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Research Article

Green Roofs: Influence of Moisture Content of the Substrate in the Thermal Regulation of a Building in CABA - Argentina

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Abstract

Urbanization is defined as the physical growth of urban areas. About half of the world's population now lives in cities and expected that this amount will increase to 61% by 2030; this growth will be more pronounced in developing countries. Cities are the habitat for excellence of human, and present environmental characteristics (urban climate) common in many parts of the world, as for example the presence of the island of urban heat (ICU). The urban heat island reveals the impact of habitat built on the physical environment and the increase in temperature that produces. Climatic change effects and the processes of urban growth caused environmental deterioration in the city of Buenos Aires. The increase of the temperature according to the models established by the Intergovernmental Panel on climate change could emphasize over the next decades. For Buenos Aires the models predict, specifically in the 2020-2029 period, an increase of average maximum temperatures in 0.6°C to 2° C (for the minimum temperature average). One of the proposed solutions is the green roof, which, mainly can help as buffer against temperature extremes and the urban heat island. The objective of the present study was to determine, for the climatic conditions of the Autonomous city of Buenos Aires (CABA), if the moisture content of the substrate of green roof due to rains, has influence on the thermal regulation. The results obtained allow us to conclude that for the conditions of the study site and in the analyzed months, the Vegetated Roof (CV) allows a regulation of the temperature inside the building (on average) of around 2 degrees Celsius. However, statistically significant differences could not be verified on days with rain.

Keywords: Heat Island; Vegetated Roofs; Thermal Regulation

Introduction

Villalba., *et al*. [1], citing Evans and Schiller [2], argue that the heat island of urban areas due the impact of the built habitat on the physical environment and the increase in temperature it produces. The same authors, citing [3], mention that cities constitute the habitat of the human being, and although are different, they present environmental characteristics (urban climate) common in many parts of the world, such as the presence of Isla de Urban Heat (UCI), which corresponds to an increase of anthropic origin in the temperatures of the city compared to its immediate natural and rural environment, this difference being more intense at night. La urbanización genera un impacto significativo en la formación de las islas de calor urbano (ICU), debido a que las áreas verdes son reemplazadas por construcciones [4].

The impact of the urban heat island (UHI) on urban residents' health, energy consumption, and urban air quality has become more significant in cities [5].

The Urban Heat Island phenomenon, which causes problems for the population (in summer), is increasing attention in cities, especially in a context of growing urbanization. Surface alterations, inadequate urban planning, air pollution, among others, are causing this increasingly important phenomenon that is responsible for human discomfort [6].

Ordóñez., *et al.* [7], argue that the approach to the problem of energy sustainability of buildings should be carried out considering that it is easier to reduce energy needs than to cover a growing demand.

Reducing energy consumption in buildings is a global challenge. In order to reduce it, it must be considered that the greatest potential for energy savings can be found in buildings, since about 40% of final energy consumption occurs in homes, offices, stores and other buildings [8,9].

Nuruzzaman [6], mentions mitigation strategies that can be functional (using high albedo materials and pavements, green vegetation, urban planning, permeable pavements, shade trees and creation of water bodies in city areas), among which he includes naturalized roofs or green roofs, mentioning that green vegetation seems to be among the most effective measures and together with other strategies can play an important role in the right conditions.

With the same orientation, Arabi., *et al*. [10], argue that one of the best practices to combat the urban heat island (UHI) phenomenon is to increase the use of green approaches, including green technologies and vegetation. They also mention that, due to the few spaces available to build up green elements (because of the high density of urban development and the high cost of urban land), the use of green roofs, can contribute to mitigate the hottest spots in a city, recommending the use of green roofs as a main strategy to decrease the harmful impacts of urban heat island, especially high air temperatures.

Different authors in recently published works and in previous ones mention the use of natural roofs in the mitigation of the Urban Heat Island phenomenon [11-18].

It should be mentioned that the Vegetated Roofs are not all the same and have different characteristics and degree of complexity.

Nevertheless its diversity, and analyzing different authors: Jim [17], Goussous., *et al*. [19], van Hooffa et. to the. [20], Voskamp and Van de Ven [21], Lee., *et al*. [22], Sultana., *et al*. [23], Hashemi., *et al*. [24], Yang., *et al*. [25], Gagliano., *et al*. [26]; we can establish that all roofing systems can be summarized into two large groups according to the thickness of the substrate: the intensive type and the extensive type.

Carson., *et al.* [27], argue that extensive systems are implemented more frequently than intensive systems, especially in existing buildings, where roof weight limitations come into play.

In our country (Argentina), studies on the ecosystem services of green roofs have been published [1,28-30]. However, there are few who address the contribution of natural roofs in mitigating the urban heat island based on thermal benefits [31,32].

Justification

The "Urban Heat Island" phenomenon also occurs, as has been reported in large cities around the world, in the Autonomous City of Buenos Aires (CABA).

Different authors [33-38], mention that it has been determined that heat transfer in a green roof depends, among other factors (such as vegetation shade and its physiological processes, soil density, substrate thickness), on the moisture content of the substrate.

In a previous study by the same team [32], which presents this study, it was determined that, for the conditions studied, Green Roofs could make a contribution in the "urban heat island" phenomenon, but it was suggested that the rains occurred during the test could have masked the result obtained.

General objective

In the context of the climatic conditions of CABA, and considering that, according to the research review, vegetated roofs (built with substrates and vegetation available at the study site) can contribute to thermal stabilization in the city, it is necessary to determine whether the moisture content of the substrate due to rainfall has an influence on thermal regulation.

Specific objectives

To determine if the moisture content of the substrate of a vegetated cover without artificial irrigation, on days with precipitation, influences the regulation of the interior temperature of a house, in one of the months of the year (February) where rainfall and high temperatures can occur.

To determine if the moisture content of the substrate of a vegetated cover without artificial irrigation, in days with precipitation, influences the variation of the temperature inside the implanted vegetation and at the base of the substrate of a vegetated cover, in one of the months of the year (February) where rainfall and high temperatures can occur.

Hypothesis

The hypotheses proposed for the area and the conditions of the study.

- The moisture content of the substrate of a vegetated roof without irrigation, on rainy days in the month of February, does not influence the decrease in the interior temperature of the building, compared to days without rain.
- The moisture content of the substrate of a vegetated roof without irrigation, on rainy days in February, does not influence the decrease in the temperature inside the vegetation and at the base of the substrate, compared to days without rain.

Materials and Methods

Through the mediation of Leveratto and courtesy of the Environmental Protection Agency (APA) of the Ministry of Environment and Public Space of the Government of the City of Buenos Aires, it is possible to access the generation of thermal information from the use of a green roof built (existing) of extensive type on the terrace (accessible roof) of an existing building construction in the CABA and owned by the Government of the City. In this way, we try to follow what is recommended in the bibliography regarding the importance and necessity of linking the academic-research with the managers and governmental authorities of application.

The General Direcccion of Environmental Strategies of the Environmental Protection Agency (APA) - Ministry of Environment and Public Space of the Government of the Autonomous City of Buenos Aires, created in 2010 the “Green Roofs in Public Buildings Program” with the aim of promoting the installation of green roofs in buildings managed by the public sector of the City.

As a result of this program, a green roof was built on the terrace of a public building, selected for having a terrace accessible by the main staircase and with protective railings around its perimeter, good sunlight and a building design that facilitates comparative measurements. The roof is oriented to the northeast, with direct sun access throughout the year, even though it is located in a densely built-up area of the city.

Based on this initial situation, a green roof was built on one sector of the terrace, leaving another sector unaltered, to be used as a witness.

Under the premise that the maximum total weight of the finished green roof should be less than 180 kg/m2, with wet substrate, a green roof was designed and built using traditional materials and construction systems that were reasonably easy to obtain in the local market.

Treatments

One sector of the roof was constructed without irrigation and one sector was left with only a waterproof membrane as a control. The temperature sensors were located in these sectors.

The treatments selected for this trial are listed in table 1.

The Witness temperature was measured outdoors (rooftop without green roof) and indoors (room under the rooftop without green roof). Ultimately, the following data were recorded

Outside, the following were measured

- Air temperature (outside sensor) as Witness (roof without green roof, only membrane)

Sensor location Treatments	Temperature inside the vegetation (canopy)	Temperature at the base of the substrate (at terrace level)	Air temperature (Outdoor)	Air temperature (Indoor)
Terrace without Green Roof: Control Treatment (Outside of the building) witness	------	------	X	------
Terrace (Green Roof) without irrigation (Outside of the building)	X	X	------	------
Terrace without Green Roof: Classroom Inside Control Treatment (Inside the building - ceiling slab) witness	------	------	------	X
Terrace with Green Roof without irrigation (Inside the building)	------	------	------	X

Table 1: Treatments.

Note: Data collection, observations are made in the month of February (summer in the Southern Hemisphere).

- Air temperature, inside the vegetation (sensor inside the canopy) of the green roof without irrigation
- Substrate base temperature, under green roof without irrigation
- Rainfall occurred

In the interior, we measured

- Air temperature: indoor sensor under the witness (rooftop without green roof, only membrane)
- Air temperature, sensor in indoor environment under green roof without irrigation

Temperature data collection was captured on a weekly basis.

From the data obtained by the indoor and outdoor sensors (Figure 1), both in the area with the green roof and in the control without green roof, the criteria established in the statistical evaluation item (see below) were applied to check if the hypotheses were verified.

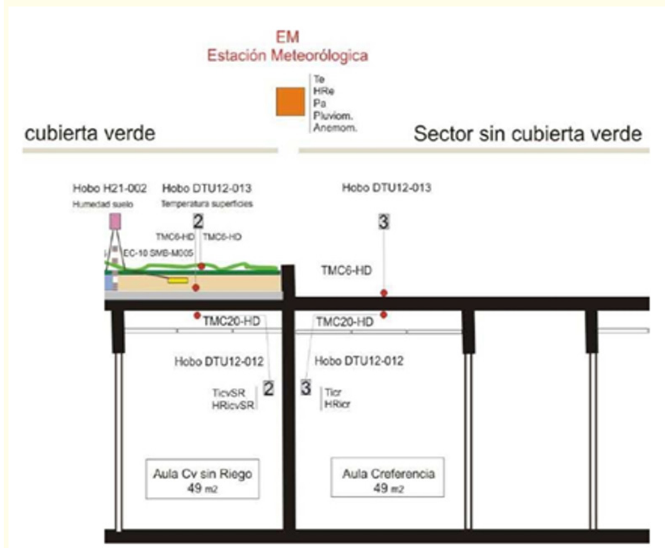

Figure 1: Location of the outdoor and indoor temperature sensors. Source [32].

Statistical Valuation

One of the statistical values most recommended by the literature [39-41], to study data series, is the RMSE (Root Mean Squared Error).

In our case this accuracy index was used to determine the tolerance to be used (three times the RMSE) in order to eliminate from the data series all those anomalies due to sensor malfunction and that cannot be considered errors.

The critery for data validation was: that they did not exceed the stipulated tolerance, (3 times the RMSE) in case of exceeding them, they were eliminated from the series, updating in each data elimination the RMSE, until no more data above the fixed tolerance.

With the data obtained within the tolerance, the average daily temperature was calculated for each treatment, and a comparison was made between them. The above averages for the days when precipitation was recorded were then plotted on graphs.

With the raw temperature data received, the temperature evolution throughout the day was compared between treatments without irrigation versus the controls, both indoors and outdoors, for the rainy days. The hourly temperature averages were then plotted on graphs.

With the data obtained, an ANVA was performed with Duncan's comparison method and a significance level of 0.99, to verify the hypotheses.

Results and Discussion

As explained above, the data analyzed were from the month of February because rainfall was recorded during that month (which did not occur in January) and this allows us to know whether the assumption that, in the presence of rainfall, the treatments do not indicate differences is fulfilled.

In the first instance, the data from the days when rainfall occurred were evaluated in order to evaluate the assumption of equality of treatments listed above.

Table 2 Contains the data for the rainy days of the treatments evaluated

For the days with the highest rainfall, i.e., 10/2, 24/2 and 2/3, the average temperature of the internal and external control exceeded the average of the treatments without GR irrigation.

Treatments/ Temperature (C°)	10/2	19/2	20/2	21/2	24/2	2/3
Registry	64,28mm	12,18mm	23,39mm	13,42mm	27,42mm	67,82mm
OUTDOOR						
Terrace (Green Roof) without irrigation	26.91	26.32	25.00	24.48	24.47	22.86
Vegetation (Green Roof) without irrigation	26.50	21.84	22.18	23.01	24.13	22.23
Outside Control Treatment (Terrace without Green Roof) witness	29.17	18.99	20.69	24.30	25.75	24.78
INDOOR						
Classroom Inside Terrace with Green Roof without irrigation	26.89	28.77	26.93	25.74	24.97	24.87
Classroom Inside Control Treatment (Terrace without Green Roof) witness	30,00	29.58	26.54	25.51	26.09	26.11

Table 2: Rains and treatments.

On 19/2, 20/2 and 21/2 the lowest precipitations were recorded (12.18mm, 23.39mm, 13.42mm respectively), verifying that the average temperatures of the external control (roof without natural cover, only covered with membrane) is lower than the external treatments (GR vegetation -sensor inside the canopy of the green cover- and substrate base temperature, under the green cover), but the difference is gradually reduced from 19/2 to 21/2. In the case of the internal treatments, on 20/2 and 21/2 the temperature averages of the GR ceiling slab treatment without irrigation (Air temperature, sensor in the interior environment under the green canopy without irrigation) exceed the average temperatures of the control (Air temperature: interior sensor under the control).

The greatest differences of temperature averages between the control and the treatments are observed when the greater precipitation was recorded.

Figures 2 and 3 summarize the information listed above

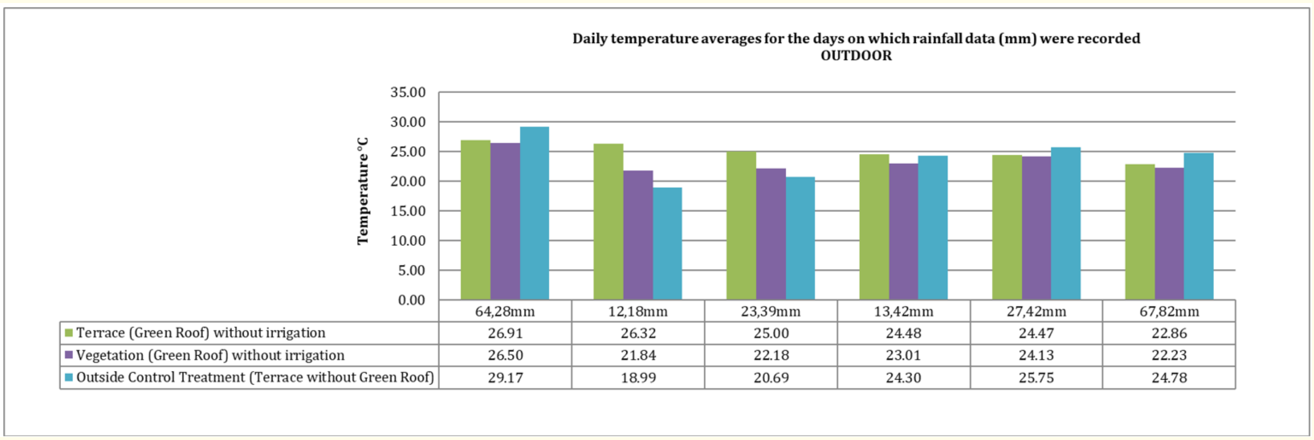

Figure 2: Daily temperature averages for days when rainfall was recorded - Outdoor.

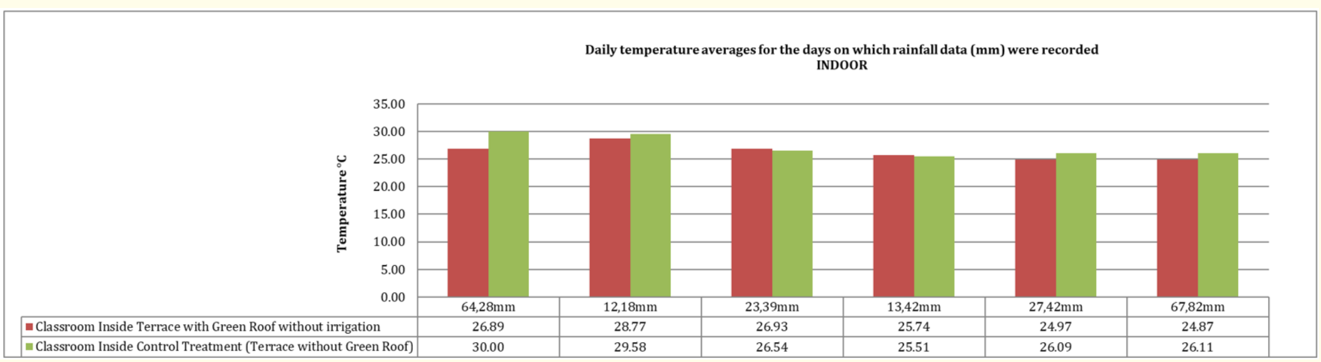

Figure 3: Daily temperature averages for rainy days - Interior.

Variance análisis for temperature across treatments for rainy days indicate

For outdoor temperature (canopy and substrate base in February)

Variable	N	R^2	R^2 Aj	CV
Column 2	30	0,14	0,01	9,38

Table a: Variance análisis.

F.V.	SC	df	CM	F	p-value
Model.	21,10	4	5,28	1,05	0,4035
Column1	21,10	4	5,28	1,05	0,4035
Error	126,09	25	5,04		
Total	147,19	29			

Table b: Variance análisis Table (SC type I).

Column	Means	n	E.E.	
TVCVSR (canopy)	23,32	6	0,92	A
TSCVSR (substrat)	25,01	6	0,92	A
Witness	23,95	6	0,92	A

Table c: Test: Duncan Alfa = 0,01.

Error: 5,0435 df: 25.

Means with a common letter are not significantly different (p > 0.01).

For Temperature inside the building (February)

VariableN	R^2	R^2	Aj	CV
Column 2	18	0,06	0,00	6,03

Table d

F.V.	SC	df	CM	F	p-value
Model.	2,68	2	1,34	0,51	0,6086
Column1	2,68	2	1,34	0,51	0,6086
Error	39,18	15	2,61		
Total	41,86	17			

Table e: Variance análisis Table (SC type I).

It can be seen that the assumption of equality of treatments during rainy days has been validated, because both for the interior and exterior there were no significant differences between different treatments and the witness.

Secondly, the data from the days when NO rainfall occurred were evaluated in order to evaluate the assumption of the existence of differences in internal and external temperature (canopeo and substrate base) respect to the witness.

Below, we indicate the results of the daily temperature averages corresponding to the second range of data (05/02- 05/03) that we will group as the month of FEBRUARY (Table 3) and the graphs (3 and 4) corresponding to the mentioned results

Table 4 indicate the differences between the daily temperature averages between the treatments with Green Roof (GR) versus the witness in February, days without rain.

Analysis of Variance for temperature across treatments for days WITHOUT rain indicate

For Temperature inside the building (February)

The result indicate that there are significant differences between the witness and the treatment, which has a lower average temperature than the control.

For outdoor temperature (canopy and substrate base in February)

Treatments/ Temperature (C°)	6/2	7/2	8/2	9/2	11/2	12/2	13/2	14/2	15/2	16/2	17/2	18/2	22/2	23/2	25/2	26/2	27/2	28/2	1/3	3/3	4/3	5/3
OUTDOOR																						
Terrace (Green Roof) without irrigation	25.84	25.93	26.16	26.46	26.41	26.77	27.25	27.22	27.29	27.55	28.08	27.32	24.25	24.30	24.06	23.28	22.80	22.70	22.79	22.81	22.12	21.86
Vegetation (Green Roof) without irrigation	25.71	26.14	26.91	27.94	25.98	27.08	26.46	26.18	26.83	28.05	26.91	23.76	23.66	24.44	22.49	20.67	21.00	21.61	23.26	21.41	20.17	20.31
Outside Control Treatment (Terrace without Green Roof)	28.32	29.91	29.22	31.40	30.23	32.97	30.49	29.16	30.77	32.82	30.99	25.80	26.31	27.89	23.92	24.14	24.40	24.09	26.60	22.69	23.44	23.18
INDOOR																						
Classroom Inside Terrace with Green Roof without irrigation	26.26	26.23	26.29	26.47	26.91	27.09	27.36	27.48	27.47	28.94	30.41	30.62	25.37	25.10	24.87	25.27	25.94	25.59	25.31	24.16	23.80	24.03
Classroom Inside Control Treatment (Terrace without Green Roof)	28.63	28.94	29.17	29.53	30.19	30.34	31.03	31.26	30.95	31.05	31.51	30.49	25.56	25.71	25.93	25.39	25.90	25.52	25.73	25.50	24.85	24.61

Table 3: February data for days without rain.

	Outdoor						Indoor		
Treatments/ Temperature (C°)	Terrace (Gren Roof) w/o irrigation	Control Treatment (Terrace without Green Roof)	Difference	Vegetation (Green Roof) without irrigation	Control Treatment (Terrace without Green Roof)	Difference	Classroom Inside Terrace with Green Roof without irrigation	Classroom Inside Control Treatment (Terrace without Green Roof)	Difference
6/2	25.84	28.32	-2.48	25.71	28.32	-2.61	26.26	28.63	-2.37
7/2	25.93	29.91	-3.97	26.14	29.91	-3.77	26.23	28.94	-2.71
8/2	26.16	29.22	-3.06	26.91	29.22	-2.31	26.29	29.17	-2.88
9/2	26.46	31.40	-4.94	27.94	31.40	-3.45	26.47	29.53	-3.06
11/2	26.41	30.23	-3.82	25.98	30.23	-4.25	26.91	30.19	-3.28
12/2	26.77	32.97	-6.19	27.08	32.97	-5.89	27.09	30.34	-3.25
13/2	27.25	30.49	-3.24	26.46	30.49	-4.03	27.36	31.03	-3.67
14/2	27.22	29.16	-1.94	26.18	29.16	-2.98	27.48	31.26	-3.77
15/2	27.29	30.77	-3.48	26.83	30.77	-3.94	27.47	30.95	-3.48
16/2	27.55	32.82	-5.27	28.05	32.82	-4.77	28.94	31.05	-2.11
17/2	28.08	30.99	-2.91	26.91	30.99	-4.08	30.41	31.51	-1.10
18/2	27.32	25.80	1.51	23.76	25.80	-2.05	30.62	30.49	0.13
22/2	24.25	26.31	-2.06	23.66	26.31	-2.65	25.37	25.56	-0.19
23/2	24.30	27.89	-3.60	24.44	27.89	-3.45	25.10	25.71	-0.61
25/2	24.06	23.92	0.14	22.49	23.92	-1.43	24.87	25.93	-1.06
26/2	23.28	24.14	-0.86	20.67	24.14	-3.47	25.27	25.39	-0.12
27/2	22.80	24.40	-1.60	21.00	24.40	-3.40	25.94	25.90	0.03
28/2	22.70	24.09	-1.39	21.61	24.09	-2.48	25.59	25.52	0.07
1/3	22.79	26.60	-3.81	23.26	26.60	-3.34	25.31	25.73	-0.42
3/3	22.81	22.69	0.13	21.41	22.69	-1.27	24.16	25.50	-1.33
4/3	22.12	23.44	-1.33	20.17	23.44	-3.27	23.80	24.85	-1.05
5/3	21.86	23.18	-1.33	20.31	23.18	-2.88	24.03	24.61	-0.57

Table 4: Difference in temperature between canopy treatments (GR) versus witness in February, days without rain.

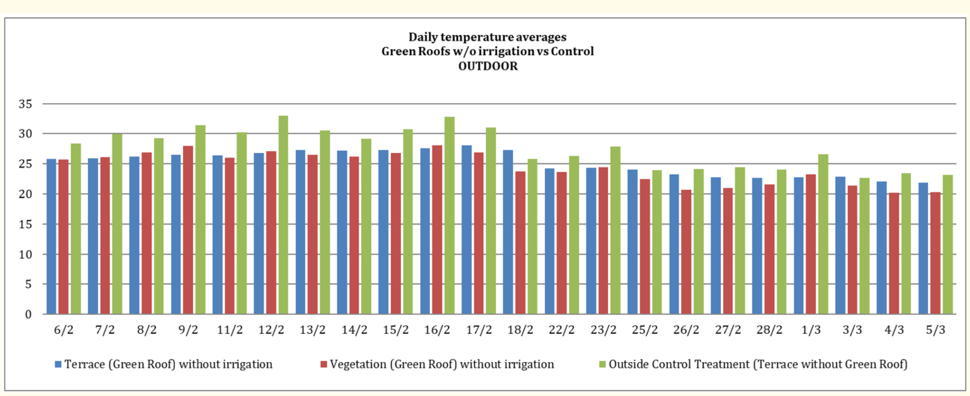

Figure 4: Outside.

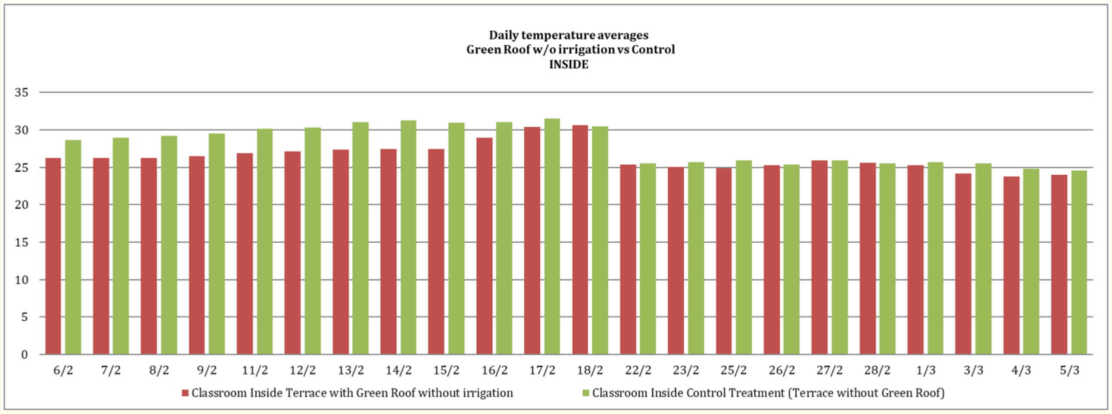

Figure 5: Inside.

Column1	Means	n	E.E.	
I AIR CVSR	26,36	6	0,66	A
I AIR Test-Ins	27,30	6	0,66	A

Test: Duncan Alfa = 0,01.

Error: 2,6117 df: 15.

Means with a common letter are not significantly different (p > 0.01).

VariableN	R^2	R^2 Aj	CV	
Column 2	66	0,16	0,13	7,30

Table g: Variance análisis.

F.V.	SC	df	CM	F	p-value
Model.	44,98	4	22,49	5,82	0,0048
Column1	44,98	4	22,49	5,82	0,0048
Error	243,55	63	3,87		
Total	288,53	65			

Table h: Variance análisis Table (SC type I).

Column1	Means	n	E.E.	
I AIR CVSR	26,41	22	0,42	A
I AIR Test-Int	28,08	22	0,42	B

Table i: Test: Duncan Alfa = 0,01.

Error: 3,8659 df: 63.

Means with a common letter are not significantly different (p > 0.01).

VariableN	R^2	R^2 Aj	CV	
Column 2	110	0,21	0,18	10,18

Table j: Variance análisis.

F.V.	SC	df	CM	F	p-value
Model.	182,91	4	45,73	6,94	0,0001
Column1	182,91	4	45,73	6,94	0,0001
Error	691,45	105	6,59		
Total	874,36	109			

Table k: Variance análisis Table (SC type I).

Column1	Means	n	E.E.	
TVCVSR (can.)	24,41	22	0,55	A
TSCVSR (sust.)	25,15	22	0,55	A
Witness	27,67	22	0,55	B

Table l: Test: Duncan Alfa = 0,01.

Error: 6,5852 df: 105.

Means with a common letter are not significantly different (p > 0.01).

Here again, the result indicate that there are significant differences between the witness and the treatments, all of which have lower average temperatures than the control.

If we remember the hypotheses raised

- The moisture content of the substrate of a green roof without irrigation, on rainy days in February, does not influence the decrease in the temperature inside the building, compared to days without rain.
- The moisture content of the substrate of a green roof without irrigation, on rainy days in February, does not influence the decrease in the temperature inside the vegetation (canopy) and at the base of the substrate, compared to days without rain.

The results show that the two hypotheses have been validated since no significant statistical differences were found either indoors or outdoors for any of the treatments in days with rainfall, compared to the statistical results obtained for days without rainfall, with respect to the Witnesses.

Conclusions

The results and statistical analysis performed so far would allow us to ensure that, within the framework of the climatic conditions of CABA, green roofs (built with substrates and vegetation available at the study site) can contribute to thermal stabilization in the city.

In the conditions and for the site studied, with rainfall, no differences were recorded in the treatments with respect to the control.

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