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

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Abu Dhabi, October 29th – November 2nd 2017
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
PV plant

Electronic power device

DRIVING POWER

Exchanger

Chiller

Thermal Storage

cooling

PDN/Battery

Battery/local use
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)

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

- \( T_{\text{ext}} \): outdoor temperature
- \( T_{\text{set}} \): indoor setpoint temperature
- \( G \): volume heat loss coefficient \([\text{W/m}^3.\text{°C}]\) (\(G=2.5\) - poorly insulated building)
- \( V \): the cooled volume. \(V=325\ \text{m}^3\)
- \( P_{\text{Sol.Ir}} \): Power of solar irradiation \([\text{W/m}^2]\)
- \( S_{\text{build}} \): time average wall surface of building exposed to solar irradiation (40 \(\text{m}^2\))
- \( K \): 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 (\(\tau = 1\ \text{hour}\))
PV-COOLING main components

- Armoire réchauffeur
- Coffret instrumentation
- Champ PV
- Coffret électrique, Onduleur, Variateurs, parc batterie
- 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”

- PV power
- System consumption
- Battery power
- Grid power

**Electric powers (W)**

**Thermal powers (W)**

**Building thermal load**

**Cooling power**
Sunny day – “comfort” mode

PV power  System consumption  Battery power  Grid power

Building thermal load  Cooling power
Disrupted sunny/cloudy day – “comfort”

PV power  System consumption  Battery power  Grid power
Disrupted sunny/cloudy day – “comfort”

PV power  System consumption  Battery power  Grid power

Building thermal load  Cooling power
### PV-COOLING – SYNTHESIS OF DATA

<table>
<thead>
<tr>
<th>data</th>
<th>&quot;ECO&quot; mode</th>
<th>&quot;COMFORT&quot; mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>sept 5th</td>
<td>sept 6th</td>
</tr>
<tr>
<td>overall electric PV-COOLING consumption (kWh)</td>
<td>14,52</td>
<td>17,87</td>
</tr>
<tr>
<td>PV-COOLING PV consumption (kWh)</td>
<td>14,11</td>
<td>16,64</td>
</tr>
<tr>
<td>PV energy production (kWh)</td>
<td>26,56</td>
<td>19,94</td>
</tr>
<tr>
<td>Battery consumption (kWh)</td>
<td>0,00</td>
<td>0,01</td>
</tr>
<tr>
<td>Grid consumption (kWh)</td>
<td>0,40</td>
<td>1,22</td>
</tr>
<tr>
<td>building thermal load (kWh)</td>
<td>38,64</td>
<td>51,74</td>
</tr>
<tr>
<td>Cooling production (kWh)</td>
<td>43,03</td>
<td>53,87</td>
</tr>
<tr>
<td>Compressor COP</td>
<td>3,40</td>
<td>3,36</td>
</tr>
<tr>
<td>PV-COOLING COP</td>
<td>2,96</td>
<td>3,02</td>
</tr>
<tr>
<td>PV-COOLING EER (Q_{th}/Q_{grid})</td>
<td>106,34</td>
<td>44,11</td>
</tr>
</tbody>
</table>
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 optional thermal storage)

R290/AIR Condenser → Compressors (×2) → PV-COOlING → Optionnal chilled water storage tank → Electric resistor

Legend:
- Refrigerant circuit
- Chilled water circuit
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)

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

- \( \Delta T \): \( \Delta T = (T_{ext} - T_{set}) \) (outdoor temperature - indoor setpoint temperature)
- \( i \): index associated to each building element “i”
- \( D_i \): volume heat loss coefficient \([\text{W/m}^3.\degree\text{C}]\)
- \( V_i \): the cooled volume; \( \Sigma V_i = 325 \text{ m}^3 \)
- \( P_S \): Power of solar irradiation \([\text{W/m}^2]\)
- \( S_i \): time average wall surface of building element “i” exposed to solar irradiation \((\Sigma S_i = 40 \text{ m}^2)\)”
- \( K_i \): 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 \((\tau = 1 \text{ hour})\)