Smart Grid Energy Management Staff Exchange

D3.2 Guidelines for smart buildings and smart grids. Report on the operational phase

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1. Introduction

This report presents research work and findings in the context of Work Package 3 (WP3) “Smart Buildings and integration in smart grids” of the Smart GEMS project. WP3 refers to the investigation of common projects between the industry and academia in order to accelerate the process towards zero energy buildings. WP3 focuses on a) the smart buildings’ design phase, b) smart buildings’ operational phase and c) zero energy buildings and integration with smart grids.

Deliverable 3.2 “Guidelines for smart buildings and smart grids: Report on the operational phase” contains work carried out in Task 3.2 related to the development of skills for smart buildings’ operation in order to assist the promotion of smart technologies.

Smart controls and advanced monitoring for buildings operational phase have been thoroughly examined and assessed in terms of energy performance at an industrial and a residential building of the Leaf Community in AEA, Italy. This was combined with the development of building energy dynamic models, indoor and outdoor environment measurements and a careful consideration of power production and consumption data. Specific issues have been addressed and generic as well as case specific conclusions have been drawn to be used as the basis for establishing and implementing solutions in the near future.

Moreover, the energy efficiency of the New Technologies Laboratory Building (NTLB) of Cyprus Institute with a Linear Fresnel Collector and combined HVAC systems’ operation has been assessed in terms of minimization of consumption and full exploitation of solar plant integration.

In addition, dynamic modelling and evaluation of Concentrated Solar Power (CSP) technology and in specific, the IDEA FRESCO system was investigated as a solution for integration in Near Zero Energy Buildings (NZEBs) and smart grids. A model of the Fresnel System was developed and exploited to fully understand the operational phase and coupling possibilities of such systems.

Furthermore, assessment of primary and secondary optic elements in CSP systems and their performance is being carried out as part of Task 3.2 to evaluate the effects of ageing and dust deposition and assess the performance on new materials and components.

Finally, work on building modelling, energy performance assessment and improvement has been performed in building No 20 in Fiera del Meditteraneo of Palermo, Italy.

1.1 Secondments linked to Research Activities

Table 1 provides an overview of the secondments involved in the research activities included in Deliverable 3.2.

Table 1: Seconded personnel and link to research activities in Task 3.2

Researchers	Sending Organization	Organization of Destination	Research field
Christina Georgatou	TUC	IDEA	Modelling Linear Fresnel Collector (FRESCO IDES) in TRNSYS
Kostas Gobakis	TUC	AEA	Leaf House / Leaf Lab Optimisation in Open Studio / Energy Plus
Nikos Kampelis	TUC	AEA	Leaf House / Leaf Lab Optimisation in Open Studio / Energy Plus
Theoni Karlessi	UoA	IDEA	Testing of new materials / components' optical properties for ageing and dust deposition in CSP applications
Fabio Montanigno	IDEA	Cyl	NTL and Fresnel collector integrated control
Pietro Muratore	IDEA	Cyl	NTL and Fresnel collector integrated control
Filippo Paredes	IDEA	Cyl	NTL and Fresnel collector integrated control

Andri Pyrgou	CyI	IDEA	Energy modelling / optimization of building No 20 in Design Manager / Energy Plus
Vagias Vagias	TUC	AEA	Leaf House / Leaf Lab Optimisation in Open Studio / Energy Plus
Luca Venezia	IDEA	CyI	NTL and Fresnel collector integrated control

2. Smart Buildings Operational Phase for Smart Grids

Buildings are nowadays increasingly expected to meet higher and potentially more complex levels of performance. They need to be sustainable, use zero-net energy, be healthy and comfortable, grid-friendly, yet economical to build and maintain. Energy requirements from low-cost, locally available, non-polluting sources need to be met linked to the generation of renewable energy on site to equal annual energy use.

European strategy and legislation places a strong emphasis on buildings to achieve the EU's 2020 targets and meet the longer term objectives of the climate strategy in the low carbon economy roadmap 2050 [1]. The main vehicle for implementing this strategy is the Energy Performance of Buildings Directive (EPBD) which sets the framework for NZEB and establishes links with the EU strategy for climate change adaptation. In specific the EPBD establishes the 'nearly zero energy building' as the target from 2018 for all public owned or occupied by public authorities buildings and from 2020 for all new buildings. Under the agreed legislative framework Member States are responsible to report on the detailed application of NZEB in practice reflecting national, regional or local conditions. In ZEB or NZEB buildings currently in operation or in development stages, energy efficient technologies are used in combination with solar, wind and other sources of energy i.e. geothermal or biomass to attain "nearly zero-energy" behaviour [2]–[5]. Particular importance in the transition to smart ZEB have a) the development of standardized interfaces to ensure that different components can be interchanged or adjusted and ensure collective performance and b) the implementation of innovative technologies such as innovative HVAC systems, efficient wind and solar energy producing components, energy storage, energy management etc. Moreover, advanced technologies such as solar thermal technologies can in certain cases be exploited to meet the cooling demand during the summer season and partially the heating demand during winter time. The real challenge with such systems lies in the design of a suitable and efficient solution to utilize maximum heat from the sun in order to fulfil the required energy demand [6]. Also, Innovative Building Integrated Photovoltaic (BiPV) Systems have a great potential for architectural use thanks to their versatility and customizability in terms of colours, transparency and design. BiPV support the increase of renewable energies share and improve building envelope performance. Integrated solar inverter and storage systems offer capabilities such as Maximum Power Tracking and storage control [7]–[9]. Significant research is performed in the area of storage control and in particular in storage systems either using batteries or other technologies [10]. Combined Solar and Wind driven energy systems is a breakthrough technology to have entered the market of building integrated renewable energy systems. On the other hand indoor environment quality control and BEMS have evolved considerably in the last decades, leading to a better understanding and penetration of the term "smart buildings" [11] being very much in line with the ZEB concept. Advanced BEMS can have a major impact on the design, operation, optimization, and control of energy-influencing building elements (e.g., HVAC, solar, fuel cells, CHP, shading, natural ventilation, etc.) In the last years advanced control techniques inherited from other industrial markets such as Model Predictive Control and smart predictive control algorithms contribute to 20-30% in annual energy consumption reduction [12], [13]. Energy load prediction is becoming increasingly relevant and cost effective [14], [15]. Intensive research is focused on renewable energy production predictions. Furthermore, data processing and interpretation extracted by smart metering can provide useful information for the buildings' energy behaviour. Automation Systems allow the effective management of indoor comfort for the building users. Last but not least Demand Response (DR) offers the capability to apply changes in the energy usage by the consumers to altering their normal consumption patterns in response to changes in the energy pricing over time.

Demand management systems are usually connected to the low-voltage distribution network. DR developments entail a shift away from traditional power grids, towards more bi-directional networks structure capable of accommodating fluctuations in both supply and demand. With the introduction of DR it is expected that decentralized market players will take on new roles i.e. consumers become 'prosumers' (producer-consumers) and some new commercial and non-commercial actors will enter the market.

The relation of the ZEB concept and building users is considered to be strong in the sense that there is a physical proximity between consumers, energy production and energy resources management that may be beneficial in increasing end users' awareness and user engagement. This requires monitoring and the provision of meaningful information to the users combined with specific incentives. User engagement is strongly linked with DR and requires among other an effective Regulatory framework and investments in advanced metering infrastructures.

In the above framework research work performed in Task 3.2 involves analysis, modelling and evaluation of the buildings operational performance and of their installed smart, energy efficient, conversion and production technologies as presented in table 2. A conventional commercial building (building no.20) has also been modeled and analyzed in an attempt to evaluate its energy performance and propose alternative measures and techniques for its transition to NZEB operational performance levels.

Table 2: Smart buildings energy efficient, conversion and production technologies

Technology	Advanced Envelope				HVAC			Lighting		Energy Production			Energy Storage		Energy Management	
Pilot Case Studies	Ventilated Roof	Sky windows	Double Facade	Automated Shading	Heat Pumps	Advanced Monitoring	Advanced Controls	LED	Illuminance/ presence control	Linear Fresnel	biPV	Geothermal	Thermal storage	Electrical Storage	My Leaf	Other BEMS / Remote Platform
Leaf Lab - Industrial AEA /Italy		x		x	x	x	x	x	x		x	x	x		x	
Leaf House - Residential AEA /Italy	x				x	x	x	x			x	x		x	x	
NTL - Tertiary CyI /Cyprus			x		x	x	x		x	x	x		x			x
Building No.20 - Commercial, Italy																

Each of the pilot case buildings in Table 2, facilitate different uses and fulfil special requirements in distinct building sectors. The Leaf Lab, Leaf House and NTL comprise unique operational infrastructures with a particular emphasis on minimizing net energy consumption. This is achieved with a combination of measures including responsive building envelope applications, energy efficient

HVAC systems coupled with storage, smart controls, renewable energy systems and advanced energy management.

The Leaf Lab is a state of the art industrial building hosting world class research and innovation in a high tech settlement with advanced energy monitoring, production of energy, thermal energy storage and smart controls. Similarly, state of the art equipment has been installed in the Leaf House to operate as a Near Zero Energy Residential building structure. The Leaf House deploys high-end energy efficient technologies, a holistic monitoring system, user engagement features and building integrated renewable energy with electrical storage. Furthermore, a top-end renovated tertiary building, the National Technologies Laboratory (NTL) of Cyprus Institute incorporates energy efficient technologies and integrates modern HVAC technology with a rooftop Linear Fresnel System significantly reducing energy demand from the power grid.

3. Towards Zero Energy Buildings for buildings in Operational Phase

3.1 The Leaf Lab (Industrial)

The Leaf Lab is an industrial building located in the Leaf Community, one of the very few smart microgrids in Europe. Buildings in the Leaf Community located in Angeli di Rosora of Ancona in Italy are interconnected with Photovoltaic (PV), Geothermal Systems, electric and thermal storage, 3 micro-hydroelectric plants, electric vehicles (EV) etc.

The evolution of energy technologies becomes gradually more attractive for both economic and environmental reasons. Energy production and consumption in a decentralized way can have many benefits regarding the savings of raw sources, reduction of CO_2 emissions and energy costs. The Leaf Lab incorporates the newest technology making its structure very tolerant to external weather conditions. This reduces to the minimum the amount of energy needed to cover the energy demand, regarding heating, cooling, ventilation and lighting. The Leaf Lab is considered a Near Zero Energy Building since it is characterized by passive systems, energy efficient technologies, integrated monitoring and control as well as renewable energy production. Renewable energy is exploited with the use of PV systems and heat pumps. Thermal storage is also employed to store energy and use it to optimize HVAC performance.

In this section the 3D modeling, validation and energy performance assessment of the Leaf Lab is presented. The first step of the methodology followed was to develop a 3D energy model as close to the real case as possible. This is done using Open Studio plugin in SketchUp and Energy Plus as a simulation engine. After creating the energy model, validation takes place using indoor temperature measurements with the aid of specialized equipment and energy related data from MyLeaf platform. Applied on building infrastructure and especially on an industrial building, the approach followed can produce optimal results for users' comfort and energy performance

The main steps of the methodology followed are briefly described below:

- Data collection, analysis and processing
- Division of the building structure into various thermal zones
- Building 3D design using Open Studio SketchUp Plugin
- Open studio - Import of the physical and thermal characteristics of building structural elements (walls, ceilings, floors, openings).
- Import of HVAC and lighting systems data
- Import of schedules for working days/hours, holidays, equipment use & occupancy
- Validation using MyLeaf and specialized measuring equipment
- Energy performance and indoor conditions simulation and analysis

3.1.1 Data collection, analysis and processing

In order to develop an accurate model several data were collected, analyzed and processed. The architectural drawings were used to design the structure's envelope and merge the several spaces into thermal zones properly. Also electro-mechanical and HVAC system drawings were taken into consideration. Moreover there was data collection about the physical and thermal characteristics of the external and internal walls, of the roof, ground floor and ceiling, alongside with similar information about the external windows. The lights of each space, total average number of persons and equipment power approximations were encountered in order to count for the internal thermal gains and related electrical energy consumption. Access to myLeaf platform provided the basis for collecting reliable data on environmental conditions, energy consumption and production. In addition the internal temperature for (seven) main spaces of the building was recorded for several periods using portable equipment. Finally energy utility bills were used for the year 2015 as a reference even though they refer to a single point of delivery for the whole settlement of the Leaf Community.

3.1.2 Division of the building structure into various thermal zones

The thermal zones are divided in terms of the use, orientation, schedule and construction materials of each space. These criteria were chosen based on international experience and related standards. The following drawings were taken under consideration in the process of the division of the thermal zones (fig.1).

Caratteristiche sintetiche: edificio principale		
Superficie edificio in pianta coperta	3.640	m²
Superficie totale	6.000	m²
Volume totale	32.800	m³

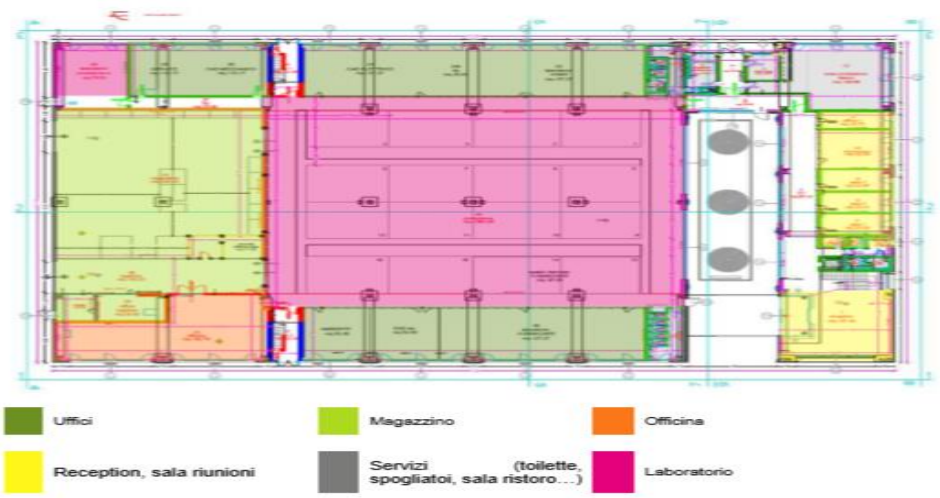

Fig 29: Planimetria edificio con aree funzionali in evidenza

Figure 1: Space use in Leaf Lab ground floor

In this process the following adaptations were required to avoid extra complexity and computational overload:

- ➢ Merging conditioned or non-conditioned thermal zones in case of insignificant size
- ➢ The Central Lab together with the corridors between the lab and the open offices in both first and second floor were taken as one thermal zone. This happens because the corridors are connected with the lab and they form all together a single air node.
- ➢ The Warehouse was merged with a small office which is included in it, since it is a very small space to form a separate thermal zone and the door of the office is often open eventually forming a common air node.
- ➢ The kitchen together with the infirmary, the dressing room and the corridor between them were taken as a single thermal zone. This was done for three reasons. Although the infirmary has much different use and schedule than all the others, it is a very small space to form a thermal zone of its own. The second reason is that the existence of the corridor as a separate thermal zone would create automatically another very

small thermal zone, the dressing room. Thirdly, considering the kitchen, the infirmary, the dressing room and the corridor all together, as a single thermal zone results in no different thermal loads and energy use.

- The meeting rooms of the ground floor were taken as one thermal zone since they have the same use and schedule and if taken separately would unnecessarily increase computational load.
- The small lab at the northeast side of the first floor together with the closed office were taken as one thermal zone in terms of simplification of the model
- The archive room at the east side of the second floor was merged with the two meeting rooms, since it is quite small and it was considered preferential not to merge it with the closed room rather than with the non-conditioned space hosting the HVAC equipment.
- The data center and the ventilation system room at the north side of the 2nd floor are considered as one since they are in contact and they are also both non-thermal spaces.
- Finally the two separate offices that are in contact between them at the west side of the second floor were matched since they are rather small and of the same use and size.

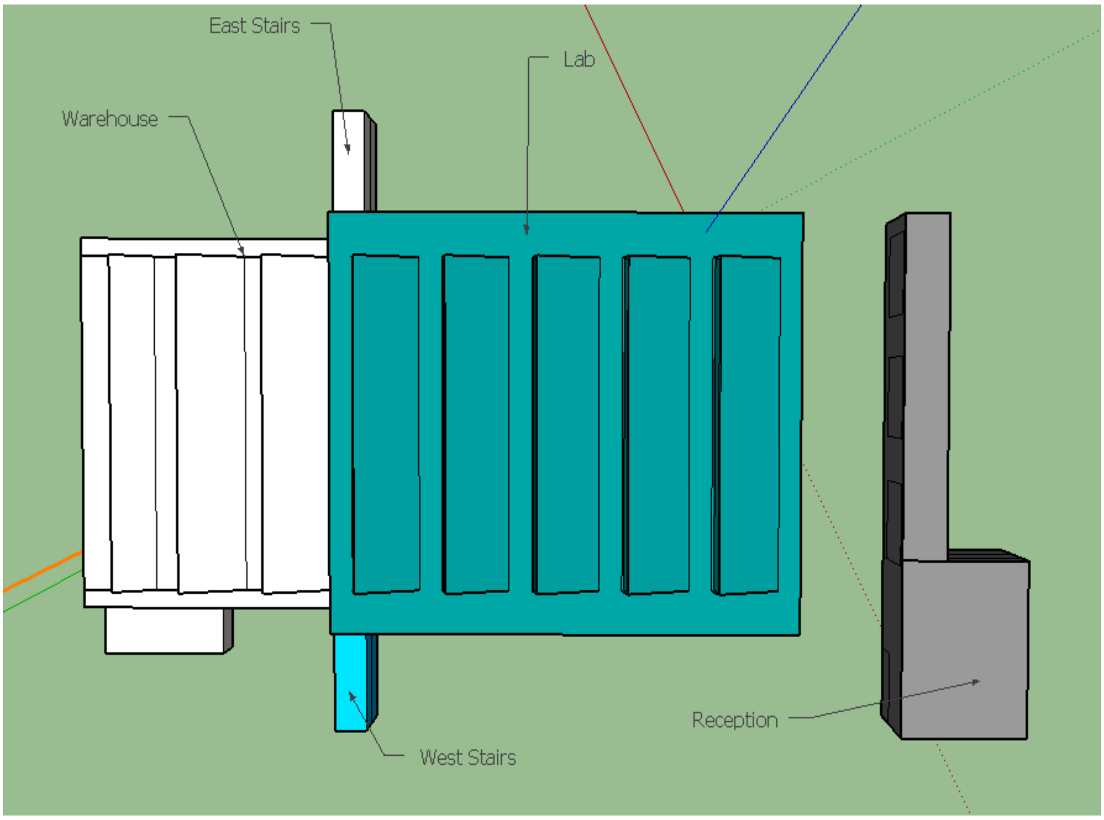

Figure 2: Division of the building structure into various thermal zones - Ground to 1st floor

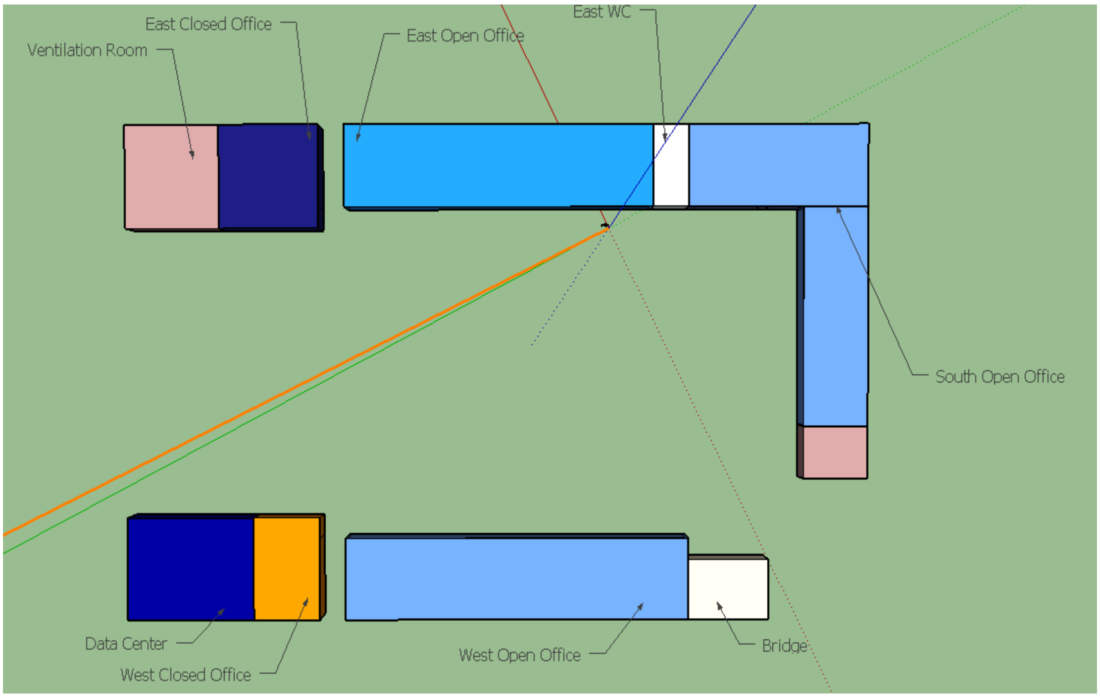

Figure 3: Division of the building structure into various thermal zones - 1st Floor

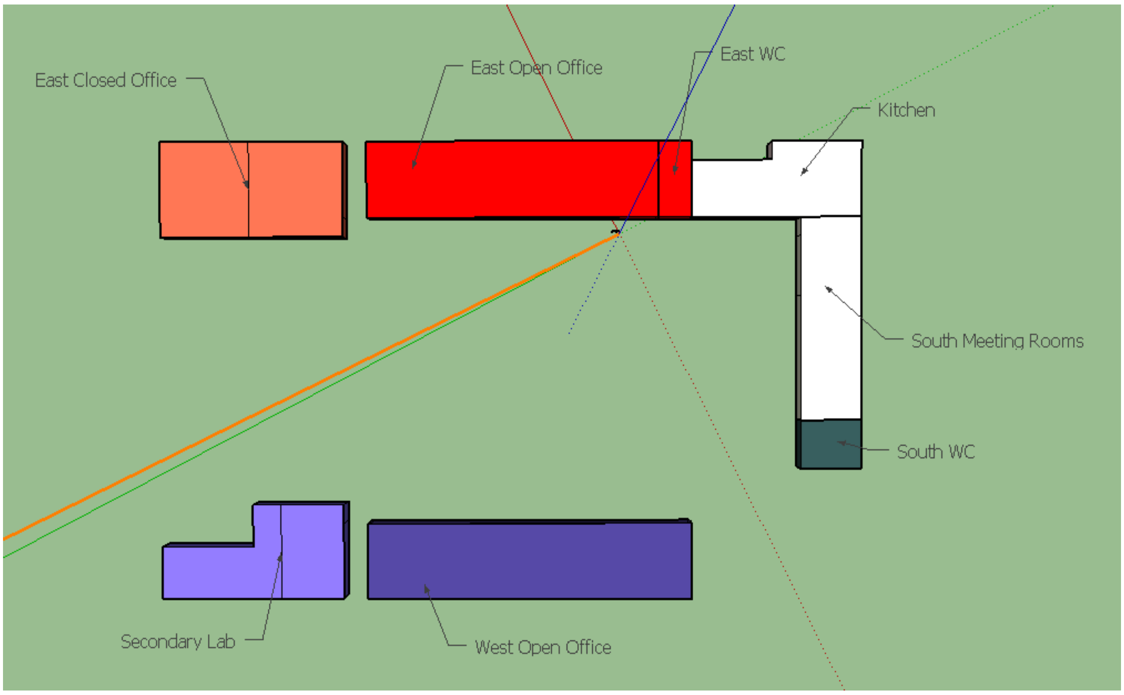

Figure 4: Division of the building structure into various thermal zones: Ground Floor

3.1.3 Leaf Lab Final 3D model

The final 3D model concludes all together the surfaces and subsurfaces (windows, and doors). Several views of the final 3D model are presented bellow (fig.5-7). Via Open Studio various building specific data is inserted:

- weather conditions and systems design parameters
- materials for each building element (wall, ceiling, floor and roof)
- technical specifications of the HVAC, artificial lighting and other equipment
- systems and activity schedules

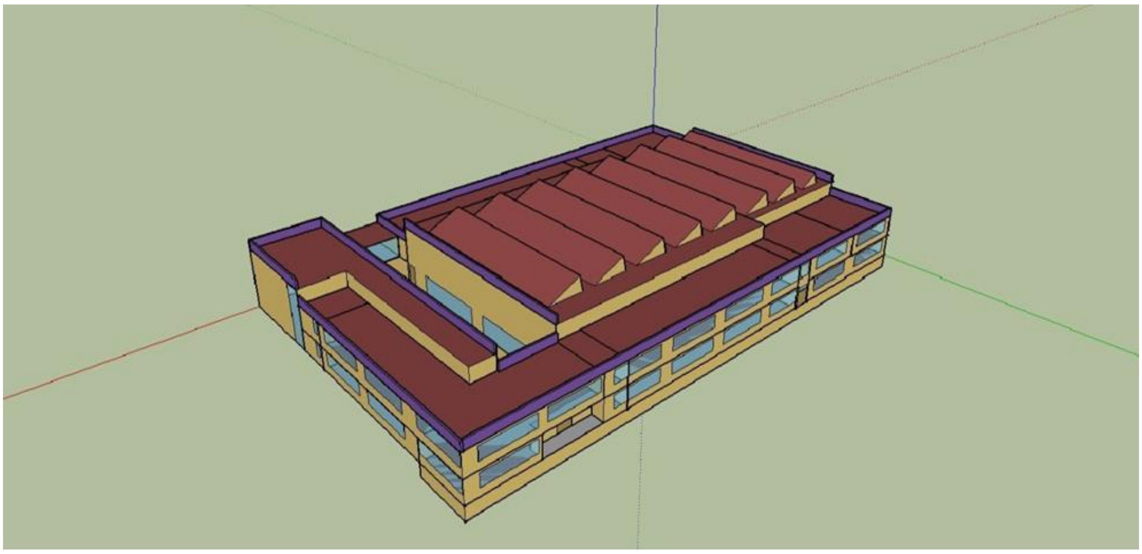

Figure 5: Leaf Lab 3D model - South view

Figure 6: Leaf Lab 3D model - West view

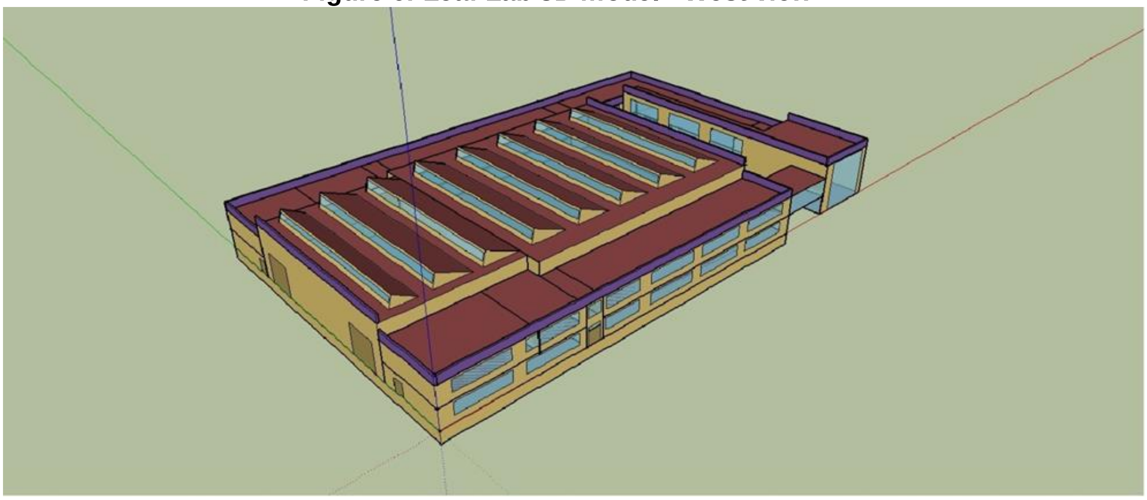

Figure 7: Leaf Lab 3D model - North view

3.1.4 HVAC systems, Thermal Storage and Control

The HVAC System installed in Leaf Lab is comprised by heat pumps of the technical characteristics described in table 3 and fan coils in various spaces as shown indicatively in the drawing provided in figure 8:

Table 3: Leaf Lab HVAC heat pumps technical characteristics

Leaf Lab HVAC Units	Heating Power (kW)	Heating COP	Cooling Power (kW)	Cooling EER
NECS-WN/S 0412	130	4.8	159.2	6.89
NECS-WN/S 0904	286.9	4.19	239.3	6.19
NECS-WN/S 0904	286.9	4.19	239.3	6.19

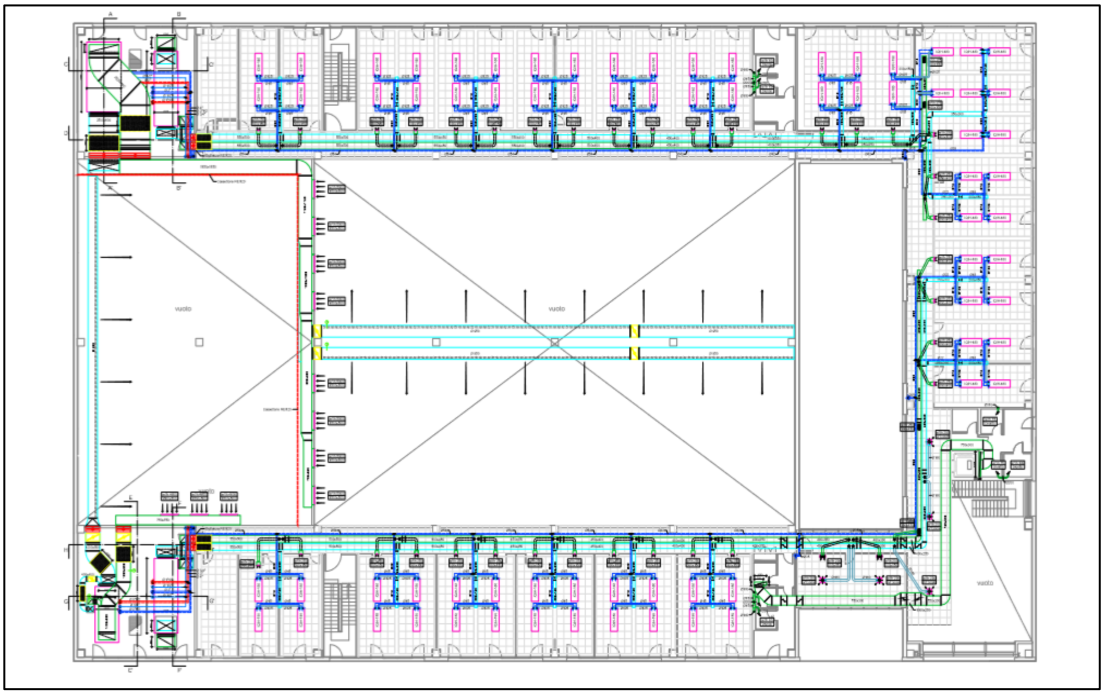

Figure 8: HVAC central units, distribution and fan coils

A thermal storage water tank of 400m^3 is coupled to the HVAC system of the building. Thermal storage in Leaf Lab is used to reduce peak power and improve the efficiency of the HVAC system. This is implemented by using energy excess from the PV i.e. during weekends, holidays etc. to operate the heat pumps and store heating or cooling energy in the thermal tank. Stored energy is then used to optimise the HVAC efficiency and reduce peak demand during working hours.

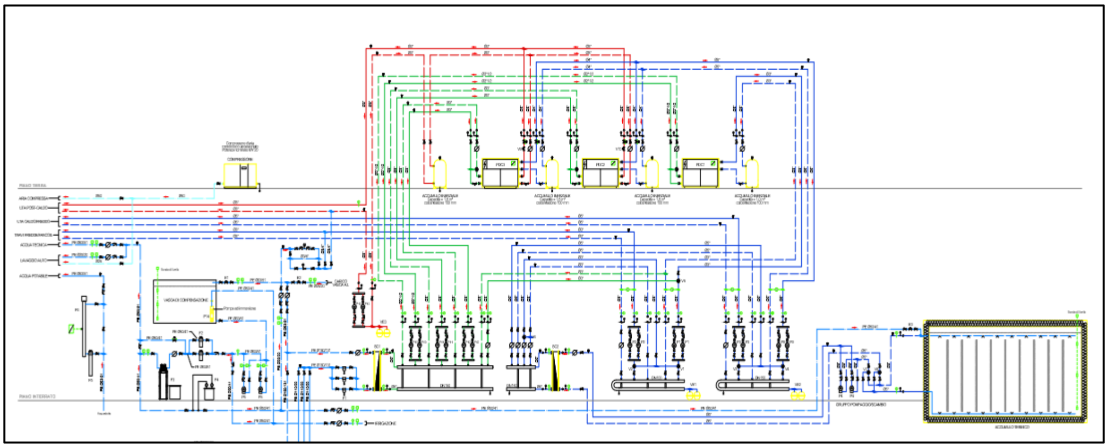

Figure 9: HVAC system diagram with thermal storage

The HVAC operates according to the set points of table 4, controlled with digital thermostats distributed in the various thermal zones:

Table 4: HVAC setpoints for heating and cooling mode

HVAC Setpoints	Industrial spaces	Offices
Cooling mode	25°C for working hours	26°C for working hours
	28°C outside working hours	29°C outside working hours
Heating mode	21°C for working hours	22°C for working hours
	18°C outside working hours	18°C outside working hours

3.1.5 Artificial Lighting and Automated Shading Systems

Artificial lighting in the indoor spaces of the Leaf Lab is controlled by illuminance sensors activated when levels due to natural lighting fall below 500 lux. Artificial lighting installed per thermal zone category in the Leaf Lab is presented in table 5.

Table 5: Artificial lighting type and power per thermal zone in Leaf Lab

Thermal Zone	Type	Total Power (kW)
Laboratory, Warehouse	GRAFT LED840 140W	8.68
Workshop	SCUBA LED 55W	1.65
Offices, meeting rooms	FEC2 41W LED840	8.73
Lobby, hallways, bathrooms	226 FD 1000 25W LED	5.65

Furthermore, automated shading is installed in the majority of the buildings' windows and operated according to the altitude of the sun. This allows for natural lighting to be sufficient for visual comfort while avoiding glare but also minimises energy consumption for artificial lighting.

3.1.6 Photovoltaic (PV) System & RES Energy Production

Figure 10: Leaf Lab, AEA, Angeli di Rosora, Marche, Italy

As shown in figure 10, a rooftop photovoltaic system of 236.5 kWp is installed in Leaf Lab producing, according to MyLeaf for the year 2015, approximately 276,000 kWh on an annual basis.

3.2 Leaf House (Residential)

The Leaf House is a residential building of exceptional bioclimatic design and smart technologies. It consists of six highly insulated apartments, a ventilated roof, solar tubes, smart monitoring and controls, building integrated photovoltaics, geothermal air preconditioning with heat pumps, solar thermal collectors, electrical storage and a user friendly energy management system for residents.

In the following sections the modeling process and the energy performance assessment of Leaf House located in Angeli di Rosora (AN) is analysed. The first step of the methodology followed was to design a reliable 3D energy model using Open Studio SketchUp plugin and Energy Plus as the simulation engine. Next power measurements from MyLeaf were collected and used as a benchmark for the model's validation. Indoor measurements of internal temperature were conducted to observe conditions and draw conclusions on thermal inertia when the HVAC system is turned off. Finally performance analysis was carried out to draw generic conclusions regarding the contribution of each technology on Leaf House operational phase and propose measures for further improvement.

3.2.1 Methodology

The main steps of the methodology are briefly described below:

- Data collection, analysis and processing
- Division of the building structure into various thermal zones
- Building 3D design using Open Studio SketchUp Plugin
- Open studio - Import of the physical and thermal characteristics of building structural elements (walls, ceilings, floors, openings).
- Import of HVAC and lighting systems data
- Creating schedules for working days/hours, holidays, equipment use, occupancy etc.
- Validation using MyLeaf and specialized measuring equipment
- Energy performance and indoor conditions simulation and analysis

3.2.2 Data collection, analysis and processing

Several data were collected and analyzed in terms of designing an accurate energy model. The architectural drawings were used to design the structure's envelope and merge the several spaces into thermal zones properly. Also electro-mechanical and HVAC system drawing were taken into consideration. Moreover there was a collection of data collection about the physical and thermal characteristics of the external and internal walls, of the roof, ground floor and ceiling, alongside with similar information about the external windows. The lights of each space, total average number of persons and equipment power approximations were recorded through energy auditing in order to establish an estimate of the internal thermal gains and related electrical energy consumption. Moreover, access to MyLeaf platform provided the basis for collecting reliable data on environmental conditions, energy consumption and production. In addition the internal temperature in one of the apartments was recorded to evaluate the responsiveness of the HVAC system. Finally, energy utility bills were used for the year 2015 as a reference for validation and energy analysis purposes.

3.2.3 Division of the building structure into various thermal zones

The thermal zones are divided in terms of the use, orientation, schedules and the construction materials of each space. These criteria are considered to having a central role in the thermal behavior of the various building zones.

Figure 11: Leaf House South View

Figure 12: Leaf House North View

In the selected residential building the thermal zone division was performed with great attention to detail having as a result every room being considered a separate thermal zone to best capture differences in indoor comfort. This is indicated in figures 31 and 32 for ground and 1st floor apartments of the Leaf House.

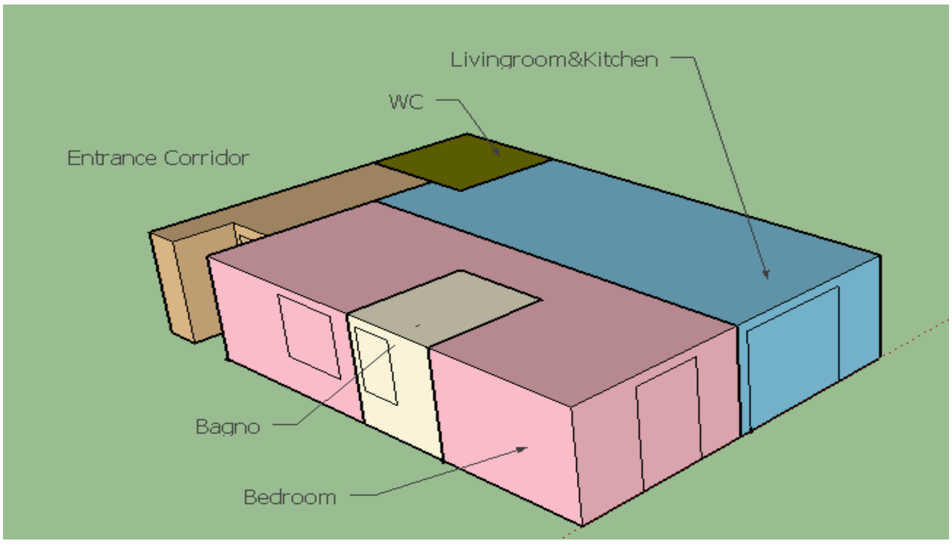

Figure 13: Leaf House 3D Model Ground Floor West Apartment

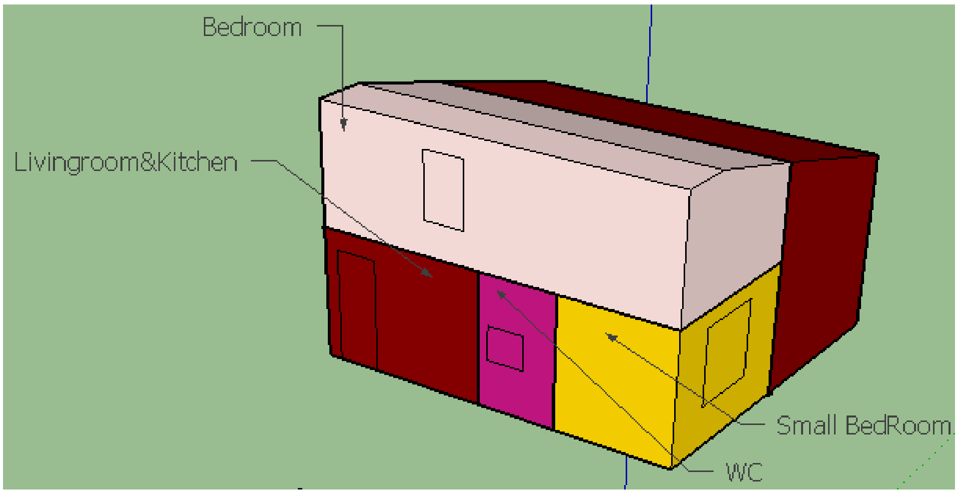

Figure 14: Leaf House 3D Model 2nd floor West Apartment

3.2.4 Leaf House 3D Model

The complete 3D model of the Leaf House with surrounding shading from objects in various sides is illustrated in figures 33 and 34.

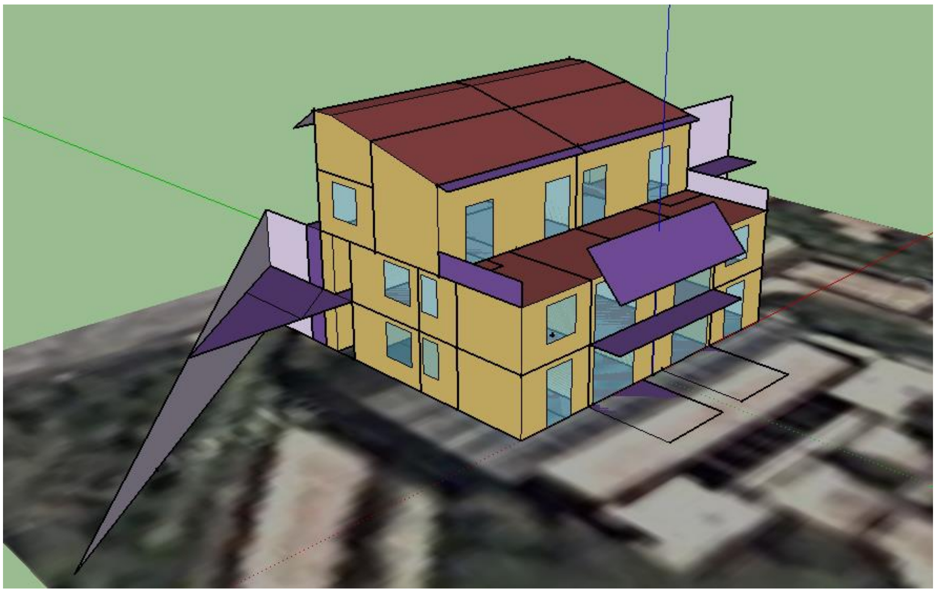

Figure 15: Leaf House 3D Model south/west view

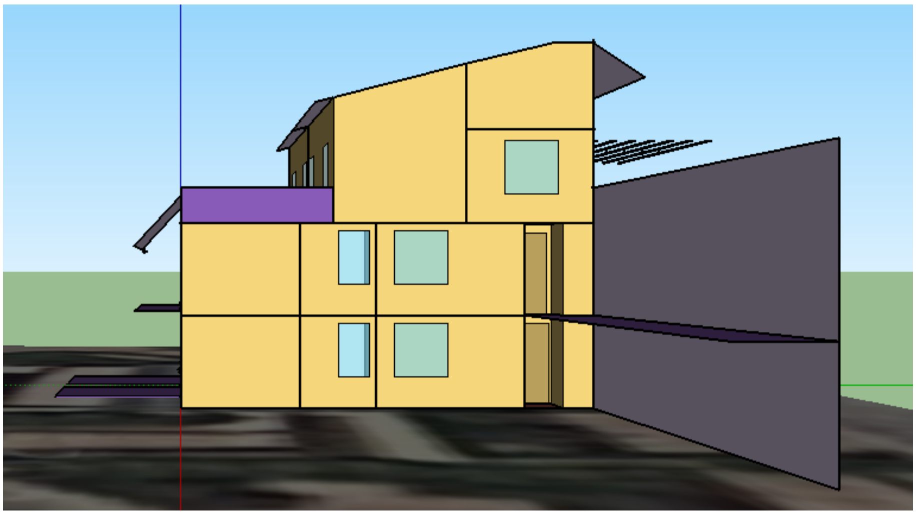

Figure 16: Leaf House 3D Model east side

3.2.5 Physical and thermal characteristics of building structural elements (walls, ceilings, floors, openings).

Via open studio various data concerning weather conditions, the simulation period, the construction materials of each building element (wall, ceiling, floor and roof) were inserted as well as information of the electrical equipment and artificial lighting systems their schedule, the schedule of activity and occupancy etc.

With regards to the building construction, data on the physical and thermal characteristics of the envelope were imported based on well documented data of the several layers as shown in table 9:

Table 6: External wall thermal and physical characteristics

Cod.	DESCRIZIONE STRATO	s	λ	C	ρ	δax10[12]	δux10[12]	R
	(dall'interno verso l'esterno)	[cm]	[W/m°C]	[W/m²°C]	[kg/m³]	[kg/msPa]	[kg/msPa]	[m²°C/W]
1	Malta di gesso per intonaci	2.00	0.290	0.00	600.00	24.13	26.54	0.07
2916c	Blocco Poroton	30.00	0.210	0.70	950.00	19.30	21.23	1.43
146	Polistilene Rofix EPS-100	18.00	0.036	0.00	93.00	149.61	164.57	5.00
11	Intonaco plastico per cappotto	0.50	0.300	0.00	1.300.00	6.43	7.08	0.01

3.2.6 Import of HVAC and systems data

The HVAC System installed in Leaf House is comprised by heat pumps with geothermal air preconditioning and heat recovery connected to a radiant floor distribution system. A schematic of the central HVAC system is presented in figure 35 and the heat pumps' technical characteristics are described in table 10.

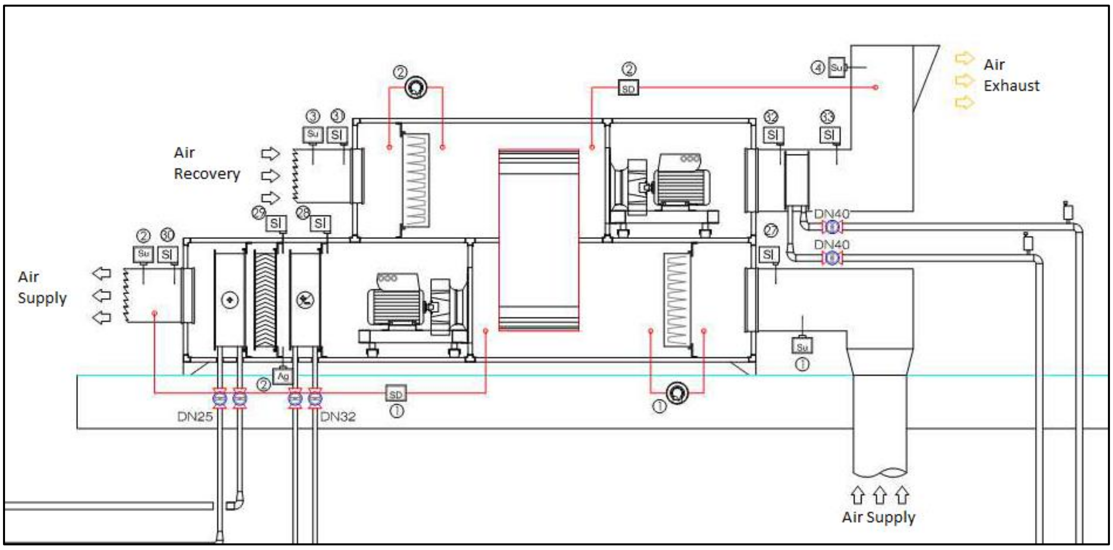

Figure 17: Leaf House Central HVAC system

Table 7: Leaf House Heat Pumps' Technical Characteristics

Type of Heat Pump	Heating Power (kW)	Heating COP	Cooling Power (kW)	Coolin g COP	Electrical Power Installed (kW)
B0/W35	16.6	4.6	13	3.61	3.6
B2/W45	17	3.76	12.5	2.78	4.5
B3/W55	16.2	2.94	10.6	1.93	5.5

Solar thermal collectors (7) of a total area of 19 m^2 are connected to a 1000l thermal storage boiler of 15kW electrical power for domestic hot water and space heating.

3.2.7 Building integrated Photovoltaic (biPV) System

The 20kWp PV system of the Leaf House is integrated in the building roof meeting the architectural requirements and reducing the visual impact of the photovoltaic technology. Energy produced by the photovoltaic system is mainly exploited to power the geothermal heat pumps and reduce overall power consumption. To accomplish this, 115 PV panels covering a total area of 150 m² with the technical characteristics described in table 11 were installed.

Figure 18: Leaf House building integrated Photovoltaic System (biPV)

Table 8: Leaf House biPV System Technical Data

PV System	Number	Model	Power (kWp)
Panels	115	Schüco 175-SMG-S	20.125
Inverters	3	SMA SMC 6000TL-IT (1) / SMC 7000TL-I (2)	

3.2.8 Building Energy Management System

Apartments in the Leaf House are equipped with a touch display providing access to an energy management interface for observing indoor conditions, energy related data and managing automatic controls of HVAC, lights, window shutters etc. Also, power measurements the apartments in the Leaf House are accessible through MyLeaf platform.

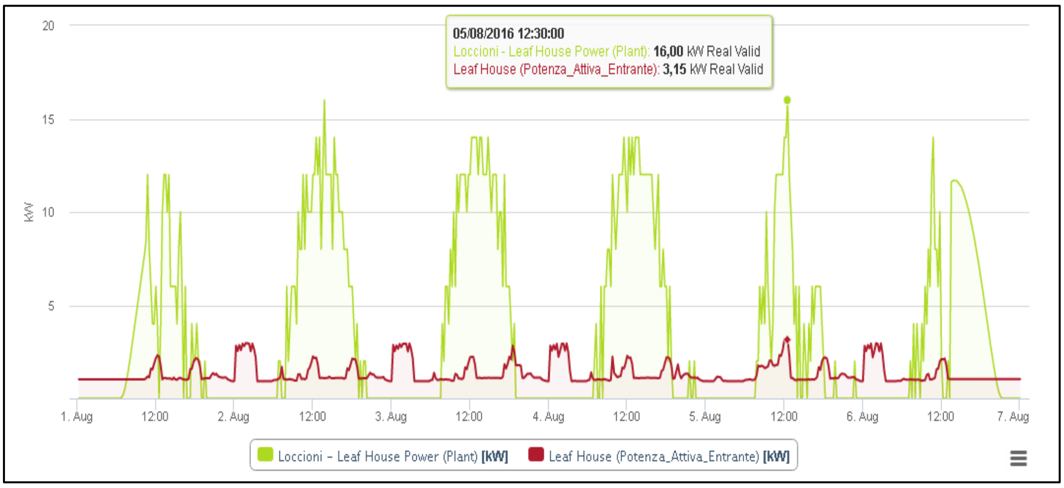

Figure 19: PV Power Production and Total Power Demand in Leaf House during 1-7/8/2016 (MyLeaf)

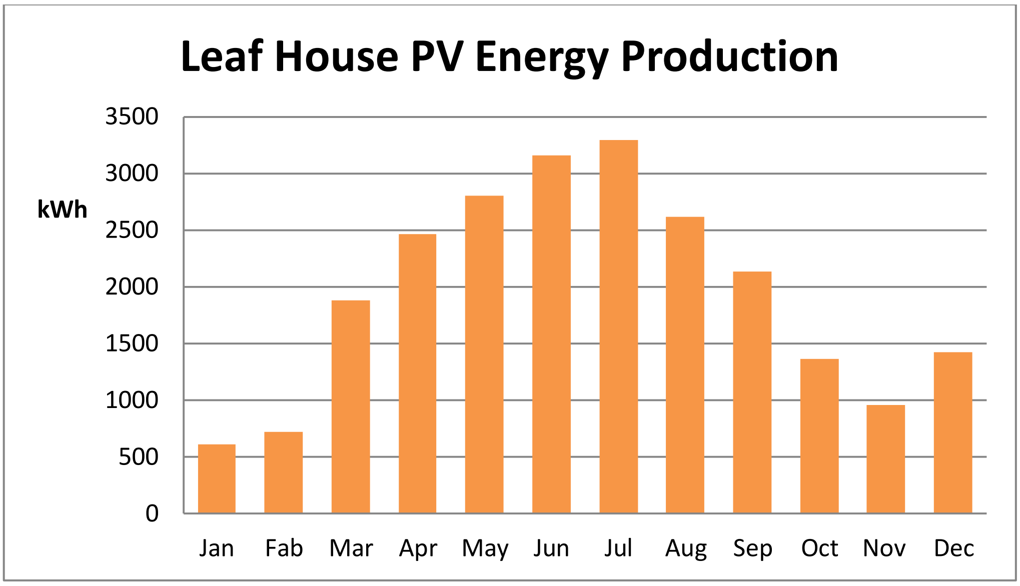

Figure 20: Leaf House PV System Monthly Energy Production for 2015 (MyLeaf)

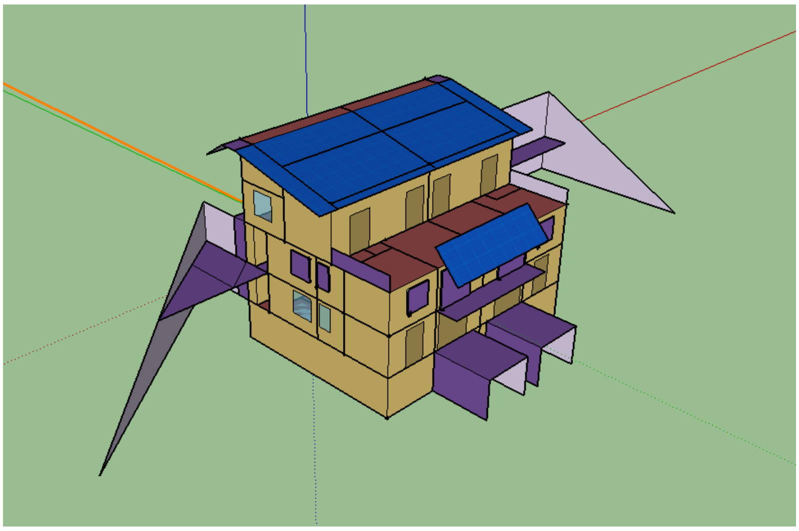

Figure 21: Modelling of building integrated photovoltaic system

3.3 Novel Technologies Laboratory (Tertiary)

The NTL, Novel Technologies Laboratory (NTL) building is located in Nicosia, at the Athalassas Campus designed as a smart and efficient building, recently integrated to a solar cooling installation that is presently in the tuning phase. The new system is constituted by a Fresnel solar collector, an oil buffer storage, a heat exchanger to generate hot water and a single stage chiller to be integrated with the existing HVAC units. The solar collector has been designed by Idea Srl and it is implementing the possibility to install PV panels on the back of the primary optics, as to produce electricity when the direct solar radiation is poor.

The research activities have been devoted to the study of the main issues emerging in such a kind of integrated system and, specifically, on tuning, liability, automation, building integration and hybridization with the in-place air conditioning systems.

3.3.1 Research Innovativeness vs State of the Art

The installation of the new solar cooling plant at the NTL premises has been supported by the STS-Med project1 financed by the ENPI (CBCMED) program of the European Union. It is part of a constellation of 4 pilot plants which should

[1] www.stsmed.eu

demonstrate the potential application of solar energy in built environment, with a deep integration of the neighborhood energy demand.

As a matter of fact, in Cyprus the energy system is seriously impacted by the growing demand of energy in the summertime due to the air conditioning services [16]. This situation is very common to all south Mediterranean regions as well other areas with a high level of solar irradiance.

Indeed, global space cooling energy consumption increased by 60% in the period between 2000 and 2010 reaching 4% of global consumption in 2010 and it is still growing [17]. On the other hand heat consumption accounts for more than 50% of the global consumption [18]. Therefore, alternative heating and cooling systems driven by renewable or recovered energy have driven the interest of many researchers that have carried out experimental and theoretical studies of Solar Heating Cooling (SHC) systems [19-23]. Absorption heating and cooling systems were studied more than any other systems. These systems have many advantages over other refrigeration systems [24] as they offer quiet operation, high reliability, long service life while meeting the variable load efficiently, having minimum mechanical moving parts, no lubricants and requiring no atmosphere-damaging refrigerants. There are not many tools available for accurate dimensioning and evaluating the solar thermal contribution to the total energy requirements. Dynamic simulation tools are used by many researchers [25-27]. Also theoretical comparative studies between different solar cooling systems (i.e. solar electrical compression, solar mechanical compression, solar absorption, solar adsorption and solid desiccant cooling system) [28] are available. The results show that solar electrical compression compared to solar absorption systems has better performance results. Moreover, the advantages of two-stage systems over other systems have been investigated [29], concluding that such cooling systems can work steadily in spite of unsteady solar input, lower generator input and outlet temperature, provided they are operated on higher temperature heat.

The aim of the plant that has been installed in NTL is to explore the opportunities offered by solar poly-generation for Near to Zero Energy Buildings, identifying an approach that is suitable for building integrated systems that is able to maximize the utilization of the collected solar energy to the largest possible extent.

However, there are several challenges facing this approach: (1) the cost of the system components is still high, partly because (2) no commercial technology is available for some components of the system, (3) it is difficult to match the building load with the system output, especially in winter and nights.

The specific, innovative approach that has been chosen in this plant is to apply a Fresnel model on a rooftop, with independent actuators for each of the mirrors. This is allowing the installation of PV panels on the back side of the mirrors that can be used to generate electricity while the DNI is low, or after the working hours and during the weekend, when the heating/cooling demand goes to zero.

3.3.2 Methodology

The methodology followed is outlined in the steps below

- Study of the NTL building, data collection analysis and processing
- Identification of the critical points of the new plant
- Optimization of the new plant and of the integration with the existing services
- Identification of feedbacks and drawbacks.

3.3.3 Data collection, analysis and processing

Novel Technologies Laboratory is an educational/research building mainly containing offices and laboratories. It contains four levels; basement, ground floor, first floor and second floor. The basement encloses laboratories, WC and two offices. Ground floor is composed of the main lobby/entrance, two laboratories, six offices, a storage room, a small kitchen and WC. First floor has a lecture hall, five offices and a conference room, a small kitchen and WC. Second floor contains a laboratory, five offices, a kitchen and WC.

The Novel Technologies Laboratory operates 8 hours/day, Monday to Friday and for about 240 days/year.

Figure 22: The NTL building

The area and volume of each floor of the building is shown at the following table.

Table 9: Area, height and volume of each floor at Novel Technologies Laboratory

Floor	Area [m²]	Height [m]	Volume [m³]
Basement	930.0	5.5	5115.0
Ground	420.0	5.0	2100.0
First	420.0	4.75	1995.0
Second	420.0	4.75	1995.0
Total	**2190.0**		**11205**

This construction finished in April 2013, and has been built according to the regulations of energy performance of the building, N.142(I)/2006 and N.30(i)/2009. Cooling and heating of the building are provided by three air-cooled chillers with partial heat recovery connected to Fan Coil Units (FCU) in office areas and Air Handling Units (AHU) in laboratories and lecture hall. Two of them are cooling only with a capacity of 243.27 kW with EER=2.35, ESEER=4.17, while the other one has a cooling capacity of 234.29 kW with EER=2.24 and ESEER=3.97 and a heating capacity of 293 kW with COP=3.15.

Ventilation at offices is achieved with local heat recovery units (HRUs), at lecture hall and laboratories with AHU's and at the WC areas with local extract fans.

The six AHUs are supplied with hot and cold water, generated by the 2 chillers and the heat pumps. Each unit has a heat recovery unit where indoor air and fresh air are mixed. Fresh air flow is adjusted by motorized dampers which are controlled by temperature and indoor air quality sensors. Moreover, the AHUs have a free-cooling function to increase the supply of fresh air if the outdoor air temperature is lower than the indoor. AHUs are manually controlled by local controllers in spaces and they are connected to BEMS from where they are monitored and controlled as well. AHUs have a nominal power of 44.300 W and a nominal air flow of 49.310 m^3/h.

Heat Recovery Units (HRUs) extract air from the return grilles of rooms and supply fresh air at the return of Fan Coil Units to be cooled or heated. HRUs are controlled by local air-conditioning controllers in offices and they are connected to BEMS from where they are monitored and controlled as well. HRUs have a nominal power of 1.972 W and a nominal air flow of 4.960 m^3/h.

Lighting is achieved with compact fluorescent lamps, T8 fluorescents and metal halide lamps, which are controlled by local on/off switches. Total lightning power is 41.700 W.

Four different wall types have been implemented in the building as they are illustrated in figure 45.

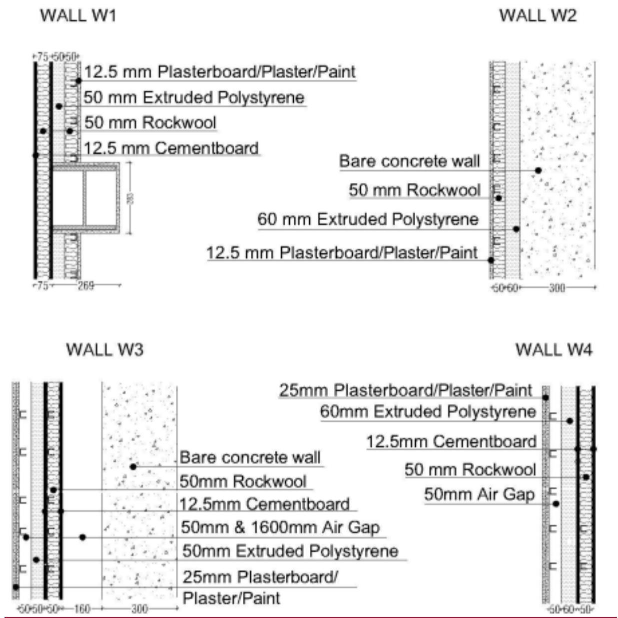

Figure 23: Walls of the Novel Technologies Laboratory

Both extruded polystyrene and rockwool have been used for thermal insulation.

The U value varies between 0.249 and 0.305 W/(m^2K). In addition, for the windows and window doors, double glazing has been used from AGC YourGlass. The glazing is consisted of 4mm Planibel Energy N pos.2 – 16mm Air – 4mm Planibel Clear with Ug-value=1.4W/(m^2K), light transmission 71% and solar factor 42%. Moreover, at the east and west side of the building, perforated galvanized sheet iron has been installed with 60% percentage of perforation.

The following table and two graphs present the monthly electricity consumption and cost for 2014.

Table 10: Monthly Energy Consumption and Energy Cost (2014)

Month	Consumption [KWh]	Cost [€]	Average Cost [€/KWh]
January*	18048	3746.00	0.207
February*	16252	3373.22	0.207
March	12110	2474.27	0.204
April	11600	2472.02	0.213
May	11680	2424.27	0.207
June	14870	5076.54	0.341
July	20240	6413.76	0.316
August	18750	5874.10	0.313
September	20952	6837.37	0.326
October*	11600	2407.00	0.207
November*	12110	2513.00	0.207
December*	17000	3528.48	0.207
TOTAL	**179130**	**44932.35**	**0.25 (average)**

The demand of energy in NTL has a distribution that is typical in hot countries. Figure 46 shows that maximum power demand is required in August and the minimum in April: the red line indicates the average basic load demand (general appliances elevator, ventilation, hot water) the blue line artificial lighting, while remaining electricity consumption, in cold and warm months, refers to the load demand for heating and cooling.

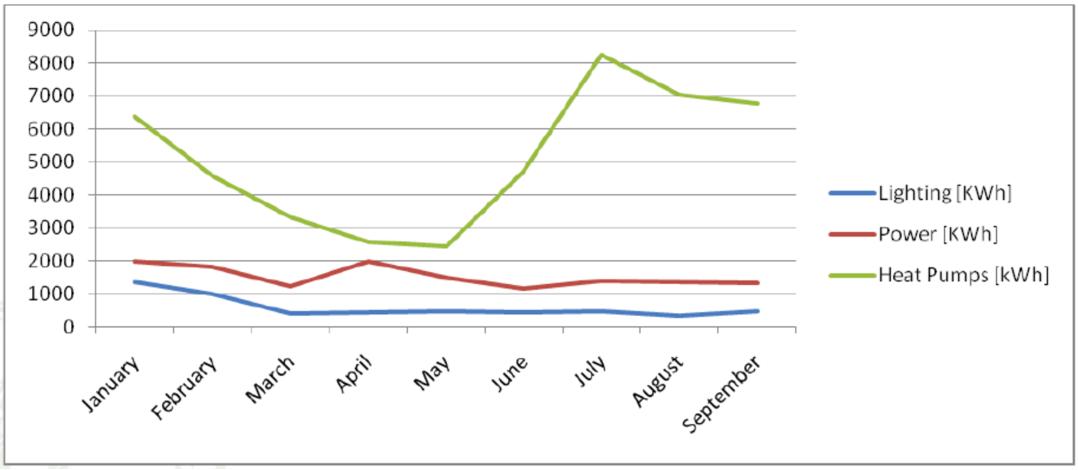

Figure 24: Annual distribution of the monitored energy consumption per type of use

The annual percentage of energy consumption per type of use is shown at the following pie chart.

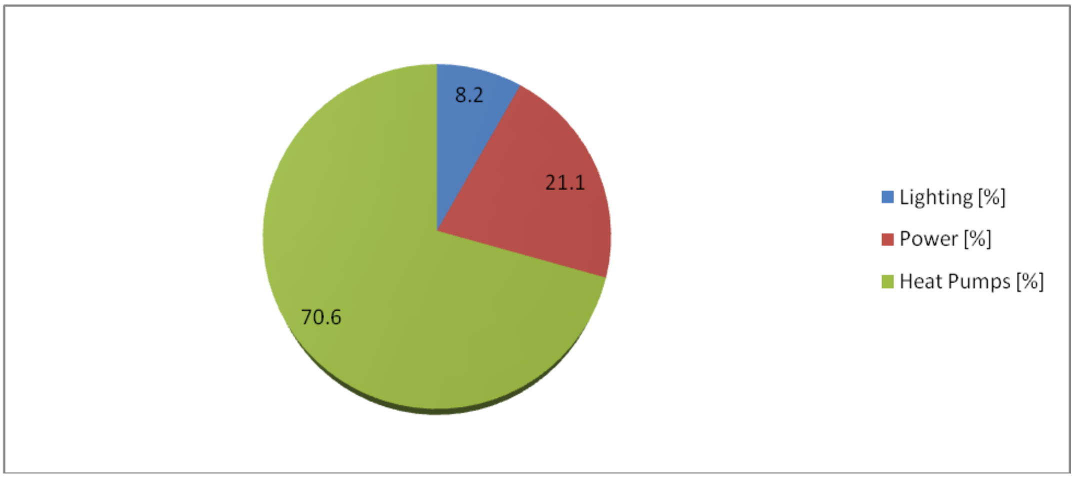

Figure 25: Annual energy consumption share for lighting, heat pumps and power for other purposes

A rooftop installation of 62 panels, 180 Wp each (11.16 kWp) with a small installation of 54 biPV shadowing panels, 62 Wp (3.348 kWp) in the south façade partially covers the electricity consumption of NTL.

3.3.3 Research activities in the Smart GEMS Project

During energy auditing, it has been observed that the initial design of the building was aimed to ensure the minimum energy consumption: insulation and shadowing has been introduced, efficient lamps have been used for lighting and controls for ventilation, heat recovery units and air flow have been installed. However, geothermal and solar thermal systems have not been envisaged from the beginning, neither have lighting control systems and intelligent control of the air flow in each room or section.

The introduction of an innovative system has been taken into account and, in particular, the installation of an integrated solar cooling system at an advanced state under the STS-Med (ENPICBC MED) project. This pilot plan at the Cyprus Institute relies on a Fresnel collector that has been installed on the rooftop of a school just in front of the NTL building. A view of the collector is reported in figure 48 below.

Figure 26: The Linear Fresnel system installed on the roof of adjacent School

This collector has been specifically designed by Idea Srl to assure the independent rotation of each collecting element of the primary optics. This allows the complete rotation of the supports that can host a PV panel on the back to provide electrical energy in the absence of a suitable direct radiation for thermal energy exploitation.

The technical specifications and main features of the Linear Fresnel (LFR) collector connected to Novel Technologies Laboratory are listed in table 15.

Table 11: Main features of the installed LFR System

Element	Characteristics
Mirrors	288 mirrors (2,000 mm x 320 mm dimension per unit) Global aperture area of 184.32 m^2 3 focusing distances according to the position of each row 144 collecting units distributed into18 rows x 8 modules

Motorization	72 DC motors (1 for a couple of collecting units) controlled by 18 PLC/36 drivers
Receiver	32 m long Secondary reflector on top Vacuum tube receiver
Weight	8 tons distributed on 9 beams
Orientation	Receiver is aligned with the local meridian
Heat transfer fluid	White oil (Duratherm 450)
Maximum thermal power	70 kW 170°C outlet nominal temperature

The main thermal loops that have been implemented are:

1. Thermal oil loop: the heating medium which circulates inside the Fresnel collector, equipped with small buffer in order to preheat the oil and Nitrogen pressurized (3 bar) system in order to maintain the oil above a minimum pressure.
2. Thermal storage loop: pressurized water, able to store the heat produced by the Fresnel collector up to 2 hours for cooling and 4 hours for heating; an expansion tank maintains the water at high pressure (up to 8 bar).
3. Heating-medium loop: hot water to fire the absorption chiller, equipped with a small buffer.
4. Heat recovery loop: hot water to support heating in winter,
5. HVAC chiller loop: chilled circuit that is connected to the previously implemented HVAC system of the Novel Technologies Laboratory.

A schematic representation of the loop is provided in figure 49.

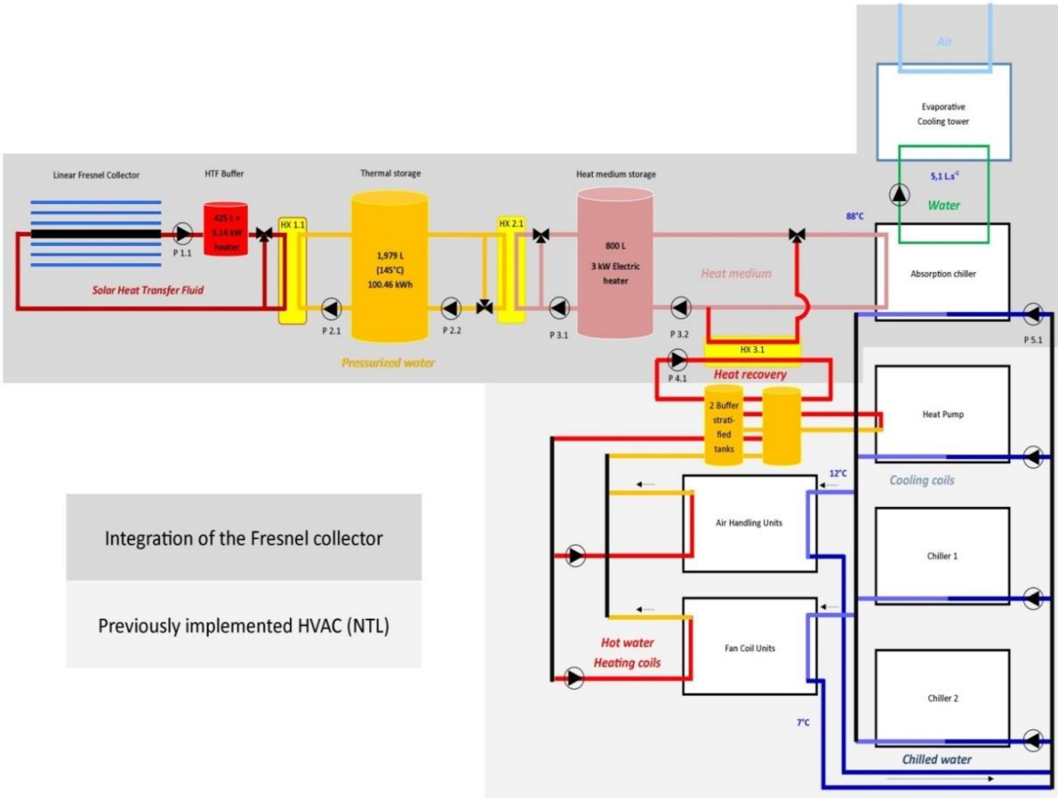

Figure 27: Layout of the SHC (Solar Heating and Cooling) system and integration with HVAC system

The integrated control of these five loops, together with the control of the independent mirrors' focalization is one of the most challenging issues. The 72 independent supports must follow the position of the sun, reflecting the radiation inside the secondary mirror, placed at about 4 meters above the reflecting plan. The total accuracy of the tracking system must be very high, as an error superior to 0.1 degrees would seriously affect the efficiency.

The control of the solar field is based on Siemens PLC architecture. The system is designed by a main PLC - series Simatic S7 1200, working as master, installed close to the technical area in order to control the inverter pump and the flow-meter and 18 slaves PLCs, placed in the solar field for the direct control of the motor rotation.

Figure 50 shows the position of the Master PLC for the main control and the "on field" PLCs boxes.

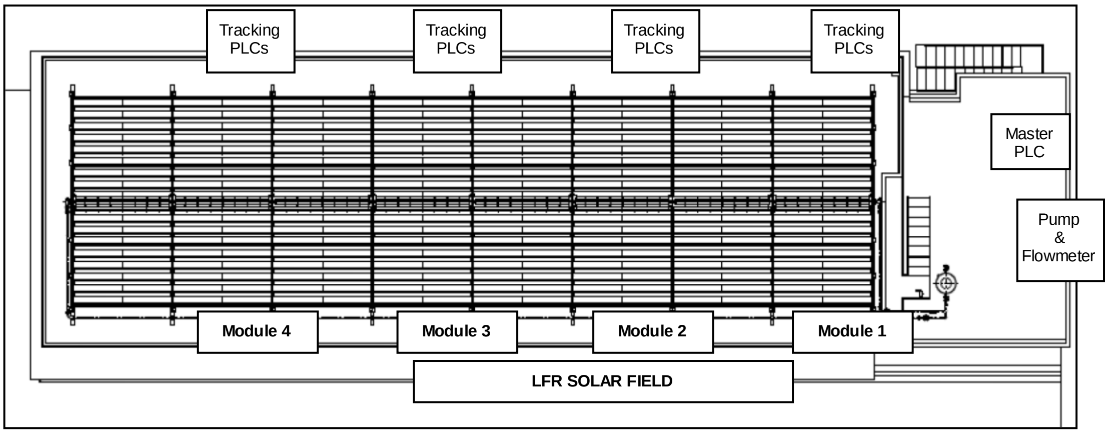

Figure 28: Position of the Master PLC for the main control and the "on field" PLCs boxes

The master PLC, connected to each PLC installed for tracking, reads real time temperatures and the flow rate of the oil into the circuit and either maintains the mirrors in the tracking mode or starts their defocusing for overheating. The master PLC shuts down the system. It is accessible through a web service that is constantly updating the values of temperatures in the field, the oil flow rate and the thermal power gained by the sun.

The control configuration of the solar field is based on the same Simatic S71200 model by Siemens.

As the solar field is composed by 4 different modules, each one of 18 mirrors, encoders and motors, and each PLC can control 4 motors, it is required to install a total of 18 PLC for the full control of the 72 motors.

Each PLC controls the tracking of the sun position in order to reflect the solar beams into the secondary optic. Tracking is based on NREL solar position algorithm. The tracking accuracy is gained verifying in real time each mirror angular position with an absolute magnetic encoder fixed into the rotation axis. This sensor returns the real position of each mirror that is compared with the one calculated by the PLC. The angular position error is kept within a range of 0,1°C by the activation of the control loop of the motor.

At the inlet, the nominal temperature is 130°C, while the nominal outlet temperature is 170°C. The pump of thermal oil is controlled by an inverter in order to adjust the flow rate with respect to the nominal conditions mentioned before. Control is ensured with sensors of temperatures at the inlet and outlet of the receiver. At the same time a pyrheliometer measures the solar DNI

(Direct Normal Irradiance), in order to calculate of the overall efficiency of the system.

A bypass valve for the heat-exchanger closes when heat exchange is not recommended with the loop of the thermal storage. Such a case occurs for instance when the temperature of the oil tank is low (below 120°C).

An oil buffer is associated in this loop in order to stabilize its average temperature. The buffer of oil contains 425l and the rest of the piping encloses 250l. The maximum allowed temperature in the tank is 165°C. Around the tank, pre-heating tapes of 3kW capacity are installed. To start-up the circulation in the loop, the temperature of the oil is required to be higher than 38°C to avoid mechanical stress on the receiver. The tapes maintain the average temperature of the tank to be higher than this threshold.

The total volume of the oil in the loop is about 700l. The loop is maintained under pressure (3 bar) and the oil is free to expand in the buffer tank with the high quality Nitrogen gas (>99.9%) that fills the remaining volume. The schematic representation of the expansion vessel oil tank and oil thermal storage is illustrated in figure 51.

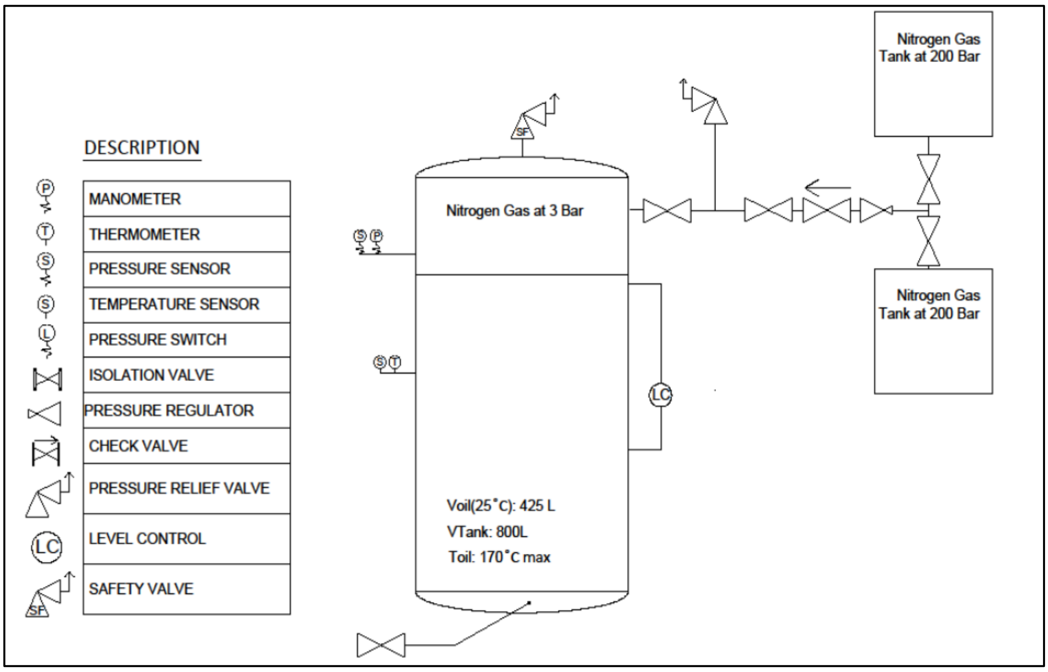

Figure 29: Expansion vessel oil tank and oil thermal storage

The thermal storage medium is pressurized water. Water has been chosen because it is low cost and works at compatible temperature range with the design of the platform. As a matter of fact, even though the collector could have been able to reach temperatures above 200°C, making the installation a more efficient two-stage absorption chiller, a conservative approach has driven to the adoption, in this first phase, of a single-stage chiller, with a nominal inlet temperature of 88°C. An upgrade to a high temperature after the testing phase has been envisaged.

The storage volume is about 2m^3. Thermal storage is a key element for the system because it permits to stabilize the restitution independently from the weather conditions. The size volume of the pressurized water has been calculated through a TRNSYS model as to store heat for 2 hours of continuous operation for the absorption chiller at nominal conditions in summer. In winter the same storage can provide 4 hours of restitution for the heat recovery loop. The heat is exchanged with oil and then stored at a maximum temperature of 146°C. The circulator feeding the thermal storage is ruled by a thermostat function based on the temperature of the oil buffer (dead-band interval: 145°C-165°C).

The second circulator of the loop is in operation when the average temperature of the thermal storage is higher than the average temperature of the heat-medium storage. But also this circulator is in operation when the thermal storage average temperature is higher than 100°C. A bypass valve for the heat-exchanger closes when heat exchange is not recommended with the loop of the heat medium, i.e. when temperature of thermal storage tank is low.

The final heating medium is water and it is stored in a 500l buffer to stabilize the temperature of the loop at the inlet of the absorption chiller. In summer the heat is used to fire the absorption chiller and in winter to heat water directly. Piping of the loop is illustrated in figure 52. The system provides also hot domestic water to the building.

Figure 30: SHC piping system (integration with HVAC system)

The circulator of the loop is in operation when the average temperature of the heat-medium tank is lower than 88°C and heating/cooling required.

The service pump goes in operation only if heating or cooling is required by the users of the building. Also the average temperature of the tank of water must be higher than 88°C.

In winter the heat which is produced by the Fresnel collector heats the water of two stratified tanks of the Novel technologies Laboratory. The heat recovery loop provides hot water to the heating coils of the AHU and fan coil units, reducing their energy consumption. When heating is required the absorption chiller is bypassed. Figure 53 is showing the two stratified tanks with the different loops.

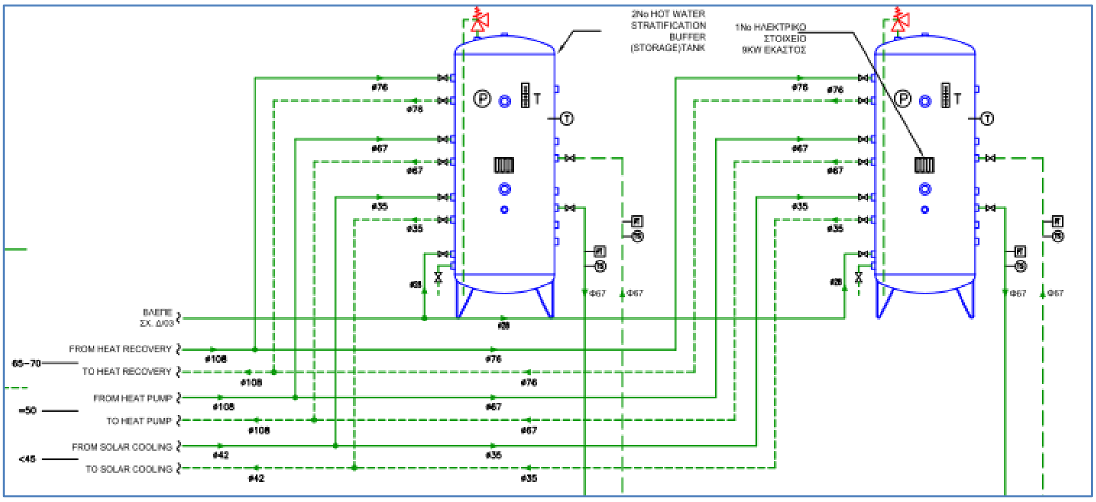

Figure 31: Layout of hot water thermal storage

The main purpose of the system is to provide cooling to the Novel Technology Laboratory with a Yazaki WFC-SC10 single effect absorption chiller of 35 kW cooling power and a COP of 0.7. When cooling is required and the average temperature of the heat medium tank is higher than 88°C, the chiller is initiated. Such a facility reduces the dependency of the Novel Technology Laboratory to electric heat-pumps or chillers by the help of the absorption chiller and heat recovery loop. HVAC is partially provided by the Fresnel collector, which use has the priority before the electric elements.

In figure 54 the installation including the Yazaki chiller and the cooling tower is displayed.

Figure 32: Absorption chiller and cooling tower

With the integration of the solar Fresnel facility, the NTL building represents a unique facility to study the combined application of smart energy management and integrated solar energy production. A very few examples of Concentrating Solar Systems advanced building integration are available and, taking into consideration the bioclimatic design and smart technologies of NTL classify it as a one-of-a-kind pilot case study.

The research activity conducted by the Cyprus Institute is then directed towards the full optimization of the premises, within a comprehensive approach: on one side, to reach the overall energy efficiency by optimizing the consumption, on the other side, addressing the improvement of the building the control systems and the full exploitation of the solar plant integration, with a specific work on its liability under the specific operating conditions.

The integration of the Fresnel collector into the HVAC network is supported by SAUTER platform to control the loops and more particularly the pumps, heaters and valves. SAUTER permits to retrieve data, visualize it in real time and program control strategies.

Figure 55 illustrates the general system with all the loops including valves, pumps, piping, thermal storage, heat-exchangers, electric heaters and the Fresnel collector. The schematic includes the visualization in real time of some of the installed temperature sensors. Also the platform provides the user the feature to plot charts for the data stored.

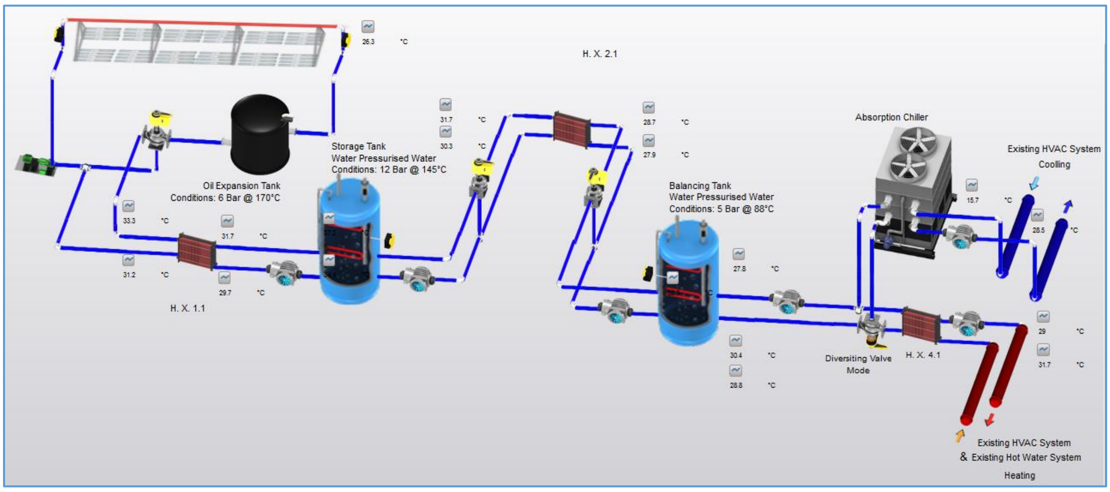

Figure 33: Holistic view of the NTL HVAC loops

For instance, figure 56 shows the temperature of the oil at the inlet of the heat-exchanger with pressurized water during the commissioning of the Fresnel collector from the 29th of July 2016 at 8.00 AM to the 30th of July 2016 at 8.00

AM. Heat was transferred during the day through cycling of thermal charge and discharges of the buffer of oil followed by a temperature decrease during the night.

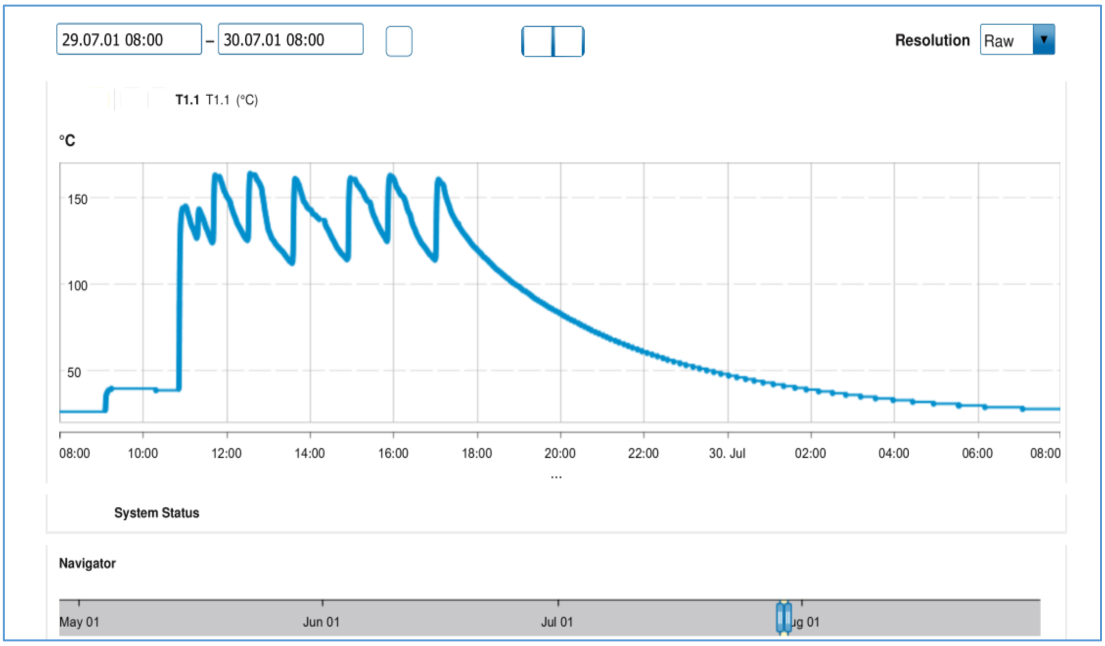

Figure 34: Temperature of the heat-exchanger with water

The start-up of the control system has been a task performed during the Smart GEMS secondments from IDEA to CyI. At the time, the control of the plant was not fully automated but under advanced and gradually progressing levels of integration. Activation of valves, pumps and heaters needs to be safely performed taking into accounts limits of temperature and pressure in the loops. Therefore, loops are monitored separately with the aid of additional sensors and the integration of control gauges. Figure 57 illustrates the thermal oil loop. In this particular loop, the valve V1.1 and heater (EL. ELEMENT 1) can be either controlled manually or automated (crossed hand sign). On this specific figure the heater is OFF and the valve rules the bypass of the heat-exchanger (HX 1.1, “To Fresnel”).

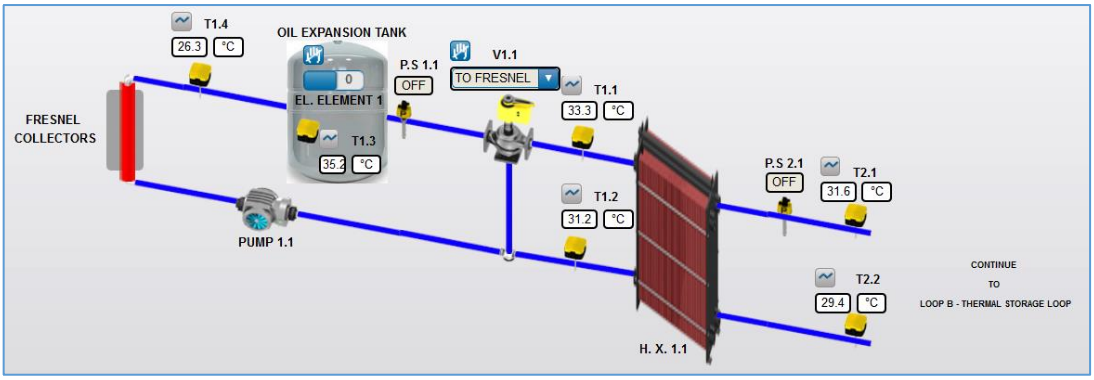

Figure 35: Thermal oil loop

In figure 58, the heating element has been activated and the user is changing the menu of valve V1.1 to the heat-exchanger HX1.1. By clicking on the "hand" sign, the control is automated. The control is based on a thermostat strategy considering the temperature of the buffer of oil and the operation of the Fresnel collector.

Pump 1.1 and the Fresnel collector are controlled independently from SAUTER solution with the use of Totally Integrated Automation Portal (Siemens) controlling 5 PLCs, as already described. The control of the collector takes into account the time of the day and inlet/outlet temperatures on the receiver.

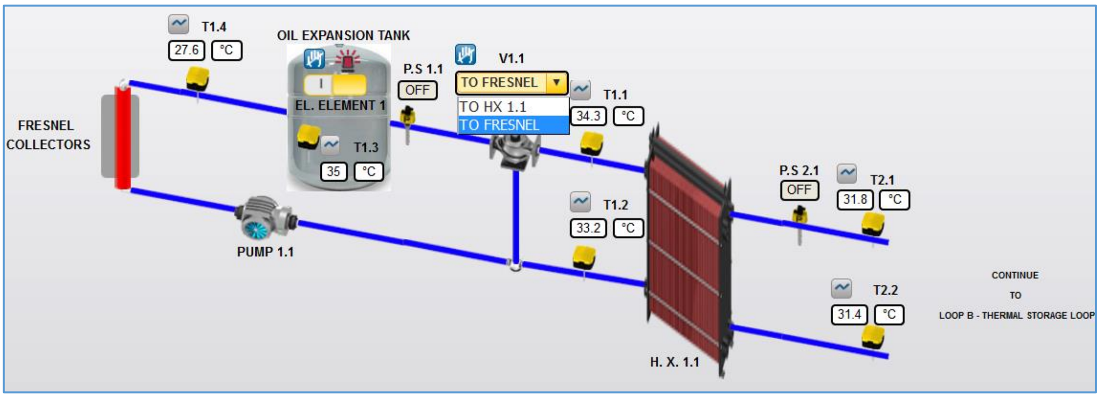

Figure 36: Manual control of thermal oil loop

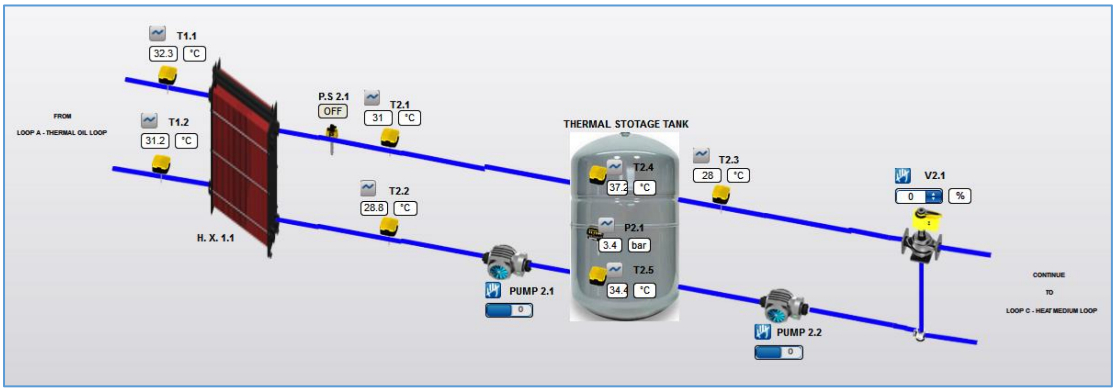

Figure 37: Thermal storage loop

Figure 59 illustrates in detail the thermal storage loop of pressurized water. All the pumps and valves can be activated by this interface. Temperature sensors are equipped with charts. The by-pass pipe regulated by valve V2.1 permits to preheat the water in the pipes and homogenize the temperatures before transferring to the heat medium loop.

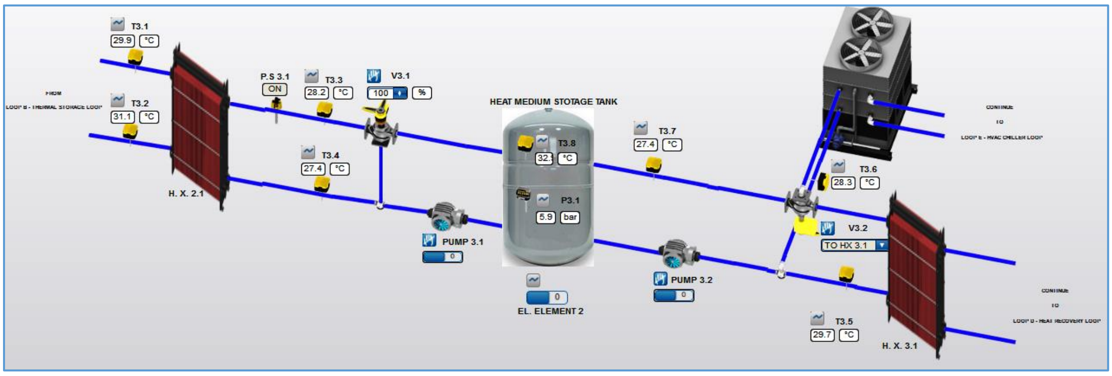

Figure 38: Thermal storage loop

Figure 60 illustrates the heat medium loop, to fire the absorption chiller and for heat-recovery. Valve V3.3 is controlled proportionally in order to regulate the outlet temperature from the heat exchanger. Pressure sensors data is recorded. After the tank, V2.2 diverts hot water either to the absorption chiller (in summer as shown by figure 61) or to the heat exchanger of the heat recovery loops, as in figure 62.

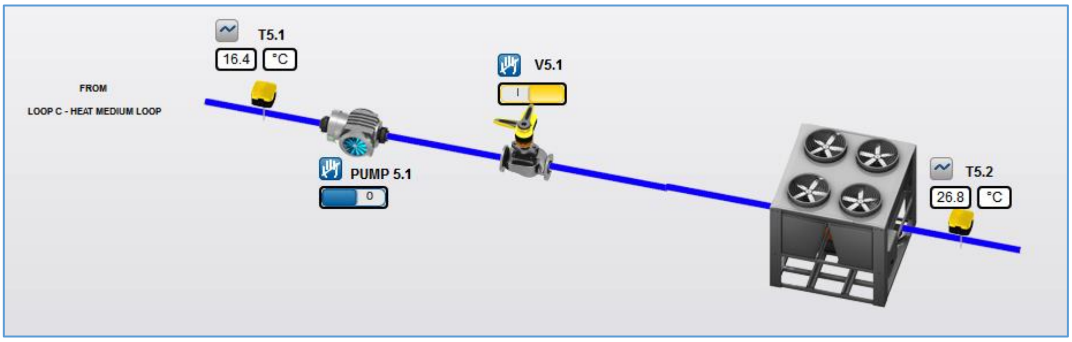

Figure 39: Absorption chiller loop

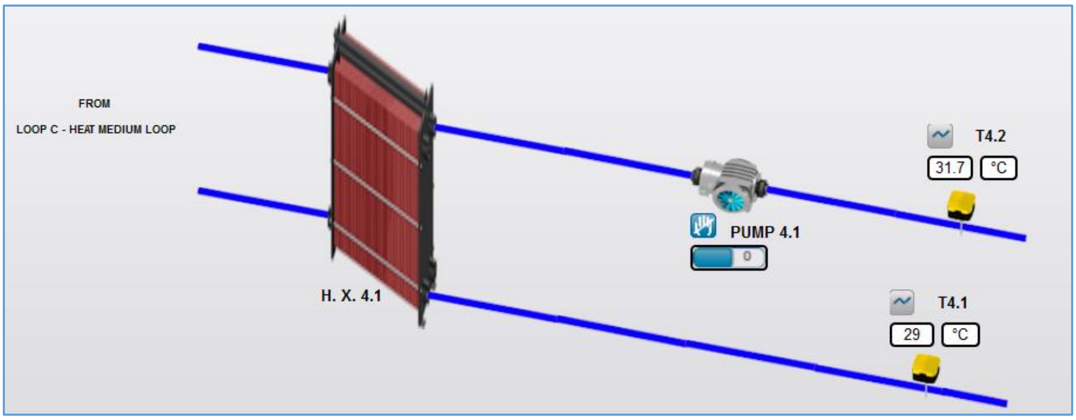

Figure 40: Heat recovery loop

To summarize, three different control management systems are regulating the HVAC of the Novel Technologies Laboratory:

1. The Fresnel collector by SIEMENS, Totally Integrated Automation Portal: piloting the mirrors and the pump of the oil, working but under improvement (for the PIDs on the motors and pump);
2. The integrated loops by SAUTER : independent control from the Fresnel collector, still under development,
3. The BEMS of the NTL: already integrated and works independently from the two previous controls systems. If the cooling/heating provided by the absorption chiller / heat recovery is not sufficient, the electric heat-pumps and chillers are activated.

3.4 Concentrated Solar Power (CSP) FRESCO technology, IDEA

The IDEA FRESCO technology is presented as an advanced technology for the integration in NZEB buildings and smart grids. A model of the Fresnel system was developed in order to understand and study the operational face of these systems.

3.4.1 Introduction to CSP technologies

One of the main applications of Concentrated Solar Power (CSP) technology is the production thermal energy and its conversion to electrical energy by means of a thermodynamic cycle [30]. However, the produced thermal energy can also be used directly in the build environment for the activation of solar cooling applications or for covering the thermal demands. One of CSP technologies called Linear Fresnel Reflector (LFR) technology is particularly suitable for process heat, mainly due to its high temperature generation capacity, low cost and low land occupancy. LFR produces heated oil, with temperatures ranging between 120°C and 500°C, from 6 bar to 100 bar. Results from studies have shown that the thermal production coming from the solar unit can account for 25-35% of the total required thermal energy for a direct solar normal irradiance (DNI) of around 2,250 kWh/m²/year, while having a payback period of 5-6.5 years.

Linear Fresnel Reflectors (LFR) show a number of advantages when compared to other CSP technologies in building, settlement or industrial applications, including the following:

- highly variable temperature and pressure ranges that can be adapted depending on the application
- lowest land occupancy, knowing that a large chunk of steam-consuming facilities are located in industrial zones where land availability is scarce
- high modularity, ranging from a few hundred kilowatts to several megawatts
- low environmental impact due to the limited raw material use and deletion of synthetic fluids(capability possible in other CSP technologies but rarely used)

- lowest levelized cost of energy (LCOE) due to its modularity, simple and efficient design, and low O&M requirements

In table 25, the advantages and disadvantages of CSP technologies are presented according to [31], including the linear Fresnel collectors.

Table 12: Advantages and disadvantages of CSP technologies

	Line Focus Technologies		Point Focus Technologies		
Design	**Parabolic Through**	**Linear Fresnel**	**Solar Tower**	**Bean Down**	**Dish – Stirling engine**
Technology Maturity	Most mature	Few installations	Commercial Deployments	Early development	Proposed instalations
Preferred Scale	Large	Large	Large	Large	Small
Capital Cost	Moderate	Low	High	Moderate to high-low storage cost	High (low per Unit)
Operating Cost	High	Low	High	Similar to solar tower	High (one engine per dish)
Annual Solar to Net electricity conversion efficiency	~15%	~11%	~17%	~15%-19%	22%
Thermal storage	Feasible	Feasible	Feasible and more efficient due to higher temperature	Feasible with very little energy cost	Not currently possible
Characteristics	-Significant construction and operational experience -High radiative and convective energy losses	-Low cost due fewer moving parts and no tracking -Lower efficiency -High temperature heat transfer fluid possible	-High cost due to expensive heliostat field -High temperature heat transfer fluid possible -High efficiency	-Lower storage cost	-High engine efficiency -High cost due to expensive engines (one for each dish)

3.4.2 Technical description of the solar plant

The solar plant consists of a compact LFR solar collector for multi-generative applications which is based on a Fresnel concentration system. The solar rays are reflected to the same target by means of appropriate mirrors that constantly pursue the solar position during the day. The collector has been optimized to reduce the space required for its installation thanks to a compact and lightweight design and a reduced focal length.

The solar collector is able to concentrate the solar radiation onto a receiver tube in which a high temperature heat transfer fluid is heated. The thermal energy is collected at about 260°C and is stored inside a storage tank, which can either:

- Serve chillers for its transformation into cooling energy or
- Directly heat civil estate or industrial processes.

Moreover, using concentrated solar energy enables to convert solar power into heat before running thermodynamic cycles. The system is equipped with an Organic Rankine Cycle (ORC) unit, which is able to produce electricity to be served directly to the users or delivered to the grid.

As a result a multi-generative energy production system is being composed which can serve the heating and cooling needs of a building as well as powering with electricity the building or the power grid.

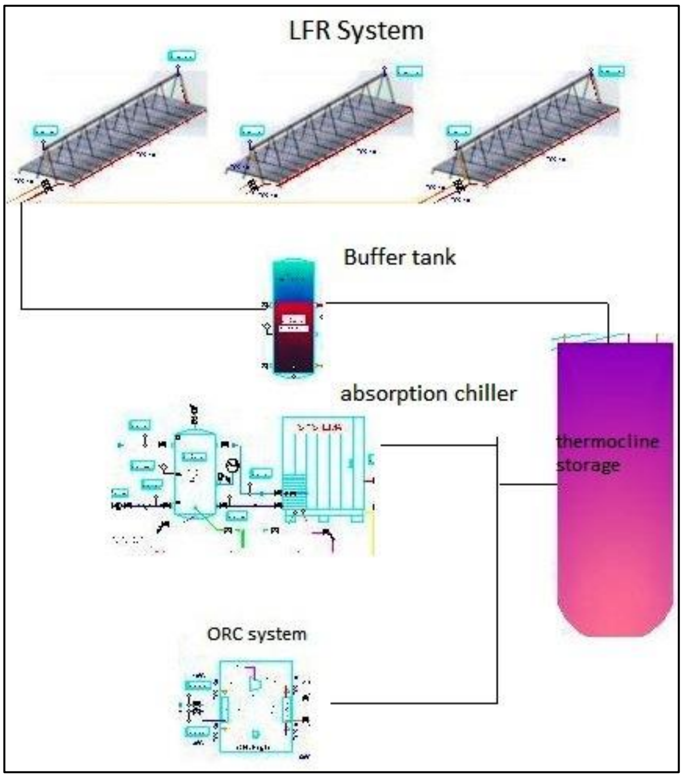

Figure 74: The Fresnel system outline

3.4.3 The Solar Field

The Solar field consists of 3 strings consisting of 7 modules solar mirrors linear Fresnel of a total surface of about 475 m^2. The design parameters of the solar plant are depicted in Table 13.

Table 13: Fresnel parameters used for the efficiency calculation

Inner absorber tube diameter (m) Vacuum glass/steel pipe CERMET coated	0.066
Outer absorber tube diameter (m)	0.07
Mirror width (m)	0.31
No of mirror row(m)	18
Centre focal length	3.564
Module length (m)	4
No of module	21
Internal diameter of glass cover(m)	0.1
External diameter of glass cover(m)	0.106
Receiver coating absorbance	0.958
Glass cover transmittance	0.964

The heat transfer fluid is a synthetic oil with a specific heat coefficient of about 2 kJ/(kg K), which depends on the oil temperature. When selecting thermal oil as a transfer fluid, the main limiting factor to be taken into account for the maintenance of stability is the maximum temperature of the oil. Above this temperature decomposition of the hydrocarbon oil occurs and rapid chemical degradation. The transfer fluid of the IDEA LFR system is synthetic oil and the maximum exit temperature is 270°C. [32]

The advantages and disadvantages of hot oil utilisation in the Fresnel system (Solar Energy Generating Systems SEGS) compared to water utilization as direct steam generation DSG are [33], [34]:

• With the synthetic oil probable absorber flow instability due to two-phase flow of water/steam in the collector is avoided.

• Avoidance of possible process instability due to large changes in fluid volume during boiling, and possible changes in collector output steam state and flow-rate.

• If superheated steam is generated in the collector, risk of thermal stress exists as a result of the movement of the ‘dry-out’ point.

• High temperature wet/dry conditions require higher-grade materials.

The upper temperature limit imposed upon the synthetic oil utilization as heat transfer fluid due to its chemical stability also directly implies an upper limit on the temperatures in the Rankine cycle used to drive the turbine. Second-law efficiency of Rankine cycles are greatly improved when the maximum available temperature is increased, so removal of the upper temperature limit will help a great deal in improving solar thermal system efficiency leading to significantly lower-cost solar electricity.

Nevertheless the oil as heat transfer fluid implies following disadvantages:

• Fire and pollution risk

• Need to observe the upper temperature limit of ~270 required for the use of synthetic heat transfer oil.

• Need for replacement of oil (~5% of oil each year) and need for antifreeze of about below 14◦C).

3.4.4 Short-Term Thermal Energy Storage - The buffer tank

When the heated oil exits the absorber tube, the heat transfer fluid enters short-term buffer storage of 700 m^3, as the effective specific heat of the heat transfer fluid increases. This first buffer serves for stabilizing the exchange processes within the LFR. The integration of buffer storage capacity simplifies the control of the power plant and allows an extended reaction time for backup systems, which are intended to compensate longer periods of reduced insolation [35]. This short-term storage is important for damping fluctuations in power output associated with short-term disturbances such as passing clouds. The short-term thermal storage mechanism uses a pressurized vessel. This accumulator is ideal for short-term buffer storage and has the advantage of using a simple, inexpensive storage medium. In the specific LFR system, pressurized N_2 is used at 3 bars. Storage is limited to small capacities and on the order of some hours [36].

3.4.5 The thermal storage tank

The heated oil from the receiver tube, after the first short term buffer, is diverted to a heat exchanger to heat a thermal energy storage (TES) fluid, typically a molten salt. In this mode of operation, fluid from the cold salt tank is heated as it is pumped to the hot salt storage tank. The fluid from the hot storage tank can be used to heat the synthetic oil when production from the solar field is not adequate. Molten salt storage is a reliable technology that has been used in thermal energy storage for residential or industrial purposes.

Using molten-salt in the thermal energy storage system eliminates the need for expensive heat exchangers[2]. It allows the solar field to be operated at higher temperatures than current heat transfer fluids allow. This combination also allows for a substantial reduction in the cost of the thermal energy storage (TES) system.

Unfortunately, molten-salts freeze at relatively high temperatures 120 to 220°C. This means that special care must be taken to ensure that the salt does not freeze in the solar field piping during the night.

Newer linear Fresnel designs may allow use of higher-temperature molten salts [31]. Furthermore, new salt mixtures with the potential for freeze points below 100°C (212°F) are developed. At 100°C the freeze problem is expected to be much more manageable.

In the LFR system, during the day the molten salt is pumped from the cold tank to the hot tank at a specific flow rate. The molten salt passes the oil-to-salt-heat exchanger, is heated up and continues as hot molten salt to the hot storage tank where the solar thermal energy is stored. At the same time the thermal oil is cooled down, before it returns to the solar field for reheating. Whenever heat is needed, the hot molten salt is pumped back to the cold tank, transferring thermal energy to the absorption chiller or to the ORC system [36]. This thermal storage system represents the current practice in thermal energy storage and has important advantages in terms of ease of operation and the ability to provide very large storage capacities. On the other hand, it can cause efficiency losses because of heat losses in the HTF-to-TES fluid heat exchanger. [31]

3.4.6 The absorption chiller

An absorption chiller is integrated in the LFR system, which aims to serve the cooling loads of the offices of IDEA during the summer. Thermally driven chillers using solar energy are a good alternative to conventional electricity driven chillers to meet the growing air-conditioning demand and to cut electrical peak loads during the summer. Also, their use allows to save primary energy and to reduce greenhouse gas emissions associated with the electricity generation from fossil fuels [37]. Solar thermal cooling systems have been

[2] http://www.nrel.gov/csp/troughnet/thermal_energy_storage.html#heat

widely used and particularly absorption cooling systems. Solar cooling using single-effect water-LiBr has been studied since the mid 70's and until now many studies have been performed. In literature applications of various configurations have been reported such as:

- Flat plate collectors and single-effect chillers
- Evacuated tube collectors and single-effect chillers
- Compound parabolic collectors (CPC) and single-effect chillers
- Parabolic trough collectors (PTC) and single-effect chiller
- Parabolic trough collectors and double effect chillers and systems
- Linear Fresnel collectors (LFC) and double-effect chillers [37]

While single-effect absorption chillers work at relatively low driving temperatures (between 80ºC and 95ºC) produced by efficient flat plate or vacuum tube collectors and delivering low COPs (between 0.55 and 0.75), double-effect absorption chillers demand a higher driving temperature (up to 160ºC) which results in higher overall efficiency.

The IDEA LFR system is equipped with a double effect absorption chiller, of a thermal COP about 1 and an inlet temperature of 160 ^{o}C. It is adjusted to a cooling tower of 200l, which keeps the cooled water from 7 – 12 ^{o}C.

3.4.7 The Organic Rankine Cycle system

The Organic Rankine Cycle generator has an electrical output of 10 kW. The basic concept of its operation is presented in figure 75 and the operational characteristics of the ORC are depicted in figure 76. The heat transfer fluid transfers its heat energy to the high temperature working fluid through the evaporator. The high temperature fluid vapour enters the high temperature turbine expander and produces mechanical work for electricity generation. The turbine exhaust steam is condensed in the condenser and is pumped again to the evaporator for recirculation [36]. The ORC cycle working fluid thermal characteristics are thermal stability, toxicity, flammability and cost. As an example, toluene has good thermal characteristics regarding stability, temperature range and high energy density but condenses at sub-atmospheric pressures. The n-pentane on the other hand operates at super-atmospheric pressures over a wide range of condensing conditions.

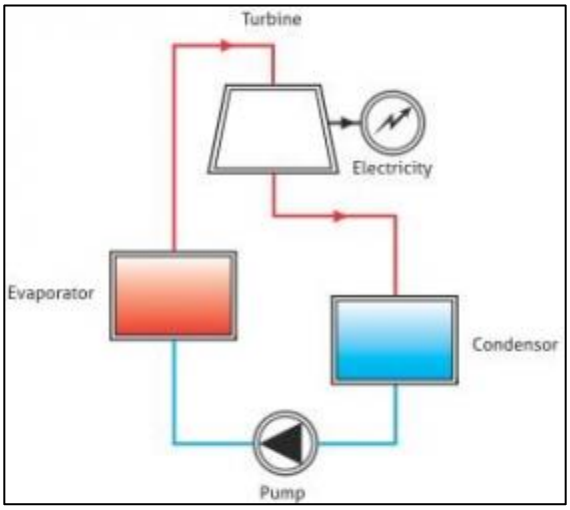

Figure 75: The Organic Rankine Cycle Generator

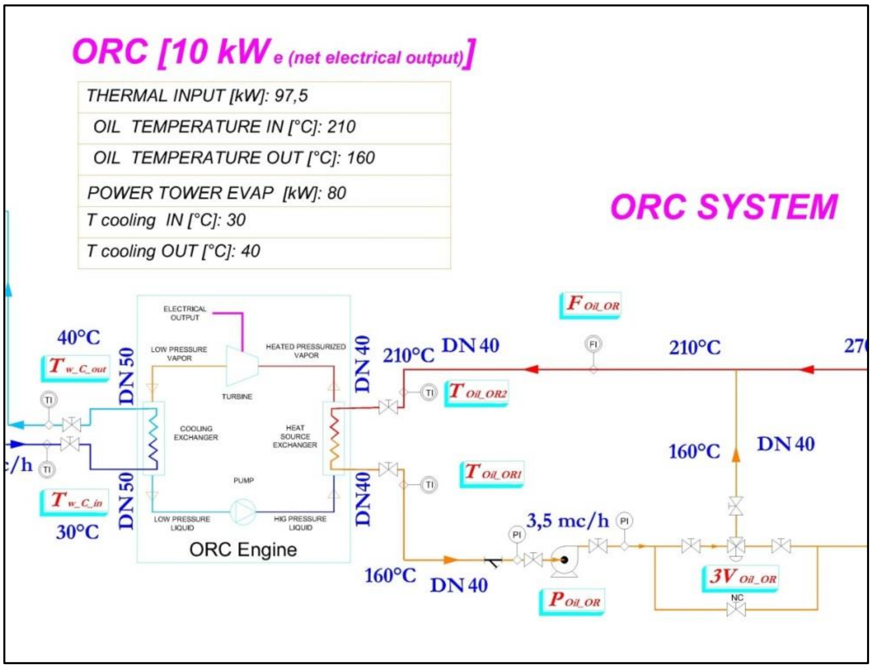

Figure 76: The LFR plant IDEA ORC system

The number of fluids that could be used is many, and the suitability of one fluid depends on following aspects:

- The location of the power plant. If it is located in the vicinity of populated area, more flammable and toxic fluids might be exchanged for less hazardous mediums.
- The environmental aspects i.e. the fluid global warming potential.
- The cost of the fluid. The best performing fluid might not be the best economically.

Figure 77 shows how the properties of three fluids from the same changes in T (temperature) –S (entropy) diagram with a fix evaporation and condenser temperature that's been set to 100 °C and 20 °C respectively. The figure shows that three fluids that are very alike have different properties [38].

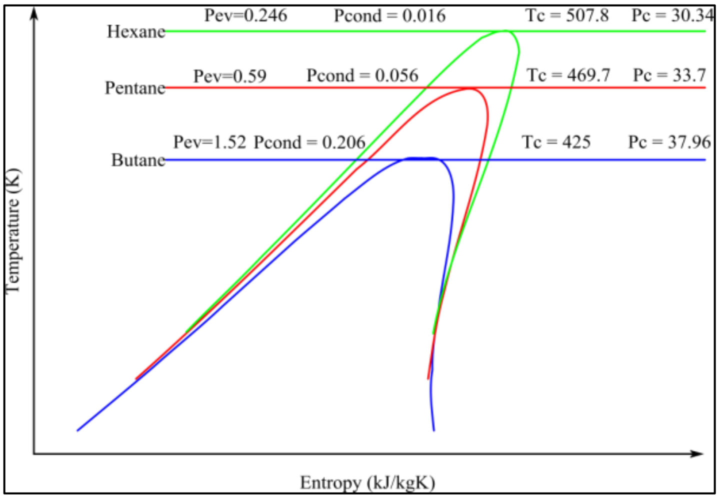

Figure 77: Different working fluids isothermal properties

The working fluid for the IDEA ORC system selected according to the isothermal properties given the input temperatures and the efficiency of the turbine is the R245fa, with a T-S diagram presented in figure 78. A very solid database of several fluids is listed in the Nist Chemistry Webbook[3][39].

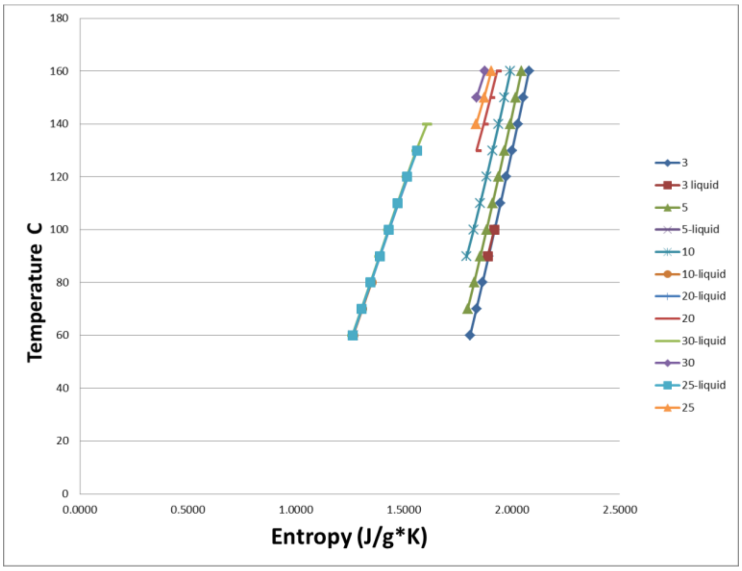

Figure 78: Isothermal properties of the R245fa[4]

3.4.8 Operational characteristics of the LFR solar plant.

In order to assess the operational characteristics of the LFR system, a model is developed which can be validated and fine-tuned after the first period of

[3] http://webbook.nist.gov/
[4] The excel file with the detailed R245fa properties is listed in the ANNEX 9.1 – Matlab files link

operation of the LFR system in the ongoing months. The LFR is planned to be in a test operational phase with the increase of the solar radiation, from April 2016.

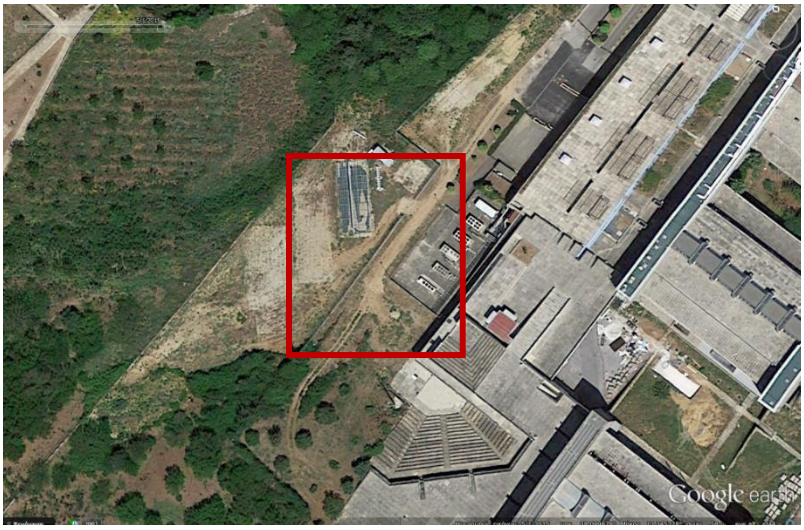

Figure 79: The installation site at IDEA srl. (Long 38.10º Lat 13.34º). The first string is visible in this satellite image, the two outlined areas are the two later modules installation of total 475m^2.

Figure 80: The LFR system at IDEA srl

3.5 Building 20, Fiera del Meditteraneo (Commercial)

As part of the research activities a simulation of an existing commercial building was performed in order to compare its energy performance with actual values and propose measures for decreasing its energy requirements.

Fiera del Meditteraneo is an area in Palermo that consists of 24 buildings which are used for exhibitions and various other events. Exhibitions are made every one or two months and usually last from 5-7 days. Due to the high power consumption of the buildings during these exhibitions an analysis was made to the main exhibition building (building no. 20) in order to provide an energy performance report for the building.

During the first phase, a full and detailed simulation of the energy performance of the proposed building was performed using appropriate tools for HVAC systems, occupancy and construction materials. The performance of each energy conservation and energy production component is calculated in full detail by considering the whole combination of the involved technologies.

During the second phase, improvements were suggested and their expected effect on the overall power consumption was estimated using the building energy model. Given the estimation of the technical and economic optimum for each innovative component and system, optimization techniques were exploited to select the final sizing of each component.

This report gives the details of the first and the last phase of building no 20 situated in Fiera del Mediterraneo.

3.5.1 Methodology

A number of studies investigate buildings' energy performance and the possible strategies to improve the buildings' resilience to extreme thermal stress and high electricity prices. Based on the researcher's background and competences it was decided to follow the methodological steps below:

- Draw the building in DesignBuilder software using .dwg architectural drawings from the municipality of Palermo

- Quantify its energy performance throughout the year
- Propose ideas for the improvement of its energy performance.

Palermo is a community with more than a million residents. With the increasing temperatures the need for conditioning is essential and triggered the present research study as a single event organized for a few days at Fiera del Meditteraneo has a high cost for the municipality of Palermo. The use of dynamic simulations is able to export results about the energy consumption on an annual, monthly, daily and hourly basis but also investigate improvements in the operational characteristics of the building and quantify their contribution in decreasing energy consumption.

3.5.2 Technical specifications of building No. 20

This section describes the dimensions of the building envelope including walls, windows, floors, ceiling and roof. Schematics and drawings are used for better understanding. The building is located in the area of Fiera del Mediterraneo, Palermo (38.145793°, 13.355913°).

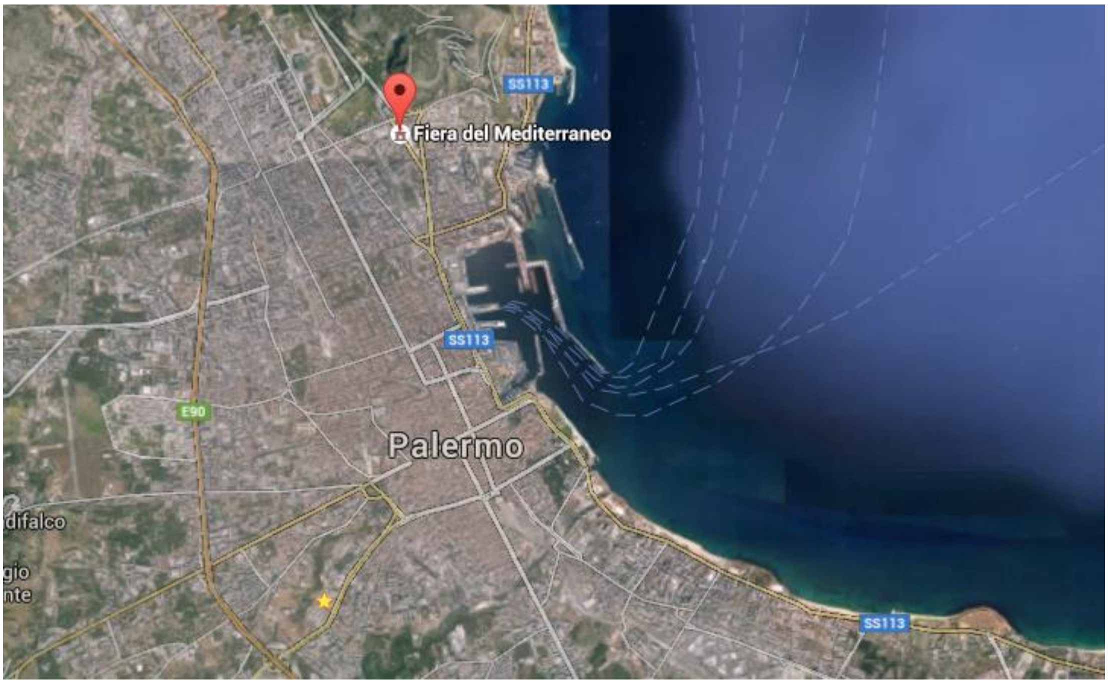

Figure 86: Location of Fiera del Mediterraneo in Palermo city

Building no. 20 consists of the ground floor area of 5,168.71m^2 (volume: 54,113.01m^3) and a semi-underfloor area of 1,982.61m^2 (volume: 6,810.39m^3).

All this area, total of 7,151.32m^2 is conditioned during the events. The envelope and orientation characteristics are presented in table 28.

Table 14: Building envelope characteristics

	Total	North (315º-45º)	East (45º -135º)	South (135º -225º)	West (225º -315º)
Gross Wall Area [m²]	**4510.33**	1545.31	709.85	1545.31	709.85
Window Opening Area [m²]	**1172.33**	376.76	138.94	489.71	166.92
Gross Window-Wall Ratio [%]	**25.99**	24.38	19.57	31.69	23.51

Figure 87: Ground floor of Building No.20 in Fiora del Meditteraneo

Figure 88: Semi-basement floor of Building No.20 in Fiora del Meditteraneo

Table 29 describes the material and thickness of each subpart of the building envelope (walls, windows, floors, ceiling and roof) for building no. 20. The U-value in W/m^{2}K of all subparts is included in the last row of the table.

Table 15: Construction materials' parameters

	Walls at Under ground floor	**Walls at ground floor**	**Roof**	**Floor**	**Windows**
Outermost Layer	Cement (0.025m)	Mild Steel (0.005m)	Mild Steel (0.005m)	Carpet synthetic (0.01m)	Generic Clear (0.003m)
Layer 2	Brick (0.15m)	-	-	-	-
Innermost Layer	Cement (0.025m)	-	-	Cast Concrete (dense) (0.15cm)	-
U-value (W/m2K)	**2.233**	**5.879**	**5.879**	**1.839**	**5.894**

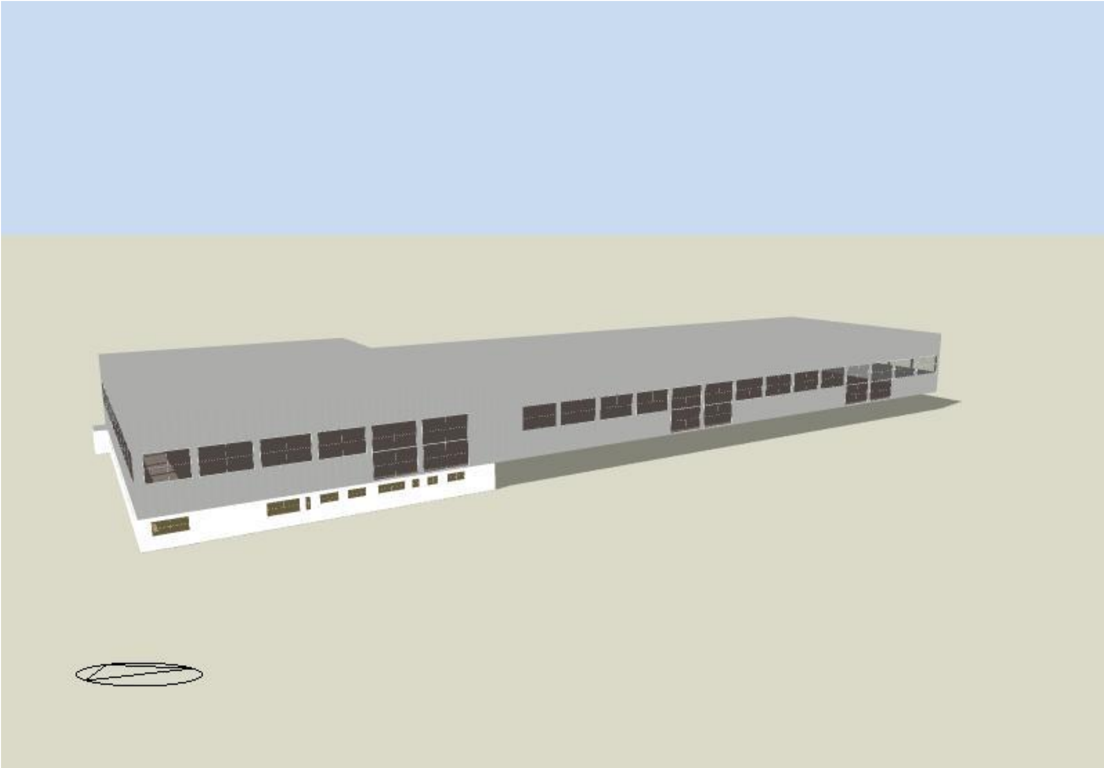

Figure 89: 3D building model representation in Design Builder

3.5.3 HVAC systems and occupancy

No HVAC system is installed in building no. 20. For the dynamic simulations it was decided to deploy central heat pump HVAC systems of average COP 3.0 to cover the heating and cooling requirements of the establishment. The heating temperature is set at 20^{o}C in the winter and the cooling temperature at 23^{o}C in the summer. The operation time of the mobile HVAC systems actually being used in the building is from 9:00 – 21:00 every day.

The activity level was set to be as a generic sales area with density 0.2 people per square meter. The hours of operation of the exhibitions are from 9am-9pm. The occupancy of the area during these times was 100% from 10:00-13:00 and from 17:00-20:00 and 50% from 9:00-10:00, 13:00-17:00 and 20:00-21:00 as shown in figure 90.

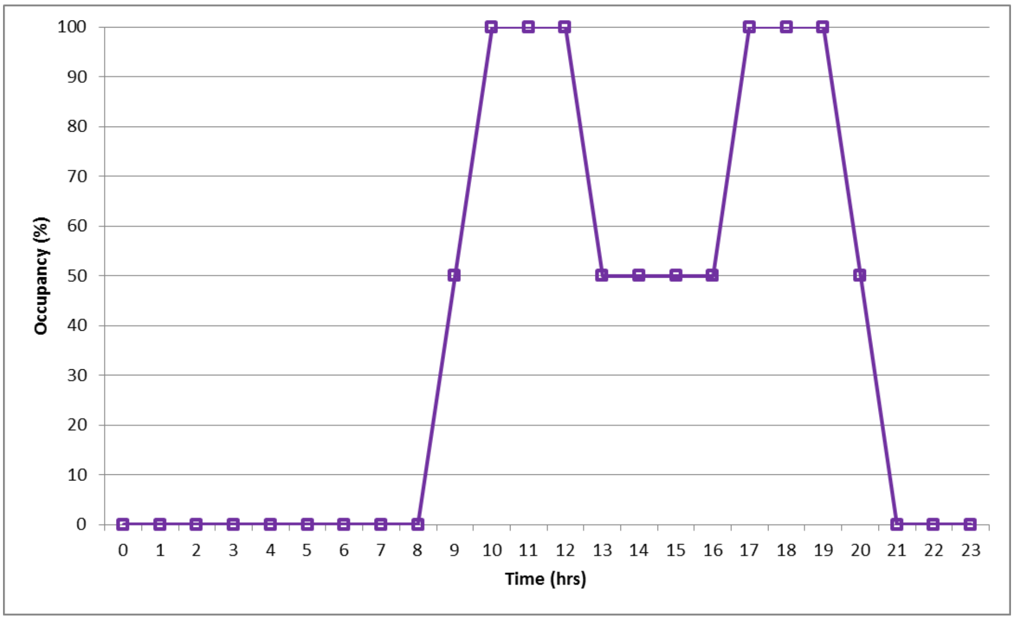

Figure 90: Occupancy schedule

Regarding lighting; tungsten lamps are used with normalized power density 28W/m^2. These are surface mount lamps with radiant fraction of 0.72. Exterior lighting is also available with design level 300W and is switched on during the entire night.

3.5.4 Weather profile

The weather data were optimized for Palermo as a TMY2 weather file from the EnergyPlus website.

The average annual dry bulb temperature in Palermo is 18.82^{o}C. Figure 91 shows the hourly dry bulb temperature throughout the year in Palermo. The lowest temperature is observed in January (4.8^{o}C) and the highest in July (34^{o}C).

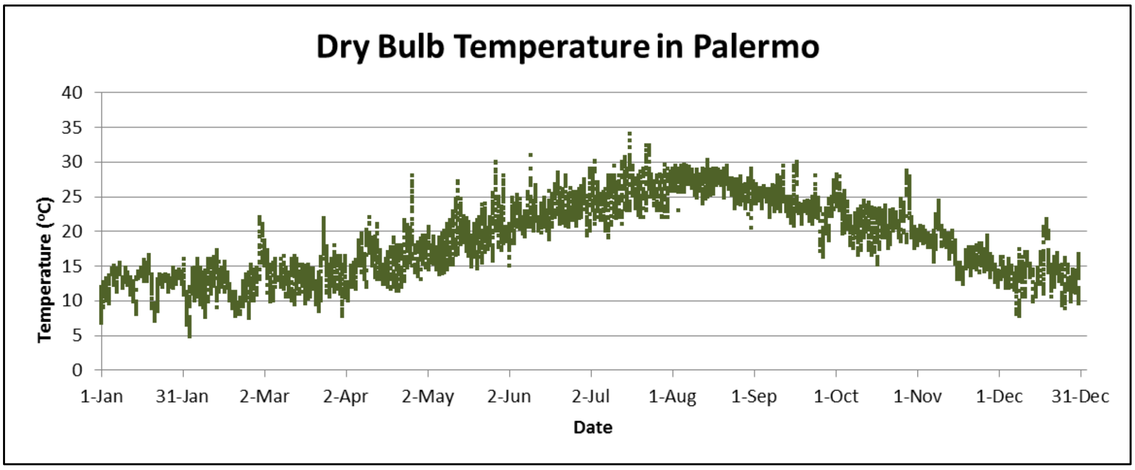

Figure 91: Dry bulb temperature annual variation in Palermo

Figure 92 illustrates the relative humidity in Palermo. Palermo is a coastal city and is characterized by high humidity levels, as shown in the figure below. The average annual relative humidity is 74.43%.

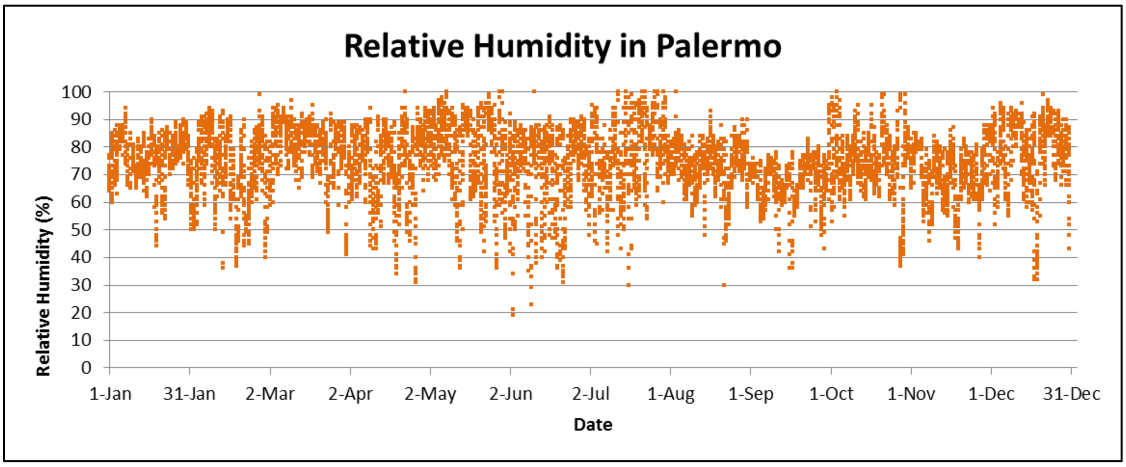

Figure 92: Annual variation of Relative Humidity in Palermo

Regarding wind direction and speed figures 93-94 show the existence of mainly northern winds in Palermo with low speed 0-1m/s. In some extreme cases there is occurrence of high speed winds over 15m/s in March and July. According to figure 94 the high speed winds come from different directions, northeast, west and south.

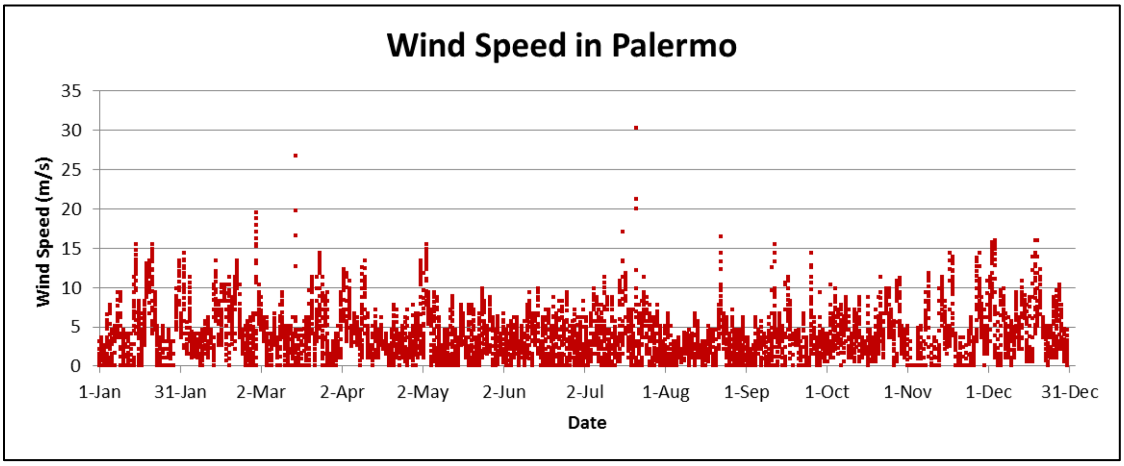

Figure 93: Annual representation of wind speed in Palermo

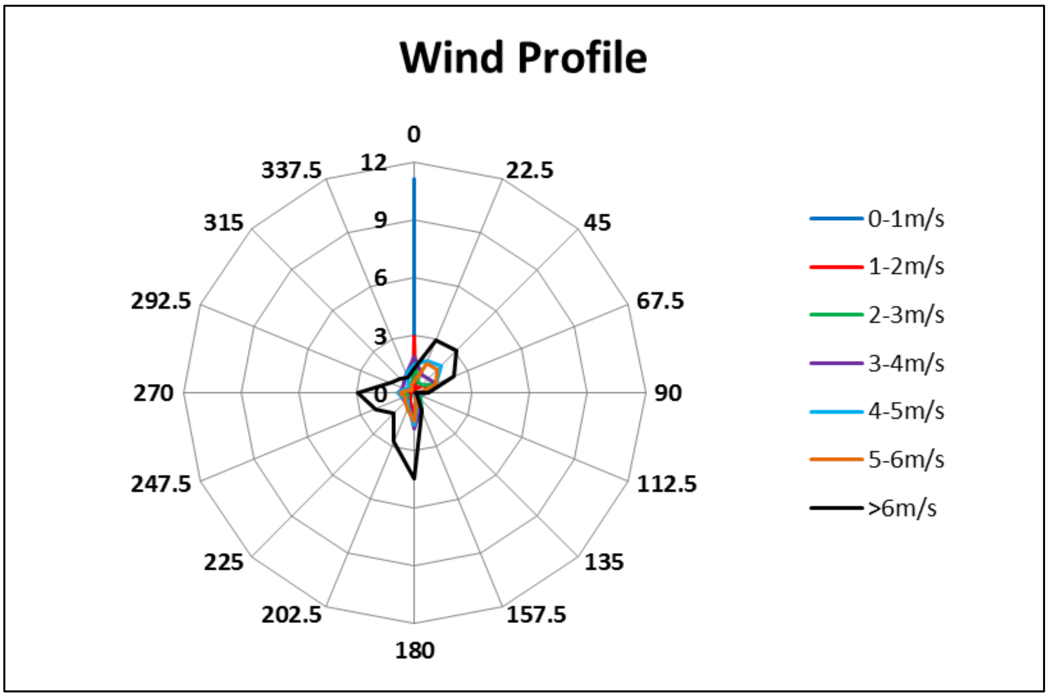

Figure 94: Annual wind profile representation in Palermo

Global horizontal Radiation and direct radiation are important factors for the evaluation of the irradiance in Palermo and to evaluate the efficiency of solar systems. Figure 95 presents the monthly global radiation in Palermo. The highest monthly global radiation occurs in July and the lowest in November.

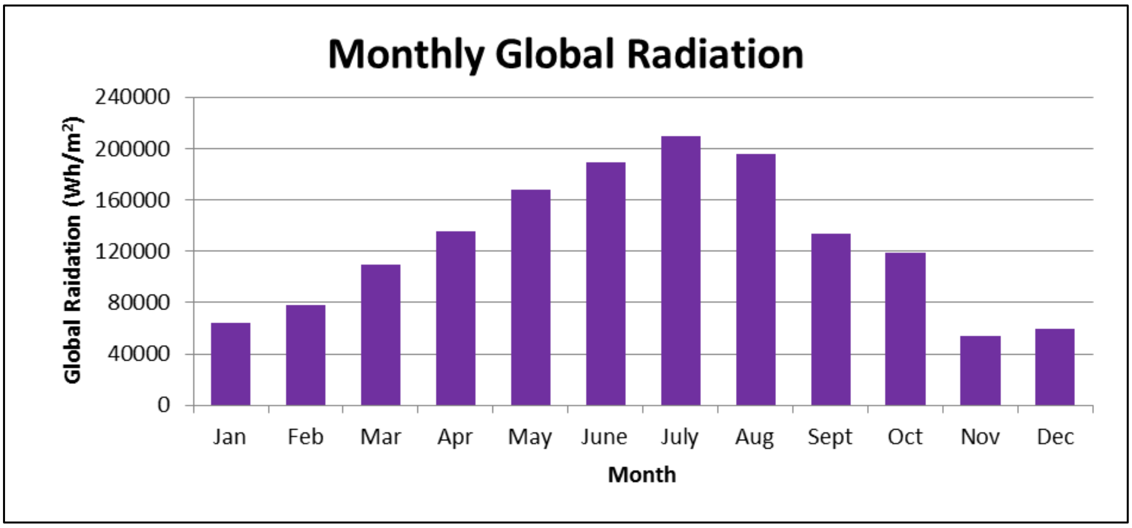

Figure 95: Monthly Global Radiation in Palermo

3.6 Conclusions

In this report, the operational performance of industrial, residential, educational and commercial buildings has been investigated, analyzed and optimized with the use of dynamic and quasi dynamic simulation tools. Energy efficient technologies, renewable energy technologies, storage, as well as smart monitoring and controls have been audited to highlight their significance for integration of different sector buildings in smart grids. Various performance indicators have been used in this analysis including normalized energy consumption, energy saving contribution and potential, primary energy consumption and operating energy cost. Smart monitoring and indoor conditions measurements have been fully exploited to allow the extraction of robust results and the validation of dynamic building energy models. In this direction specific and generic conclusions are outlined below:

- The optimization of the operational phase of buildings is a complicated task which requires deep knowledge and holistic data collection about building design and systems performance long termly.
- Data from monitoring and measurements of energy related parameters is a prerequisite for the reliable analysis, design and implementation of effective solutions to improve energy performance.
- Monitored energy data analysis needs to be carefully conducted to avoid misinterpretation or extraction of wrong conclusions due to errors in the data sets or misconception of what is actually being measured.
- The role of renewables and storage in buildings is of major importance to minimize energy demand and allow flexibility in their integration in smart grids.
- Significant space of improvement exists in energy management both in terms of exploiting advanced control algorithms and energy pricing information.
- User active engagement for the improvement of energy performance is a major challenge which in most cases is not adequately addressed.

- Reaching Near Zero Energy Building (NZEB) operational performance requires a combination of bioclimatic design, efficient energy technologies, smart monitoring and effective renewable energy deployment.
- Advanced technological solutions for buildings to become net zero energy prosumers are available but still require a high investment cost and a long payback period.
- The integration of Linear Fresnel Concentrating Solar Thermal systems in buildings is a technically feasible and energy prominent solution of minimum visual impact.
- Advanced and robust building energy models provide the basis for advanced real time energy management solutions to be designed, implemented and tested.

In overall reducing energy consumption to zero net levels requires a) a systematic approach including technological advances, scientific state of the art techniques, c) organizational measures d) continuous efforts and investments to make the most of each measure and minimize energy losses and e) active user engagement.

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