Task 53 Workshop

"NEW GENERATION OF SOLAR COOLING AND HEATING SYSTEMS DRIVEN BY PHOTOVOLTAIC OR SOLAR THERMAL ENERGY"

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Investigation on advanced batteries for PV electric cooling and building energy demand

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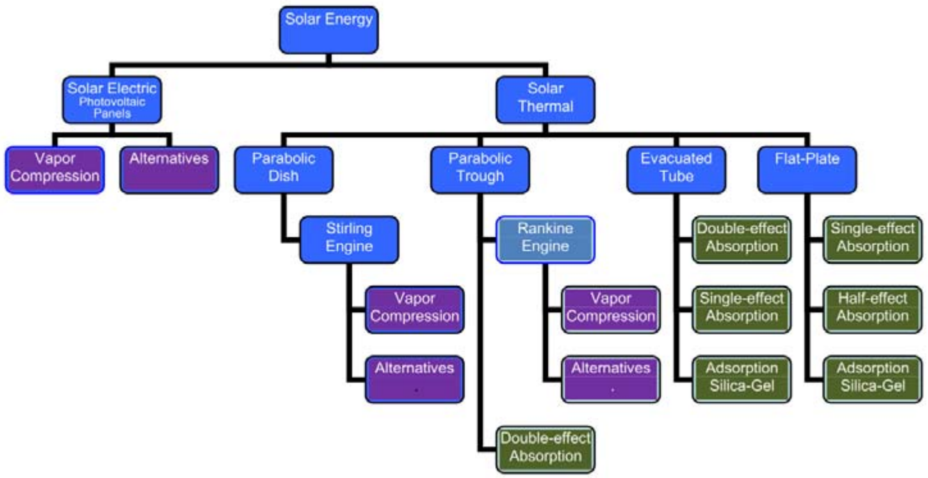
Consiglio Nazionale delle Ricerche

Solar cooling

PV COOLING

Advantages:

- When solar radiation is high, the need of refrigeration is also high → contemporaneity between energy production and energy consumed
- More efficient is the conditioner (COP >>) more efficient is the chain from solar radiation to air cooled
- Energy can be stored in the form of electricity (batteries) to use it for cooling porpoises when needed → demand side management
- Energy can be stored also in the form of heat/cold (reducing the battery size → cooling/heating available directly for demand side management



Alternative routes from solar energy into cooling/heating effect using thermodynamic cycles.

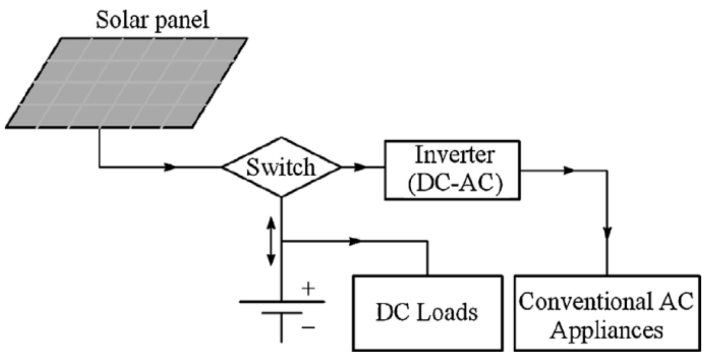
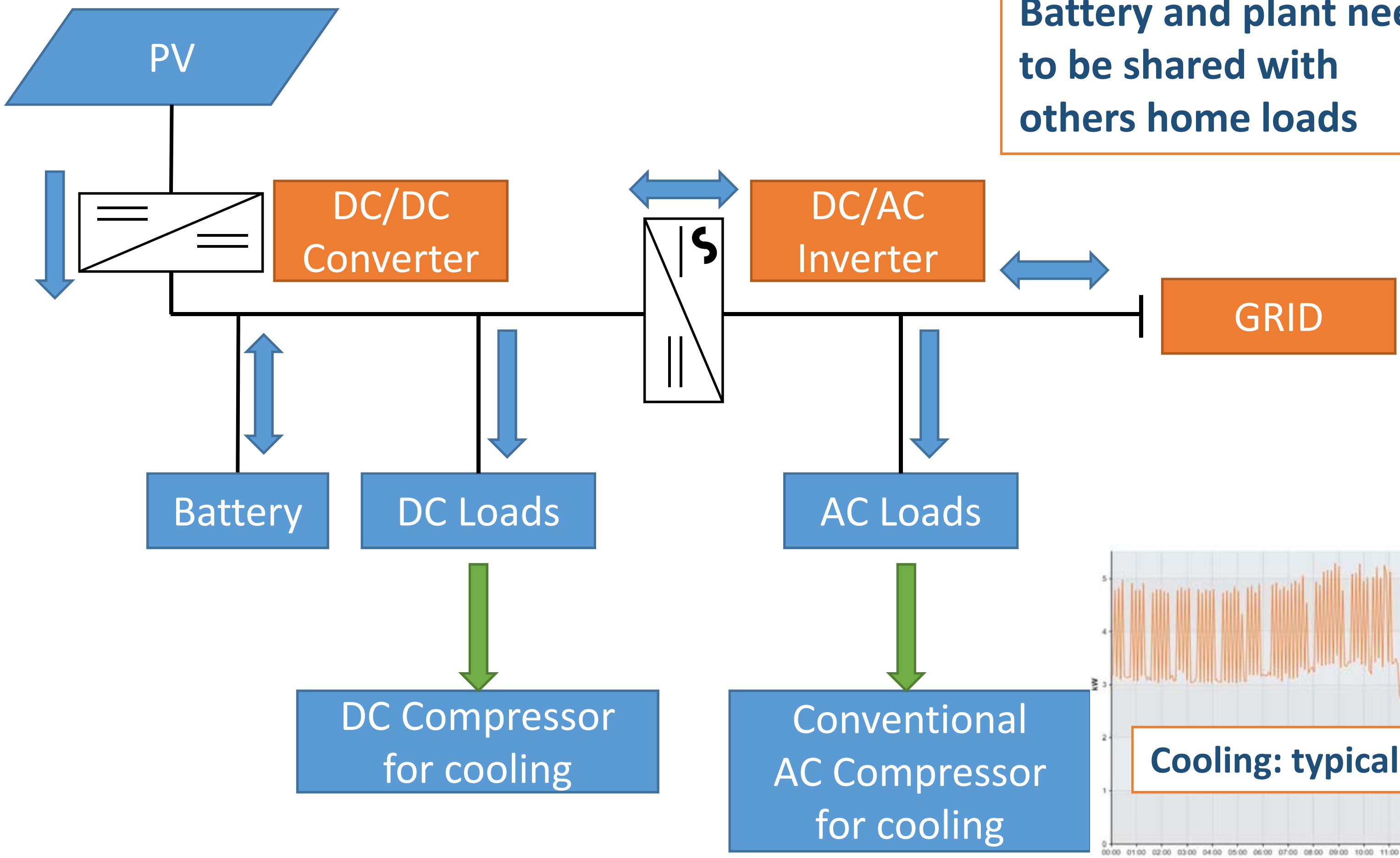


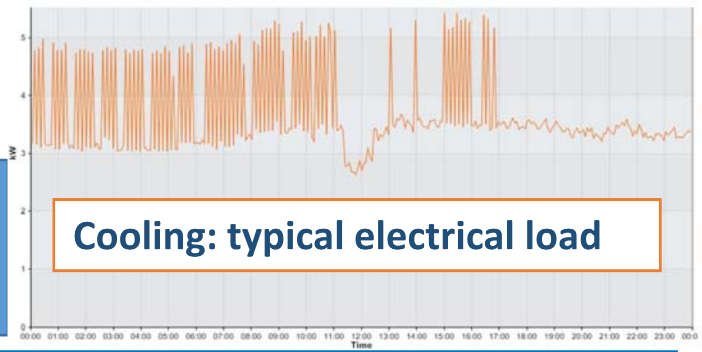
Fig. 3. Schematic of a stand-alone PV system.

PV cooling and batteries

Solar electric cooling system consists mainly of the components reported in the schematics



Battery and plant need to be shared with others home loads



Batteries: types and costs

Characterization and comparison among different Lithium-Based Batteries: $LiFeMgPO_4$, $LiFePO_4$ and Lithium-Polymers

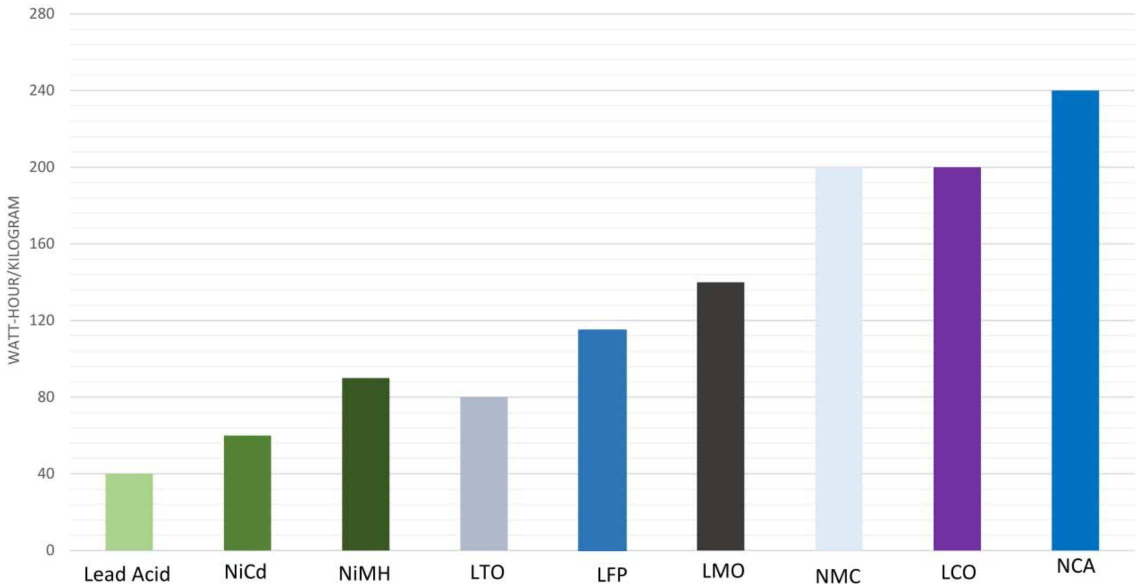
Comparison of different chemistries

Battery choice based on the following parameters:

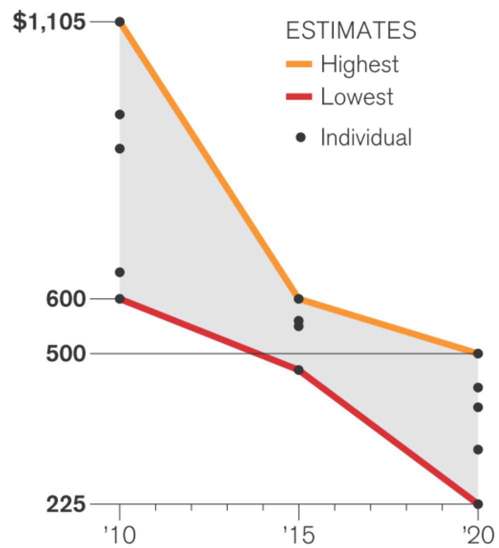
- ✓ Electrical behavior
- ✓ Energy and amperometric efficiency
- ✓ Safety (installation in home environment)
- ✓ Costs

Cost prevision

- ➢ Lithium Iron Phosphate driven by the automotive and stationary market
- ➢ Lithium polymer driven by the portable and automotive market
- ➢ Lithium titanate: optimal features but too expensive



Typical specific energy of lead-, nickel- and lithium-based batteries.
NCA enjoys the highest specific energy; however, manganese and phosphate are superior in terms of specific power and thermal stability. Li-titanate has the best life span.
Courtesy of Cadex Source: "Types of Lithium Batteries- A Handy Summary" and "BU-205: Types of Lithium-ion", Battery University



Sources: Advanced Automotive Batteries, Boston Consulting Group, Deutsche Bank, Electrification Coalition, National Research Council, and Pike Research

Batteries testing

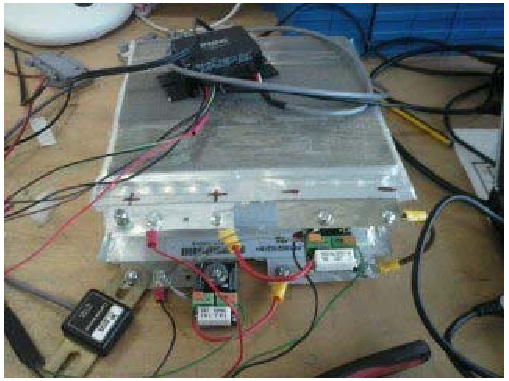
Characterization and Comparison among different Lithium-Based Batteries: $LiFeMgPO_4$, $LiFePO_4$ and Lithium-Polymers

Test Samples

Parameters	LiFeMgPO4	LiFePO4	Lithium-Polymer
Rated Voltage [V]	12.8	3,2	3.7
Rated Capacity [Ah]	40	40	40
Max Voltage [V]	14.6	3,65	4.2
Cut-off Voltage [V]	10	2,5	2.7
Max continuous current in discharge [A]	80 (2C)	120 (3C)	200 (5C)
Peak current [A]	120 (3C)	400 (10C)	400 (10C)
Energy density [Wh/kg]	79	85	134.5
Operating temperature [°C]	-20/55	-20/55	-20/60
Dimensions [mm]	197 x 131 x 182	46x115x181	215 x 10.7 x 220
Weight [kg]	6,5	1,5	1,1

LiFePO4

LiFeMgPO4

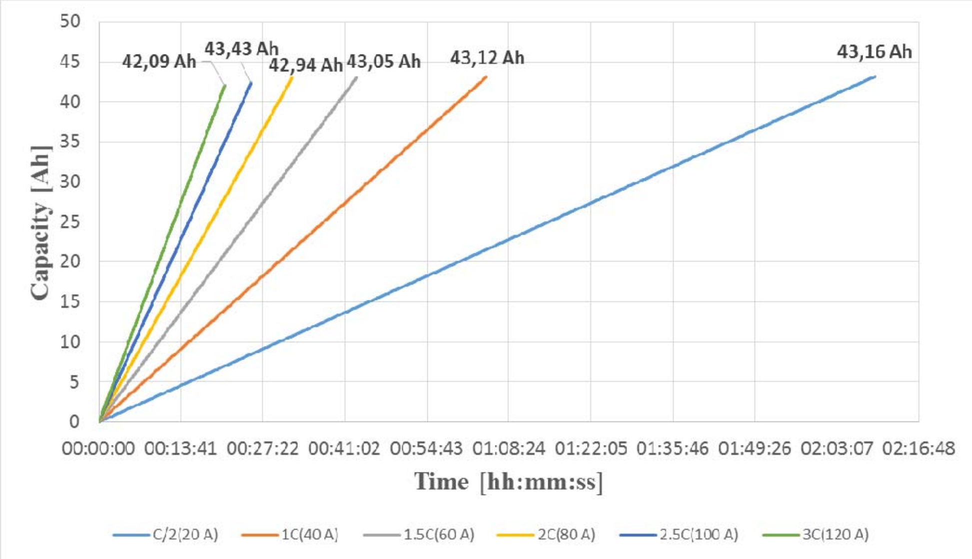


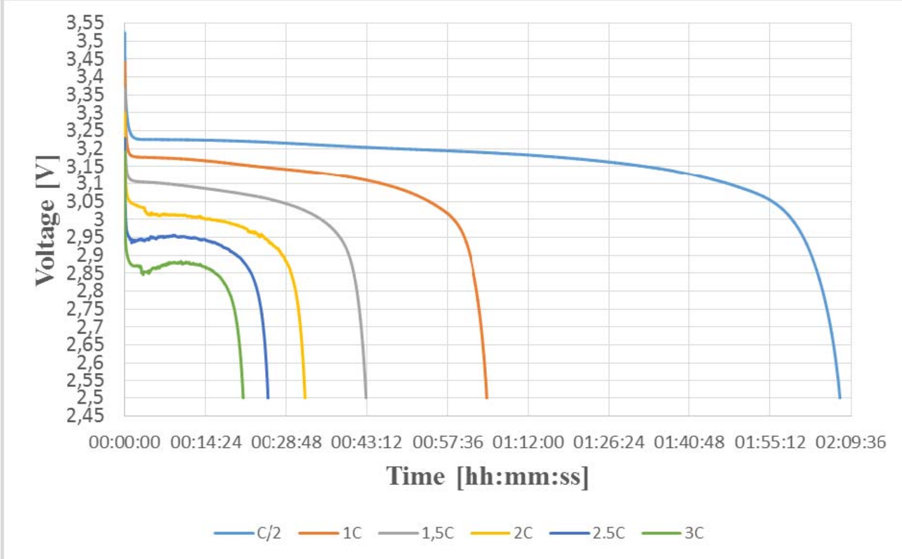
Lithium-Polymer

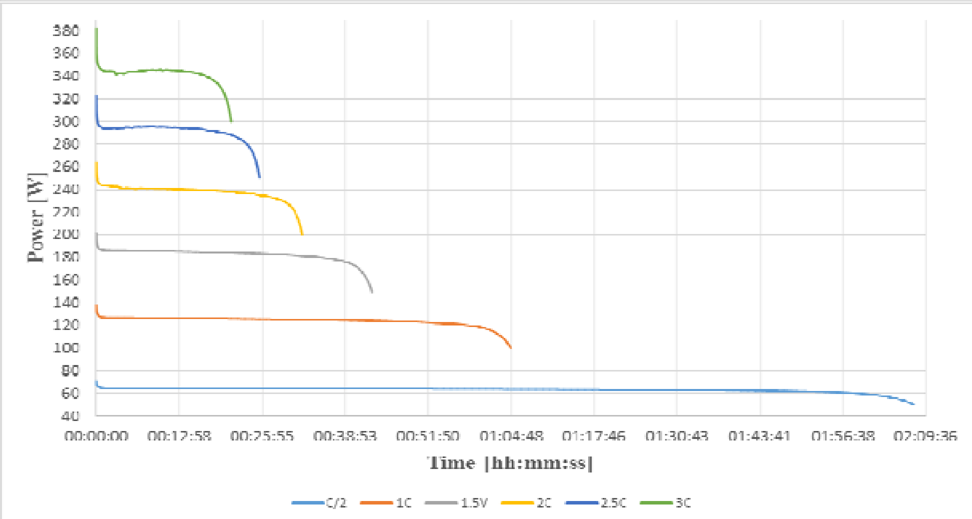
Batteries testing

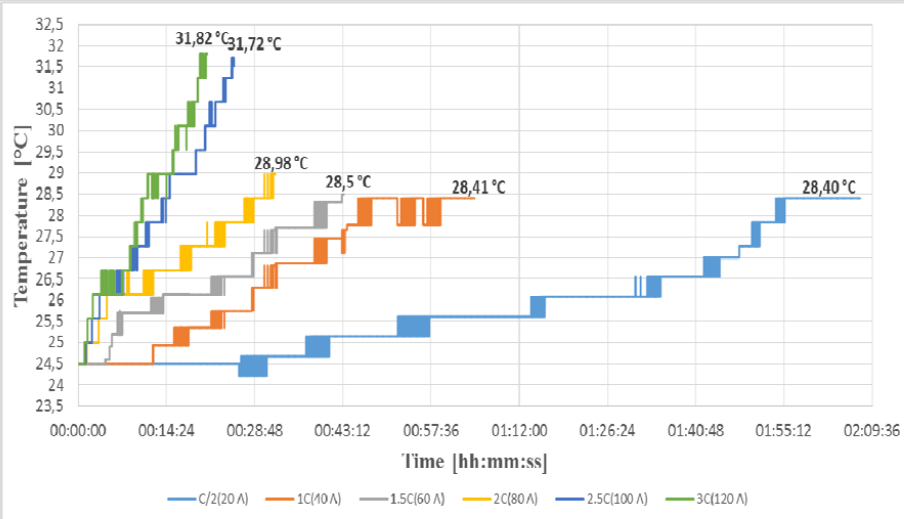
Discharging test: LiFePO4

- **Initial Voltage drop: 0,15 V;**
- **Flat voltage trend during discharging (Voltage variation: 0,2 V)**
- **Capacity reduction (C/2-3C): 2,5 %**
- **Max temperature: 31,82 °C at 3C**









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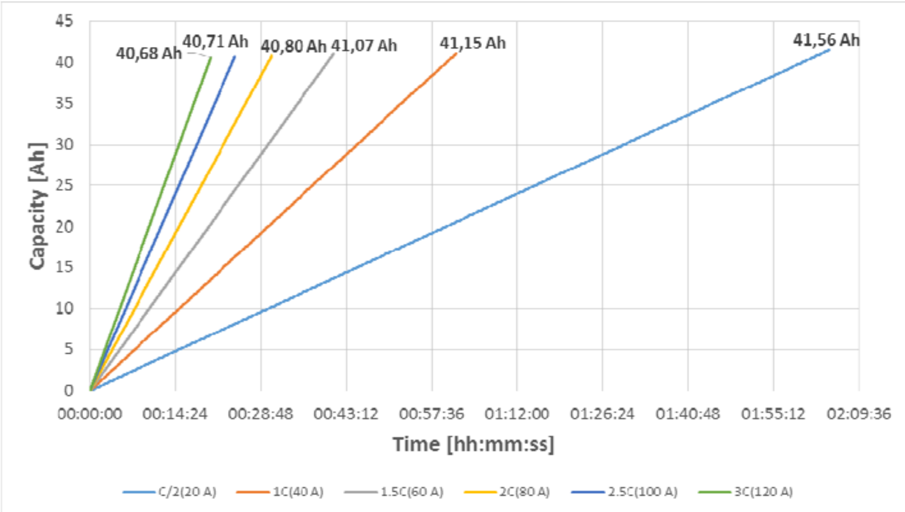
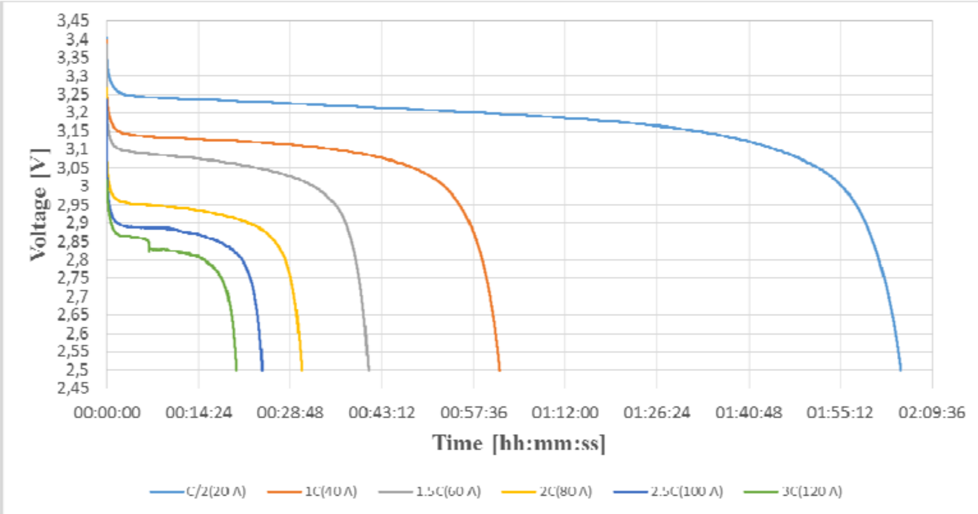
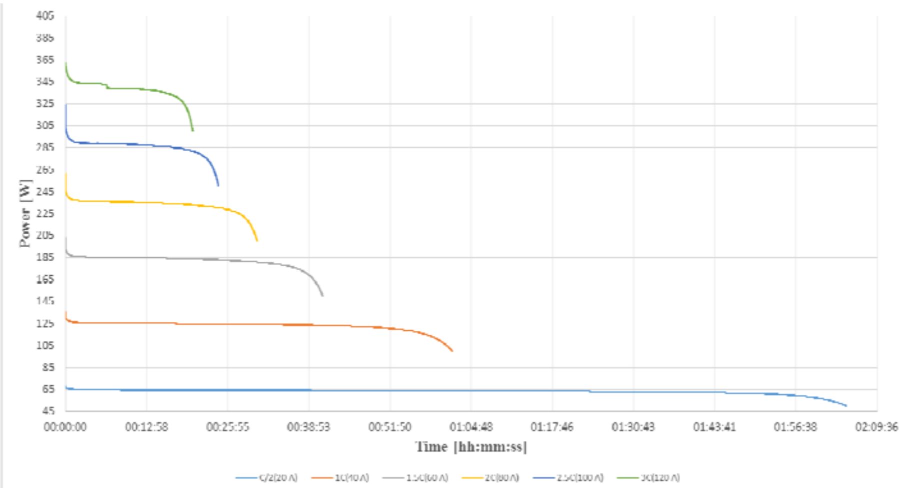
Batteries testing

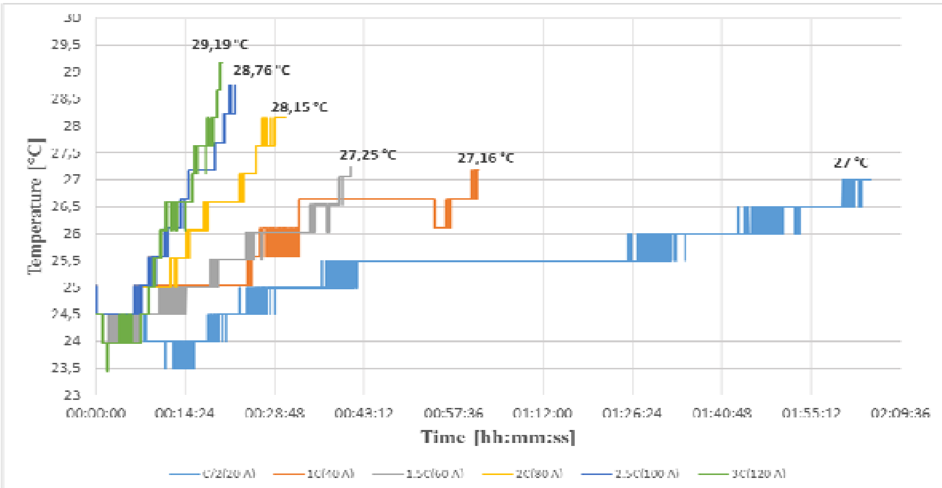
Discharging test: LiFeMgPO4

- **Initial Voltage drop: 0,1 V;**
- **Flat voltage trend during discharging (Voltage variation: 0,2 V)**
- **Capacity reduction (C/2-3C): 2,1 %**
- **Max temperature: 29,19 °C at 3C (Lowest temperature)**









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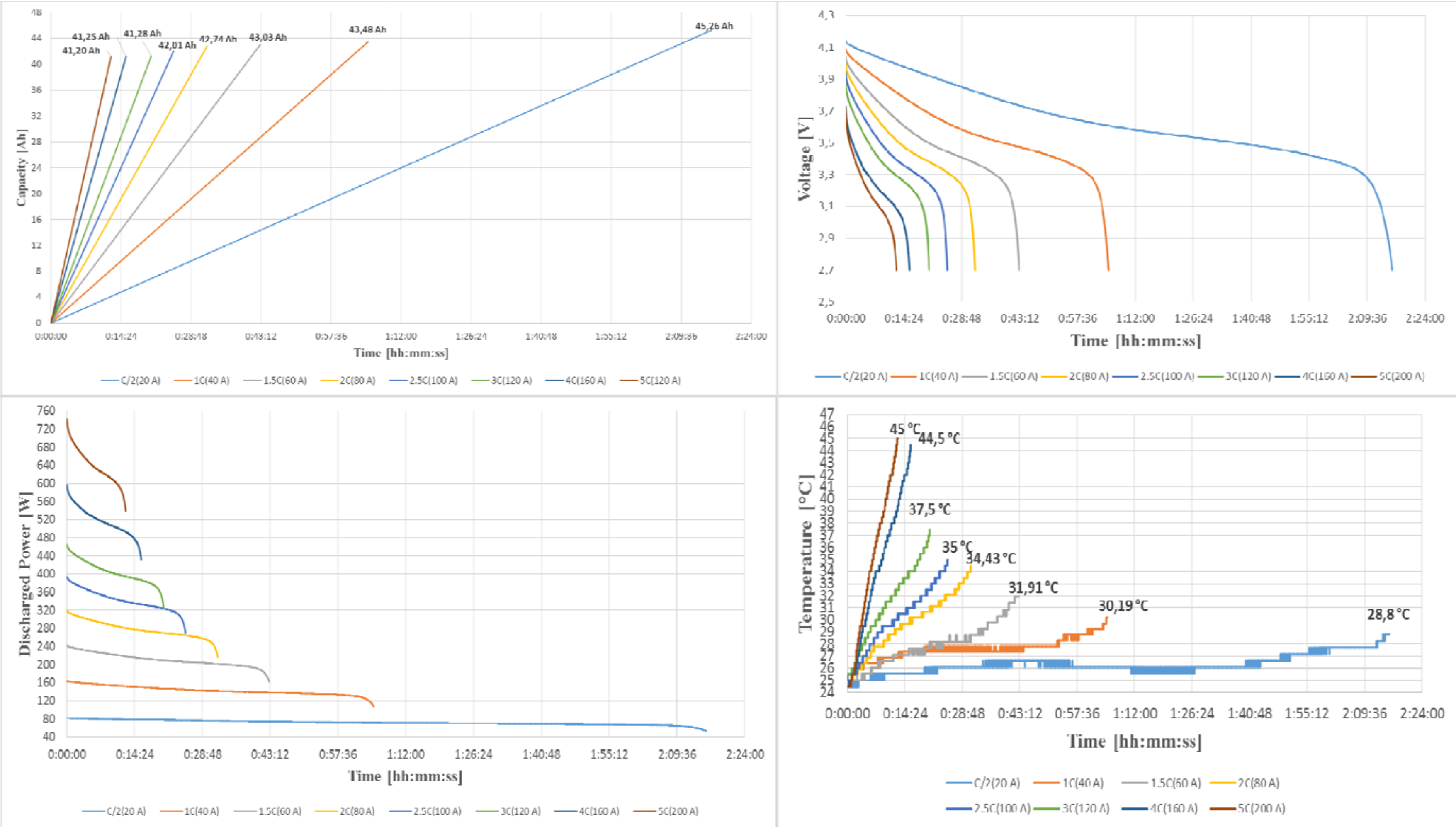
Batteries testing

Discharging test: Li-Polymer

- Big voltage variation during discharging (100% - 0%: 0,8 V)
- Capacity reduction (C/2-3C): 8,79 %
- Capacity reduction (3C – 5C): 0,19 %
- Max temperature: 37,5 °C at 3C and 45 °C at 5C (Possibility to work at higher temperatures)



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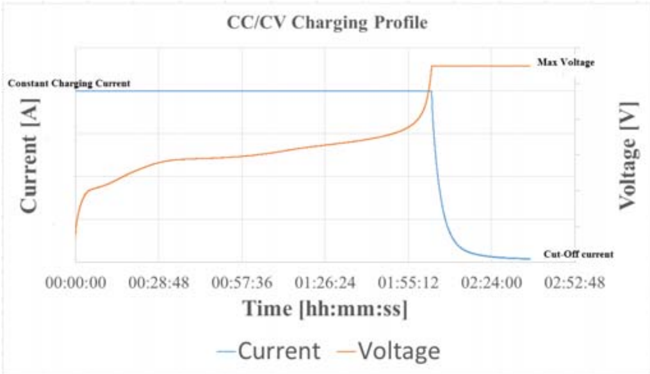
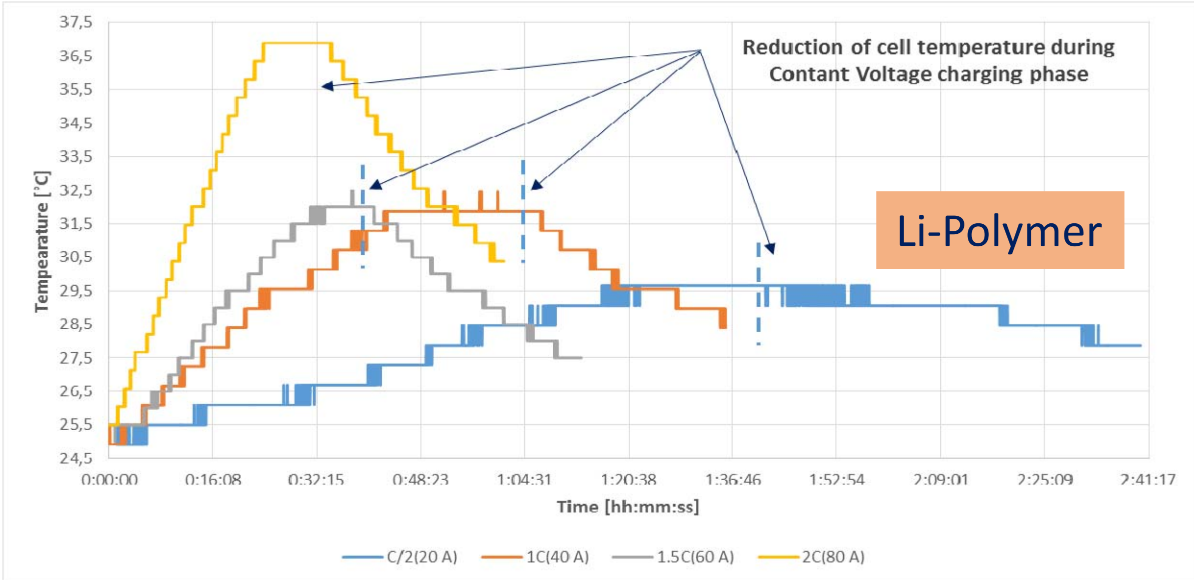
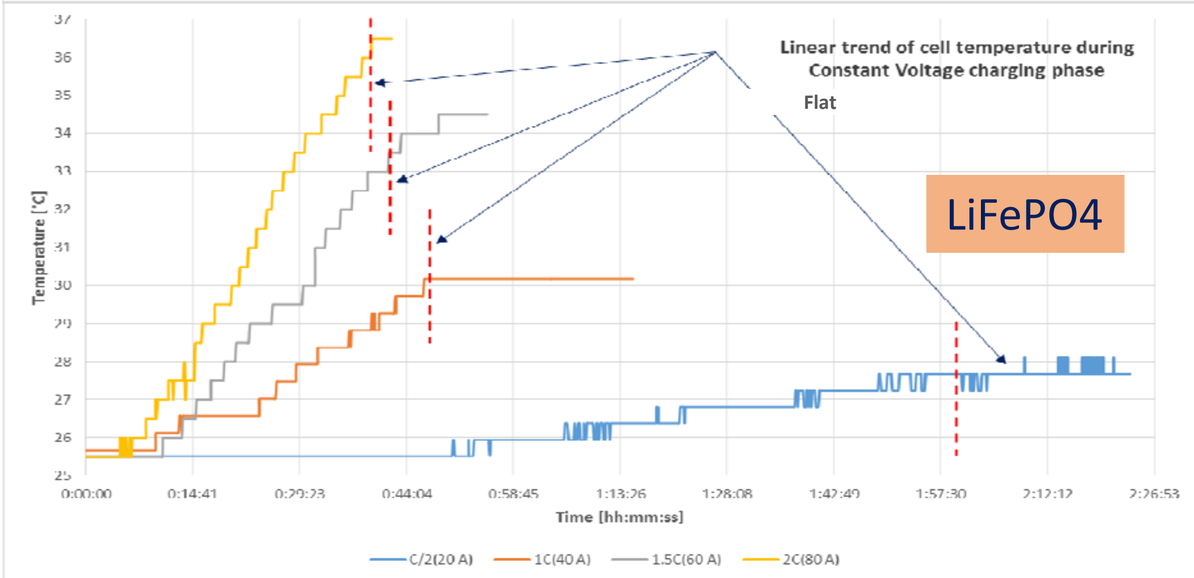
Batteries testing

Charging test CC/CV

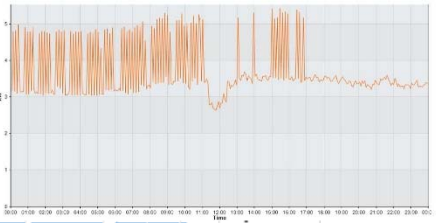


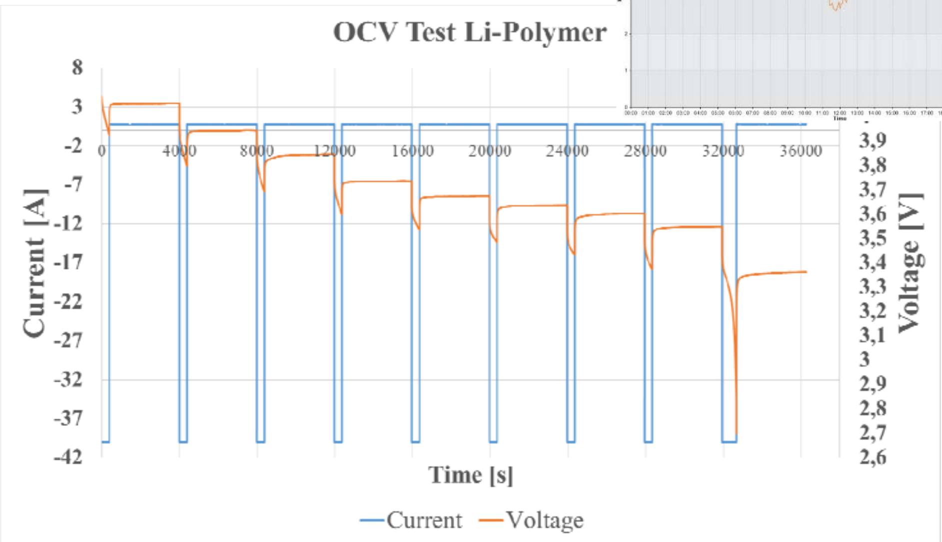


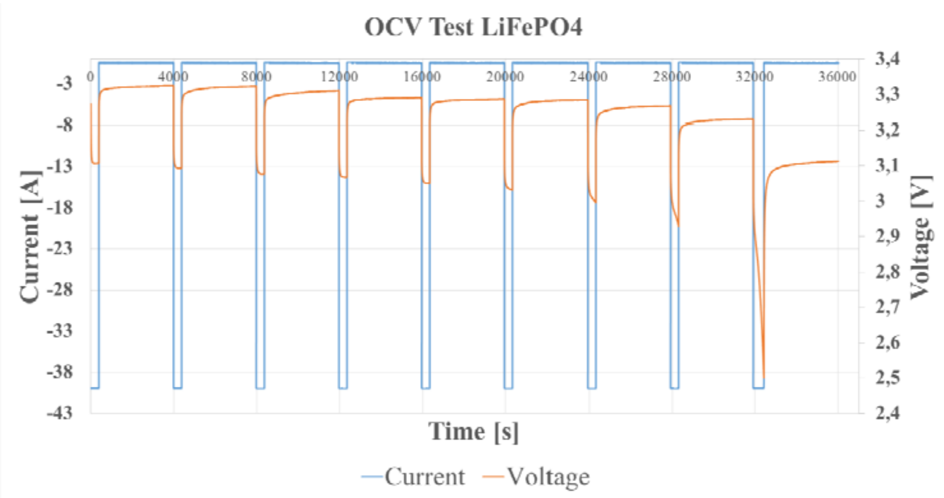


Batteries testing

OCV TEST



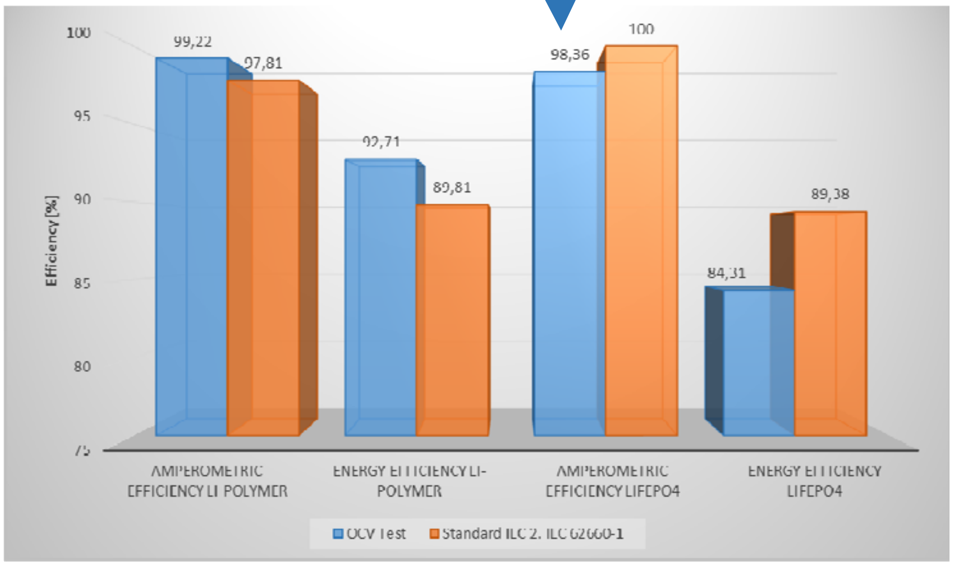




Test Procedure:

1. Starting from 0% SOC, constant current charge at C/2 (20 A) up to max voltage cell;
2. Constant voltage charge up to cut-off current;
3. Constant current discharge at 1C from 100% SOC to 90% SOC;
4. Rest phase up to stabilization of voltage.

Test has been repeated discharging continuously each cell with SOC% step of 10% up to final SOC of 0%.



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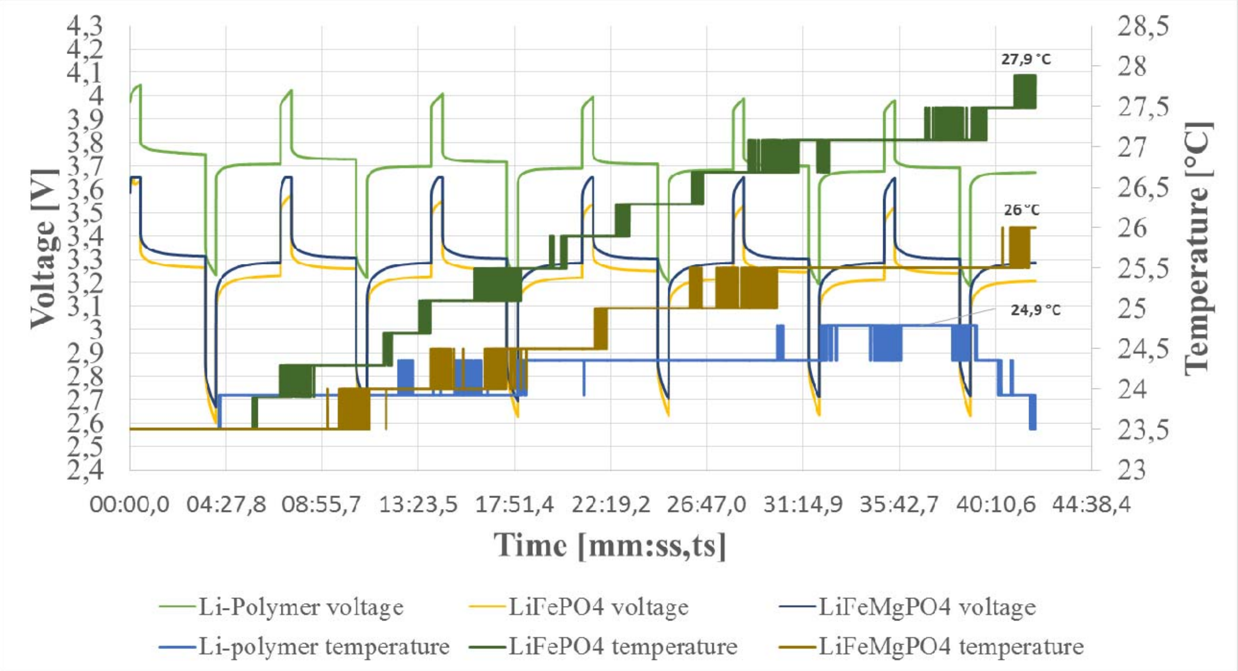
Batteries testing

Pulse current test

A Hybrid pulse test consisting of a sequence of constant-current discharge and charge pulses and rests were conducted.

Test procedure:

1) From 100% SOC, discharge to 1C up to 50% of SOC;
2) Rest for 6 min;
3) Charge at constant current value of 100 A (2.5C) over a period of 30 seconds;
4) Rest for 3 min;
5) Discharge at constant current value of 160 A (4C) over a period of 30 seconds;
6) Step of "Rest open circuit" in which the current is reduced to zero;
7) Charge at 40 A (1C) up to 50% of SOC;
8) Pause for 6 min;



Li-Polymer cells completed all charging and discharging in the period of 30 seconds for each step.
For LiFePO4 cells, despite the initial SOC of 50%, in the first three charging steps maximum voltage has been reached before the 30 seconds set for the test. This greatly reduces the SOC% useful range of LiFePO4 at high charging C-rate.
The larger voltage range for Li-Polymer cells allow a better capability in charge.

Batteries testing

Identification of the most appropriated battery: $LiFeMgPO_4$

- ✓ Lowest temperature at high discharge (safety)
- ✓ Flat electrical behavior during load changes
- ✓ OCV test: energy efficiency about 85%
- ✓ Capacity reduction at high current (3C): 2,1 %

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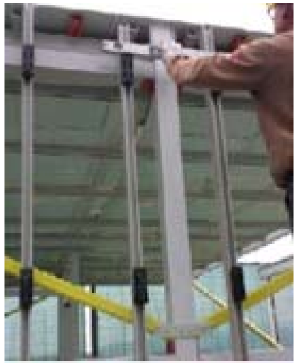
PV cooling, batteries and building demand

Framework: an Italian case study

Development of an innovative living module
Integrating innovative energy technologies

Project: "CNR for the South - Advanced technologies for energy efficiency and mobility with zero impact"

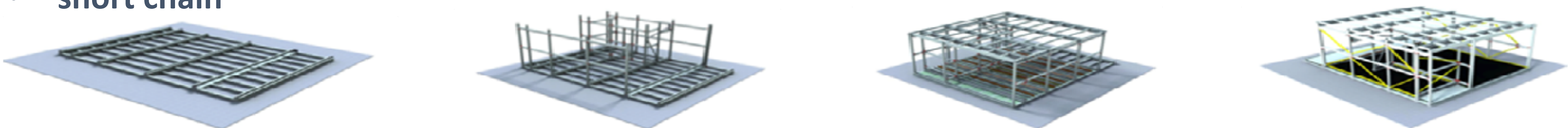





- Quick assembly
- Reduction of processing times
- Reduction of waste and scrap
- short chain

The assembly technologies is interlocking, using various fiberglass profiles, assembled with screws self-tapping type, and bolts.

Fiber Reinforced Polymers (FRP)



Reducing time and costs of the construction site

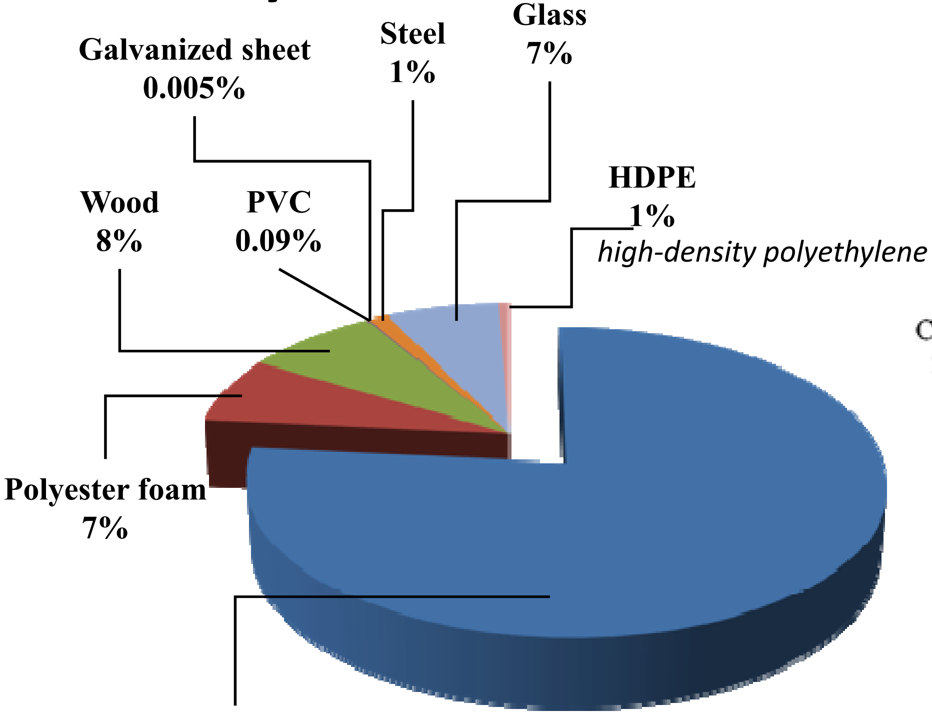
Fiber Reinforced Polymers (FRP) are composed by fiber glass and polyester foam. The final material is obtained through the pultrusion (pull+extrusion) procedure.

PV cooling, batteries and building demand

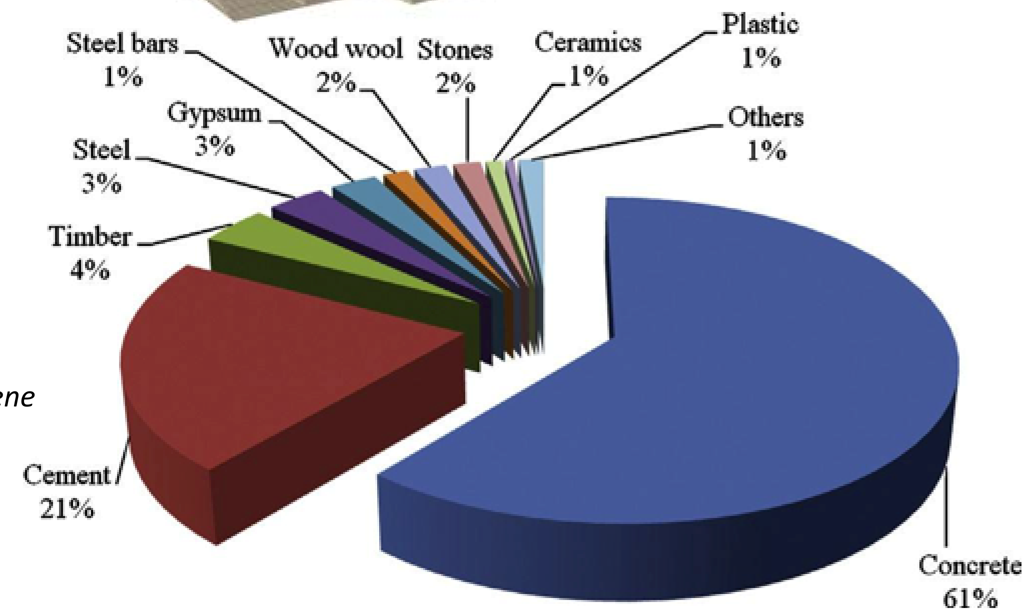
Environmental impact

Composition of building envelope, in terms of weight

Case study



Passive house



S.Proietti, P.Sdringola, U.Desideri, F. Zepparelli, F. Masciarelli, F.Castellani, Life Cycle Assessment of a passive house in a seismic temperate zone; Energy and buildings 64 (2013); 463-472

PV cooling, batteries and building demand

Energy Management System

- ✓ Lightning control with dimmerable strip leds (white and RGB) over DMX protocol-Implementation of scenes
- ✓ Energy consumption monitoring and loads control (demand response)
- ✓ Energy generation monitoring (Photovoltaic and fuel cell)
- ✓ Energy storage system regulation for self consumption and grid services
- ✓ Local control panel and remote control via web services

$LiFeMgPO_4$ Batteries
Energy =5 kWh

250W Solid
Oxide Fuel Cell

Control panel and bidirectional
AC/DC converter

PV policristalline
roof top plant P=3kW

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PV cooling, batteries and building demand

Framework

IEA Task 40/Annex 52
Towards Net Zero Energy
Solar Buildings

NET ZEB
TASK 40 / ANNEX 52

Contribution from Palermo University

ANALYSIS OF LOAD MATCH AND GRID INTERACTION INDICATORS IN NET ZERO ENERGY BUILDINGS WITH HIGH-RESOLUTION DATA

The term load matching (LM) refers to the degree of agreement or disagreement of the on-site generation with the building load profiles;
grid interaction (GI) refers to the energy exchange patterns between a building and the utility grid, and its impact on the overall load of the grid. Collectively, both issues are denominated LMGI.

"Analysis of load match and grid interaction indicators in net zero energy buildings with high-resolution data. A report of Subtask A – IEA Task 40/Annex 52 Towards Net Zero Energy Buildings, March 2014

UNDERSTANDING NET ZERO ENERGY BUILDINGS: EVALUATION OF LOAD MATCHING AND GRID INTERACTION INDICATORS
Jaume Salom , Joakim Widén , José Candanedo , Igor Sartori , Karsten Voss , Anna Marszal

PV cooling, batteries and building demand

LOAD MATCH INDICATORS

Load cover factor

the percentage of the electrical demand covered by on-site electricity generation

$$\gamma_{load} = \frac{\int_{\tau_1}^{\tau_2} min[g(t) - S(t) - \zeta(t), l(t)]dt}{\int_{\tau_1}^{\tau_2} l(t)dt}$$

Supply cover factor

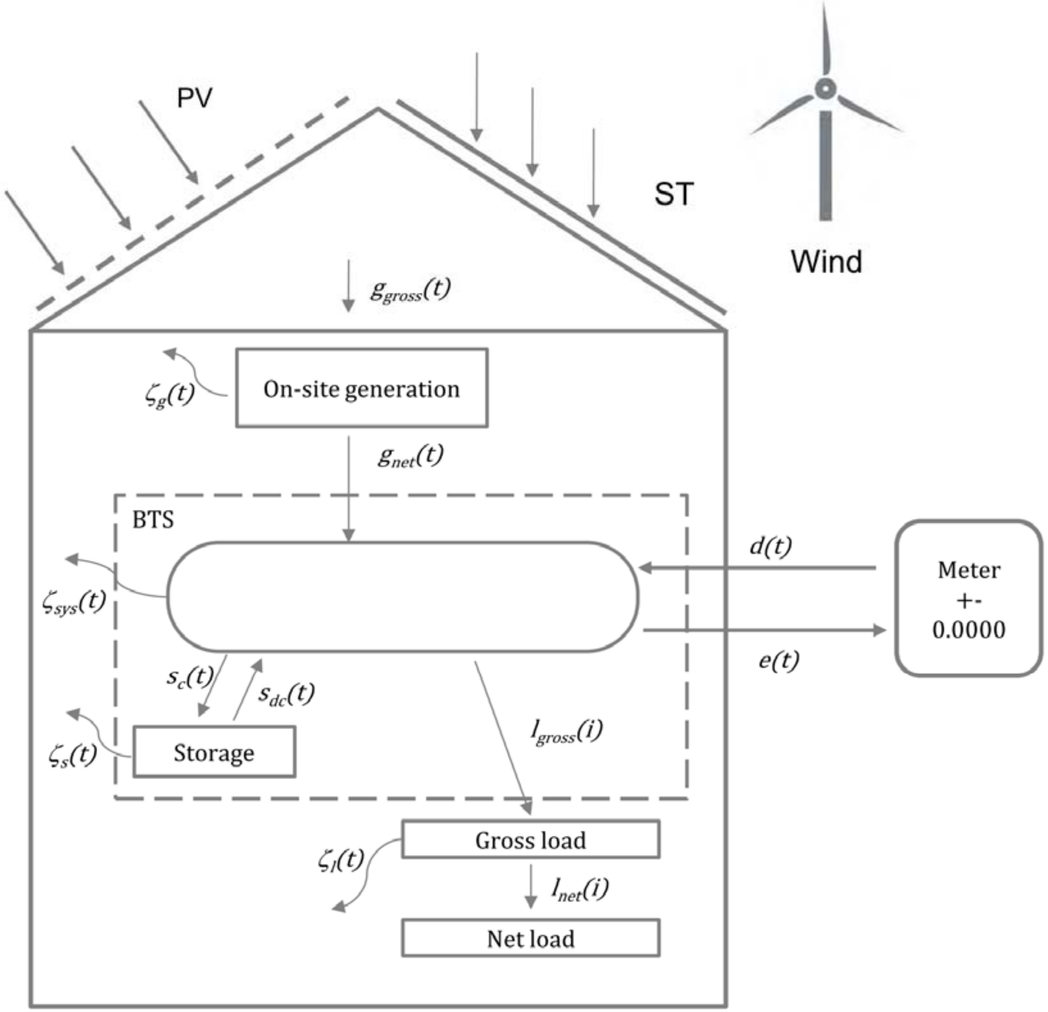
the percentage of the on-site generation used by the building

$$\gamma_{supply} = \frac{\int_{\tau_1}^{\tau_2} min[g(t) - S(t) - \zeta(t), l(t)]dt}{\int_{\tau_1}^{\tau_2} [g(t) - S(t) - \zeta(t)]dt}$$

Net exported

Normalized energy exported (E_{des}=connection capacity)

$$\overline{ne(t)} = \frac{ne(t)}{E_{des}}$$



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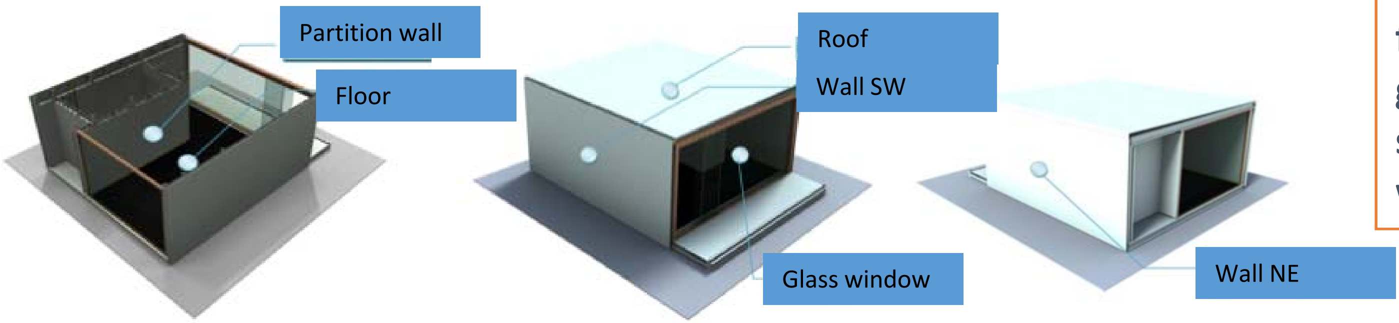
PV cooling, batteries and building demand

Work done:

- Thermo-physical model of the house through on-field measurements
- Calculation of the demand for heating and cooling
- Determination of the electrical load
- Development of the model for load match and grid interaction
- Simulations with different scenarios

PV cooling, batteries and building demand



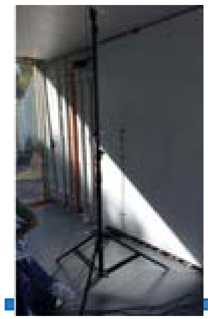
The building has an area of 60 m2 , it has two main façades almost fully glazed, while on the other sides there are no windows.

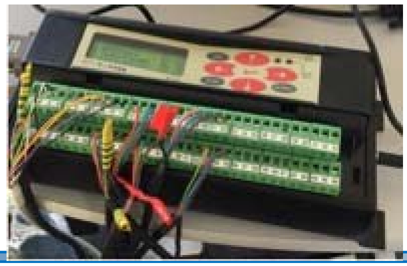
Building thermo-physical model

Energy Plus environment using conduction transfer function modelling for the envelope and the heat balance method to analyze the thermal zones.

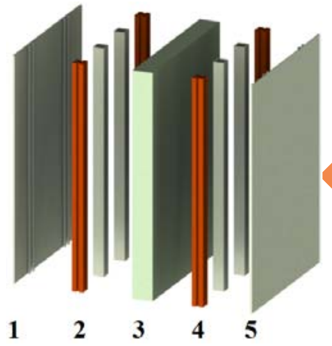
LOCATION DATA					
Location	**Altitude**	**Latitude**	**Longitude**	**Degree days**	**Climatic zone**
Messina (Italy)	132 m AMSL	38° 8’ N	15° 31’ E	707	B

METEONORM database





PV cooling, batteries and building demand

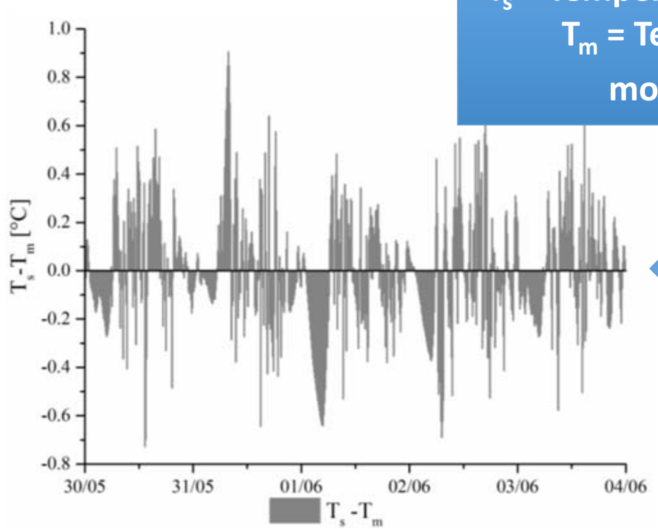


Section of the wall:
1and 5: Fiberglass panels,
2 and 4: Fiberglass profiles,
5: Thermal insulation

The windows are made of double low-emissivity insulated glazing with 0.005 m external glass, 0.016 m gap filled with argon and 0.004 m internal glass; the average global window U-value is 1.19 W/(m2 K), solar heat gain coefficient (SHGC) is equal to 0.3 while the visible transmittance (VT) is 0.4.

The vertical and horizontal surfaces U value is equal to 0.3 W/(m2 K) for all surfaces.

Calibration results:
T_s = Temperature simulated
T_m = Temperature monitorted



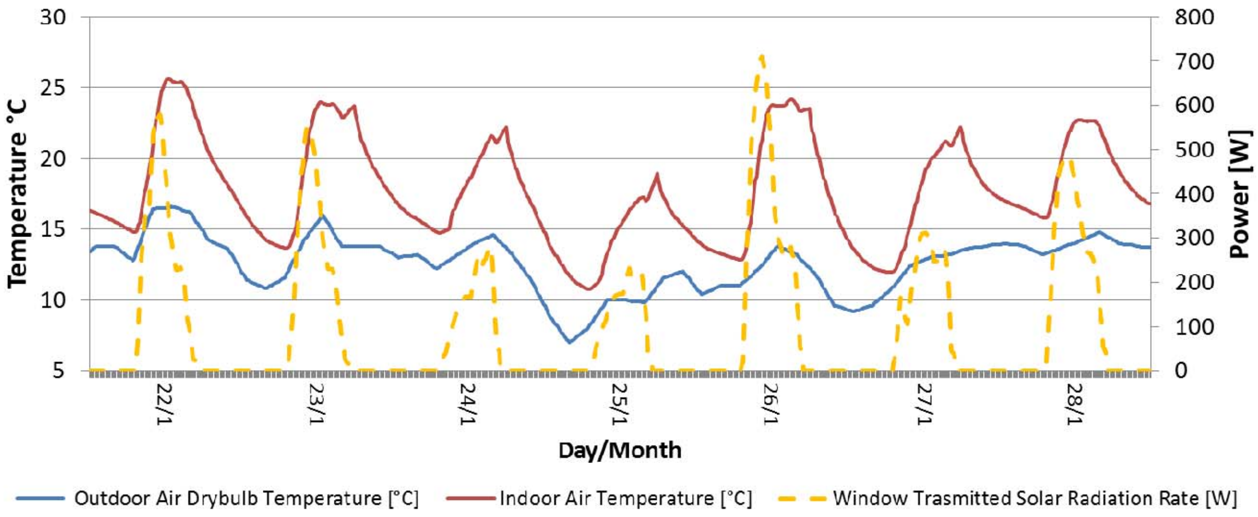
Thermal properties of the building envelope

External structures	U value [W/(m² K)]	Windows	U value [W/(m² K)]
Walls	0.3	Overall	1.3
Roof	0.3	Glass only	1.1
Floor	0.3		

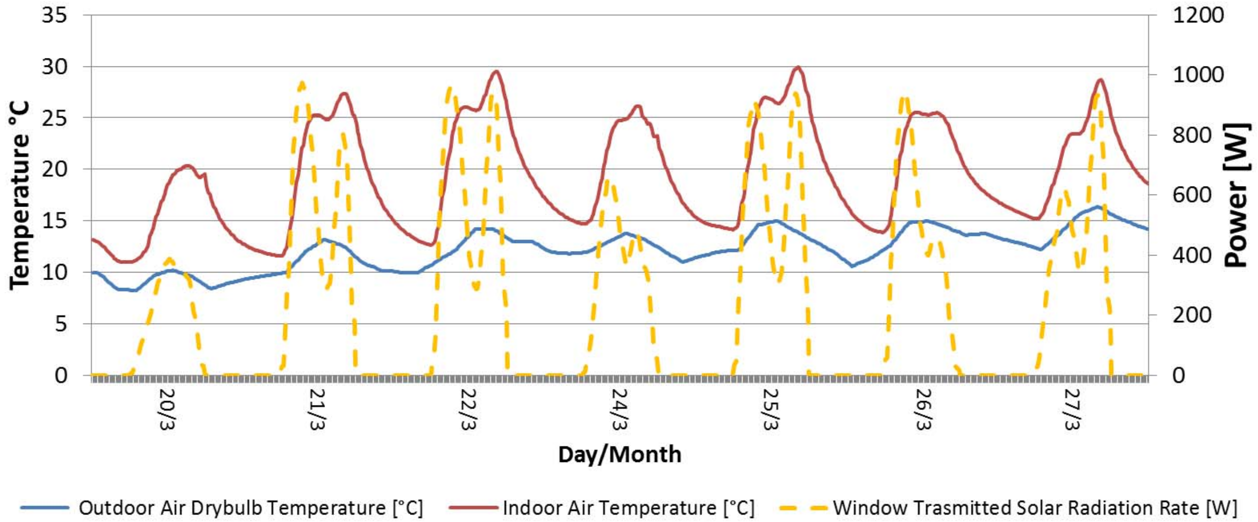
In all cases the differences are below 0.9 °C. In 90% of the data, the absolute error is below 0.41° C, for 75% it is below 0.27 °C, while for 50% of the calibration data it is below 0.15 °C.

PV cooling, batteries and building demand

Free-floating winter trend

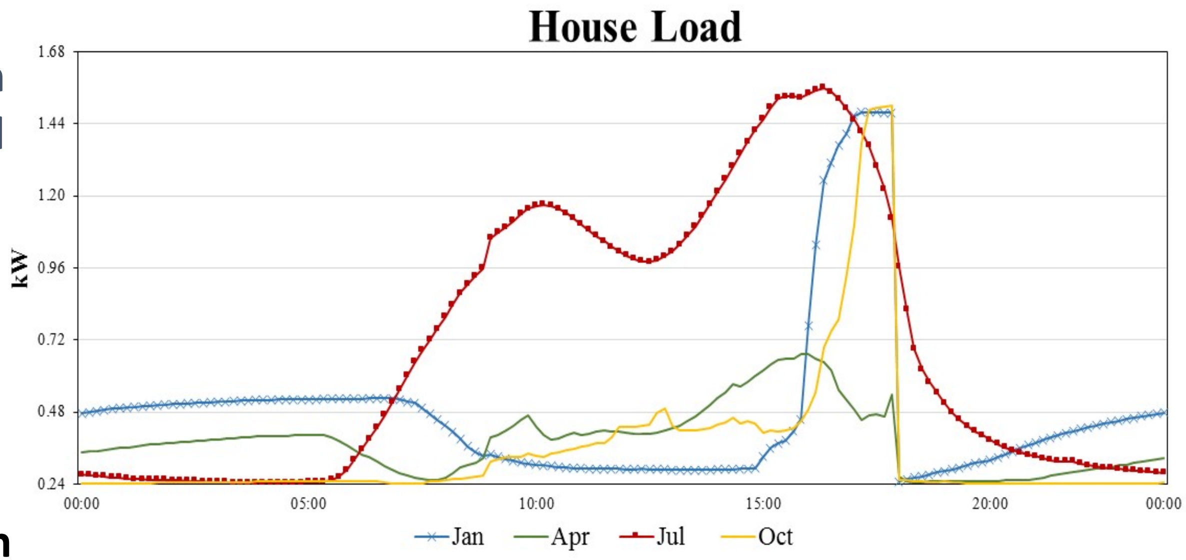


Free-floating middle season trend



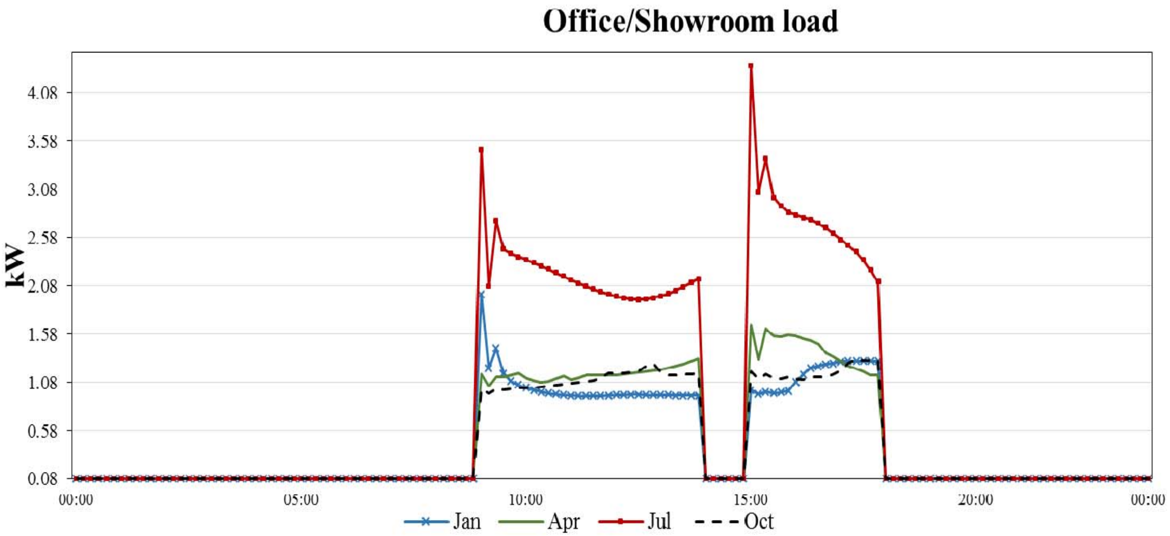
PV cooling, batteries and building demand

Calculation of load profile in the four months selected



Typical electrical loads are included (17 W/m 2), lighting installed power is 6.7 W/m 2 , controlled by an illuminance dimmering with a setpoint of 300 lux. The PV model has also been implemented in the Energy Plus environment by using the Equivalent One-Diode model

Extrapolation for an office/showroom load without nighttime air conditioning and creating a different load to compare



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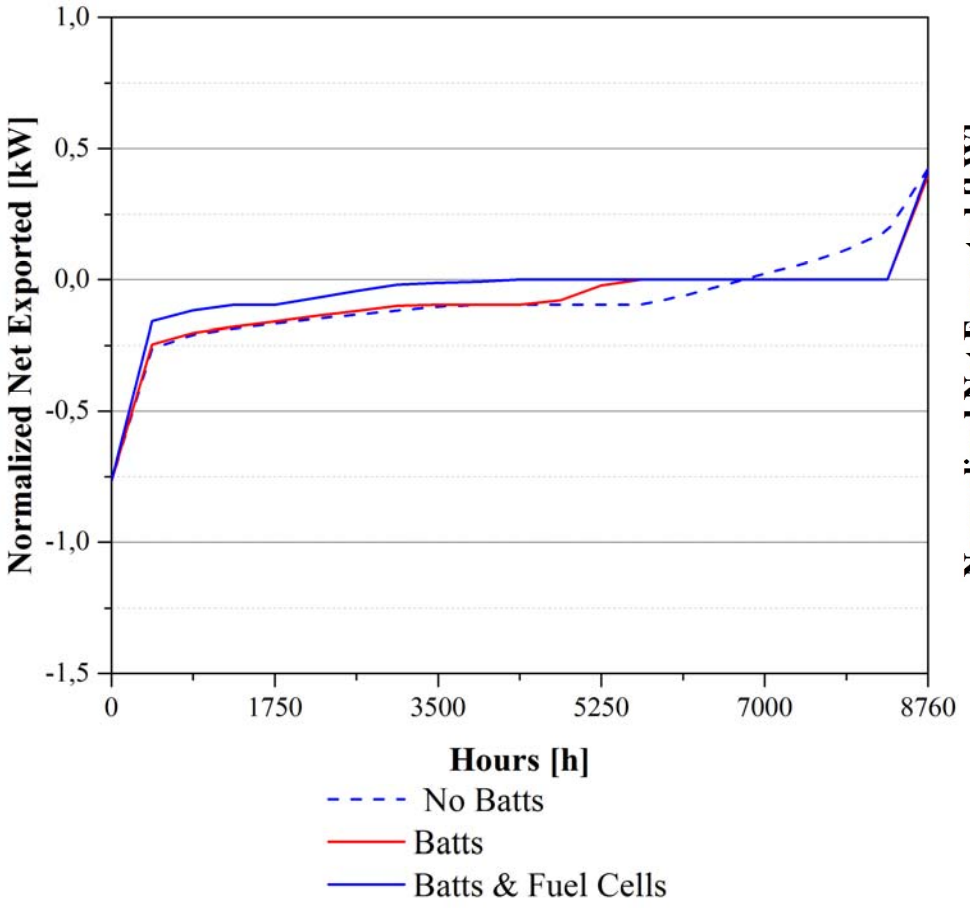
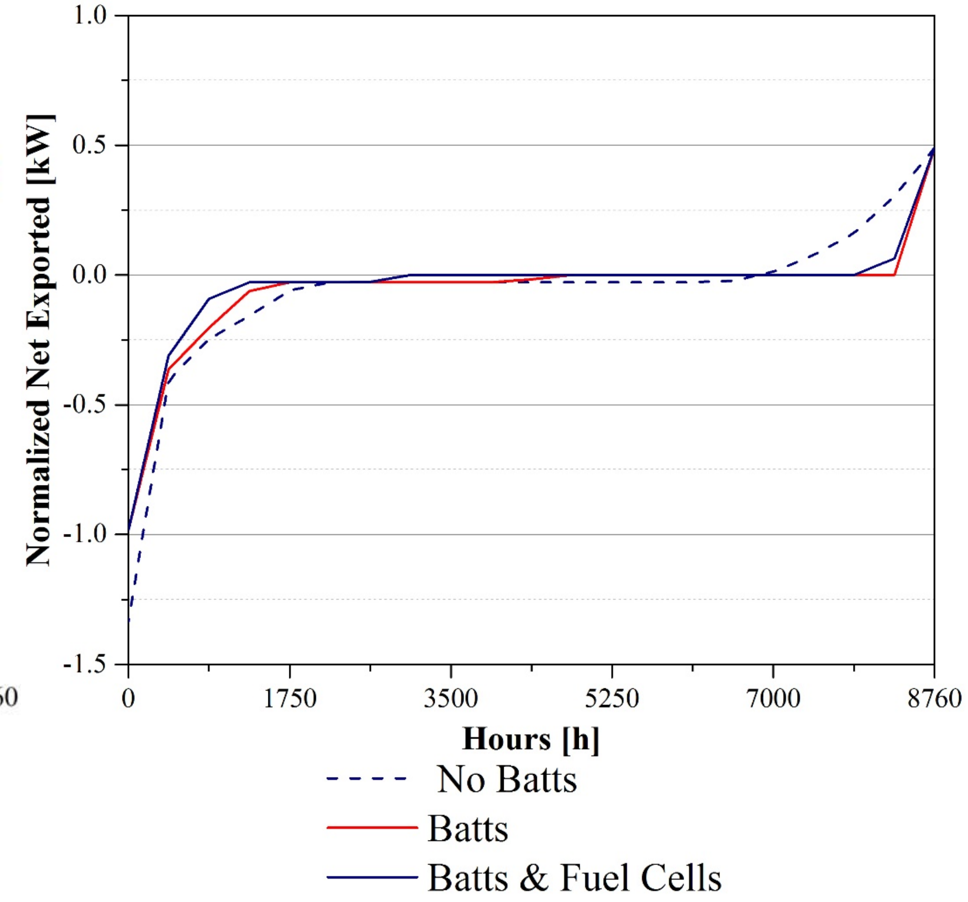
PV cooling, batteries and building demand

Net exported → $\overline{ne(t)} = \dfrac{ne(t)}{E_{des}}$

House load



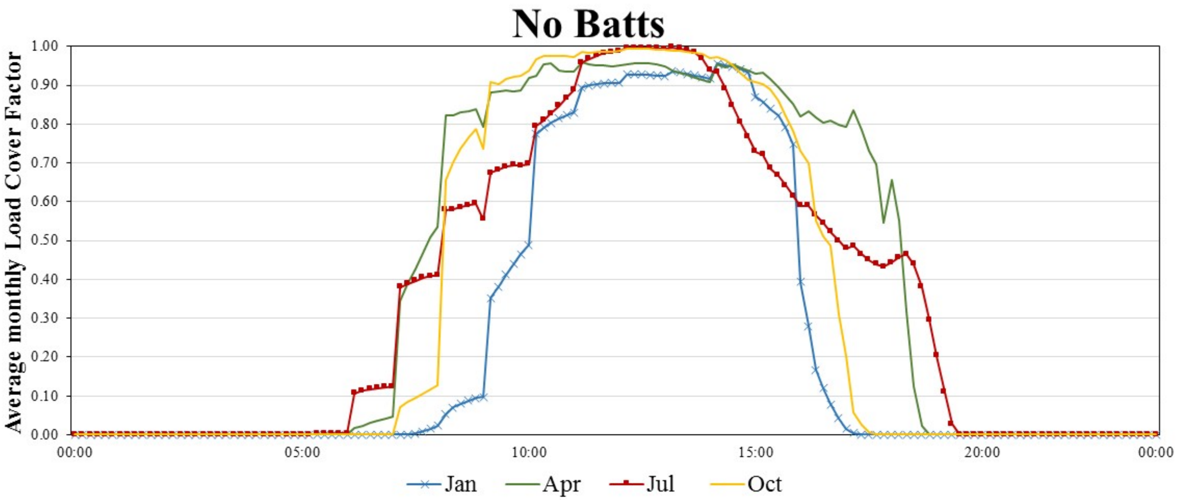
Office/Showroom

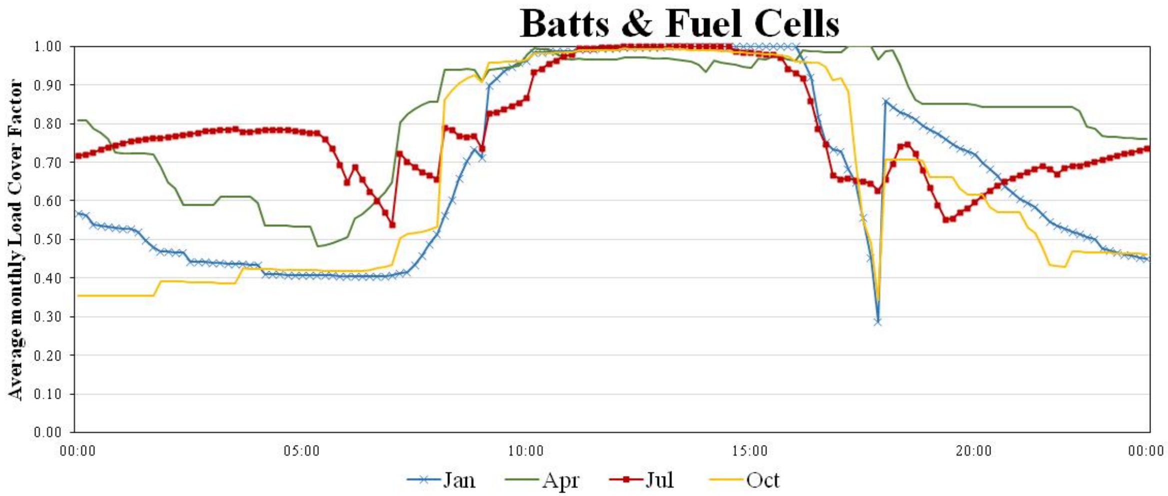


PV cooling, batteries and building demand

Load Cover Factor

House load





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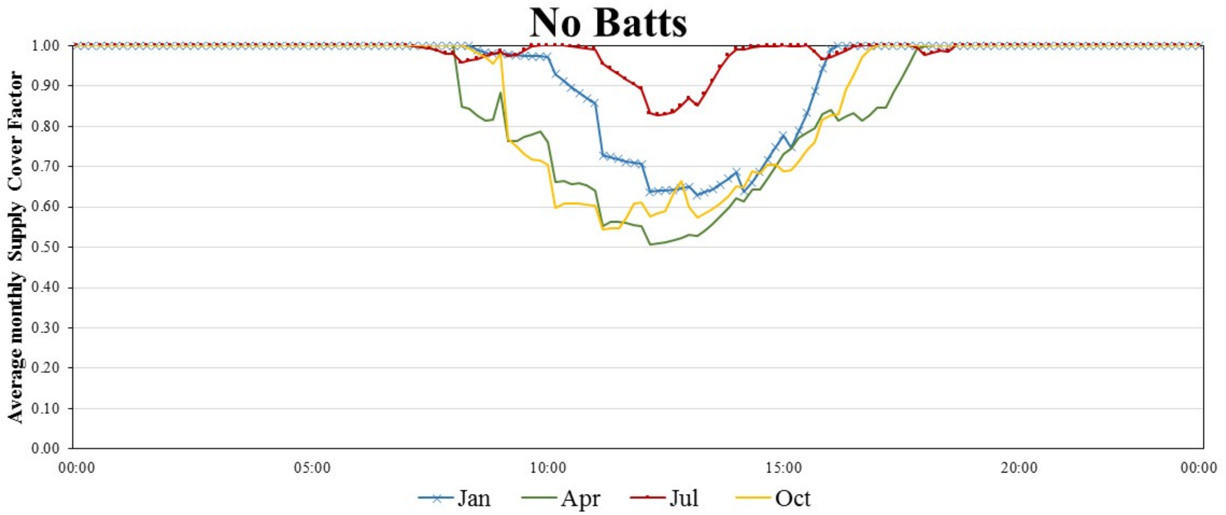
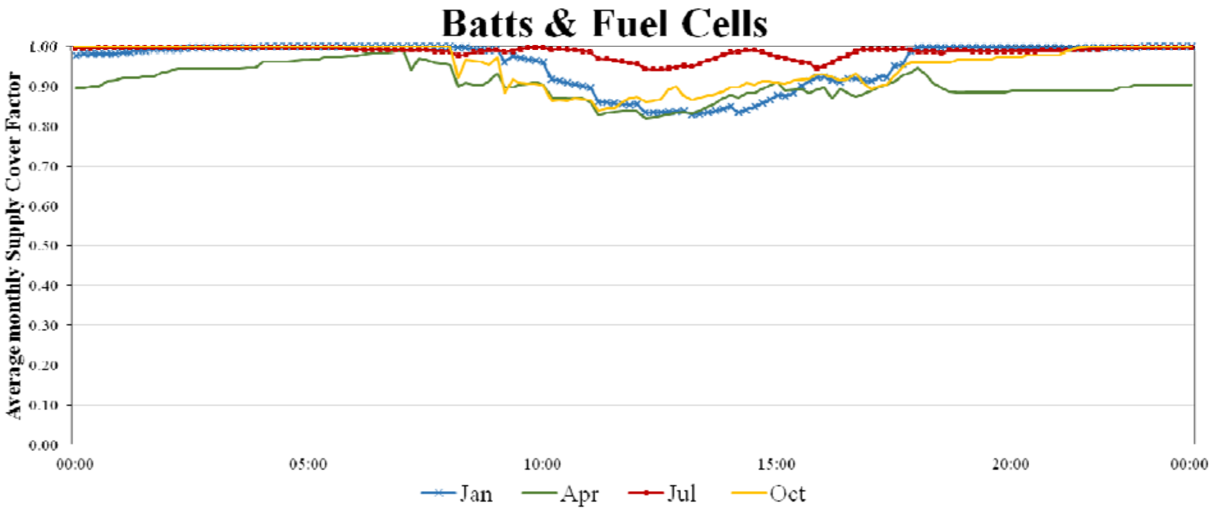
Supply Cover Factor

House load





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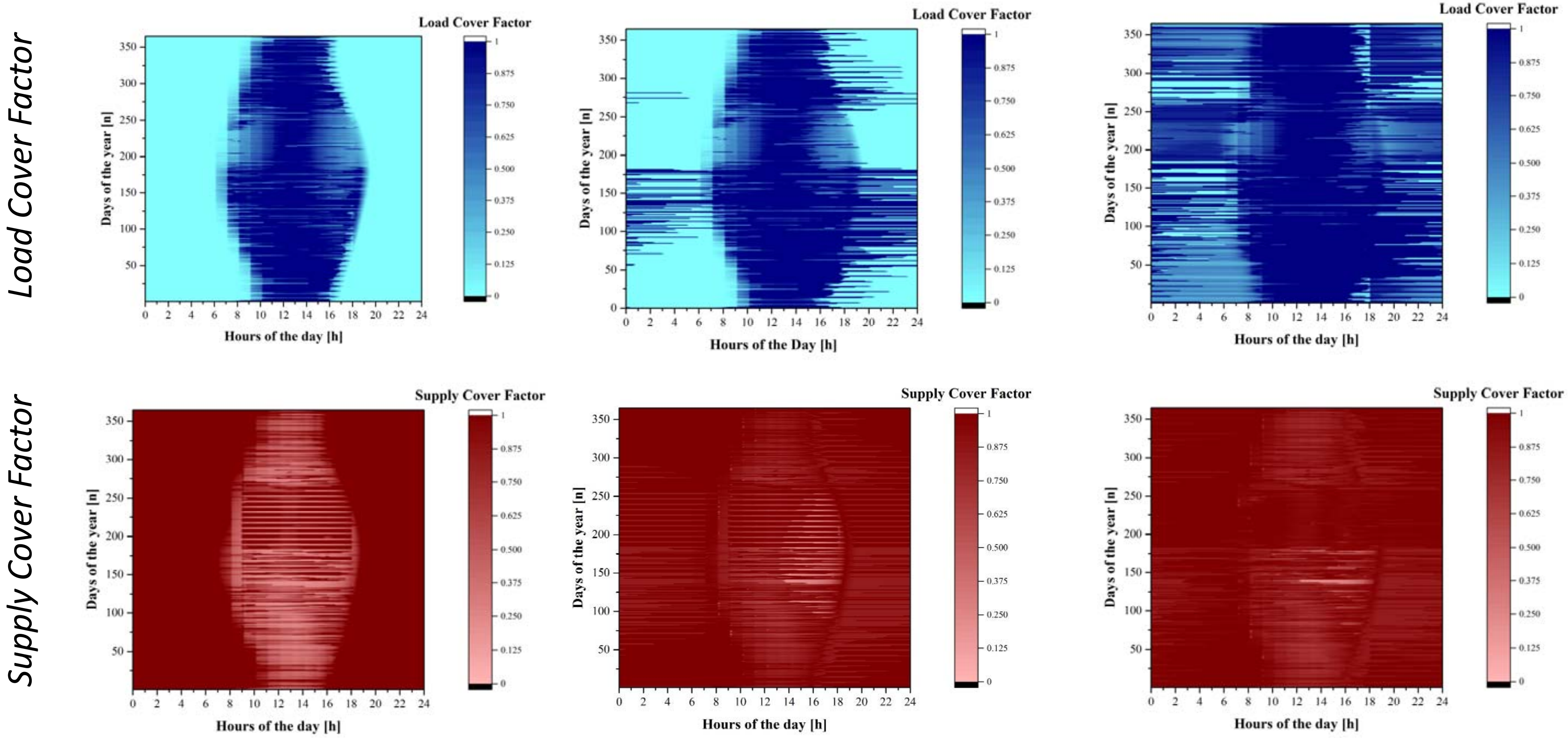
PV cooling and batteries

House load

Simulation over the whole of a year

No Batts | *Batts* | *Batts + Fuel Cell*



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PV cooling, batteries and building demand

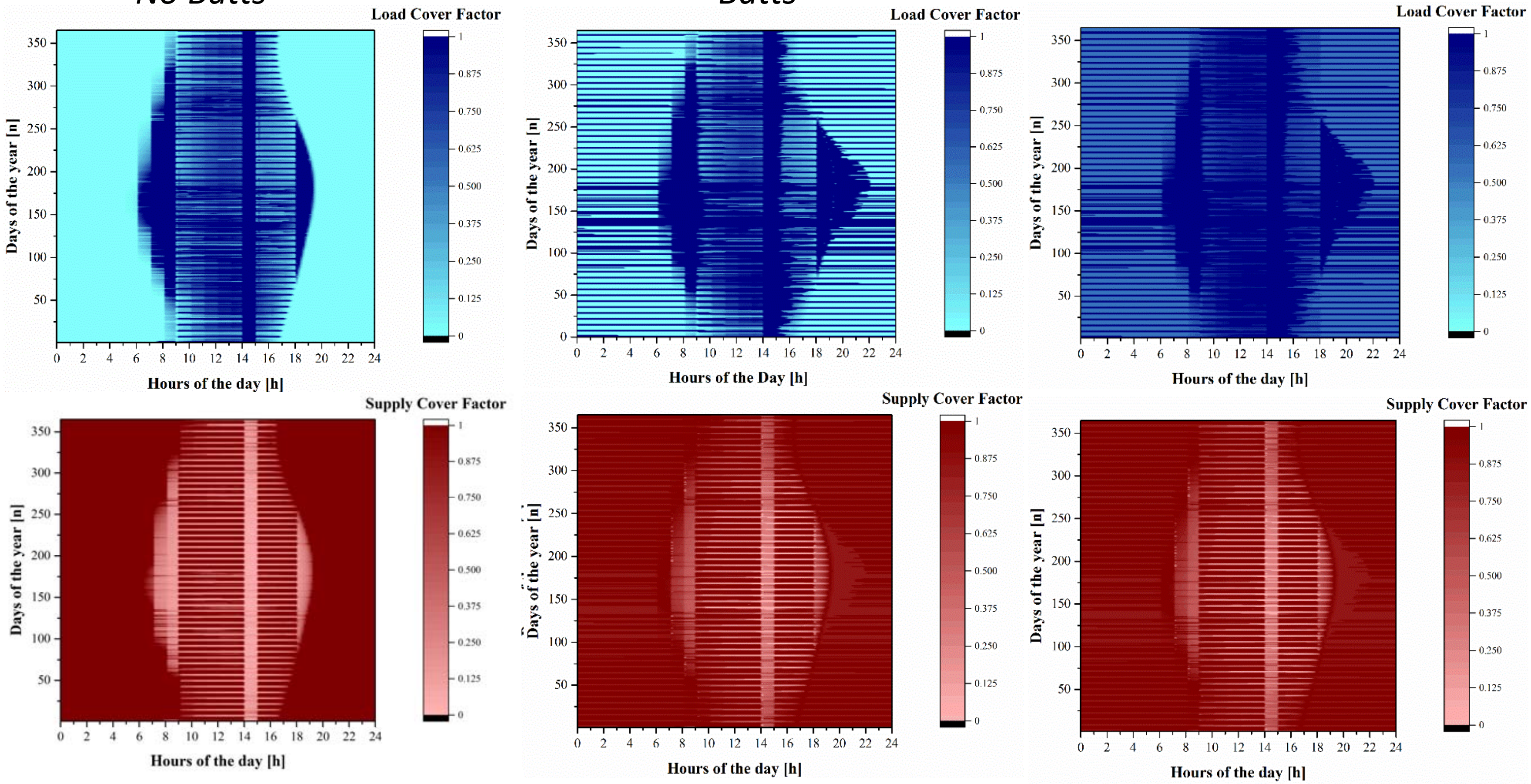
Office/Showroom load

Simulation over the whole of a year

No Batts | *Batts* | *Batts + Fuel Cell*

Load Cover Factor

Supply Cover Factor



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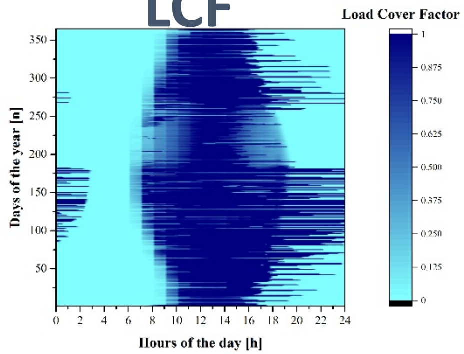
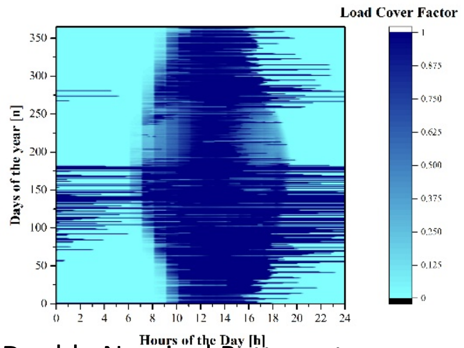
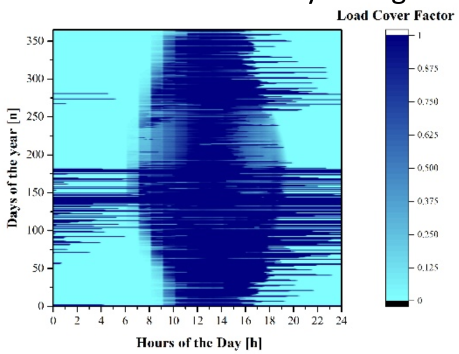
PV cooling, batteries and building demand

LCF



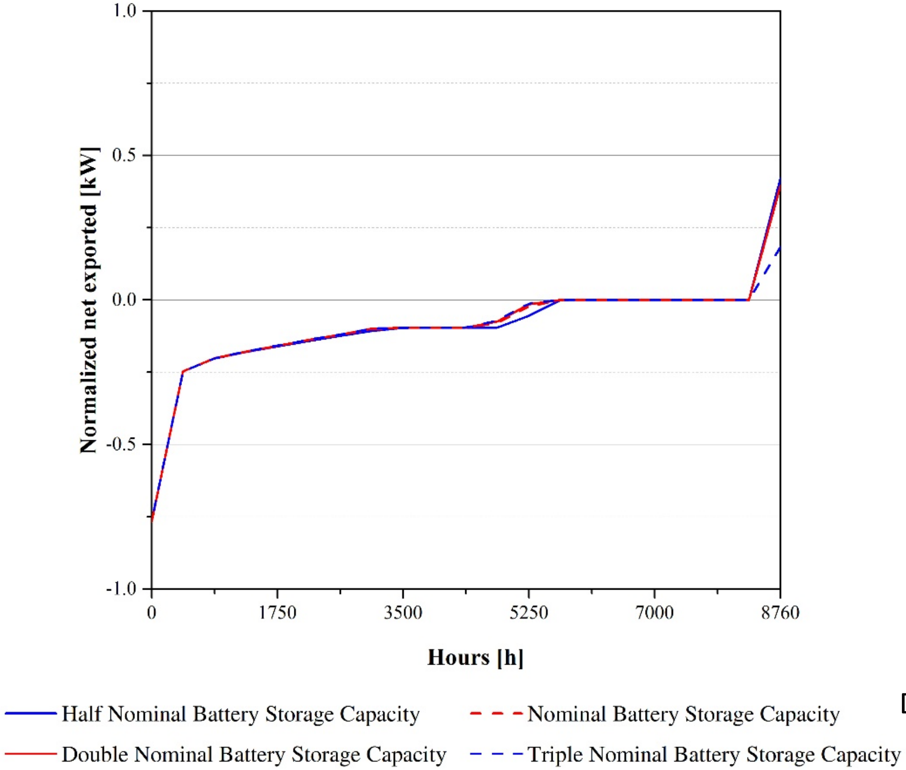


Double Nominal Battery storage



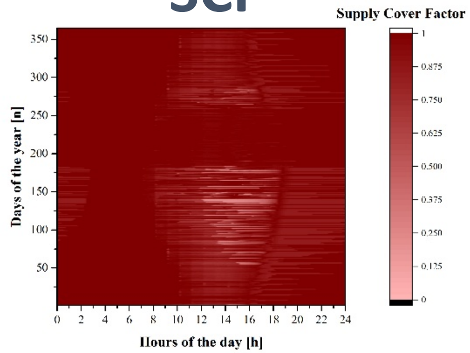
Triple Nominal Battery storage

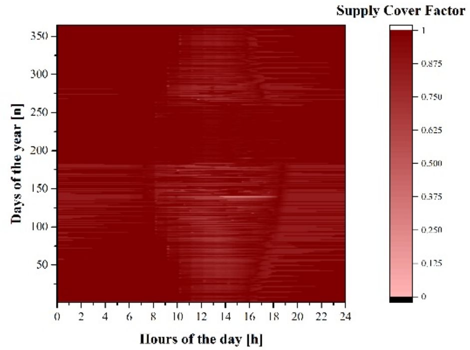
House load



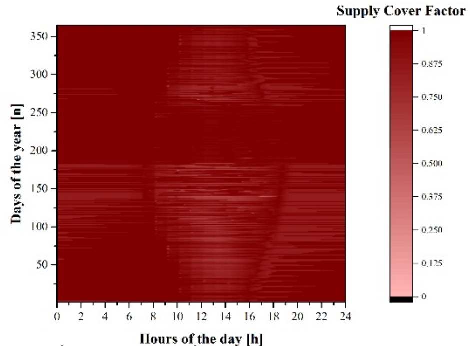
No big improvement from over sizing battery capacity!!

SCF





Double Nominal Battery storage



Triple Nominal Battery storage

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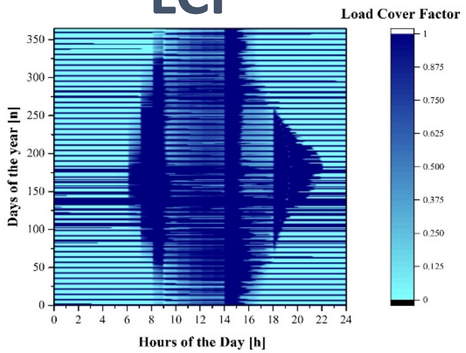
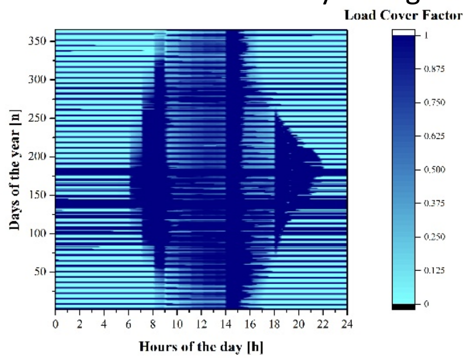
PV cooling and batteries

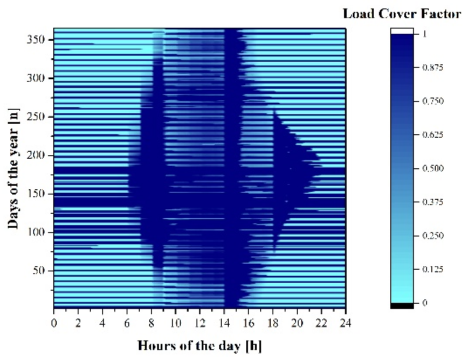
LCF



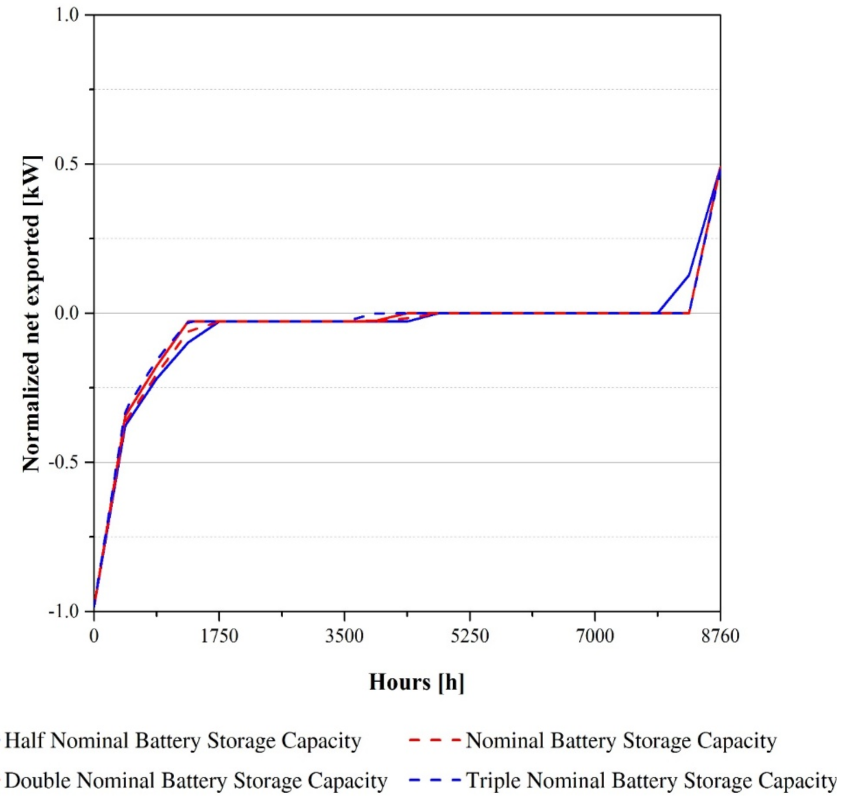
Double Nominal Battery storage



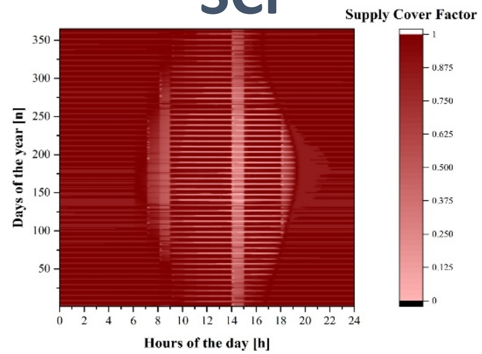
Triple Nominal Battery storage



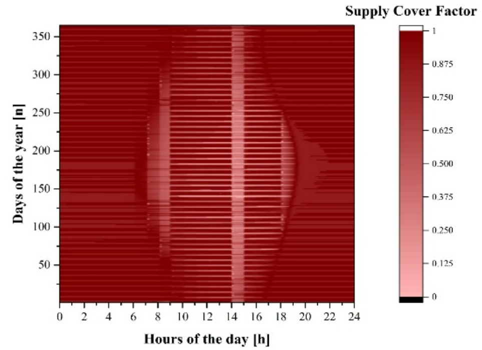
Office/showroom



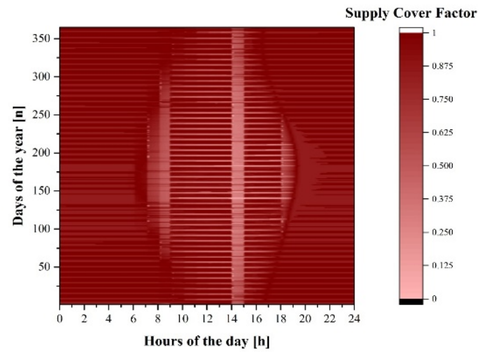
SCF



Double Nominal Battery storage



Triple Nominal Battery storage



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PV cooling and batteries

Conclusion:

- A method to determine and compare different batteries (chemistries) for PV heating/cooling evaluation was tested
- A powerfull instrument for sizing PV/STORAGE plant was developed also in evaluation for heating and cooling and building demand
- The tool is able to foresee the ability of the combined generation and storage to cover the load, minimizing the electricity exchange with the grid
- Next steps
  - ➢ Development of an economic model to support the current one in choosing the best compromise between costs and sizes of the batteries

Task 53 Workshop

"NEW GENERATION OF SOLAR COOLING AND HEATING SYSTEMS DRIVEN BY PHOTOVOLTAIC OR SOLAR THERMAL ENERGY"

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

SyS Working Group on engineering topics: M. Ferraro, L. Andaloro, G. Brunaccini, G. Dispenza, G. Napoli, D. Aloisio, N Randazzo, S. Di Novo, S. Micari and V. Antonucci

Speaker: Francesco Sergi
Researcher

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