Green infrastructure: green roofs and green facades as passive systems for energy savings

Jornada Tècnica. Selecció d’espècies, maneig de l’aigua i eficiència energètica en cobertes i façanes verdes
IRTA Torre Marimon, Caldes de Montbui. 13 Novembre 2015

Dr. Gabriel Pérez
Phd. Julià Coma
Prof. Luisa F. Cabeza
Contents

• Introduction
• Parameters
• Green roofs
  – Puigverd
  – Gardeny
  – Thermal improvement
  – LCA
• Green facades
  – Golmés
  – Puigverd
• Future work
Contents

• Introduction
• Parameters
• Green roofs
  - Puigverd
  - Gardeny
  - Thermal improvement
  - LCA
• Green facades
  - Golmés
  - Puigverd
• Future work
Introduction

- **Green facades and green roofs** are known as **sustainable construction systems** that offers interesting **environmental advantages** over traditional solutions.
  - improve the durability of roof waterproofing materials
  - reduction rain water runoff
  - etc
  - contributes to the **energy savings**
Introduction

• But the good operation of these **green solutions as passive systems for energy savings** depends on different aspects:
  - The **typology system**. There are different green roof and green facades systems available in the market.
  - The **species behaviour** in local weather conditions.
  - Others.

• Thus, the main objective of this study is:
  - to study the **energy consumption** of **extensive green roofs** and **green facades** in **Mediterranean continental climate** in controlled conditions.

• A secondary objective is
  - the study and design of new construction solutions according to a more **sustainable approach**.
Contents

• Introduction
• Parameters
• Green roofs
  – Puigverd
  – Gardeny
  – Thermal improvement
  – LCA
• Green facades
  – Golmés
  – Puigverd
• Future work
Parameters that influence in the behaviour of the green roofs and green facades as passive energy-saving systems

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Thermal insulation and storage</th>
<th>Interception of solar radiation. Shade</th>
<th>Evaporative cooling</th>
<th>Variation of the effect of wind on the building</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Green roofs</strong></td>
<td>LAI: leaf area index</td>
<td>LAI: leaf area index</td>
<td>Type of plant</td>
<td>Foliage density and penetration</td>
</tr>
<tr>
<td></td>
<td>Angle of the foliage</td>
<td></td>
<td>Exhibition</td>
<td>Wind speed and direction</td>
</tr>
<tr>
<td></td>
<td>Substrate: thickness, bulk density, moisture content and colour</td>
<td></td>
<td>Climate (dry / wet)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Density of the foliage (number of layers)</td>
<td></td>
<td>Wind speed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Barrier effect of wind</td>
<td></td>
<td>Substrate moisture</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Changes in the air in the intermediate space</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Substrate: thickness, bulk density and moisture content</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Green facades</strong></td>
<td>Density of the foliage (number of layers)</td>
<td>Density of the foliage (number of layers)</td>
<td>Type of plant</td>
<td>Foliage density and penetration</td>
</tr>
<tr>
<td></td>
<td>Barrier effect of wind</td>
<td></td>
<td>Exhibition</td>
<td>Wind speed and direction</td>
</tr>
<tr>
<td></td>
<td>Changes in the air in the intermediate space</td>
<td></td>
<td>Climate (dry / wet)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Substrate: thickness, bulk density and moisture content</td>
<td></td>
<td>Wind speed</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Substrate moisture</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Selecció d'espècies, maneig de l'aigua i eficiència energètica en cobertes i façanes verdes
IRTA Torre Marimon, Caldes de Montbui. 13 Novembre 2015
Contents

• Introduction
• Parameters
• Green roofs
  – Puigverd
  – Gardeny
  – Thermal improvement
  – LCA
• Green facades
  – Golmés
  – Puigverd
• Future work
• Two previous actions was carried out (2009-2011):
  - Action 2: Possibility of use recycling rubber crumbs from tires as drainage material in green roofs instead of puzolana.
Green roofs. Puigverd

- Action 1: Thermal behaviour extensive green roof
  - An extensive green roof was installed on an existing experimental cubicle in a large installation that the research group GREA has in Puigverd de Lleida (Lleida, Spain). Dry Mediterranean Continental climate.
• Action 1: Thermal behaviour extensive green roof
  - An **extensive green roof** was installed on an existing experimental cubicle in a large installation that the research group GREA has in *Puigverd de Lleida* (Lleida, Spain). **Dry Mediterranean Continental** climate.
Green roofs. Puigverd

- Action 1: Thermal behaviour extensive green roof
  - The evolution of the internal temperature during summer and autumn 2009 was measured
• Action 1: Thermal behaviour extensive green roof
  - Green roof cubicle recorded indoor temperatures of between 2 to 5 °C lower in free floating conditions.
• **Action 2: Recycled rubber instead puzolana**
  - The same drainage capacity was found in lab for both materials, puzolana and rubber (half and small crumbs size)
- **Action 2: Rubber instead puzolana**
  - Similar water retention capacity was observed when we use recycled rubber instead than puzolana as drainage layer in green roofs trays.
Green roofs. Puigverd

- As the results of the first actions were positive two new cubicles were built, three identical cubicles was built, with the only difference on the roof structure.

- Objectives:
  - Inside comfort conditions (temperature and humidity)
  - Energy consumption
  - Acoustic properties
Green roofs. Puigverd

- **Reference** cubicle: Conventional flat roof with 3 cm of insulation
- **Pozzolana** cubicle: 9 cm extensive green roof without insulation, with pozzolana as drainage material
- **Rubber crumbs** cubicle: 9 cm extensive green roof without insulation, with recycled rubber crumbs from tyres as drainage material
Green roofs. Puigverd

- First results during summer 2011, with only 20% plant cover:

![Graph showing energy consumption comparison between volcanic gravel, rubber crumbs, and reference over different periods](image)

**Controlled temperature at 24 °C**

- [Image of green roofs](image)
• First results during summer 2011, with only 20% plant cover:

![Free floating chart]

- Volcanic gravel
- Rubber crumbs
- Reference
• Data was recorded during all 2012 with 80% of cover plant
- Data was recorded during all 2012 with 80% of cover plant.

**Controlled temperature at 24 °C**

- Cumulative electrical energy consumption [kWh]

<table>
<thead>
<tr>
<th>Period</th>
<th>Pozzolana roof</th>
<th>Rubber crumbs roof</th>
<th>Reference roof</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-8</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>17-8</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>18-8</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>19-8</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>20-8</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>21-8</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>22-8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>
Contents

• Introduction
• Parameters
• Green roofs
  – Puigverd
  – Gardeny
  – Thermal improvement
  – LCA
• Green facades
  – Golmés
  – Puigverd
• Future work
Green roofs. Gardeny

- This 2000 m² extensive green roof is a part of a renovation project located in the *Gardeny Science and Technology Park* in the city of Lleida.

- The commercial type is named “ecological roof”, from INTEMPER.
Green roofs. Gardeny

• This system was designed with the aim to adapt the concept of green roof to the climate of the Iberian Peninsula, which is characterized by low rainfall.
Green roofs. Gardeny

- Two different finish material
  - Green areas
  - Gravel areas (paths)
Recorded parameters location

Temperature
- T(30 cm)
- T(5 cm)
- T(subst -2 cm)
- T(subst -4 cm)
- T(subst -8 cm)
- T(cistern -16 cm)
- T(cistern -23 cm)
- T(cistern -30 cm)
- T(under roof structure -48 cm)
- T(indoor)

Humidity
- HR(30 cm)
- HR(5 cm)
- HR(subst -4 cm)
- HR(subst -8 cm)
- HR(indoor)

Substrates
- Sedum SP
- Geotextile felt 150 (filtering + capillarity)
- "Filtro N" SALB
- Substrate
- Cistern with adjustable supports
- Waterproof membrane
- Roof structure
- Water content subst (-4 cm)
- Water content subst (-8 cm)
Green roofs. Gardeny

- Installation process
Results (10% cover). **Green area** temperatures. Summer

![Graph showing temperature variations in green area]

- Temperature variations in different substrates:
  - T substrate (-8 cm)
  - T substrate (-4 cm)
  - T substrate (-2 cm)
- Temperature variations in indoor and outdoor conditions:
  - T indoor
  - T outdoor (30 cm)
• Results (10 % cover). **Green area** temperatures. **Winter**
Green roofs. Gardeny

- Referring to the floristic composition, both temporal (seasonally) and spatial changes were found.
Contents

• Introduction
• Parameters
• Green roofs
  – Puigverd
  – Gardeny
  – Thermal improvement
  – LCA
• Green facades
  – Golmés
  – Puigverd
• Future work
Green roofs. Thermal improvement

- In Puigverd and Gardeny research we realised the importance of the substrate layer in the thermal behaviour of the green roof.
- It is known that because the type of plants and the low maintenance levels, extensive green roofs hardly reach 100% of the vegetation cover.
Green roofs. Thermal improvement

• The composition of the substrate is variable
  – Example 1: 40 % organic matter + 60 % mineral matter
    • humus + coconut fiber + gravel
  – Example 2: 5 % organic matter + 95 % mineral matter
    • compost plant + volcanic gravel + fertilizer
Green roofs. Thermal improvement

- This composition influences the thermal behaviour of the green roofs
  - Due to the thermal conductivity of the materials (MO, minerals, etc)
  - Due the capacity to retain the water (moisture of the substrate)
  - Due to the grown of the plants, and consequently the shadow effect (LAI)

- In previous research (simulations) the soil conductivity is assumed as a function of moisture content or simply as a constant parameter
Green roofs. Thermal improvement

- There is necessary more data about thermal properties of substrates
- An own methodology is being applied in GREA lab for this purpose
- Test-Box is a device developed at University of Lleida
Green roofs. Thermal improvement

- Materials used in the building envelopes must be well chosen depending on the climate conditions.

- It is important to specify thermal properties of the multilayered constructive systems:
  - thermal conductivity
  - heat storage capacity of the envelope
  - dynamic thermal response

- Equipment described in this work is a simple tool for testing thermal behaviour of building solutions.
Green roofs. Thermal improvement

- Equipment and instrumentation
Green roofs. Thermal improvement

- Experiment 1.

Thermal transmittance **U-value** (W/m² °C)
• Experiment 2.

Heat storage capacity of the sample $C_p$ (J/Kg*ºC)
Green roofs. Thermal improvement

- Experiment 3.

Dynamic thermal characteristics

- **Thermal lag** (hours)
- **Thermal stability coefficient** (TSC)

Free Floating conditions
• First Results of 4 different substrates

Thermal Stability Coefficient (TSC) and Time lag of the four substrates

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Substrate 2</th>
<th>Substrate 3</th>
<th>Substrate 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Stability Coefficient</td>
<td>0.37</td>
<td>0.35</td>
<td>0.32</td>
</tr>
<tr>
<td>Time lag [h]</td>
<td>1.19</td>
<td>1.36</td>
<td>1.21</td>
</tr>
</tbody>
</table>
Contents

• Introduction
• Parameters
• Green roofs
  – Puigverd
  – Gardeny
  – Thermal improvement
  – LCA
• Green facades
  – Golmés
  – Puigverd
• Future work
Life Cycle Assessment (LCA) is a tool used to assess the potential impact on the environment of a product, process or activity throughout its life cycle by quantifying the use of resources ("inputs" such as energy, raw materials, water) and environmental emissions ("outputs" in the air, water and soil) associated with the system being evaluated. Moreover in this way we can know what stage is the largest energy consumer or the largest issuer of pollutants and waste.
Green roofs. LCA

• Life cycle assessment can be carried out at **different scales**

• For the construction sector we can consider the following:
  - LCA of building **material**
  - LCA of a **construction system**
  - LCA of a whole **building**
  - LCA of an **area** or region

• **Different Green Roof systems**
  - RB: Extensive green roof with recycled materials (Rubber crumbs)
  - PZ: Extensive green roof with conventional materials (Pozzolana)
  - IN: Conventional flat insulated roof (3 cm of polyurethane + Gravel)
  - NO: Conventional flat non-insulated roof (Gravel)
First results showed that: The use of recycled rubber crumbs as drainage materials can be a good solution from the point of view of sustainability.

Methodology:
**ISO 14040**

Software:
**LCA Manager**

Data base:
**Ecoinvent (El 99)**
Introduction
Parameters
Green roofs
- Puigverd
- Gardeny
- Thermal improvement
- LCA
Green facades
- Golmés
- Puigverd
Future work
Green façades. Golmés

- The main objective of this experiment was to study and monitor during one year a double-skin green facade or green curtain, with modular trellis and Glycine (Wisteria sinensis), in Mediterranean continental climate.
• Description of the facade
• Description of the facade
Green façades. Golmés

- Material and methods

![Images of equipment: Digital Thermo-Hygrometer, Luxometer, Infrared Thermometer, Thermo-graphyc Camera]
• Results and Discussion: Plants development

September 2007
Area occupied, aprox.19%

September 2008. Area occupied, aprox.48%
• Results and Discussion: Plants development

June 2009. Area occupied, approx. 62%
Green façades. Golmés

- Results and discussion: Thermographic analysis

February

July
Results and discussion: Illuminance

- In the months without leaves: about 10,000 to 30,000 lux difference between the intermediate space illuminance and the outside illuminance.
- In July, with leaves: differences of more than 80,000 lux.
• Results and discussion: Building wall surface temperature
  - The surface temperature in sunny areas was on average 5.5 ºC higher than in shade areas.
  - This difference was higher in August and September, reaching maximum values of 15.2 ºC on the south west side in September.
Results and discussion: Illuminance

- The light transmission factor, calculated as the ratio between the illuminance in the intermediate space and the illuminance outside.
- This value varies from 0 to 1, indicating the amount of light radiation that passes through the green screen.

### Results

<table>
<thead>
<tr>
<th>Facade</th>
<th>Light Transmission Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW</td>
<td>0.49</td>
</tr>
<tr>
<td>SE</td>
<td>0.64</td>
</tr>
<tr>
<td>NW</td>
<td>0.57</td>
</tr>
<tr>
<td>All</td>
<td>0.57</td>
</tr>
</tbody>
</table>

### Discussion

- The SW facade has the highest light transmission factor, indicating it allows more light to pass through.
- The SE facade follows, allowing moderate transmission.
- The NW facade has the lowest transmission, making it suitable for shading purposes.
- The all-facade average transmission is also moderate, indicating a well-balanced light distribution across the building.

### Tables

#### Table E.13: Factor of shadow for obstacles on the facade: lamas

<table>
<thead>
<tr>
<th>Orientation</th>
<th>ANGULO DE INCLINACIÓN (α)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-60</td>
</tr>
<tr>
<td>SUR</td>
<td>0.37</td>
</tr>
<tr>
<td>SURESTE/SUR OESTE</td>
<td>0.46</td>
</tr>
<tr>
<td>ESTE</td>
<td>0.39</td>
</tr>
<tr>
<td>OESTE</td>
<td>0.44</td>
</tr>
<tr>
<td>SUROESTE</td>
<td>0.38</td>
</tr>
</tbody>
</table>

**NOTAS:** Los valores de factor de sombra que se indican en estas tablas han sido calculados para una relación DIL igual o inferior a 1. El ángulo α debe ser medido desde la normal a la fachada hacia el plano de las lamas, considerándose positivo en dirección horaria.
Contents

• Introduction
• Parameters
• Green roofs
  – Puigverd
  – Gardeny
  – Thermal improvement
  – LCA
• Green facades
  – Golmés
  – Puigverd
• Future work
Green façades. Puigverd

- Previous actions
  - Action 1: Shadow capacity of different climber species. 2009-2010
  - Action 2: Thermal behaviour of green facades in an existing cubicle. 2010-2012
Action 1: Shadow capacity of different climber species. 2009-2010

- The ability to intercept solar radiation of vegetation, even at low densities of the foliage, is similar to that offered by artificial barriers such as awnings, slats, etc. according to the Spanish technical code of buildings (CTE).
Green façades. Puigverd

- Action 1: Shadow capacity of different climber species. 2009-2010
  - The ability to intercept solar radiation of vegetation, even at low densities of the foliage, is similar to that offered by artificial barriers such as awnings, slats, etc. according to the Spanish technical code of buildings (CTE).

<table>
<thead>
<tr>
<th>Artificial barrier</th>
<th>Shadow factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cantilever</td>
<td>0.16 – 0.82</td>
</tr>
<tr>
<td>Setback</td>
<td>0.17 – 0.82</td>
</tr>
<tr>
<td>Opaque awnings</td>
<td>0.02 – 0.43</td>
</tr>
<tr>
<td>Translucent awnings</td>
<td>0.22 – 0.63</td>
</tr>
<tr>
<td>Horizontal slats</td>
<td>0.26 – 0.49</td>
</tr>
<tr>
<td>Vertical slats</td>
<td>0.32 – 0.44</td>
</tr>
</tbody>
</table>

![Graph showing transmissivity of light for different plants and artificial barriers.](image)
Green façades. Puigverd

- Action 2: Thermal behaviour of green facades in an existing cubicle. 2010-2012
• Action 2: Thermal behaviour of green facades in an existing cubicle. 2010-2012
  - The shadow effect is evident over the wall surface temperature, reaching 14 degrees less than in the reference cubicle with 50% of the surface covered.
• Action 2: Thermal behabiour of green facades in an existing cubicle. 2010-2012
  - Shadow effect influences over indoor temperature too. The reduction was about 1 degree less in the facade cubicle in free floating conditions
• Action 2: Thermal behaviour of green facades in an existing cubicle. 2010-2012
  - Some savings was observed for the accumulated energy consumption under indoor controlled conditions (24 °C)
Green façades. Puigverd

- As the previous results were positive the thermal behavior of three identical cubicles was compared, with the only difference on the façades (east, south and west)
  - Reference cubicle
Green façades. Puigverd

- As the previous results were positive the thermal behavior of three identical cubicles was compared, with the only difference on the façades (east, south and west)
  - **Reference cubicle**
  - **Green façade cubicle**: Double-skin green façade made by means wire mesh as lightweight support and Boston Ivy (*Parthenocissus tricuspidata*) as deciduous climber plant
The plant growth was appropriate (summer 2015)
• As the previous results were positive the thermal behavior of three identical cubicles was compared, with the only difference on the façades (east, south and west)
  • **Reference cubicle**
  • **Green façade cubicle**: Double-skin green façade made by means wire mesh as lightweight support and Boston Ivy (*Parthenocissus tricuspidata*) as deciduous climber plant
  • **Green wall cubicle**: Pre-cultivated modular-based green wall system (BURÉSINNOVA), and perennial bushes *Helichrysum stoechas* and *Rosmarinus officinalis*
Green façades. Puigverd

- The plant growth was appropriate (summer 2015)
The results showed a great shade effect due to the VGS, with interesting reductions on the external surface temperatures (summer 2014).
Green façades. Puigverd

- And, energy consumption reductions during the **cooling period** up to 50% (summer 2014, Indoor set-point 24 °C)
During the **heating period**, the Green Wall provides a slight thermal insulation (winter 2015, indoor set-point 21 °C)
Acknowledgments

- The work was partially funded by the Spanish government (project ENE2011-28269-C03-02 and ULLE10-4E-1305) and the European Commission Seventh Framework Program (FP/2007-2013) under Grant agreement Nº PIRSES-GA-2013-610692 (INNOSTORAGE) and from European Union’s Horizon 2020 research and innovation program under grant agreement Nº 657466 (INPATH-TES)

- Catalan Government for the quality accreditation given to their research group (2014 SGR 123)

- To City Hall of Puigverd de Lleida, to Gestión Medioambiental de Neumáticos S.L and Flag Soprema S.L.U. companies and To the company BURÉSI INNOVA S.A

- To Gardeny Science and Technology Park in Lleida (Spain)

- Department of Crop and Forest Science, Universitat de Lleida

- Departamento de Agronomía, Universidad de Almería

- Julià Coma would like to thank the Departament d'Universitats, Recerca i Societat de la Informació de la Generalitat de Catalunya for his research fellowship

- To all co-authors of this work
THANK YOU FOR YOUR ATTENTION

Jornada Tècnica. Selecció d’espècies, maneig de l’aigua i eficiència energètica en cobertes i façanes verdes
IRTA Torre Marimon, Caldes de Montbui. 13 Novembre 2015

Dr. Gabriel Pérez
Phd. Julià Coma
Prof. Luisa F. Cabeza