SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Development of a low carbon coupling device for solar cooling (photovoltaic + heat pump)

Task 53

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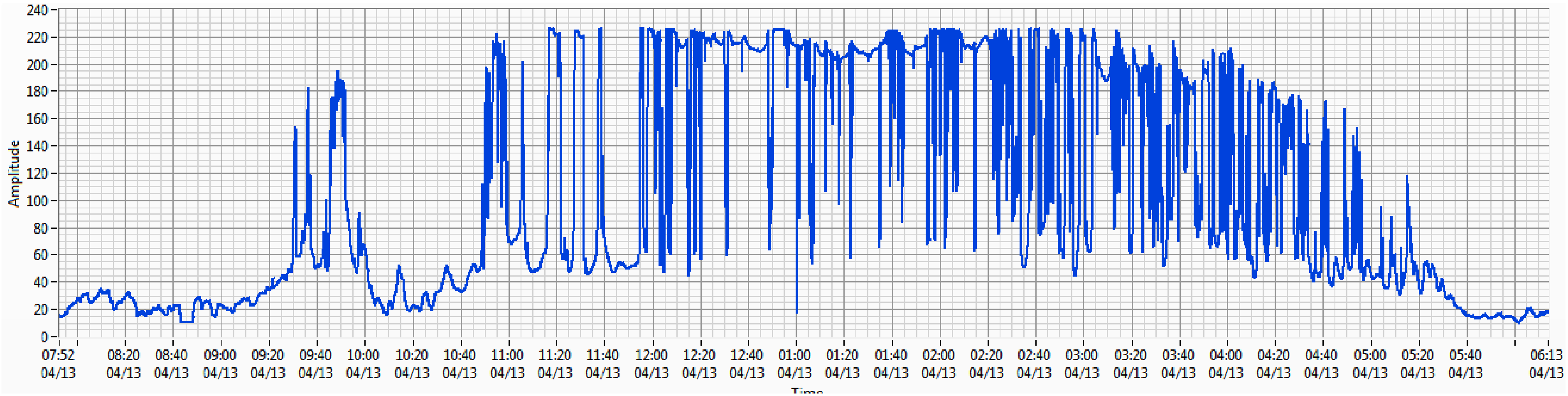
Goal of the project

- Produce cooling effect using low GWP* thermodynamic system **coupled to PhotoVoltaic** (PV) plant for driving, monitoring and supervision;
- Expect 80 % solar self sufficient;
- Monitor performances *«proof of the pudding is in the eating»*.

*GWP: Global Warming Potential (PROPANE ≃ 10)

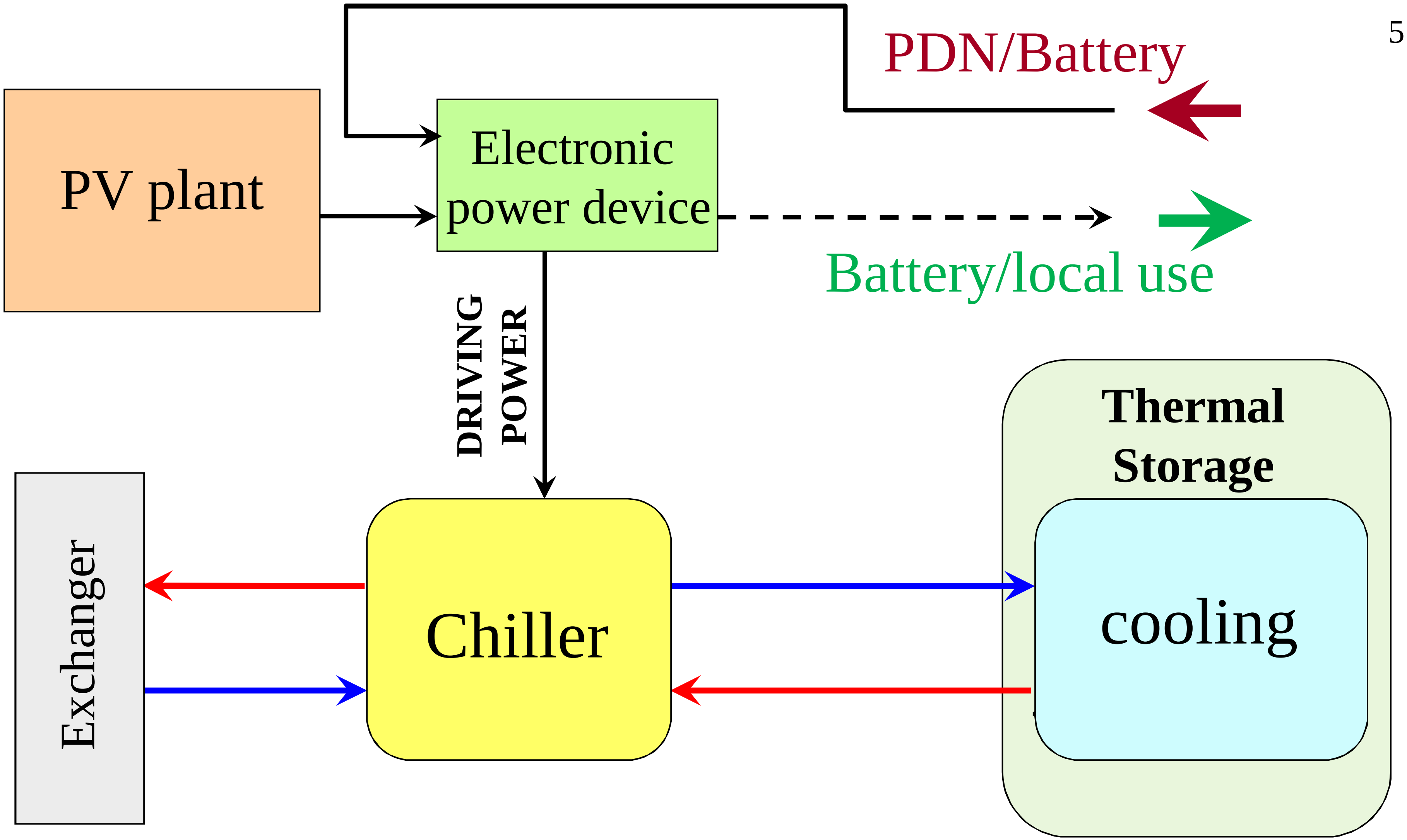
Journée du 13 Avril 2016 (TOULON)



Electric problem

Compressor power supply needs being secured by external reliable complement (PDN, battery storage, …)

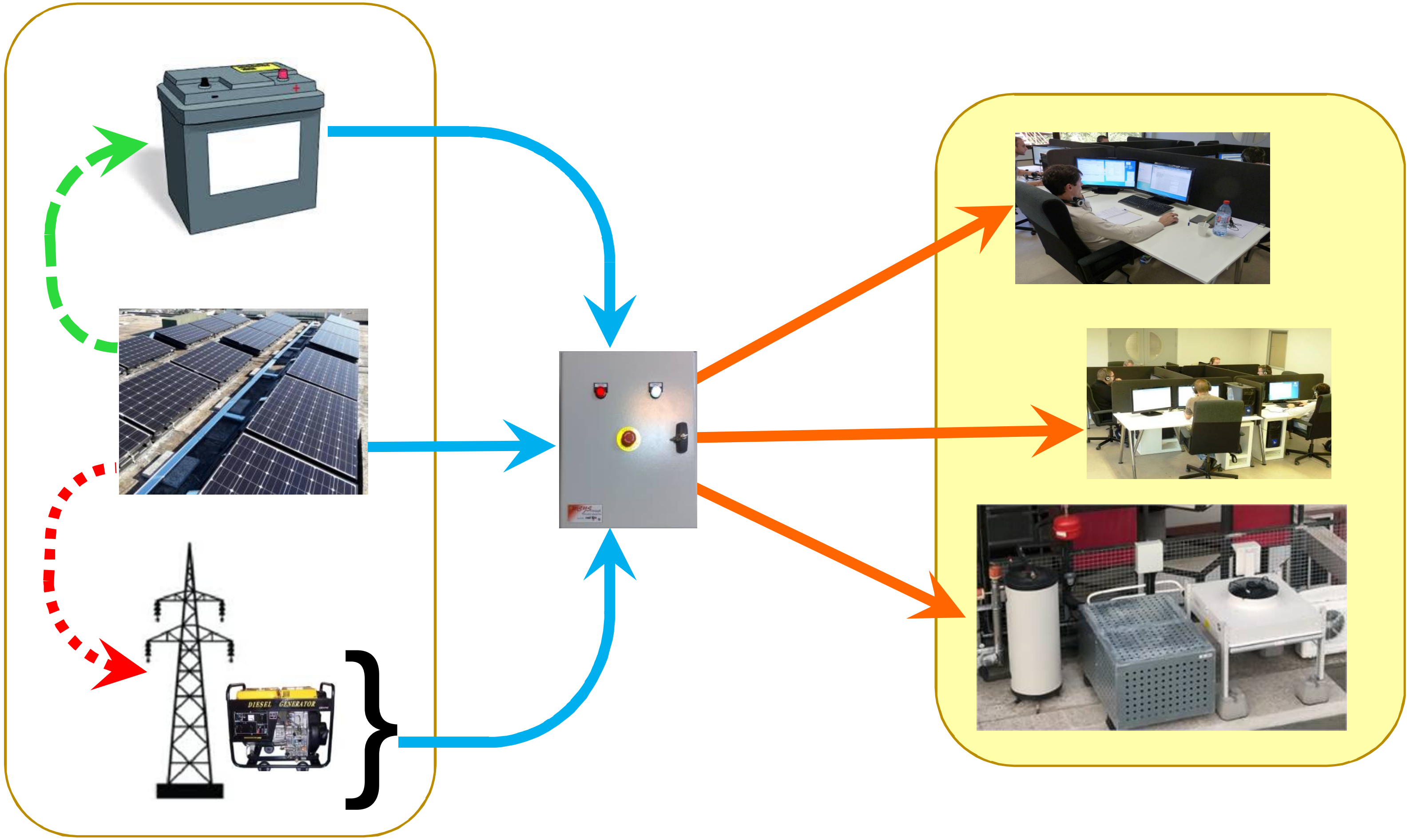
- Possible **power complement** provided by external supply (PDN, generator, battery …)
- PV **power excedent** is used for **thermal energy storage** or local inner use
- **power excedent** not injected to PDN because perturbations


PDN/Battery
PV plant
Electronic power device
Battery/local use
DRIVING POWER
Thermal Storage
Exchanger
Chiller
cooling

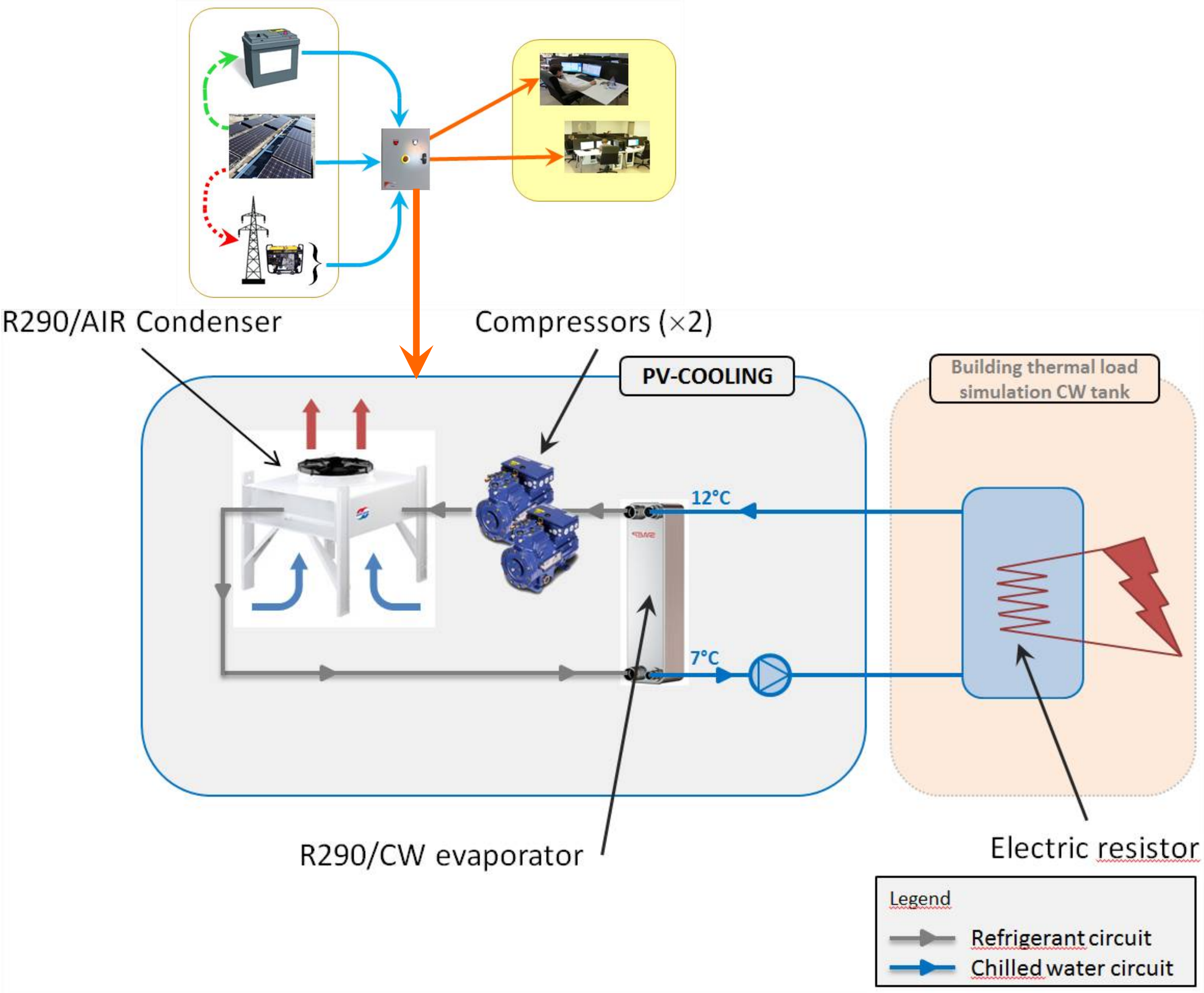
The thermal problem

- Define acceptable COP **chiller compressor working domain** (adjustable power)
- Analysis of **heat transfer fluid** regime for optimizing performances
- Storage and distribution **management**
- **Dimensioning** whole system

PV-COOLING power driving principle



PV-COOLING basic architecture



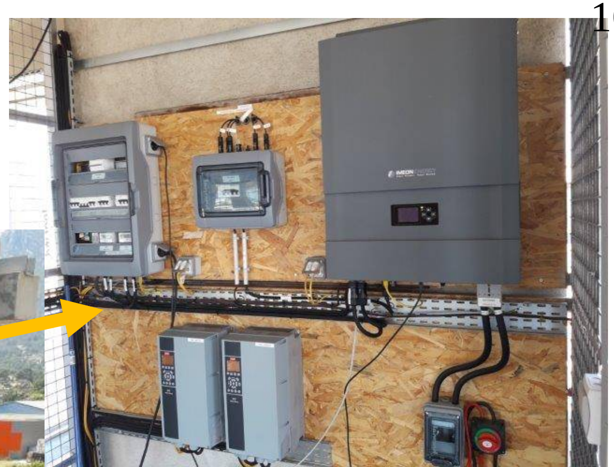
BUILDING THERMAL LOSS ESTIMATION (1)

$$P_{BuildLoad}(t) = G \times V \times \left[T_{ext}(t) - T_{set}(t)\right] + K \times S_{Build} P_{Sol.Ir}(t) * \delta(t-\tau)$$

- T_{ext} : outdoor temperature
- T_{set} : indoor setpoint temperature
- G : volume heat loss coefficient [W/m^3.°C] (G=2.5 - poorly insulated building)
- V : the cooled volume. V=325 m^3
- $P_{Sol.Ir}$: Power of solar irradiation [W/m^2]
- S_{build} : time average wall surface of building exposed to solar irradiation (40 m^2)
- K : solar power absorption sensitivity of building walls [$0 \leq K \leq 1$](0.20)
- $\delta(t-\tau)$: delay function - thermal inertia of building to solar irradiation (τ = 1 hour)

PV-COOLING main components

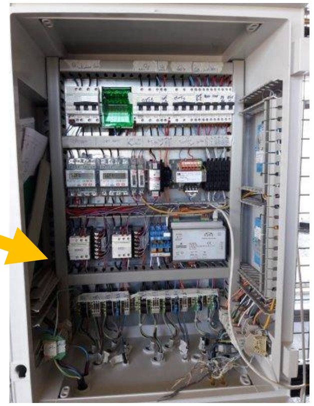
Armoire réchauffeur



Coffret électrique, Onduleur, Variateurs, parc batterie

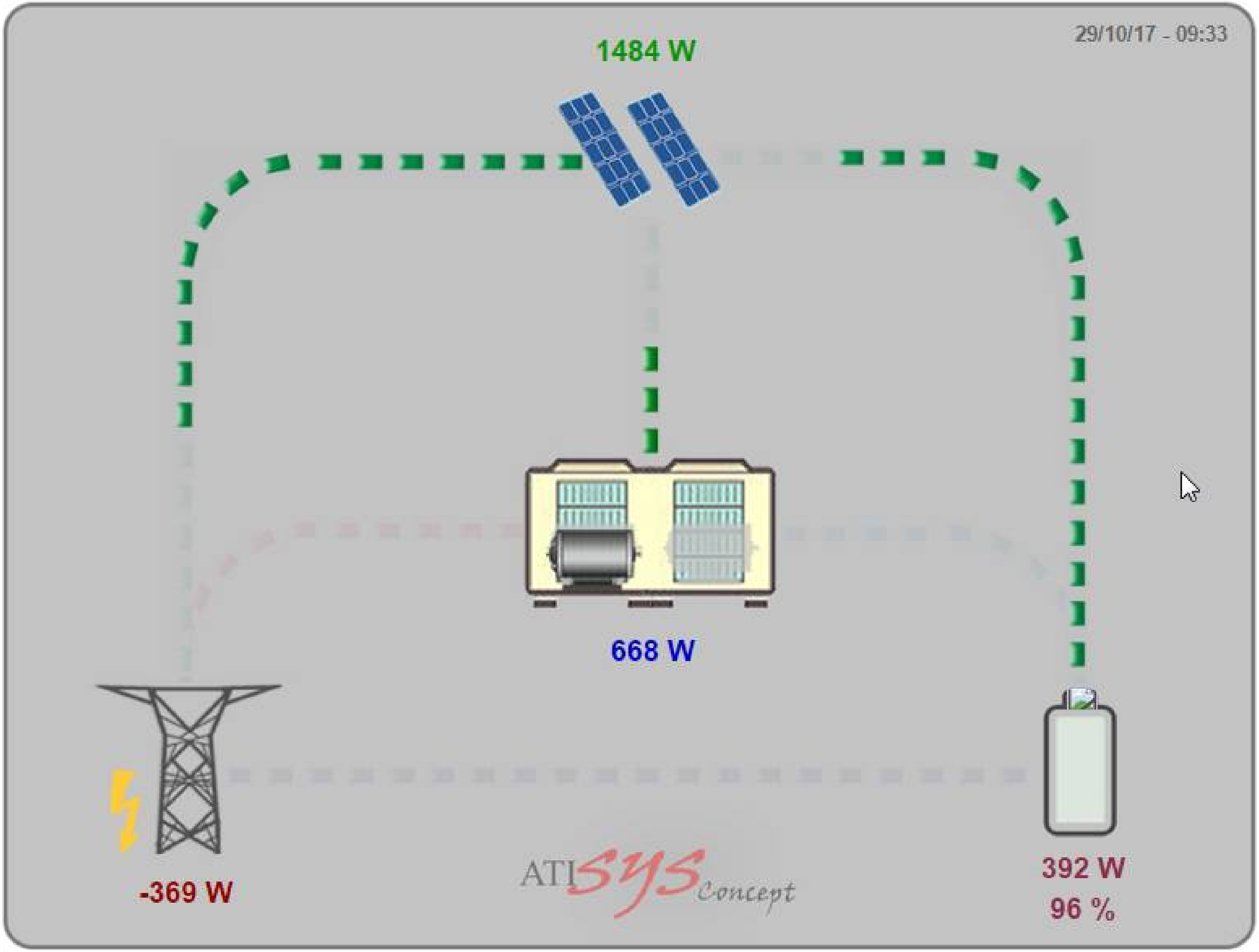
Coffret instrumentation

Champ PV



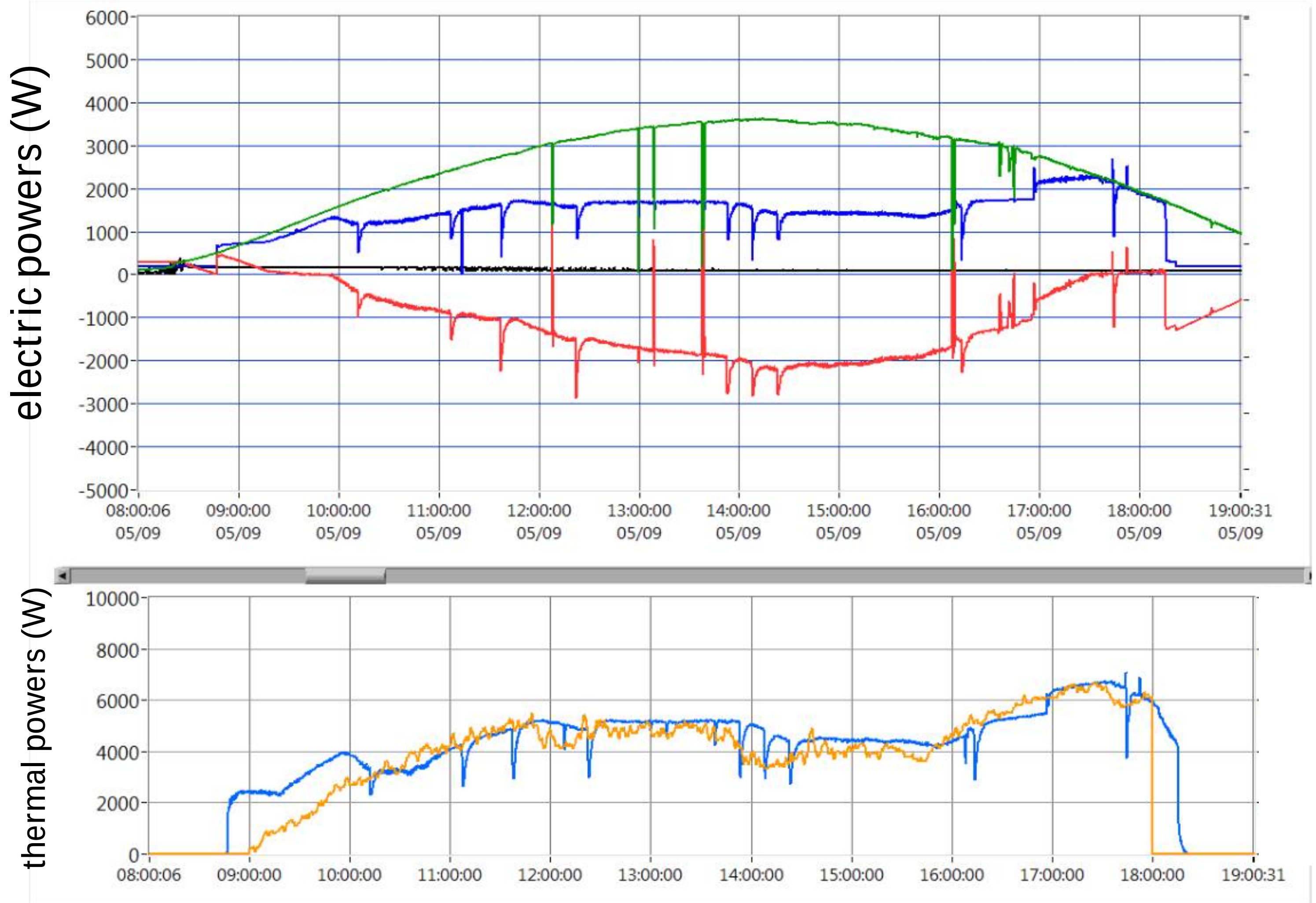
Armoire commande PV-COOLING

PV-COOLING real-time remote monitoring



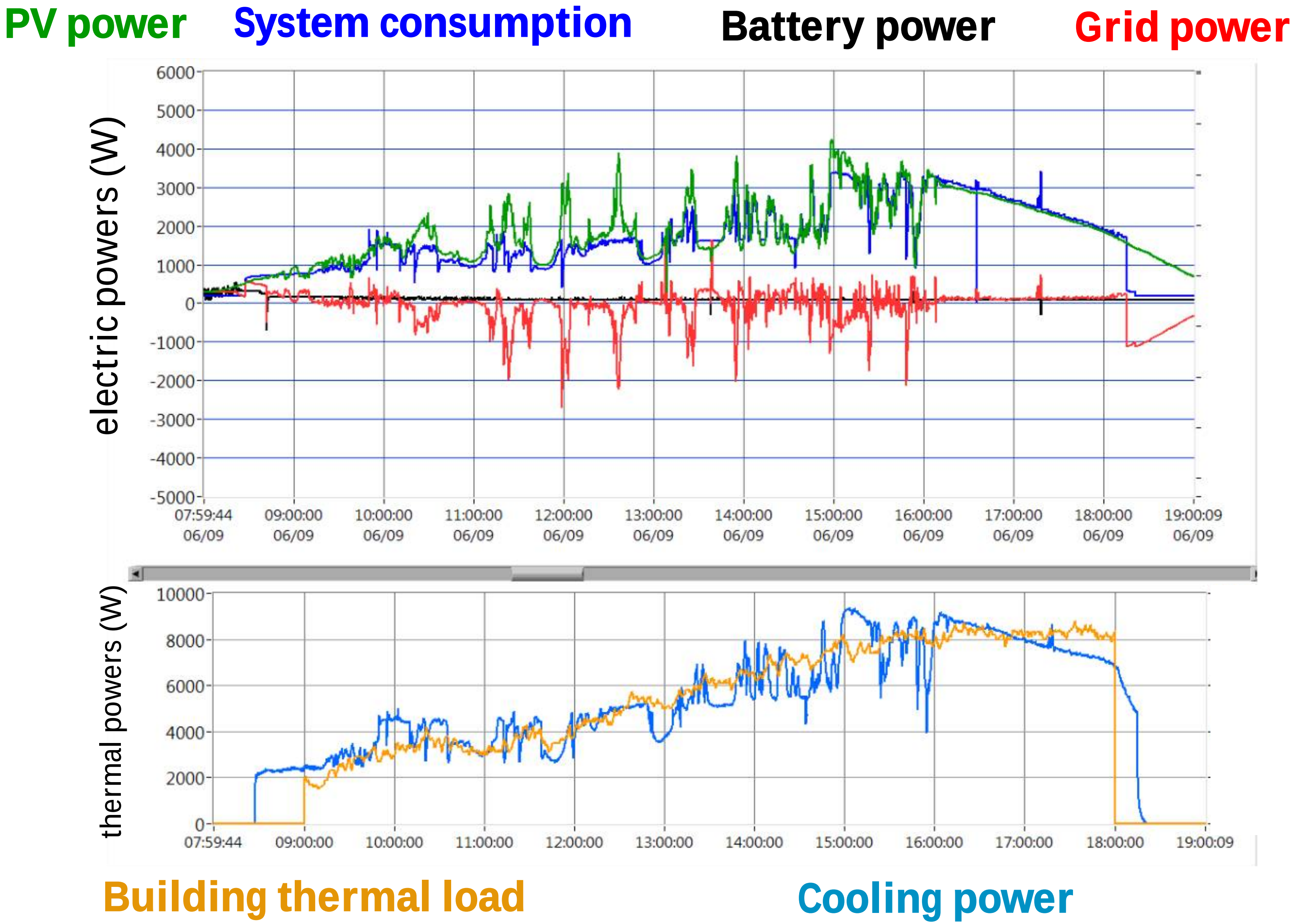
Sunny day – “eco” mode

PV power System consumption Battery power Grid power

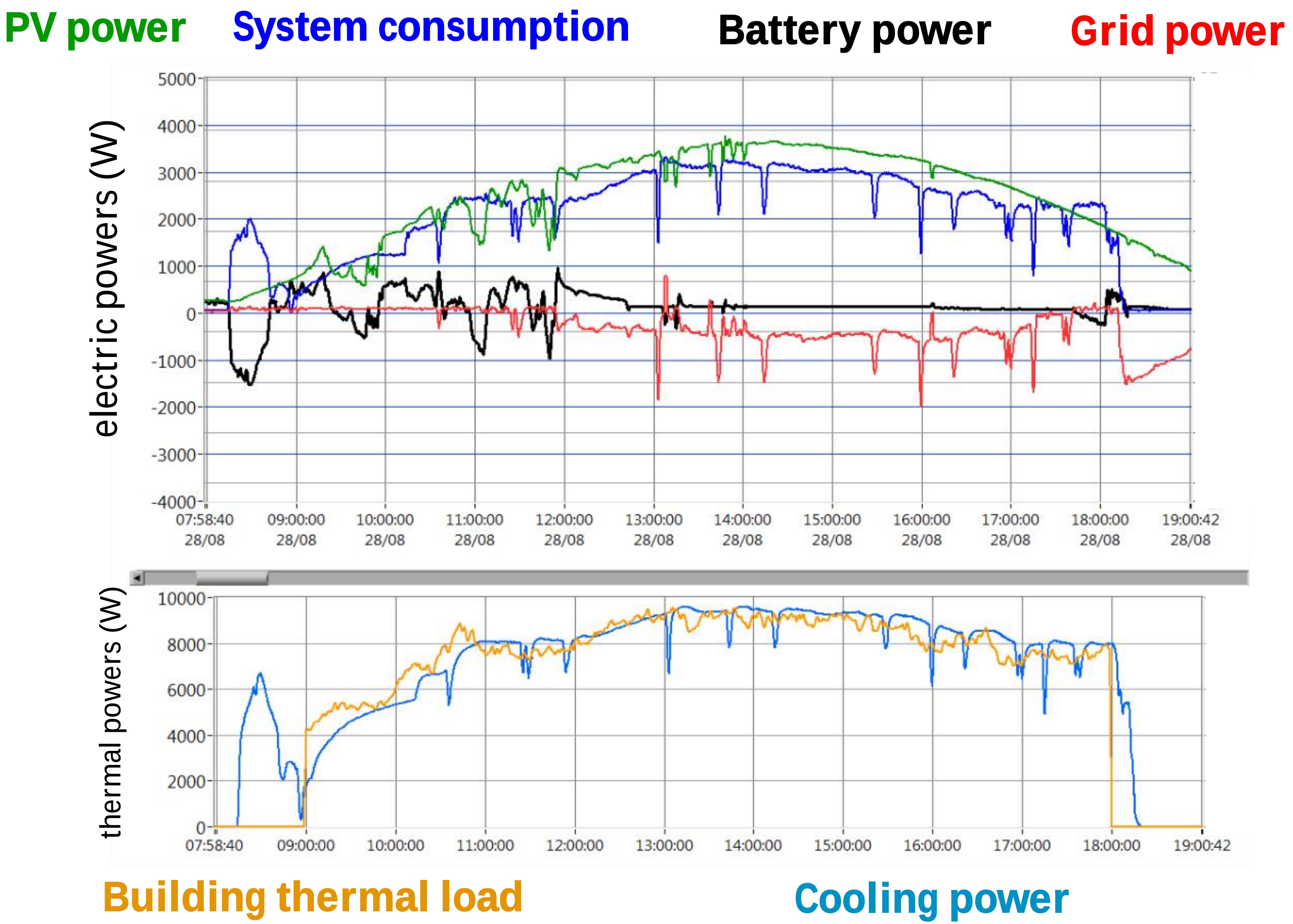


Building thermal load Cooling power

Disrupted sunny/cloudy day – "eco"

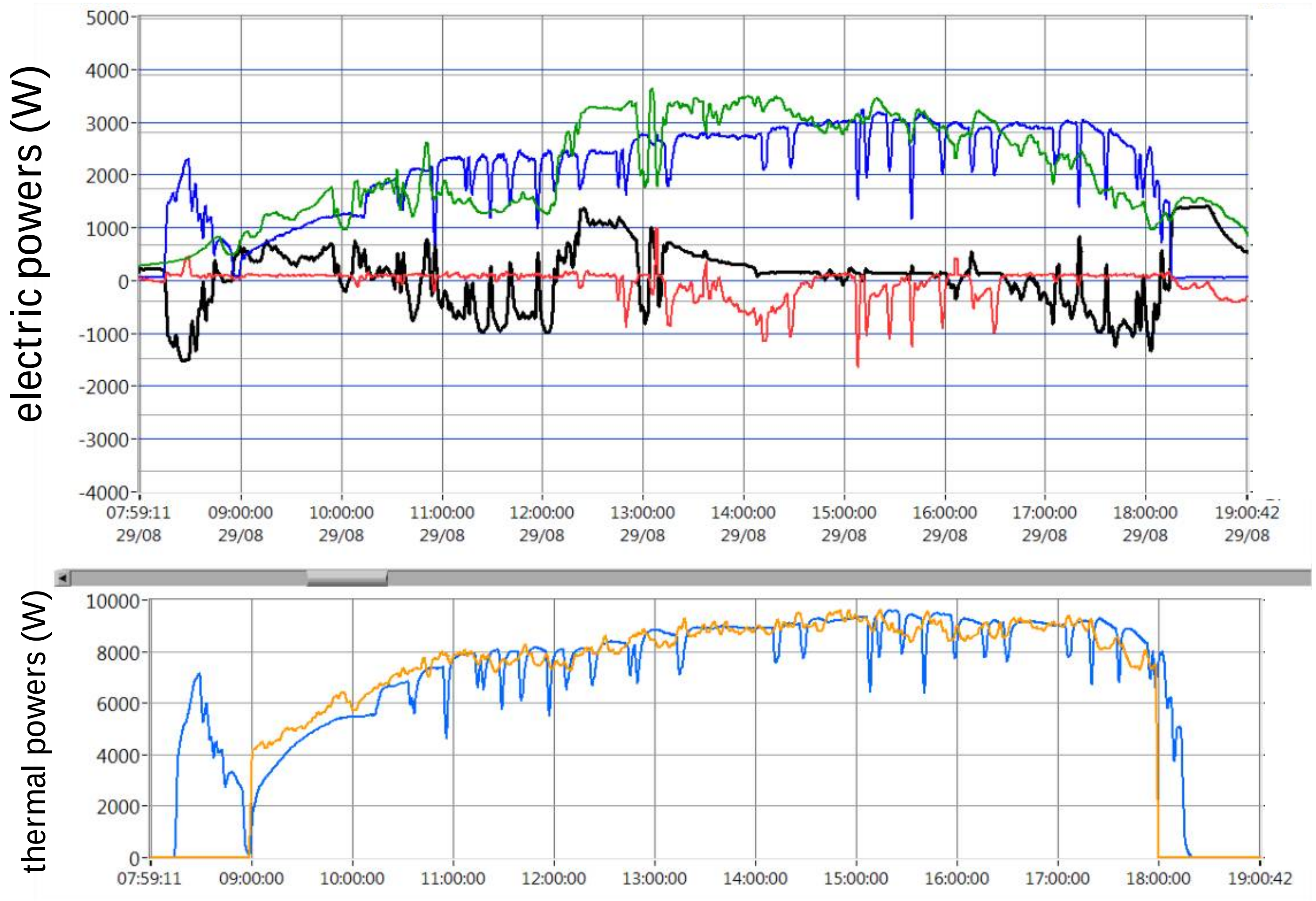


Sunny day – "comfort" mode



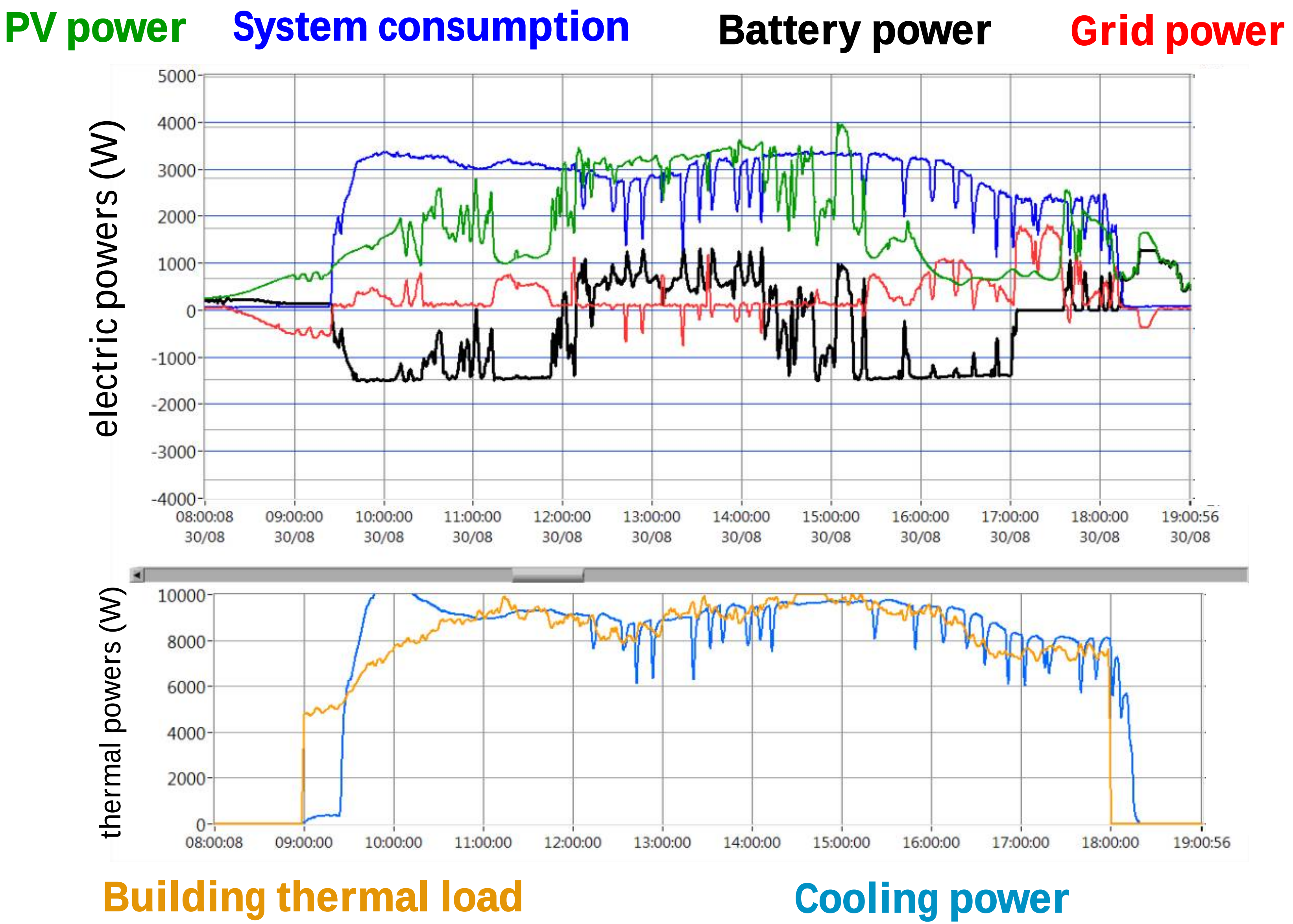
Disrupted sunny/cloudy day – "comfort"

PV power System consumption Battery power Grid power



Building thermal load Cooling power

Disrupted sunny/cloudy day – “comfort”



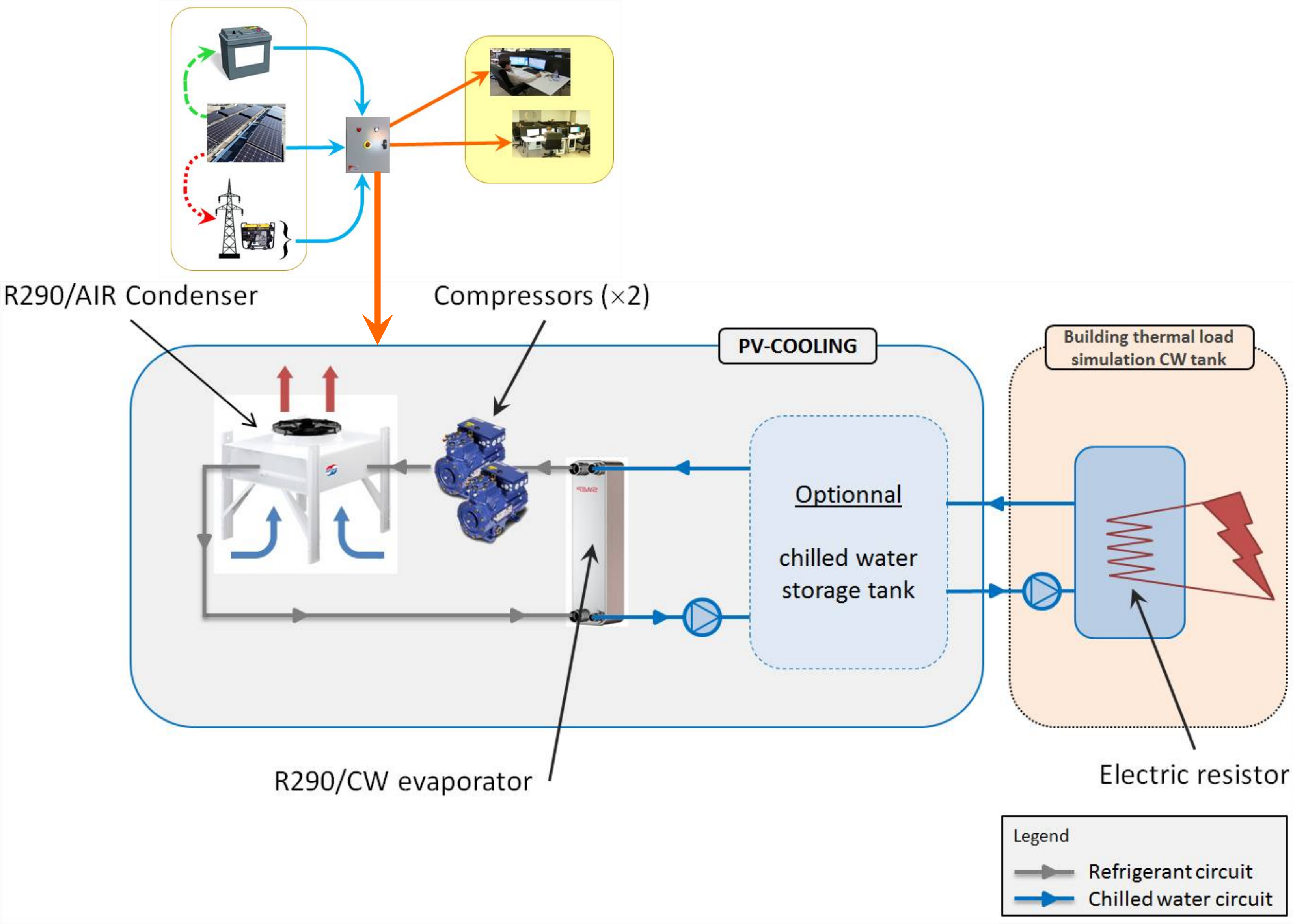
PV-COOLING – SYNTHESIS OF DATA

	"ECO" mode		"COMFORT" mode		
data	**sept 5th**	**sept 6th**	**Aug. 8th**	**Aug. 29th**	**Aug. th**
overall electric PV-COOLING consumption (kWh)	14,52	17,87	22,62	22,22	25,24
PV-COOLING PV consumption (kWh)	14,11	16,64	21,29	19,26	15,95
PV energy production (kWh)	26,56	19,94	25,88	22,94	18,72
Battery consumption (kWh)	0,00	0,01	0,87	2,18	6,13
Grid consumption (kWh)	0,40	1,22	0,47	0,78	3,15
building thermal load (kWh)	38,64	51,74	71,15	72,04	75,99
Cooling production (kWh)	43,03	53,87	75,46	75,14	77,89
Compressor COP	**3,40**	**3,36**	**2,91**	**2,96**	**2,82**
PV-COOLING COP	2,96	3,02	2,72	2,76	2,64
PV-COOLING EER (Q_{th}/Q_{grid})	**106,34**	**44,11**	**161,93**	**95,82**	**24,71**

CONCLUSION

- possible to **combine photovoltaic (PV) power plant to drive vapor compression thermodynamic system** for the sake of producing cooling energy ;
- **Securing PV** plant with external power supply to drive thermodynamic system was successfully demonstrated ;
- Part of **efficiency results in** possibility to **real-time adapting cooling power to solar irradiation** ;
- EER obtained values shows that only **a limited amount of grid supply** is necessary
- Proper management permits one to consider **fully autonomous systems** disconnected from grid ;

PV-COOLING architecture (with optionnal thermal storage)



CONCLUSION

- **investigate** clever ways of **using PV excessive power:**
  - cold storage ,
  - electric storage
  - compare which is better to improve autonomy of PV-COOLING.

- Eventually, PV-COOLING concept open wide perspective for **insulated areas** and may constitute a **tool for land-use planning**, and especially in the **developing world**.

Thank you for attention

Video : http://pvcooling.atisys.fr/video.php

Real-time display : http://pvcooling.atisys.fr/

BUILDING THERMAL LOSS ESTIMATION (2)

$$P_{BuildLoad}(t) = \Delta T(t) \times \sum_i (Cp.V_i.\rho + D_i) + P_S.\sum_i S_i.K_i * \delta(t - \tau_i)$$

- ΔT : $\Delta T = (T_{ext} - T_{set})$ (outdoor temperature - indoor setpoint temperature
- i : index associated to each building element "i"
- D_i : volume heat loss coefficient [W/m^3.°C]
- V_i : the cooled volume; $\Sigma V_i = 325\ m^3$
- P_S : Power of solar irradiation [W/m^2]
- S_i : time average wall surface of building element "i" exposed to solar irradiation ($\Sigma S_i = 40\ m^2$)"
- K_i : solar power absorption sensitivity of building walls [$0 \leq K \leq 1$](0.20)
- $\delta(t-\tau_i)$: delay function - thermal inertia of building to solar irradiation ($\tau = 1$ hour)

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