SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Report on a new and universal classification method “new generation solar cooling square view” for generic systems

IEA SHC TASK 53 | NEW GENERATION SOLAR COOLING & HEATING SYSTEMS (PV OR THERMALLY DRIVEN)

Report on a new and universal classification method "new generation solar cooling square view" for generic systems

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1. Scope of the activity A4

The activity will study in a conceptual approach called "square view" develop among IEA SHC Task 44 consisting on simply presenting the different configurations of integration of solar cooling and heating systems among buildings, micro grids and the central grid. One criteria of limitation of the possibilities of configuration will be to consider systems available on the market to close to be commercialized.

2. Executive Summary

According to the international work plan, this activity aims to carry out a classification of the new generation of solar heating and cooling systems by a suitable graphical illustration. With the help of the developed square view, the topology of the system configuration is easy to understand and is presented in a standardized manner.

Representatives of the AIT coordinated this activity and proposed a square view displaying schematically the configuration of the new generation of heating and cooling systems. In several iteration loops, the proposal has been improved through feedback from IEA SHC Task 53 participants. Figure 1 shows the basic structure of the square view. The developed visualization contains on one hand the technical energy source and on the other hand, essential system configuration and its technical components.

In this publication the application of the developed square view is demonstrated for three USE CASES: a) USE CASE of a references air-conditioning or cooling system without using local solar energy, b) USE CASE of a solar-assisted energy system for an innovative office building (ENERGYbase) in Vienna and c) USE CASE Multi-functional façade with PV for a solar autonomous cooling application.

In report D2 of IEA SHC Task 53 the system configuration of around ten identified NG solar heating and cooling system (commercially available and R&D) is visualized by using the developed square view.

Especially some conclusion and advice related to PV technology choices is integrated in the final section of this publication, where readers get an overview of PV technology applicable for NG solar heating and cooling systems.

3. Work performed in Activity A4

3.1. Energy Flow charts

In the task energy flow charts of high complexity have been provided. These are useful and essential as they map the functioning, technical operation and detailed schematic construction of the units discussed or developed. Nevertheless, for a quick view of the system type, by providing information on the essentials (central vs. decentralized, energy source, provision and dissipation of cooling etc…) this might be too detailed. For this purpose, a second kind of schematics has been developed, i.e. the schematic reduced square view.

3.2. Reduced square view introduction

As the energy flow charts, the square view is giving a graphical scheme of the given heating/cooling system. It differs for several aspects from it: It is not so detailed; it gives only essential flows of energy and only shows essential main components; it is graphically invariant.

By this the main advantages are:

- Fast comparing different systems
- Categorizing systems
- Understanding operation principles easy
- Scheme has always the same look
- Components are always found at the same position

3.3. Basic Scheme

In the following the basic graphical principle is described. Figure 1 shows the basic scheme. It is composed by the following parts. In the scheme all technical resources or components or units are given by boxes containing the name if the resource, component or unit.

A. Frame of the scheme (grey part): Resources and Legend
   1. Technical resources – at the top of the view
   2. Installation type – at the left side of the view
   3. Output type – at the right side of the view
   4. Identification / legend – at the bottom of the view

B. Center of the scheme (white part): Technical components
   5. Production / provision – left row
   6. Conversion – middle row
   7. Supply – right row.

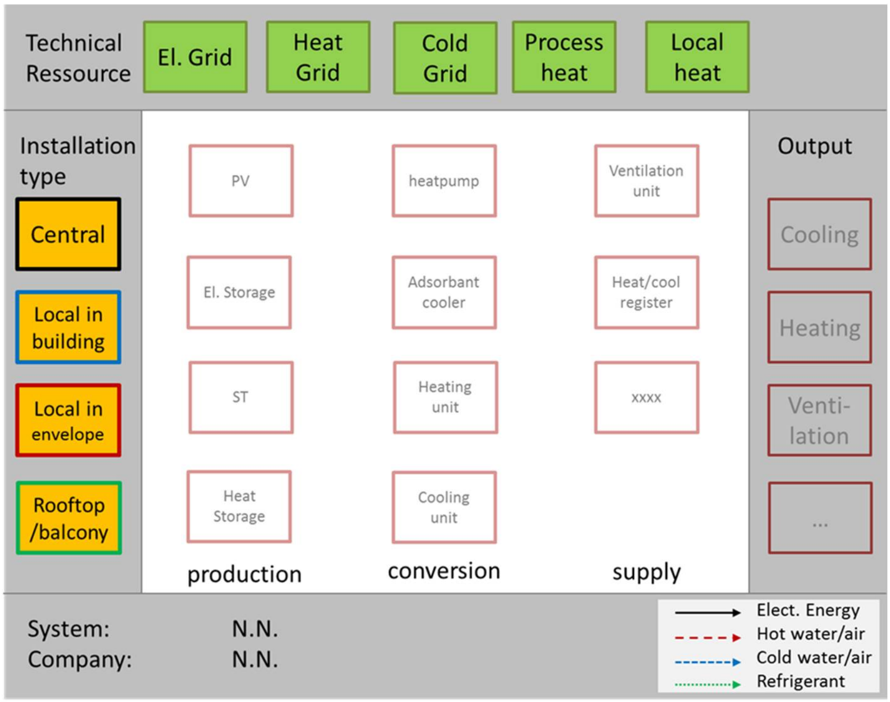


Figure 1: Schematic reduced square view. Basic graphic of all components, no system layout is described (Source: AIT)

In detail the single categories are:

- The technical resources are considered ‘environmental’ compared to the technical systems of the building, they are feed from outside (grid, ground, sole water etc.).
- The installation type of the system defines the type by the color of the frame of boxes (black = central type of installation, blue = decentralized in the building, red = in the building envelope and green = externally attached to the building.
- The output of the system provides hot/cold water or conditioned/ fresh air in order to control the air temperature and humidity of the room to meet the comfort requirements.
- The identification gives the name of the system or project, the company planner or producer and a legend of mass or energy flows.
- The production section gives the means of provision of energy driving the HVAC system components.
- The conversion section defines the components which are used for energy conversion from the energy sources to the heat, cold or ventilation.
- The supply defines the technical components used to deliver the HVAC flow.

3.4. Usage of the scheme

For using the scheme, the technical components used in a defined system are colored. The frames of these boxes are colored corresponding to the integration type. All boxes forming a system are connected by lines, describing the flow of energy, heat or cold in the corresponding colors given in the legend. In the view the fixed boxes their positions are never changed. The boxes are highlighted when operational and sallow when not operational. In this way the view of the scheme is always the same and allows fast comparing differing systems. The scheme then gives a topological view of the type and formation of a system as well as the technical components used.

3.5. Examples of the reduced square view

In the following the square view is used to describe different HVAC systems:

A) A standard air-conditioning or cooling system as reference case

B) Solar-assisted energy system in the office building ENERGYbase, Vienna

C) MULTI-FUNCTIONAL FAÇADE WITH PV FOR SOLAR AUTONOMOUS COOLING APPLICATIONS developed within the Austrian research project “COOLSKIN”

The examples were chosen because they show diverse and complementary systems.

A) Reference System

The chosen reference system is a standard cooling system, where as an example a conventional compression chiller is fed by electricity from the grid. The chilled water produced is supplied to an air handling unit, that ventilates mechanically cooled and dehumidified air to the rooms. All technical units are central (i.e. black box line color) and the ventilation of air and chilled water is transported and/or circulated by air ducts and water pipes of the distribution system. The schematic reduced square view is shown in figure 2.

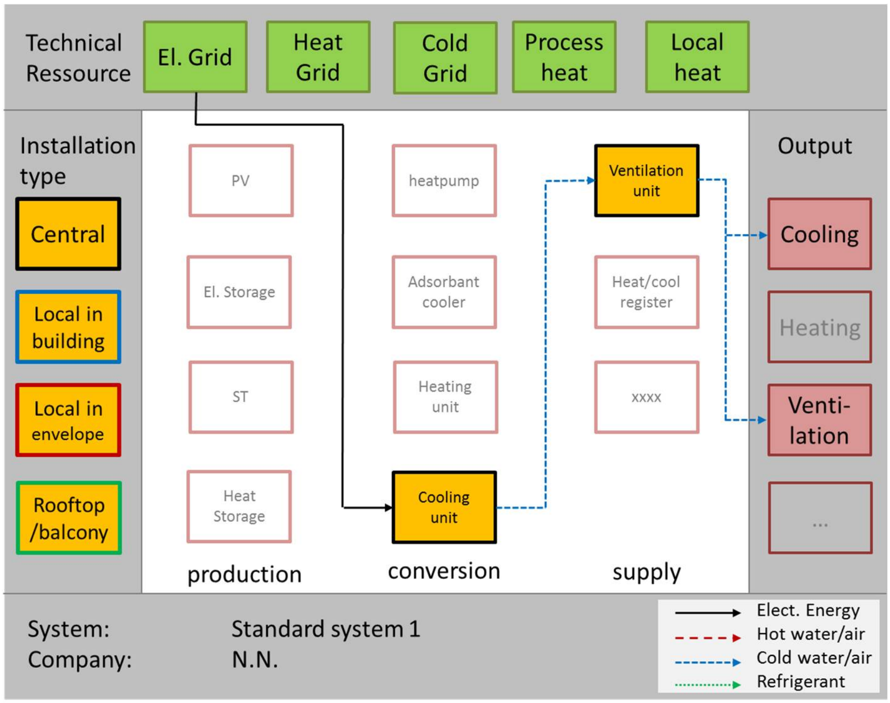


Figure 2: Schematic reduced square view of a standard HVAC system for cooling and ventilation (Source: AIT)

B) Solar-assisted energy system in the office building ENERGYbase, Vienna

Energy system

The ENERGYbase office building fulfils the requirements of the ‘Passivhaus’ standard. The heating, cooling and ventilation system is designed to use both a) water and b) air based energy distribution systems. The office air temperature in ENERGYbase is controlled by thermally activated building elements, i.e. concrete core activation (CCA). The CCA covers the sensible load for heating and cooling; due to the controlling of the water inlet temperature into CCA and the different air temperature levels in the office rooms heat is extracted from or delivered to the building construction mass. For controlling the indoor air humidity and for supplying fresh air, a solar heat driven Desiccant Evaporative Cooling (DEC) system is put into operation, which is an air-conditioning system without using conventional vapor compression chiller for cooling and dehumidification purposes.

Geothermal energy is exploited by means of ground water in the ENERGYbase building. Two heat pumps coupled to the ground water temperature levels raises the water temperature up to 45 degrees Celsius in winter and the hot water is supplied on one hand to the CCA and on the other the hand to several heating coils of the air treatment system. In summer the ENERGYbase is cooled by extracting heat from CCA with the help of circulated water. Finally, a water to water heat exchanger transfers the extracted heat to the ground water. The ground water temperature in summer time is approx. 14 degrees Celsius and is raised by around 4 Kelvin. In summer high ambient air temperature and humidity values are treated by the DEC system. The collector area is around 285 m² and mounted on the upper part of the south façade. First of all, the solar heat is used for the regeneration process of the humidity loaded sorption material used in the DEC system and additionally for covering partly the heating demand of the CCA and the heating coils.

Building facts

Building facts are listed in Table 1. Figure 1 shows two photos of the ENERGYbase, one shows the south and west façade and the other one north and east façade. The geographical position of the ENERGYbase location and some selected weather parameter are presented in Table 2.


Figure 3: Photo of ENERGYbase showing
left) south and west facade and right) north and east façade (Source: Hurnaus)

Table 1: Building facts of ENERGYbase

Type of building	Office
Location	1210 Vienna / Austria
In operation since	2008
System operated by	Siemens Facility Management
Area (Gross/ Useful/ Air-conditioned)	9,430 m²/ 7,544 m² / 5,000 m²
Use of solar energy	Photovoltaics 48.2 kW (peak) power
Use of shallow geothermal energy	Ground water coupled heat pump
Other innovation	Green ventilation (i.e., biological supply air treatment in wintertime for pre-humidification and filtering)
	Costume-made south façade oriented to the South and 7° to West
	Thermal mass activation for sensible heating & cooling

Table 2: Climate

Located	48°12' N/ 16°22' E
Tmean (Tmax / Tmin hourly)	9.5°C (28.9 / -14.6°C)
Global radiation on horizontal	1,122 kWh/m² year
Global diffuse on horizontal	627 kWh/m² year
Global direct on horizontal	495 kWh/m² year

Photovoltaic system

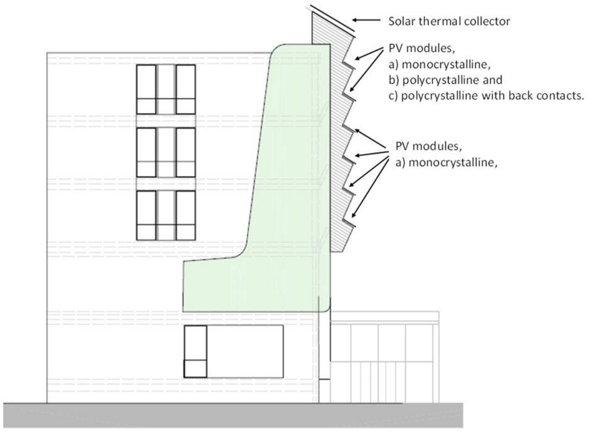
The photovoltaic system with a nominal capacity of 48.2 kWp is attached to a custom-made stepped south façade. Six module lines with three different kinds of cell and module technologies are attached to the façade. The PV modules are naturally ventilated by ambient air and tilted with an angle of 31.5 degree in order to maximize the solar electricity yield.

In addition, the façade added photovoltaic systems was designed and planned as well for research purposes and a scientific monitoring system is implemented beside other measurement equipment of the inverter. The upper two

PV module lines are designed and installed for research activities and three different kinds of cell technologies are integrated; namely a) monocrystalline, b) polycrystalline and c) polycrystalline with back contacts. Since February 2009 the PV system is in operation. Table 3 lists the facts of the technical data of the PV system.

Table 3: Technical data of the PV system (Source: ATB-Becker 2008)

Type of	Attached to façade/ natural
Orientation / tilt	South and 7° to West / 30°
Total nominal	48.2 kW$_p$
Total PV module	400 m²
Module type 1	Solarwatt M135-55 GEG LK
Cell type	monocrystalline
number of pieces	286
Nominal power	134 W$_p$
Module type 2	Solarwatt P 125-55 GEG
Cell type	polycrystalline
number of pieces	40
Nominal power	122 W$_p$
Module type 3	Solarwatt M135-55 GEG
Cell type	polycrystalline
number of pieces	40
Nominal power	127 W$_p$
Inverter	10 x Sunways, 2 x SMA



The Square view

The schematic reduced square view is shown in figure 3.

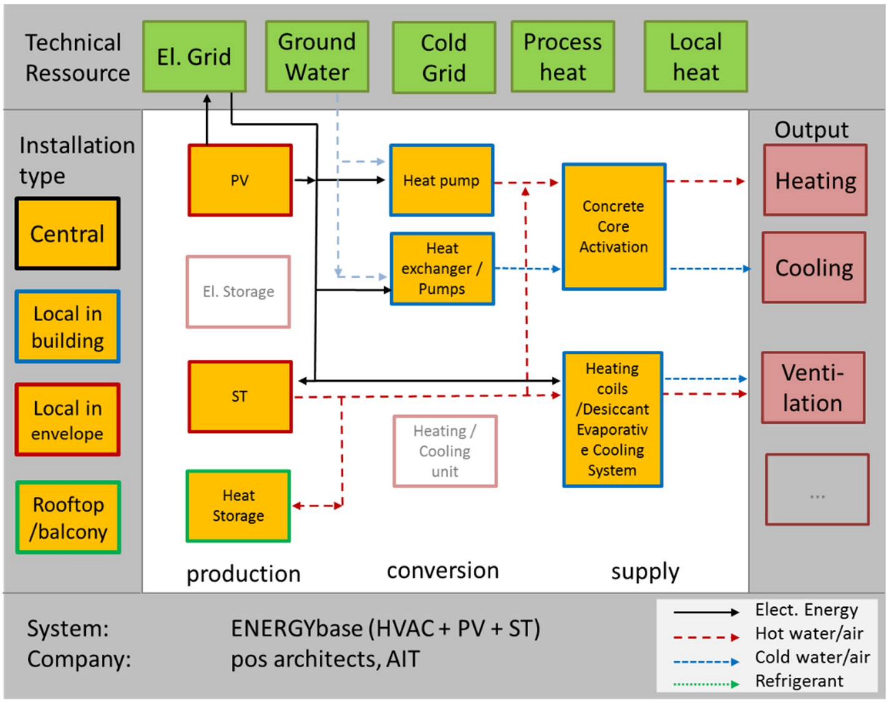


Figure 4: Schematic reduced square view of the ENERGYbase system (Source: AIT)

C) MULTI-FUNCTIONAL FAÇADE WITH PV FOR SOLAR AUTONOMOUS COOLING APPLICATIONS

Introduction

The objective of the Austrian research project COOLSKIN is the development, assessment and functionality approval of a façade-integrated energy system for cooling. Façade integrated photovoltaic modules directly convert the solar irradiation onto the vertical surface into electricity, which operates the compressor unit of a heat pump cycle for controlling the indoor temperature of the adjacent room. The COOLSKIN system concept addresses a) decentralization of the energy supply and b) energy autarky by the usage of solar electricity, i.e. no external energy sources are required. Methods to fulfil the project requirements are i) elaborated system simulations, ii) experimental tests with a functional model of the system and iii) field tests under real operating conditions. This project 'COOLSKIN' is funded by the national 'Klima- und Energiefonds' within the programme ,e!MISSION' 1st Call 2014.

The square view

The developed COOLSKIN concept is shown in figure 5 and herewith the strength of the schematic reduced square view is very well visible. The electricity for driving the entire energy system is provided by a façade integrated PV system, where the solar electricity can be consumed directly at once or a battery function as an energy storage. A compact heat pump system integrated as well in the façade extracts heat from the office room for cooling purposes via conditioned air or circulated cold water. In this case all technical components of the energy system are integrated in the building envelope (façade) (i.e. red box line color).

By comparing figures 2, 4 and 5 the simplicity of the schematic view is visible, i.e. giving fast layout view of the main system components, its basic operation, connection principle and its integration site. Figure 6 displays the COOLSKIN system implemented in the field test. Note the difference in the flow of electric energy, i.e. the battery can be bypassed. Figure 7 is a photography of the Test-Mock-Up of the COOLSKIN-Façade at the test site of the Technical University of Graz.

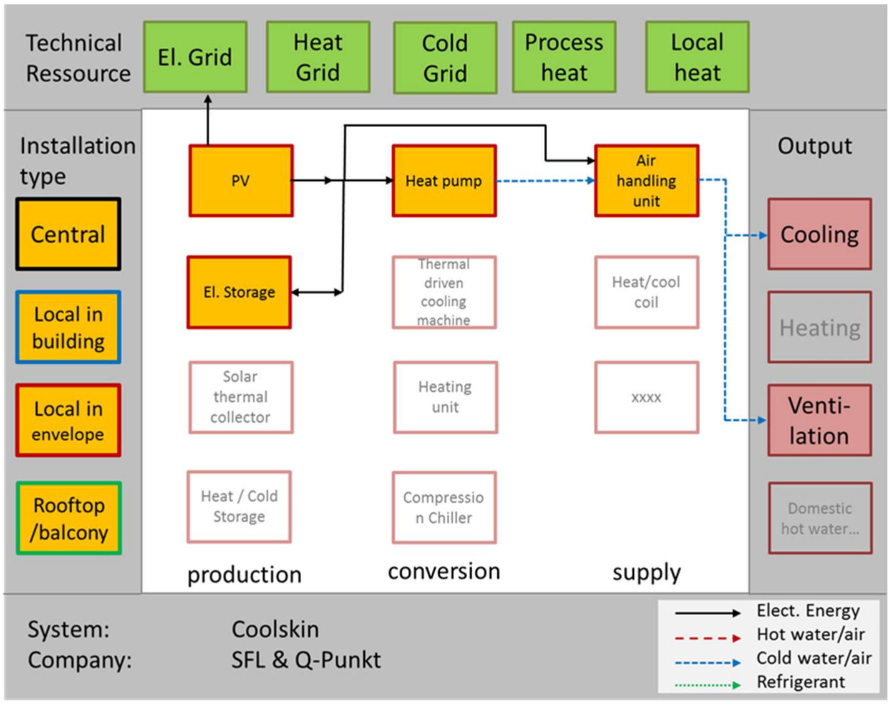


Figure 5: Schematic reduced square view of the COOLSKIN system as planned. (Source: AIT)

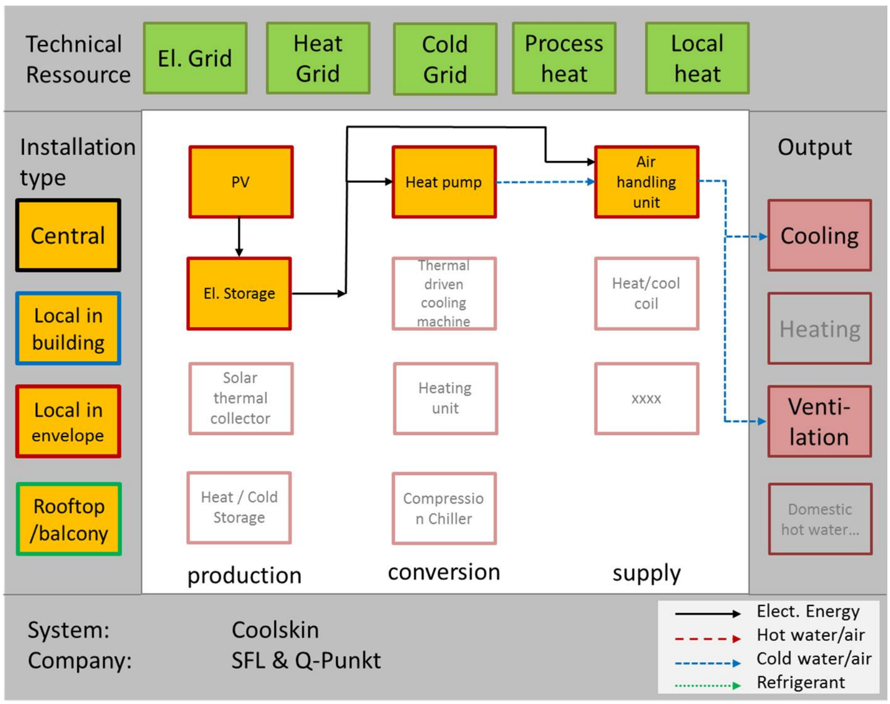


Figure 6: Schematic reduced square view of the COOLSKIN system as realized (Source: AIT)

Figure 7: Test-Mock-Up of the COOLSKIN-Façade at the test site of the Technical University of Graz (Source TU Graz).

Conclusion on Test-Setups:

COOLSKIN-Façade was realized in 2017 in a test mock-up, see figure 6. The test facade is set in front of the test rooms. One room is kept as reference; the other room is conditioned by the COOLSKIN set-up. The PV is realized as architectonic representative installation of grey-emailed and “black-line” by an Austrian module manufacturer (ERTEX-solar). The cooling system is a special designed compressor by the Technical University of Graz. The setup was beforehand tested in by AIT in a static solar simulator using the same PV-Modules. Following key findings were made on the results from laboratory tests:

First, the direct coupling of the battery and the load in series does not allow to bypass the battery. This might be useful in a real setting, when the battery is empty and should be loaded, there is enough solar energy to run the load, but it will take some time to recover the battery voltage above the security threshold. If load priority is wished the bypass is essential, in a setting like figure 6. Please note, that in the exclusively topological scheme of figure 6, no control strategy is visualized.

Further is was important to test all critical settings of the systems: the lower voltage of the battery and switch of, meaning that there is not enough solar electricity but the load was powered. Very important for the real running of the system out-doors was also the operation point where the load is powered, the battery is full, but the solar production is slightly decreasing, leading to a discharging of the battery. This behavior can show if the PV-system size it at all big enough (including the losses due to the inclination for the modules in the façade).

The last important test is the test showing the “flickering” of the whole system. For a certain irradiation budget, the system layout from battery capacity and PV-array size is too weak. From such a behavior it would follow that the PV-size or the battery size and the PV-size should be increased. In a setting where the system components can be programmed one should try to avoid this behavior, e.g. by increasing the level, where the battery is reconnected to the load.

Conclusion on PV-system design

In a worst-case scenario there will be days with cooling demand but not enough sun irradiation to run the load. From this scenario the needed storage size could be extracted for running the cooling system only via the battery: then the storage system capacity SC is given by the time interval t where the demand is provided, the electric load demand ELD and the DoD of the battery system by: SC = t*ELD / DoD. For running for n days this can be expanded by n*t. This does not include a small amount which may be provided by the solar array anyway (e.g. 10% - 20% on rainy days).

4. Conclusions on PV Technology choice

Different PV technologies may be used for implementation in decentralized energy production for cooling. Today, mainly crystalline technologies are in the building market. But also, other may be useful. All technologies in laboratory or before market entry are given in the figure 8.

Currently offered PV technologies (see Figure 8) are subdivided in crystalline

- Mono crystalline silicon (mc-Si), efficiencies up to above 20%
- Poly crystalline silicon (pc-Si), efficiencies up to above 17% and thin film cells
- Si-based (a-Si:H, µc-Si:H, poly-Si), efficiencies up to above <10 %, the technology was sold as integrated glass-solution instead of windows or as light-weight steel-roof top foil. The main market shifted from BIPV options towards consumer electronics and camping devices. The outstanding issue of a-Si is its low losses when heated by the sun and its ability to partially repair its degradation durung the summer month.
- Copper-indium-diselenide (CIS, CIGS), „CIS Family", most common and possible on all substrates, available are commercial, prototype and laboratory productions, efficiencies up to above <20 (16) %. This technology is offered as well as high-end BIPV solution as well as standard modules or on flexible substrates.
- Cadmium-telluride (CdTe), toxic (Cd), efficiencies up to above <19 (13) %. This technology is offered mainly for big free field installations. It is not used in BIPV applications, most likely due to containing Cd in the module.
- Gallium-arsenide (GaAs), indium-gallium-arsenide (InGaAs), efficiencies up to above 34%. This technology is uncommon in terrestrial use, solely as multijunction with wafer transplantation, terrestrial relevance in future with mc-Si / GaAs multijunctions, One manufacturer now offers (after 2017) a terrestrial solution as light weight foil with above 30% efficiency.
- Organic / polymer-cells and dye-sensitized solar cells (DSC, DSSC), short life span, low efficiency, high affinity to degradation

Further hybrids of different cell types are also possible. These "multi junctions" or hybrid cells (HIT, a-Si/µc-Si-tandem, mc-Si/GaAs, …) are able to use a broader range of the solar spectrum or avoid surface reflections, which increases the efficiency. A new technology is the perovskite type solar -cells, which reaches current laboratory efficiency of 19%, but is not close to a commercial product.

The advantage of thin films in contrary to crystalline cells is a better temperature coefficient (power loss / temperature rise) of 0.2 – 0.3%/K compared to 0.35-0.5%/K. Except for high efficiency cells like HIT and mc-Si backside contacted cells.

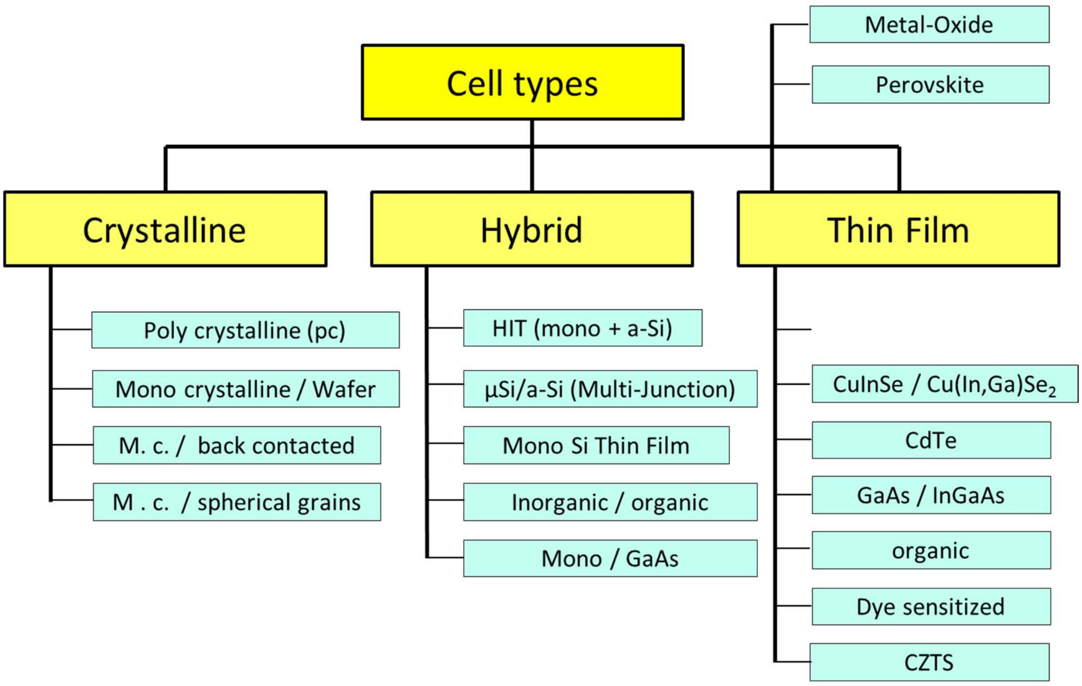


Figure 8: Cell technology overview. Only a view of the given families are represented in the market © AIT

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