Smart Grid Energy Management Staff Exchange

SMARTGEMS
energy network

# D4.2 Cost benefit analysis for polygeneration and CSP/CPV for smart communities: Infrastructure and connectivity
# - public version -

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# Summary

This report summarizes activities performed within the task 4.2 of the Smart Gems project, aimed at the integration of Concentrated Solar Power / Concentrated Photovoltaic (CSP/CPV) polygeneration systems into local smart grids.

Solar energy is a grooving component of the energy sources mix in our communities. In the solar belt regions, with a high level of direct irradiance, solar concentration may represent a plus, as the quality of the harvested energy would be higher, both in terms of enthalpy – if thermal – and efficiency – if electrical. Hybrid generation of heat and electricity can be implemented by innovative CPV collectors plant design at a building and settlement level. Also the large CSP systems can be redesigned and scaled down at a size that is more compatible with built environments. Many accessories and subsystems are needed as storage systems, monitoring and control architectures, integration with cooling cycles, forecasting methodologies.

Also the hybridization with other local renewable sources as the biomass comes out as a priorities of study and analysis, as well as new business and management models of production and distribution of energy that could boost the new prosumer paradigm.

All these multifaceted aspects of solar polygeneration have been explored in connection with the real sites available within the framework of the Smart GEMS partnership. Especially the site in Palermo (Italy), made available by the partner Idea, has been exploited in this task. It is the physical infrastructure of the Solar Living Lab, hosted by the Consorzio ARCA in the university campus of the town, where both solar thermal LFR collectors and HCPV/T trackers, designed by Idea, have been installed and connected in a polygenerative scheme. In this context the data collection and processing model developed by TUC has been tested by the seconded researchers. A PCM thermal storage has been specifically designed for the HCPV/T as an additional module to be integrated into the collector network and new building materials have been considered for improving efficiency. As a hybrid solar thermal model has been selected for the strategic development of the energy infrastructure in the rural area of Madonie, close to Palermo, a study has been devoted to the creation of a biomass collection and treatment process at a local level, in a circular economy frameset. Finally DSS tools and Demand Aggregation agents have been discussed, because of their relevance in the real world implementation of such innovative generation technologies at a community level.

**All the activities have seen the constant interaction among researchers both from industry and academia. The specific contribution of each seconded researcher is summarized in Table 1. Most of the secondment reports have been considered in this document, some of them are still in a draft stage as data processing activities are still on going and the results will be made available in an addendum.**

| Researcher | Sending Organisation | Hosting Organisation | Research Field |
|---|---|---|---|
| Nikos Kampelis (author, work in progress) | TUC | IDEA | Application of advanced monitoring and control technologies at the model site of the Solar Living Lab in Palermo. |
| Angeliki Mavriginniaki (author, work in progress) | TUC | IDEA | Application of advanced monitoring and control technologies at the model site of the Solar Living Lab in Palermo. |
| Filippo Paredes(author) | IDEA | CYI | Integration of water treatment services into an HCPV building integrated system. |
| Luca Venezia (author) | IDEA | CYI | Application of solar concentrating technologies for distributed generation in hotels and wineries. |
| Miltiadis Samanis (author) | CUT | IDEA | Study of a local biomass processing system to be integrated into an hybrid solar+biomass small scale plant |
| Harry Varnavas (author) | CYI | EXE | Integration of a polygenerative solar platform – new building materials |
| Thiago Santos (author) | BRU | IDEA | Design of a PCM (Phase Change Material) storage tank to be used in HCPV systems |
| Miltiadis Samanis (author) | CUT | EXE | Integrated processes for smart grids and decision support tools; the Galileo's Eye at Exergy |
| Assoc. Professor Georgios Chalkiadakis (author) | TUC | LOC | Towards a Multiagent Architecture employing Mechanism Design for the Aggregation of Demand Flexibility |

**Table 1**: Seconded researchers and activities presented in Deliverable 4.2

# 1. Introduction

## 1.1 Solar Thermal LFR Concentrator

The innovative concentrating solar system designed by Idea is focused to develop cost-effective polygenerative plants (Figure 1). Technology is based on a Fresnel concentration system that reflects solar rays to the same target, concentrating the solar radiation. Thermal energy is collected at about 250-300 °C, stored inside a thermal storage tank and able to provide heat or cold (through an absorption chiller) to buildings or industrial processes or produce energy through an Organic Rankine Cycle (ORC).

**Figure 1**: FRESCO system with the LFR collector reflecting the sun radiation onto a CERMET receiver

The evaluation of Solar Thermal technologies at a settlement level has been developed with reference to the need of wineries of Cyprus. Especially the integration of solar cooling solution into the production process has been analyzed, in particular for small scale wineries, especially diffused in the rural Troodos region. The benefits connected to the introduction of Linear Fresnel collectors and chillers driven by renewable sources, placed near to the production site, were evaluated. The preliminary study of Zambartas winery, has been conducted by evaluating energy consumption and available spaces for an integrated implementation of a concentrated solar system.

## 1.2 HCPV/T system

Idea has developed FAE technology, which explores the capacity of HCPV (high concentrator photovoltaics) for electrical and thermal energy generation. HCPV system uses a rectangular parabolic mirror which concentrates the solar rays under a level higher than 1000 suns and efficiency up to 44%. HCPV is suited for areas with high direct normal irradiance (as the Sun Belt region, Figure 2) with strengths and weakness of CPV pointed by Fraunhofer ISE and NREL (National Renewable Energy Laboratory) and presented on Table 2.

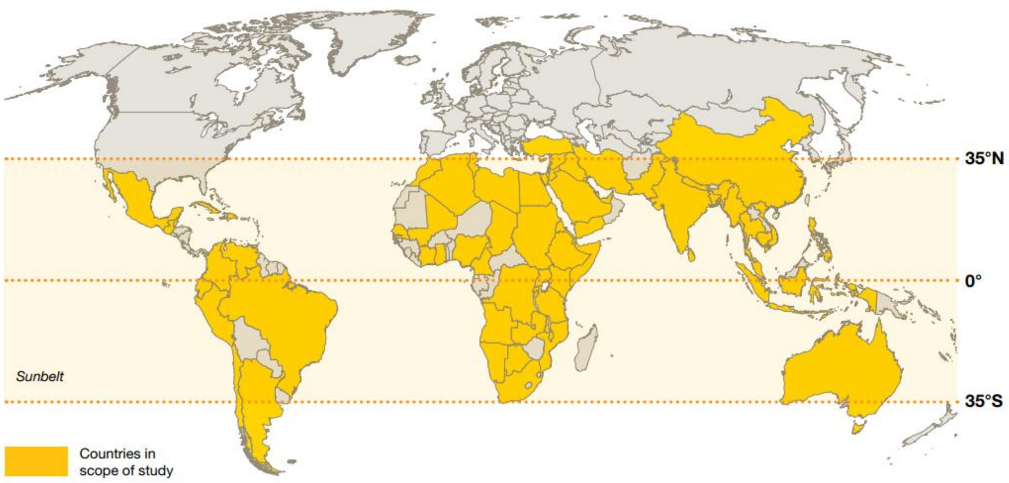


**Figure 2**: Sun Belt Region

| CPV Strengths | CPV Weaknesses |
|---|---|
| High efficiencies for direct-normal irradiance | HCPV cannot utilize diffuse radiation<br>LCPV can only utilize a fraction of diffuse radiation |
| Low temperature coefficients | Tracking with sufficient accuracy and reliability is required |
| Additional use of waste heat possible for systems with active cooling possible (e.g. large mirror systems) | May require frequent cleaning to mitigate soiling losses, depending on the site |
| Low CapEx for manufacturing infrastructure enables fast growth | Limited market – can only be used in regions with high DNI, cannot be easily installed on rooftops |
| Modular – kW to GW scale | Strong cost decrease of silicon flat plate modules makes market entry very difficult for even the lowest cost technologies |
| Increased and stable energy production throughout the day due to tracking | Bankability and perception issues due to shorter track record compared to PV |
| Very low energy payback time [3,4] | New generation technologies, without a history of production (thus increased risk) |
| Potential double use of land, e.g. for agriculture | Additional optical losses |
| Opportunities for cost-effective local manufacturing of certain steps | Lack of technology standardization |
| Less sensitive to variations in semiconductor prices | |
| Greater potential for efficiency increase in the future compared to single-junction flat plate systems could lead to greater improvements in land area use, system, Balance of Plant costs | |

**Table 2:** CPV strengths and weaknesses

HCPV (high concentrator photovoltaic) is a compact system compared to a normal PV module or a concentrator photovoltaics. The HCPV system developed by IDEA is a prototype composed by a concentrator of 2,000 suns with a InGaP/InGaAs/Ge triple-junction solar cell. A primary optic made by an off axis parabolic mirror is reflecting the sun rays onto a secondary optic made by a high transparent light pipe in glass directly connected to the solar cell.

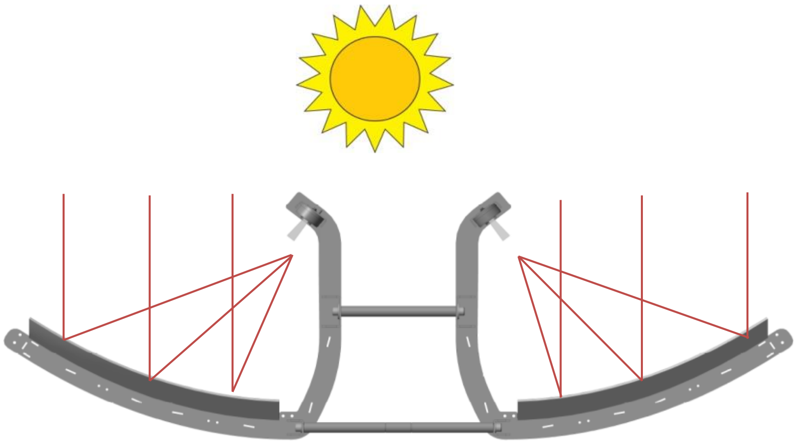

**Figure 3:** Geometric disposition of primary and secondary optic of HCPV system

The solar cell converts it in electricity and, by means of a specific cooling system, in thermal energy.

The frustum made of BK7 glass is glued in optical contact with a TaiCrystal cell and the 20 multijunction cells compose the 1 kWe HCPV prototype with each multijunction integrated with the secondary optic and the active heat sink mounted on a 2-axis tracker (Alt-Alt type) with a tracking algorithm managed by an open and closed loop control. The mirrors used have a reflectivity up to 95% with no significant scattering losses. Due to this elevated irradiation, a cooling system is needed to dissipate the energy and keep the cells in the working temperature range (up to 100 °C) and this is done by a water cooling system.

**Figure 4:** Solar radiation focused on the surface of the secondary optic

An active heat sink was designed after different design tested through CFD simulations to cool the multi-injection solar cell and the module tested on-field confirmed the forecasts. An electric power of 50 W and a thermal output of 100 W per cell at a DNI of 900 W/m² were found at a water fluid temperature of 80 °C. With thermal output of 100 W per cell and temperatures reaching 80 °C, water can also be used for domestic purposes by storing it in a thermal energy storage system. Working temperature could reach even 110°C without damaging the MJ cells.

The main characteristics, used in the mathematic models are reported in Table 3.

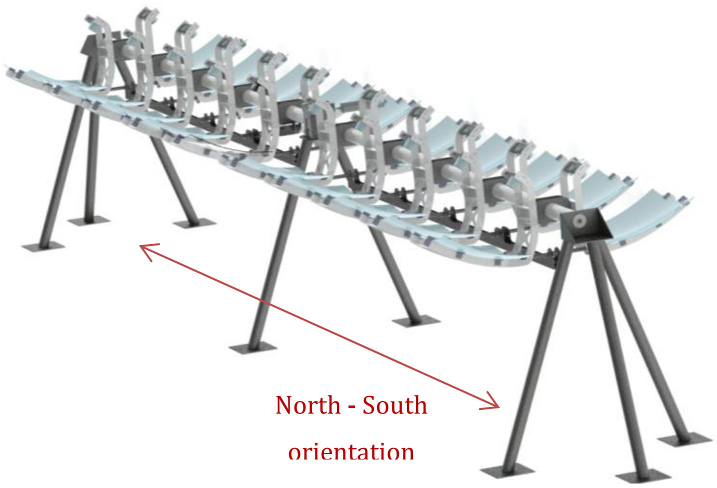


**Figure 5**: HCPV Module with 20 MJ cell

| | |
|---|---|
| Net surface single mirror | 2,025 $cm^2$ |
| Solar concentrator | ≈ 2,000x |
| Optical efficiency | 90% |
| N. Mirrors per module | 20 |
| n. Cells per module | 20 |
| Module Elect.efficiency | ≈ 30% |
| Module Thermal efficiency | ≈ 45% |
| Overall efficiency | ≈ 75% |
| Peak electrical power | ≈ 1.000 Wep |
| Peak thermal power | ≈ 2.000 Wthp |
| Tracking system | Alt-Alt |
| Dimension | 1,4 x 6,5 m |
| Weight | 280 Kg |
| Heat transfer fluid | glycol & water |
| Flow rate per module | 4 l/min |
| Heating temperature | 70°C |

**Table 3:** Technical feature of the HCPV system

**Figure 6**: View of a FAE HCPV system

As HCPV is a compact system, a small and integrated thermal energy storage tank is desirable. This can be achieved by the introduction of a Phase Change Material (PCM) in the thermal storage tank. The design of this unit represents a main achievement of task 4.2 coming from the interaction between Brunel University London and Idea researchers.

The collaboration of the Idea team with the researchers of the Energy Environment and Water Research Center (EEWRC) of the Cyprus Institute targeted an investigation of the possible integration of systems for seawater desalination and greywater treatments with HCPV systems.

Seawater desalination and greywater treatment can help addressing the water-shortage problem. The separation of salts from seawater requires, for example, a large amount of energy. Therefore, it is beneficial to employ renewable energy sources for this type of treatment.

Solar energy which is particularly abundant in dry areas, can be used for this purpose in order to produce potable or recycled water with reduced energy cost. Solar thermal desalination comprises direct and indirect processes. Direct processes are such that all parts are integrated into one system whereas indirect processes are those for which heat is coming from a separate solar collecting system such as solar collectors or solar ponds. The most common solar thermal arrangements that are used in practice for desalination are solar stills and solar ponds.

Solar stills were recognized to be more efficient for small production scale. Natural convection takes place in solar stills because of the buoyant force caused by density variation due to the temperature and concentration gradients. Various numerical approaches were considered in order to study evaporation and condensation in a humid air-filled cavity, which constitutes the physical representation of solar stills.

The solar still is a basin enclosing saline or grey water. It is covered by a transparent envelope constituted with glass or plastic material. The principle of operation of these devices is evaporation and condensation. The solar still cover traps solar energy within the enclosure, which heats then the water to be treated. This causes evaporation and condensation on the inner surface of the sloped transparent cover. The resultant condensed water on the underside of the roof cover runs down into troughs in which the purified distillate is collected. The solar still technology in connection with a HCPV field has been considered during the task. In particular, a case study has been developed for the Athalassa Cyprus Institute Campus. CYI Campus is located in Athalassa Park and it is composed by 5 buildings connected in the same settlement. More than one hundred people use all buildings for 10 hours per day with a sensible reduction during 3 weeks both in August and December. The main consumption of energy is dedicated to cool buildings during the summer season; NTL invested on the reduction of energy consumption shadowing and filtering direct sun rays by means of shields placed on its façade and reducing its cooling needs. PV panels added on the roof and, partially, on the south façade integrate the electric needs. An LFR collector of 70kWth of peak drives a single effect absorption chiller, producing 35kW of cooling energy used for the NTL needs. It has been considered to increase the overall energy saving using high-concentrated photovoltaic solar collector (HCPV) to produce electric and thermal energy at 70°C in order to drive processes of solar still distillation for the grey water treatment and its internal re-use. In this work a simulation model has been developed to evaluate the interaction between a solar desalination units with a high performance concentrated photovoltaic system.

New and conventional solar technologies can be integrated in hotels in order to satisfy their energy demand. A specific study has developed for the Crystal Spring Beach Hotel located in the Protaras area on the South-East coast of Cyprus. The cooling and electric energy required by hotels and resorts represents the main energy cost, increased in particular during the summer season. During this task, a preliminary energetic audit was implemented in order to define an appropriate solution for energy saving, integrating renewable energy systems for thermal and electric energy production. In this report, we analysed the energy consumption of Crystal Springs Beach Hotel and considered the integration of photovoltaic and HCPV solar system on the available surfaces of the building evaluating their impact on energy costs.

## 1.3 New wall module

FAE HCPV/T modules have been considered for a pilot installation at two villa houses in Peyia village in Cyprus. The use of environmental friendly wall modules could help in the full exploitation of their potential. A wall module was developed by Exergy Ltd and its application has been simulated on a single unit building as a part of an universal building module, which is characterised by a green wall on the external side and a catalytic side in the interior and aims to reduce the waste generated by construction and demolition while improving energy efficiency in buildings and fast installation.

The results of simulations where compared in order to come to conclusions and understand its benefits if applied in a more urban and communal neighbourhood where houses will produce and save energy, supporting each other.

## 1.4 Demand side management

Demand-side management is a broad term, encompassing many related problems and solution methods. One classification is over those DSM types dealing with: energy efficiency; time-of-use; demand response; and spinning reserve. Energy efficiency DSM measures have permanent impacts in reducing demand, via, e.g. building insulation upgrades, and equipment replacements. Time-of-use DSM focuses on the economic incentives to consumers to modify their demand during specific time intervals, which is usually achieved by offering electricity tariffs that differ across intervals. Demand response, on the other hand, mainly includes the transmission of a signal to registered users when demand curtailment is needed. Finally, spinning reserve incorporates virtual power plants for Grid load regulation (e.g., for controlling the frequency, or providing additional active power). Demand-side management can boost the penetration of polygenerative systems at settlement and community level as it has the aim to optimize consumption schedules given a specific scenario.

The specific user preferences optimization or decision-theoretic (DT) largely use techniques originating in optimization and decision theory. Typically, these methods aggregate individual preferences, turn them into constraints, and solve the resulting joint optimization problem centrally, to produce altered demand profiles for the individuals. Their usual objective is to minimize a cost (or to maximize a payoff) function. Costs (payoffs) can be monetary or associated with participant discomfort minimization, maximizing the use of renewable or locally produced energy, and similar concerns.

DT methods can be deterministic or stochastic, and focus on either real-time or longer-term planning. Regardless, an assumption they commonly make is that stated individual preferences are exactly as provided, and not subject to change. Moreover, unlike their game-theoretic counterparts, these methods do not tackle conflicts arising among users due to optimization (e.g., due to unfair sharing of DSM profits), nor do they explicitly incentivize users to participate or cooperate in the DSM process.

By contrast, mechanism design (MD) and other game-theoretic (GT) approaches provide the necessary setting for the coordination and cooperation of large-scale DSM actions, to end up with optimized social welfare, fair payments, and guarantees for the satisfaction of individual user preferences. Usually, a key property sought after by MD approaches is incentive compatibility. This means that the design must be such that actors are better-off being truthful regarding the private preferences they reveal to the scheme, while untruthful ones suffer penalties, exclusions, and are in general subject to negative incentives. Another desired property of a mechanism is budget balancedness. Budget-balanced mechanisms guarantee that the utility that is to be redistributed among participants is generated by their own participation, and no external funding is required. A third property that is a pre-requisite to any solution mechanism is individual rationality: since individuals are assumed to participate in the mechanism only if it is rational for them to do so, the mechanism ensures that participation incentives do in fact exist. These aspects have been extensively investigated during the task.

## 1.4 Decision support tools

Also processes decision support tools for smart grids (market analysis, life cycle assessment, socioeconomic aspects, energy consumption, energy and exergy profile of buildings and smart grids) have a crucial role in expanding the adoption of innovative solar generation technologies. A benchmarking study of existing decision tools has been conducted in order to identify the impact on the performance of smart grids. The study covered decision making tools for technology selection as well as for building certification making emphasis on the impact of these decisions on the final performance of smart grids. These tools have been compared with the approach adopted for the Galileo's Eye methodology being developed at Exergy Ltd which aims to implementing a unique and noteworthy software platform that allows comparison of actual scarce resource and actual emissions with optimal results. Building and smart grids are considered as a general use case as part of this study to analyze its potential to assess the energy and exergy profile of buildings and identify the roadmap to make the tools more useful and reach more clients.

Buildings of the future have to take into account the challenges and the opportunities brought about by technological, environmental and societal changes. Smart buildings have the advantage of automated systems that control the environment and communicate with users. With the increasing levels of sophistication in technology, communications and connectivity, smart buildings will become an integral part of our lifestyles. There are a lot of tools worldwide to use them in order to create a smart building but most of them are complicated, located in specific regions, focused on different certification models. In this context, the unique methodology of Galileo's Eye Methodology is to reach best exergy (thermodynamic) performance. Exergy is a measure of the quality of energy and is defined as the maximum theoretical work that can be obtained from a quantity of energy or matter by bringing this energy or matter into equilibrium with a reference environment. Thus, any system in a state different from the environment contains exergy or can produce work. Exergy can have various components: chemical (due to differences in chemical composition), thermal (due to differences in temperature), and mechanical (due to differences in kinetic energy).

When the surrounding environment is the reservoir, the exergy is the potential of a system to make a change as it achieves the equilibrium with the environment. Exergy, as a term, is the energy (quality) that is available to be used. The term "exergy" was coined in 1956 by Zoran Rant (1904–1972) by using the Greek ex and ergon meaning "from work", but the concept has been developed by J. Willard Gibbs in 1873.

The energy is never destroyed during a process; it changes from one form to other (First Law of Thermodynamics), but, in contrast, exergy is always destroyed when a process involves an irreversible process, for example loss of heat to the environment

(Second Law of Thermodynamics). This destruction is proportional with the increase of entropy of the system, together with the surroundings. The destroyed exergy is called anergy. For an isothermal process, exergy and energy are interchangeable terms, and the anergy does not exist.

Exergy analysis is performed in the industrial fields for the more efficient usage of the energy. Engineers use the exergy analysis for the optimization of applications with physical restrictions, such as the choosing of the best use of roof space for solar energy technologies. Galileo's Eye is a tool that counts the exergy efficiency of systems (houses, industries, cities, grids etc.) than the energy efficiency of the systems.

# 2. Methodology

## 2.1 Integration of concentrating solar systems in built environments

The activities were conducted by the research team according to the following methodology:

- Site visit and evaluation of the available area for solar system installation.
- Analysis of the energy demand.
- Definition of the technologies to be integrated.
- Construction of a mathematic model (where possible) to evaluate the integration building-solar plant.
- Definition of a database for weather parameters related to the site.
- Evaluation of results.

During the site visit, the main architectural features of the building and the activities responsible for the energy demand are identified. Furthermore, available space, close to the building or to the production site, are considered in order to choose the best kind of technology, size and installation type.

Energy consumption data are collected and analysed for typologies and period to define an energy profile of the building or production process.

The evaluation of the value of the energy required by the building permits to find the best solution in terms of technology and size in order to reduce the annual energy bill.

For each solution, a specific mathematic model can be created (the level of detail of the model depends by the information available for the site) in order to analyse and evaluate the energy performance of the building (or production process) interacting with passive and active energy saving solutions.

Specific software packages, such as Meteonorm permit to build, for any location, a weather database useful to use the main parameters as input for the mathematic model.

The iterative process permits to balance the energy consumption with the energy produced by renewable sources. Results are evaluated in the form of graphs and annual trends, in order to consider the benefit of the integrated solutions.

## 2.2 Aggregating distributed energy resources and flexibility estimates

Mechanisms for the effective coordination of decentralized energy resources (DER) have been proposed in recent years, equipping these with the tools and incentives to participate in *DER cooperatives* (which could also be viewed as *virtual power plants).* Such cooperatives could either be cooperatives of *energy producers, energy consumers*, or *energy prosumers*. These approaches are, broadly speaking, viewing the coordination/aggregation problem as a cooperative game played among the individual agents, and mechanism design tools are often used to provide incentives to the players to report their true capabilities. These are also aided by machine learning and statistical tools to enable (a) decision-making under uncertainty, and (b) the detection of errors and the correction of individual consumption/production estimates to the degree possible.

A MAS-based aggregator architecture can be implemented to manage different kind of assets playing a role in a hypothetical smart grid environment. The aggregator, or curtailment service power, undertakes the responsibilities to manage DR events, identify curtailable load at customer levels, enrol new customers, and calculate payments/penalties. Players' behavioural strategies are stochastically assigned. Six typical consumer profiles are simulated (two residential, two industrial, and two commercial).

A demand-response exchange platform has been suggested where aggregators can buy and sell flexibility. The architecture focuses exclusively on residential consumers (PHEV, appliances, air conditioners, water heater). Electrical water heater and air conditioning units are modelled as TCL. Appliances and PHEV usage schedule are modelled using a probabilistic approach. The objective is to reduce the overall aggregator load under a threshold for a given duration. One day before an event, the ISO call for a bidding session at the DR exchange and then the aggregators inform their consumers.

Other approaches focus on predicting the demand-response potential of *prosumers.* A centralized optimization algorithm is used as a planning mechanism. An incentives-based contribution system is theorized, for which at a certain incentive level a certain shredding potential is expected. A common language for MAS architecture for smart grid management is needed. This requires interoperability issues and robust data models.

As the penetration of renewables into the Grid increases, so do the uncertainty and constraints that need to be taken into account during *demand-side management (DSM)*. *Multiagent systems (MAS)* in conjunction with *Mechanism design (MD)* can provide effective DSM solutions that aggregate the end-users' preferences and uncertain capabilities, without jeopardizing their comfort.

During the task a multiagent architecture has been envisaged, which can be used for the effective aggregation of distributed *demand flexibility estimates* (corresponding, e.g., to estimates of energy reduction capabilities) owned by different entities (for instance, individuals or companies) that do not necessarily trust each other and do not necessarily wish or possess the ability even to directly communicate or coordinate with each other. This architecture is accompanied by an algorithm for effective flexibility demand aggregation. This algorithm employs a mathematical tool from the Mechanism Design research field, with the purpose of incentivising the accurate reporting of the private individual flexibility estimates to coordinating aggregators (trusted central managers). Both architecture and algorithm can be utilized within any market that calls for and rewards the implementation of demand flexibility services.

## 2.3 Analysis of decision support tools

The Galileo’s Eye methodology will be applied on the exergy efficiency on houses and smart grids in future steps and this will provide a sustainable use and investment on the buildings in order to save money and have an environmental friendly house-building.

In order to create that exergy efficiency software-methodology, the existing tools of the market and the possible competitors of Exergy Ltd who have the same target market, the same clients should be analyzed. Moreover, a benchmarking that compares the existing tools with the Galileo’s Eye methodology is needed.

There are many tools available in the market, among which the 5 most popular have been selected:

- VTT
- Breeam Communities
- Leed-Arc
- Casbee for cities
- Star Community

### 2.3.1 VTT

VTT is the Technical Research Centre of Finland Ltd, which is a research and technology company in the Nordic countries. The company develops smart technologies, innovative services and creates profitable solutions about environmental and industrial problems and issues; they create new products, production processes, methods, and services. As they do that, they help the promotion of the sustainable development and well-being.

Their research depends on the demand of the client, and they are focused on the research and development. They have a lot of laboratories (chemical, mechanical environmental etc.) and they use new methods to produce sustainable solutions.

### 2.3.2 Breeam Communities

BREEAM Communities is a simple and flexible methodology for improving, measuring and certifying the sustainable, large-scale development plans of cities and neighborhoods. It provides the framework to support the managers, the local authorities as the government and the municipalities, the developers and the investors through the master planning process, before the embarking on procurement and the detailed building level design and construction.

The benefits for the local authorities, the local people who work and live there, the developers, master planners are:

- Creation of a sustainable community friendly for the environment, its people and economically successful.
- Provision of the framework for the improvement of the efficiencies during the planning process, helping to save money throughout the project.
- Facilitating the process of the planning with essential tools and targets to assist with the decision making.
- Independent certification for the sustainability of a masterplan.
- Added value to the participants and tenants corporate, including social responsibility, valuable business reporting and sustainable business leadership.

The framework is applied in the early stage of planning and design stages. It offers the holistic framework with target benchmarking that assists the makers of the decisions to better understand, choose and improve upon the impact their decisions according to the long term environmental and economic aspects associated with the development of the community.

### 2.3.3 Leed-Arc

U.S. Green Building Council (USGBC) and Green Business Certification, Inc. (GBCI) created sustainable green buildings and have gathered business data and information. Together, USGBC and GBCI, have created a useful platform of engagement addressing the built environment at all levels. This platform is combined with data, the mobility and the most disruptive technologies in the market [8]

Arc Skoru Inc., as the organization is officially named, was created by GBCI with the goal to make USGBC, GBCI and their partners' visions reality, to connect people and developers in order to find the best solutions and actions from other people from the global in order to make the most informed decisions. That empowers people to connect through the platform and collaborate. Arc Skoru is the methodology that allows to place and track all the sights of developing, connections and actions related to the sustainability of the built environment.

Arc Skoru uses the Arc platform to help the users measure the performance of processes, make improvements on the actions and on the buildings and benchmark in comparison with other projects. Arc is a supplement to LEED and other building rating systems, protocols and guidelines and allows buildings and the processes to compare their performance between the users of the platform and connect those metrics to building strategies. Arc enables incremental improvements and can put a project on track for LEED or other rating system certification.

### 2.3.4 Casbee for cities

Nowadays, the world is aware of the sustainability and the low carbon emissions of the societies from the human actions. The countries around the world have adopted a variety of programs and policies in order to become more environmental friendly. In order to estimate the effectiveness of these policies, the Japan Sustainable Building Consortium (JSBC) developed a new assessment tool for cities (Casbee for cities), which applies the methodology of a Comprehensive Assessment System for Built Environment Efficiency (CASBEE) — a widely used system-methodology in Japan.

"CASBEE for Cities" is a system for comprehensively evaluating the performance of the cities that is applied to count the environmental issues, using a triple-line approach of "environment", "economy" and "society".

The JSBC has developed this new tool in cooperation with the Promotion Council of Future City Initiative (PCFCI). The PCFCI is considering the Eco-Model Cities, Master planning of future cities and other governments, organizations, ministries and agencies, private companies and other important parties in Japan.

CASBEE City sets a hypothetical boundary, when evaluating a city, to enclose the city. Because of that, it can count the performance of the built-Environment Efficiency (BEE) of the community.

### 2.3.5 Star Community

The STAR Community Rating System (STAR) is an inclusive framework and a program that gives certification for the evaluation of the local sustainability, the economy, the environmental issues, and the social performance measurements. The local authorities use the rating system for the evaluation measures to assess their level of sustainability, to set new goals for moving ahead, and measure the progress along their actions.

STAR has been developed by local governments. It has been released in October 2012; STAR represents an essential tool in the national group of actions to create more friendly communities for all. The rating system measures the community sustainability and efficiency and presents the actions on how to become more healthy, inclusive, and prosperous across seven goal areas. The goals and objectives provide a needed vocabulary, which is very useful for the local governments and the communities and can be used to more effectively strategize and define their planning actions.

The use of the rating system is to show to the communities how to identify, validate, and support best practices and actions in order to improve the conditions of the community. That rating system is able to adopt in any change over time, incorporate innovative research or adapt on changing conditions of the community's sustainability.

Over time, the company builds a model that includes temporal, spatial and level of effort details to expand the data base about the level to which various actions advance sustainability conditions in the community.

### 2.3.6 Advantages and disadvantages of Competitors

| Company-Tool | Advantages | Disadvantages |
|---|---|---|
| VTT | •professional laboratories and reasearch rooms<br>•experience on exergy analysis<br>•Good future partner for Exergy Ltd | • no vision for any platform or data base<br>•no focus on the holistic sustainability of communities, cities or systems |
| Arc-LEED | •database from buildings and cities (feed the platform)<br>•good rating system | •There platform is too complicate to use<br>•No exergy analysis (It is hidden in the goals on the rating system)<br>•not useful it for industries or compiliated systems |
| BREEM | •The actions are under the local law<br>•Master planning<br>•Sustainable systems | •helpful only for the developers<br>•Not for existing buildings,<br>•not exergy analysis<br>•no compicated systems as industries |
| STAR COMMUNITIES | •They use data base, case studies, credit methodology. | •The Technical Guide is 200 pounds. They do not do exergy analysis<br>•It is more for experts and not for citizens |
| CASBEE for Cities | •They include enough data in the platform, it is the beginning of Glaileo's Eye mrthodology.<br>•Very organized | •It is very complicated<br>•the platform is not modern, it is not for citizens |

**Table 4:** Advantages and Disadvantages of Competitors

| Company -Tool | Country | Certification | R & d | Buildings | Cities | Products | Energy | EXergy | App-Platform | BQ |
|---|---|---|---|---|---|---|---|---|---|---|
| VTT | Finland | - | x | x | x | x | x | x | x | - |
| Arc-LEED | US | x | x | x | x | - | x | - | x | - |
| BREEM | | x | x | x | - | - | x | - | - | - |
| STAR COMMUN ITIES | US | x | - | - | x | - | - | - | - | - |
| CASBEE for Cities | Japan | x | x | x | x | - | x | - | x | - |

**Table 5:** Comparative analysis among competitors

### 2.3.5 Galileo's Eye

Exergy Ltd has been working for the past years in the development and testing of the successful Galileo's Eye methodology, an exergy based technology that allows the optimization of actual scarce, resource and actual emissions.

The software is based on a new universal sustainability measuring ("*exergy*") methodology that was developed to correct inherent flaws of past piecemeal, fragmented sustainable measurements that only measure a small isolated segment of overall sustainability. The fundamental flaw of piecemeal sustainable measurements is that they focus on reducing consumption of energy, water or other small group of scarce resources or focus on reducing carbon, mercury, or other small group of harmful emissions without addressing how all other resources and emissions are affected.

The primary function of the exergy based sustainability software is to provide citizens with an unbiased accurate scientific basis to overcome any misrepresentations by governments and businesses as they inherently seek to serve their own interests.

The universal sustainability evaluation methodology ("Galileo's Eye") was developed in 2010 as part of an extensive research effort of the 28 nation International Energy Agency, which has been the mainstay of international energy and environmental research since it was formed in 1974. This project started ten years ago in the USA and comprised of four phases. In phase one the exergy methodology has been applied in the Twin cities at Minnesota obtaining savings of

73% of water use and 39 % in fossil use. In phases two and three the project will extend in the entire state of Minnesota and at the waste treatment system in Medellin, Columbia. Finally in phase four a software and an application will be produced capable of obtaining optimal sustainable performance of any communities, facilities in any country around the world.

Task activities have been planned to develop a software module and a corresponding app which will be based on the universal sustainability measuring. That software will help the saving of energy and resources so the investor will make the right decision when purchasing goods and services, investing in sustainable companies and supporting sustainable government policies.

# 3. Polygeneration and Concentrated Solar systems

## 3.1 Available solar thermal polygeneration infrastructures

Both at the Cyprus Institute in Nicosia and at Idea, in agreement with Consorzio ARCA, in Palermo (Italy) North-South aligned Linear Fresnel Reflectors (LFR) are available. These LFRs, specifically designed for integration in built environments, have been developed by Idea.

**Figure 7:** LFR at Palermo, Italy (left) and Nicosia, Cyprus (right)

| | Cyprus | Italy |
|---|---|---|
| Location | Aglantzia, on the roof of a school, next to the NTL | University of Palermo, on the ground at ARCA premises |
| *Latitude Longitude Elevation (Above the sea level)* | *35°08'28.1"N 33°22'50.7"E 176m* | *38°06'01.0"N 13°20'37.3"E 50m* |
| Average DNI per year (Source: SolarGis) | 2142 kWh.m$^{-2}$ | 1703 kWh.m$^{-2}$ |
| Type of collector | LFR - Idea | PTC - Soltigua |
| Global aperture area | 184.32 m$^2$ | 483.84 m$^2$ |
| Thermal oil, Heat Transfer Fluid (HTF) | Duratherm 450 | Paratherm NF |
| Peak thermal power | 70 kW | 190 kW |
| Total receiver length | 32 m | 84 m (3 x 28 m receivers rows) |
| Working temperatures (outlet) | 170°C | 280°C |

**Table 6:** Characteristics of the solar fields

Both collectors are working with thermal oil as heat transfer fluid (HTF) at different temperature: 170°C and 280°C. Figure 8 shows the simplified layout of the solar plant installed in Sicily.

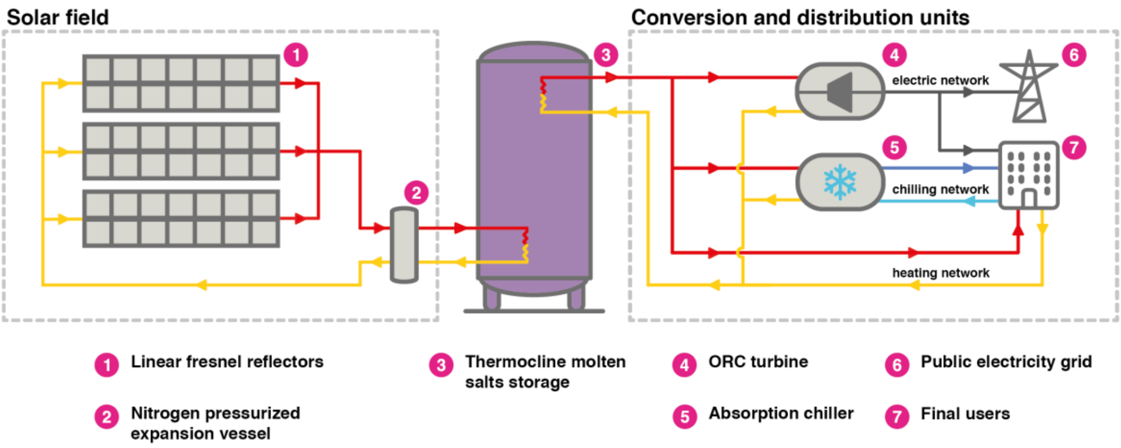


**Figure 8:** Layout of the field at ARCA (Sicily)

Thermal storage is a key element of the four platforms. It permits to buffer the production for some minutes to several hours. Details of the thermal storage in use in the 2 platforms are exposed in Table 7. In both systems, a heat-exchanger transfers the heat from the oil to TES system. In Cyprus thermal storage is based on water pressurized with nitrogen up to 146°C ensuring 2 hours of autonomy for cooling in summer or 4 hours for heating in winter. The same nitrogen tank is used to pressurize the thermal oil (Figure 9). Storage with water is a low cost technology and vessels are available in Cypriot market.

| | Cyprus | Italy |
|---|---|---|
| Medium | Pressurized water | Ternary molten salts mixture |
| Storage Volume | 2.0 m$^3$ | 8 m$^3$ |
| Storage capacity | 100 kWh | 400 kWh |
| Average temperature | 146°C | 260°C |

**Table 7:** Thermal storages

**Figure 9:** Buffer of oil, expansion vessel, thermal storage tank (left to right) at CyI (left) and molten salts storage, oil storage and expansion tank (left to right) at ARCA (right)

Safety relief-valves are installed on the tank in case of over-pressure. The developed TES integrated in the pilot plant built in Sicily includes innovative features. Different options have been reviewed. TES systems commonly applied in conventional CSP plants operate with "solar salts" (molten nitrates mixture NaNO3/KNO3 60%/40% of weight distribution), in two-tanks heat storage system operating from 290°C (cold tank) to 385°C (hot tank) when oils are used as Heat Transfer Fluid in the solar field. In small CSP plants (lower than 1MW range) it is rather difficult to replicate such a complex scheme due to the lower operative temperatures (280°C maximum in Sicily) and principally due to the need of expert personnel to manage molten salts loops too. Therefore, an innovative TES system has been specifically developed, tailoring it for small scale, low temperature applications.

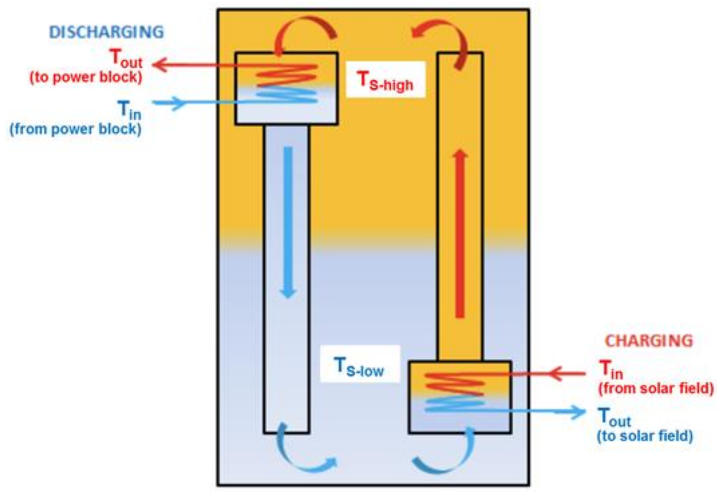


**Figure 10:** Optimized TES system developed for STS-Med: general scheme with explanatory working conditions (left) and prototype drawings (right)

This TES system is represented in Figure 10. The operation concept is based on the properties of unmixed molten salts in the tank to thermally stratify along the vertical axis, as an effect of their low thermal conductivity and the density variability with temperature. Two heat exchangers are immersed in the zones where the temperature is lower (bottom) and higher (top) to be operated during the charging and discharging phases. In a conventional two-tanks TES systems with the high temperature tank at TS-high = 385°C (and the low temperature tank at TS-low = 290°C) about 280 m$^3$ of "solar salts" shall be loaded to store 20 MWh thermal energy, to drive a steam Rankine cycle.

The same principle can be applied to a smaller TES system with maximum temperature of 300°C, combined with an Organic Rankine Cycle. In the pilot plant in Sicily, TES is filled up with about 7 m$^3$ of eutectic ternary salt mixture (42%/15%/43% of weight distribution). Considering the reduction of the overall amount of salt, the use of a single tank instead of two tanks and the avoidance of external molten salt pumps and pipelines, the capital cost (€/kWh thermal) of this

optimized heat storage system developed can compete with the large scale CSP benchmark.
The effective heat capacity of the unit is about 400kWh (thermal). The charging/discharging thermal power averages 250/125 kW (thermal). The tank has been insulated with a 20cm coating of rock wool.
Cooling is the central task of both polygenerative platforms, due to climate considerations in the Mediterranean areas concerned by the project. The plants rely on absorption chillers to provide chilled water at 7°C. The global cooling capacity of the platforms averages 110.1kW. Both chillers are LiBr (Lithium Bromide) based. In Cyprus, the model used is YAZAKI WFC-SC10. It is water-fired at low temperature (88°C inlet, 83°C outlet). Its cooling capacity is 35kW with a COP (Coefficient of Performance) of 0.7.

| | Cyprus | Italy |
|---|---|---|
| Model | YAZAKI WFC-SC10 | Broad BCT 23 |
| Type | LiBr – Single effect | LiBr – Double effect |
| Firing medium | Water | Thermal oil |
| Cooling capacity | 35 kW | 23 kW |
| Inlet temperature | 88°C | 200°C |
| COP cooling | 0.7 | 1 |
| Heating capacity | | 23 kW |

**Table 8:** List of absorption chillers

The heat is transferred to the absorption chiller from the thermal storage medium through a heat-exchanger (pressurized-water and water). Then the heat is stored in a 500L tank of water. This stabilizes the inlet temperature for the chiller. A cooling tower dissipates the heat from the absorber and condenser chambers. In Italy, the double effect absorption chiller is the most efficient with a COP of 1 and it includes its own cooling tower. The cooling capacity is 23kW.

The absorption chiller in Italy is also heating in winter with better COP than cooling. Heating capacity is 23 kW. In Cyprus the absorption chiller is simply by-passed to heat directly two water stratified tanks (2000L each). The heat is supplied to the Air Handling Units (AHU) and through Fan Coil Units (FCU) is passed to the offices of the NTL.

In Italy an ORC (Organic Rankine Cycle) cogeneration unit fired with thermal oil is installed. It has an electric capacity of 10 kW and gross efficiency of 10% and needs a cooling tower to dissipate the heat rejection. It can produce electricity in parallel with heating or cooling.


**Figure 11:** ORC Rank turbine in Palermo with its cooling tower

## 3.1 Competitiveness of FAE HCPV/T system

High concentrating PV systems (HCPV) exploit the property of lenses or curved mirrors to focus the sun radiation on a small area occupied by one or more high efficiency photovoltaic (HEP) cells to generate electricity at a cell conversion rate of up to 44%. If properly managed, an HCPV system can act as a combined heat and power (CHP) solar system, generating both electricity from the photovoltaic (PV) cells and thermal energy (heat) (T) extracted from the cell's back surface. A hybrid- HCPV/T configuration represents a major advancement in comparison with the state of the art of commercial PV/T systems where a flat silicon plate collector gives an electrical output with low efficiency (10-20%) and heat suitable for domestic hot water (DHW) at 30 to 45 °C, which is inadequate for driving even an adsorption chiller for producing cold for small or large scale heat, power and cold multi-generation applications.

An HCPV/T module has been developed and experimentally tested by Idea under indoor and outdoor conditions. The module contains reflective optics based on a point-focus rectangular off-axis parabolic mirror with aperture area of 2,116 $cm^2$. The receiver is made by a BK7 frustum attached in front of a triple junction InGaP/InGaAs/Ge solar cell with active area of 108 $mm^2$, providing a concentration ratio of about 2,000 suns. A liquid cooling system passing across an aluminium heat sink behind the cell has been developed. The experimental investigation of the developed single cell module showed a CHP efficiency of 72 to 85% with an electrical efficiency ranging from 27 to 30% and a thermal efficiency of about 45 to 55% within the temperature range of 40 to 70 °C of the cooling heat transfer fluid. An appropriate redesign of the hybrid receiver should allow reaching higher outlet temperatures. Enhancing the temperature of the heat transfer fluid to 90 °C is expected to decrease the electrical efficiency by at most 2%. These results are very promising, especially if compared with fossil-fuelled motor CHPs and represent a unique improvement in the efficiency of multi-generation RE-based energy systems.

The experimental trackers have been assembled incorporating 20 multi-junction cells and 20 mirrors 45x45cm each for application in single-family houses. The electricity peak power target of each unit is 1,000 W and the thermal peak power target is 2,000 W. The footprint of the solar system is estimated to 1.35 m x 6.5 m. The total efficiency of the solar CHP system is targeted to be higher than 75%.

Such combined or integrated "thermal+electrical" solutions have been proposed both by the academy and the industry to maximise the yield and the economics of poly-generation and to reach an optimal use of the surface available in buildings. Compared Life Cycle Assessment of PV/T with standard PV and T systems confirmed the environmental advantage of integrated PV/T systems. Flat PV/T collectors are the simplest combination as photovoltaic cells convert solar radiation into electricity, while water or air circulation on the backside of the modules, removes the thermal energy and make it available for heating purposes.

PV/T collectors have been under development for some time but they have not been widely adopted in the market due to the limited advantage, as the generation of heat at reasonable temperature has a heavy trade-off on the efficiency of the solar cells. Unglazed PV modules are usually heating the Heat Transfer Fluid at about 40°C, thus they can be used for preheating DWH. Some commercial flat type PV/T collectors are Multi Solar System (MSS) from Millenium Electric, for water and air heating, Twinsolar (Grammer), Solar, SolarVenti (Aidt Miljo), TIS (Secco Sistemi), SolarDuct (SolarWall), PVTWIN, SES, Solimpeks, Solarhybrid. By glazing the collectors, temperature can be raised up to 80-90°C, but with a severe drop in electrical efficiency (from 12% at 20 °C to 7% at 90 °C) as shown in Figure 12.

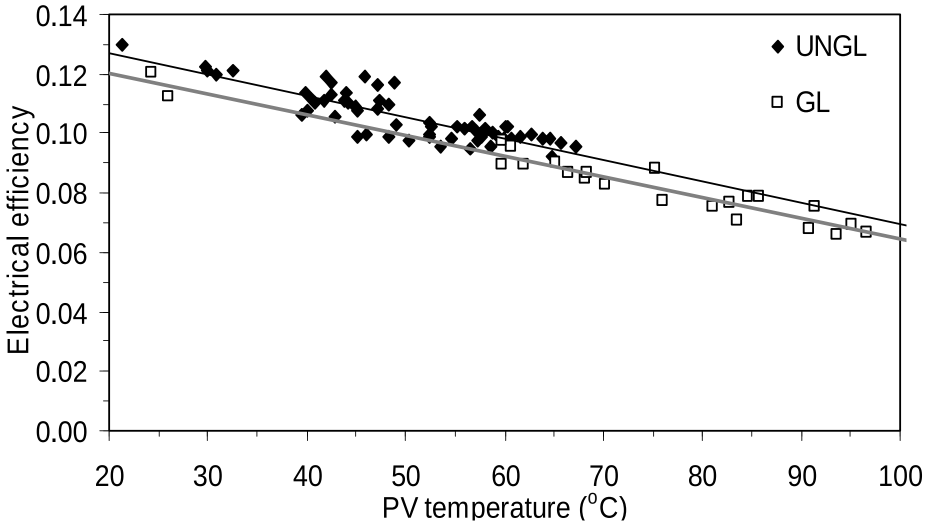


**Figure 12:** Electrical efficiency vs PV temperature

For the described reasons, flat PV/T collectors have not been considered as a possible solution for integrated SHC systems. Some studies were focusing on improving their thermal and electrical efficiency, but high heat losses, protection against overheating and complexity of layering are still unsolved challenges.

Concentrating photovoltaics systems have been proposed as a possible approach to boost the combined generation of solar electricity and heat at a reasonable temperature for poly-generative applications. In CPV/T systems active PV cooling is needed to protect cells from overheating and tune the performance of the receiver higher cell temperatures. In that case, the circulated heat transfer fluid can be heated to a considerable temperature level for practical applications.

Concentrating photovoltaic collectors require, however, a sun tracking system, in order to obtain a homogenous radiation distribution, which is necessary for the optics quality to get the best performance from the receiver. Some simple solutions, combining low concentrating Compound Parabolic Collectors (CPC) with PV/T receivers have been proposed, together with linear parabolic CPV/T systems, linear Fresnel and punctual receivers. In the last five years some commercial units have been presented, opening a path towards the CPV/T potential market.

# 4. Research activities in the Smart GEMS Project

## 4.1 Integration of solar still and HCPV/T collectors

Solar still have been modeled adapting the equation used by Hamadou and Abdellatif using, as input data, the hourly values of the thermal energy produced by the HCPV system at the Athalassa campus location in Nicosia (Cyprus).

The solar still has the form of a basin with a certain depth of saline water and a glass transparent cover that let solar radiation to enter while blocking the long wavelength radiation emitted by the interior surfaces of the still. The transparent sloped cover provides a cool surface for condensation of water vapour and makes easy the flow of the water droplets into the condensate trough.

The liner basin of the still is blackened on the interior surface to maximize absorption of solar radiation. It contains also an embedded copper plate which enables fast heating of the water by means of a heat transfer fluid that is circulating beneath it. The bottom and the lateral sides of the still are insulated on the exterior surface to minimize heat losses. Basic assumptions in the modelling of the desalination system take account of negligible temperature stratification within the evaporator basin.

Temperatures are supposed to be uniform within each still component, while they are time-dependent. The governing equations express conservation of water mass and that of the contained salts as well as energy balance of the system which is a consequence of the first law of thermodynamics. Only pure water contained in saline water is assumed to be evaporated and the still is considered to be free from any vapour leakage.

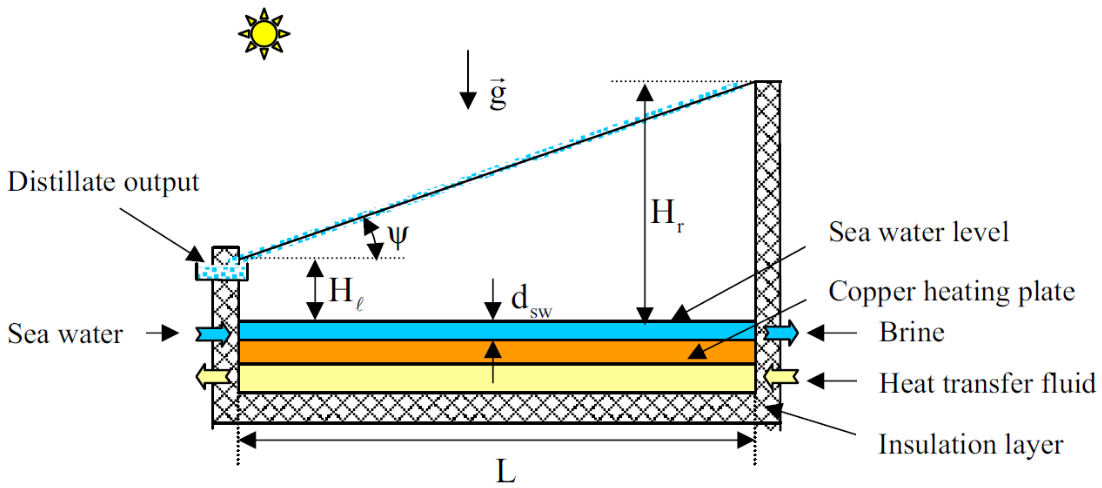


**Figure 13:** Layout of simple active solar still (used in the model)

The kind of solar still, used in the model, and its main dimensions are represented in **Figure 13**.

The model of an active solar still, with a circulating heat transfer fluid that supplies heat to the still bottom, has been designed considering three correlations giving explicitly the intervening heat transfer coefficients.

The energy balance equations for the different components of the active solar still are derived. A set of coupled nonlinear ordinary differential equations is obtained as a function of the temperatures in each still component, as well as, material and geometry parameters of the still and the heat transfer fluid. This system is solved numerically by using a program developed under Matlab software package.

Calculations are then carried out to assess the instantaneous productivity and the yield of the still as a function of the saline water rate, the heat transfer fluid rate, still basin depth, ambient temperature, wind speed and relative humidity.

The input parameters and the system design parameters and relations used for the calculation of solar radiation and environmental conditions are considered in the following tables.

| **Input Parameter from database, generated using Meteonorm 7.0 and HCPV model** | |
|---|---|
| $G_h$ | [W/m$^2$] Global Irradiation on horizontal surface |
| DNI | [W/m$^2$] Direct Normal Irradiation |
| $T_{amb}$ | [°K] Ambient temperature in Kelvin |
| RH | [-] Relative humidity |
| wspd | [m/s] wind speed |
| HCPV_Q | [kWh] Thermal energy produced by the HCPV system (according to the weather data) |

**Table 9:** Model Input Parameter (referred to the location of Nicosia-Athalassa Park)

| **Solar still dimensions** | |
|---|---|
| Hl = 0.263 | [m] height at low end |
| Hr = 0.627 | [m] height at high end |
| L = 1 | [m] lenght of solar still |
| w = 5 | [m] width of solar still |
| $\psi = \tan^{-1}(\frac{H_r - H_l}{L})$ | [rad] inclination angle of cover |

**Table 10:** Solar still geometrical features

| **Glass cover** | |
|---|---|
| tg = 0.003 | [m] thickness of glass cover |
| $\alpha$ g = 0.1 | [-] fraction of solar energy absorbed by the glass |
| kg = 1 | [W/m*K] thermal conductivity of glass |
| $\rho$ g = 1500 | [kg/m$^3$] density of glass |
| cp_g = 840 | [J/kg*K] heat capacity of glass |
| $A_g = \frac{L \times w}{\sin(\psi)}$ | [m$^2$] glass cover area |
| $V_g = A_g \times t_g$ | [m$^3$] glass cover volume |
| $M_g = \rho_g \times V_g$ | [kg] weight of glass |
| $\varepsilon$ g = 0.9 | [-] emissivity of glass |

**Table 11:** Geometrical and physical properties of glass cover

| **Treated water** | |
|---|---|
| Tsw_in = 25+273.15 | [K] treated inlet temperature |
| $\chi$ sw = 40 | [g/kg] salinity |
| Xb = 70 | [g/kg] max salinity |
| $\eta = \frac{\chi_b}{\chi_{sw}}$ | [-] concentration factor |
| $\varphi = \frac{(\eta - 1)}{\eta}$ | [-] recovery rate |
| dsw = 0.05 | [m] depth of seawater in still |
| $A_{sw} = w \times L$ | [m$^2$] area of seawater |
| $V_{sw} = A_{sw} \times d_{sw}$ | [m$^3$] volume of seawater |
| $\rho$ sw = 1000 | [kg/m$^3$] density of seawater |
| $M_{sw} = A_{sw} \times d_{sw} \times \rho_{sw}$ | [kg] mass of seawater |
| $\varepsilon$ sw = 0.9 | [--] emissivity of seawater |
| $\beta$ sw = 2.4276e-4 | [1/K] volumetric thermal expansion of seawater |
| $\mu$ sw = 9.64e-4 | [Pa*s] viscosity of seawater |
| cpsw = 4100 | [J/kg-K] heat capacity of seawater |
| ksw = 0.61 | [W/mK] thermal conductivity of seawater |

| | |
|---|---|
| cp_b = 3850 | [J/kg-K] heat capacity of brine |
| $\alpha$sw = 0.2 | [-] fraction of solar energy absorbed by glass |
| Dsw = 0.01/3600 | [m3/s] seawater volume flow rate |
| $m_{sw} = D_{sw} \times \rho_{sw}$ | [kg/s] seawater flow rate |
| $m_{ev} = \varphi \times m_{sw}$ | [kg/s] evaporate flow rate |
| $m_b = \dfrac{m_{sw}}{\eta}$ | [kg/s] brine flow rate |

**Table 12:** Geometrical and physical properties of glass cover

Heat transmission is supported by a copper plate placed in the bottom of the solar still and in contact to the water to be treated. The following tables contain the value used in the mathematic model as input data.

| **Copper plate** | |
|---|---|
| kc = 400 | [W/mK] thermal conductivity of copper |
| $\alpha$c = 0.7 | [-]fraction of solar energy absorbed by copper |
| cp_c = 850 | [J/kg] heat capacity of copper |
| $\rho$c = 9000 | [kg/m$^3$] density of copper |
| $A_c = w \times L$ | [m$^2$] area of copper plate |
| tc = 0.002 | [m] thickness of copper plate |
| $V_c = A_c \times t_c$ | [m$^3$] volume of copper plate |
| $M_c = V_c \times \rho_c$ | [kg] mass of copper plate |

**Table 13:** Copper plate physical and geometrical features

| **Heat transfer fluid - water** | |
|---|---|
| Th_in = 25+273.15 | [K] heating fluid inlet temperature |
| $\rho$h = 1000 | [kg/m$^3$] density of HTF |
| kh = 0.68 | [W/mK] thermal conductivity of HTF |
| $\beta$h = 9.45e-4 | [1/K] coefficient of thermal expansion |
| $\mu$h = 8.12e-4 | [Pa*s] viscosity of heat transfer fluid |
| cp_h = 4200 | [J/kg-K] heat capacity of HTF |
| $A_h = w \times L$ | [m$^2$] area of copper plate |
| th = 0.02 | [m] thickness of heat transfer fluid layer |

| | |
|---|---|
| $V_h = A_h \times t_h$ | [m$^3$] volume of heat transfer fluid |
| Dh = 4/1000/60 | [m$^3$/s] heating fluid volume flow rate |
| $m_h = D_h \times \rho_h$ | [kg/s] mass flow rate of HTF |

**Table 14:** Features of Heat Transfer Fluid of HCPV providing thermal energy to the solar still

| **Insulation** | |
|---|---|
| kis = 0.04 | [W/m*K] thermal conductivity, insulation |
| tis = 0.05 | [m] insulation thickness |

**Table 15:** Thickness and thermal conductivity of the insulation material used in the solar still

| **Ambient temperature** | |
|---|---|
| $\varepsilon$ sky = 1 | [-] emissivity of the sky |
| $\varepsilon_{eff} = \left(\frac{1}{\varepsilon_{sw}} + \frac{1}{\varepsilon_g} - 1\right)^{-1}$ | [-] effective emissivity |

**Table 16:** Hypothesis about the sky emissivity affecting the thermal losses to the ambient

The energy balance equations are associated to outer glass, inner glass, sea water, copper plate and heat transfer fluid while the mass balance equations are related to the mass of treated water, the evaporated water and the brine.

The mathematic model calculates, in stationary condition, the convective and radiative exchange coefficients for each of heat transfer according to the environmental conditions such as external temperature, solar radiation, relative humidity and wind speed.

Each analysis has been developed considering the yearly value of mass of evaporated water in the solar still (mev). This value represents the quantity of desalinated water produced with different thermal energy values from HCPV system.

The first mathematic simulations consider the production of desalinated water in a solar still without any thermal energy support (passive system). The yearly production of desalinated water is 550kg/year

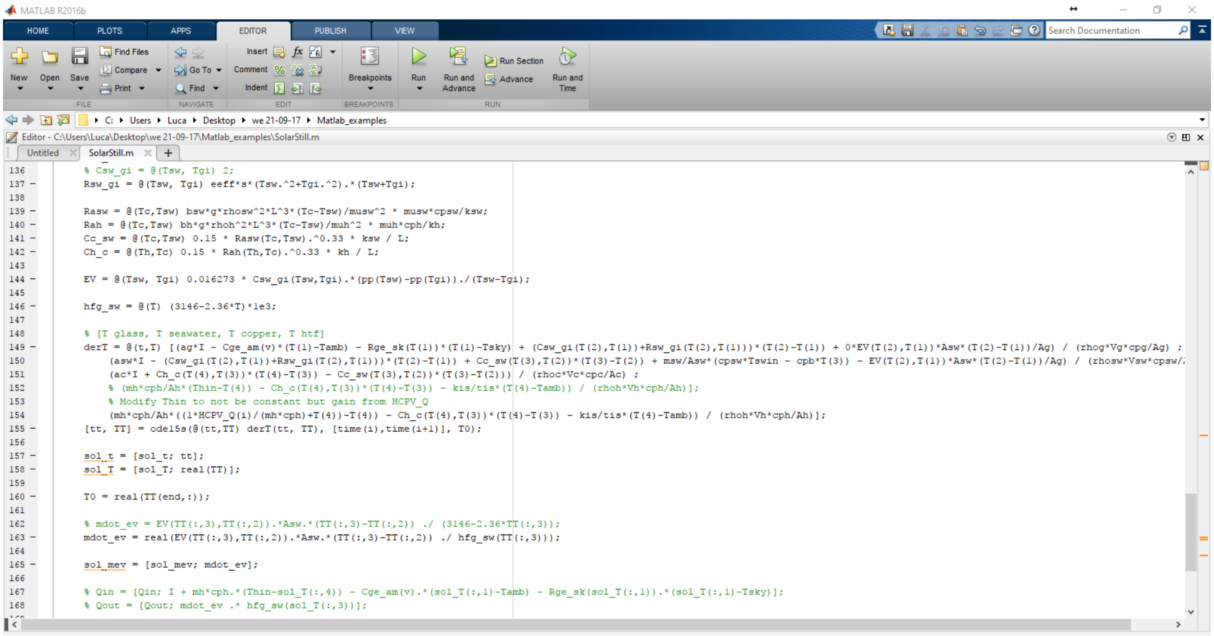


**Figure 14:** Screenshot of the active solar still Matlab model with the list of energy balance equations

## 4.2 Integration of solar systems in settlements

### 4.2.1 Crystal Palace Hotel

Hotels and resorts, in the Mediterranean regions, require energy mostly for cooling private and common areas especially during the touristic season. But if on one side high energetic costs are required to guarantee the necessary comfort of rooms, on the other, touristic circuits valorize the image of structures that use renewable energies. For this reason, managers of hotels and resorts start to be interested both to reduce the annual energy cost and to improve the “green image” of their buildings.

Several contacts with Crystal Spring Beach Hotel of Cyprus have been put in place, in order to evaluate if opportune activities, for energy saving and integration of energy production systems, can be applied in the building.

Crystal Spring is a four star hotel located on the south east coast of Cyprus in the area of Protaras. During the site visits made during the secondment period, Idea’s researchers were involved in a preliminary study of energy efficiency of the building finding appropriate solution addressed to a sensible reduction of the electric yearly consumption.

Preliminary evaluations were made on the kind of electric consumptions, the condition of the building envelopes and their architectonic constrains, time of use and typologies of equipment installed in the hotel.

Finally, a deep evaluation was developed about the available surfaces for the installation of renewable energy systems like solar panels and solar concentrators for the overall reduction of hotel's energy consumption.

The Crystal Spring Beach Hotel is composed by one main building with 6 floors and an external green park in connection with the neighboring beach. The façade showed in the Figure 15 represents the North - East side of the building with the pool areas and glass window door access to the hall.


**Figure 15:** Crystal Spring Hotel, view of north east side

At the entrance, the main volume of the building hosts the reception, the restaurant and lounge bar; this area, connected by glass doors to the pool and to the parking area is highly lighted by large single glass windows and its temperature is continuously maintained at about 25°C during the day. 200 rooms for 500 visitors are cooled continuously by a centralized cooling system. In the basement the gym area and the SPA with a sauna room are located.

**Figure 16:** Hall area and internal room access

A thermal power plant is located in a separated area of the basement with 2 boilers, connected to diesel burners, and a hot storage tank at 60°C, used for DHW or space heating during the winter season. One tank is used to store the preheated water from cooling chillers. A laundry uses, for 10 hours per day, two wash dryer machines with an electric power of 20kW each.

**Figure 17:** Thermal power plant and laundry

The following pictures show some details of the roofs with the available space for the installation of solar panels. Corrugated sheet metal with inner coating are installed on the roof in order to reduce the energy consumption on the last floor.

Two water condensation chillers are used for summer air conditioning of the whole building.

The Figure 18 shows 3 main roof surfaces, slightly inclined, with chillers and metal coating.

**Figure 18**: Roofs of the Hotel with 2 chillers placed in the center

The air conditioning system uses two Aermec chillers (with refrigeration technology) with a cooling capacity of 375 $kW_f$. The chillers are condensed with water and, through a heat exchanger, it is possible to recover the waste heat for preheating DHW in the power plant located in the basement

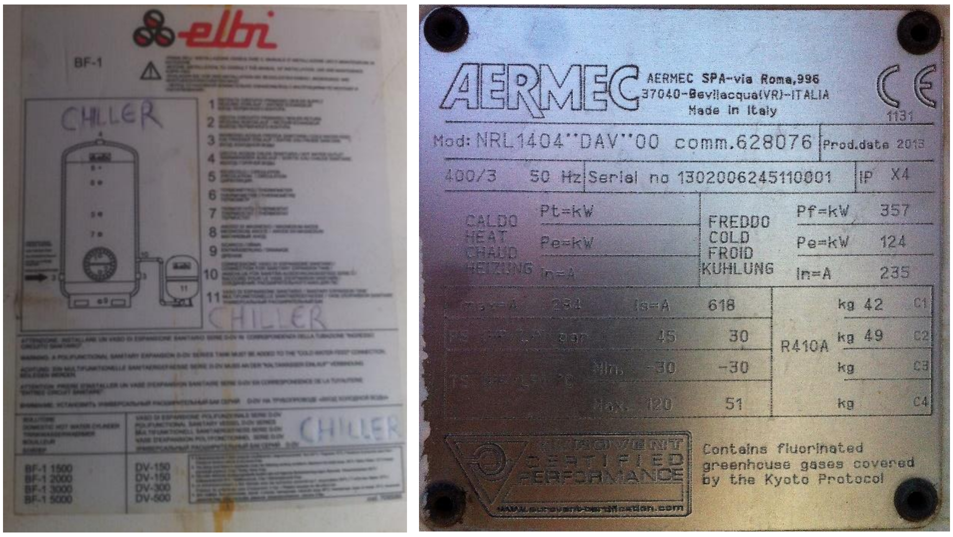


**Figure 19:** On board data-sheets of chiller and domestic hot water tank

The hydronic circuit feeds with chilled water at 12-18°C the HVAC circuit placed between the roof and the corrugated metal coating.

The air distribution system is made by metal canalizations and distribution nozzles into each room without automatic valves. With this configuration, cooling energy is used for empty rooms as well. Air, from the extraction circuit, is directed into regenerators through an enthalpic heat recovery system.

The following table reports the main electric power specifications for each equipment.

| DESCRIPTION | N° of equipment | Load/equipment [KVA] |
|---|---|---|
| CHILLER 1 | 1 | 200 |
| CHILLER 2 | 1 | 200 |
| PLANT ROOM | 1 | 20 |
| LAUNDRY | 1 | 20 |
| KITCHEN | 1 | 50 |
| RESTAURANT | 1 | 20 |
| COLD ROOMS | 4 | 10 |
| LOBBY | 1 | 15 |
| SWIMMING POOL | 1 | 40 |
| SPA | 1 | 20 |
| POOL BAR & POOL AREA | 1 | 20 |
| LIFTS | 3 | 10 |
| ROOMS | 5 | 1 |
| OTHER AREAS | 1 | 50 |

**Table 17:** List of equipment used in the hotel and electric load

By the electric metering system located into the hotel, the electric consumption data were analyzed in order to evaluate the distribution of the load during the day and year.

A period between August 2015 and July 2016 was evaluated based on a 15min resolution.

Figure 20 reports the electric consumption registered in the Cristal Spring Beach Hotel for one year. The graph shows the working period between April and November with a peak of 4,500kWh/day during the period of July/August and an average base load of 150-200kWh/day during the winter season.

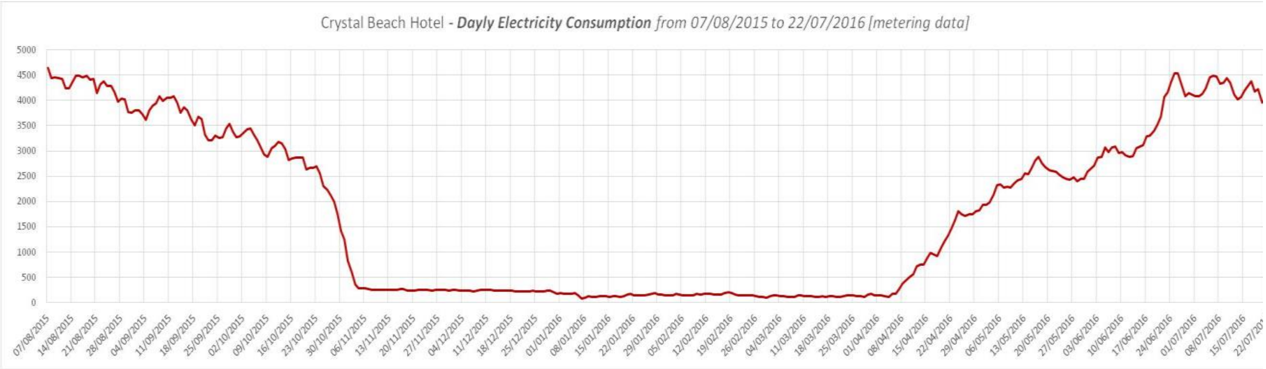


**Figure 20:** Daily electric consumption from the 7th of August 2015 to 22nd July 2016

In Figure 21, the daily electric energy consumption during one August day is reported. The diagram shows a peak of load between 7.00PM and 8.00PM due to the simultaneous use of all rooms' services before dinner.


**Figure 21:** Hourly consumption registered on a day of August 2015

The same trend is reported in Figure 22 where hourly energy consumption with the evening peaks are reported.

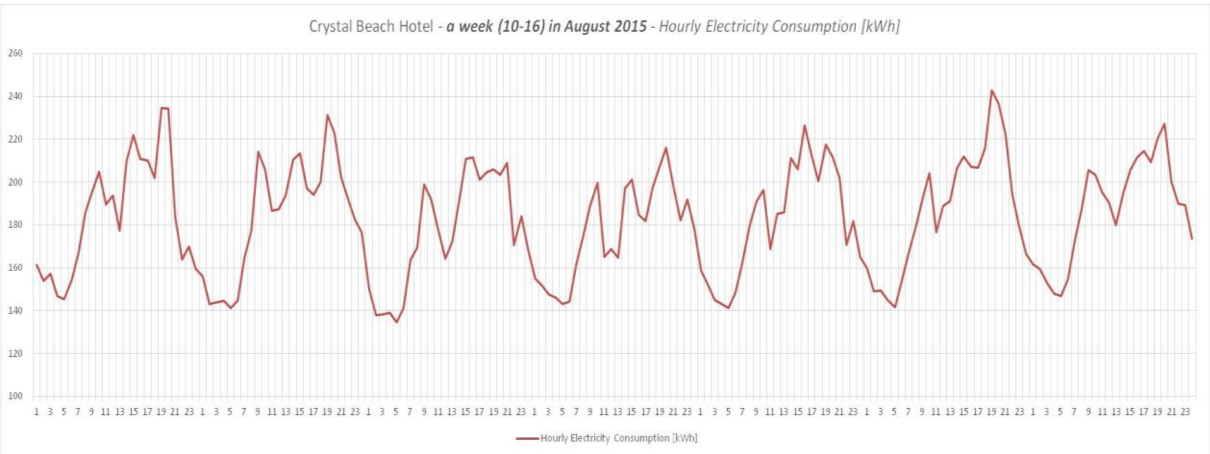


**Figure 22:** Hourly consumption registered during a week of August

The results of the on-site visits and the analysis of energy loads demonstrate that the main percentage of electric consumption is to be addressed to the HVAC system. The

cooling power plant reduces its efficiency due to the large glass windows of the south facing surface in the hall. Furthermore, glass windows are installed with a single glass and aluminium frames (no double glass are still installed for a thermal loss reduction).
Ventilation nozzles installed in all rooms are not provided with automatic valves. For this reason, empty areas are cooled even if not used and not necessary.
After the energy audit, energy saving solutions were suggested in this preliminary step. A deeper analysis of cost-effective benefits is to be done by a dynamic model in order to evaluate the effectiveness of improvements on the structural modifications.
On this direction, the main energy saving suggestions were addressed to:

- Replacing of glass windows with double glass
- Installation of automatic shadowing shields on the south façade of the hotel.
- Use of automatic ventilation nozzles in each room in order to activate the cooling circuit only at times people are inside.

If the installation of energy saving elements can reduce the yearly electric consumption, the installation of active systems of electric and thermal production from solar source can integrate, especially during the summer season, the energy needs of the hotels.
The analysis of the available spaces was conducted considering the parking area, the pool area and the roofs of the building. The area considered of main interest for an integration of the solar installations was limited to the roof surfaces and to the south façade of the hotel.
The electric and thermal energy production was maximized using all the available surface.
Figure 23 shows the 3 main roof surfaces of Crystal Spring Hotel.
Two kind of plants were considered:

- HCPV modules for electric and thermal production. Thermal energy produced at 70°C is integrated to the heat circuit of existent chillers and used to integrate heat on DHW storage.
- PV panels will be placed on the available roof surfaces integrating the electric energy consumption of the hotel.

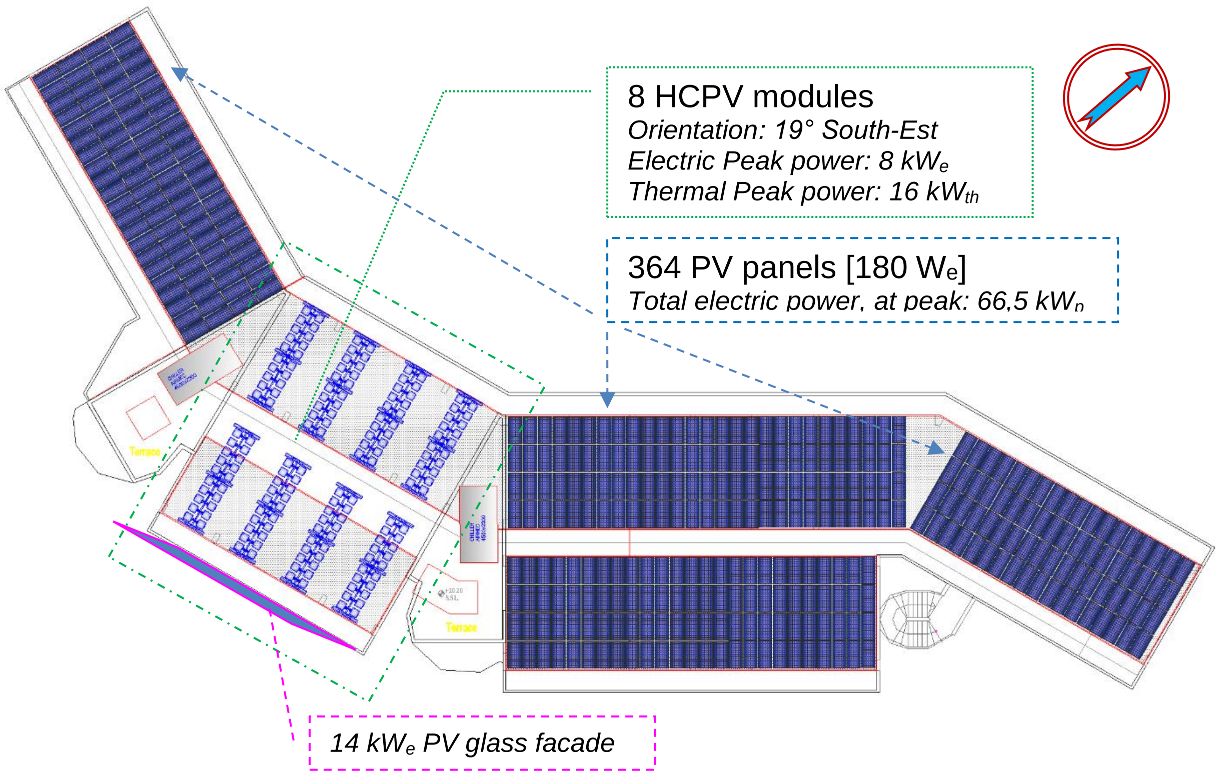


**Figure 23**: Layout of the roof with the solar systems installed

The size of the solar plants installed on the roof and on the façade is defined according to their orientation and the size of the available surfaces.

The size and the characteristics of each installation are here reported:

- Photovoltaic solar plant with 364 crystalline silicon modules to be installed on the metal corrugated covers with 6° of slope on South direction and 6° in North direction. Total electric power: 66,5 kWe in standard condition
- High concentrated photovoltaic (HCPV) solar plant with 8 modules installed with about 20° in north-west direction. The modules provide 8 kWe of electric power and 16kWth of thermal power.
- Photovoltaic solar plant covering the glass surfaces and shadowing the south façade of the hotel. The PV surface follows the curved profile of the south façade as reported in the Figure 24. The 90m$^2$ of PV panels reduce the direct sun radiation on the hall of the hotel and produce about 14kWe.

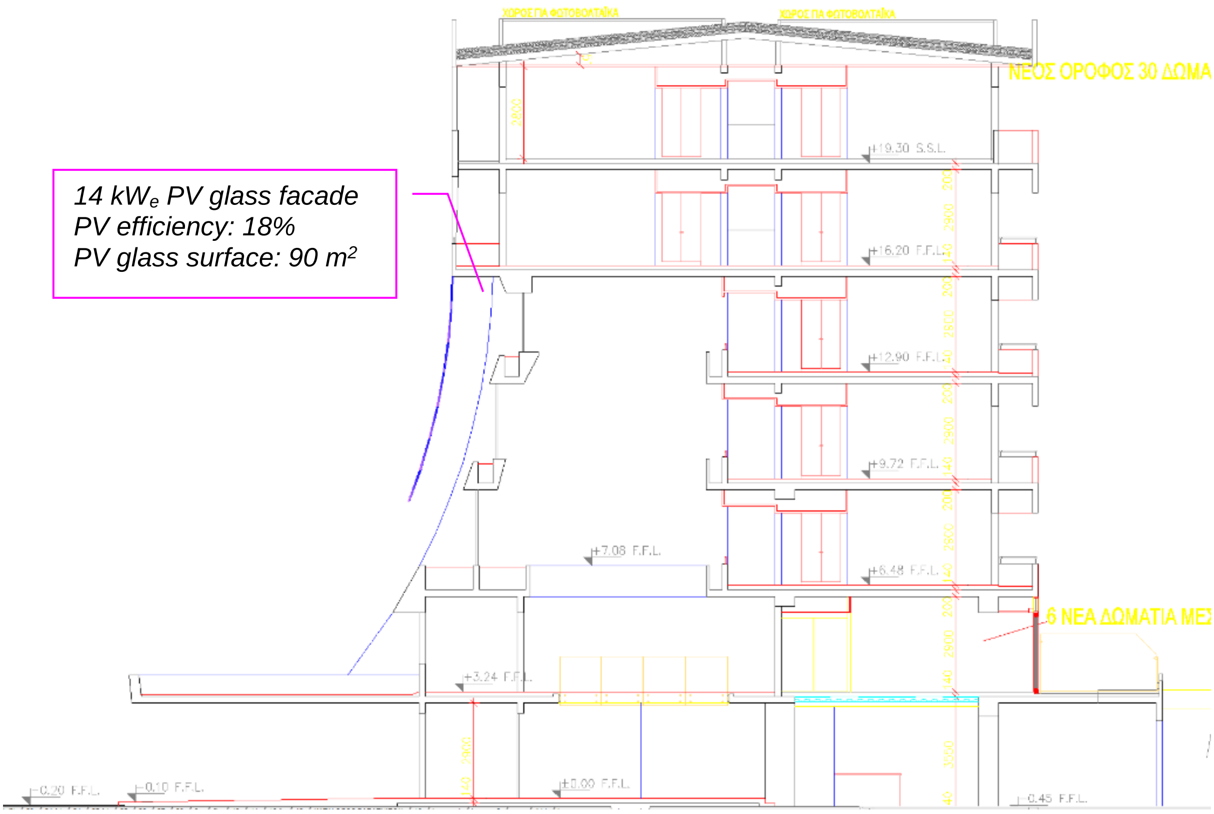


**Figure 24**: Section of the building with the façade covered by PV system

The annual electric energy produced by the PV solar plant installed on the roof is calculated using PV-GIS software. PV panels are considered with an efficiency of 14% and electric loss of 15%. The panels' slope is considered 0° (horizontal panels).

Thermal and electric energy of HCPV plant is calculated by specific mathematic models of the system, the hourly data of direct normal incident radiation (DNI) and environmental temperature generated for Protaras area by the software Meteonorm 7.0. The yearly electric energy produced by the PV system installed on the south façade of the hotel is calculated considering the panels in vertical position and an average efficiency of 14% with 15% of system losses.

### 4.2.2 Wineries in Troodos area

An interesting application of solar systems for industrial application is represented by cooling systems driven by solar energy.

Small wineries are diffused in particular in Troodos region, the mountain area on the West side of Cyprus. The favourable environmental condition and the traditional techniques for the production of wines developed in small wineries require cooling energy for storing grapes and wines in tanks before their bottling.

Specific site visits took place to design the installation of solar plants for thermal and cooling energy exploitation in the production process. Wineries placed in the local community of Agios Ambrosius, Zambartas and Agia Mavri, were visited and their specific production process from grape harvesting to bottling was analysed in terms of the energy consumption perspective. This study demonstrates the energy costs reduction obtained thanks to the integration of solar plants particularly efficient during the wine production period.


**Figure 25**: Zambartas and Agia Mavri Winery

Each winery has a production capacity of about 10,000 bottles of wine per year. The production process is characterized accordingly to the period.

**Figure 26**: Box where grapes are cooled and his chiller

During August and September months, grapes are harvested and transferred to the

winery where they are stored. Grapes are placed in chilled rooms of 60-80 $m^3$ of volume at 10-12°C in order to avoid the starting of any fermentation processes. An electric chiller with a cooling power of 23,4$kW_{cool}$ is directly connected to the refrigeration box and used during all the harvesting period.
Figure 26 shows the refrigerated room and the chiller used for its cooling. An equipment used for separating grape marc from grapes is used to feed wine into specifics vats for the next fermentation process.


**Figure 27**: Equipment for the separation of grape berries and marc

Fermentation requires the storing of wine at 12°C for about 2 months. Figure 28 shows the area of Zabartas winery dedicated for storing in chilled tank red and white wines.

**Figure 28**: Steel vats with heat exchangers on the external liner for cooling the wine

During the months of November and December, red wines are bottled and placed in cellars. On February white wines are processed for the tartaric stabilization with chemical and physical action at 4°C. White wines, mostly produced by Troodos wineries are stored at 12-15°C.

Analysis conducted during site visits and the evaluation of consumption data demonstrates a prevalent use of electric energy for the cooling processes of wine during production and storage phases. For the Zambartas production site, we evaluated the direct effect of thermodynamic CSP systems connected with solar chillers. The analysis of electric consumption of the production process is based on the electric power value indicated on each equipment. Two chillers have been installed: Chiller 1 - 23,4kW for the cooling wines into the vats, and Chiller 2 – 12 kW for storing grapes during harvesting period.

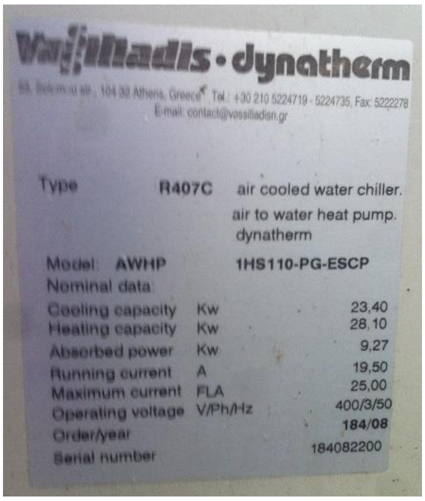


**Figure 29**: Detail of the cooling capacity of the Chiller 1

## 4.3 HCPV at ARCA and the Thermal Energy Storage tank

The HCPV system installed at ARCA consists of 4 trackers. Each tracker contains 20 cells oriented E-W with 10 cells on the West and 10 on the East. The cooling system is divided into two circuits where the water flows in series through 10 cells with a flow rate no more than 1.1 l/min (0,01808 kg/s). The cooling system runs while the system is in operation to keep the cell temperature below 100 °C. Over that temperature, the system enters in security mode and is turned off to not damage the cells.

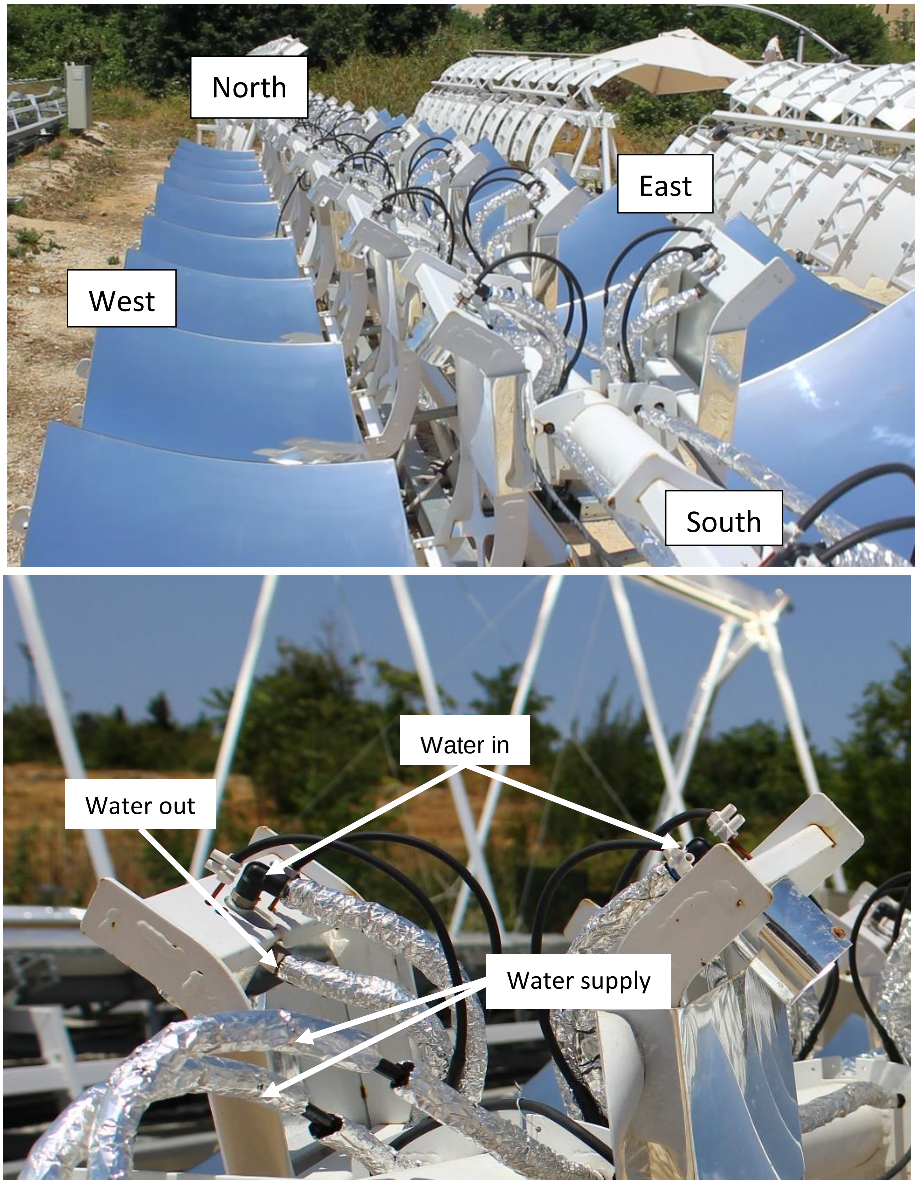


**Figure 30:** HCPV with solar rays focalized, and indication of orientation and cooling system

A sensible storage tank was installed to store the thermal energy absorbed by the cooling system. Due to the compact size of this system a smaller and lighter tank is desired. To achieve that, PCM can be introduced inside the tank. With qualities described in the previous section, an organic PCM was selected to be introduced into the HCPV Thermal Energy Storage tank and this section will describe the designing procedure to select the PCM with the respective weight reduction. The best-case scenario was used to design the storage tank for the system.

A clear day and a solar irradiance of 900 W/m$^2$ was assumed. With this solar irradiance, each cell generates approximately 50 W of electricity and 100 W of thermal energy. It was also considered that the system operates 12h per day which reflects in 77,76 kWh of thermal energy and the storage tank temperature start the day with a temperature of 25 $^o$C.

When the storage tank is designed to operate only with water and a HCPV with 4 trackers (80 cells) the minimum amount of water needed is 1500 l (considering a water temperature elevation from 25 to 70 $^o$C). As the temperature stored achieves 70 °C, the water can also be used for domestic applications. Due to that, the amount of PCM used to reduce the overall size and weight of the thermal storage tank need also to consider the minimum of hot water needed for domestic use and to cool the cells. Furthermore, in case of the hot water is not used, the system needs to be able to release the energy stored and cool the cells on the next day.

Based on that, organic PCMs with a melting point from 29 until 60 °C were preferred due to the lower density and have their properties presented in Table 18.

| PCM Type | Phase Change Temperature (ºC) | Density (kg/m³) | Latent Heat Capacity (kJ/kg) | Energy from 25 to 70 (Wh/kg) | Latent Heat Wh/kg | Latent Heat kWh/m³ | Volumetric Heat Capacity (MJ/m³) | Specific Heat Capacity (kJ/kg K) | Thermal Conductivity (W/m K) | Max Operating Temp (ºC) |
|---|---|---|---|---|---|---|---|---|---|---|
| A29 | 29 | 810 | 226 | 89,65 | 62,78 | 50,85 | 183 | 2,15 | 0,18 | 300 |
| A25H | 25 | 810 | 226 | 89,65 | 62,78 | 50,85 | 183 | 2,15 | 0,18 | 400 |
| A22H | 22 | 820 | 216 | 95,63 | 60,00 | 49,20 | 177 | 2,85 | 0,18 | 400 |
| A16 | 16 | 760 | 213 | 88,79 | 59,17 | 44,97 | 162 | 2,37 | 0,18 | 250 |
| A37 | 37 | 810 | 235 | 100,90 | 65,28 | 52,88 | 190 | 2,85 | 0,18 | 300 |
| A36 | 36 | 790 | 217 | 89,90 | 60,28 | 47,62 | 171 | 2,37 | 0,18 | 300 |
| RT35HC | 35 | 880 | 240 | 91,67 | 66,67 | 58,67 | - | 2 | 0,2 | 70 |
| S34 | 34 | 2100 | 115 | 58,19 | 31,94 | 67,08 | 242 | 2,1 | 0,52 | 70 |
| S32 | 32 | 1460 | 200 | 79,43 | 55,56 | 81,11 | 292 | 1,91 | 0,51 | 60 |
| S30 | 30 | 1304 | 190 | 76,53 | 52,78 | 68,82 | 248 | 1,9 | 0,48 | 60 |
| S44 | 44 | 1584 | 100 | 47,90 | 27,78 | 44,00 | 158 | 1,61 | 0,43 | 120 |
| S46 | 46 | 1587 | 210 | 88,46 | 58,33 | 92,58 | 333 | 2,41 | 0,45 | 56 |
| A60 | 60 | 910 | 145 | 68,03 | 40,28 | 36,65 | 132 | 2,22 | 0,22 | 300 |
| A58H | 58 | 820 | 243 | 103,13 | 67,50 | 55,35 | 199 | 2,85 | 0,18 | 300 |
| A58 | 58 | 910 | 132 | 64,42 | 36,67 | 33,37 | 120 | 2,22 | 0,22 | 300 |
| A55 | 55 | 905 | 135 | 65,25 | 37,50 | 33,94 | 122 | 2,22 | 0,22 | 300 |
| A53H | 53 | 810 | 166 | 71,36 | 46,11 | 37,35 | 134 | 2,02 | 0,18 | 300 |
| A53 | 53 | 910 | 130 | 63,86 | 36,11 | 32,86 | 118 | 2,22 | 0,22 | 300 |
| A52 | 52 | 810 | 222 | 88,54 | 61,67 | 49,95 | 180 | 2,15 | 0,18 | 300 |
| A50 | 50 | 810 | 218 | 87,43 | 60,56 | 49,05 | 177 | 2,15 | 0,18 | 300 |

**Table 18:** PCM's from *PCM products* and *Rubitherm* used to design the Thermal Energy storage tank.

## 4.4 Demand-side management systems

Managing conventional electricity grids requires the continuous control of energy supply in real time, so as to maintain a supply-demand balance. However, the integration of *renewable energy sources (RES)* into the electricity Grid, means that generation cannot be easily controlled anymore, as it is largely performed by huge numbers of RES that are distributed across the network and whose production relies on weather conditions. This calls for the use of effective *demand-side management (DSM)*, that is, the use of schemes or algorithms aiming to move electricity demand to periods where either consumption is lower or RES production is more abundant, for example by offering better utility prices during such periods. However, the varying electricity consumer *preferences* are expected to become even more complex in the future due to the usage of electric vehicles (EVs); and once one takes also into account distribution-related constraints and variable electricity prices, the much coveted optimization of the Grid's operation becomes even harder to achieve.

On the Grid side, this increased complexity requires replacing human intervention with *intelligent agents* and *multiagent systems*. By employing autonomous agents for Grid management and user (consumer or prosumer) decision making, important functionalities and activities---such as *forecasting*, *real-time monitoring*, and *immediate reaction* to emergent situations (e.g. achieving *demand reduction* when sudden peaks arise)---become more effective and system reliability can be improved.

Now, DSM operations have to be not only *large-scale*, but also *coordinated*, since even when all individual actions do coordinate, herding effects may occur and new imbalances between supply and demand can arise at different points of the demand curve. Moreover, end-user's individual preferences have to be respected at all times. To this end, DSM contributors often join forces in *cooperatives* or *virtual power plants* so as to either consume, or produce electricity in a coordinated fashion, mimicking the performance of a single large entity meeting the Grid requirements. The smooth operation of such entities and related DSM schemes is aided by the existence of *rules* and *incentives* that lead potentially selfish individuals to adopt a cooperative behaviour and coordinate their actions.

This is exactly the problem studied by *mechanism design (MD)*, a subfield of *game theory (GT)* that explores how to design a setting (viewed as a *game*) so that *rational actors* (or *players*) adopt behaviours which help meet the designer's objectives. In other words, MD schemes seek to offer incentives or counter-incentives for achieving desired social outcomes, to individuals that aim to maximize their own utility. Typically, such schemes strive to be *incentive compatible*, meaning that participants are incentivized to be *truthful* regarding their private preferences, and that ``gaming'' the scheme leads to worse outcomes for ``misbehaving'' actors. As such, MD can be used to create DSM schemes that promote more *efficient network operation*, by granting *economic and/or social gains* (or, reversely, threaten to inflict similar loses) to the participating individuals, for instance, monetary prizes, and increased status in social networks.

Of course, MD scheme participation is determined by each actor individually; and the incentives must be sophisticated, so as to drive changes to human behaviour and habits, while maintaining the profitability of energy sector businesses. It is therefore only natural that distinct actors are represented by autonomous, intelligent artificial agents, able to undertake the computational burden imposed on the actors. At the same time, it is important to remember that, employing MD for DSM, does not only involve providing incentives for demand reduction, but also for storage or demand shifting: more generally, there is a need to incentivize and coordinate the perceived *demand flexibility,* that is, the ability of an entity to alter its energy demand levels by either providing or absorbing/storing energy at a given time.

Against this background, the need for truly distributed (and potentially, though not necessarily decentralized) architectures that would enable the *aggregation* of distributed demand flexibility- located and offered on various points in the electricity Grid, and possibly owned and managed by different entities *that do not necessarily trust each other* – is an imperative one. Such an architecture can be designed following the guidelines and practices of multi-agent systems research; and can employ "aggregators/managers" with which the individual entities interact in order to facilitate the eventual coordination of their joint energy consumption management (e.g. reduction) effort.

After a long online research a lot of companies can be found which are focusing on energy efficiency buildings, cities, grids, systems, products. A lot of them are depended on universal, European and local certifications about environmental friendly systems or buildings.

## 4.5 Biomass supply chain for solar hybridization in Madonie

Sicily is the largest island of Italy and it is located in the Mediterranean Sea, south of Italy. Madonie is the third larger mountainous region in Sicily, in terms of its area. It has a typical Mediterranean climate with high uniformity of rain around the year.


**Figure 31:** Region of Madonie, Sicily.

Madonie region is located in northern Sicily, east of Palermo and it is composed of 21 communities with around 62.000 inhabitants. It is an area of 1,278 $km^2$ with the highest peak at 1,979 m.

"Parco delle Madonie" is the natural park of Madonie with a surface area of 161 $km^2$. It is a natural reserve but also an inhabited area with some villages (21 municipalities). The wild mountainous areas host a lot of wild animals and a variety of flora species. The region of Madonie is included in the SNAI project of the Italian policy as "The lab for the future". With this step the region took the chance to improve in a sustainable way and to have an inclusive growth under the European and local policies supported by national and European funds.

According to the "Strategia d'area Madonie" under the 5th axis "Develop local supply chains for renewable energy and the capacity of the "green community", specific structures and measures are proposed in the wider area of Petralia Sottana, mainly focused on sustainable development and renewable energy introduction in the area.

Petralia Sottana has 3,000 inhabitants and it is one of the biggest communities of the Madonie. It covers an area of 178 $km^2$ in the elevation of 1km.

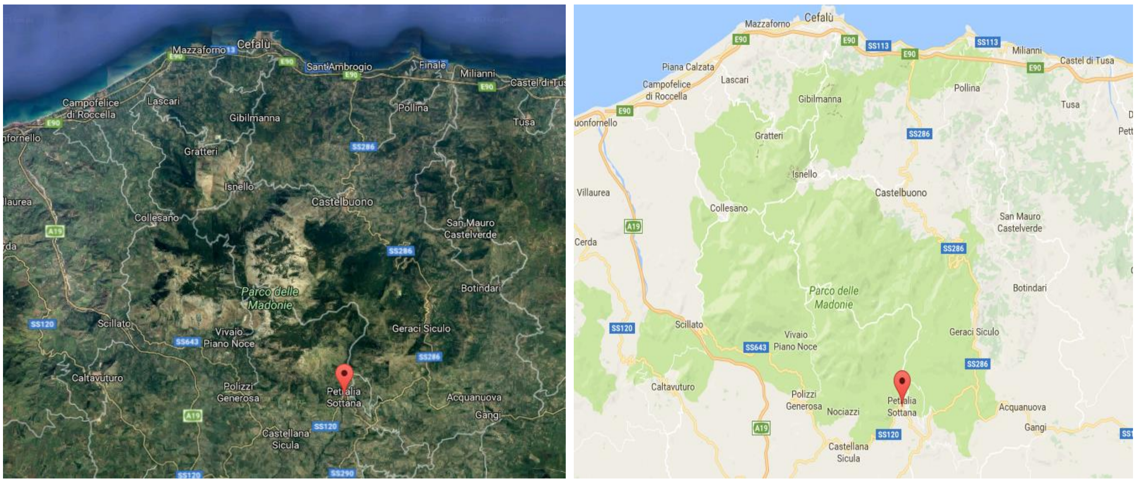

**Figure 32:** Petralia village in Madonie, Sicily.

In Petralia are located two main buildings that are being studied under the SNAI project for the sustainability and the energy efficiency. These two buildings are the hospital and the sporting center which are close to each other and have specific needs for heating and energy.

There is a need for a combined heat and power system, also known as co-generation, to generate electricity and useful thermal energy in a single, integrated system. CHP is not a technology, but an approach to applying technologies.

The basic action at the current system is the application of a hybrid system of a biomass and solar co-generation consisting of a solar-thermal system, as the CLFR system (compact linear fresnel reflectors), and the biomass combustion.

During the task, a preliminary study has been developed for the management of waste biomass to produce pellets from the local biomass which will be then used for combustion to produce heat in the co-generation system.

### 4.5.1 Biomass of Petralia's region

Petralia is a mountainous region where a lot of acricultural activities take place, located near a very large forest. Therefore a high volume of biomass from a variety of trees is produced. The quantity of biomass comes from olive trees, vineyards, orchards, citrustrees, eucalyptus, coniferous, cork and oak trees. Distinct species of trees produce a varying output of biomass. Some biomass is harder than other; some has thick trunks, some small brunches etc. It is important for the management of the biomass to consider the varying characteristics as this affects the selection of the equipment to be used for the treatment processes.

### 4.5.2 Analysis of the pellets production

The use of pellets for combustion, gasification, or pyrolysis is a considered preferable as the most robust way to feed a combustion system with solid fuel of a specific size and density. In addition, there is a variety of feeders available in the market to drive this process and acquire technical support whenever this may be required.

The pelletizing process includes some necessary steps in order to convert the waste green biomass to pellets:

1. Collection of raw material
2. Storage of raw material
3. Chipping of raw material
4. Crashing the wood chips to sawdust
5. Sieving the sawdust
6. Drying the sawdust
7. Storage of dry sawdust
8. Pelletizing
9. Sieving the pellets
10. Cooling the wood pellets
11. Packaging and store the wood pellets
12. Removal of metals and rocks

**Collection of the raw material**

The collection of the biomass from the fields nearby Petralia village depends on the agreement that will be done in the end of the project with the farmers and also the forest protection authority. The biomass, in all the forms can be transported by trucks and private agriculture vehicles of the farmers.

The use of a portable wood chipper in the collection of biomass out in the fields, provides a way to load the truck with more biomass as it is more compound with less density. Also, there is an opportunity to break down thick stems and branches of trees so smaller trucks can be loaded.

### Storage of raw materials

After you collect the raw material from the fields, there is a need to store them in order to protect them from the weather conditions. The biomass needs to be dry enough to produce good quality of pellets, on the contrary if it is wet it will require energy in the form of heat to get dry and this is not sustainable.

### Chipping of raw materials

The chipping of raw materials can be done on the arrival of the raw material or after storage. If the chipping is done before the storage, on the arrival of the biomass, better management of space can be achieved.

Chipping can be done with portable or fixed wood chippers. Portable equipment can be used everywhere, under all conditions. There is a huge variety of portable wood chippers in the market.

The size of the wood chips depends on the kind of the wood chipper that has being used, but it is enough to be 5-7cm X 5-7 cm. The size of the chips has to be small enough to be fed in the next operation with the hammer mill.

### Crashing the wood chips to sawdust

After chipping of the biomass, the crashing of the wood chips to sawdust follows. This action can be done with a hammer mill for biomass, breaking down the chips of biomass to dust.

**Figure 33:** Hammer mill grinder- blades.

The size for the sawdust depends on the size of the pellets to be produced. Sawdust particles need to be small enough to pass through the holes of the pelletizer in the next steps.

**Sieving the sawdust**

The sawdust has to be sieved to avoid the existence of particles of bigger size in the pelletizer. To sieve the sawdust wood sawdust rotary sieve machines can be used. In this process, big wood particles are removed and returned to the hammer mill for more treatment. This action is taking place as many times as necessary.

**Drying the sawdust**

The majority of the biomass that is used for the production of pellets require drying in order to produce good quality of pellets. Limited quantity of raw material is collected dry, like the straw, which is able to bypass the stage of drying. The optimal humidity in the biomass is between 10-15%.

The three main choices for dryer are shown below:

1. Rotary dryer
2. Superheated steam dryer
3. Belt dryer

Rotary dryers are the most tolerant with respect to the magnitude of matter they can process at a time and also due to their low risk of fire.

They consist of a large, rotating, cylindrical tube, which is usually supported by a specific kind of steel. It has a slight inclination so the discharge of the content is assisted by gravity.

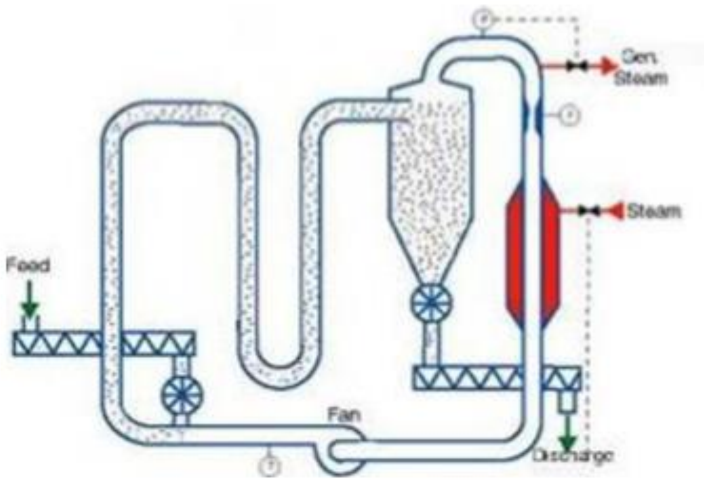


**Figure 34:** Superheated steam dryer.

The superheated steam dryer is using superheated steam for driving the heat in order to dry the biomass. Under normal conditions the steam is mixed with the biomass to dry it.

There are belt dryers designed specifically for the treatment of the biomass. A perforated belt feeds the dryer continuously. The strap is in a horizontal position to carry the biomass into the drying area, divided into several sections. Into the cells warm air is flowing into and over the biomass in order to dry it. Each cell is equipped with a heat exchanger and a ventilation fan. This provides the opportunity for cells to work autonomously so that temperature and humidity in each cell can be different and separately controlled.
After the drying process, biomass has very low content of humidity (3-5%), so it is necessary to check the humidity and add the necessary volume of humidity into the biomass (10-15%). This humidity is necessary for the production of good quality pellets.

**Storage of dry sawdust**

After the sawdust is dried out, it has the proper humidity and particle size for the production of the pellets. For that reason the material has to be stored again in controlled conditions for the protection of the optimal humidity because generally the dry matter absorbs the humidity of the air. The safe storage of the dry sawdust can be realized in silos e specially designed to protect the biomass from the humidity.

**Pelletizing**

The pellet mill or pellet press is a type of mill or mechanical press used in the production of pellets. There are many types of pellet machines categorised based on their capacity and size. Two types of large scale pellet mills are the flat die pellet mill and the ring die pellet mill.
The flat die pellet mill is using a flat mold with holes. The biomass sawdust enterers from the top of the mold and as the mold is rotating a press compresses the small particles of biomass through the mold holes to give the pellets their characteristic cylindrical shape. After that a metal blade at the other side of the mold cuts the exposed pieces of compressed wood creating the pellets.

The ring die pellet mill has radial holes throughout the surface of the mold. The sawdust is entering the mold and the beck spreads it equally into the holes. Then two cylindrical presses compress biomass through the mold holes to create the pellets. Finally, in the outside surface of the mold there are two metal cutter-blades cutting the compressed biomass to pellets.

Small scale pellet machines are distinguished in screw and hydraulic presses both of which make use of the same basic process. The design of a custom systems needs to take into account the size and quality of the sawdust as well as the shape and size of the final product-pellet. A plate is applied to the end of the screw (screw press) or the plunger (hydraulic press), which compresses the sawdust. Heat is applied to some plates to increase the quality of the pellet production.

As the applied pressure increases, the friction between the biomass grains increases with direct increase of the temperature. High temperature softens lignin (one of the three basics groups of biomass compounds with cellulose and hemicelluloses) which acts as a glue between and inside the biomass particles.

The adjustment to appropriate temperature is achieved from the proper design of the mold which creates the appropriate resistance to the flow of biomass to reach the desired lever of pressure. If the size of the particles are much smaller compared to the holes of the mold, then the particles pass freely from the holes and because of insignificant resistance the temperature does not increase so the pellets are very soft and destroyed immediately as they come out of the press. On the contrary, if holes are very small then temperature increases due to the high friction and pyrolysis or fire can take place.

The production of the pelletizers may range from several to thousands kilograms per hour. Also, if lignin level in the sawdust is not satisfactorily chemical ingredients could be added to assist this process taking into consideration health, safety and environmental regulations within the current legal framework and EU regulations.

Finally a critical dimension in the selection of the pelletizer is the consistent rate of feeding the pelletizer which can be key for the pelletizer’s optimal operation.

### Sieving the wood pellet

After the pellets are produced, some of them are not suitable for use as they do not form a solid structure, appropriate shape and may disintegrate easily. Therefore further sieving is used to differentiate and feed them back to the pelletizer. This can be with done with a pellet siever as the one depicted in Figure 35.

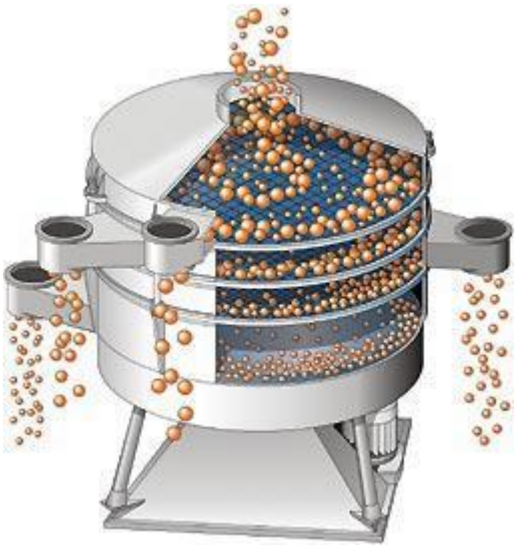

**Figure 35:** Pellet siever .

### Cooling the wood pellets

As mentioned before, the application of high pressure on the biomass, causes temperature to increases (70-90 C) and the lignin to melt. After the pelletizing process cooling of the pellets is needed so lignin can solidify and their shape is stabilised. This can be achieved if the pellets are left on a conveyor belt for some minutes to cool down to room temperature.

### Packaging and store the wood pellets

Because pellets are high quality, sensitive fuel, storage and packaging are very important steps. The conditions of the storage are essential to ensure that the pellets are properly maintained. This can be achieved by packing them or keeping them in a suitable protected silo. The humidity of the pellets has to be 10-15% so that their combustion is successful and efficient.

### Removal of metals and rocks

The removal of metals and rocks, from the biomass, is an initial step that cannot be eliminated. The removal has to be done before the braking down of the biomass with the hammer mill. Rocks and metals must not be fed into the mill as this would seriously damage the equipment. The treatment of the biomass has to be very careful with a lot check points. The technic varies between different equipment but in general a strong magnet is used for the removal of metals. For the removal of the rocks techniques focus on the different density of the particles.

## 4.6 New Wall Module

The aim of the research task was to detail and apply this module system to the Cypriot demo site on BIM, as a complementary and sustainable way to the improvement of the electrical grids, in reaching a more sustainable building/district on energy and thermal consumption. Therefore, energy and thermal simulations were exploited in order to evaluate performance and suggest improvements.

The universal building module is characterised by a green wall on the external side and a catalytic side in the interior, aiming to reduce the waste generated by construction and demolition while improving energy efficiency in buildings and fast installation.

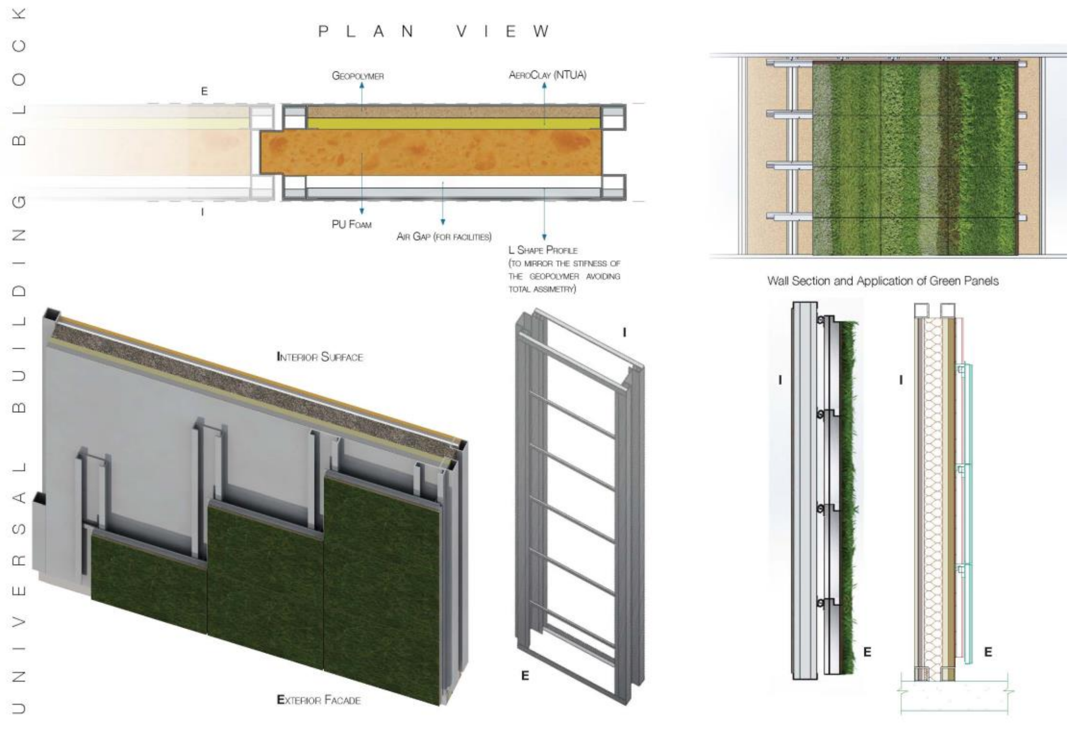


**Figure 36:** Plan view of the New Wall Module

The method for running the simulations was VE- Integrated Environmental Solutions (IES). VE - IES software is used from Engineers and Architects to run thermal, solar, wind and energy simulations on their ongoing projects. The main task was to import the Villa House into the software and prepare a 3D model. Each material type was tested in terms of UV values to obtain a consistent performance.

The aim of the research task here was to detail and apply this module system at the Cypriot demo site on BIM as a complementary and sustainable way to the improvement of the electrical grids, in reaching a more sustainable building/district energy and thermal consumption.

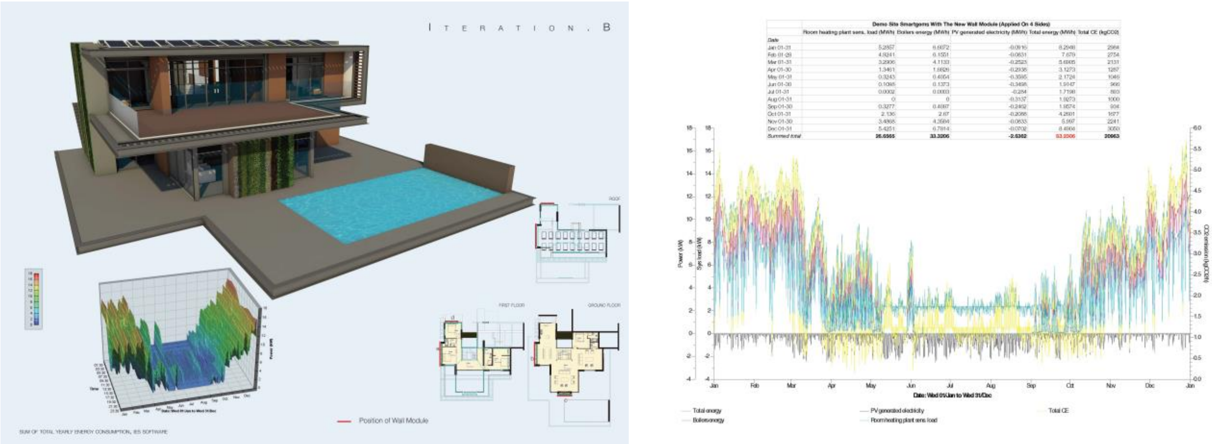


**Figure 37:** Plan view of the New Wall Module

## 4.7 PCM Energy storage system

Energy storage is a very active area of research in recent years as it provides a sustainable solution to energy demand fluctuations and increases energy efficiency. Different energy storage methods can be used, such as mechanical energy storage (gravitational energy, flywheels); electrical storage (e.g. batteries); thermal storage (sensible, latent) and thermochemical heat storage. The last one absorbs and release energy by breaking and reforming molecular bonds in a reversible reaction. Thermal Energy Storage (TES) systems use sensible and latent heat and is very important in relation to buildings because a high percentage of their energy demand relates to heating, ventilation and cooling needs. Sensible thermal storage systems apply when storage depends on a temperature increase or decrease. It requires large storage tanks and can be easily used in combination with an existing chiller system. Latent thermal energy storage (LTES) on the other hand has the potential to store more energy per

volume in comparison with a sensible thermal storage system, making LTES a solution for buildings either integrated into building envelope (passive PCM TES), in ventilation systems to reduce cooling demand (active PCM TES) or provide heating power. LTES with solid-solid PCM's (e.g. Trombe walls), change their crystalline form into another, offering the benefit of a less stringent container and greater design flexibility but have the disadvantage of a small latent heat. Solid-gas and liquid-gas have a higher latent heat but they are associated with inconvenient high volume expansion making their use challenging and their enclosure of certain specifications to avoid gas leakages.
Conversely, solid-liquid has small latent heat when compared to solid-gas with changes in volume lower than 10%. Due to this, solid-liquid PCMs are commonly used and containers must be designed to absorb these volume changes. They are mainly divided in Organic (Non-paraffin and Paraffin), Inorganic (Salt Hydrates) and Eutectic as presented in Figure 38 with melting enthalpy and temperature presented in Figure 39.

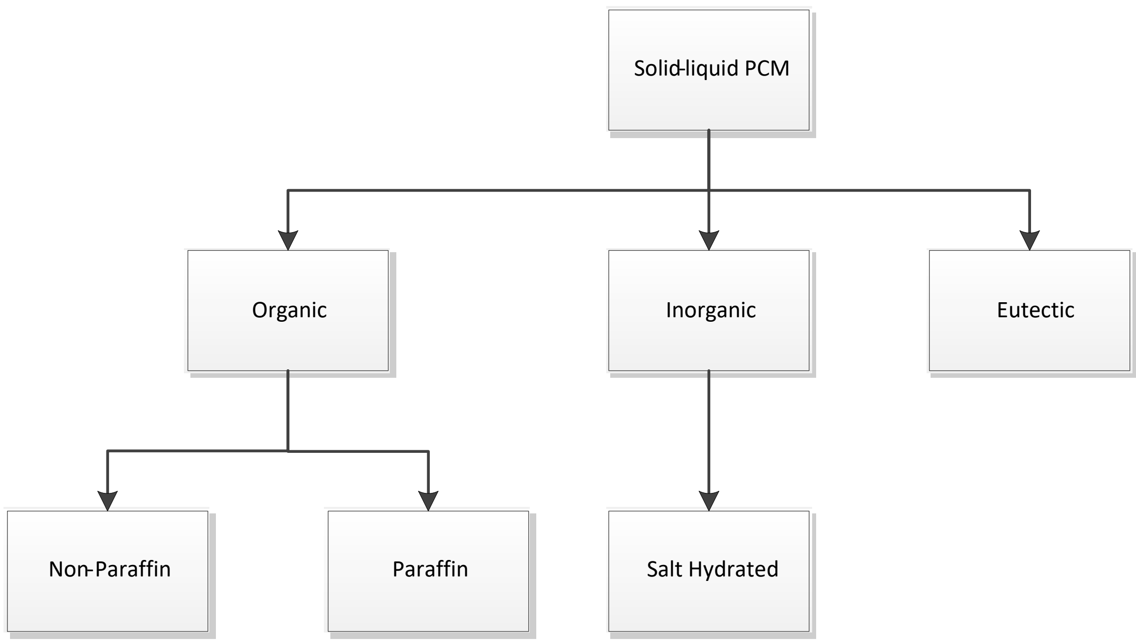


**Figure 38**: Solid Liquid PCM flowchart

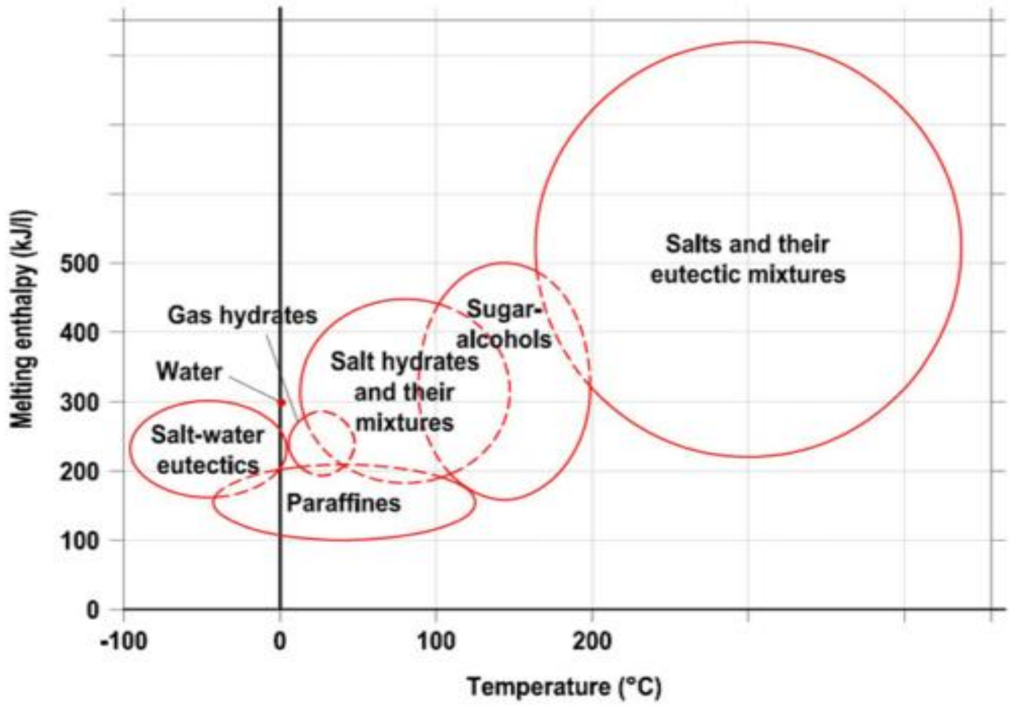


**Figure 39:** Melting enthalpy and temperature for different PCM

## Organic PCMs

Organic PCMs are mainly divided in paraffins and non-paraffins. Paraffins are safe, reliable, predictable, less expensive and non-corrosive, chemical inert and stable below 500°C**.** Conversely, they have low conductivity, a large volume change during phase transition, they are non-compatible with plastic container and moderately flammable. One of the major categories is called Alkanes (CnH2n+2) and contain 14-40 C atoms with a melting point between 6 to 80 ºC. Alkanes are generally termed as Paraffin. They are presented in two allotropic modifications in their solid phase that differ in their physical properties and physical structure. One is slightly above the melting point with a plastic, soft, and crystals needle shaped. The second is below melting point and is hard, brittle and crystals are disc-shaped.

Non-paraffins are all organic structures different from paraffins. The difference is that paraffins have very similar properties compared to non-paraffins. Fatty acids have a wide range of melting and freezing with no supercooling. However, they are mildly corrosive and their costs are 2-2.5 times greater than technical grade paraffins.

### Inorganic PCMs

Inorganic PCMs are mainly salt hydrates and their operation is based on the arrangement and breaking of the salt-water (hydrate-dehydrate) reaction. They have a high latent heat per unit volume, high conductivity, **double** volumetric heat capacity (128-400 kg/dm$^3$) compared to organic (128-200 kg/dm$^3$) and their volume changes slightly during melting process. However, salts have a density higher than water and stay at the bottom of the container, turning the freezing process more complicated. Three types of salts are identified:

- Congruent melting is when the salt is completely soluble at melting temperature;
- Semi-congruent melting is when the salt is not completely melted;
- Incongruent is when the salt is not soluble at melting temperature.

To solve incongruent melting it is possible to (i) introduce a mechanical stirring, (ii) encapsule the PCM to reduce separation, (iii) add thickening agents to prevent setting of the solid salts by holding it in suspension, (iv) use of excess of water so that melted crystals do not produce supersaturated solution, (v) modify the chemical composition of the system and making incongruent material congruent. General Electric Co., NY designed a rolling cylinder heat storage vessel system mounted horizontally with two sets of rollers and a rotational speed of 3 rpm. This produces sufficient motion to the solid content (i) to create effective chemical equilibrium, (ii) to prevent nucleation of solid crystals on the walls and (iii) to assume rapid attainment of axial equilibrium in long cylinders. Herrick et al. presented some of the advantages of this system: (i) complete phase change, (ii) latent heat released in the range of 90–100% of theoretical latent heat, (iii) repeatable performance over 200 cycles, (iv) high internal heat transfer rates, (v) freezing occurred uniformly.

### Metallic PCM's

In this group low melting and eutectic metals are included. In general, they have a low latent heat. As suggested by their name, the eutectic transformation congruently forms a mixture of component crystals during crystallisation and nearly always melts and freezes without segregation. Metallic PCMs consist of two solids and divided in (i) organic–organic, (ii) inorganic–inorganic and (iii) inorganic–organic. Some PCM compositions has a peritectic reaction instead of a eutectic but they are also called eutectics. [8,12]

As noticed, there are several alternatives to store energy and the selection of the best one is important to obtain the best performance from the equipment. The designer needs to take into consideration the thermophysical, kinetic and chemical properties (Table 19) in to select the PCM more adequate for each purpose. It is also important when a Latent Energy storage system (LHES) is designed that the PCM is suitable for the desired temperature, the heat exchange surface is enough, the container can absorb volume variations and whether the PCM is abundant, available and cost effective.

| | |
|---|---|
| **Thermal properties** | • must have the high latent heat<br>• thermal conductivity<br>• density and properly melting point<br>• congruent melting: material should melt completely and identically at desired temperature; otherwise, different melting points will result in segregation |
| **Physical** | • must have stability on freezing<br>• small volume changes and small vapour pressure at operating temperatures |
| **Kinetic** | • supercooling is not expected<br>• sufficient crystallisation rate is expected |
| **Chemical** | • PCM can suffer from degradation<br>• chemical decomposition or incompatibility with construction materials<br>• should not be toxic, flammable and explosive |

**Table 19:** Thermophysical, kinetics and chemical properties needed to be considered in a PCM storage tank design process

## 4.8 Thermal modelling of a case study solar cooled building

The scope of the work was to validate the thermal model of ARCA Consortium building in Palermo (Italy) using EnergyPlus and integrate it with a hydronic system component powered by an absorption chiller. ARCA infrastructure is connected to the Solar Living Lab, where the LFR solar polygenerative plant is installed and the design of a detailed thermal model of the premises is considered essential for holistic investigation of the interaction between the building and the solar plant.

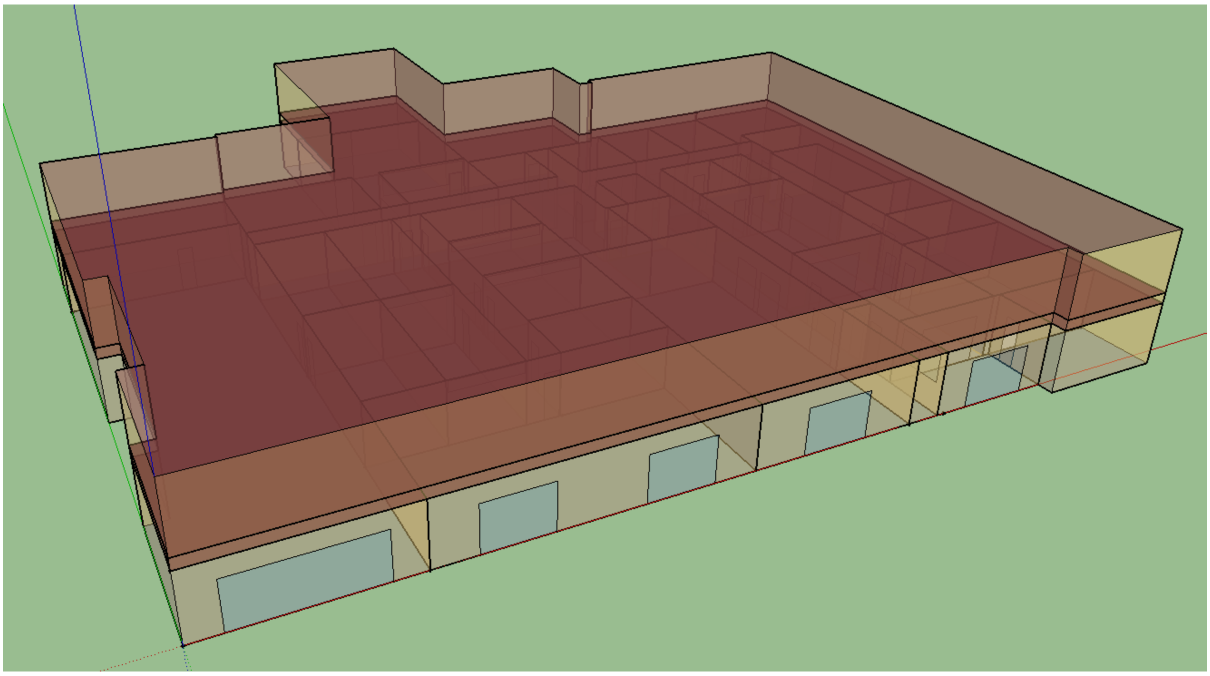

**Figure 40:** 3D model of ARCA consortium building

To validate the 3D thermal model of the building, measurements of indoor temperature were obtained in different conditions with respect to the operation of the HVAC system. Specifically, indoor temperature was recorded in various representative thermal zones as shown in Figure 41.

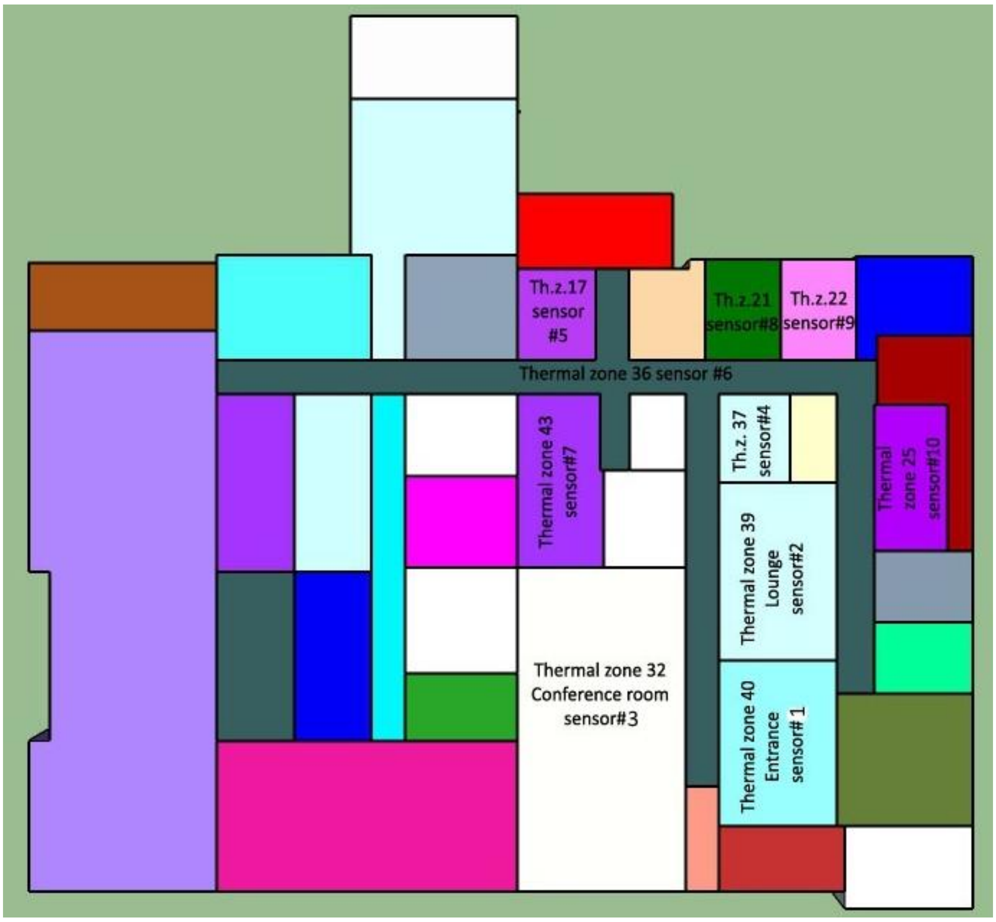


**Figure 41:** Thermal zones in ARCA premises

The analysis is focused in the part of the building conditioned by the coils of a hydronic system. Configuration was identified with the aid of installation designs and IR camera observations while the system was in operation. Technical specifications of the system were defined and imported in the EnergyPlus building / HVAC model.

The energy consumption of the building in peak and off-peak time and the cost of energy components were assessed (Figure 42). Testing of the model is in progress as various technical difficulties related to the modelling and simulation of the integrated system were faced.

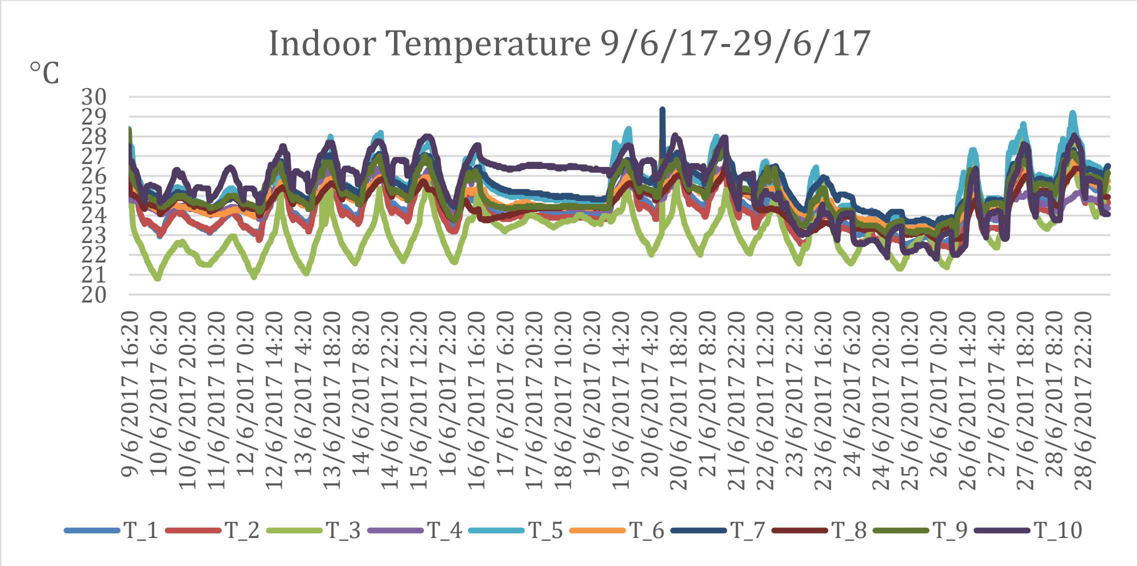


**Figure 42:** Indoor temperature recorded by the monitoring system in the different thermal zones

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