Report on the green roof monitoring in Benaguasil

E²STORMED PROJECT
Improvement of energy efficiency in the water cycle by the use of innovative storm water management in smart Mediterranean cities
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Benaguasil
AJUNTAMENT

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INDEX

EXECUTIVE SUMMARY

In urban areas roofs are a critical part of the building envelopes which are highly susceptible to solar radiation and other environmental changes, thereby, influencing the indoor comfort and energy consumption.

During E²STORMED (from July 2013 to Jannuary 2015) thermal behavior and energy consumption of the air conditioning system has been monitored[1], on a public building (located in Benaguasil (Valencia, Spain), before and after the implementation of a green roof of about 300 m^2.

In February 2014 the external gravel layer of the conventional roof was substituted by a green roof, so since March 2014 to January 2015 the energy consumption corresponded to the building with green roof. Monitored building area is not being used during the testing period to guarantee control on internal loads and other factors that could affect the energy consumption. Hence, the test conditions are the same except the differences provided by the green roof installation.

On the one hand, the effects of heat storage of the materials were analysed. In conventional roof, gravel layer had a significant heat storage effect, in fact, temperatures of approximately 45-55ºC were recorded in summer. Once green roof layer was installed, maximum temperatures were about 30-35ºC, so heat storage effect was softened and delayed.

On the other hand, power consumption before and after installing the green roof was compared, during similar days (according, mainly, to solar radiation and outdoor temperatures) from 9:00 to 13:00 (to avoid start and final operating times). It was concluded that consumption in summer is reduced in about 30 – 35%, and minor changes can be observed in winter. On an annual basis it can be concluded about 20-25% of electricity saving for the air conditioning systems which represents about 70% of the total electricity consumption of the building.

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[1] Also called, in a general way, HVAC – Heating, ventilation and air conditioning system.

1. INTRODUCTION

Buildings consume about 40% of total final energy requirements in Europe in 2010. It is the largest end use sector, followed by transport (32%), industry (24%) and agriculture (2%). Thus, the building sector is one of the key energy consumers in Europe, where energy use has increased a lot over the past 20 years. As shown in the Report on Energy in the urban water cycle of the E²STORMED project, energy consumption in buildings relies mainly on non-renewable resources, so it is important to find ways to save energy as a first step to mitigate environmental impacts and to preserve fuel resources.

In urban areas roofs are a critical part of the building envelopes which are highly susceptible to solar radiation and other environmental changes, thereby, influencing the indoor comfort conditions for the occupants. Roofs account for large amounts of heat gain/loss, especially, in buildings with large roof area and not many floors. Additionally, in urban areas roofs play a very important role on stormwater management and present many environmental benefits.

Drainage infrastructures are not related with building insulation but for the case of green roofs. They can block solar radiation, and reduce daily temperature variations and thermal ranges between summer and winter. The thermal effects of green roofs can be divided into two aspects (Sam C.M. Hui, 2009):

- Direct effect to the building (internal): Reduce the heat transfer through the roof to the building interior, reducing the energy use inside the building.
- Indirect effect to the surrounding environment (external): Reduces the heat transfer from the roof to the surrounding environment, reducing the urban heat island effect. When the urban temperature is reduced, all the buildings in the area or city will benefit and enhance energy conservation.

Thermal behaviour of a building and so, the impact of green roof installation on the building energy consumption is not an easy subject. Thermal conductivity of used materials is an important factor, but also other variables as internal loads (lights, computers, people,..) or roof reflectance to solar radiation can play a very important role, especially in summer period. In the frame of the present project a green roof was installed on a public building and the impact on building thermal behavior and energy consumption of the air conditioning system were monitored.

In addition, from the stormwater management point of view, it is expected that the green roof will reduce the runoff peak and volume, which will improve stormwater management in the area and it will reduce the energy requirements for the downstream water pumping and treatment.

The objective of this work is to show the results on energy saving of the green roof on buildings with Mediterranean climate, evaluating also its benefits for the stormwater management.

Figure 1.1.General view of the green roof in Benaguasil.

1.1. Heat Transfer in Building Element

Heat transfer in buildings is usually analysed by subdividing the structure into different enclosures or elements (facade walls, openings, floors and roofs), to calculate separately heat loss.

This type of calculation is usually based on a one-dimensional model, which assumes that the elements are thermally homogeneous and are composed of a number of layers in parallel to the heat flow, as shown in the next figure.

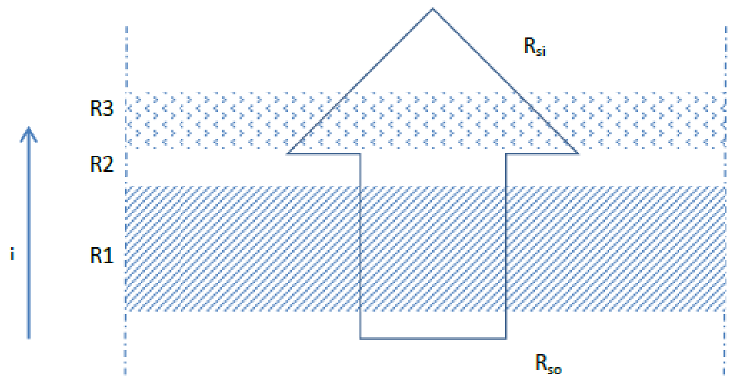

Figure 1.2.One-dimensional model of heat flux (Díaz and Tenorio, 2005).

Heat transfer is defined as the **Heat Transfer Coefficient (U)**, considered in a simplified, steady state. This value gives the heat loss through each building element per unit surface area and temperature difference of the considered element (W/m^2·K).

U-value for each element of the building is calculated by the following general equation:

$$U\left(\frac{W}{m^2\cdot K}\right)=\frac{1}{R_{SI}+R_{SO}+R_1+R_2+\cdots+R_n} \qquad \textit{Equation 1.1}$$

Where:

$$R_{SI}\left(\frac{m^2\cdot K}{W}\right)=thermal\ resitance\ of\ internal\ surface\ (outside\ air)$$

$$R_{SO}\left(\frac{m^2\cdot K}{W}\right)=thermal\ resitance\ of\ outside\ surface\ (indoor\ air)$$

$$R_i\left(\frac{m^2\cdot K}{W}\right)=thermal\ resitances\ of\ layers\ which\ compounds\ the\ element$$

Thermal resistance, R_i of a thermally homogeneous layer is defined as follows:

$$R_i\left(\frac{m^2\cdot K}{W}\right)=\frac{t}{\lambda} \qquad \textit{Equation 1.2}$$

Where:

$$t=layer\ thickness\ (m)$$

$$\lambda=thermal\ conductivity\ of\ the\ material\ which\ compounds\ the\ layer\ \left(\frac{W}{m\cdot K}\right)$$

The prevalent materials in a roof and their thermal conductivities are the ones showed in the table below. The values are for normal temperature and should be regarded as average values for the type of material specified:

Material	Thermal conductivity W/(m·K)
XPS (Extruded Polystyrene) Insulation	0.04–0.14*[a]
Polyethylene	0.33 -0.52*[a]
Air	0.025[a]
Concrete	0.1-1.8*[a]

* Values depend on density. generally increasing with increasing density.

[a] (Kaye and Laby, 2013)

Table 1.1. Thermal conductivities of common materials found in roofs.

The heat losses through an element of the building are characterised by the following equations:

$$Q\ (W) = U \cdot A \cdot \Delta T \qquad \textit{Equation 1.3}$$

$$Q\ \left(\frac{W}{m^2}\right) = U \cdot \Delta T \qquad \textit{Equation 1.4}$$

Where:

$Q = heat\ losses\ through\ the\ element\ (W)$

$U = overall\ heat\ transfer\ coefficient\ \left(\frac{W}{m^2 \cdot K}\right)$

$A = element\ area\ (m^2)$

$\Delta T = difference\ between\ outside\ and\ inside\ temperature\ in\ the\ building\ (K)$

For the comparison of heat losses (in winter) or heat gains (in summer) between different buildings or to evaluate the effect of a new insulation layer (or green roof), the outdoor temperature is important but what is really determinant is the temperature difference between building indoor and building outdoor.

Heat flux transfer of green roofs is governed by four mechanisms: shading, thermal insulation, evapotranspiration and thermal mass. The thermal and energy performance of green roofs has been studied worldwide using three different approaches: field experimentation, numerical studies, and a combination of laboratory or field experiments with numerical models. In general, of total solar radiation absorbed by the green roof, about 27% is reflected, 60% is absorbed by the plants and the soil through evaporation and 13% is transmitted into the soil (Hui, 2009).

1.2. HYDRAULIC FEATURES

Urban development produces higher and more rapid peak discharge, with higher runoff volume and a more rapid return to low flows (Figure 1.3). The alteration of natural flow patterns may lead to flooding and channel erosion downstream of the development. Moreover, the decrease in percolation into the soil can lead to low baseflows in watercourses and reduced aquifer recharge (Woods-Ballard *et al.*, 2007).

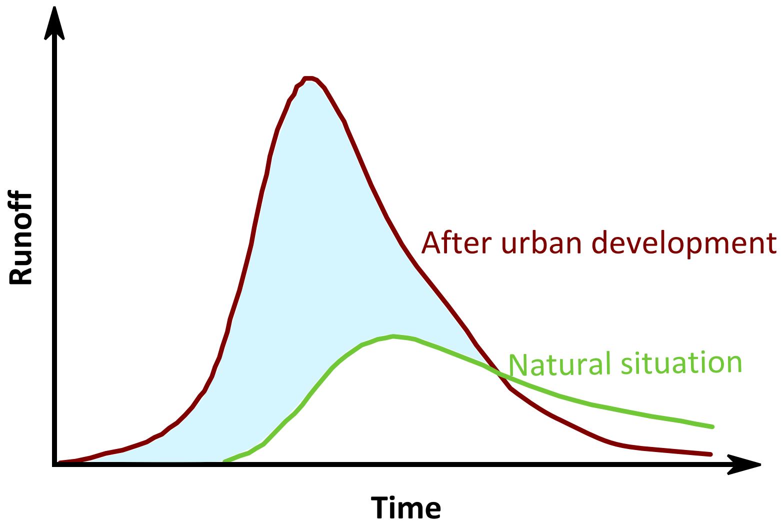

Figure 1.3. Runoff production in natural situation and after urban development.

In response to these changes in the local hydrology, cities have generally been designed to remove rainfall from the urban environment as rapidly as possible using drainage channels and underground pipes (Philip, 2011b). In this sense, conventional roof are usually completely impervious and remove water from buildings directly to the urban drainage system.

In contrast to the conventional roofs, it is expected that the green roof will reduce runoff peaks and volumes, helping to minimise the impacts to local hydrology of urban developments. This water is consumed by the green roof vegetation, reducing the amount of water that enters into the combined system. In this report, the runoff quantity results of the green roof and a conventional roof are compared in order to analyze the benefits of the green roof for the urban drainage system.

In addition, in the green roof water is in contact with the vegetation, so there could be changes in the runoff water quality in comparison with a conventional roof. Therefore, runoff water quality has also been analyzed to study the impact of this infrastructure.

2. GREEN ROOF AND BUILDING DESCRIPTION

2.1. GENERAL BUILDING INFORMATION

The building where the green roof was built is situated in the town of Benaguasil (25 km from Valencia, SPAIN) and it is known as “Centre de Dia” which in English means “Senior Center”.

This Senior Center was initially intended to be a day care center for senior citizens. The building was built by the Regional Government. Due to the scarcity of funds it was not feasible to put it into operation as a Senior Center and it was finally transferred temporally to the town council. Now the building serves as Social Center for the town of Benaguasil.

It is a single floor building of approximately 1 160 m² located in the south-east of the town. Within the area between the building and the surrounding fence there are some trees and small gardens. The building was designed in 2006 and its construction finished in 2012.

Since it was initially designed as day care center for senior citizens the building has some facilities that are common in those kind of building such a dining room, changing rooms, kitchen, etc.

Figure 2.1. Building main façade.

Building Use

As mentioned above the building is currently used for the Social Services of the town. There are between 4 and 6 workers working in the building depending on the day, and mainly in the mornings from 8:00 am to 15:00 pm from Monday to Friday. The whole building is not being used at the moment. This is an important issue that has to be taken into account in order to monitor the building in an effective way. To compare the thermal efficiency of a green roof and a conventional one it is necessary to analyze rooms with similar conditions of use. Hence, knowing the way the building is being used at the moment, it is necessary to decide where the green roof will be allocated.

The next figure shows the area used by social workers at the beginning of the project (June 3rd 2013), before the green roof installation.

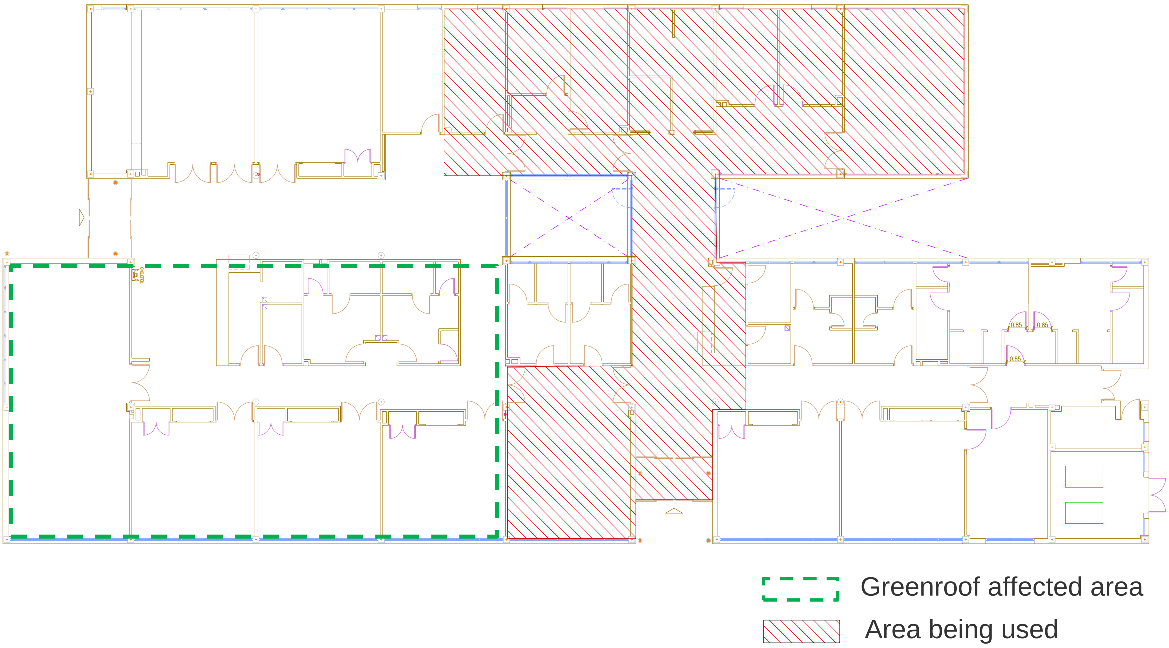

Figure 2.2. Building used areas and Green roof afffected area.

The building use has been the same from July 2013 to January 2015.

During all the monitoring period the green roof affected area is a non-used area, so neither internal loads, air conditioning users nor unexpected activities will disturb the monitoring tests.

2.2. BUILDING ENERGY CONSUMPTION

The building has only electricity supply (no fuel) and consumption is about 34500 kWh per year. According to physical description of the building envelope, orientation, climate conditions and present equipment (air conditioning system, lighting system, computers, photocopy machine,…) the building was modelled with CALENER VYP software (Simplified Building Certification[2] software for residential and small commercial buildings). It was

[2] The Building Energy Certification is a requirement directly derived from the European Directive 2002/91/CE, which is translated in the legal Spanish system through the royal decree RD. 47/2007, of January the 19th. This law establishes the procedure that must be achieved by the new buildings. The Certification gives the building an Energy Class, which is similar to that ones we can find on the household appliances, in several categories: from A, the most efficient, to G, the least

obtained that main energy use is air conditioning with about 71% of total electricity consumption. Additionally it was concluded that the building is Energy Class C (33,6 kg CO_2/m^2) so better than most Spanish buildings, which are usually Energy class D or E, showing that the building has a good thermal behavior (well insulated).

2.3. Conventional roof. Initial situation

The building has a flat roof. It has "inverted roof" typology which is characterised by having the thermal insulation (XPS) over the waterproofing membrane. Over the thermal insulation usually lays a geotextile filter and a gravel layer.

Figure 2.3. General view of building roof (green dotted line indicating green roof affected area).

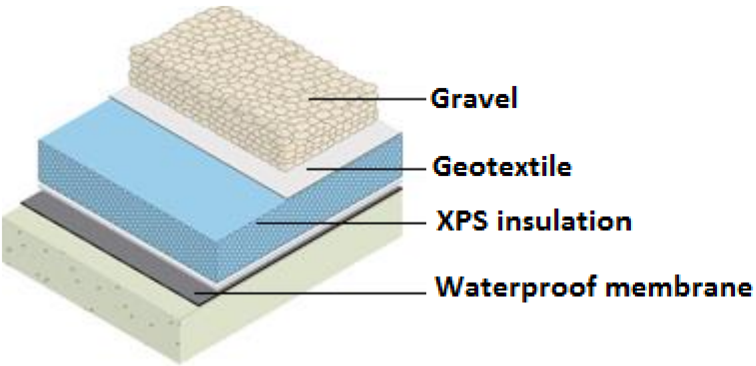

Figure 2.4. Constructive layers of conventional "inverted roof" (initial situation).

The roof of "Centre de Dia" building has exactly the same layers of the picture above. These are the layers and their widths:

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efficient. Moreover, this document must be included in the Executive Project and must be displayed before a General Register of Building Energy Certifications Documents.

- 5 cm of a 1700 kg/m^3 gravel layer (gravel diameter 2-5 cm)
- Geotextile filter layer
- 4 cm of XPS insulation
- Waterproofing membrane

2.4. Greenroof description and affected area

The green roof was constructed over an “inverted roof”. These kinds of roofs have a thermal insulation over the waterproofing membrane.

Green roofs can be built over an inverted roof without removing the gravel. This green roof is going to be compared with a conventional one; therefore it was decided to remove the gravel layer, since most of the green roofs are not constructed over one of these layers.

The green roof built in Benaguasil incorporates a storage layer below the growing medium (separated with a filter fabric layer). This storage layer increases the capacity of the roof for retaining water after a rain episode and reduces significantly the amount of runoff generated downstream.

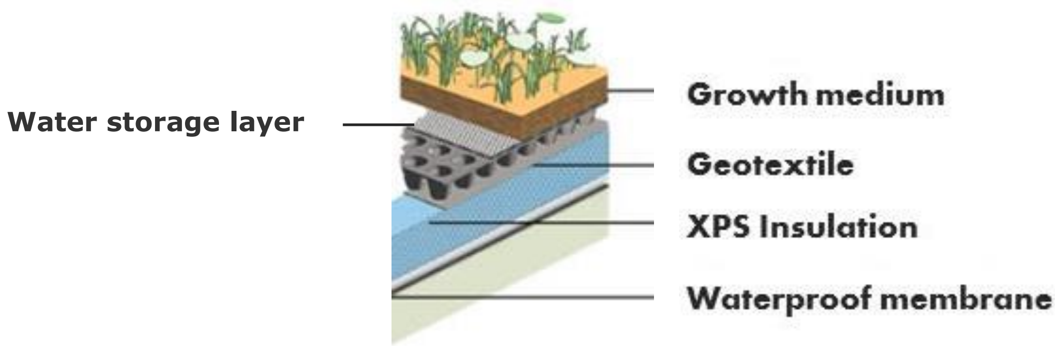

Figure 2.5. Constructive layers of green roof (present situation).

The green roof has exactly the same layers of the picture above. These are the layers and their widths:

- 8 cm of growth medium.
- Water storage layer (with upper permeable textile layer).
- Geotextile layer.
- 4 cm of XPS insulation.
- Waterproofing membrane / root barrier.

In the upper part of the green roof there are plants covering about 80-100% of its area with a height in the range 5 – 15 cm (see Figure 2.6). The plants are genus sedum (a mixture of sedum album AH, sedum floriferum AH, sedum sediforme AH, sedum reflexum AH, sedum spurium AH, sedum moranense AH, sedum acre AH).

The growth medium is a mixture of conventions gardening organic substrate (40%), volcanic lava rocks (40%) and silica sand (20%).

Figure 2.6. Vegetation, genus Sedum, used for the green roof (February 2014).

2.5. Green roof evolution during the monitoring year

In the following figures, it can be observed the time evolution of the green roof in Benaguasil during the monitoring period. The vegetation looks drier in winter and greener in spring and summer.

Figure 2.7. Time evolution of the green roof in Benaguasil in the monitoring period (1).

Figure 2.8. Time evolution of the green roof in Benaguasil in the monitoring period (2).

2.6. AIR CONDITIONING SYSTEM

The building is divided in 4 different air conditioned areas and the temperature is managed from 4 main controllers (one in each area). The air conditioning system is based on electric heat pumps, and in each area the system is composed by two external units and one internal unit. There are 4 “twin” external units (so a total of 8 machines), see Figure 2.10, on the roof and 4 internal units, Figure 2.11, inside the building. Internal units are usually called “impulsion units” because they provide the cold or hot air to the rooms through specific ducts.

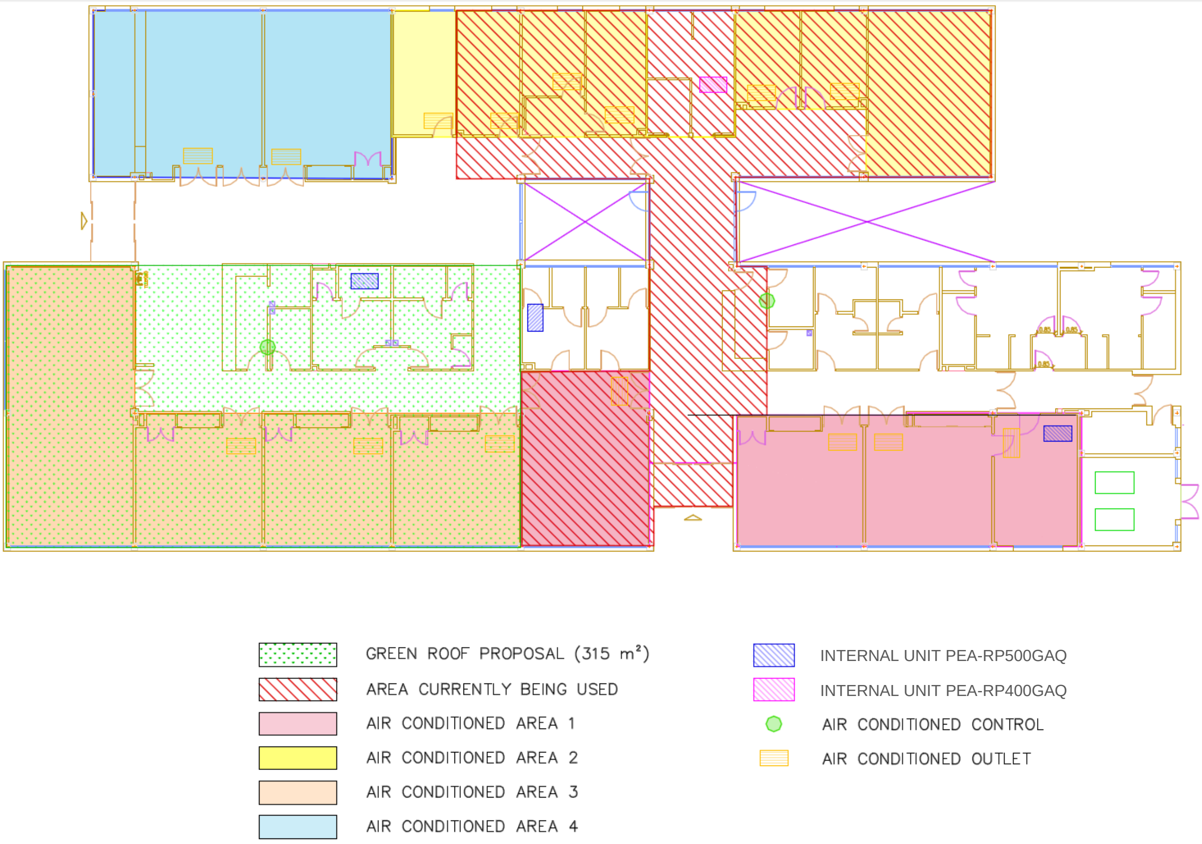

Figure 2.9. Air-conditioning areas and green roof location.

External units (OUTDOOR UNITS)

OUTDOOR UNIT: P250YHA

Figure 2.10. Air-conditioning outdoor unit.

Internal units (INDOOR UNITS)

INDOOR UNIT: PEA-RP400GAQ / PEA-RP500GAQ

Figure 2.11. Air-conditioning indoor unit.

3. EXPERIMENTAL SETUP AND PROCEDURE

3.1. MONITORING PROCEDURE AND METHODOLOGY

The monitored building area is not being used during the testing period to guarantee control on internal loads and other factors that could affect the energy consumption. Hence, the test conditions are the same except monitored variables (temperature, solar radiation, wind,…).

The green roof was built in March 2014 and the monitoring period of this infrastructure was from April 2014 to April 2015. Although the energetic monitoring of the building began in July 2013, so the behaviour of the building was controlled during one year before the construction of the green roof.

For the energetic monitoring, the experimental procedure was to set a temperature setpoint (most test performed around 24 ºC) for the air conditioning system during all the morning (from 8:30 to 14:00) without changing it nor turning off the air conditioning system. Both energy consumption and temperature metering was performed every 5 minutes.

For comparison purposes raw data was filtered so only data from testing days was used, where these instructions where fully followed ("valid testing days", it was checked with electricity consumption metering and indoor temperature metering).

Comparison of energy consumption before and after green roof installation was performed averaging energy consumption for valid testing days for the period 9:00 to 13:00. Additionally, it has been selected a group of valid testing days with similar solar radiation, outdoor temperature and temperature setpoint. In the averaging process, only 75% of the values are considered, so avoiding extremely high and low values.

The hydraulic monitoring focused in the comparison between the outflow of the green roof and the outflow of the adjacent conventional roof. The water quantity and quality of these outflows was also analysed. This data has been downloaded and checked monthly.

3.2. ENERGY MONITORING

The power consumption (through current metering) of the air conditioning system that covers AIR CONDITIONING AREA 3 (where the green roof has been installed) has been monitored for 19 months (July 2013 to January 2015).

The following table includes the list of machines (three phase, so each machine requires three current meters) that were metered, model and some additional information:

Current meter code	Description
HP01	Heat pump 1. Oudoor unit model P250YHA
HP02	Heat pump 2. Oudoor unit model P250YHA
IU01	Impulsion unit. Indoor unit model PEA-RP500GAQ

Table 3.1. Equipment for the air conditioning system.

The current meters (maximum current of 80 A) are located in the general electric box of the building and are communicated with the monitor through wireless radio signal (433 MHz SRD).

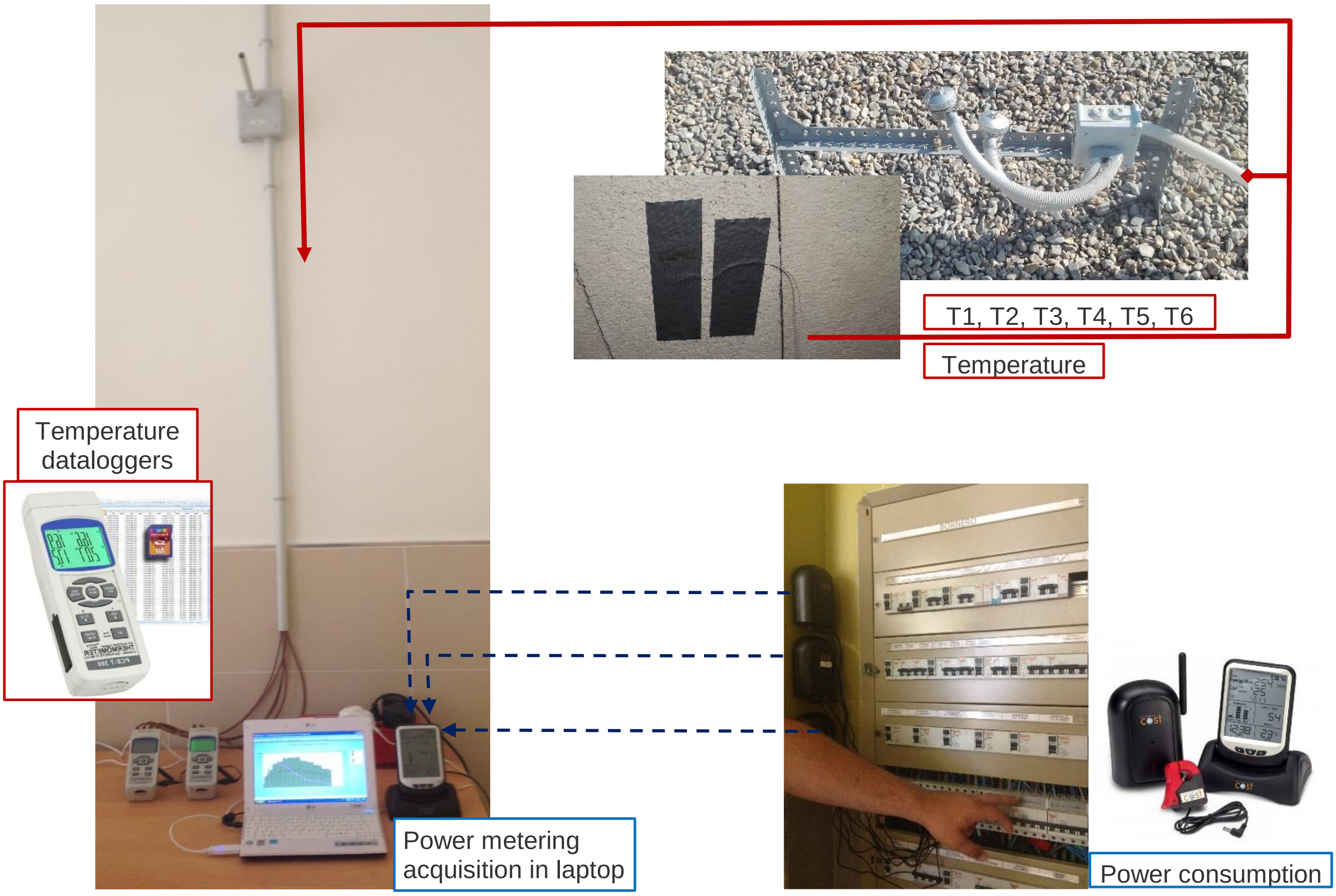

Figure 3.1. General scheme of energy monitoring system (power and temperatures).

3.3. TEMPERATURE MONITORING

The temperature profile (6 thermocouples type T, T1 to T6) of the roof has been monitored for 19 months (July 2013 to January 2015):

The following table includes the list of thermocouples, their location and some additional information:

Thermocouple code	Description
T1	-Temperature under gravel (initial situation). -Temperature under substrate (after green roof installation).
T2	-Temperature under XPS insulation
T3 (T3.REF)	-Temperature under XPS insulation (as T2), metering since the beginning of the project in an area of the roof non affected by the green roof.
T4	-Outdoor temperature
T5	-Indoor temperature
T6	-Temperature in the internal face of the roof

Table 3.2. Thermocouples description (location).

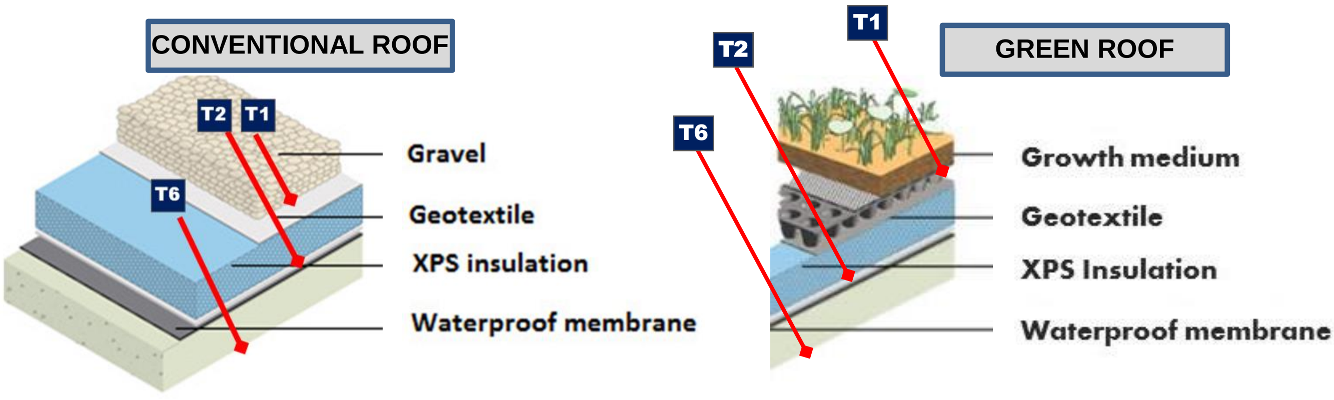

Figure 3.2. Scheme of thermocouple location on conventional and green roof.

During the whole monitoring period the same thermocouples Type T were employed, no substitutions were necessary. These thermocouples have a maximum error of 0.5 ºC.

Two four-channel datalogger (PCE T-390) were employed for the six temperature acquisition systems.

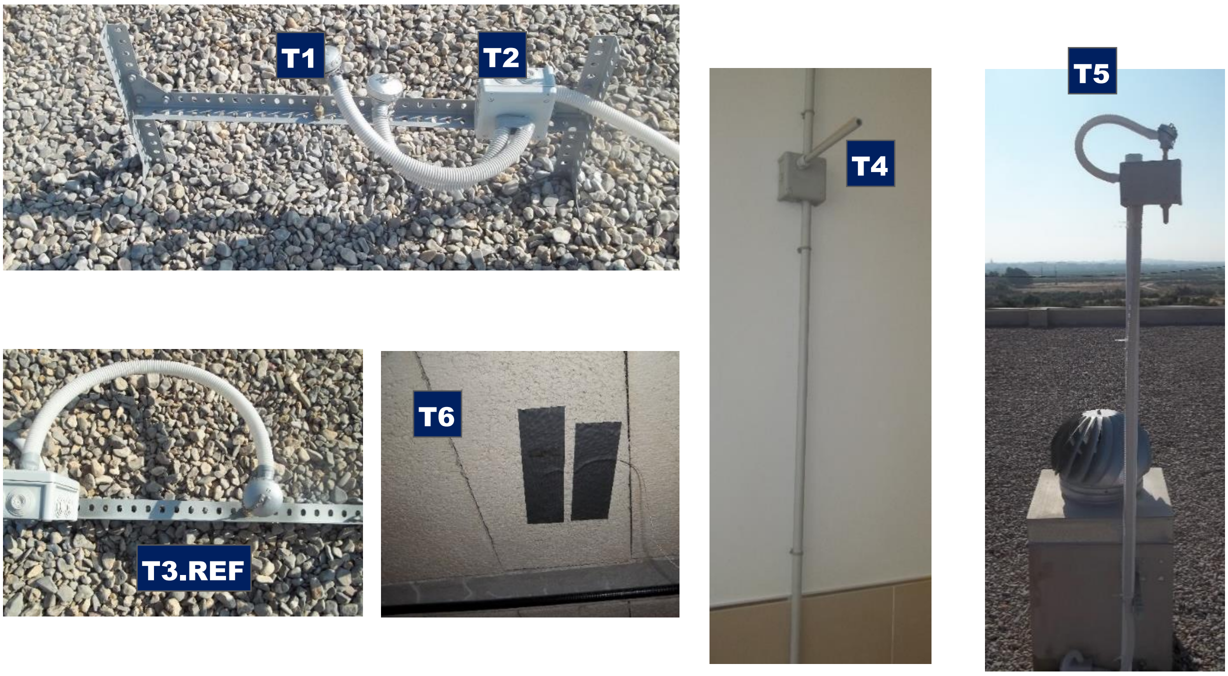

Figure 3.3. Images of thermocouple location on conventional and green roof (*).

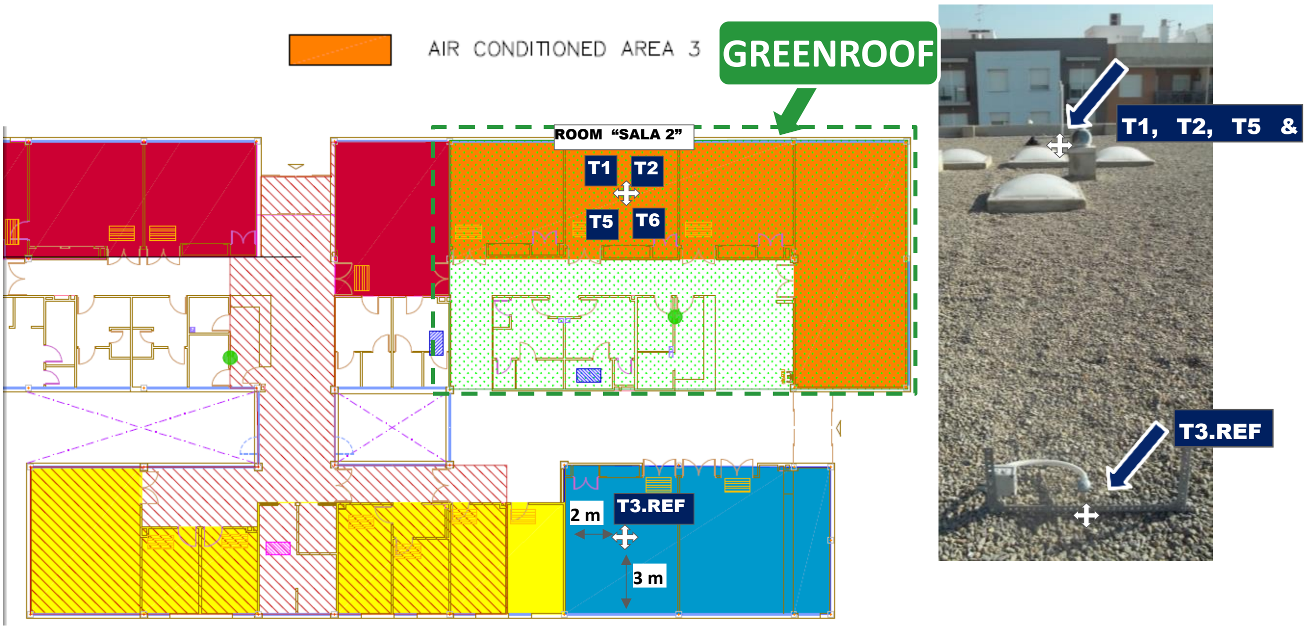

Figure 3.4. Addition scheme and real view of thermocouple location.

3.4. Outdoor conditions monitoring

Rainfall with a rain gauge and outdoor temperature with thermocouple T4 (as described in previous point) were recorded. Additionally, solar radiation, outdoor temperature, wind speed, humidity and rainfall was also obtained from a weather station located in Lliria (5 kilometer from Benaguasil). Weather daily data for 2013 and 2014 was provided by Spanish government (through AEMET agency).

3.5. Runoff water quantity monitoring

The hydraulic monitoring focused in the comparison between the outflow of the green roof and the outflow of the adjacent conventional roof. The main hydraulic variable of interest is the outflow rate from the downpipes of each roof (conventional and green). The flow rate through the downpipes of the green roof was monitored with tipping bucket flow gauges (Figure 3.6). In this case, every time the bucket tips, an electrical pulse is recorded. All this equipment was previously calibrated in the laboratory, especially the tipping buckets to know accurately the volume of water causing each tip. Finally, data loggers recorded the outputs from these tipping buckets. In the conventional roof, the water is registered before being stored in a rainwater harvesting tank, used for irrigation purposes.

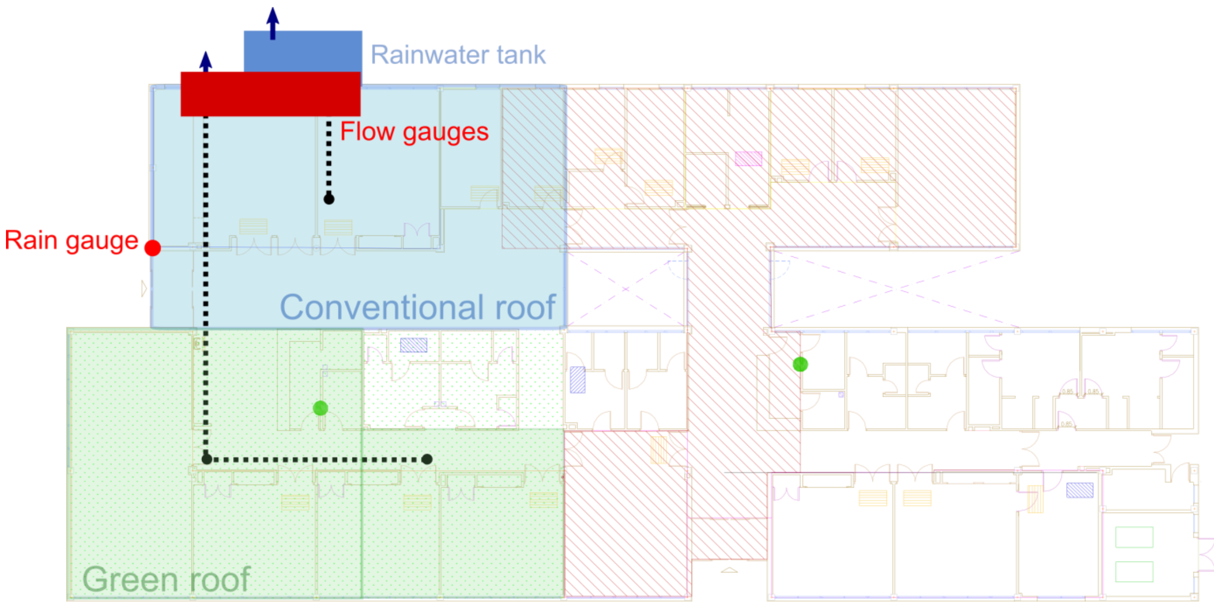

Figure 3.5. Hydraulic monitoring system in the green roof building.

Outflow rates from the roofs are compared with the rainfall data measured with a rain gauge located in the building roof (Figure 3.7).

Figure 3.6. Tipping buckets to measure outflow rates from the conventional and the green roofs.

Figure 3.7. Rain gauge located in the green roof building.

3.6. Runoff water quality monitoring

Water quality samples aim to compare the difference in the water quality processes between the green roof and its adjacent conventional roof. Samples were collected in four bottles linked to the tipping buckets (two bottles per tipping bucket). The boxes where the buckets were placed were designed to allow the bottles to be filled consecutively at the start of the rain event and thus, there were a total of four samples per event.

Figure 3.8. Outflows in the tipping buckets for the four water quality sampling bottles.

Water quality samples were taken after four different rainfall events. In two of these events, the four bottles were analysed, while in the other two only the two bottles that are filled first were analysed. In total, twelve different samples have been analysed during the monitoring year.

Water samples have been analysed for chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), Five day biological oxygen demand (BOD5), Total suspended solids (TSS), volatile suspended solids (VSS) and turbidity.

In addition, four more samples weretaken to compare the water in the rainwater harvesting tank (which comes from the conventional roof) and the water in a small tank that stores part of the outflow from the green roof. These samples have been taken one month after the rainfall event, in order to check if water from these roofs, after being stored one month, fulfils the water quality requirements to be used for irrigation. Then, in these cases the E. coli and the Intestinal nematodes were also analysed.

4. RESULTS

In this point, main monitoring results regarding temperature, power consumption and hydraulic monitoring are shown.

The effects of heat storage of the materials through the thermocouple located below the gravel layer (for the conventional roof), and below the organic substrate (for the green roof) is analyzed in this section. In conventional roof, gravel layer had a significant heat storage effect; in fact, temperatures of approximately 45-55ºC were recorded in summer. Once green roof layer was installed, maximum temperatures where about 30-35ºC, so heat storage effect was softened and delayed.

Regarding energy consumption it is shown a representative data or energy consumption of the air conditioning system, for winter and summer, in the initial situation (conventional roof) and the final situation (green roof). Additionally, power consumption before and after installing the green roof was compared during similar days (according, mainly, to solar radiation and outdoor temperatures) from 9:00 to 13:00 (to avoid start and final operating times).

About the hydraulic monitoring, runoff volumes from the green roof are much lower than the runoff from the conventional roof, as expected.

4.1. TEMPERATURE MONITORING

The following graphics show, for winter and summer, how the green roof changes the thermal behavior of the roof. In the comparative graphics very similar days are included (average temperatures difference < 1ºC, from 7:00 to 13:00, and solar radiation difference<10%, for the same period).

Comparative SUMMER results:

According to data acquisition during monitoring periods (see Table 4.1 and Table 4.2, valid testing days for summer), it can be concluded that, for conventional roof, peak temperature is reached about 2-4 hour later than outdoor peak temperature, and that peak temperature is 10-12º degrees higher than outdoor temperature due to the heat storage effect of the gravel layer.

For the green roof, in summer, conclusions are:

- Peak temperature is reached about 7-9 hours later than outdoor temperature.
- Peak temperature (below substrate) is 4-6 ºC degrees lower than peak outdoor temperature.

An example of these thermal behaviour conclusions is included in Figure 4.1.

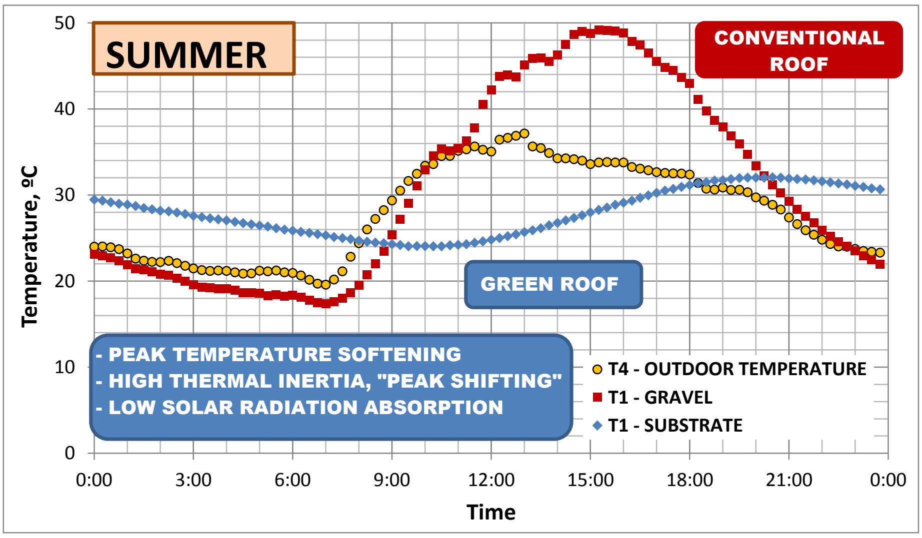

Figure 4.1. Comparative temperature profiles for summer.

Comparative WINTER results:

According to data acquisition during monitoring periods (see Table 4.1 and Table 4.2, valid testing days for winter), it is observed that, for conventional roof, peak temperature is reached about 1 hour later than outdoor peak temperature, and that peak temperature is 2-3 degrees higher than outdoor temperature due to heat storage effect of gravel layer.

For the green roof, in winter, conclusions are:

- Peak temperature is reached about 4-6 hours later than outdoor temperature.
- Peak temperature (below substrate) is 4-6 ºC degrees lower than peak outdoor temperature.

An example of these thermal behaviour conclusions is included in Figure 4.2.

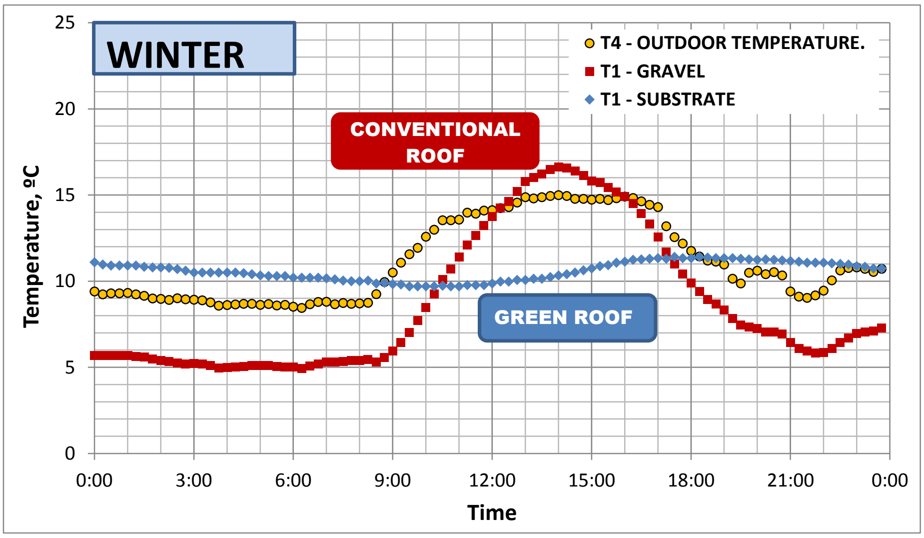

Figure 4.2. Comparative temperature profiles for winter.

4.2. ENERGY MONITORING

The following tables show, for winter and summer, the energy consumptions associated to the air conditioning system and other measured parameters. The first table (Table 4.1) refers to the **conventional roof** and the second one (Table 4.2) to the **green roof**.

Parameter	SUMMER	WINTER
Average daily consumption [9:00-13:00]	**31.3 kWh** (30 -35 kWh).	**22.6 kWh** (20 -25 kWh).
Gravel (upper exterior layer) MAX temperature	45-55ºC "Heat storage" effect.	20-30ºC
PERIOD (valid testing days)	23/07/2013 to 3/09/2013.	26/11/2013 to 4/02/2014.
Average OUTDOOR temperature [7:00-13:00], (ºC)	29.4ºC	10.9ºC
Average solar radiation [7:00-13:00], kWh/m^2	0.67 kWh/m^2	0.24 kWh/m^2

Table 4.1. Energy monitoring results of the conventional roof

It is concluded that in the case of the conventional roof (initial situation) energy consumption in summer is much higher than in winter. This fact is especially important taking into account that the building is located in Mediterranean climate, which is characterized by hot and long summers versus mild and short winters).

Table 4.2 includes main energy monitoring results for the **green roof**:

Parameter	SUMMER	WINTER
Average daily consumption [9:00-13:00]	**21.9 kWh** (20 -25 kWh)	**23.7 kWh** (20 -29 kWh).
Gravel (upper exterior layer) MAX temperature	20-35ºC	5-15ºC
PERIOD (valid testing days)	01/07/2014 to 11/09/2014	09/12/2014 to 07/01/2015
Average OUTDOOR temperature [7:00-13:00], (ºC)	29.4ºC	11.05ºC
Average solar radiation [7:00-13:00], kWh/m^2	0.70 kWh/m^2	0.25 kWh/m^2

Table 4.2. Energy monitoring results of the green roof.

It can be concluded that in the case of the green roof, energy consumption in summer and winter is very similar. Compared with conventional roof, green roof provides:

- Consumption in summer is 30% lower.
- Consumption in winter is slightly higher, about 5%.

It can be concluded that, in an annual basis, electricity saving in the air conditioning system would be in the range 15-20%, and about 10-15% in the whole annual electricity consumption.

Figure 4.3 and 4.4 include real data of power consumption in summer and winter, respectively. It is observed, as expected, 25-30% of power savings for summer and slightly higher power consumption for winter.

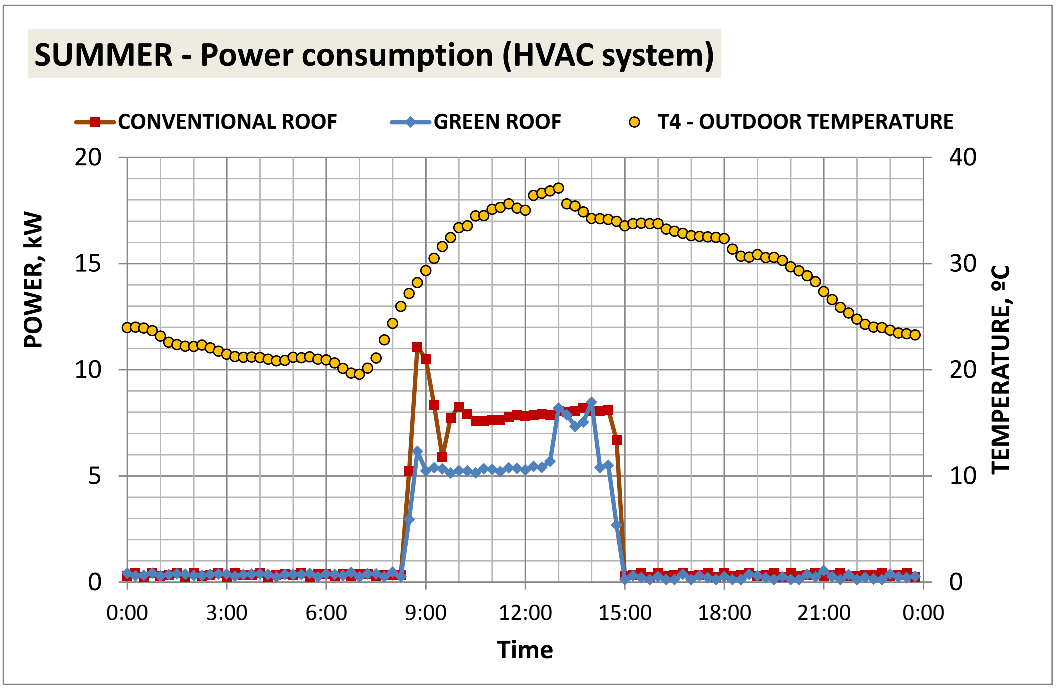

Figure 4.3. Comparative power consumption profiles for summer.

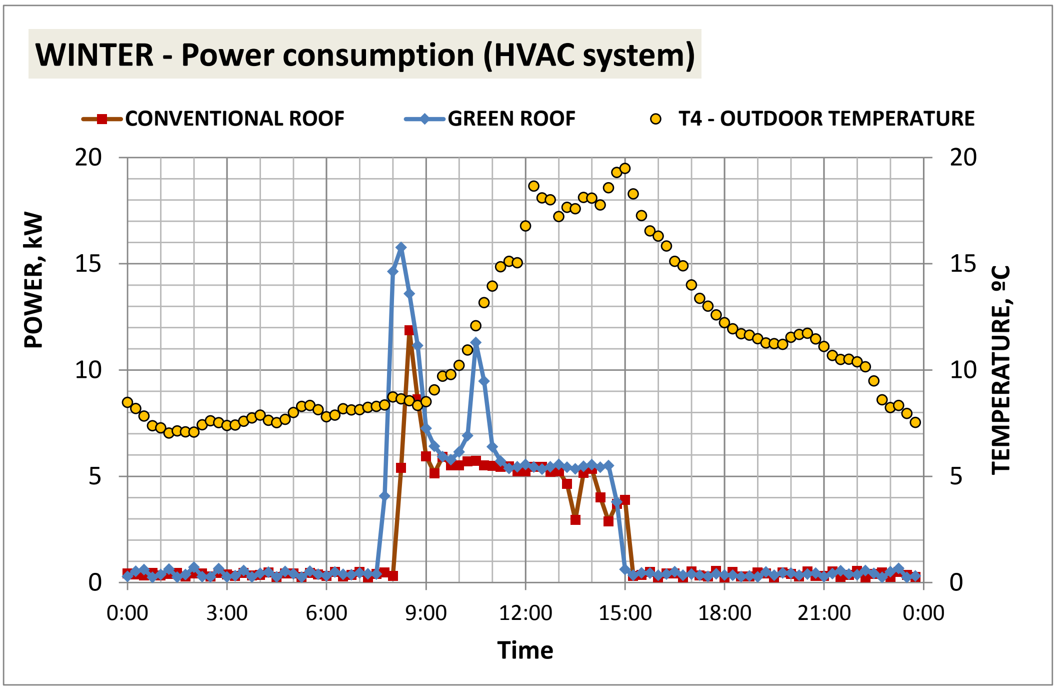

Figure 4.4. Comparative power consumption profiles for winter.

4.3. Runoff water quantity monitoring

The hydraulic performance of the green roof and the adjacent conventional roof was monitored from April 2014 to May 2015. In the following table, a summary of these results is presented taking into account the most significant rainfall events (total precipitation higher than 3 mm).

Strating date	Rainfall (mm)	Volume reduction in conventional roof	Volume reduction in green roof
14/06/2014	3.2	47%	59%
02/07/2014	17.6	20%	53%
07/09/2014	3.2	76%	98%
22/09/2014	23	21%	69%
28/09/2014	6.2	45%	76%
12/10/2014	6.2	43%	88%
04/11/2014	9.4	29%	93%
11/11/2014	10.8	17%	88%
27/11/2014	89	2%	57%
14/12/2014	27.8	0%	57%
18/01/2015	4.6	44%	95%
30/01/2015	3.6	62%	97%
11/02/2015	3.4	59%	98%
17/02/2015	4.4	50%	96%
18/03/2015	125.2	0%	55%
19/05/2015	14.4	2%	90%
TOTAL	**352**	**9%**	**63%**

Table 4.3. Hydraulic monitoring results of the conventional roof and the green roof.

The volume reduction shows the ratio between the runoff managed by the roof and the total runoff produced by the contributing area in this rainfall event. Thus, a volume reduction of 80% means that only 20% of the event runoff volume produced overflow.

In this table, it can be observed that the volume reduction produced by the green roof is higher than the one produced by the conventional roof in all the cases. The total average volume reduction during the year is 63% in the green roof and 9% in the conventional roof.

In the first rainfall events, the volume reduction provided by the green roof was lower since it was being over irrigated. This fact produced that the soil was saturated so the water volume stored was lower.

The most significant event began on 18/03/2015, with a total precipitation of 125.2 mm during four days. The performance of both roofs during this event is shown in the following figure:

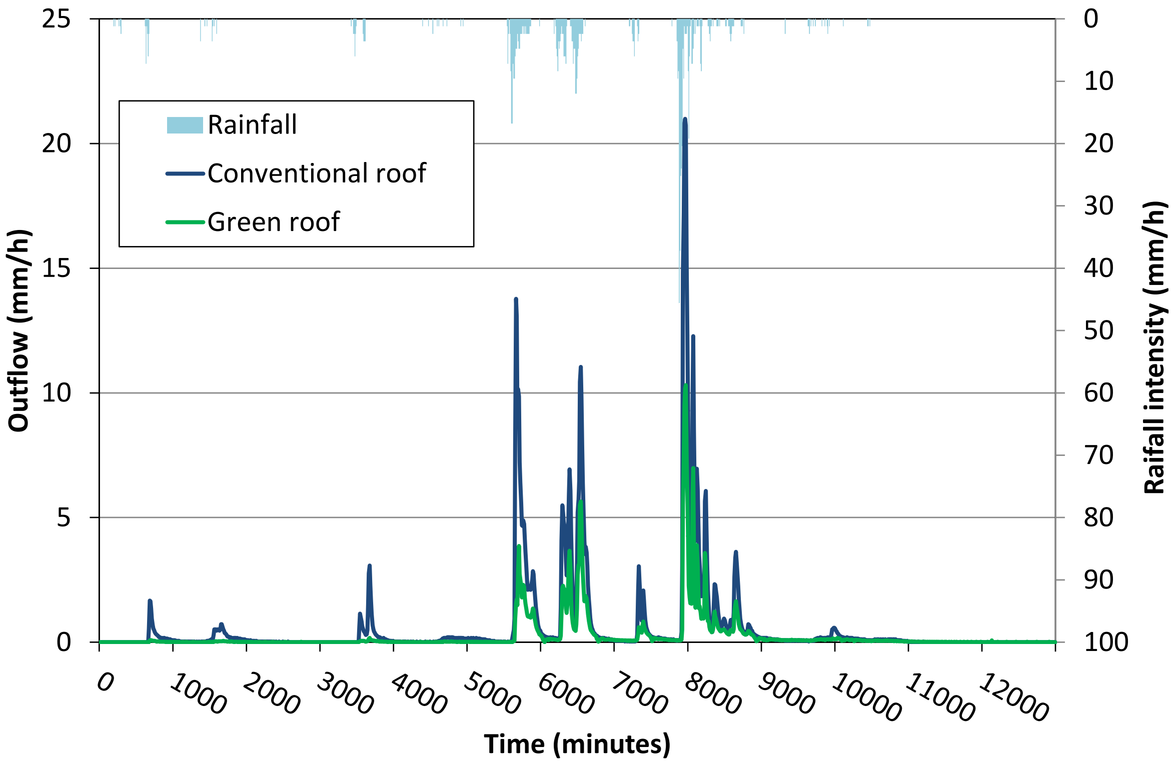

Figure 4.5. Performance of the two roofs during the rainfall event that started on 18/3/2015.

Results show that the peaks of the outflow from the green roof are lower in all the cases, especially for lower intensity periods. If we focus on the highest intensity part of this rainfall event (Figure 4.6), this difference can be observed more clearly.

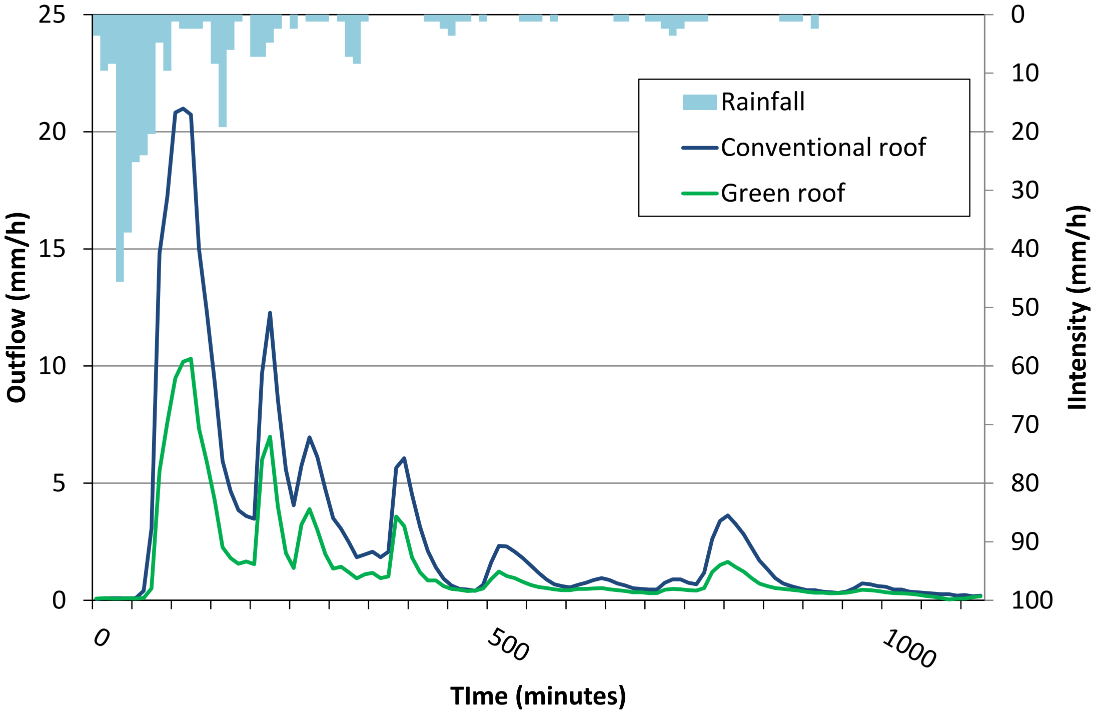

Figure 4.6. Performance of the two roofs during the highest intensity part of the rainfall event that started on 18/3/2015.

This reduction of runoff peaks and volumes is especially significant during low intensity events. For instance, in the following hydrograph the performance of the two roofs during the 12/10/2014 event is shown in Figure 4.7. As it can be observed, the runoff reduction in the green roof is significant, being about 88% of the total rainfall volume.

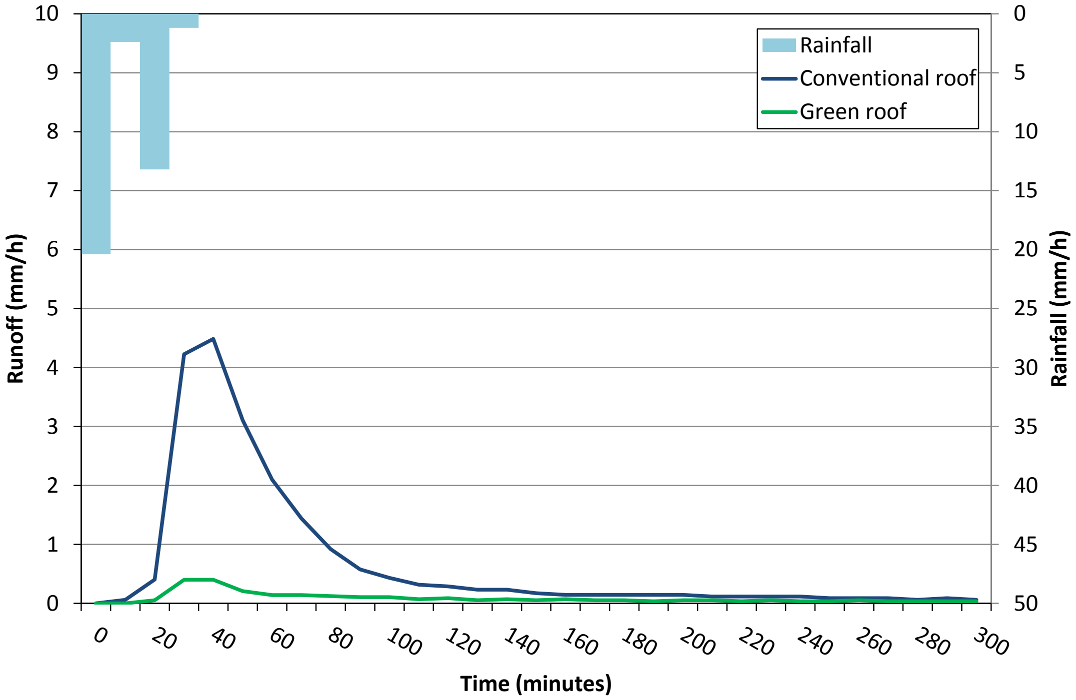

Figure 4.7. Performance of the two roofs during the event that started on 12/10/2014.

In conclusion, the green roof has produced lower runoff peaks and volumes than the conventional roof for all the monitored period. The same results and performances were obtained during the monitoring of a green roof in Xàtiva (Spain) during the AQUAVAL project (Perales-Momparler *et al.*, 2014).

4.4. Runoff water quality monitoring

As explained in Section 3, water quality samples were taken after four different rainfall events. In two of these events, four bottles were analyzed (first and second filling of each roof), while in the other two only the two bottles that are filled first were analysed. In total, twelve different samples were analysed during the monitoring year. The results of these tests are summarised in the following table:

		Event 22/9/14				Event 27/11/14			
		Conventional		Green		Conventional		Green	
		Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
Turbidity	N.T.U.	2.3	3.7	1.1	0.3	0.1	-	1.5	-
Suspended soils	mg/l	12	10	11	7	< 5	-	9	-
BOD5	mg O2/l	5	< 5	12	60	< 5	-	8	-
COD	mg O2/l	28	19	116	186	12	-	166	-
Total Nitrogen	mg N/l	8.6	6.5	< 5	7	12.7	-	< 5	-
Total Phosphorus	mg P/l	0.2	0.3	0.4	0.7	0.08	-	0.5	-
		Event 14/12/14				Event 17/2/15			
		Conventional		Green		Conventional		Green	
		Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
Turbidity	N.T.U.	19.7	20.4	1.4	12.3	2	-	34.2	-
Suspended soils	mg/l	< 5	10	< 5	7	5	-	100	-
BOD5	mg O2/l	< 5	< 5	< 5	7	< 5	-	12	-
COD	mg O2/l	8	12	133	90	25	-	50	-
Total Nitrogen	mg N/l	< 5	< 5	< 5	< 5	6.6	-	5.4	-
Total Phosphorus	mg P/l	0.1	0.1	0.6	0.2	< 0.05	-	0.07	-

Table 4.4. Water quality results of the outflow of the two roofs.

The results show that green roof does not have clear benefits for water quality, since some of the parameters are higher and other are higher than in comparison with the conventional roof. On one hand, in general, water from the green roof was highly brown in color but clearer than water from the conventional roof (lower turbidity). Generally, the outflow from the green roof also presented lower concentrations of suspended soils and total nitrogen.

On the other hand, organic matter concentration in the green roof outflow is much higher than the concentration in the conventional roof in all the cases, as shown by BOD5 and COD results. Total phosphorus is also higher in the green roof outflow.

In addition, four more samples were taken to compare water in the rainwater harvesting tank (which comes from the conventional roof) and water in a small tank that stores part of the outflow from the green roof. These samples were taken one month after the rainfall event, in order to check if water from these roofs, after being stored one month, fulfils the water quality requirements to be used for irrigation. The results of these tests are shown in the following table:

		Sample: 4/12/14 After event 4/11/14		Sample: 16/3/15 After event 17/2/15	
		Conventional	Green	Conventional	Green
Turbidity	N.T.U.	7.2	< 0.1	0.2	0.5
Suspended soils	mg/l	< 5	10	12	9
BOD5	mg O2/l	< 5	10	< 5	9
COD	mg O2/l	12	150	8	28
Total Nitrogen	mg N/l	< 5	< 5	< 5	< 5
Total Phosphorus	mg P/l	0.2	1.2	0.1	0.06
E. coli	CFU/100 ml	8	0	2	0
Intestinal nematodes	HH/10l	< 1	< 1	< 1	< 1

Table 4.5. Water quality results of the rainwater harvesting tanks.

According to these results, it can be concluded that the water from both roofs can be used for irrigation after being one month in the tank, since water quality requirements are 200 CFU/100ml for e.coli and 1 HH/10l for intestinal nematodes. For the rest of parameters, the conclusions obtained are the same that the obtained for the rest of water quality analysis.

5. CONCLUSIONS

A green roof has been constructed and monitored during one year in Benaguasil from an energetic and hydraulic point of view.

About the energetic monitoring, on field measurements showed that in the initial situation, conventional roof, electricity consumption of the air conditioning system is much higher (about 38%) in winter rather than in summer.

On the one hand, the effects of heat storage were analysed (from solar radiation absorption) and thermal inertia provided by the outer constructive layer (in which the change has occurred) of the roof. In the conventional roof, the gravel layer had a significant heat storage effect, in fact, temperatures of approximately 45-55ºC were recorded in summer. Once the green roof was installed, maximum temperatures below growth medium where about 30-35ºC, so heat storage effect was softened (lower net solar radiation absorption) and delayed (so peak heat gains in summer occurs in the afternoon, out of the normal operating schedule).

On the other hand, power consumption before and after installing the green roof was compared during similar days (according, mainly, to solar radiation and outdoor temperatures) from 9:00 to 13:00 (to avoid start and final operating times). It was concluded that consumption in summer is reduced in about a 30%, and minor changes can be observed in winter. On an annual basis it can be concluded about 20-25% of electricity saving for the air conditioning systems which accounts for 65-70% of the total electricity consumption of the building.

Regarding the hydraulic monitoring, runoff water quantity results show that the green roof reduces significantly the runoff volume and peaks in all the registered rainfall events in comparison with the adjacent conventional roof. This reduction is especially important for the low intensity events.

Finally, water quality results show that the green roof may increment the concentration of organic matter in the water, although in general outflow water turbidity and suspended solids are lower.

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LIST OF FIGURES AND TABLES

Figures

Tables

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