Experimental evaluation of the thermal performance of semi-intensive green roofs in Mediterranean climate

Diogo F. Neves
diogo.f.neves@tecnico.ulisboa.pt

DECivil, Instituto Superior Técnico
Lisbon University, Lisbon, Portugal

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Abstract

The use of green roofs in new buildings has been getting more attention. There are many known environmental benefits to its use in urban zones, where permeable areas with vegetation are usually almost inexistent, however its thermal performance is not yet that well known. It's important to understand how green roofs behave in order to design more environmental and energy sustainable buildings. Vegetation and substrate are important distinguishing elements that influence the behavior of green roofs. In order to study and optimize green roofs, there were assembled, in Instituto Superior de Agronomia, models of semi-intensive green roofs, with different vegetation and substrate types, originaly built for the project NativeScapeGR. The variables that were monitored in the experimental campaign are: indoor, outdoor, surface temperatures, and along the growth medium, solar radiation, heat flux and relative humidity for two seasons, winter and summer. In the winter, denser vegetation reduced the heat loss but it also reduced solar gains, however they weren't very significant. In the summer, denser vegetation yielded more benefits by reducing the amount of solar radiation that was absorbed by the substrate, from shading effects, and by evapotranspiration, preventing the indoor from overheating.

Keywords
Semi-intensive green roofs
Thermal performance
Heat transmission
Thermal behavior
Mediterranean climate

1 Introduction

The fast development of big cities has been creating many problems regarding its habitability. From the inception of cities, problems such as salubrity has been an important issue. Urban mobility issues and over industrialization leads to other problems such as air pollution. Being a big problem on its own, air pollution also causes temperatures to rise, creating the Urban Heat Island (UHI) phenomenon (Wong & Lau, 2013). Increasing the greenery in cities is a way to mitigate the problems that are affecting these over populated urban areas. However, that is not always an easy solution. Older cities are very crowded spaces, with narrow streets and has little space to implement gardens and parks inside its perimeter. Plant trees in the sidewalks is one of the possibilities but it is far from enough to overcome that problem. There are special limitations because of the high density that characterizes cities. Since the rooftops have little to no use in many cities and buildings, implementing green roofs might be a solution to this issue.

Many advantages of using green roofs in urban areas have been researched from sustainability of the building to environmental issues. They are a great way to manage the concerns felt in the cities, regarding its habitability. The most obvious benefit is cleaning polluted air, since plants recycle harmful gases and convert them to oxygen. Placing plants on rooftops allows them to get much more sunlight than if they were between buildings, maximizing photosynthesis phenomena and its ability to produce oxygen. This solution also helps reducing temperatures. By blocking and absorbing the solar radiation from reaching the roof surface, the vegetation reduces the effects of UHI and the energy gained by the building leading to less cooling needs, so its energetic efficiency is better than the traditional roofs (Sfakianaki et al., 2009). Also aiding in cleaner air indirectly, by reducing the use of energy from polluting power plants (Vijayaraghavan, 2015). Since the plants need water, the growth medium has to absorb water, this makes this roof solutions to retain significantly more water than traditional roofs. During storm events, many stormwater drainage systems work near full capacity, so green roofs have the capacity to prevent floods (Simmons et al., 2008). The quality of the water that flows through green roofs might also increase, for example acid rain. The urban aesthetical appeal is also a factor to consider when developing new projects, giving back to the cities some nature that they lost to construction.

Green Roofs have been used in the past, mostly as decoration for important buildings, but some cultures have realized its thermal capabilities. The extra layers provide thermal inertia to the building and the vegetation also acts as an isolation layer protecting reducing the absorption of solar radiation (Fioretti et al., 2010). These layers also better the acoustic properties of the buildings, while protecting the waterproof membrane from being damaged by the thermal amplitudes that occur during the day (Liu, 2004), this means they could be more durable.

Those benefits must come with a price. Because of it being a more complex solution, there are more layers to install, higher loads and even automated watering systems to implement, these solution have higher initial costs. Sometimes they even require a special structure to hold the load, increasing the overall building costs. During its life cycle they often carry more maintenance, to ensure the preservation of the vegetation, and that must be considered in the economic evaluation.

With many building codes demanding higher thermal and energetic efficiency, it's important to investigate thermal performance of these techniques to ensure that the regulations have been met and improve on its efficiency. Many studies have been conducted, in different climates, to determine the optimal solution. This study focuses mainly on the effect that the vegetation the growth medium have on the system's thermal performance.

Using small scale models, it was analyzed the thermal performance of semi-intensive green roofs in a Mediterranean climate, as it affects Portugal. To build the model it was used trays from the NativeScapeGR (FCT, 2015) project which are located at the Instituto Superior de Agronomia (ISA), in Lisbon, Portugal.

For this experimental situation it was intended to evaluate the thermal performance of the experimental tray tables during the winter and summer seasons. The goal is to compare the thermal performance of various types of soils as well as the use of insulation, and lastly it is planned to analyze the influence of different species of vegetation and identify other parameters that can be of influence to the thermal performance of green roofs in a Mediteranean climate. Extreme days for each season's campaign will also be used in order to understand the thermal behavior of the green roof in a severe seasonal situations.

Nomenclature

S1	Substrate nº1
S2	Substrate nº2
T3	Tray nº 3
T5	Tray nº5
T6	Tray nº6
T7	Tray nº7
wi	With insulation
x	Random variable representative of each table tray, x = [3, 5, 6, 7]
U	Heat transmission coefficent [W/(m2.ºC)]
Q	Heat flux [W/m2]
α	Absorption coefficient

2 Green roofs

Green roofs are type of living roof, characterized by having a growth medium, on top of a building, where vegetation is planted with specific species. These plants can be grass, shrubs and even trees. Some living roofs start as brown roofs, with local growth medium, and are naturally colonized by local species over time. The term brown roofs is used because of its color at the time of installation, turning green once the plants establish themselves (Brownroofs, 2015).

To be successful and durable, a green roof has to have many layer that maintain good conditions, both for the vegetation and the building. Under the growth medium, or substrate, there must be a drainage element, to keep the substrate moist but not oversaturated, protected by a geofilter, so the smaller particles don't get washed away and clog the system. Beneath this there should be a protection layer and a root barrier, protecting the insulation layer and the waterproof layer. Waterproof layer is fundamental for the success of any green roof because any leak is very hard to detect because it is covered by the mentioned layers (Vijayaraghavan, 2015).

Green roofs can be divided into three categories depending on the thickness of the substrate layer and the planed use given to the green roof (accessible or not) as well as the maintenance costs: extensive, semi-intensive and intensive (Henry & Frascaria-Lacoste, 2012). Extensive roofs have a thin layer of soil (i.e. between 6 and 20cm), are easily implemented on site, require little maintenance and are not accessible therefore less expensive (Fioretti et al., 2010). Intensive roofs have a greater thickness (more than 15cm) and may contain various types of vegetation (e.g. trees). This kind of roof is used in accessible rooftops of heavier buildings and garages and requires a more regular maintenance. The last category is semi-intensive roofs and these have mixed characteristics of both extensive and intensive green roofs. A table comparing these characteristics was elaborated and shown in IGRA (2012).

2.1 Previous studies

The modern technologies of green roofs have been developed in Germany, where it's been strongly adopted by many years and it's properties have been continuously investigated. Other countries like USA Canada, Australia, Singapore and Japan are also developing initiatives to implement green roofs (Vijayaraghavan, 2015). Some cities also have made regulations to make green roofs mandatory in new buildings: Copenhagen, Munich, Portland and Singapore (IGRA, 2012).

There have been many studies conducted about green roofs in several other countries and in different climates: in cold climates (Liu, 2004; Lanham, 2007; Sailor et al., 2008; Sailor et al, 2011; Squier & Davidson, 2016), tropical climates (Wong et al., 2003; Simmons et al., 2008; Feng et al., 2010; Qin et al., 2012; Lin et al., 2013; Dvorak & Volder, 2013; Yang et al, 2015) and Mediterranean climates (Niachou et al., 2001; Lazzarin et al., 2005; Sfakianaki et al., 2009; Ouldboukhitine et al., 2014; Schweitzer & Erel, 2014; Bevilacqua et al., 2015).

In cold climates it has been found that, a vegetation with a high LAI (Leaf Area Index), a high relation in aggregate/sand and a low quantity in organic matter in the soil, and also low tenor of moisture, are factors that favor cooling of a building in warm seasons, while in cold seasons, the insulation layer is the main factor to maintain the inner temperature, hence green roofs are more efficient in warmer climates. However, during the rainy seasons, water retention values overcome the 50% for normal showers but it lowers as the rain intensity rises.

In tropical climates, the substrate and vegetation characteristics have a big influence on the preformance of the green roofs. By being located in places with high humidity, it was shown that green roofs are efficient even without a constant irrigation and also on days without rainfall. It was observed that green roofs can reduce the UHI efect in urban areas and can also decrease thermic fluctuations on rooftops. During rain events, it was found that the bigger the event lower the water retention capacity, although to small events, water retention capacity can reach levels above 50%, as shown for cold climates.

Investigations conducted in Mediterranean climates concluded that the shadow effect caused by the vegetation on the soil and its moisture content, had significant influence in cooling processes of the building, since these two factors help green roofs to cool the buildings, in a passive way during summer. Without insulation, there was a reduction in heat fluxes through green roofs, over 50%, and in some cases being nonexistent, when the soil was wet. Resembling tropical climates, the need of refrigeration has been lowered over 10 %. It was proven that 8cm of substrate is sufficient to stabilize the temperature in the roof deck.

3 Case Study

To model the thermal behavior of green roofs, it was used four metallic trays with different vegetation and substrates. They were chosen out of twelve trays, from NativeScapeGR project (FCT, 2015), to have two different samples of substrate with the same vegetation and other two types of vegetation. The trays are located in ISA, each 2,5m long, 1m wide, 20cm high and a constant thickness of 1,5mm. Trays are supported by a metal frame that elevates them about 0,8m height from the roof floor.

All trays has a growing medium with a thickness of 13cm. Under the substrate there's a drainage system, consisting of a mechanical protection layer (i.e. geotextile), followed by a drainage layer (i.e. Floradrain FD 25-E) and topped with a filter (i.e. geotextile) which with the resistant support (i.e. tray plate) represents a total thickness of 2 cm (Figure 1).

Under the trays were created compartments to simulate the inside of a building. The walls and floor were made by extruded polystyrene (XPS) plates with 10cm of thickness. The walls were closed together with straps and braced between themselves to improve its airtightness.

Bellow the tray, on the ceiling of the compartments was placed a 3cm plate of XPS to create an insulated area on each tray, being the rest non.isulated. In Figure 1 it's represented a profile of the insulated area of the tray, the non-insulated is the same but without the extruded polystyrene.

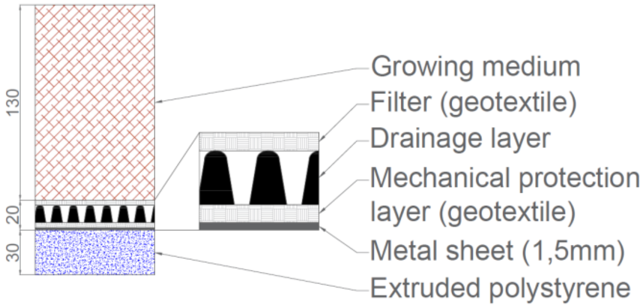

Figure 1 - Profile of the layers of the trays [mm]

There are two types of substrates (i.e. substrate S1 and S2) that differ in concentrations of sand, silt, clay and organic matter. The S1 substrate has more organic matter and S2 is sandier. Regarding the plant composition there are three bushes (i.e. *Brachypodium Phoenicoides*, *Rosmanirus Officinalis*, *Lavandula Luisieri*) and a moss (*Pleurochaete*). Its distribution per tray is presented on Table 1. The absorptivity for each tray was determined by Meneses (2015).

Table 1 - Substrates and vegetation of each tray

Tray	**GM**	**Vegetation**			**Absor. (α)**
		Common name	**Scientific name**	**Height (cm)**	
T3	S2	N/A	Brachypodium Phoenicoides	20-25	0,76
T5	S1	French Lavender	Lavandula Luisieri	50-60	0,82
		Rosemary	Rosmanirus Officinalis	30-50	
		N/A	Brachypodium Phoenicoides	20-25	
		Moss	Pleurochaete	1-2	
T6	S1	Rosemary	Rosmanirus Officinalis	30-60	0,82
T7	S1	N/A	Brachypodium Phoenicoides	20-25	0,71

All trays were subjected to automated irrigation, with the same daily amount of water which was equal to 60% ET_0. The only difference between irrigation was the timing and methods. On the tray with moss, T5, watering was carried out at 8am, 10am and at 7pm, through two systems (i.e. drip and misting irrigation systems); in the remaining trays (i.e. T3, T6 and T7) there was only a daily watering at 8am performed using the drip irrigation system.

3.1 Experimental procedure

The equipment installed in each tray is present in Table 2 and Table 3**Error! Reference source not found.** and its location is displayed on a tray-type illustrated in Figure 2.

A total of 48 thermocouples, 4 heat flux sensors, 4 thermo hygrometers, 1 pyranometer, 2 data acquisition systems (Delta-T - DL2e Data Logger and Campbell – CR10) and a heating system with 4 100w lightbulbs and a thermostat have been used.

Table 2 - Equipment on tray T3

Tray	Cell	Description	Unit
T3	Tse,3	Exterior surface temperature in NIA	°C
	Th1,3	Soil temperature (h=6.5cm) in NIA	°C
	Th2,3	Soil temperature (h=0cm) in NIA	°C
	Tsi,3	Interior surface temperature in NIA	°C
	Tsewi,3	Exterior surface temperature in IA	°C
	Th1wi,3	Soil temperature (h=6.5cm) in IA	°C
	Th2wi,3	Soil temperature (h=0cm) in IA	°C
	Tsiwi,3	Interior surface temperature in IA	°C
	Ti,3	Interior temperature	°C
	Ti,3,R	Interior temperature by Rotronic	°C
	Hi,3,R	Interior relative humidity by Rotronic	%

NIA - non-insulated area

IA - insulated area

Tray	Cell	Description	Unit
T5	Te,5	Exterior temperature	°C
	Tse,5	Exterior surface temperature in NIA	°C
	Th1,5	Soil temperature (h=6.5cm) in NIA	°C
	Th2,5	Soil temperature (h=0cm) in NIA	°C
	Tsi,5	Interior surface temperature in NIA	°C
	Tsewi,5	Exterior surface temperature in IA	°C
	Th1wi,5	Soil temperature (h=6.5cm) in IA	°C
	Th2wi,5	Soil temperature (h=0cm) in IA	°C
	Tsiwi,5	Interior surface temperature in IA	°C
	Ti,5	Interior temperature	°C
	Fl,5	Heat flux in NIA	W/m2
	Flwi,5	Heat flux in IA	W/m2
T6	Tse,6	Exterior surface temperature in NIA	°C
	Th1,6	Soil temperature (h=6.5cm) in NIA	°C
	Th2,6	Soil temperature (h=0cm) in NIA	°C
	Tsi,6	Interior surface temperature in NIA	°C
	Tse^{wi},6	Exterior surface temperature in IA	°C
	Th1^{wi},6	Soil temperature (h=6.5cm) in IA	°C
	Th2^{wi},6	Soil temperature (h=0cm) in IA	°C
	Tsi^{wi},6	Interior surface temperature in IA	°C
	Ti,6	Interior temperature	°C
	Ti,6,T	Interior temperature by Tinytag	°C
	Hi,6,T	Interior relative humidity by Tinytag	%
T7	Te,7	Exterior temperature	°C
	Tse,7	Exterior surface temperature in NIA	°C
	Th1,7	Soil temperature (h=6.5cm) in NIA	°C
	Th2,7	Soil temperature (h=0cm) in NIA	°C
	Tsi,7	Interior surface temperature in NIA	°C
	Tse^{wi},7	Exterior surface temperature in IA	°C
	Th1^{wi},7	Soil temperature (h=6.5cm) in IA	°C
	Th2^{wi},7	Soil temperature (h=0cm) in IA	°C
	Tsi^{wi},7	Interior surface temperature in IA	°C
	Ti,7	Interior temperature	°C
	Ti,7,R	Interior temperature by Rotronic	°C
	Hi,7,R	Interior relative humidity by Rotronic	%
	Fl,7	Heat flux in NIA	W/m^2
	Fl^{wi},7	Heat flux in IA	W/m^2
Ext.	Te,T	Exterior temperature by Tinytag	°C
	He,T	Exterior relative humidity by Tinytag	%
	SR	Solar radiation in horizontal plan	W/m^2

Table 3 - Equipment o

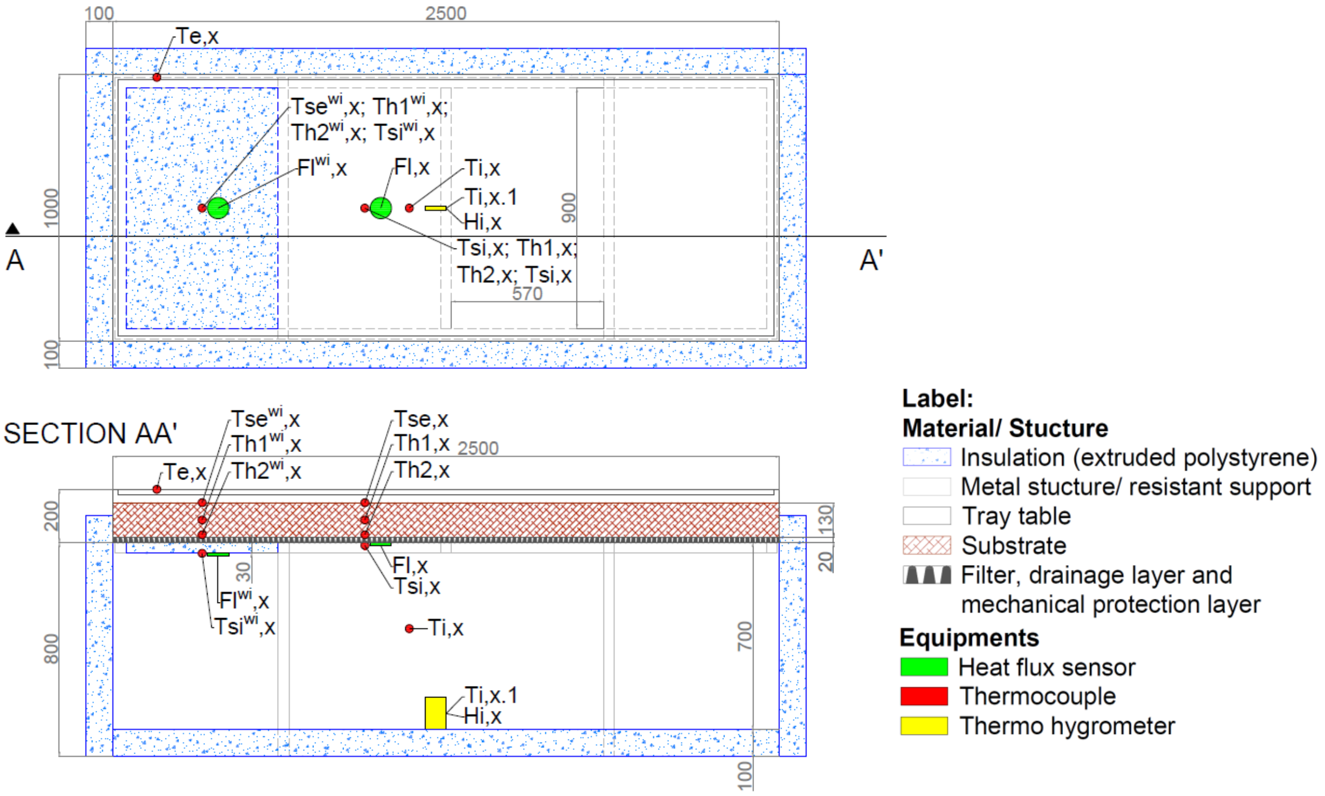

Figure 2 - Tray-type with probes in plant (top) and in profile (bottom)

4 Discussion and Analysis of Results

For both seasonal campaigns, winter and summer, it was created a database to organize and display the data. There were 51 sensors collecting data every minute, returning their average in 10 minute periods.

The general data for each campaign was analyzed using graphs and comparing the variables measured and other weather data available.

Solving the Fourier's law for heat transmission coefficient leads to:

$$U = \frac{Q}{T_e - T_i} \left[{}^{W}/_{m^2 . {}^{\circ}C} \right] \qquad (1)$$

Using this expression it's possible to evaluate the influence of water and wind in the thermal performance of the reference tray in each season by estimating its heat transmission coefficient.

4.1 Winter campaign

Data collection started in January 18th and ended in February 24th 2016. The period between February 6th and 10th was selected to be representative of the season. In this season it was used lightbulbs as heating system connected to a thermostat inside the tray T7. The lightbulbs were connected in a series circuit with the thermostat, turning on/off at the same time. The thermostat was set to keep indoor temperatures between 18 and 20ºC. However, in the selected period the lightbulb inside T3 wasn't working.

In Figure 3 is shown the temperatures felt inside all compartments and outdoors, complemented with solar radiation on horizontal plane for the winter campaign.

It's been observed that highest temperatures occur simultaneously with solar radiation, but the day with most radiation also got the lowest temperatures. The clouds keep the heat inside the atmosphere not letting it dissipate.

Indoors, the heating system was rather successful, keeping the indoor temperature of all trays close to the setpoints. The T7 tray was always inside the interval because it was the one controlling the temperatures.

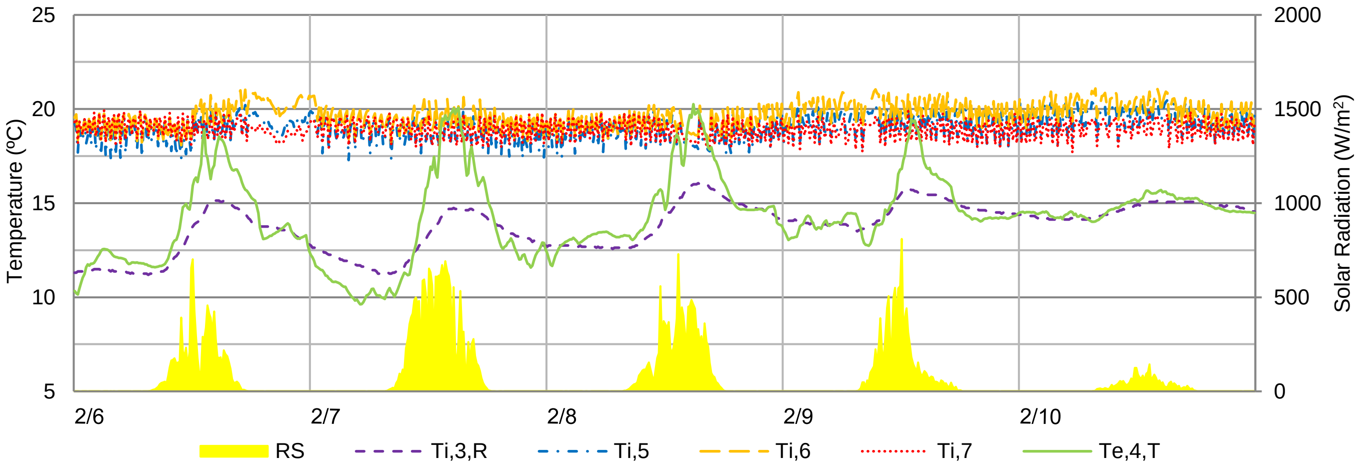

Figure 3 - Outdoor and indoor temperatures from all trays and solar radiation in the winter campaign

The others fluctuated mostly because of the wind that had higher intensities when the temperatures dispersed. This occurred because the compartments weren't airtight and, because the T7 tray was the westernmost, from where the wind blew, the controlling compartment was the coolest, making the other overheat until it reached the set temperature. Overall, when wind speed wasn't high, this tray was the one with higher temperatures. T6 also kept its temperatures high but it was also between the other two, being more protected from the wind and breeze, making it harder for it to loose energy through its sides. As it wasn't heated, T3 followed the temperatures from the outdoors, with less amplitude, it was insulated.

From the analysis of the Figure 3 and crossing it with the weather data from meteoTécnico and what is known about the trays, we can conclude the following for each tray:

- T7 - braquipodium, a rather dense bush covering the surface of the tray, offered a good protection of the surface from the wind and outdoor temperatures. It also reduced solar gain, which is not that desirable in this season. Generally, this is a good option because it makes the thermic amplitudes lower;
- T6 - the surface of this tray was very exposed, because rosemary is a tall bush with spare foliage. Since this tray was better protected from the wind and its temperature didn't rise that much we can assume its losses through the tray were bigger. Although, this bush cast a faint shadow there were bigger solar gains, when compared with the other trays, it also has the highest absorptivity of them all, along with T5;
- T5 - with a rather denser vegetation than T6 this tray had the same absorptivity, mainly due to the moss. This tray was the coolest when the wind was slower because the moss retained more water making it easier for evapotranspiration to occur leading to bigger heat losses. It did ease the solar

gains because of its dark color, but they didn't transfer to the inside;

- T3 - it's outdoor surface temperature were lower than T7, which had the same vegetation, that's because of it not being heated, so the indoor temperature influences the outdoor surface, making it warmer.

For the most part, vegetation influences the thermal performance of the green roof in cold climates, objectively denser vegetation has better insulation qualities.

In Figure 4 is shown the heat fluxes in the reference tray, T7. Positive flux is ascending, out of the tray, and negative is descending, to the inside of the tray.

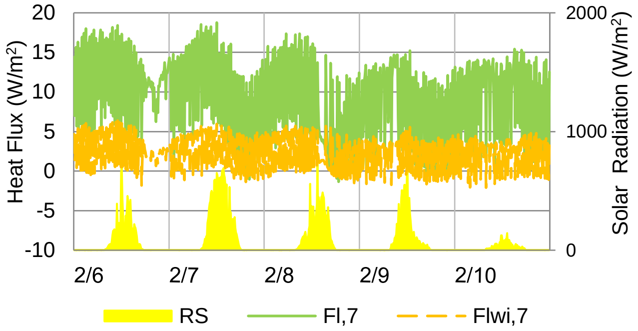

Figure 4 - Heat flux of the non-insulated area and solar radiation in the reference tray,T7, in the winter campaign

In Figure 4 there is a clear distinction between the insulated and non-insulated zones, with the latter having triple the flux in many cases. Sometimes the flux is descending when there is no heating, that's because the heat comes from radiation, heating the surfaces first and then the air. This was also the cause of so much oscillation in the flux, since temperatures were kept in a small interval, it would be expected for the flux to be more constant. Contrary of what was expected heat fluxes were higher when the outside temperatures were closer to the indoor temperatures. There appears to be a correlation between the flux and solar radiation, when the outside air is warmer.

Comparing to the flux of T5 there isn't much difference amongst insulated zones as for non-insulated zones, T5 has lower fluxes. The placement of the sensor might not represent the whole area of the tray getting better results than the overall area.

In Figure 5 it's represented an estimate of the heat transmission coefficient for the tray T7, reference tray.

When the outdoor and indoor temperatures are close together, their difference near zero, drawing asymptotes in the graph, 2/6-2/9. Besides that, it's possible to observe an increase in heat transmission when there is rain, 2/6 and 2/10. This only affects the non-insulated area, in both cases. The most notable one happened in the 2/10, having a significant rise in the non-insulated area whilst the insulated area doesn't vary much. This means that when the substrate is wet there is an increase in heat loss.

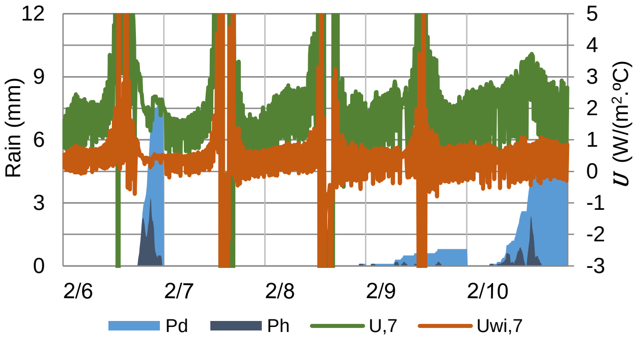

Figure 5 - Heat transmission coefficient and rain in T7 in the winter campaign

All things considered, the thermal benefits of green roofs in cold climates are very limited. Without insulation the green doesn't perform very well. Despite of reducing the solar gains, denser vegetation proved to have superior advantages by reducing the heat dissipation during the night, keeping the outside surface at higher temperatures. The effects of the vegetation weren't that substantial in the non-insulated area and even less significant in the insulated area.

4.2 Summer campaign

Data collection for this campaign went from July 4th until July 26th. The period between the 16th and 26th was selected as representative. Opposite of the winter campaign, there wasn't a system controlling the indoor temperature.

In Figure 6 is shown the indoor temperatures of all compartments and outdoor, complemented with solar radiation on horizontal plane for the summer campaign.

Comparing the data from Figure 6 and the weather data from metoTécnico, there was a direct influence in outside temperatures by the wind speed, higher wind speeds lead to lower temperatures, July 21st and 22nd.

During the day, the trays with denser vegetation, trays T3 and T7, had slightly lower indoor temperatures than the trays with less dense, trays T5 and T6. At night, it was reversed, the indoor temperatures of tray T3 and T7 were higher than trays T6 and T6. This happened because the vegetation provided a shading effect, protecting the outdoor surface of the tray, keeping it cooler. The denser vegetation also kept energy from being dissipated because its outdoor surface was warmer than the other two trays that were more exposed.

This analysis lead to the following conclusions for each tray:

- T7 - the protection offered by the *braquipodium* plant in the winter turned out to be also an advantage in this season, this time by protecting the outdoor surface from the solar radiation and preventing it from heating the inside of the tray. The

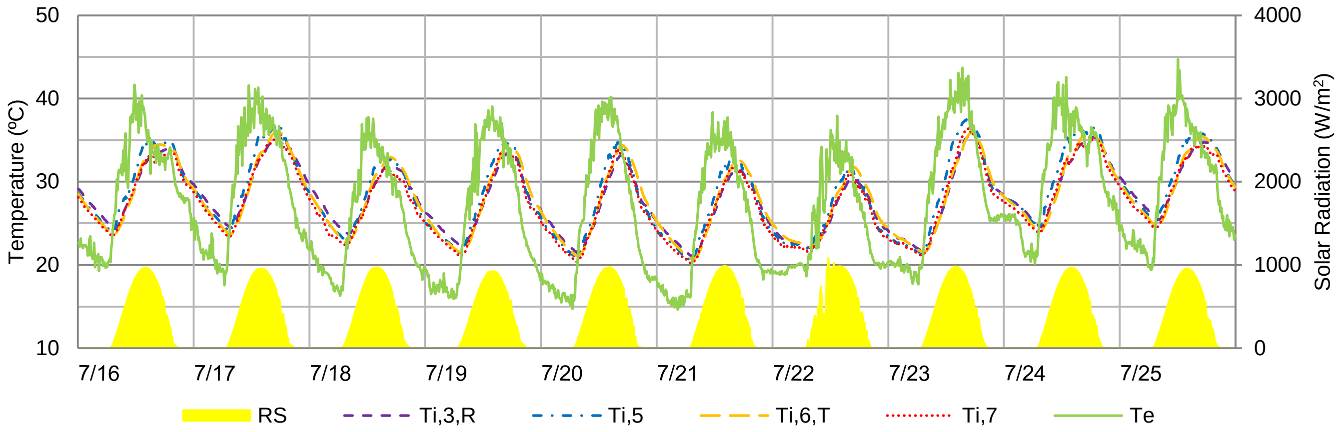

Figure 6 - Outdoor and indoor temperatures from all trays and solar radiation in the summer campaign

organic substrate, S1, in the tray T1, allowed for more heat transmission than the sandier and less organic, S2, in tray T3, keeping the tray T3 warmer at night than the tray T7;

- T6 - as rosemary has thin leaves it doesn't block much sunlight, letting solar radiation reach the outdoor surface of the tray and heating it. Solar gains are high and in the summer they easily reach the inside warming the indoor temperatures. However, it cools fast when the there's no solar radiation, making it one of the colder trays, along with T7;
- T5 - the tray T5 is consistently the tray with the highest indoor temperatures, both during the day and the night. The low shading level provided by the vegetation (rosemary, French lavender and *braquipodium*) and the dark colors of dry moss contributed for this tray being the one that absorbed the most heat during the day, although its outdoor surface temperature wasn't the highest, probably because the sensor was in a shaded area. The moss also didn't allow for the temperatures to dissipate during the night keeping the tray warmer than the others;
- T3 - the denser vegetation of this tray have been proven to be the most efficient, of the analyzed types of vegetation, by reducing the solar gains during the day but it also kept the heat from dissipating at night. The fact that the tray T7, with the same vegetation had the coolest indoor temperatures at night while the T3 had the highest evidenced that the sandy texture of the substrate, S2, provided better thermal insulation than the organic substrate S1.

It was observed that, in the summer, there was a great influence by the vegetation on the thermal performance of the green roofs tested. Denser types of vegetation lead to reduced solar gains and proved to be beneficial in warm seasons. The texture and the organic matter also had an important role when transmitting the temperatures from inside to the outside or vice-versa. Sandier and less organic substrates proved having better thermal insulation properties.

In Figure 7 is shown the heat fluxes measured on insulated and non-insulated areas of the tray T7, and solar radiation for the summer campaign.

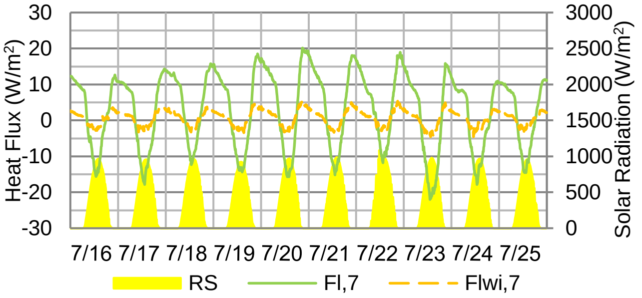

Figure 7 - Heat flux of the non-insulated area and solar radiation in the reference tray,T7, in the summer campaign

Figure 7 shows a significant difference between the heat fluxes measured in the insulated and non-insulated areas, with the non-insulated area reaching values four times higher than the insulated area. The fluxes from the insulated area were also very consistent throughout the campaign, having similar behaviors each day. The same didn't happen with the non-insulated area where the higher the outdoor temperature caused higher descending fluxes and lower outdoor temperature caused higher ascending fluxes.

In an effort to understand the effects of irrigation in the thermal behavior of the green roofs it was estimated a heat transmission coefficient for the campaign, illustrated in Figure 8.

Unfortunately, the asymptotes, caused by the closeness of the outdoor and indoor temperatures, occurred simultaneously with the irrigation period making the analysis of its influence impossible. However, we could verify that in the non-insulated area the heat transmission had higher values ascending than descending. This is due to the texture of the substrate, being a grainy medium makes it harder to conduct temperature downwards because it starts heating the air in the pores which rises and dissipates energy. This fact can also be observed in windier days, 7/22 and 7/23, where the wind infiltrates the pores aiding in the cooling process of the green roof.

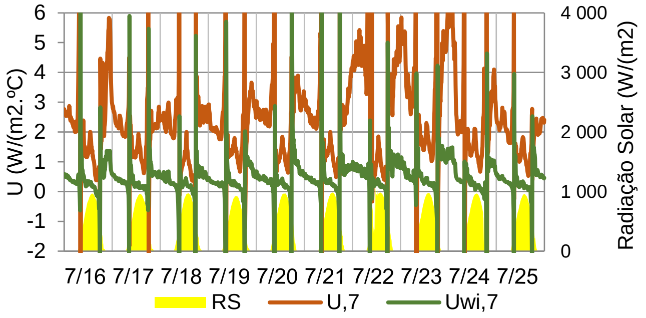

Figure 8 - Heat transmission coefficient and rain in T7 in the summer campaign

For the most part of the summer campaign, denser types of vegetation bring more benefits to the thermal performance of green roofs. Sandier and less organic substrates have more insulation properties than more organic ones and with more clay.

5 Conclusions

This paper studies the thermal performance of semi-intensive green roof in a Mediterranean climate. It was conducted experimental evaluation of four models with different types of semi-intensive green roofs, different vegetation and growth medium.

The main conclusion from the experimental campaigns was that the type of vegetation and substrate have influence in the thermal performance of green roofs.

During the winter, simple semi-intensive green roofs benefit from the use of dense vegetation, such as *braquipodium*, because it provides light protection from weather agents, like the wind. It had a significant effect in non-insulated green roofs but in insulated green roofs its effects were very limited. During the summer the influence of the vegetation prove to be more significant. By providing shading effects on the outdoor surface, the vegetation reduced solar gains that otherwise would be transferred indoors. *Braquipodium* and other dense types of vegetation behave like a light insulation layer on the outside surface.

The types of the evaluated substrate had different behaviors. It was not possible to evaluate the effects of the substrate in the thermal performance of green roofs in the winter season. In the summer, the sandier and less organic substrate was able to offer a little more insulation than the one with more clay and organic matter. The water content of the substrate had also influence in the performance of the green roofs, as the more water content it had, more thermal conductible it was.

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