Integration in Historical Buildings, Thin film[74] [75]

- Solar Information Board, La Spezia, Italy
- Location: La Spezia, Italy
- Installation on monument castle San Giorgio, house of archaeological museum.
- Replacement of original info banner, located next to the entrance.
- Screen-printing of even matrix of dots
- use of weather resistant ceramic color
- First application of idea developed by PVACCEPT
- Modules: 6 x 1.20m x 1.20m
- Technology: Thin-film
- Installation size: 2.40m x 3.60m
- Custom-made support system (steel and aluminium)
- Power generated used to illuminate the banner during night.
- Energy output: 720 Wp
- Energy yield: 350 kWh/a
- Area: 8.6m2


Image 40: Screen-printing Solar Information Board [75]

Image 42: Screen-printing Solar Information Board [75]

[72] *Solar Design, Photovoltaics for Old Buildings, Urban Space, Landscapes, Ingrid Hermannsdorfer & Christine Rub, p64*
[73] *http://www.pfauarchitekten.de/templates/pfau-project-detail.php?vars=39|projekte_2004|11*
[74] *http://www.pvaccept.de/eng/*
[75] *Solar Design, Photovoltaics for Old Buildings, Urban Space, Landscapes, Ingrid Hermannsdorfer & Christine Rub, p92.*

24.2 PHOTOVOLTAIC MODULE - MANUFACTURER DATA SHEET

Data sheet
In order to calculate the power generation of a PV module, information provided by the manufacturers data sheets (Figure 10, page 55) must be used in conjunction with site specific environmental data (ambient temperature and solar irradiation). PV module data sheets include a number of specification, which are explained in this chapter[76] [77].

STC
STC: PV modules are tested and rated under Standard Test Conditions (STC), in order for making different modules/types comparison possible. STC are at solar irradiance of 1000 W/m2 and cell temperature of 25oC. One site conditions can and will vary from STC in terms of irradiance and temperature, affecting the PV module power generation. STC is used for comparison reasons between different types of PV modules.

Maximum Power (Pmax), rated at STC (Watts)
The module power rated under STC conditions.

Rated Output Power Tolerance (%)
Rated Power Tolerance refers to the potential range of under-performance or over-performance under STC. For Example: Product X has a rated power 100W and a tolerance of +-5%. The actual power rating can be 95W or 105W.
Because modules are often rated in small increments, it is not uncommon for modules that fall under the lower power tolerance of the next model to be rated as a higher wattage module. Case in point: A module with a +/-5% power tolerance rating that produces 181 W during the factory testing process could be classified as a 190 W module, as opposed to a 180 W module. For maximum production, look for modules with a small negative (or positive only) power tolerance.

Rated Power Per Square Meter (Watts)
This power output, also referred to as “power density”, is given by the division of the module’s rated power (at STC) by the module’s area in square meters (m2). Using modules of higher power densities means decreased area requirements for production of electricity[78].

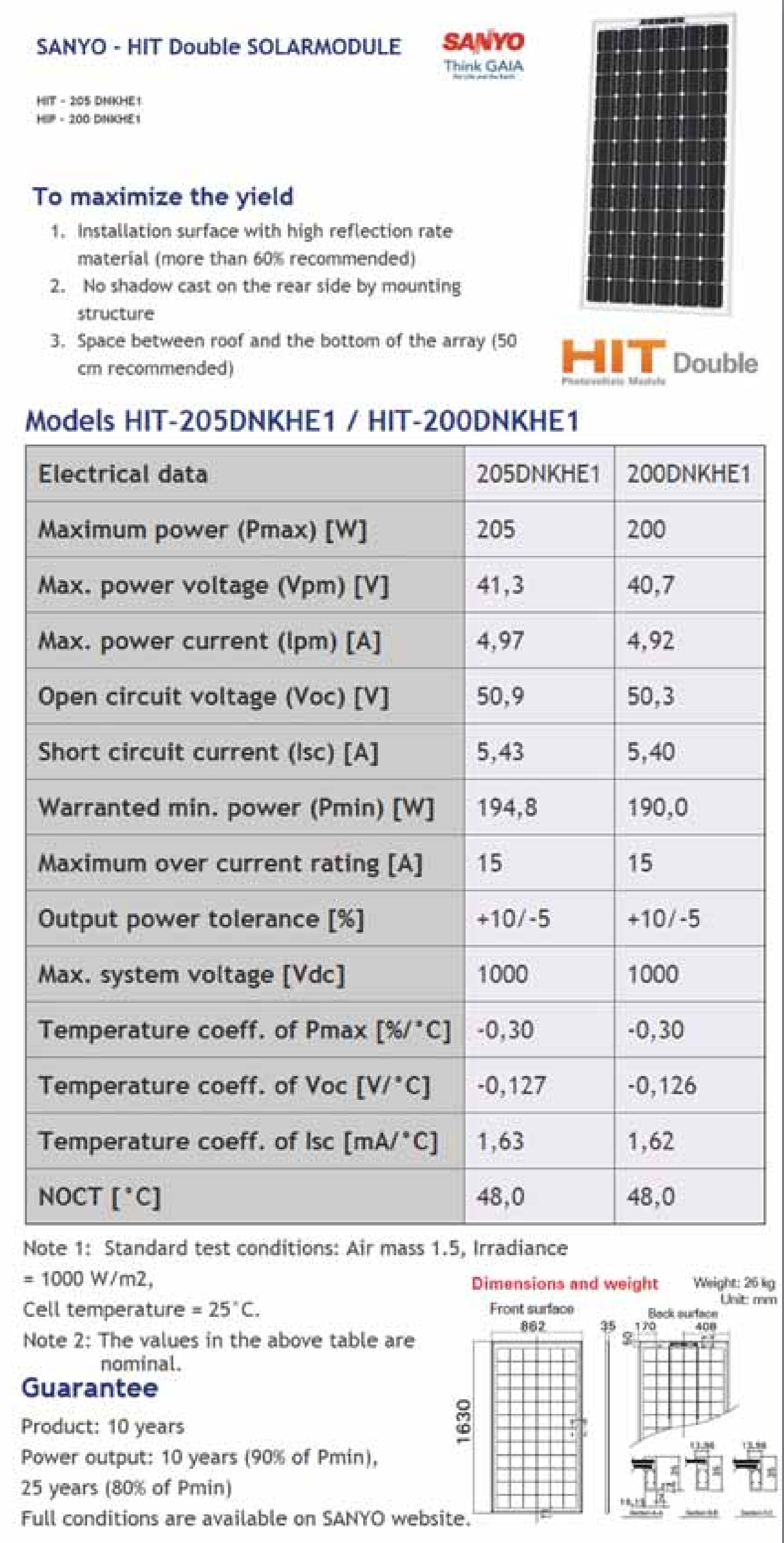
Module Efficiency (%)
The ratio of conversion of photons (input power) to DC electricity (output power) by the PV module. Higher efficiency values mean more electricity produced in a given space.
i.e. If a PV module with an area of 1m^2 generates 100W under 1000W of solar irradiation, it has an efficiency of 10%.

Series Fuse Rating (Amps)
A series fuse protects PV modules from overcurrent, in fault conditions (i.e. back-fed apms from paralleled modules or paralleled strings of modules). It is located in either a combiner box or in some batteryless inverters. The series fuse is not required if its specification is substantially higher than the module’s ISC (short circuit current.

Connector Type
The module output terminal or cable/connector configuration. Most PV modules come with “plug and play” connectors. For this reason, latest connector models are lockable, preventing untrained persons from “unplugging” the PV modules.

Materials Warranty (Years)
Refers to the limited warranty given by the manufacturers regarding the module’s materials and quality under normal application, installation, use and service conditions.

Power Warranty (Years)
Warranty given by the manufacturer regarding the power output of the module, based on the minimum peak power under STC multiplied by the efficiency factor for a certain period of time (usually 90% for the first 10 years and 80% for the next 10).


SANYO - HIT Double SOLARMODULE

HIT - 205 DNKHE1
HIP - 200 DNKHE1

To maximize the yield
1. Installation surface with high reflection rate material (more than 60% recommended)
2. No shadow cast on the rear side by mounting structure
3. Space between roof and the bottom of the array (50 cm recommended)

Models HIT-205DNKHE1 / HIT-200DNKHE1

Electrical data	205DNKHE1	200DNKHE1
Maximum power (Pmax) [W]	205	200
Max. power voltage (Vpm) [V]	41,3	40,7
Max. power current (Ipm) [A]	4,97	4,92
Open circuit voltage (Voc) [V]	50,9	50,3
Short circuit current (Isc) [A]	5,43	5,40
Warranted min. power (Pmin) [W]	194,8	190,0
Maximum over current rating [A]	15	15
Output power tolerance [%]	+10/-5	+10/-5
Max. system voltage [Vdc]	1000	1000
Temperature coeff. of Pmax [%/°C]	-0,30	-0,30
Temperature coeff. of Voc [V/°C]	-0,127	-0,126
Temperature coeff. of Isc [mA/°C]	1,63	1,62
NOCT [°C]	48,0	48,0

Note 1: Standard test conditions: Air mass 1.5, Irradiance = 1000 W/m2,
Cell temperature = 25°C.
Note 2: The values in the above table are nominal.

Guarantee
Product: 10 years
Power output: 10 years (90% of Pmin),
25 years (80% of Pmin)
Full conditions are available on SANYO website.

Figure 10: SANYO - HIT Double SOLARMODULE

[76] PV Module Buyers Guide Spec Details, http://homepower.com/home/
[77] http://www.posharp.com/photovoltaic/panelefficiency/database.aspx
[78] PV Module Buyers Guide Spec Details, http://homepower.com/home/

Cell Type
PV cells can be manufactured by different materials (silicon, organic, etc). The material used, as specified by the manufacturer, defines the type of cell.

Cells in Series
Crystalline panels are formed by individual PV cells wired in series. The modules design voltage is determined by the number of cells (usually 36 or 72). When batteries are part of the PV system, their voltage rating must be matched by the one of the PV modules. Modules with 36 cells are used for a 12V battery system, and 72 cell modules for a 24V battery system. If an inverter with a maximum power point tracking system is used, modules with different number of cells can be used, without having an effect on the batteries.

Maximum Power Voltage (Vpm) (Volts)
The maximum voltage that the PV module is generating when exposed to sunlight and connected to a load, such as an inverter or a charge controller and a battery. It is determined under STC and it directly affected by the PV module temperature. Vmp is important for correctly sizing an array to an inverter or controller.

Maximum Power Current (Ipm) (Amps)
The maximum amperage where a panel outputs the maximum power when exposed to sunlight and connected to a load. Maximum power current is used in array and charge controller sizing calculations for battery-based PV systems.

Open-Circuit Voltage (Voc) (Volts)
The maximum voltage that the PV module is generating when exposed to sunlight, without being connected to a load. It is dependent to air temperature (the lower the temperature the higher the voltage) and must be shown on the PV disconnect label. A PV array may operate close to open circuit current under low light conditions. Because all major PV system components are rated to handle a maximum voltage, Voc is used in conjunction with historic low temperature data to calculate the highest maximum system voltage.

Cells in Series
Crystalline panels are formed by individual PV cells wired in series. The modules design voltage is determined by the number of cells (usually 36 or 72). When batteries are part of the PV system, their voltage rating must be matched by the one of the PV modules. Modules with 36 cells are used for a 12V battery system, and 72 cell modules for a 24V battery system. If an inverter with a maximum power point tracking system is used, modules with different number of cells can be used, without having an effect on the batteries.

Short-Circuit Current (Isc) (Amps)
Short-circuit current is the amperage generated by a PV module or array when exposed to sunlight and with the output terminals shorted. It must be listed on the PV systems disconnect panel. Calculations of the PV circuit's wire size and overcurrent protection (fuses and circuit breakers) are based on the module/array short-circuit current.

Maximum Power Temperature Coefficient (%/°C)
The panel output power change for temperatures other than 25°C (STC conditions), in percent of change per degree Celsius, used for calculating module power changes (gains or losses) due to temperature changes. In hot climates, cell temperatures can reach an excess of 70°C.

i.e. Module maximum power rating = 200W (at STC),
Temperature Coefficient = -0.5%/°C.
At 70°C, the actual output of this panel would be approximately 155W.

Lower power temperature coefficients mean better performances in higher-temperature conditions. Thin-film panels have relatively low temperature coefficients which reflects better high-temperature performance.

Open-Circuit Voltage Temperature Coefficient (mV/°C)
Open-circuit voltage changes expressed as millivolts per degree Celsius, percentage per degree Celsius, or volts per degree Celsius, at temperatures different than STC (25°C). It is used in conjunction with the Open-circuit Voltage to calculate the maximum PV system voltage, for system design and labelling purposes.

i.e. Series string of ten 43.6 V (Voc) modules
Site record low of -10°C
Voc temperature coefficient = -160mV/°C
Then the rise in voltage per module will be
[-160 mV/°C x (-10°C – 25°C)] = 5,600mV,

making for an overall maximum system voltage of
[10 x (5.6 V + 43.6V)] = 492 V

Short-Circuit Current Temperature Coefficient (mA/°C)
The change in panel short-circuit current per degree Celsius at temperatures other than 25°C. It is most commonly used to calculate maximum system current (per NEC Article 690.7) for system design and labelling purposes. For example, consider a series string of ten 8A (Isc) panels installed at a site with a record low of 15°C. Given a Isc temperature coefficient 0.04%/°C), the decrease in current will be 0.32A, making for an overall maximum system current of 7.68A.

Nominal Operating Cell Temperature (NOCT)
NOCT is the module temperature, given at an irradiance of 800W/m2 and an ambient (air) temperature of 20oC. It is used in conjunction with the maximum power temperature coefficient to get a better real-world estimate of temperature related power loss. Differences between cell and ambient temperature are dependent to sunlight intensity in W/m2. Real condition differ from STC. The standard of 800W/m2 is used for this reason, instead of 1000W/m2, which is considered full sun.

24.3 PV SYSTEM OUTPUT CALCULATION METHODS

Calculation Method Basis

A large portion of the time for the thesis was devoted in understanding the mechanics of calculating the efficiency and the power production for photovoltaics. Although a large amount of literature was studied, the calculation method was based on the NABCEP Study Guide for Photovoltaic System Installers Version 4.2[79], T. Markvart and Luis Castaners' book *Practical Handbook of Photovoltaics: Fundamentals and Applications*[80], and Californian Energy Commission *A Guide to Photovoltaic (PV) System Design and Installation*[81]. The calculation method is as follows:

ELECTRICITY GENERATED BY THE PV SYSTEM (1 panel / 1 day)

= PV'S POWER RATING(W) X PV'S EFFICIENCY(%) X BATTERIES EFFICIENCY(%) X WIRE EFFICIENCY(%) X INVERTER EFFICIENCY(%) X PSH

= PMAX (WATTS) x PV'S EFFICIENCY(%) x 85(%) x 97(%) x 95(%) x PSH

- **PV POWER RATING(PMAX) = Given by manufacturer data sheet**
- **PV'S EFFICIENCY(%) = 100(%) X Tolerance/Dust/Mismatches efficiency factor(%)¹ x (PV module) Heat Losses efficiency factor(%)²**

> **1. Efficiency factor for module tolerance, mismatches and dust degradation = 90%**
>
> **2. Heat Losses efficiency factor(%) =**
> **100% - Heat Losses from Temp. Degradation(%)**
> **2.1 Heat Losses from Temperature Degradation =**
> **(Tc-25) x Temperature coefficient (%)**
>
> *** Tc = TA(°C) + [(NOCT-20/800) x G] ,G (irradiance) is given in W/m², and NOCT in °C**
> **Tc = PV Cell Temperature in TA condition (°C)**
> **TA= Ambient temperature (°C)**

- **BATTERIES EFFICIENCY(%) = 85% (loss 15%) (Most efficient products: The highest efficiency)**
  (do not take in an account in case of Grid-tied system)
- **WIRE EFFICIENCY(%) = The wiring losses in the best situation ≤ 3% ,Efficiency factor=97%**
- **INVERTER EFFICIENCY(%) = Inverter efficiency = 85-95%, Most efficient products= 95%**
- **PSH = PEAK SUN HOUR**

[79] *NABCEP Study Guide for Photovoltaic System Installers Version 4.2, 2009, p44*
[80] *Practical Handbook of Photovoltaics: fundamental and applications, T. Markvart & Luis Castaner, p544*
[81] *A Guide to Photovoltaic (PV) System Design and Installation, California Energy Commission, 2001*

CALCULATION EXAMPLE

FIND IN PV DATA SHEET

PRODUCT DETAILS	Type of PV: HIT Double cell Name of Product: Sanyo HIT-205DNKHE1 Double NOCT: 48°C Pmax (Front surface):205W Pmax (Back surface): 143W Temperature coefficient [%/ °C]= 0.3%/ °C

DEPEND ON SPECIFIC LOCATION

LOCAL CLIMATE SPECIFICATIONS	Summer (June-August) 92 days Ambient temperature(TA) =20°c Location: Gothenburg Sweden Installation: East facade Orientation 90° PSH 2.9 G=350W/m²

CALCULATIONS - 5 steps

1
Tc = TA(°C) + [(NOCT-20/800) x G]
= 20°C + [(48-20/800) x 350]
Tc = 32.38 °C

2
Heat losses from temperature degradation =
(Tc-25) x Temperature coefficient(%)
= (32.38-25) °C X 0.3%/ °C
= 0.022%

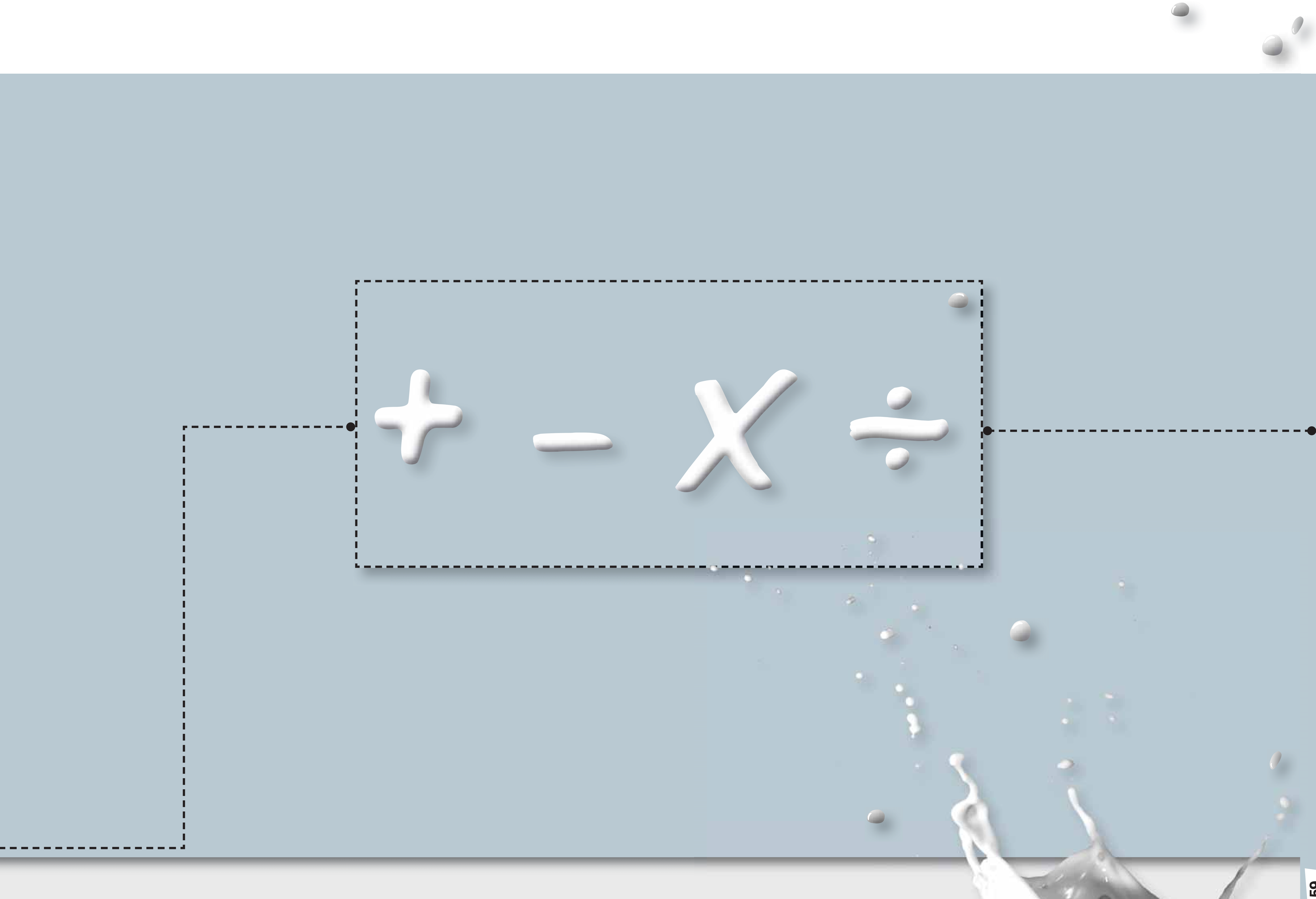
3
Heat losses efficiency factor(%)
= 100% -Heat Losses from Temp. Degradation(%)
= 100% - 0.022%
= 97.8%

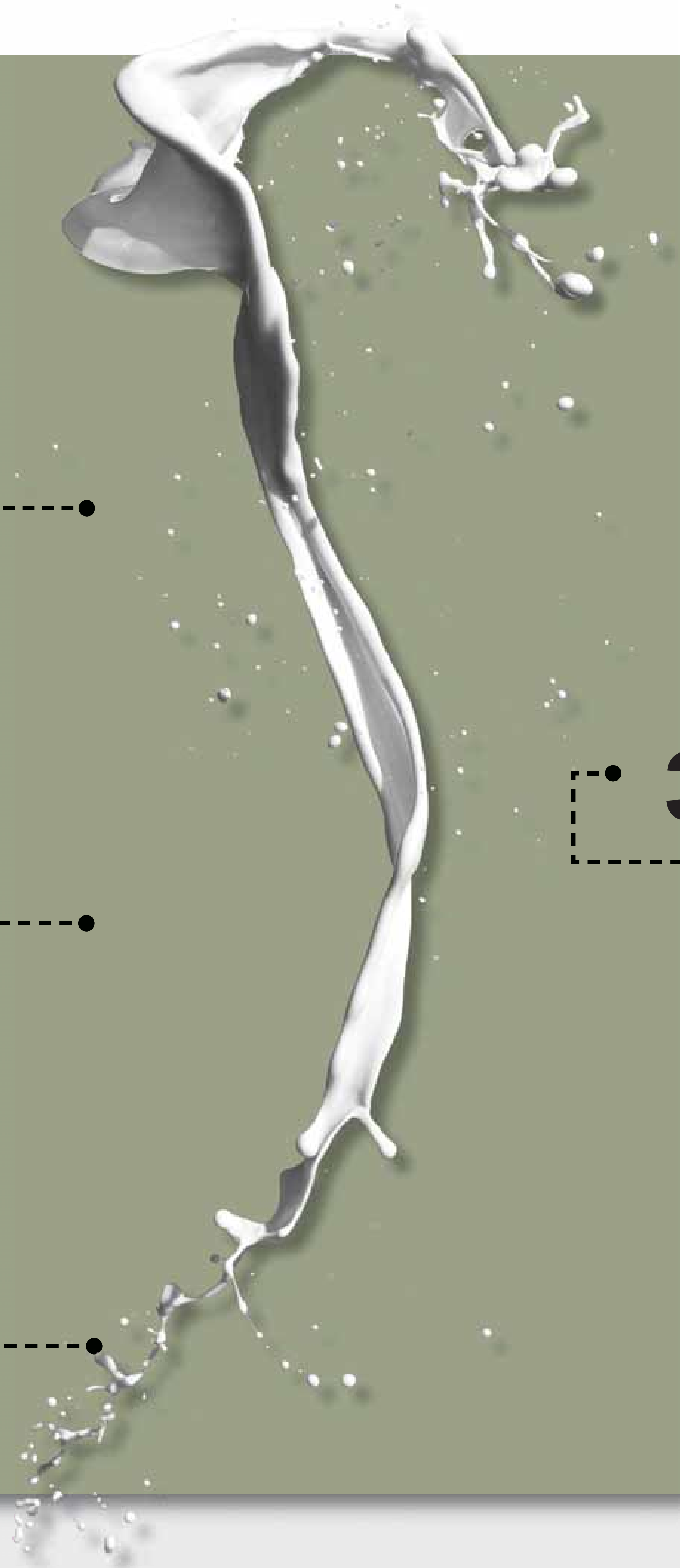
4
PV's efficiency(%) = 100(%) x Tolerance/Dust/Mismatches efficiency factor(%)
x (PV module) Heat Losses efficiency factor(%)
= 100% x 90% x 97.8% = 88%

5
= PV's Power rating(W) x Pv's efficiency(%) x Batteries efficiency(%)
x Wire efficiency(%) x Inverter efficiency(%) x PSH
= 205(W) x 88% x 85% x 97.8% x 95% x 2.9
= 409.78 Wh/day ~ 0.41 kWh/day
In summer produce = 0.41 x92(day)
= 37.72 kWh

PV ELECTRICITY PRODUCTION

If our consumption is 1000 kWh, it means we need (1000/37.72=26.5)
27 panels of installed on the East facade.
= 37.94 m² installation area needed





3. ANALYSIS

3.1 AREA LOCATION & CHARACTERISTICS

The analysis of the specific unit had as a starting point a visit to the site, where an interview with the owners took place. A number of questions was presented to them regarding uses of spaces, home appliances and patters of use related with the latter. In a second stage, a questionnaire was formed, to provide additional data.

The selected site is located in the city of Gothenburg, in the Eriksberg area, at Carmencitas gata 13, LGH 66-C4. This is an area with a purely residential character, comprised by building blocks of three story single family row houses, with exposed facades/surfaces mainly at the East and West. This means that the orientation angles are -90° (East), and 90° (West). The Building is located at row 11, and differs from most of the other houses, due to the fact of having a North facade as well. The exterior surfaces of the buildings are constructed from a layer of bricks with white color finish, while the structural elements are made from wood and concrete. Small parts like the storage rooms differ, having a dark grey colored wood finish. Window frames are also in dark coloration. The volumes are cubic, and in conjunction with the simplicity of the morphology, they result in a uniform character for the whole area (images 44 to 47, page 65).

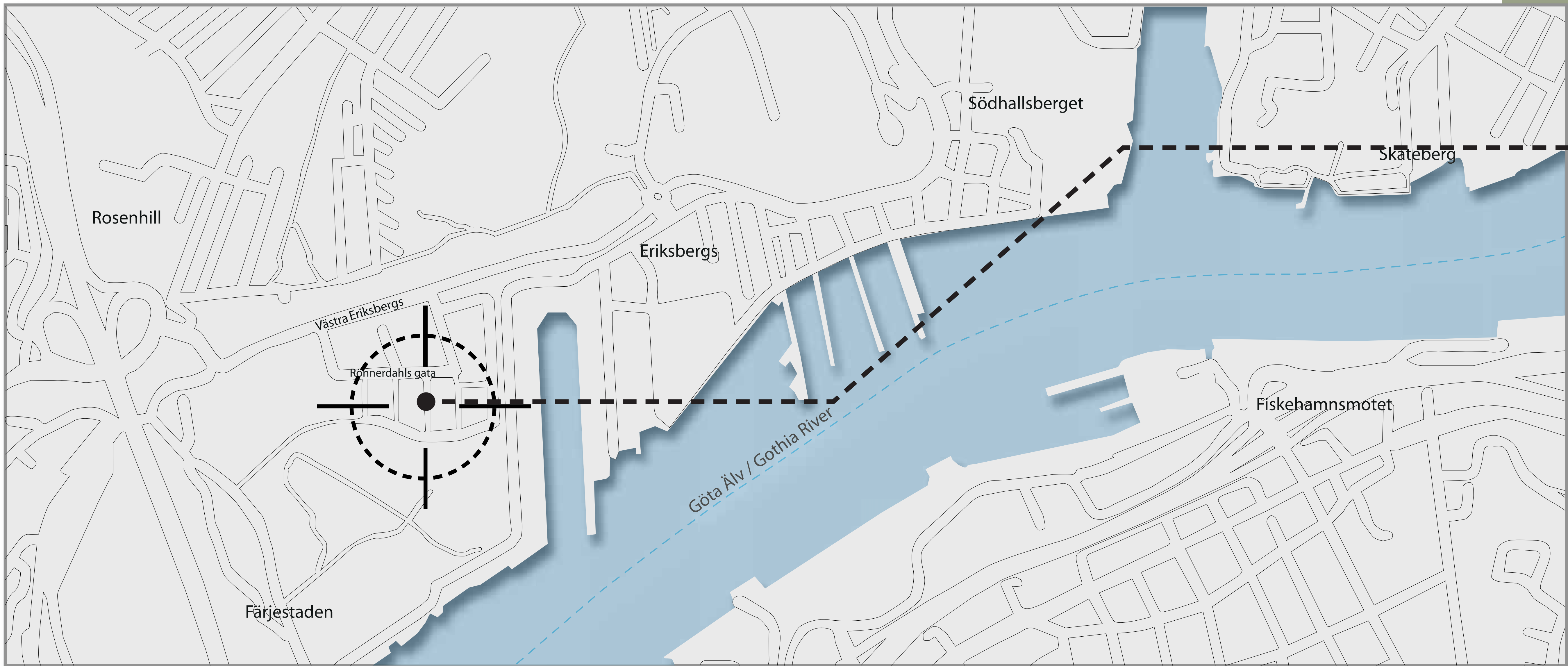


Image 43: Location map of area and building under study

MASTER PLAN / ELEVATIONS

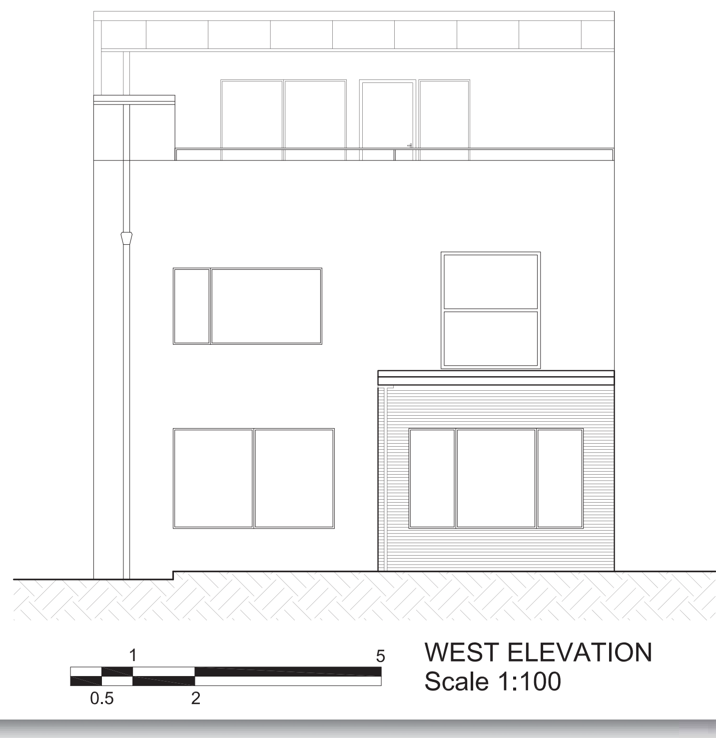
MASTER PLAN - CURRENT STATE
Scale 1:750

Carmentcitas gata 13, LGH 66-C4, row 11

Facade Material:	Brick
Color Tones:	White, Carbon
Volumes:	Cubic

Uniform character & morphology

EAST ELEVATION
Scale 1:100



WEST ELEVATION
Scale 1:100

EXISTING CONDITION

Image 44: North view of Carmencitas Gata

Image 45: South view of Carmencitas Gata

Image 46: East Facade - Main Entrance

Image 47: West Facade - Back yard

3.2 FUNCTIONS ANALYSIS

Through our interview with the owners, patterns of use for both spaces and appliances where made clear. The family members, comprised by two working parents and two young children, spends most of their time at the 1st level of the house. The most used space of the house is the living room area, while the least used appears to be the kitchen. The owner stated that due to the extended glazing towards the facade, there is an issue of glare during the evening hours. The third level of the house is consisted by a single room used as an entertainment/leisure area. The family enjoys spending time at the west terrace of this level during summer where they entertain friends or simply relax. This level, with openings to the east and a large mostly glazed west facade is overheated during the hottest months, and glare is a large issue. Sweden has extended daylight periods during spring and mostly summer. This means that the areas facing the west, being the most used during evening hours, are overexposed to the brightness of the sun, leading to visual discomfort for the users.

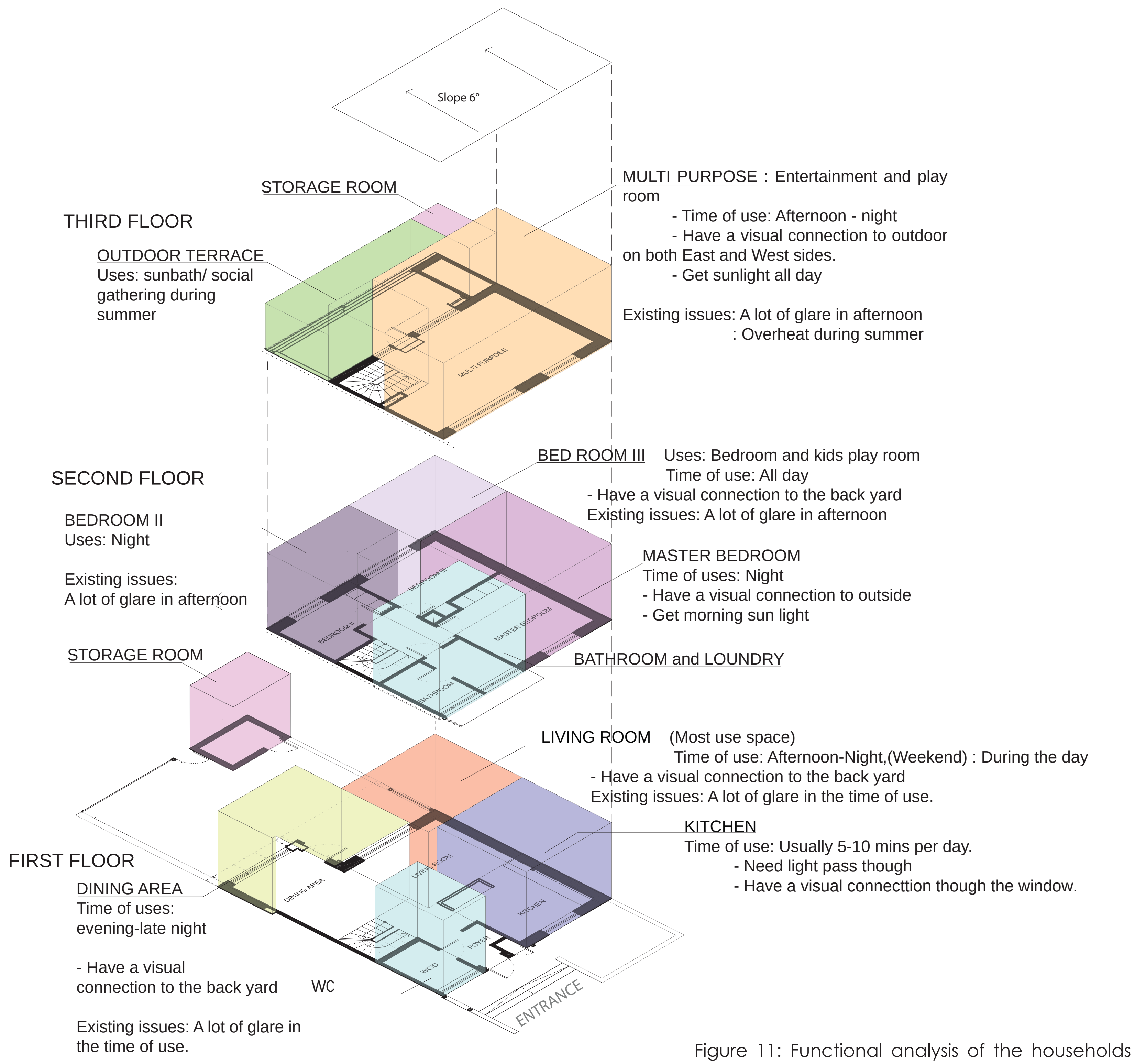


Figure 11: Functional analysis of the households existing condition. Autocad & Adobe Illustrator.

3.3 HOUSEHOLD ELECTRICITY CONSUMPTION

ELECTRICITY CONSUMPTION PER FUNCTIONAL AREA

In order to design a PV system, the electricity load must be determined. This will dictate the size of the system, and in a later stage, whether we can or not cover this load.

A questionnaire was given to the house owners, in the form of a list sheet, in order for the owners to describe the appliances types, product numbers, quantities in the house, and time of use. From here, the electricity load was calculated as seen in table 7 & 8 (page 69 and 70).

Electrical appliances								
Area	Product details							
	Brand	Model	Elec.(kW)	No.	Usage	mins/ year	Hour/year	Elec.use/year(KWh)
Kitchen								
Refrigerator	Electrolux (A+)	Inspire, ERE38400		1	24 hr/day		8760	144
Freezer	Electrolux(A)	Inspire, EUF29400		1	24 hr/day		8760	331
Microwave	Whirlpool	m24	0,7	1	5 mins/day	1825	30	21,3
Oven	Electrolux (A)	EOB64140	2,4	1	1 hr/week	3120	52	124,8
Fan (cooking)	Franke	F 215	0,07	1	1 hr/week	3120	52	3,64
Cooking (induction)	Electrolux	EHD60020P	1,4	1	10 hr/week	31200	520	728
Dishwasher	Electrolux(A)	ESL 68040	0,525	1	8 hr/week	24960	416	218,4
Toaster	Philips Brödrost	HD4816	0,8	1	1 hr/month		12	9,6
Percolator	C3	30-33610	0,875	1	1 hr/ week	3120	52	45,5
Espresso machine	Saeco	Aroma	1,25	1	≤30 mins/week	1560	26	32,5
Sum								**1658,73**
Laundry/cleaning								
Washing machine	Electrolux	EWF 12070 W	1,02	1	10 hr/week	31200	520	530,5
Dryer	Electrolux	EDD 2400	4,1	1	2 hr/week	6240	104	426,4
Vacuum cleaner	Electrolux	Ergo Rapido	0,05	1	2 hr/week		24	1,2
Vacuum cleaner	Volta lite	U 1840	1,6	1	1 hr/month		12	19,2
Sum								**977,2**
Entertainment								
TV	Philips	42PFL7665H/12		1				
		(ON mode)	0,091		35 hr/week	109200	1820	165,62
		(OFF mode)	0,00001		133 hr/week	414690	6916	0,06916
HD-TV Digital box	Canal Digital	HD104-C, Canal Digital		1				
		(ON mode)	0,035		35 hr/week	109200	1820	63,7
		(OFF mode)	0,007		133 hr/week	414690	6916	48,412
DVD Player	Philips	DVP 5960	-	1	-	-	-	-
Video player	Philips	VR607		1				
		(ON mode)	0,0137		1 hr/week	3120	52	0,7124
		(OFF mode)	0,003		167 hr/week	521040	8684	26,052
Video player	X-box Slim	X-box 360 slim	0,091	1	5 hr/week	15600	260	23,66
Stereo,sound system	Sharp	XL-HP434		1				
		(ON mode)	0,1		1 hr/week	3120	52	5,2
		(OFF mode)	0,0006		167 hr/week	521040	8684	5,2104
Stereo,sound system	Pioneer	PD-Z74T	0,01	1	30 mins/week	1560	26	0,26
Elec. Keyboard	Ensoniq	VFX SD	0,05	1	2 hr/month		24	1,2
Sum								**340,10**
Office								
Desktop computer	Compaq	Presario 6000	0,0303597	1	30 mins/week	1560	26	0,7893522
Monitor	Compaq	TFT 5015	0,04	1	30 mins/week	1560	26	1,04
Laptop computer	Dell	Latitude E6410	0,0537	1	30 hr/week	93600	1560	83,772
Laptop computer	Apple	Mac Book	0,095	1	30 hr/week	93600	1560	148,2
Printer	Epson	Epson Stylus PHOTO-RX700	0,025	1	<1 hr/month	780	13	0,325
Sum								**243,13**
Other								
Charger								
mobile	generic		0,02	2	6 hr/week	18720	312	12,48
camera	Panasonic	F511 Lumix	0,00273	1	0,5 hr/week	1560	26	0,07098
Hair dryer	generic		1,4	1	0,67 hr/week	2090,4	36,4	50,96
Wireless router	generic		0,007	1	168 hr/week	524160	8736	61,152
Sum								**124,66**
Total (kWh)	**3334,82**							

Table 7. Electricity consumption per functional area and appliances

Table 8. Electricity consumption for lighting per functional area

Lighting					
Area	Type of lighting bulb/Amount				
	Low-energy lamp	LED	Spotlight	Bulbs	Fluorescent
1st Floor					
Living Room	3	2			2
Kitchen	1		1 (5 lights)	3	
Bathroom			1 (5 lights)	1	
Corridor				3	
Storage				1	
2nd Floor					
Bedroom 1		2	1 (5 lights)		
Bedroom 2	1				1
Bedroom 3				1	
Bathroom			1 (5 lights)	1	
Laundry				1	
Corridor	2				
3rd Floor					
Funroom	5		1 (5 lights)	1	1
Outdoor					
Entrance				2	
Garden				1	
3rd Floor				1	
Storage				1	
Amount	12	4	5	17	4
Electricity Use (kWh)	216	32	16.45	391	122.64
Total (kWh)	778.09				

ELECTRICITY CONSUMPTION FOR LIGHTING & PRODUCTS USED FOR THE CALCULATIONS

Low energy lamp
Energy saving lamp E-27, 18W from Osram
Model: Superstar Reflektor 18 W
Annual consumption of electricity: 18 kWh
Electricity cost per year: 29 kr

Bulb
Energy saving bulb, 23 watts from Megaman.
Model: MU123i (Liliput)
Annual consumption of electricity: 23 kWh
Electricity cost per year: 37 kr

LED
Energy saving lamp, 8W from Philips.
Model: MyAmbiance 9W (60W)
Annual consumption of electricity: 8 kWh
Electricity cost per year: 13 kr

Spot light
MASTER LEDspotLV 3W
Model: GU4 2700K MR11 24D
Annual consumption of electricity: 3.29 kWh
(3 Hour use per day)

Fluorescent
Philips CFL (compact fluorescent light)
Model: MASTER Genie 14W WW E27 220-240V
(equivalent to 65W)
Annual consumption of electricity: 30,66 kWh
(6 Hour use per day)

In order to calculate the Electricity Use/year (kWh/y or kWh/a), we need to the power rating of each product by the hours of use during the year:

Electricity load = power rating in kW/time of use in hours

The result will be in units of kilowatt hours per year (kWh/a).
After the total load has been calculated, the distribution of electricity consumption in the household can be defined (table 7 and 8).

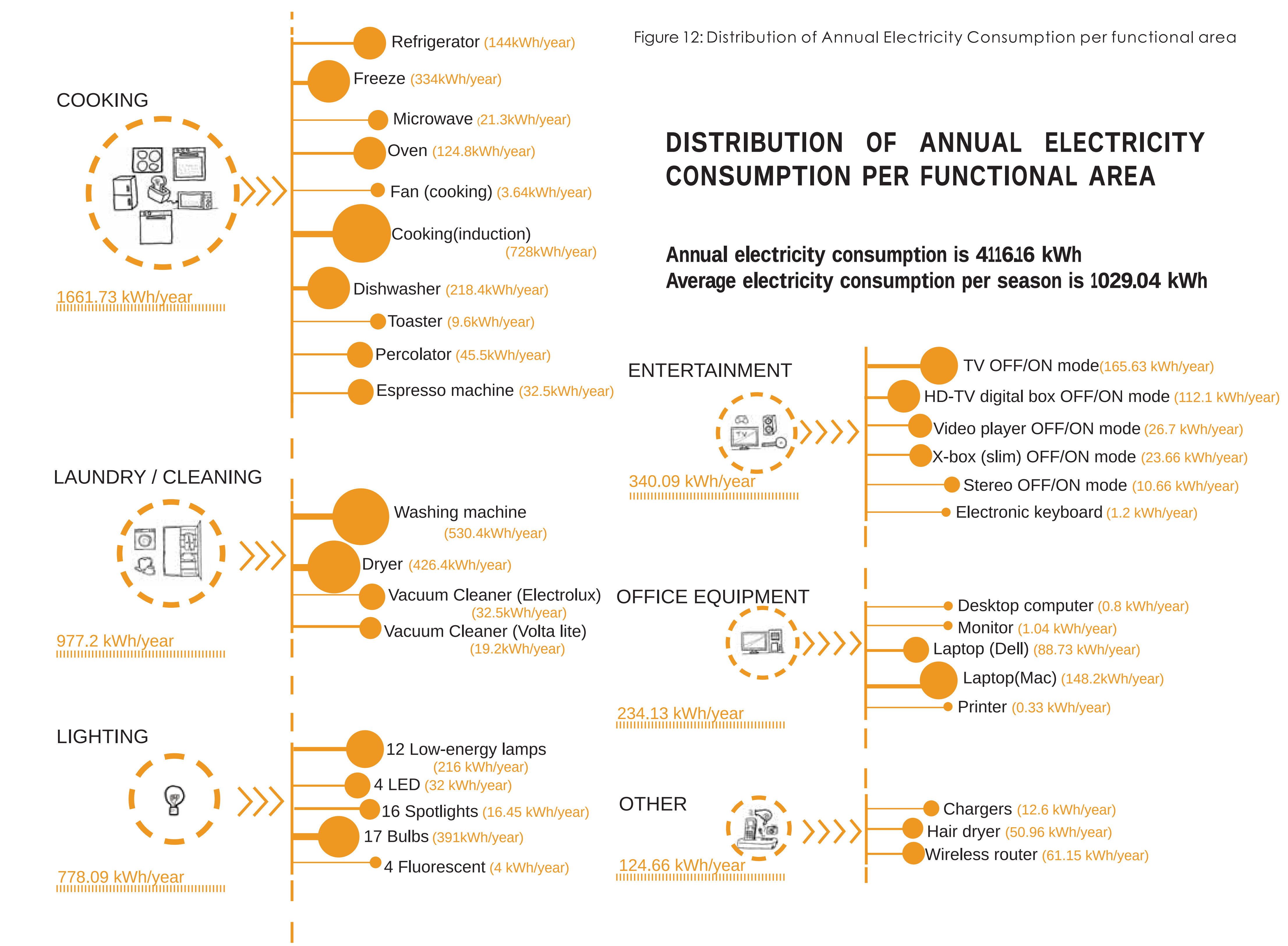


Figure 12: Distribution of Annual Electricity Consumption per functional area
DISTRIBUTION OF ANNUAL ELECTRICITY CONSUMPTION PER FUNCTIONAL AREA
Annual electricity consumption is 4116.16 kWh
Average electricity consumption per season is 1029.04 kWh
COOKING
1661.73 kWh/year
Refrigerator (144kWh/year)
Freeze (334kWh/year)
Microwave (21.3kWh/year)
Oven (124.8kWh/year)
Fan (cooking) (3.64kWh/year)
Cooking(induction) (728kWh/year)
Dishwasher (218.4kWh/year)
Toaster (9.6kWh/year)
Percolator (45.5kWh/year)
Espresso machine (32.5kWh/year)
LAUNDRY / CLEANING
977.2 kWh/year
Washing machine (530.4kWh/year)
Dryer (426.4kWh/year)
Vacuum Cleaner (Electrolux) (32.5kWh/year)
Vacuum Cleaner (Volta lite) (19.2kWh/year)
LIGHTING
778.09 kWh/year
12 Low-energy lamps (216 kWh/year)
4 LED (32 kWh/year)
16 Spotlights (16.45 kWh/year)
17 Bulbs (391kWh/year)
4 Fluorescent (4 kWh/year)
ENTERTAINMENT
340.09 kWh/year
TV OFF/ON mode(165.63 kWh/year)
HD-TV digital box OFF/ON mode (112.1 kWh/year)
Video player OFF/ON mode (26.7 kWh/year)
X-box (slim) OFF/ON mode (23.66 kWh/year)
Stereo OFF/ON mode (10.66 kWh/year)
Electronic keyboard (1.2 kWh/year)
OFFICE EQUIPMENT
234.13 kWh/year
Desktop computer (0.8 kWh/year)
Monitor (1.04 kWh/year)
Laptop (Dell) (88.73 kWh/year)
Laptop(Mac) (148.2kWh/year)
Printer (0.33 kWh/year)
OTHER
124.66 kWh/year
Chargers (12.6 kWh/year)
Hair dryer (50.96 kWh/year)
Wireless router (61.15 kWh/year)

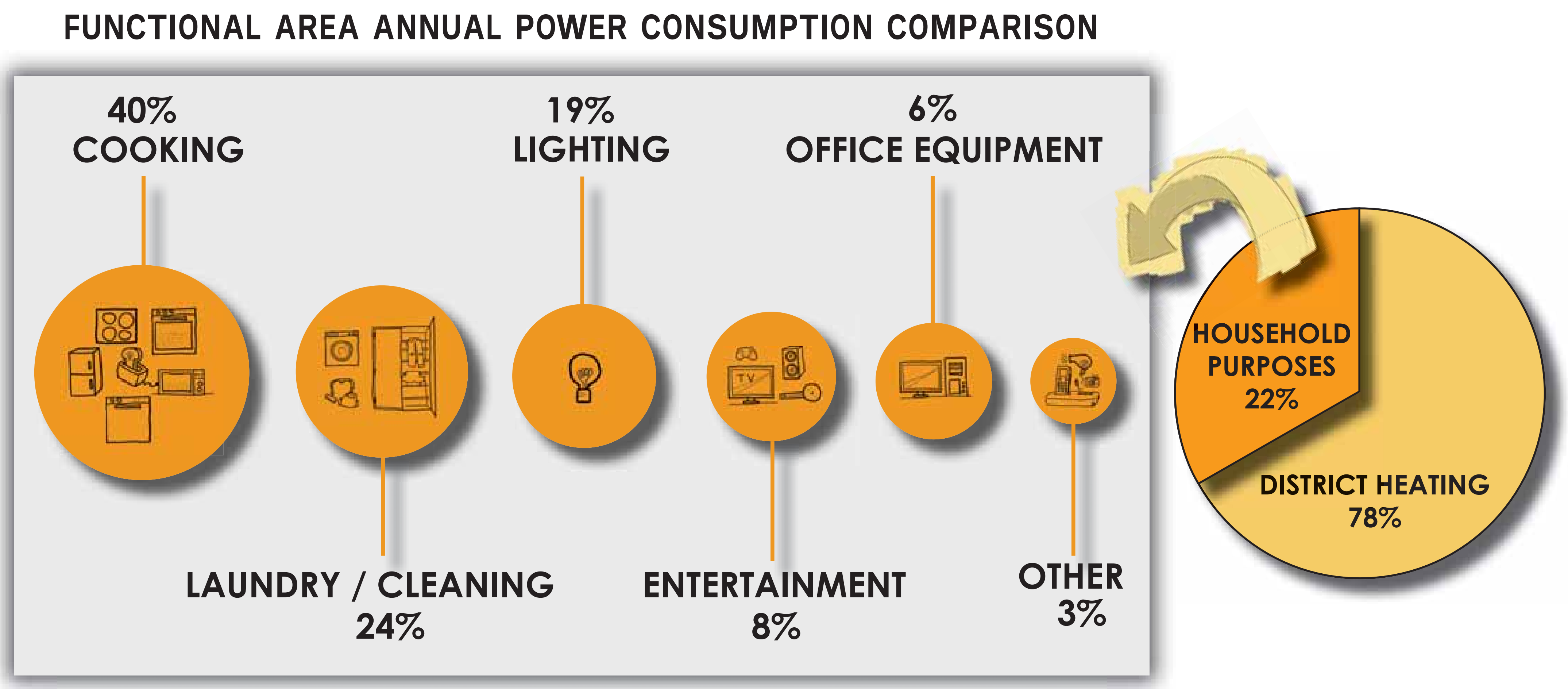


Figure 13: Functional area annual electricity consumption comparison

34 SUN ORIENTATION & AMBIENT TEMPERATURE

When designing a PV system, location is the key starting point. Climate information (sun angle, duration of day, ambient temperature), and site information and limitations/restrictions (shadow, site and building character, structure) derive from each specific location. These information are required for the integration and the calculations of the system.

Clear access to solar radiation is important for maximizing the PV systems' power generation potential. The surfaces selected for the PV modules integration should be unobstructed by other elements (trees, buildings, etc) due to the fact that shade can reduce, or even halt the power generation. Solar irradiation and surfaces-shadow studies have to be carried out, in order to get necessary figures for later calculations, as well as avoid selection of surfaces with low power generation potential, that would result only in the increase of the investment cost. The seasonal ambient temperature has to be researched as well, since it affects the efficiency of the PV modules. If the PV modules are overheated, their output potential can drop drastically. The operating temperature of the PV modules differs from the ambient temperature. The latter will be used for determining the temperature of the PV cells, a necessary step in the calculations stage. Standard Test Condition (STC) are used for the module power rating, and the temperature of 25°C that is specified for them may differ from the one on site.

Gothenburg has an oceanic climate according to Köppen climate classification. Summers have average high temperatures of 20 -21 °C and lows of 11-13 °C. Winters are cold and windy with temperatures of around -4 to 3 °C even though it rarely drops below −10 °C (table 2). Snow mainly occurs from January to March, meaning that roof PV integrations will require cleaning in order to produce electricity. During the summer(June-Aug), daylight extends 18 hours, while during winter (December-February),daylight duration is limited to about 8 hours. Figure 14 (page 74) shows the daylight time during the year in 2011 which the day in summer is 50% longer than winter period.

The optimal inclination angle for the integration of the system varies throughout the year, as seen in table 8 (page 74).

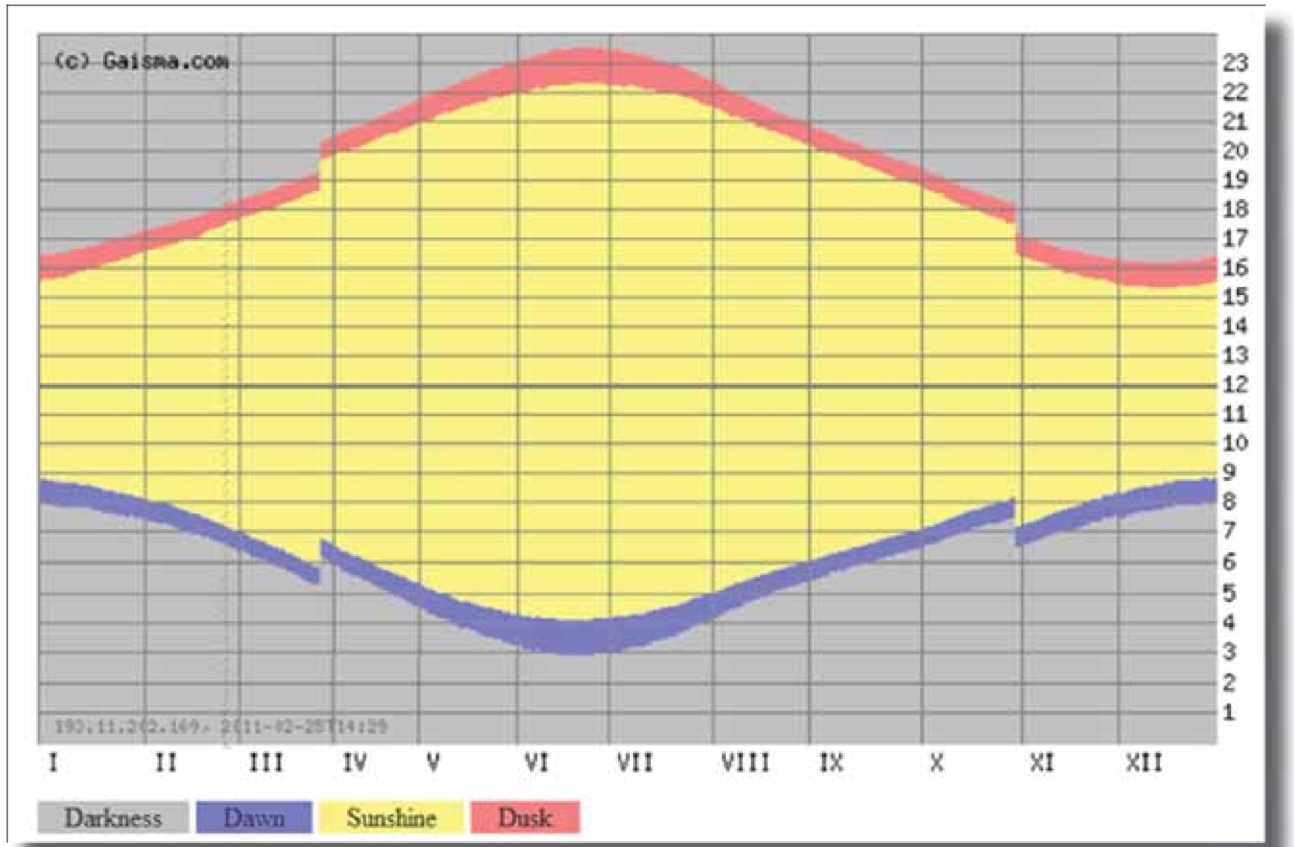
Table 7. Average Ambient Temperatures in Gothenburg, Sweden

Average Ambient Temperatures		
Season	Months	Average TAir (ambient temperature) °C
Winter	December - February	2
Spring	March - May	10
Summer	June - August	20
Autumn	September - November	11

Table 8. Optimal inclination angle[82]

Optimal Inclination Angle	
Season	Angle of inclination
Winter	17°
Summer	47°
Overall	32°

Figure 14: Daylight duration graph for Gothenburg, Sweden.



[82] http://solarelectricityhandbook.com/solar-irradiance.html

3.5 PSH

As explained in chapter 2.2.1, Peak sun hours, or PSH, are a measure of the energy emitted from the sun at a given location. This energy is expressed as the equivalent number of hours of 1000 watts or 1kW per m^2 of irradiance for the specified location (1 PSH= 1000 W/m^2 or 1kW/m^2). These values vary greatly throughout the year and between different locations. They are necessary for the estimation of the PV systems' power generation. According to the solar irradiance information from PVGIS, the available PSH for the East, West, and roof surfaces is as follows:

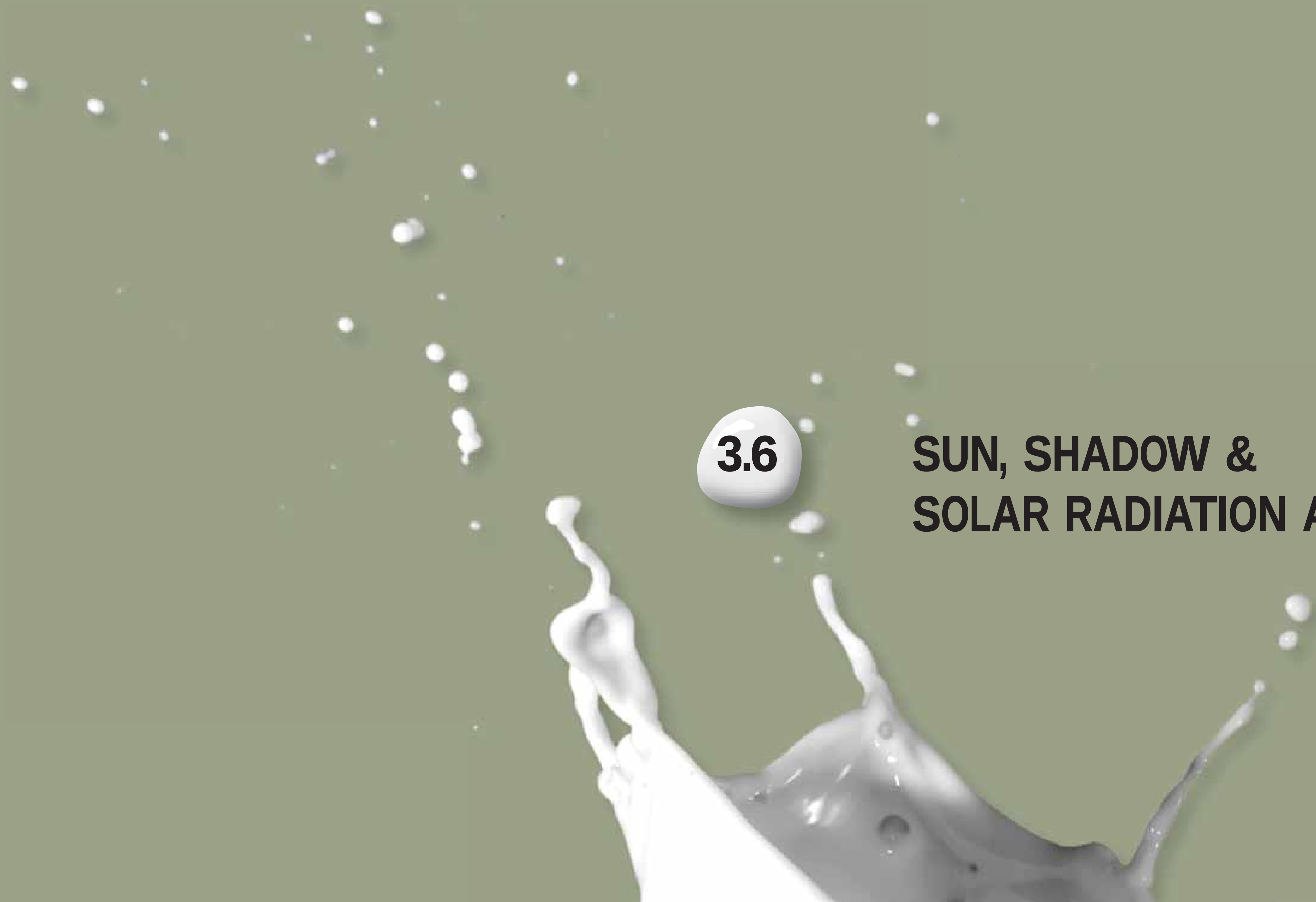
Table 9. PSH values for Gothenburg, Sweden[83]

PSH annual values		
Location	Latitude	57°41'55'' North
	Longitude	11°54'19'' East

East façade	Inclination of plane: 90° Orientation (azimuth) of plane: -90°	
	Average Peak Sun Hours per year =	1.6 PSH
	Peak sun hours for Winter (December-Febuary) =	0.4 PSH
	Peak sun hours for Spring (March-May) =	2.2 PSH
	Peak sun hours for Summer (June-August) =	2.9 PSH
	Peak sun hours for Autumn (September-November) =	1 PSH
West façade	Inclination of plane: 90° Orientation (azimuth) of plane: 90°	
	Average Peak Sun Hours per year =	1.6 PSH
	Peak sun hours for Winter (December-Febuary) =	0.3 PSH
	Peak sun hours for Spring (March-May) =	2.2 PSH
	Peak sun hours for Summer (June-August) =	2.9 PSH
	Peak sun hours for Autumn (September-November) =	0.9 PSH
Roof	Inclination of plane: 6° Orientation (azimuth) of plane: 90°	
	Average Peak Sun Hours per year =	2.5 PSH
	Peak sun hours for Winter (December-Febuary) =	0.5 PSH
	Peak sun hours for Spring (March-May) =	3.33 PSH
	Peak sun hours for Summer (June-August) =	4.7 PSH
	Peak sun hours for Autumn (September-November) =	1.4 PSH

East façade (Diffuse irradiance*)	Peak sun hours for Winter (December-Febuary) =	0.185 PSH
	Peak sun hours for Spring (March-May) =	1.032 PSH
	Peak sun hours for Summer (June-August) =	1.401 PSH
	Peak sun hours for Autumn (September-November) =	0.452 PSH
West façade (Diffuse irradiance*)	Peak sun hours for Winter (December-Febuary) =	0.18 PSH
	Peak sun hours for Spring (March-May) =	1.049 PSH
	Peak sun hours for Summer (June-August) =	1.414 PSH
	Peak sun hours for Autumn (September-November) =	0.458 PSH
Roof (Diffuse irradiance*)	Peak sun hours for Winter (December-Febuary) =	0.364 PSH
	Peak sun hours for Spring (March-May) =	1.86 PSH
	Peak sun hours for Summer (June-August) =	2.55 PSH
	Peak sun hours for Autumn (September-November) =	0.846 PSH

[83] *PVGIS (c) European Communities, 2001-2010, http://re.jrc.ec.europa.eu/pvgis/*



3.6 SUN, SHADOW & SOLAR RADIATION ANALYSIS

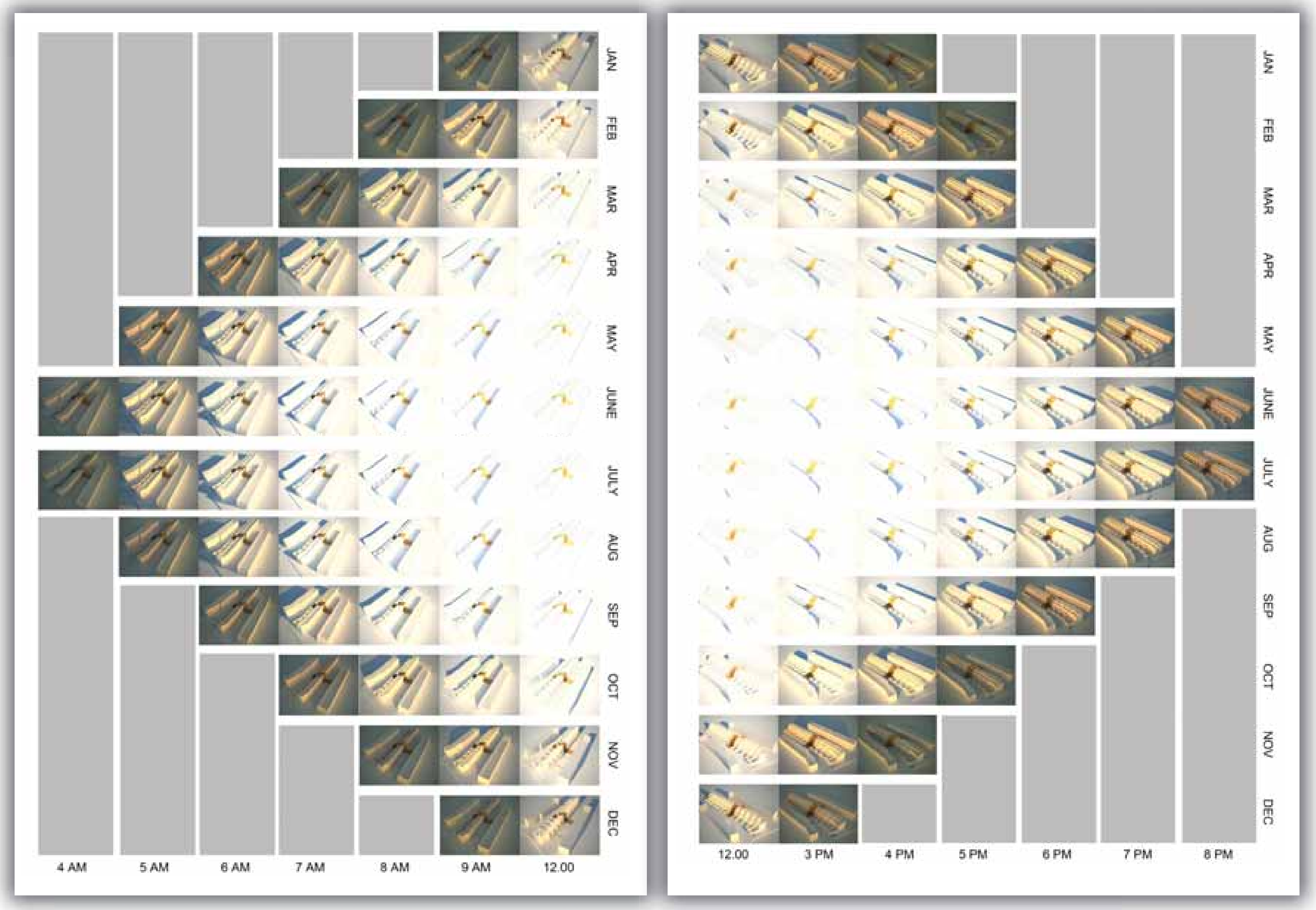
Shading and global irradiation analysis are necessary in order to obtain information on the available and more productive locations for the integration of the PV system. Shaded areas will not only produce less electricity, but depending on the array connections, may even stop the production of electricity within their array string.

The study was carried out through the use of different CAD technologies (REVIT, VASARI, 3DS MAX). A model was initially created in REVIT Architecture, based on the technical drawings provided by the house residents, and then imported in 3DS MAX, where the initial sun and shadow analysis was carried out. This software uses a daylight system based on weather data files. After the location of the project has been defined, the parameters of the system can be changed in order to get visual illustrations for the desired time period of the study (figure 15, page 78). The visualization of this information has proven extremely useful, since it provided an insight on the subject at the design approach steps. Following this step, further visual analysis was performed through REVIT Architecture and Project Vasari.

The latter programs incorporate functions of sun analysis (REVIT) and solar irradiation analysis (VASARI). The REVIT function (Figure 16, page 79) can be described as a "sun path" simulation, where the location, time and date can be defined as parameters. The result is a visualization of the effect and intensity of the sun for the given time frame. This step is useful for illustrating the shaded areas of the building envelope. As mentioned earlier, these areas should be avoided, because integration at those surfaces might not only lead to a reduction in the production of electricity, but depending on the array connections, they may even halt the production of electricity within their array string. Following this step of analysis, a new model was created within the VASARI software, which is an extension of REVIT. There, after the creation of a mesh model for the building and for the site, and defining again the location, a graphical illustration of the solar irradiation on the building envelope can be generated (Figure 17, page 79). The software can also provide numerical information on irradiation for the selected surfaces. Even so, the values used in the calculations for the power generation originate from the PVGIS online database. The reason behind this choice is mainly the more detailed specification on the numerical values provided by the aforementioned database.

The available surfaces for the integration of PVs on the selected building, and in extension for the whole area, are the East, West, and the roof. The inclination and the PSH of the respected surfaces is shown in Appendix A.

Figure 15: Sun and Shading area analysis in 3DS Max using a daylight system



Shading and radiation analysis are necessary in order to obtain information on the available and more productive locations for the integration of the PVs

Shaded areas will not only produce less electricity, but depending on the array connections, may even stop the production of electricity within their array string.

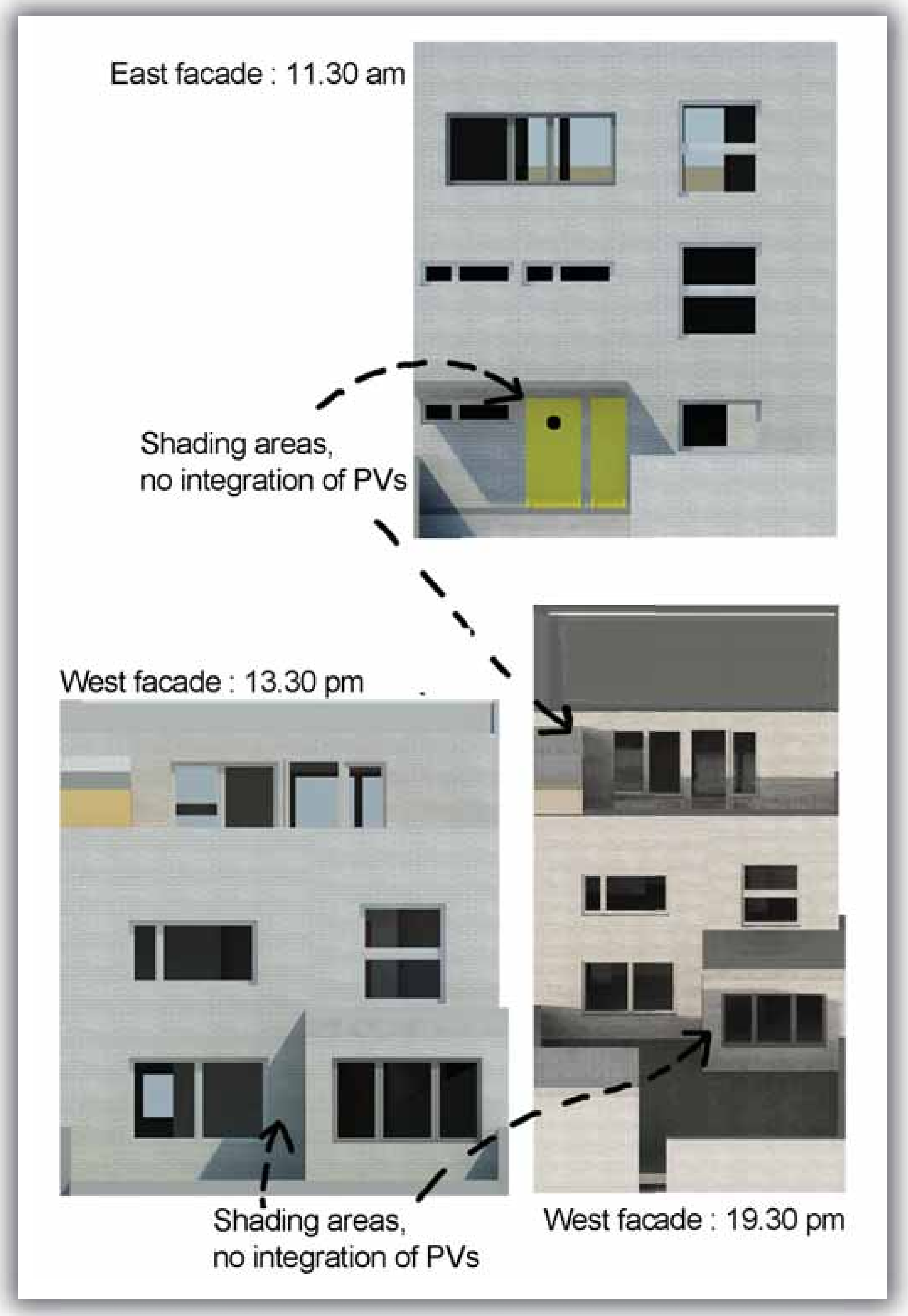


Figure 16: Shading analysis, REVIT Architecture

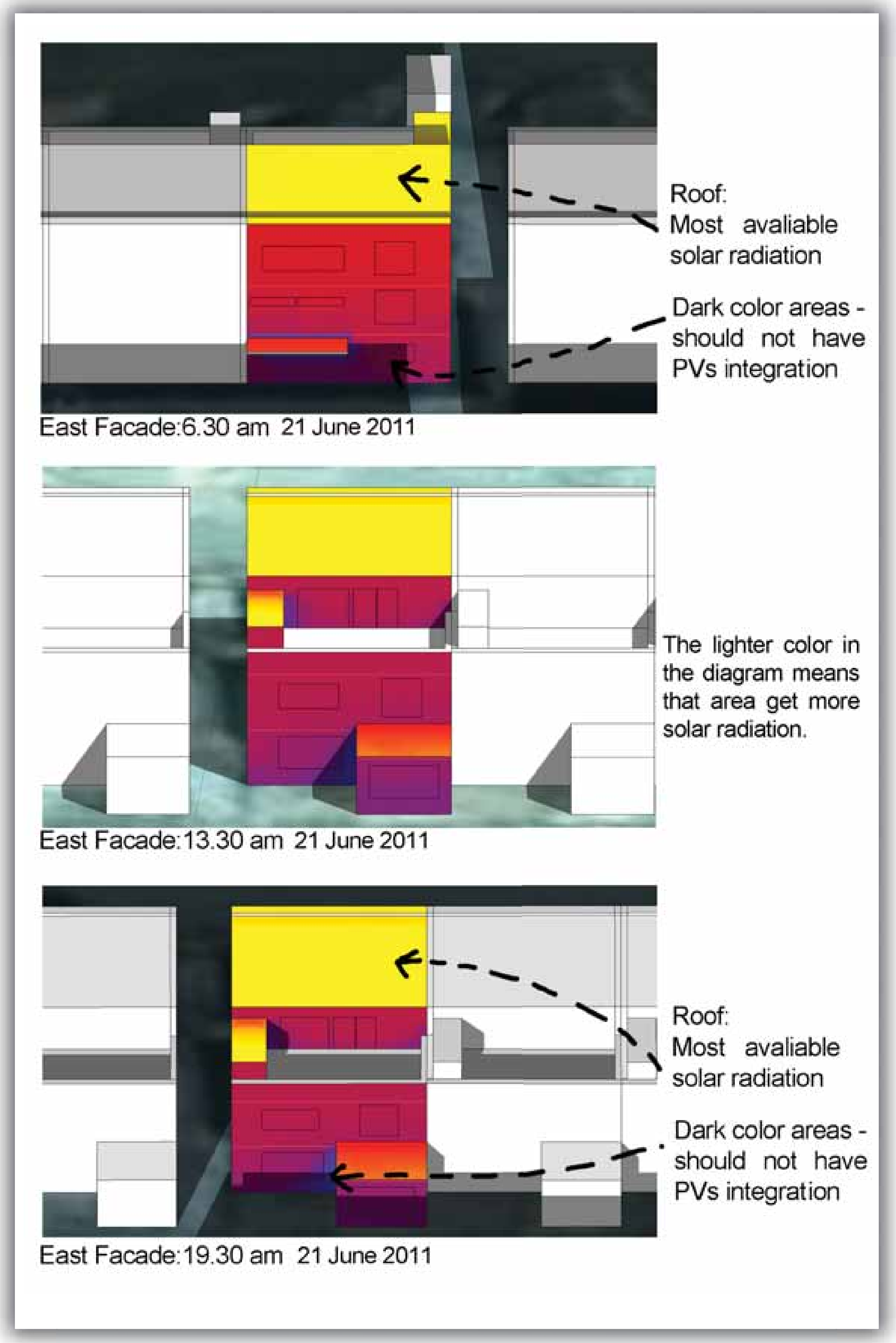
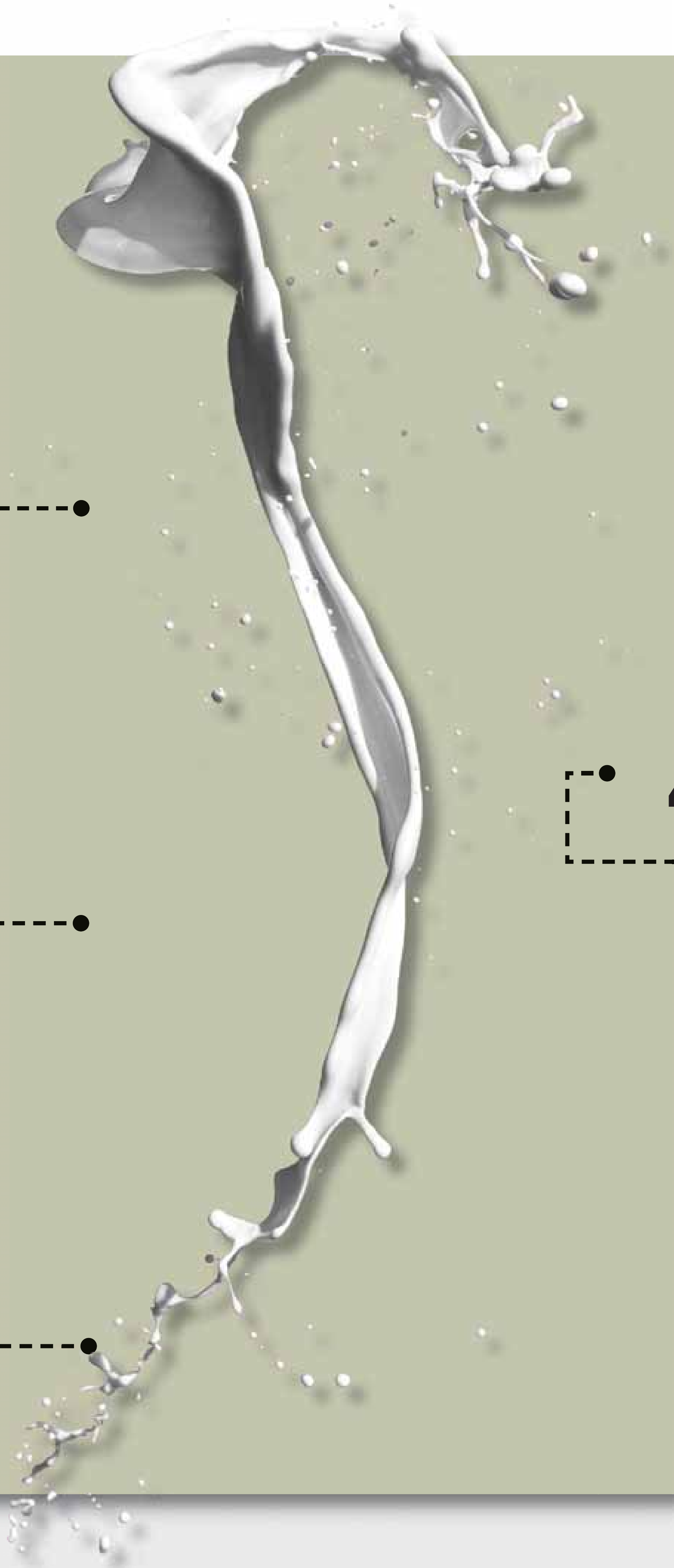


Figure 17: Solar irradiation analysis, Project VASARI



4. DESIGN

4.1 DESIGN DEVELOPMENT

4.11 PRODUCT SELECTION

Following the determination of the load, the analysis continued into the research for products available in the market. The focus was on power ratings, dimensioning and aesthetics. From a large number of products available in the market, the following where examined for the integration of the system:

I. SANYO HIT-205DNKHE1 Double
Characteristics:

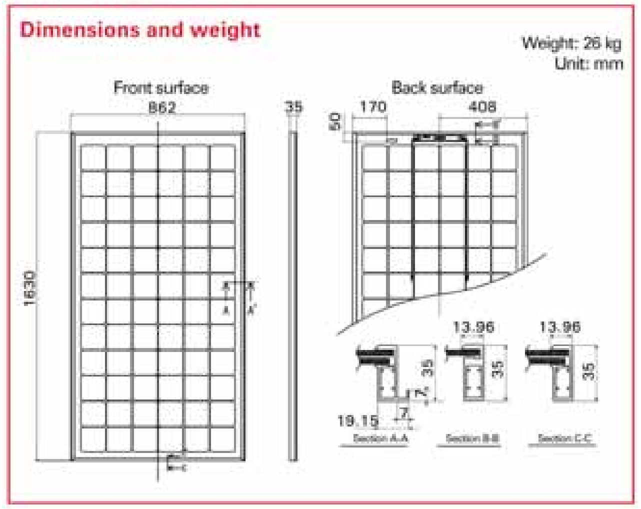
- Manufacturer: SANYO
- Type: Bifacial HIT (Heterojunction with Intrinsic Thin layer)
- Aesthetics: The black and shiny surface, the small transparency from the holes between the cells and the module frame, and the regular patterns formed by the cells, make the panel appear expressive with a high-tech character.

Image 48: SANYO HIT-205DNKHE1 Double PV module and data sheet. Source: SANYO HIT-205DNKHE1 Double brochure.

- Data sheet

Electrical data	Models HIT-xxxDNKHE1 210	205	200
Maximum power (Pmax) [W]	210	205	200
Max. power voltage (Vpm) [V]	42.8	41.3	40.7
Max. power current (Ipm) [A]	5.00	4.97	4.92
Open circuit voltage (Voc) [V]	51.6	50.9	50.3
Short circuit current (Isc) [A]	5.47	5.43	5.40
Warranted min. power (Pmin) [W]	199.5	194.8	190.0
Back surface max. power output (Pmax) [W]	147	143	140
Maximum over current rating [A]	15		
Output power tolerance [%]	+10/-5		
Max. system voltage [Vdc]	1000		
Temperature coeff. of Pmax [%/°C]	-0.30		
Temperature coeff. of Voc [V/°C]	-0,129	-0.127	-0.126
Temperature coeff. of Isc [mA/°C]	1.64	1.63	1.62

Note 1: Standard test conditions: Air mass 1.5, Irradiance = 1000 W/m², Cell temperature = 25 °C.
Note 2: The values in the above table are nominal.



II. ASI THRU 30 SG
Characteristics:

- Manufacturer: SCHOTT SOLAR
- Type: a-Si (amorphous silicon)
- Aesthetics: Thin film is divided into rectangles (about 18 x 5 mm) through the transparent track (approx. 0.5 mm). The semi-transparency filters the incoming light, making it softer and reducing glare, thus making the module fit with bright spaces. From close observation, the light and shadow effect from the cells becomes clear, while from greater distances the module appears to be homogenous. The color appears to be light grey on the interior surface, while on the outside appears to have a dark brown-red color. Both surfaces are reflective.

Image 49: ASI THRU 30 SG PV module and data sheet. Source: SCHOTT SOLAR brochure.

- Data sheet

Electrical data

Initial nominal power		33 Wp
Nominal power*	P_{nom}	27 Wp
Voltage at maximum-power point*	U_{mpp}	36 V
Current at maximum-power point*	I_{mpp}	0.75 A
Short-circuit current*	I_{sc}	1.02 A
Open-circuit voltage*	U_{oc}	49 V

Dimensions and weights

Dimensions	1000 x 600 mm²
Module glass thickness / module thickness with connection button	10 mm / 22 mm
Four-sided non-photoactive margin for clamp mounting	16 mm
Weight	14 kg

Characteristic data

Solar cell type	thin-film amorphous silicon in ASI® tandem cells
Appearance	uniformly dark-brown
Semitransparency	about 10 % transmission, colour-neutral
Electrical connection	double insulated cable (Huber & Suhner), 2.5 mm² cross-section, 100 cm length per polarity, MC® plug connectors

Temperature coefficients

Referred to nominal power	$T_K (P_N)$	- 0.2 % / K
Referred to open-circuit voltage	$T_K (U_{oc})$	- 0.33 % / K
Referred to short-circuit current	$T_K (I_{sc})$	+ 0.08 % / K

The temperature dependence of the power output is particularly low for ASI THRU®-solar modules.

Limits

Maximum system voltage	1000 V_{DC}
Temperature arrange	- 40 °C... + 85 °C
Maximum surface load	• two-sided clamping along length: 3200 N/m² • four-sided clamping: 4600 N/m²

Specifications subject to change without notice.

III. C 21 Solar Slates
Characteristics:

- Manufacturer: Solarcentury
- Type: Monocrystalline Silicon
- Aesthetics: The module, resembling a roof slate, makes it easier to accept as a building material. The dark blue reflective surface gives a high-tech character to the product. The small width allows integration on surfaces that would remain un-exploited from larger modules.

Image 50: C 21 Solar Slates and data sheet. Source: Solarcentury brochure.

- Data sheet

Dimensions

Gross Width	1220	mm
Gross Length	420	mm
Profile Depth	30	mm
Exposed Length (at 90mm headlap)	330	mm
Covering width	1180	mm
Hanging Length	395	mm
Minimum roof pitch at 90mm headlap*	22.5	degrees
Minimum roof pitch at 100mm headlap*	17.5	degrees
Maximum roof pitch*	90	degrees
Headlap (maximum)	120	mm
Headlap (minimum)	75	mm
Batten spacing at minimum gauge	300	mm
Batten spacing at maximum gauge	345	mm
Covering capacity at minimum gauge	2.8	C21e/m²
Covering capacity at maximum gauge	2.5	C21e/m²
Inidividual unit weight	8	kg
Weight as laid at maximum gauge	19.7	kg/m²
Batten size (Minimum. For rafters not exceeding 600mm centres, nailed to BS5534)	50 x 25	mm
Screws and fixings (supplied)¹	4.8mm x 45mm self tapping stainless steel screws with EPDM washers. Four per unit.	

*Subject to fixing specification
1) Edge clips may also be required in some locations. Refer to fixing specification for the tiles to be installed alongside C21s for guidance.

Electrical Specification[1]

Photovoltaic cell technology	Monocrystalline
Cell Dimensions	125 x 125 mm
Power [2]	52 Wp
Wp/m² (at 90mm headlap)	134
Wp/m² (at 100mm headlap)	138
Wp/m² (at 120mm headlap)	147
Laminate size (active area)	1174 x 318 mm
Number of cells	18
Cell efficiency	20 %
Module efficiency	14.9 %
Maximum power voltage[2]	9.80 V
Maximum power current[2]	5.30 A
Open circuit voltage[2]	12.0 V
Short circuit current[2]	5.55 A
Maximum system voltage	600 V DC
Temperature coefficient of the open-circuit voltage	-0.0342 V/°C -0.286 %/°C
Temperature coefficient of the short-circuit current	2.27 mA/°C 0.028 %/°C
Temperature coefficient of the power	-0.38 %/°C
Cables	Class II double insulated 4mm cable
Connectors	Standard MC3 IP65 push fit connectors

(1) Values of current, voltage and power +/- 10%.
(2) Measured under Standard Test Conditions of 1000W/m² irradiance, AM 1.5 spectrum, 25°C cell temperature.

initial design stages - 1

The design of the units' (house) integration has undergone some steps of development. The initial approach was intended to utilize the PV modules as exterior skin materials, thus covering surfaces of the building envelope and creating an exterior layer.

As seen in image 51 (page 84), the volume of the buildings' envelope has remained unchanged. At the same time new final exterior finish is altering the character of the building. The alteration of the character, at some level, cannot be avoided if PV modules are to be integrated on the facades.

While the C21 modules' dimensioning allows the maximum utilization of the buildings' exterior envelope, a small amount of the latter is covered by "dead" cells. This means that these cells will be made to fill in the remaining surfaces in order to maintain the uniformity of the design, but will not generate any electricity. Since these cells will not be a part of the system, it was decided that the material to be made from should be slightly different from the real cells. This creates a pattern on the surface, a game between variations of color, and at the same time an honesty to the materials of the design is maintained. The surfaces where the "dead" cells are to be placed are determined by the solar and shadow analysis. A portion of the East facade is left without any kind of cells. This space leaves a connection with the materials of the adjacent buildings.

The integration of the C21 cells on the facades would mean that the support structure system needed would be facilitated on the buildings surfaces. This structure is not only meant to support the modules, but to also to provide air flow at their back side, reducing their heat. As a side effect, the air passing behind the modules will be heated, and a portion of this heat will be transferred to the building. This could be a positive side effect during the long cold winters in Sweden. The whole system would be an additional exterior layer, also providing protection from the water elements to the brick facade and thus extending its lifespan. The drawback of this approach is that it does not solve the glare and overheating issues that have been stressed by the building analysis. As a result, a second design was drafted.

Product: C21 SOLAR SLATE CELL

C21 modules Integrated: 61 East facade, 46 West facade,60 roof
167 panels of C21 cells = 5408.14 kWh/year

- New final exterior finishing materials
- Allows the maximum utilization of the buildings' exterior envelope
- Heated air passing behind support structure can have a positive effect during cold months
- Exterior skin protects brick facade from rain and snow
- Does not deal with glare.


Image 51: Visualization of the West facade. 3DS MAX & V-RAY


Image 52: Visualization of the East facade. 3DS MAX & V-RAY

initial design stages - 2 & 3

This second approach dealt with the issue of glare, through the detachment of the system from the buildings' exterior skin. A combination of Sanyo HIT and Solyndra modules was used. The form of the design gave a strong technical character to the system, making it an easily distinguished component that stands out from the house unit.

Solyndra modules are essentially tubes of thin film material with space between them. This characteristic provides electricity generation, shadowing, as well as transparency.

Although the spacing between the tubes of the Solyndra module allows the connection between interior and exterior spaces, the visualization (Image 54 and 55, page 85) revealed that the approach had a feeling of enclosure, an effect that was not desired. The owners enjoy spending their free time during the warm months on the terrace, and creating an enclosure like this, with a cage like feeling, would have negative effects on their psychology. Nevertheless, the product appeared to have better performance than other thin-film ones, and its design made it more suitable for a roof integration. The gaps in conjunction with the cylindrical forms of the PV cells would allow snow to fall of easier, and increase the air flow between the cells. Unfortunately, before the design could be refined, the Solyndra company declared bankruptcy, and so the design was discarded.

Product: Sanyo HIT cell & Solyndra modules

- Deals with the issue of glare by being detached from the buildings' exterior
- Solyndra modules allow a level of transparency
- Design has the character of a technical system/ component, - Stands out from the house unit

Image 53: Visualization of the East facade. 3DS MAX & V-RAY

Product: Sanyo HIT cell, Solyndra modules & ASITHROU modules

- Similar approach as HIT-Solyndra.
- Deals with glare.
- Feeling of technical component.
- Although transparency is allowing interaction between interior & exterior, there is a feeling of enclosure

Image 54: Visualization of the West facade. 3DS MAX & V-RAY

Product: Sanyo Hit cell & ASITHRU modules

- **Detaching the PV system from the buildings' skin shows potential in increasing the architectural values.**
- **Structural supporting elements of system can be part of the design.**
- **More functions provided.**
- **Structure is heavy.**
- **Over-shadows East window openings**

Image 55: Visualization of the East facade. 3DS MAX & V-RAY

initial design stages - 4

The idea of detaching the PV system from the building has more possibilities to increase the architectural values of the design, since it is not restricted to the existing structure of the building a direct integration on the houses' surfaces would be. This implies that the structural elements of the system can be parts of the design, rather than serve only as supports. Also, the continuation of the relationship from the interior to the exterior has been a driving factor towards the final design approach.

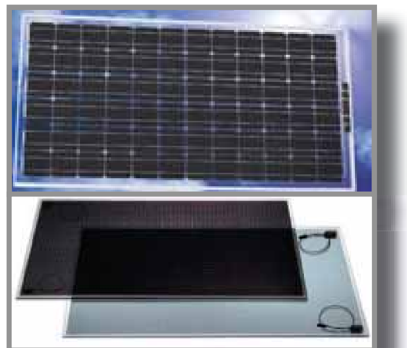
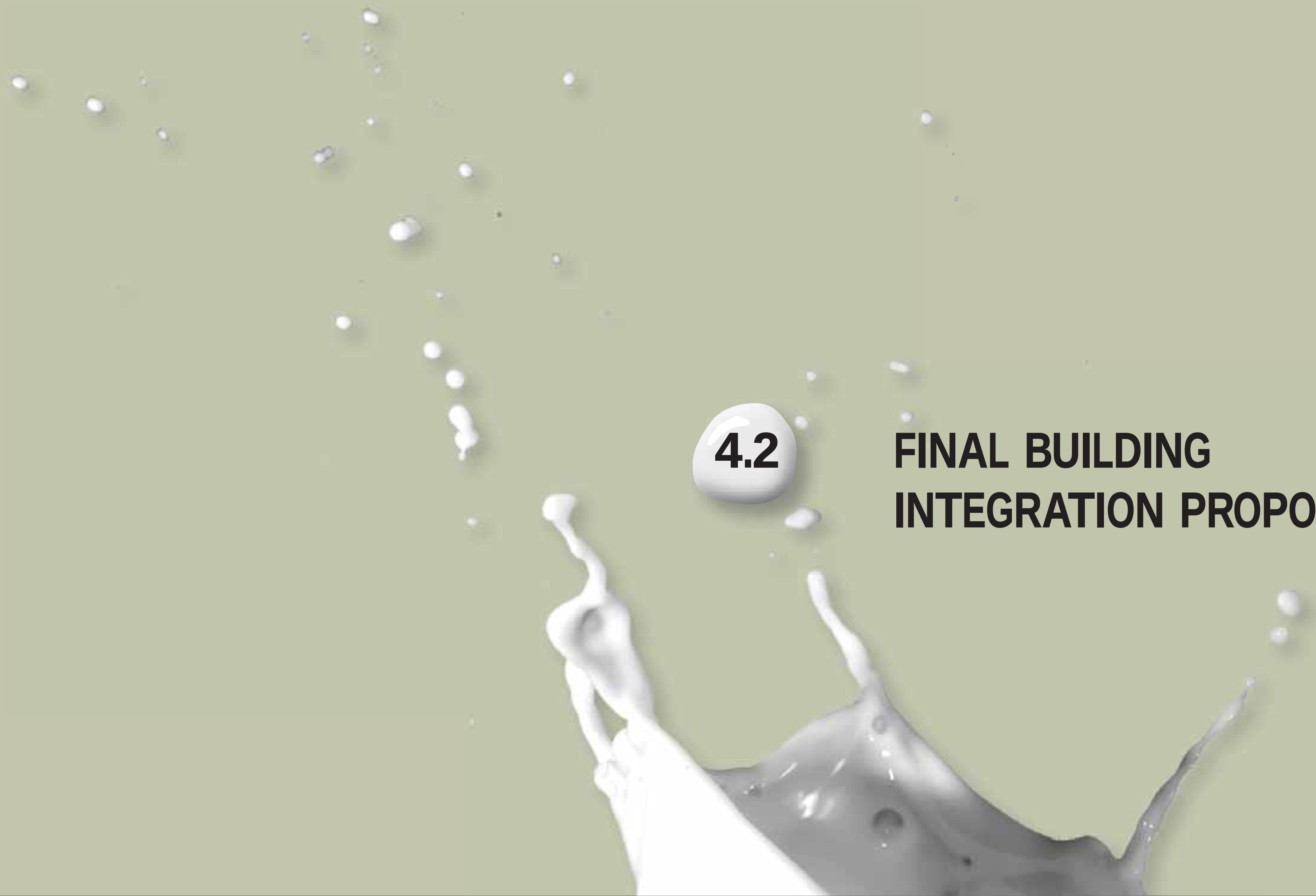


Image 56: Visualization of the East facade. 3DS MAX & V-RAY



4.2 FINAL BUILDING INTEGRATION PROPOSAL

4.21 REFINING & FINALIZING THE DESIGN

Since the glare problem is stronger on the third floor, at the entertainment/play room, the design should correspond accordingly. Furthermore, the gains from solar irradiation are greater at the higher levels of the building. In the final approach, it was decided to extend the roof surfaces of the building, through not only the addition of more surface area on the roof level, but also through the integration of new “rooms”. These spaces are located at both East and West.
Although the new spaces extend the available surface for the integration, the modules integrated to them are not Sanyo HIT. The latter would increase the power generation more than the thin-film ASI TRU modules, but if the HIT modules where to be selected, they would decrease the natural lighting of the kitchen, since this space has only one window towards the East. Additionally, the glazed roof in combination with the rhythm of semi-transparency and full transparency, grand a feeling of openness and tranquillity to the space (Image 57, page 91). The green house located at the West facade has also ASI THRU modules on its roof surface, and it offers an interesting view through the West facing opening of the house (image 58, page 92). These spaces have the advantage of being able to be incorporated to other locations as well, as individual units, since they are detached from the buildings structure.

The overall structure is mainly timber, with steel bonds between the individual member. The materials bond almost naturally with the semi-transparent panels, creating a uniform design. The timber members also add to the substance of the system. The glare issue is dealt with PV modules acting as a filter for the overexposed areas of the both sides of the house, while allowing the visual connection between interior and exterior. At the West, the extension of the roof creates a canopy in the form of a pergola, with ASI TRHU modules at the eastern side of the extension, and semi-transparent side at its the western part. A parapet of thin-film modules is located the second floor level, for the bedrooms’ protection from excess sunlight. The semi-transparency also increases the privacy of the owners without obstructing their views. At the East, two parapets are introduced at the third floor level, also acting in the same manner as the elements of the West side. The dimensions and character of the new volumes is in harmony with the buildings cubic morphology.

DESIGN GOALS

- Glare issue is stronger on the third floor. The design should correspond accordingly.
- The gains from solar irradiation are greater at the higher levels of the building.
- Extension of the roof surface and integration of new “rooms” located at East and West.
- ASI TRU modules selected, to avoid reduction of natural lighting.
- Rhythm of semi-transparency and full transparency, grants a feeling of openness and tranquillity.
- Green house can be incorporated to other locations.
- Timber and steel bond naturally with the semi-transparent panels, creating a uniform design.
- The timber members also add to the substance of the system.
- Dimensions and character of the new volumes is in harmony with the buildings cubic morphology

DEALING WITH EXISTING ISSUES

Through our interview with the owners, patterns of use for both spaces and appliances where made clear. The family members, comprised by two working parents and two young children, spends most of their time at the 1st level of the house. The most used space of the house is the living room area, while the least used appears to be the kitchen. The owner stated that due to the extended glazing towards the facade, there is an issue of glare during the evening hours. The third level of the house is consisted by a single room used as an entertainment/leisure area. The family enjoys spending time at the west terrace of this level during summer where they entertain friends or simply relax. This level, with openings to the east and a large mostly glazed west facade is overheated during the hottest months, and glare is a large issue. Sweden has extended daylight periods during spring and mostly summer. This means that the areas facing the west, being the most used during evening hours, are overexposed to the brightness of the sun, leading to visual discomfort for the users. A function diagram is presented below.

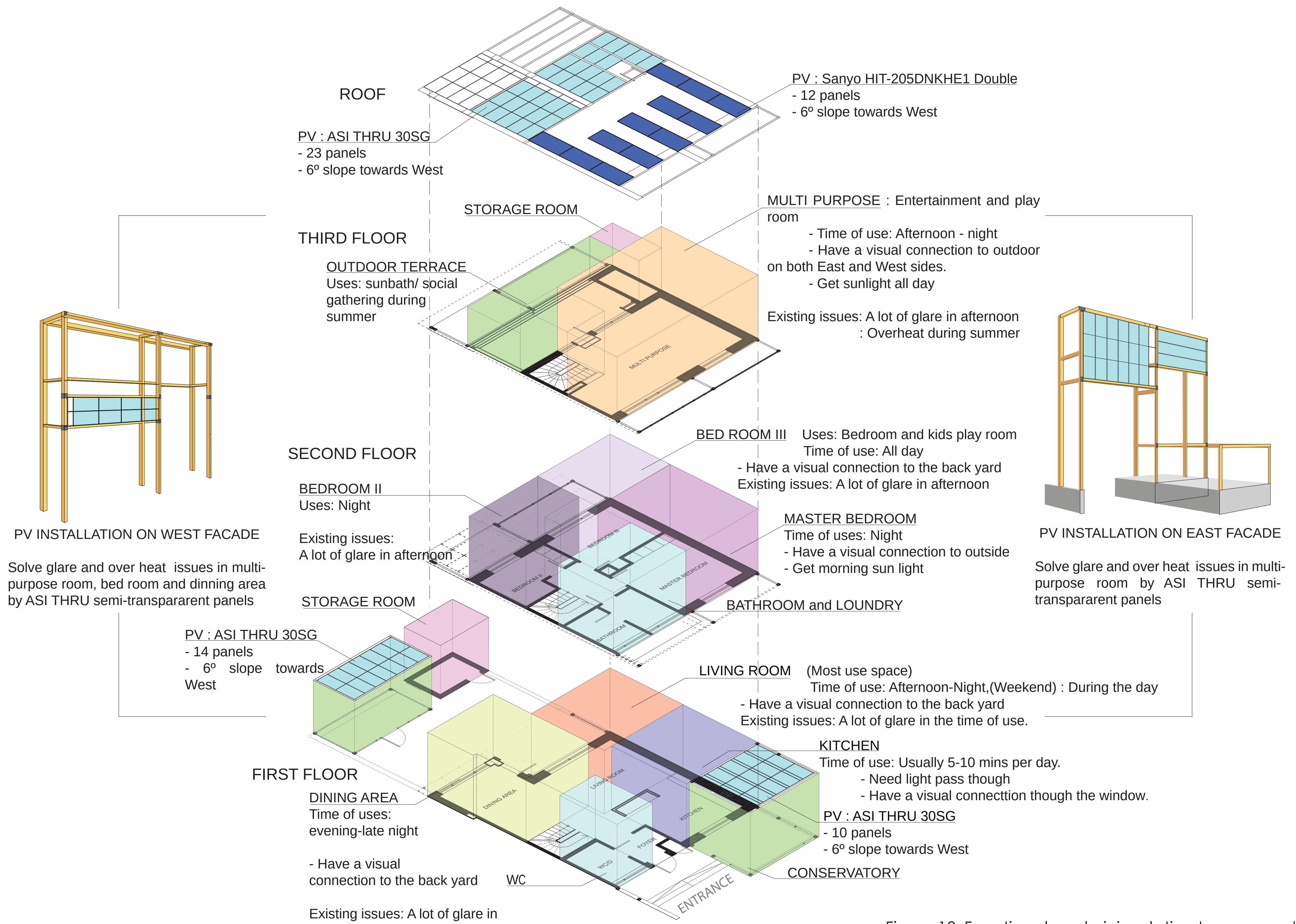
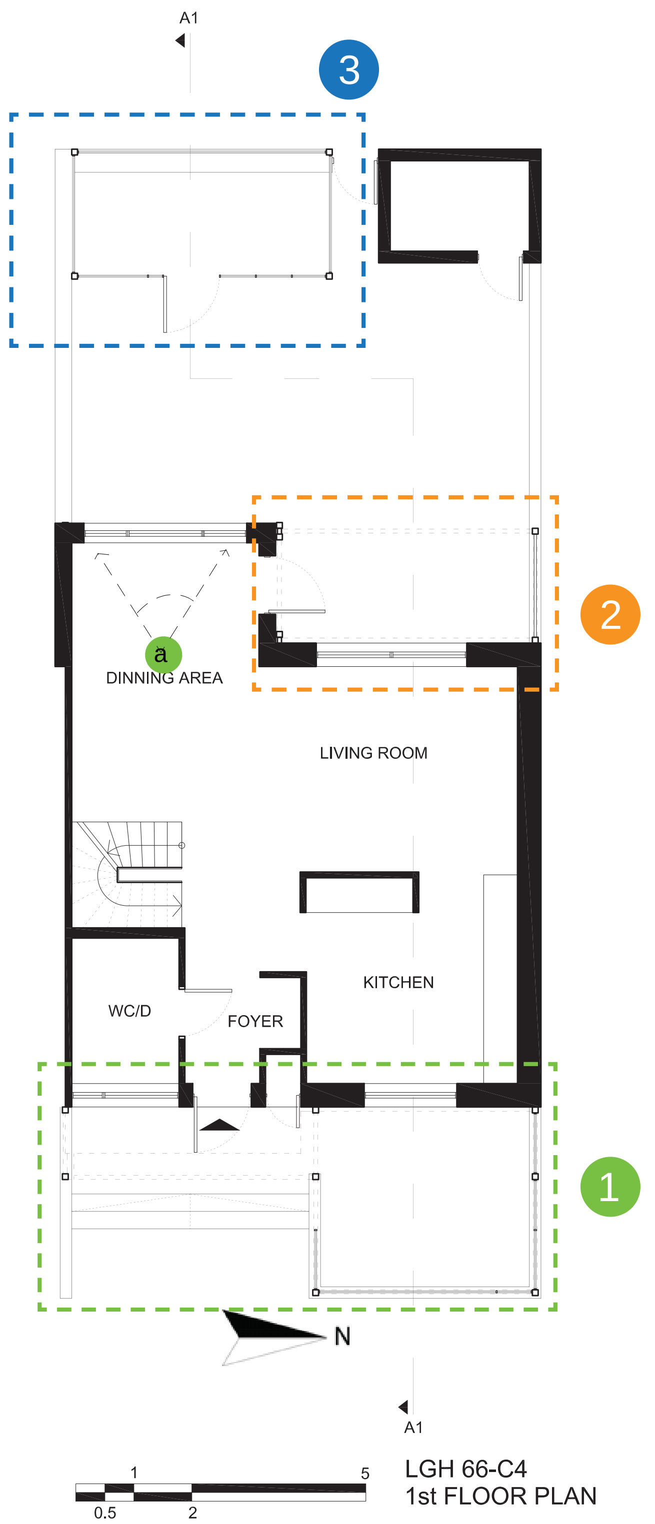
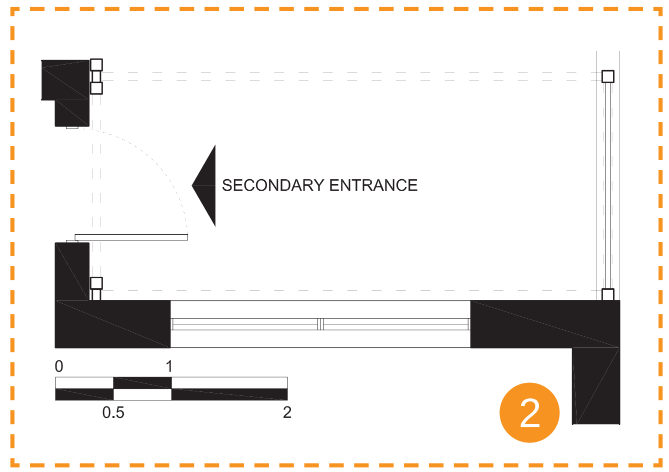
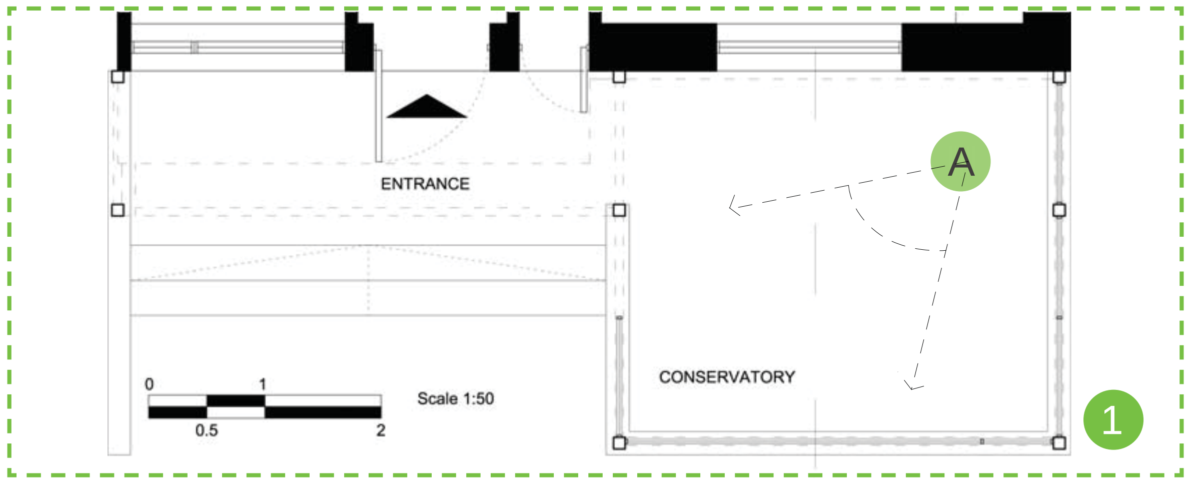


Figure 18: Functional analysis in relation to proposed integration. Autocad & Adobe Illustrator.

SINGLE FAMILY HOUSE 1ST FLOOR PLAN

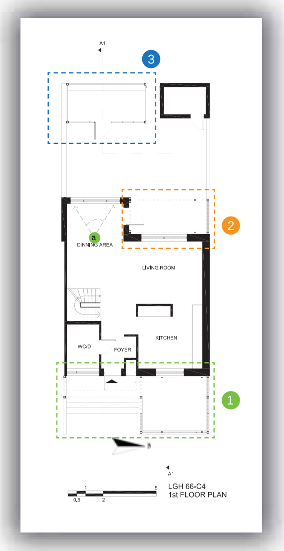






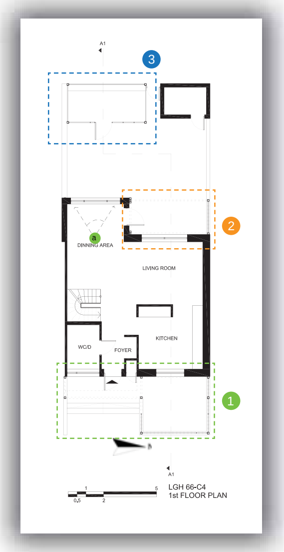
4.2.3 INTEGRATION VISUALIZATIONS

A Image 57: Visualization of the East Facade conservatory. 3DS MAX using V-RAY.



- Interaction with the public space
- Rhythm of transparency & semi-transparency
- Game of light & shadow

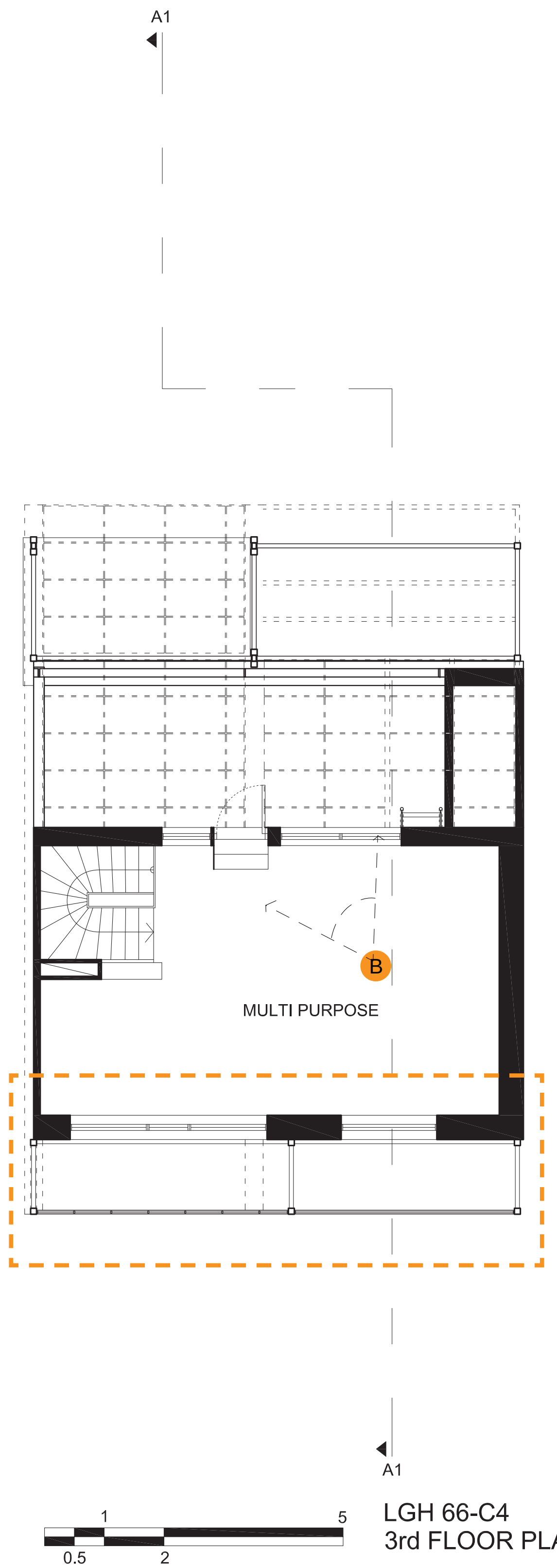
Image 58: Visualization of the green house from dining area. 3DS MAX using V-RAY. **a**



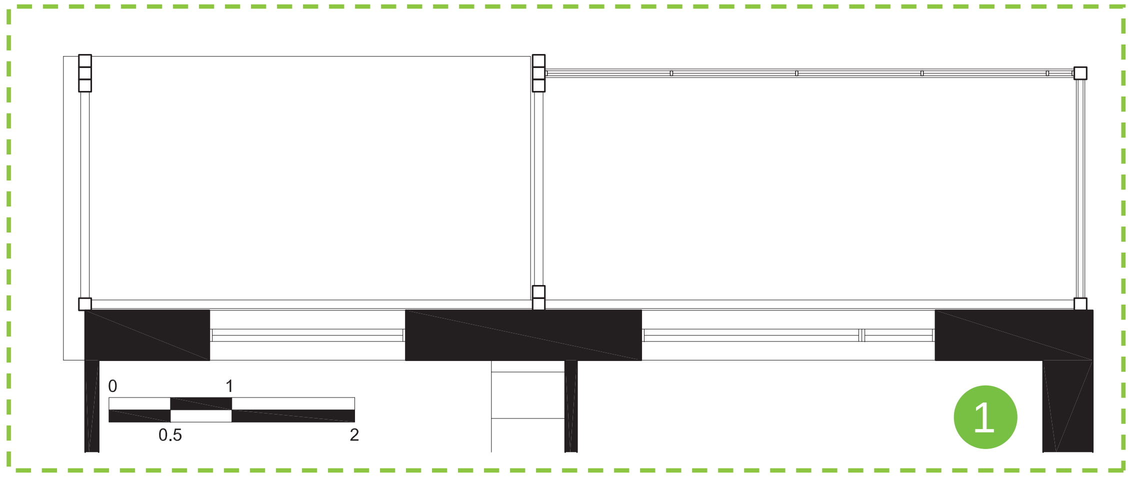
- Increased privacy of West garden
- New functional area for the family.

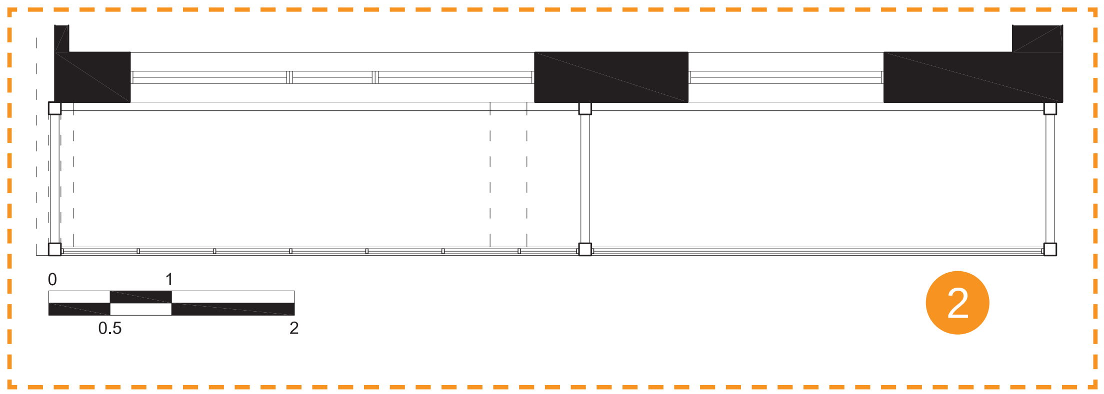
SINGLE FAMILY HOUSE
2ND & 3RD FLOOR PLAN

LGH 66-C4
2nd FLOOR PLAN



LGH 66-C4
3rd FLOOR PLAN





b

Image 59: Visualization from the multi-purpose area on the 3rd floor looking west "BEFORE" integration. 3DS MAX using V-RAY.

B

Image 60: Visualization from the multi-purpose area on the 3rd floor looking west "after" integration. 3DS MAX using V-RAY.

- Softer light
- Reduced reflections

DESIGN APPROACH: SINGLE FAMILY HOUSE
EAST FACADE

Image 61: Visualization of the proposed integration on the East facade. 3DS MAX using V-RAY.

- Softer light and reduced reflections
- Alternation of light and shadow
- Cubic morphology extended
- Maintained building character

Image 62: East facade elevation and photograph of current condition

DESIGN APPROACH: SINGLE FAMILY HOUSE
WEST FACADE

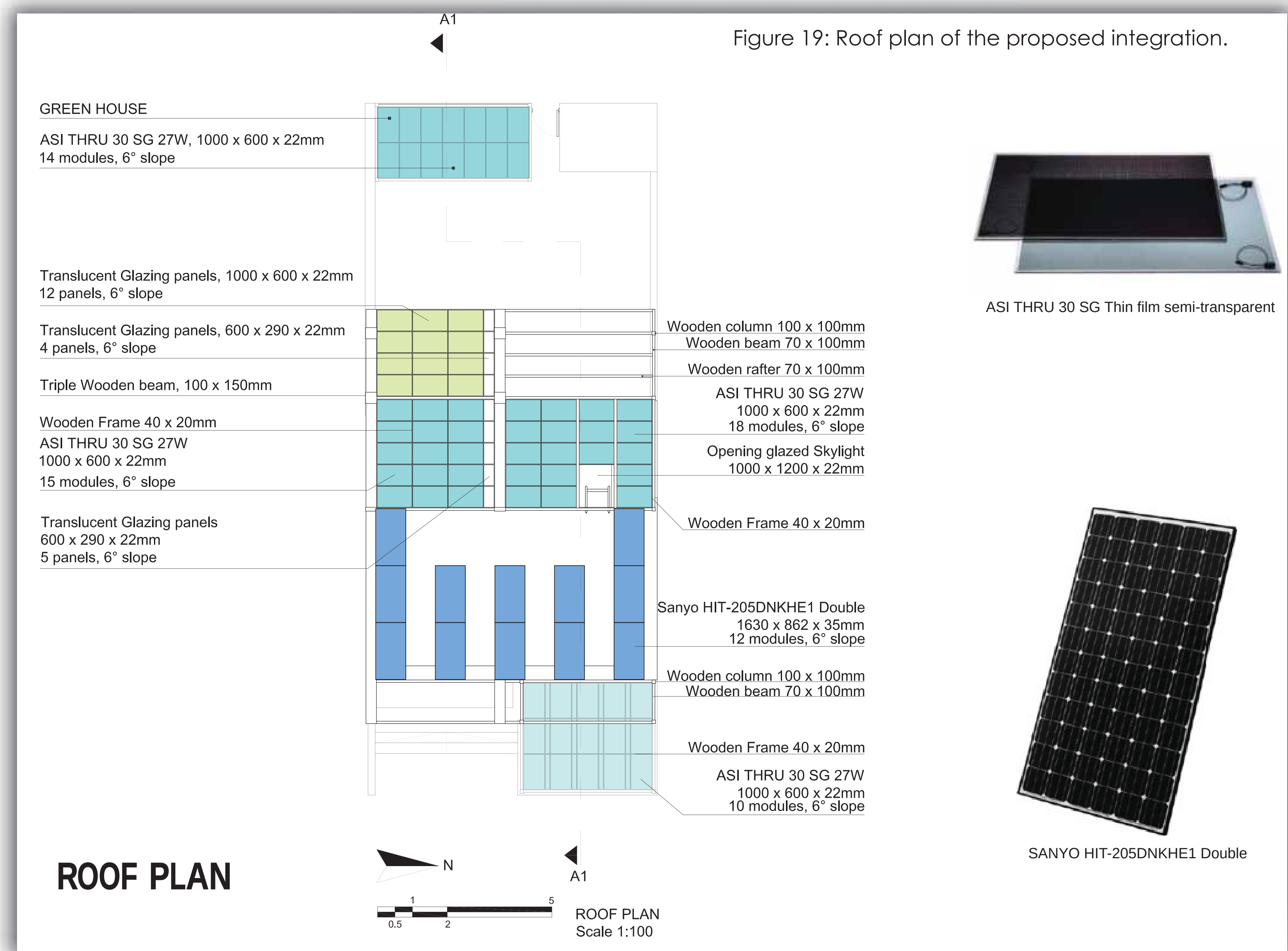
Image 63: Visualization of the proposed integration on the West facade. 3DS MAX using V-RAY.

- Softer light and reduced reflections
- Alternation of light and shadow
- Cubic morphology extended
- Maintained building character
- Increased privacy

Image 64: West facade elevation and photograph of current condition

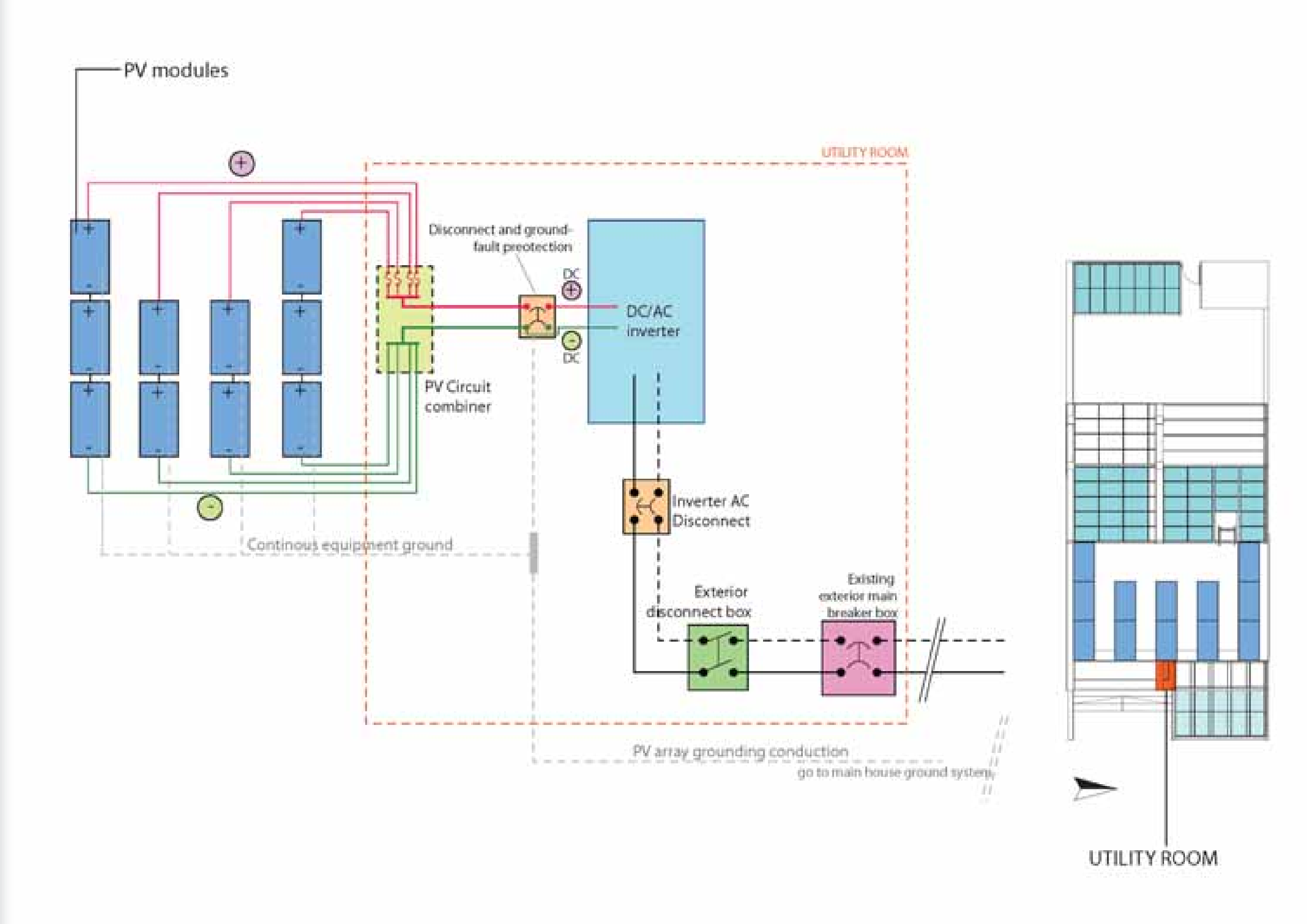
PV SYSTEM DIAGRAM & ELECTRICITY GENERATION

Figure 19: Roof plan of the proposed integration.



PV SYSTEM DIAGRAM

Figure 20: SANYO HIT PV system diagram



POWER GENERATION

Table 10. SANYO HIT PV module specification, climate and efficiency factors

PV module Specifications	
Type of PV	HIT Double cell
Name of Product	Sanyo HIT-205DNKHE1 Double
Power rating	205 watt (under STC test conditions) + up to 25% (backside)
Size of panel	862x1630x35 mm
Cells per module	60 (156mmx156mm/cells)
PV system	Grid-tied system
NOCT	48°C
Installation	12 panels on the Roof
Temperature coefficient	0.3%/°C
Tc = TA(°C) + [(NOCT-20/800) * G] , G= PSH/Average sunlight in hour	

Season	PSH	Average Sunlight in Hours	G(W/m²)	TA(°C)	NOCT	Tc
Winter	0,4	3,66	109,29	2	48	5,83
Spring	2,2	7	314,29	10	48	21,00
Summer	2,9	8,2	353,66	20	48	32,38
Autumn	1	5	200	11	48	18,00

Heat losses from Temperature Degradation	
Winter	-5,75
Spring	-1,20
Summer	2,21
Autumn	-2,1

Heat loss Efficiency Factor	
Winter	100%
Spring	100%
Summer	97,8%
Autumn	100%

PV efficiency (%)	
Winter	90%
Spring	90%
Summer	88%
Autumn	90%

Image 65: Sanyo HIT-205DNKHE1 Double PV module.
Source: SANYO brochure

Table 11. SANYO HIT PV electricity generation per panel and season

Roof

Front Surface, Winter (December - February), 90 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
205	0,9	0,97	0,95	0,9	0,5
1 panel produces	0,08 kWh/day				
Estimated production for Winter	6,89 kWh				
Back Surface, Winter (December - February), 90 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
143	0,991	0,97	0,95	0,9	0,364
1 panel produces	0,043 kWh/day				
Estimated production for Winter	3,85 kWh				
Total Estimated production for 1 panel	**10,74 kWh**				

Front Surface, Spring (March - May), 92 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
205	0,9	0,97	0,95	0,9	3,33
1 panel produces	0,51 kWh/day				
Estimated production for Winter	45,86 kWh				
Back Surface, Winter (March - May), 90 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
143	0,991	0,97	0,95	0,9	1,86
1 panel produces	0,219 kWh/day				
Estimated production for Winter	19,67 kWh				
Total Estimated production for 1 panel	**65,53 kWh**				

Roof

Front Surface, Summer (June-August), 92 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
205	0,9	0,97	0,95	0,9	4,7
1 panel produces	0,70 kWh/day				
Estimated production for Winter	63,29 kWh				
Back Surface, Summer (June-August), 92 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
143	0,991	0,97	0,95	0,9	2,55
1 panel produces	0,266 kWh/day				
Estimated production for Winter	23,95 kWh				
Total Estimated production for 1 panel	**87,24 kWh**				

Front Surface, Autumn (September - November), 91 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
205	0,9	0,97	0,95	0,9	1,4
1 panel produces	0,21 kWh/day				
Estimated production for Winter	19,28 kWh				
Back Surface, Autumn (September - November), 91 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
143	0,991	0,97	0,95	0,9	0,846
1 panel produces	0,090 kWh/day				
Estimated production for Winter	8,13 kWh				
Total Estimated production for 1 panel	**27,41 kWh**				

Table 12. ASI THRU PV module specification, climate and efficiency factors

PV module Specifications	
Type of PV	Thin Film
Name of Product	ASI THRU-30-SG , Semi transparent
Power rating	27 watt (under STC test conditions)
Size of panel	1000x600x22 mm
PV system	Grid-tied system
NOCT	50°C
Installation	27 panels installed on East façade, 8 panels on West façade, 33 panels on Roof, 10 panels on Conservatory
Temperature coefficient	0.2%/°C
Tc = TA(°C) + [(NOCT-20/800) * G] , G= PSH/Average sunlight in hour	

Season	PSH	Average Sunlight in Hours	G(W/m²)	TA(°C)	NOCT	Tc
Winter	0,4	3,66	109,29	2	50	6,10
Spring	2,2	7	314,29	10	50	21,79
Summer	2,9	8,2	353,66	20	50	33,26
Autumn	1	5	200	11	50	18,50

Heat losses from Temperature Degradation	
Winter	-3,78
Spring	-0,64
Summer	1,65
Autumn	-1,3

Heat loss Efficiency Factor	
Winter	100%
Spring	100%
Summer	98,35%
Autumn	100%

PV efficiency (%)	
Winter	90%
Spring	90%
Summer	88,5%
Autumn	90%

ASI THRU-30-SG , Semi transparent

Image 66:ASI THRU-30-SG PV module. Source: SCHOTT SOLAR brochure.

Table 13. ASI THRU PV electricity generation per panel and season

East facade

East façade, Winter (December - February), 90 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
27	0,9	0,97	0,95	0,9	0,4
1 panel produces	0,008 kWh/day				
Estimated production for 1 panel	**19,59 kWh**				

East façade, Spring (March - May), 92 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
205	0,9	0,97	0,95	0,9	2,2
1 panel produces	0,04 kWh/day				
Total Estimated production for 1 panel	**110,13 kWh**				

East façade, Summer (June-August), 92 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
205	0,9	0,97	0,95	0,9	2,9
1 panel produces	0,06 kWh/day				
Total Estimated production for 1 panel	**142,76 kWh**				

East façade, Autumn (September - November), 91 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
205	0,9	0,97	0,95	0,9	1
1 panel produces	0,02 kWh/day				
Total Estimated production for 1 panel	**48,95 kWh**				

West facade

West façade, Winter (December - February), 90 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
27	0,9	0,97	0,95	0,9	0,3
1 panel produces	0,006 kWh/day				
Estimated production for 1 panel	**4,35 kWh**				

West façade, Spring (March - May), 92 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
205	0,9	0,97	0,95	0,9	2,2
1 panel produces	0,04 kWh/day				
Total Estimated production for 1 panel	**32,63 kWh**				

West façade, Summer (June-August), 92 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
205	0,9	0,97	0,95	0,9	2,9
1 panel produces	0,06 kWh/day				
Total Estimated production for 1 panel	**42,30 kWh**				

West façade, Autumn (September - November), 91 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
205	0,9	0,97	0,95	0,9	0,9
1 panel produces	0,02 kWh/day				
Total Estimated production for 1 panel	**13,05 kWh**				

Roof

Table 13. ASI THRU PV electricity generation per panel and season

Roof, Winter (December - February), 90 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
27	0,9	0,97	0,95	0,9	0,5
1 panel produces	0,010 kWh/day				
Estimated production for 1 panel	**39,00 kWh**				

Roof, Spring (March - May), 92 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
205	0,9	0,97	0,95	0,9	3,33
1 panel produces	0,07 kWh/day				
Total Estimated production for 1 panel	**265,49 kWh**				

Roof, Summer (June-August), 92 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
205	0,9	0,97	0,95	0,9	4,7
1 panel produces	0,09 kWh/day				
Total Estimated production for 1 panel	**368,47 kWh**				

Roof, Autumn (September - November), 91 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
205	0,9	0,97	0,95	0,9	1,4
1 panel produces	0,03 kWh/day				
Total Estimated production for 1 panel	**109,14 kWh**				

Green House (optional)

Table 14. ASI THRU PV electricity generation for green house integration per panel and season

Roof, Winter (December - February), 90 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
27	0,9	0,97	0,95	0,9	0,5
1 panel produces	0,010 kWh/day				
Estimated production for 1 panel	**12,70 kWh**				

Roof, Spring (March - May), 92 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
205	0,9	0,97	0,95	0,9	3,33
1 panel produces	0,07 kWh/day				
Total Estimated production for 1 panel	**86,44 kWh**				

Roof, Summer (June-August), 92 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
205	0,9	0,97	0,95	0,9	4,7
1 panel produces	0,09 kWh/day				
Total Estimated production for 1 panel	**119,97 kWh**				

Roof, Autumn (September - November), 91 days					
Power	PV efficiency	Wire efficiency	Inverter efficiency	Tolerance/Dust/ Mismatches	PSH
205	0,9	0,97	0,95	0,9	1,4
1 panel produces	0,03 kWh/day				
Total Estimated production for 1 panel	**35,53 kWh**				

Electricity Generation from proposed PV System

Green House

Estimated Seasonal Electricity Generation for 10 ASI THRU-30-SG , Semi transparent panels (Green house integration) in kWh	
Winter	12,70
Spring	86,44
Summer	119,97
Autumn	35,53
Estimated Annual generation	**254,63**

Table 15. Total estimated electricity generation for green house integration, per season and annual

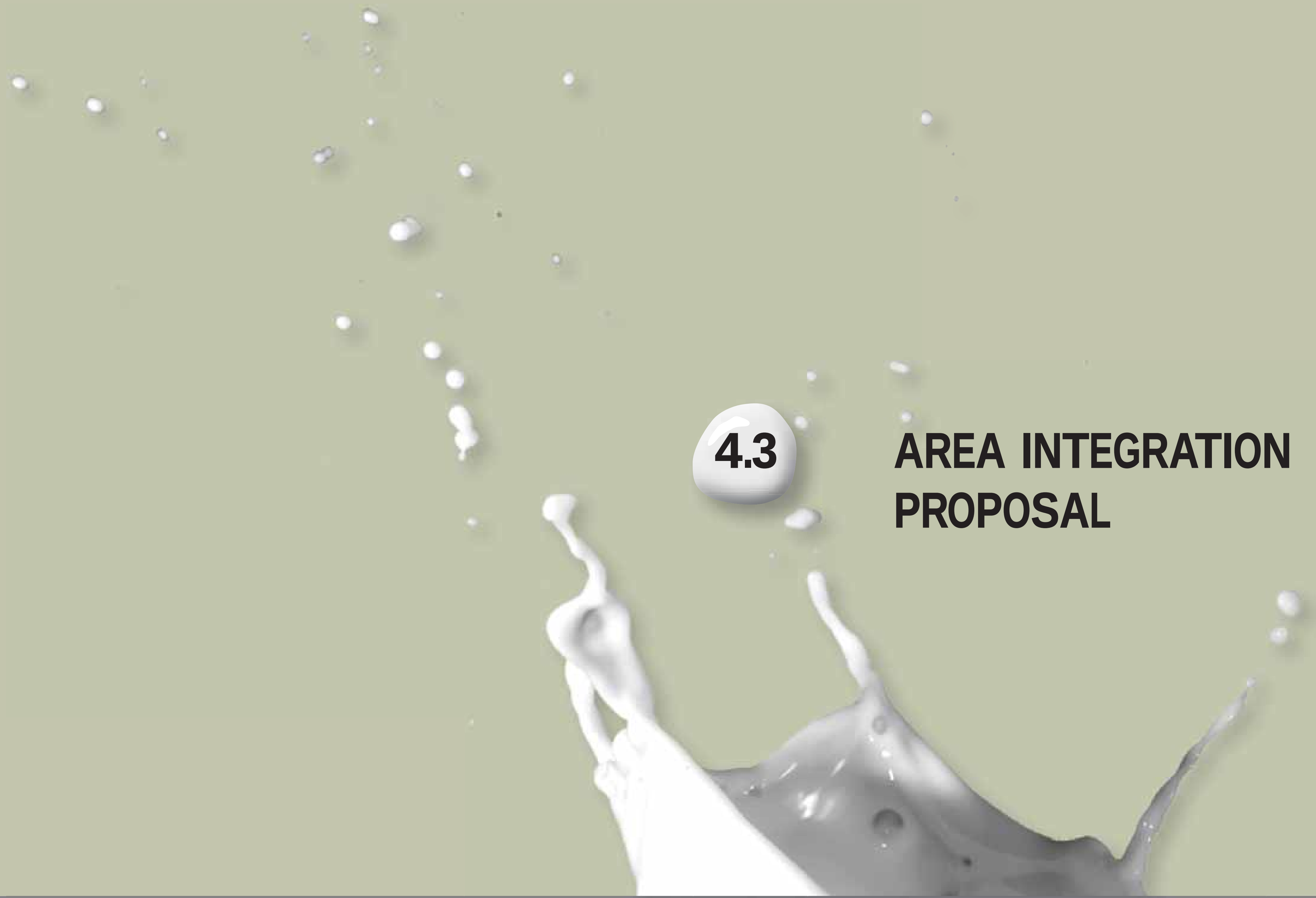
Roof, East & West Facade

Estimated Seasonal Electricity Generation for 12 Sanyo HIT-205DNKHE1 Double panels (roof installation) in kWh	
Winter	136,20
Spring	786,40
Summer	1046,87
Autumn	328,8826
Estimated Annual generation	**2298,35**

Estimated Seasonal Electricity Generation for 78 ASI THRU-30-SG , Semi transparent panels in kWh	
Winter	62,94
Spring	408,25
Summer	553,52
Autumn	171,14
Estimated Annual generation	**1195,85**

Season	Total Estimated Electricity Generation in kWh	2010 Household Consumption per season in kWh	Electricity load covered in %
Winter	199,14	1136	17,5
Spring	1194,65	962	124
Summer	1600,39	768	208,4
Autumn	500,02	970	51,5

Table 16 Total estimated electricity generation for proposed integration, per season and annual



4.3 AREA INTEGRATION PROPOSAL

DESIGN APPROACH: UNIFORM AREA DESIGN

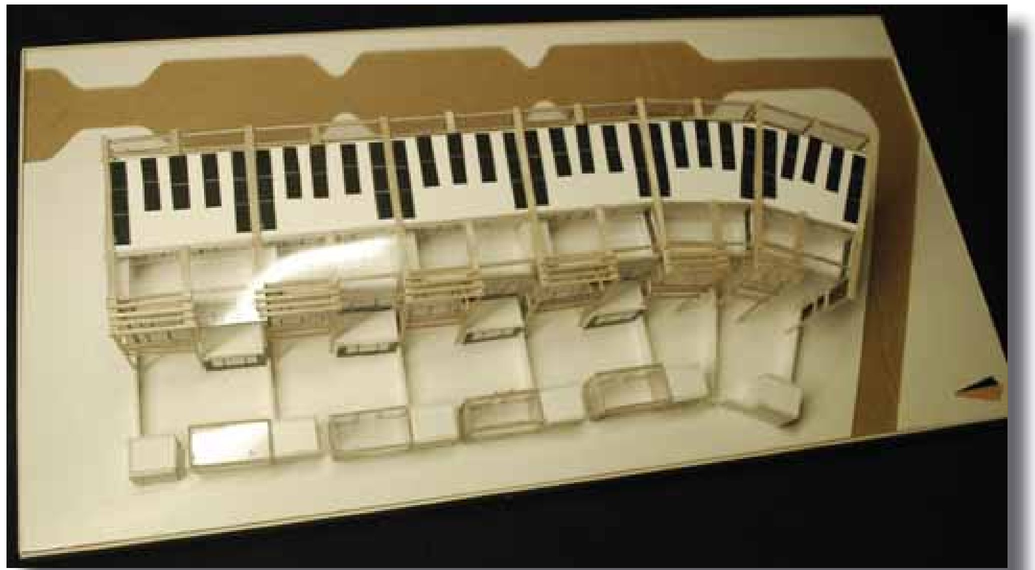


Image 67, 68 & 69: Model photographs of uniform area PV system integration

Since the morphological characteristics of the area represent an example of uniformity and repetition in the design, the authors became interested to explore the possibility of integrating a uniform design to the site. The same PV system was integrated at row 11, where the household under study is located. The method used for this approach was the construction of a physical model, in order to experience the structure of the proposed design. The result has an obvious feeling of uniformity, which follows the existing design principles imposed by the area, maintaining the repetitive character of the site.

- Uniform area integration
- One design approach for all houses
- The uniformity of the sites' build environment is maintained

44 URBAN SCALE INTEGRATION PROPOSAL

The integration of PV systems can take one step further from the strictly building localized one. This has been proven by the previous step in the design process, as shown in chapter 4.3 (page 105). The type of residents in the whole area is consistent to the one of the studied building. This could mean that the electricity consumption may possibly be similar, and that there is potential of covering a portion of the electricity needs through the use of detached structures, not as a private element/utility, but as a common power source. Nevertheless, a study should be made to define the system parameters in terms of electricity loads. The morphology of a larger common system could also increase its diversity.

This approach may take a multitude of possible morphologies. In images 70 and 71 (page 108 & 109), the proposed elements resemble trees, defining areas of shadow and light on the urban fabric. Each integrated "tree" is intended to feed the power generation to two houses, covering a portion of their electricity demands. A larger scale integration would also be possible. Both integrations, Unit and Semi-public, are designed as Grid-Tied systems.

Table 17: PV module specifications and total estimated electricity generation for proposed integration per season and electricity load coverage percentage

PV module Specifications	
Type of PV	HIT Double cell
Name of Product	Sanyo HIT-205DNKHE1 Double
Power rating	205 watt (under STC test conditions) + up to 25% (backside)
Size of panel	862x1630x35 mm
Cells per module	60 (156mmx156mm/cells)
PV system	Grid-tied system
NOCT	48°C
Installation	12 panels on the Roof
Temperature coefficient	0.3%/°C
Tc = TA(°C) + [(NOCT-20/800) * G] , G= PSH/Average sunlight in hour	

Season	Estimated Electricity Generation for 1488 Sanyo HIT-205DNKHE1 Double panels in kWh	Consumption per season in kWh for 63 Households	Electricity load covered in %
Winter	16888,80	71568	**23,6**
Spring	107298,19	60606	**177**
Summer	142371,84	48384	**294,25**
Autumn	44741,18	61110	**73,2**

- Integration taken one step further.
- Potential of covering a portion of the electricity needs through the use of detached structures as a common power source.
- Morphology of larger common system increases area uniformity.
- Elements resemble trees, defining areas of shadow and light on the urban fabric, and serve as lighting sources as well.

C

Image 70: Visualization of urban integration from the north side of Carmencitas Gata.
3DS MAX using V-RAY.

D

Image 71: Visualization from the west terrace to the semi-public space. 3DS MAX using V-RAY.
- Uniformity of area maintained
- Elements serve as lighting sources

4.5 DESIGN APPROACH: MULTIPLE INTEGRATION POSSIBILITIES....

Through the previous steps, different design approaches at varying levels of implementation were explored, presenting a multitude of possibilities when it comes to the integration of PV systems into existing buildings. The latter was a remainder for the authors, regarding an observation made during the selection of the thesis focus, the fact that as individuals we relate to the design of a building in a subjective way. Exploring the potential of an area integration based on that fact (image 72, page 111), revealed that the built environment can present a diversity that is lacking in the urban areas of Sweden. By implementing designs focusing on the individual users, there is a possibility to create spaces that radiate a feeling of a character that is unique, and increase the feeling of belonging to a place, since individual "signatures" are obvious through the area of living, working and entertainment.

Image 72: Visualization of varying integration possibilities for row 11 at Carmencitas Gata. Different solutions for different people. 3DS MAX using V-RAY.

5. CONCLUSIONS & DISCUSSIONS

5.1 DESIGN CONCLUSIONS

The development of any project is based on the analysis of all relative issues on the local context level. This analysis is a fundamental step in order to form links between the architect, the project, and the site and actors/users, and without it the final result will be disconnected from its context and therefore viewed as an unsuccessful one. Analysing the relationships of all possible aspects of a design with the site, does not only strengthen the project itself. It also allows one to have a more holistic view about the specific design and problem area and extract ideas and concepts that can prove useful when moving on to a new project as well as when viewing the issue in a larger scale.

Within the thesis time frame and progress, different steps have been taken for its completion, each one being revealed as a necessary continuation of the previous one. A large portion of time was invested in gathering information regarding PV technologies and systems, as well as understanding the mechanics of energy generation calculations. This database was not a part of the tools we had available in the start, and without it the work would have been based on grounds characterized by uncertainty. The collection of data that were deemed necessary for the completion of the thesis was a long and often extremely difficult process, since there is not just one common source from where information can be extracted, and the cross referencing between sources, especially regarding calculation methods, has been very time and energy consuming. All the steps taken within the present thesis have strengthen our initial view and aim for the formulation of a set of tools that can be used for similar projects in the future, a goal that has been met at a very satisfactory level within the time limits of the master thesis.

The study has reviled that Solar irradiation data and their visual representation on the buildings' envelope are essential for the development of the design. The same stands for the study of sunlight on the buildings surfaces, in order to identify shadowed areas. If the integration is to be related with the needs of the users, having accurate figures related to their energy demands is crucial for sizing up the PV system during the design step. Without these steps, there is a possibility of integrating PV modules in inappropriate locations, leading to a large investment that will have low returns. Calculating the estimated power generation of the system will allow the identification of the portion of energy loads that can be covered by it. Data collections and calculation processes may seem like tedious work, but choosing to skip this steps would result to unclear results regarding the final design, with the latter being disconnected from the users needs. Completing an analysis of the functions for the spaces within the building has enabled us to identify the most used areas, rooms where integration of opaque PVs would decrease the natural daylight to unwanted levels, and where issues such as excess lighting should be dealt with. Without this step, the design might have led to degradation of the living conditions for the users. In terms of power generation, it would seem that a combination of unit and semipublic integration can bring the area closer to the desired Zero Energy building, since the energy yields will be greater. The Zero Energy goal is possible.

Furthermore, integrating a PV system into a building is not just a matter of placing photovoltaic modules on it. Through the development of the project, it has also become clear that the latter are materials like any other, and as such they have to be a part of an architectural approach. As one brick on its own is only a brick, but when it is a part of a greater structure it gains new attributes, such as a feeling of a place, a part of history, so is a PV module. PVs have the potential to be more than just electricity generating elements, but also carriers of feelings and ideas, just like a simple brick. Possibilities of tackling issues such as glare and overheating are there, and values related with lighting and visual design are inherent within them, either in a way of defining space through light and shadow, altering the intensity of light within spaces, or the visual relationships between them.

5.2 DISCUSSIONS

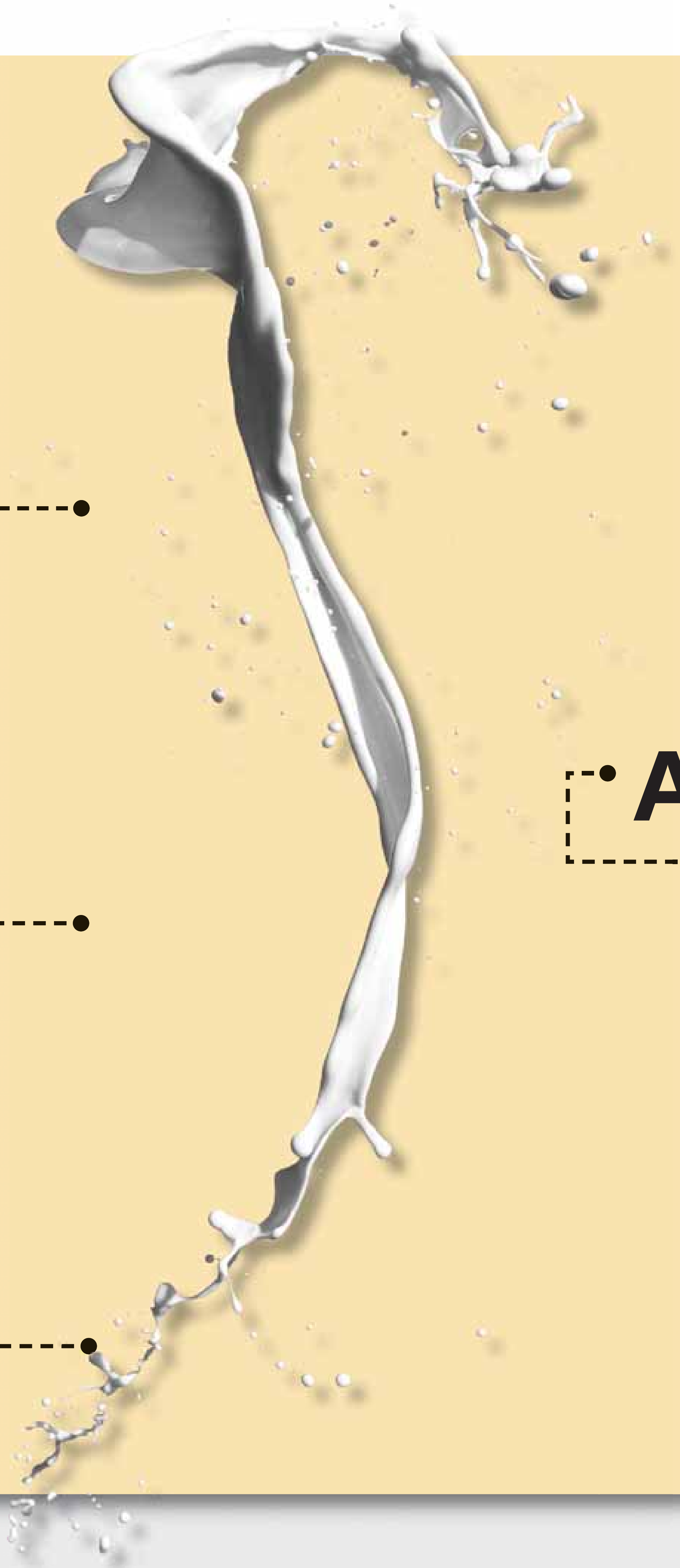
The energy payback of a Photovoltaic System is an issue that has been, and still is, widely discussed. Various approaches to the subject have been used in order to come to conclusions. Estimations vary greatly, due to the different considerations taken into account by each method, and the different types of PVs studied in each case, making them difficult, or even impossible to compare. The payback time spans from 1 years for a-Si modules (including BOS (Balance Of System)) (Kato, Hibino, Komoto, Ihara, Yamamoto & Fujihara (2001)), to 25.5 years for sc-Si (single crystalline silicon) module, if emissions are taken into account (Jungbluth, N. (2005))[84].
The U.S. Department of Energy, Energy Efficiency and Renewable Energy is presenting estimation periods for the energy payback of a PV that range from 1 to 4 years, for deferent types of modules. One to three years for thin-film PV systems of around 9% and 6% efficiency, and two to four years for crystalline silicon PV systems, of 14% to 12% efficiency[85]. With a payback time of 4 years, and a life span of 28 years, a PV system would produce pollutant free energy for 86% of its lifespan, a considerable benefit for the environment.
The PV technologies are a continuously developing field, promising more efficient products with reduced energy production requirements. The development of the DYE Sensitized cells sector could lead to availability of PV products that could find applications in more ways into the buildings that we design now, presenting an exciting prospect.

A major **drawback of PV systems is the cost**. The module cost equals around 50 - 60% of total installed cost of a Solar Energy System, making the solar module price a key element in the total price. Citizens and companies rely on subsidies to install PV systems, due to their cost, a fact that becomes clear if the installation of PV systems is examined for 2009 in Sweden. During the first half of 2009, there was no subsidy scheme, and delays in the distribution of the new subsidy in the second half of the year led to a 50% decrease in PV installed power. The new subsidy for July 2009-2011 for grid-connected systems, providing for 60 % of project costs (previously 70 %), 55 % for larger companies, with 2 million SEK to cover system components, installation and planning, led to a positive installed capacity for the 2010 calendar year. An interesting move on behalf of Sala Heby Energi AB, agreeing to purchase PV produced electricity, from the Solar cell community in the Sala and Heby municipality, at a higher price than the normal electricity price[86], thus forming Sweden's first feed-in tariff scheme, could be a forerunner for more similar schemes. Feed-in-tariffs and subsidies open to every type of system and owner, on any type of estate that has a building permit can be a great incentive for citizens.

PV products, although being in the market for a substantial period, are **still considered "something new"**. There is a lack of knowledge on the subject from the architects part, and this may be a reason why BIPV has not have the attention deserved. In a present that sustainability is so much discussed, and a turn towards renewable resources is becoming a necessity, the integration of PV and other renewable technologies should be a part of the architects study, so that we can assist in the formulation of a more sustainable build environment. PV installations are a good way of reducing the pressure on the environment, by providing for our energy needs locally, and without pollutants.

In the current state of power networks, utility power plants act like **batteries**, storing all generated power and feeding it back to the grid. Nevertheless, in a future where solar powered buildings may be the norm, it can be easily comprehended that this will not be possible, not only because a portion of the energy will be lost during transfers from and to the users, but also because of capacity capabilities of the power plants themselves. This leads to the conclusion that, smaller scale local networks should be developed, where the energy generated from the local PV systems can be stored and used when needed. The development of more efficient batteries is necessary for such a scheme to be materialized.

[84] *http://www.energybulletin.net/node/17219, Energy Payback of Roof Mounted Photovoltaic Cells by Colin Bankier and Steve Gale*
[85] *U.S. Department of Energy Energy Efficiency and Renewable Energy, PV FAQs*
[86] *National Survey Report of PV Power Applications in Sweden, 2009, Adam Hultqvist & Ångström Solar Center, Uppsala University*



APPENDIX A. PSH DATA

A1 EAST FACADE

Location: Latitude: 57°41'55" North, Longitude: 11°54'19" East

Inclination of plane: 90deg.
Orientation (azimuth) of plane: -90deg.

East façade
Season: Winter
Duration: December-February

Results for:	December					
Time	G	Gd	Gc	A	Ad	Ac
9:07	41	12	217	59	14	340
10:07	56	21	272	106	31	604
11:07	43	22	166	126	36	708
12:07	17	14	15	131	38	733
13:07	16	13	14	123	35	690
14:07	12	10	10	97	28	551
15:07	6	5	5	6	5	5
	191	97	699	648	187	3631

December = **0,2 PSH** Gd = 0,097

Results for:	January					
Time	G	Gd	Gc	A	Ad	Ac
9:07	52	19	342	74	23	528
10:07	59	26	340	106	36	744
11:07	47	26	196	120	41	827
12:07	21	17	15	123	42	847
13:07	20	16	14	118	40	813
14:07	16	13	11	100	34	709
15:07	10	8	7	10	9	7
	225	125	925	651	225	4475

January = **0,2 PSH** Gd = 0,125

Results for:	February					
Time	G	Gd	Gc	A	Ad	Ac
8:07	134	47	517	158	53	622
9:07	156	55	573	218	72	846
10:07	137	55	455	249	83	946
11:07	99	51	251	264	89	992
12:07	40	33	19	268	91	1000
13:07	38	31	18	261	88	985
14:07	34	28	16	243	81	928
15:07	26	22	13	207	69	806
16:07	15	13	7	16	14	8
	679	335	1869	1884	640	7133

February= **0,7 PSH** Gd = 0,335

Peak sun hours for Winter (December-Febuary) = 0.4 PSH diffuse 0.185 PSH

Season:Spring
Duration: March-May

Results for:	March					
Time	G	Gd	Gc	A	Ad	Ac
7:07	193	71	718	203	77	749
8:07	222	80	805	259	97	939
9:07	214	83	725	293	113	1030
10:07	181	80	543	314	124	1080
11:07	133	74	297	324	130	1110
12:07	59	49	22	327	131	1110
13:07	58	48	21	322	129	1100
14:07	54	45	20	310	121	1070
15:07	48	39	18	286	109	1010
16:07	37	31	14	248	92	905
17:07	23	19	8	181	70	669
	1222	619	3191	3067	1193	10772

March= **1,2 PSH** Gd = 0,619

Results for:	April					
Time	G	Gd	Gc	A	Ad	Ac
6:07	257	95	658	264	102	668
7:07	321	114	818	347	132	862
8:07	335	120	828	399	154	970
9:07	310	118	728	431	169	1030
10:07	257	109	545	450	178	1070
11:07	185	98	308	459	182	1080
12:07	78	65	35	462	183	1090
13:07	77	64	34	458	181	1080
14:07	75	62	33	447	176	1060
15:07	69	57	31	425	166	1020
16:07	60	50	27	388	149	949
17:07	47	39	21	330	125	824
18:07	30	25	13	236	93	596
	2101	1016	4079	5096	1990	12299

April= **2,1 PSH** Gd = 1,016

Results for:	May					
Time	G	Gd	Gc	A	Ad	Ac
4:07	143	50	305	167	56	364
5:07	314	120	656	341	132	709
6:07	399	141	845	428	160	887
7:07	434	150	911	484	181	990
8:07	424	148	873	520	196	1050
9:07	379	138	748	541	205	1090
10:07	307	125	554	552	208	1110
11:07	217	109	313	557	209	1120
12:07	88	72	30	558	209	1120
13:07	87	72	30	556	209	1110
14:07	86	71	30	550	208	1100
15:07	82	68	28	537	203	1080
16:07	76	63	26	513	193	1040
17:07	65	54	22	472	177	969
18:07	51	42	18	409	153	852
19:07	33	27	11	312	124	646
20:07	14	11	5	14	11	5
	3199	1461	5405	7511	2834	15242

May= **3,2 PSH** Gd = 1,461

Peak sun hours for Spring (March-May) = 2.2 PSH diffuse =1,032 PSH

Season: Summer
Duration: June-August

Results for:	June					
Time	G	Gd	Gc	A	Ad	Ac
4:07	185	82	383	221	95	468
5:07	296	115	634	330	132	704
6:07	368	137	793	407	163	854
7:07	401	147	853	461	186	949
8:07	395	147	820	496	202	1010
9:07	356	139	707	517	212	1040
10:07	293	127	528	529	216	1060
11:07	213	114	306	533	217	1070
12:07	92	76	40	534	217	1070
13:07	92	76	40	533	217	1070
14:07	91	75	39	526	215	1060
15:07	88	72	38	513	210	1040
16:07	82	68	36	489	199	996
17:07	72	60	31	449	181	929
18:07	59	49	26	390	156	823
19:07	42	35	18	306	124	654
20:07	24	20	10	175	70	376
	3149	1539	5302	7409	3012	15173

June= 3,2 PSH Gd = 1,539

Results for:	July					
Time	G	Gd	Gc	A	Ad	Ac
4:07	123	51	244	144	58	294
5:07	259	101	530	286	115	581
6:07	348	129	715	380	151	762
7:07	393	143	798	446	179	879
8:07	394	145	783	490	198	952
9:07	360	139	683	518	209	995
10:07	297	128	516	533	215	1020
11:07	215	114	303	540	217	1030
12:07	92	76	48	542	217	1030
13:07	91	76	48	539	217	1030
14:07	90	74	47	530	214	1010
15:07	86	71	45	512	207	987
16:07	79	65	42	481	194	937
17:07	68	57	36	432	173	854
18:07	54	44	28	360	143	724
19:07	36	30	19	257	104	522
20:07	17	14	9	103	38	212
	3002	1457	4894	7093	2849	13819

July= 3 PSH Gd = 1,457

Results for:	August					
Time	G	Gd	Gc	A	Ad	Ac
5:07	151	61	337	160	65	355
6:07	280	105	633	293	116	651
7:07	343	125	768	376	148	819
8:07	356	131	778	430	172	919
9:07	331	128	688	464	187	979
10:07	275	119	521	484	196	1010
11:07	199	106	302	494	200	1030
12:07	85	70	45	496	201	1030
13:07	84	70	44	492	199	1020
14:07	82	68	43	480	194	1010
15:07	77	63	40	457	184	967
16:07	68	56	36	419	167	899
17:07	55	46	29	358	141	785
18:07	38	32	20	266	106	593
19:07	18	15	9	113	42	254
20:07	17	14	9	103	38	212
	2459	1209	4302	5885	2356	12533

August= 2,5 PSH Gd = 1,209

Peak sun hours for Summer (June-August) = 2.9 PSH diffuse =1,401 PSH

Season: Autumn
Duration:September-November

Results for:	September					
Time	G	Gd	Gc	A	Ad	Ac
6:07	128	44	331	129	44	332
7:07	252	87	646	267	96	675
8:07	290	99	725	340	121	843
9:07	278	100	664	385	139	937
10:07	233	94	507	411	150	988
11:07	165	84	289	424	156	1010
12:07	66	55	37	428	157	1020
13:07	65	54	36	422	155	1010
14:07	62	51	34	406	148	978
15:07	55	46	31	375	135	918
16:07	45	37	25	325	116	810
17:07	30	25	17	242	88	613
18:07	12	10	7	84	26	220
	1681	786	3349	4238	1531	10354

September= 1,7 PSH Gd = 0,786

Results for:	October					
Time	G	Gd	Gc	A	Ad	Ac
8:07	165	56	551	193	66	653
9:07	179	63	570	249	84	825
10:07	157	63	452	280	96	912
11:07	113	58	255	296	102	954
12:07	45	37	28	300	104	965
13:07	44	36	27	293	101	947
14:07	40	33	24	274	93	896
15:07	32	27	20	238	80	792
16:07	22	18	13	173	60	587
	797	391	1940	2296	786	7531

October= 0,8 PSH Gd = 0,391

Results for:	November					
Time	G	Gd	Gc	A	Ad	Ac
9:07	104	36	448	149	47	682
10:07	98	37	387	185	56	835
11:07	71	35	217	201	61	901
12:07	27	22	15	206	62	917
13:07	25	21	14	199	60	890
14:07	21	18	12	178	54	807
15:07	14	12	8	16	13	9
	360	181	1101	1134	353	5041

November= 0,4 PSH Gd = 0,181

Peak sun hours for Autumn (September-November) = 1 PSH diffuse =0,452 PSH

A.2 WEST FACADE

Location: Latitude: 57°41'55" North, Longitude: 11°54'19" East

Inclination of plane: 90deg.
Orientation (azimuth) of plane: 90deg.

West façade
Season: Winter
Duration: December-February

Results for: December						
Time	G	Gd	Gc	A	Ad	Ac
9:07	8	6	7	59	14	340
10:07	13	11	11	106	31	604
11:07	16	13	14	126	36	708
12:07	26	20	46	131	38	733
13:07	48	22	201	123	35	690
14:07	55	20	276	97	28	551
15:07	6	5	5	6	5	5
	172	97	560	648	187	3631

December = **0,2 PSH** Gd = 0,097

Results for: January						
Time	G	Gd	Gc	A	Ad	Ac
9:07	12	10	8	74	23	528
10:07	17	14	12	106	36	744
11:07	20	17	14	120	41	827
12:07	32	25	52	123	42	847
13:07	51	26	239	118	40	813
14:07	60	25	360	100	34	709
15:07	10	8	7	10	9	7
	202	125	692	651	225	4475

January = **0,2 PSH** Gd = 0,125

Results for: February						
Time	G	Gd	Gc	A	Ad	Ac
8:07	18	15	9	158	53	622
9:07	28	23	14	218	72	846
10:07	35	29	17	249	83	946
11:07	38	32	19	264	89	992
12:07	62	46	71	268	91	1000
13:07	110	52	308	261	88	985
14:07	144	56	495	243	81	928
15:07	155	54	581	207	69	806
16:07	15	13	7	16	14	8
	605	320	1521	1884	640	7133

February= **0,6 PSH** Gd = 0,32

Peak sun hours for Winter (December-Febuary) = 0.3 PSH diffuse =0,18 PSH

Season:Spring
Duration: March-May

Results for: March						
Time	G	Gd	Gc	A	Ad	Ac
7:07	27	22	10	203	77	749
8:07	40	33	15	259	97	939
9:07	50	41	18	293	113	1030
10:07	55	46	20	314	124	1080
11:07	58	48	21	324	130	1110
12:07	91	68	91	327	131	1110
13:07	146	76	363	322	129	1100
14:07	191	81	595	310	121	1070
15:07	218	83	756	286	109	1010
16:07	219	79	803	248	92	905
17:07	176	67	653	181	70	669
	1271	644	3345	3067	1193	10772

March= **1,3 PSH** Gd = 0,644

Results for: April						
Time	G	Gd	Gc	A	Ad	Ac
6:07	35	28	15	264	102	668
7:07	51	42	22	347	132	862
8:07	63	52	28	399	154	970
9:07	71	58	31	431	169	1030
10:07	76	62	33	450	178	1070
11:07	78	64	34	459	182	1080
12:07	124	88	111	462	183	1090
13:07	204	101	371	458	181	1080
14:07	272	112	597	447	176	1060
15:07	319	119	762	425	166	1020
16:07	335	120	838	388	149	949
17:07	311	111	795	330	125	824
18:07	230	88	587	236	93	596
	2169	1045	4224	5096	1990	12299

April= **2,2 PSH** Gd = 1,045

Results for: May						
Time	G	Gd	Gc	A	Ad	Ac
4:07	19	15	6	167	56	364
5:07	38	31	13	341	132	709
6:07	55	45	19	428	160	887
7:07	68	56	24	484	181	990
8:07	78	64	27	520	196	1050
9:07	83	69	29	541	205	1090
10:07	86	71	30	552	208	1110
11:07	87	72	30	557	209	1120
12:07	143	97	116	558	209	1120
13:07	240	113	377	556	209	1110
14:07	327	128	608	550	208	1100
15:07	393	141	787	537	203	1080
16:07	430	149	892	513	193	1040
17:07	429	149	905	472	177	969
18:07	383	137	810	409	153	852
19:07	284	112	587	312	124	646
20:07	14	11	5	14	11	5
	3157	1460	5265	7511	2834	15242

May= **3,2 PSH** Gd = 1,46

Peak sun hours for Spring (March-May) = 2.2 PSH diffuse =1,049 PSH

Season: Summer
Duration: June-August

Results for:	June					
Time	G	Gd	Gc	A	Ad	Ac
4:07	28	24	12	221	95	468
5:07	46	38	20	330	132	704
6:07	63	52	27	407	163	854
7:07	75	62	33	461	186	949
8:07	84	69	36	496	202	1010
9:07	89	73	38	517	212	1040
10:07	91	75	40	529	216	1060
11:07	92	76	40	533	217	1070
12:07	147	103	123	534	217	1070
13:07	234	117	364	533	217	1070
14:07	311	131	578	526	215	1060
15:07	369	142	742	513	210	1040
16:07	399	148	837	489	199	996
17:07	396	146	847	449	181	929
18:07	354	133	763	390	156	823
19:07	271	108	579	306	124	654
20:07	142	60	297	175	70	376
	3191	1557	5376	7409	3012	15173

June= **3,2 PSH** Gd = 1,557

Results for:	July					
Time	G	Gd	Gc	A	Ad	Ac
4:07	22	18	11	144	58	294
5:07	41	34	22	286	115	581
6:07	58	48	31	380	151	762
7:07	72	59	38	446	179	879
8:07	81	67	43	490	198	952
9:07	87	72	46	518	209	995
10:07	90	74	48	533	215	1020
11:07	92	76	48	540	217	1030
12:07	147	102	127	542	217	1030
13:07	237	117	359	539	217	1030
14:07	315	131	563	530	214	1010
15:07	371	141	715	512	207	987
16:07	398	146	795	481	194	937
17:07	386	141	786	432	173	854
18:07	330	124	679	360	143	724
19:07	230	92	468	257	104	522
20:07	86	34	170	103	38	212
	3043	1476	4949	7093	2849	13819

July= **3,1 PSH** Gd = 1,476

Results for:	August					
Time	G	Gd	Gc	A	Ad	Ac
5:07	23	19	12	160	65	355
6:07	43	35	22	293	116	651
7:07	59	49	31	376	148	819
8:07	71	58	37	430	172	919
9:07	78	65	41	464	187	979
10:07	83	68	44	484	196	1010
11:07	85	70	45	494	200	1030
12:07	135	96	119	496	201	1030
13:07	219	110	360	492	199	1020
14:07	291	122	568	480	194	1010
15:07	340	130	718	457	184	967
16:07	357	131	786	419	167	899
17:07	332	121	747	358	141	785
18:07	255	97	576	266	106	593
19:07	106	40	237	113	42	254
	2477	1211	4343	5782	2318	12321

August= **2,5 PSH** Gd = 1,211

Peak sun hours for Summer (June-August) = 2.9 PSH diffuse = 1,414 PSH

Season: Autumn
Duration:september-November

Results for:	September					
Time	G	Gd	Gc	A	Ad	Ac
6:07	17	14	9	129	44	332
7:07	34	28	19	267	96	675
8:07	48	40	27	340	121	843
9:07	57	47	32	385	139	937
10:07	63	52	35	411	150	988
11:07	66	54	36	424	156	1010
12:07	106	75	104	428	157	1020
13:07	184	87	347	422	155	1010
14:07	247	96	553	406	148	978
15:07	285	101	690	375	135	918
16:07	286	97	721	325	116	810
17:07	233	81	596	242	88	613
18:07	84	26	219	84	26	220
	1710	798	3388	4238	1531	10354

September= **1,7 PSH** Gd = 0,798

Results for:	October					
Time	G	Gd	Gc	A	Ad	Ac
8:07	24	20	15	193	66	653
9:07	34	28	21	249	84	825
10:07	41	34	25	280	96	912
11:07	44	36	27	296	102	954
12:07	72	52	82	300	104	965
13:07	125	59	309	293	101	947
14:07	165	63	490	274	93	896
15:07	180	62	582	238	80	792
16:07	153	53	514	173	60	587
	838	407	2065	2296	786	7531

October= **0,8 PSH** Gd = 0,407

Results for:	November					
Time	G	Gd	Gc	A	Ad	Ac
9:07	16	14	9	149	47	682
10:07	22	19	13	185	56	835
11:07	26	21	15	201	61	901
12:07	43	31	58	206	62	917
13:07	79	36	266	199	60	890
14:07	102	37	416	178	54	807
15:07	14	12	8	16	13	9
	302	170	785	1134	353	5041

November= **0,3 PSH** Gd = 0,17

Peak sun hours for Autumn (September-November) = 0.9 PSH diffuse = 0,458 PSH

A.3 ROOF

Location: Latitude: 57°41'55" North, Longitude: 11°54'19" East

Inclination of plane: 6 deg.
Orientation (azimuth) of plane: 90deg.

Roof top
Season: Winter
Duration: December-February

Results for:	December					
Time	G	Gd	Gc	A	Ad	Ac
9:07	18	18	15	60	14	340
10:07	34	29	51	107	31	605
11:07	48	37	105	126	36	709
12:07	54	39	135	131	38	734
13:07	50	36	131	123	35	691
14:07	36	27	83	97	28	552
15:07	14	14	12	6	5	5
	254	200	532	650	187	3636

December = **0,3 PSH** Gd = 0,2

Results for:	January					
Time	G	Gd	Gc	A	Ad	Ac
9:07	27	27	19	74	23	529
10:07	46	39	84	106	36	745
11:07	59	47	149	120	41	828
12:07	65	49	183	124	42	848
13:07	61	46	180	118	40	814
14:07	49	38	137	101	34	710
15:07	27	22	59	62	18	446
	334	268	811	705	234	4920

January = **0,3 PSH** Gd = 0,268

Results for:	February					
Time	G	Gd	Gc	A	Ad	Ac
8:07	37	37	6	158	53	622
9:07	80	63	116	218	72	846
10:07	115	79	220	249	83	947
11:07	138	88	300	264	89	993
12:07	148	91	342	268	91	1000
13:07	145	89	339	261	88	985
14:07	127	80	293	243	80	928
15:07	96	63	205	207	69	807
16:07	48	35	83	129	40	518
	934	625	1904	1997	665	7646

February = **0,9 PSH** Gd = 0,625

Peak sun hours for Winter (December-Febuary) = 0.5 PSH diffuse = 0,364 PSH

Season:Spring
Duration: March-May

Results for:	March					
Time	G	Gd	Gc	A	Ad	Ac
7:07	61	58	33	203	77	750
8:07	115	89	165	259	97	940
9:07	162	112	304	293	113	1030
10:07	197	126	425	314	124	1080
11:07	221	134	514	324	130	1110
12:07	232	137	560	327	131	1110
13:07	230	135	560	322	128	1100
14:07	213	127	512	310	121	1070
15:07	183	113	420	286	109	1020
16:07	137	90	292	248	92	905
17:07	74	53	132	181	70	670
	1825	1174	3917	3067	1192	10785

March= **1,8 PSH** Gd = 1,174

Results for:	April					
Time	G	Gd	Gc	A	Ad	Ac
6:07	83	74	58	265	102	668
7:07	152	112	186	347	132	863
8:07	218	140	333	399	154	971
9:07	275	160	473	431	169	1030
10:07	318	172	592	450	178	1070
11:07	347	178	677	459	182	1080
12:07	362	181	722	462	183	1090
13:07	361	180	721	458	181	1080
14:07	343	175	675	447	176	1060
15:07	308	164	586	425	166	1020
16:07	255	145	461	388	149	949
17:07	186	115	310	330	125	825
18:07	106	75	151	236	93	596
	3314	1871	5945	5097	1990	12302

April= **3,3 PSH** Gd = 1,871

Results for:	April					
Time	G	Gd	Gc	A	Ad	Ac
6:07	83	74	58	265	102	668
7:07	152	112	186	347	132	863
8:07	218	140	333	399	154	971
9:07	275	160	473	431	169	1030
10:07	318	172	592	450	178	1070
11:07	347	178	677	459	182	1080
12:07	362	181	722	462	183	1090
13:07	361	180	721	458	181	1080
14:07	343	175	675	447	176	1060
15:07	308	164	586	425	166	1020
16:07	255	145	461	388	149	949
17:07	186	115	310	330	125	825
18:07	106	75	151	236	93	596
	3314	1871	5945	5097	1990	12302

April= **3,3 PSH** Gd = 1,871

Season: Summer
Duration: June-August

Results for: **June**

Time	G	Gd	Gc	A	Ad	Ac
4:07	56	54	19	222	95	469
5:07	125	101	110	330	132	705
6:07	196	138	231	407	163	855
7:07	267	167	372	461	186	950
8:07	331	188	515	496	202	1010
9:07	385	201	646	517	211	1040
10:07	426	208	756	528	216	1060
11:07	455	212	834	533	217	1070
12:07	469	214	875	534	217	1070
13:07	470	215	875	533	217	1070
14:07	455	213	834	526	215	1060
15:07	423	208	754	513	210	1040
16:07	375	195	640	489	199	997
17:07	311	174	501	449	181	930
18:07	235	143	349	390	156	823
19:07	153	104	200	306	124	655
20:07	70	54	70	175	71	377
	5202	2789	8581	7409	3012	15181

June= 5,2 PSH Gd = 2,789

Results for: **July**

Time	G	Gd	Gc	A	Ad	Ac
4:07	50	50	26	144	58	294
5:07	104	89	85	286	115	582
6:07	176	127	197	381	151	763
7:07	250	159	332	446	178	879
8:07	318	182	471	490	197	952
9:07	376	197	600	518	209	996
10:07	421	206	708	533	214	1020
11:07	452	210	785	540	217	1030
12:07	468	213	825	542	217	1030
13:07	467	213	825	539	216	1030
14:07	450	211	783	530	213	1020
15:07	414	204	702	512	207	987
16:07	361	189	587	481	193	937
17:07	292	165	449	432	172	855
18:07	211	131	299	360	143	725
19:07	126	89	155	257	104	523
20:07	46	38	42	103	38	213
	4982	2673	7871	7094	2842	13836

July= 5,0 PSH Gd = 2,673

Results for: **August**

Time	G	Gd	Gc	A	Ad	Ac
5:07	53	53	28	160	65	356
6:07	112	93	102	293	116	652
7:07	184	130	230	376	148	820
8:07	253	158	370	430	172	920
9:07	312	177	503	464	187	979
10:07	357	188	616	484	196	1010
11:07	388	194	696	494	200	1030
12:07	403	197	738	496	201	1030
13:07	402	197	737	492	199	1030
14:07	384	192	692	480	194	1010
15:07	347	182	607	457	184	967
16:07	291	163	486	419	167	899
17:07	220	134	342	358	141	786
18:07	137	94	189	267	106	594
19:07	51	41	52	113	42	254
	3894	2193	6388	5783	2318	12337

August= 3,9 PSH Gd = 2,193

Peak sun hours for Summer (June-August) = 4.7 PSH diffuse = 2,55 PSH

Season: Autumn
Duration:September-November

Results for: **September**

Time	G	Gd	Gc	A	Ad	Ac
6:07	39	39	22	130	44	333
7:07	90	75	87	267	96	675
8:07	154	106	215	340	121	844
9:07	212	128	347	385	139	938
10:07	257	142	461	411	150	989
11:07	288	150	543	424	156	1010
12:07	303	153	586	428	157	1020
13:07	301	152	584	422	155	1010
14:07	281	145	537	406	148	979
15:07	242	131	448	376	135	919
16:07	185	109	324	325	116	811
17:07	114	75	179	242	88	614
18:07	35	28	40	85	26	220
	2501	1433	4373	4241	1531	10362

September= 2,5 PSH Gd = 1,433

Results for: **October**

Time	G	Gd	Gc	A	Ad	Ac
8:07	61	54	60	193	65	654
9:07	106	77	171	249	83	826
10:07	144	93	276	280	95	913
11:07	169	101	355	296	102	955
12:07	180	104	395	300	104	965
13:07	177	102	392	293	101	948
14:07	158	93	345	274	93	896
15:07	124	77	257	238	80	793
16:07	76	53	140	174	60	588
	1195	754	2391	2297	783	7538

October= 1,2 PSH Gd = 0,754

Results for: **November**

Time	G	Gd	Gc	A	Ad	Ac
9:07	40	36	36	149	47	683
10:07	68	51	123	185	56	836
11:07	87	59	193	202	61	902
12:07	95	62	231	206	62	918
13:07	92	59	228	199	60	891
14:07	76	51	184	178	54	808
15:07	47	33	97	132	40	607
	505	351	1092	1251	380	5645

November= 0,5 PSH Gd = 0,351

Peak sun hours for Autumn(September-November) = 1.4 PSH diffuse = 0,846 PSH

BIPV: TOOLS FOR IMPLEMENTATION AND DESIGN APPROACHES