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THERMAL INFLUENCE OF LIVING WALL IN THE WINTER OF SUBTROPICAL CLIMATE IN BRAZIL

INFLUÊNCIA TÉRMICA DE PAREDE VIVA NO INVERNO DE CLIMA SUBTROPICAL NO BRASIL

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Abstract

The continuous living wall is a type of vertical garden built with different layers, which allows the cultivation of a wide variety of species and protects the façade from direct sunlight. From this, this experimental study aimed to identify and quantify the influence of a continuous living wall on the variations of the internal and external surface temperatures (Ist and Est) of an East façade, in the winter period, in the Cfa climate. The garden had the differential of being built with Tetrapak® recycled boards to differentiate it from the other technologies already studied and to test a material used in environmental compensation projects. The surface temperatures of the living wall, the protected and the control plot were monitored and compared to analyze the intensity of the shading mechanism. The results demonstrate that, in the early morning, the living wall prevented heat loss from the façade and, from direct sunlight, kept the protected plot's surface temperatures lower than the control plot. This difference reached up to 9.4 °C at Est (morning period) and 2.8 °C at Ist (afternoon period), as well as a maximum thermal delay of 06h30min between Est peaks. These findings show the positive influence of the living wall in winter, considering the characteristics of the Cfa climate (cold in the morning and hot during the day), expand knowledge about the thermal influence of the continuous living wall in the building and reinforce the use of living walls beyond aesthetics.

Keywords: vertical garden, thermal performance, green infrastructure, vertical greenery system, green wall.

Resumo

A parede viva contínua é um tipo de jardim vertical construído por diferentes camadas, que permite o cultivo de grande variedade de espécies e que protege a fachada da incidência solar direta. A partir disso, este estudo experimental objetivou identificar e quantificar a influência de uma parede viva contínua nas variações das temperaturas superficiais interna e externa (Tsi e Tse) de uma fachada Leste, em período de inverno, em clima Cfa. O jardim teve o diferencial de ser construído com placas de reciclado Tetrapak® tanto para diferenciá-lo das demais tecnologias já estudadas, quanto para testar um material utilizado em projetos de compensação ambiental. As temperaturas superficiais da parede viva, da parcela protegida e da parcela controle foram monitoradas e comparadas para análise da intensidade do mecanismo de sombreamento. Os resultados demonstram que no início da manhã a parede viva impediu a perda de calor pela fachada e, a partir da incidência solar direta, ela manteve as temperaturas superficiais da parcela protegida menores em relação à controle. Essa diferença atingiu até 9,4 °C na Tse (período da manhã) e 2,8 °C na Tsi (período da tarde), assim como, um atraso térmico máximo de 06h30min entre os picos de Tse. Esses achados evidenciam a influência positiva da parede viva no inverno, considerando as características do clima Cfa (frio de manhã e quente durante o dia); ampliam o conhecimento sobre a influência térmica da parede viva contínua na edificação e reforçam o uso das paredes vivas para além da estética.

Palavras-chave: jardim vertical, desempenho térmico, infraestrutura verde, sistema de jardim vertical, parede verde.

Authors' contribution:
MCB: conceptualization, data curation, formal analysis, investigation, methodology, project management, visualization, writing - original draft, writing - review and editing. **MSGCF:** conceptualization, data curation, formal analysis, methodology, project management, supervision, validation, visualization, writing - original draft, writing - review and editing. **MAA:** conceptualization, formal analysis, methodology, supervision, validation, visualization, writing - original draft, writing - revision and editing.

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Introduction

From the hanging gardens of Babylon (SHARP *et al.*, 2008) to the vertical gardens of Caixa Forum in Madrid, the vertical gardens have established themselves as an essential aesthetic and functional element due to their influence on the built environment and contribution to the improvement of the thermal performance of the edification. In Brazil, they are present from small balconies to the edge of entire avenues, such as Avenida 23 de Maio in São Paulo.

The living wall is a type of vertical garden that stands out in the Brazilian market for its easy installation and maintenance technique and allowing good efficiency in cultivating vegetation. It consists of a succession of layers and planting modules that fix the garden to vertical surfaces and will enable the cultivation of a wide variety of species (SHARP *et al.*, 2008; PÉREZ *et al.* 2011; PERINI; OTTELE, 2012).

The French botanist Patrick Blanc was responsible for the creation of the continuous living wall, which consists of 1- metallic profiles attached to the wall, 2- waterproofing and structuring PVC plate, 3- layers of geotextile felt fixed to the board and 4- irrigation system (BLANC, 2008), and that receives the name "continuous" for not presenting limitations for the roots in its planting area (MANSO; CASTRO-GOMES, 2015; BARBOSA; FONTES, 2016). From Blanc's initial model and with technological evolution, the living wall began to add a more functional character to the landscaping and contribute, for example, to the improvement of thermal performance and efficiency of the building energy (CHAROENKIT; YIEMWATTANA, 2016).

Its influence on the thermal performance of the building occurs through changes in the internal microclimatic conditions and its immediate surroundings through four mechanisms of action: 1- shading mechanism, 2- thermal insulation mechanism, 3- barrier mechanism against the wind currents and 4- evapotranspiration cooling mechanism (WONG *et al.* 2009; WONG *et al.* 2010; PERINI *et al.* 2011; PÉREZ *et al*. 2011; PÉREZ *et al.*, 2014).

Pérez *et al.* (2014) point out that the shading mechanism is the most significant in the thermal influence of the living wall. It occurs through the total coverage of the façade by the constructive structure of the garden and by the vegetation, which acts as a shield that prevents the incidence of direct solar radiation, reduces surface temperatures and heat gain or loss by the building (MAZZALI *et al.*, 2013; PÉREZ *et al.,* 2014; SUDIMAC *et al.*, 2019).

Thus, when considering the living wall as a new coating system and its shading mechanism, research related to its thermal performance and its influence on the building had increased in quantity in recent years, although concentrated in high latitude climatic regions, limited to some seasons and without a well-defined data collection methodological protocol.

The maximum reductions ranged from 20 °C to 30 °C in external surface temperatures in the works by Chen, Li and Liu (2013), Mazzali *et al.* (2013), Caetano (2014), Coma *et al*. (2017) and Perini *et al.* (2017). While the internal surface temperatures had maximum reductions ranging from 10 °C to 12 °C in the works of Caetano (2014) and Charoenkit and Yiemwattana (2017). However, these maximum values were always recorded in the hottest seasons (spring/summer) and in different climate types such as temperate mediterranean, continental, mediterranean and humid subtropical.

In winter conditions, studies are fewer and show a reduction in external surface temperatures from 3 °C to 16.5 °C (MANSO; CASTRO-GOMES, 2015 CHAROENKIT; YEMWATTANA, 2017; BIANCO *et al.,* 2017; COMA *et al.,* 2017; DJEDJIG; BELARBI;

BOZONNET, 2017; OTTELÉ; PERINI, 2017) and internal surface temperatures of 0.7 °C to 5.9 °C (MANSO; CASTRO-GOMES, 2015; CHAROENKIT; YEMWATTANA, 2017; RAZZAGHMANESH; RAZZAGHMANESH, 2017).

These studies were carried out in mediterranean (mostly), tropical, humid subtropical and oceanic climates (1 study each). However, only the works by Charoenkit and Yemwattana (2017) and Razzaghmanesh and Razzaghmanesh (2017) did not occur in high-latitude locations with more severe winters. In addition, only Ottelé and Perini (2017) and Bianco *et al.* (2017) investigated the continuous living wall. Thus, the thermal influence of the continuous living wall is still poorly understood in more significant climate variability, especially in tropical and subtropical climates (KOHLER, 2008; OTTELÉ; PERINI et al, 2017).

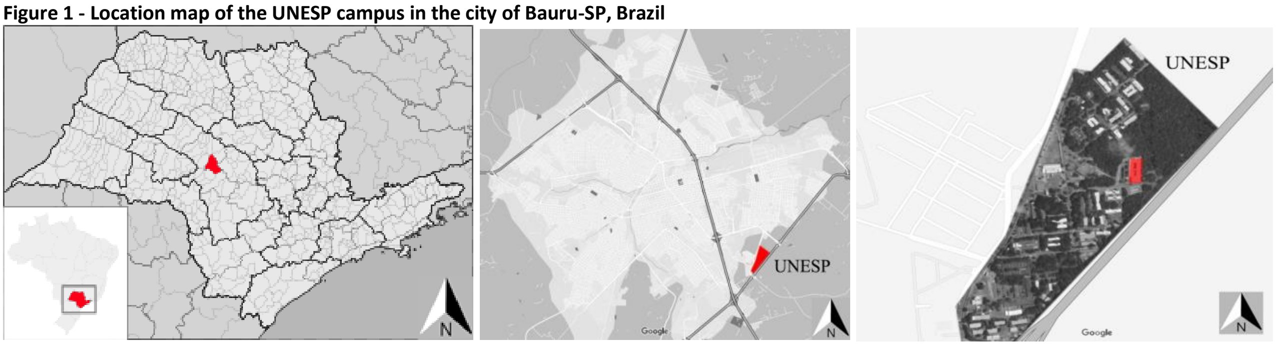
In this context, this article identifies and quantifies the influence of a "continuous living wall" on the variation of surface temperatures (internal and external) of an eastern façade in the winter conditions of a Brazilian city with a Cfa climate. In addition to the climatic differential, the experimental living wall was built with Tetrapak® recycled boards, which differentiates it from other technologies investigated in the literature, as well as tests a material used in urban environmental compensation processes such as in the projects of Elevado João Goulart (REOLOM, 2015) and Avenida 23 de Maio in the city of São Paulo (BARBOSA; FONTES, 2018).

The experimental study starts from the initial hypothesis that the vertical garden influences the reduction of temperatures, even in winter weather conditions. That would be positive considering the characteristics of the studied climate.

Materials and methods

The experimental study was conducted under "cold and dry" weather conditions, in the winter, in the city of Bauru (Lat. 22°18'54" South, Long. 49°03'39" West) within the campus of Universidade Estadual Paulista (UNESP) (Figure. 1). The city is characterized by a Cfa climate (subtropical climate, with hot summer), according to the Köppen classification (ALVARES *et al*., 2013) and has winter characterized as the driest season and with high maximum temperatures during the day, which may exceed the 30°C (IPMET, 2020) (Table 1).

Figure 1 - Location map of the UNESP campus in the city of Bauru-SP, Brazil



Source: adapted from Google (2021).

Table 1 - Average historical values for winter in the city of Bauru. Measurements from 1981 to 2009

Months	Tmin (°C)	RTmin (°C)	Tmax (°C)	RTmax (°C)	P (mm)
June	13,6	3,0	24,9	31,4	55
July	13,0	1,7	24,9	32,8	38
August	14,2	3,0	27,5	36,4	35

Notes: Tmin: Minimum temperature; RTmin: Minimum temperature record; Tmax: Maximum temperature; RTmax: Maximum temperature record; P: Precipitation. Source: IPMET (2020)

Experimental set up

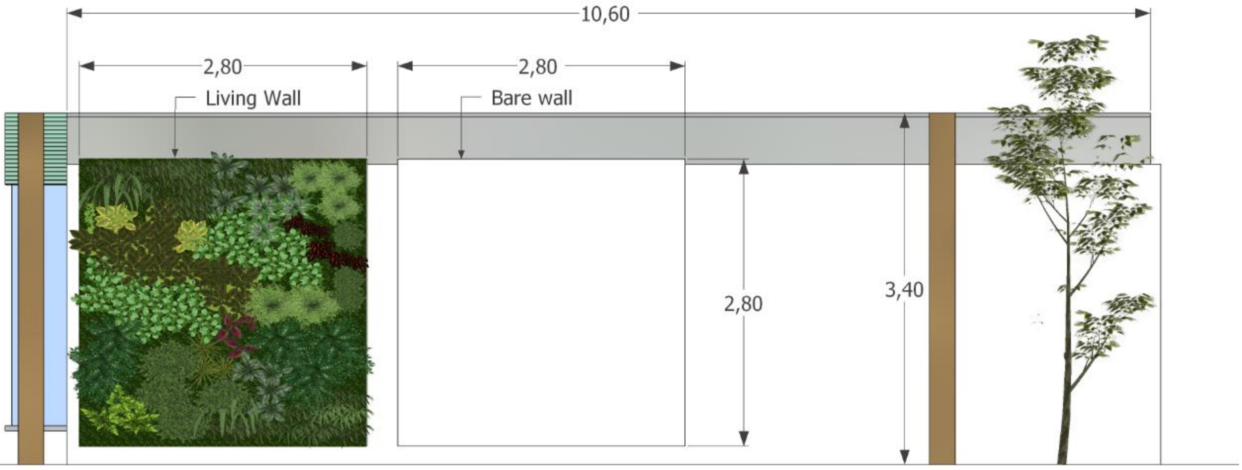
The living wall was installed on the eastern façade of an exhibition room, which receives solar radiation from 8:00 am to 12:00 pm and is directly related to a space for students to socialize (Figure 2). The other façade orientations are protected by roofs of adjacent buildings (west), do not receive direct solar radiation (south) and are shaded by trees (north). This reinforces the contribution of heat input to the building from the east orientation and the roof of the building.

Figure 2 - East façade in front of a student lounge

Notes: S: South façade; E: East façade; T: trusses; W: west. Source: the authors.

The east façade was divided into two sample plots (protected wall and bare wall) with a size of 2.80m x 2.80m (Figure 3) and positioned outside the influence of the shadow of the trusses. The protected wall is the plot of the façade protected by the living wall, and the bare wall is the control plot. The garden was supported by wooden rafters attached to the wall that pulled it away from the building, creating an air cavity three inches thick. Modules made with waterproof ecological boards derived from recycled Tetrapak® and the layers of geotextile blanket were attached to the rafters. On top of the geotextile, an irrigation system was installed with an automatic timer and a drip button per planting pocket (Figure 4). Finally, metal gutters were installed around the entire perimeter of the garden to finish off the Tetrapak® and geotextile layers, prevent convection in the air cavity and collect excess irrigation water.

Figure 3 - Façade with delimited sample plots (living and bare walls)



Note: measures in meters. Source: the authors.

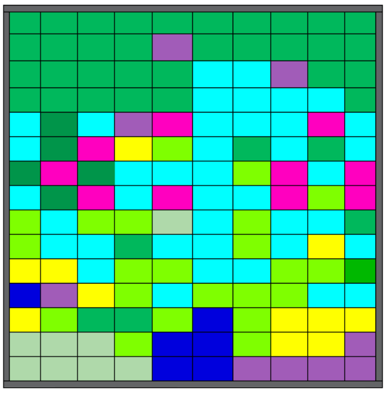
Figure 4 - Experimental Living Wall Composition

Notes: 1. Rafters, 2. Seal and drainage gutters, 3. Eco-plate modules with geotextile layers and 4 and 5. Irrigation lines and controller. Source: the authors.

The seedlings were prepared in geotextile wrappings with substrate suitable for gardening, which was enriched with super simple fertilizer (100 g/m²) and vermiculite (100 g/bag) to increase moisture retention. Later, the seedlings were embedded in the pockets formed by the blanket. The garden also received periodic maintenance with foliar fertilization every 15 days and pest and predator control. Irrigation was turned on twice a day outside of the measurement hours to avoid the influence of humidity on temperatures.

Species used (*Asparagus densiflorus* (Kunth) Jessop 'Sprengeri', *Tradescantia pallida* (Rose) DR Hunt, *Pelargonium peltatum* (L.) L'Hér, *Callisia repens* (Jacq.) L., *Rumohra adiantiformis* (G. Forst) Ching, *Sphagneticola trilobata* (L.) Pruski and *Epipremnum pinnatum* (L.) Engl) (LORENZI; SOUZA, 2008) were chosen based on botanical manuals provided by specialized companies (SKYGARDEN, 2015) in vertical garden projects and in its characteristics of resistance to local environmental conditions (Figure 5).

Figure 5 - Continuous Living Wall Planting Diagram



Planting Table

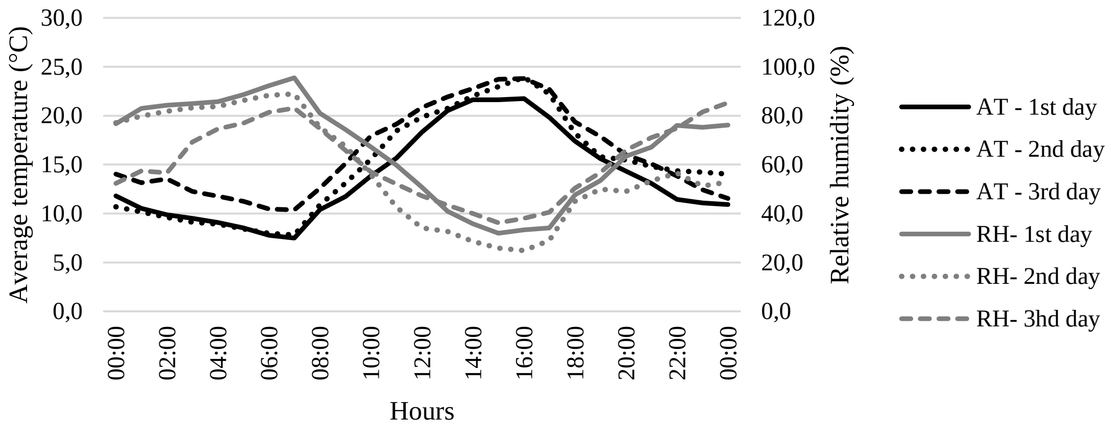
CODE	SCIENTIFIC NAME	PLANTING DENSITY
	Asparagus densiflorus	1 uni/pocket
	Callisia repens	3 uni/pocket
	Rumohra adiantiformis	1 uni/pocket
	Tradescantia pallida	3 uni/pocket
	Epipremnum pinnatum	1 uni/pocket
	Pelargonium peltatum	1 uni/pocket
	Sphagneticola trilobata	3 uni/pocket
	Tradescantia zebrina	3 uni/pocket
	Syngonium angustatum	3 uni/pocket

Source: the authors.

Data monitoring

Microclimate monitoring took place in the winter period, on August 10, 11 and 12, 2018, called in this work the 1st, 2nd and 3rd day of monitoring. Figure 6 shows the mean values of temperatures in the three days of monitoring and allows identifying that the maximums are within the historical range for August, as shown in Table 1. In addition, the days were characterized by clear skies, without the formation of clouds, a drop in humidity throughout the day and low temperatures at night.

Figure 6 - Daily averages of monitoring days in August 2018



Notes: AT: Average temperature; RH: Relative humidity. Source: the authors.

During the measurements, the following variables were monitored: the external surface temperature of the control plot (EstBw), the internal surface temperature of the control plot (IstBw), the external surface temperature of the garden (EstLw), the internal surface temperature of the garden (IstLw), the external surface temperature of the protected plot (EstPw) and internal surface temperature of the protected plot (IstPw).

Two digital thermometers model Instrutherm TH-1000 connected to K-type sensors were used to monitor the variables. The equipment was duly calibrated and previously tested. Measurements took place every 15 minutes, from 08:00 to 17:45. The time frame chosen for the measure aimed to investigate the thermal influence of the living wall on the building through direct sunlight and after incidence until the beginning of dusk. Also, due to the model of equipment used and the location of the experiment, continuous performance at night was not feasible for safety and team size.

Chart 1 shows the equipment specifications used in the campaign and their distribution in the plots shown in Figure 7. The local microclimatic conditions were monitored with a TESTO 175-H1 temperature and humidity data logger kept 4 m from the plots. In addition, a net radiometer with sensors parallel to the wall was used to measure the direct solar radiation that reached the vertical surface (Figure 7).

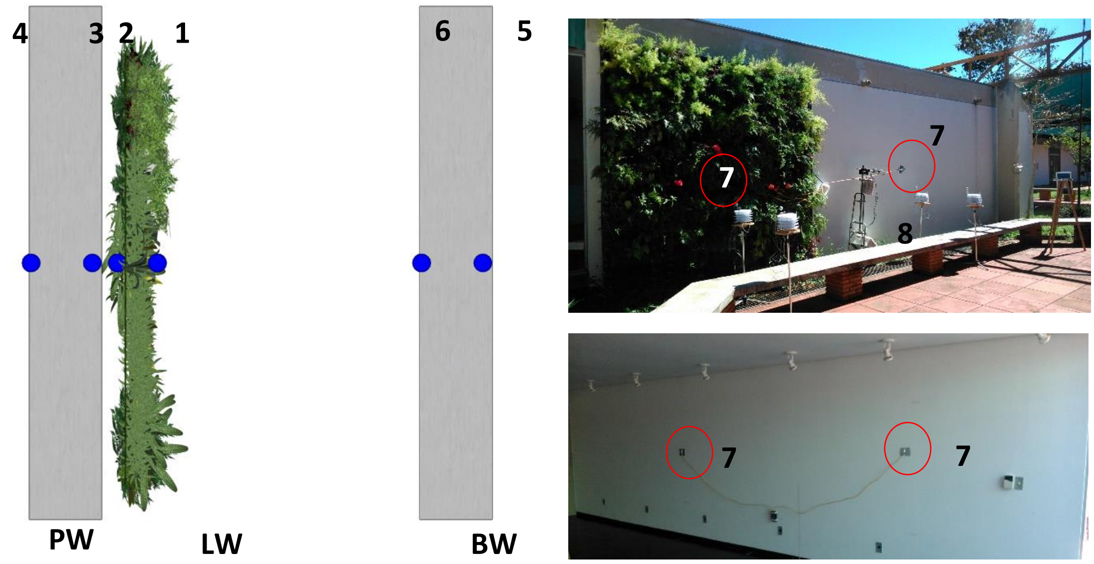
An access door to the air cavity was designed in the middle of the garden to install equipment for monitoring the surface temperatures inside and outside the protected plot.

Chart 1 - List of equipments used in campaigns with vertical garden

Variables	Equipments
Surface temperatures	Instrutherm TH-1000 digital thermometer with 5 measuring points. Range -40°C - 199.9°C. Accuracy +/- 0.5°C. Type K sensor with 20 mm length X 5 mm diameter. Accuracy 0.5%
Local air temperature and relative humidity	Testo 175-H1 datalogger. Accuracy: inner channel + 2% HR (0…+100%HR), + 0,5°C (-20…+70°C); external channel +0,2°C (-25…+70°C).
Thermal images	Flir E6 Thermal Camera (Temperature range -20° to 250°C, Accuracy: ± 2% or 2°C, Measurement modes: 3 modes, Point (center); area (min / max); isotherm (above / below)).
Direct and diffuse solar radiation	Kipp & Zonen CNR-1 net radiometer. Accuracy: ± 10% on sunny days. Campbell Datalogger model CR1000. Real-time accuracy +/- 3 min / year.

Source: the authors.

Figure 7 - Distribution of surface temperature monitoring equipment



Notes: PW: protected wall; LW: living wall; BW: bare wall/control plot. 1-Tsej; 2- Tsij; 3- Tsepp; 4-Tsipp; 5- Tsepc; 6- Tsipc; 7- Sensors for monitoring surface temperatures; 8- Net-radiometer. Source: the authors.

Data analysis

For the analysis of the results, the data obtained in the monitoring were treated and analyzed in the form of graphs and statistical tests. The study of the behavior of the external and internal surface temperatures of the wall aims to demonstrate the influence and intensity of the shading of the entire structure of the living wall on the protected plot. At the same time, the analysis of the garden's external and internal surface temperatures aims to identify the thermal gradient existing along the "garden-protected plot" system and the intensity of shading only of the vegetation concerning the external surface of the control plot.

The use of statistical tests aims to verify whether the differences between the means of the variables “external and internal surface temperature of the plot with garden (independent variable) and without garden (dependent variable)” were statistically significant. For this purpose, ANOVA-type analysis of variance and the Tukey test was used to verify comparisons of means between samples of equal sizes at a significance level of 0.05 and with the aid of the SPSS Statistics software.

Results and discussion

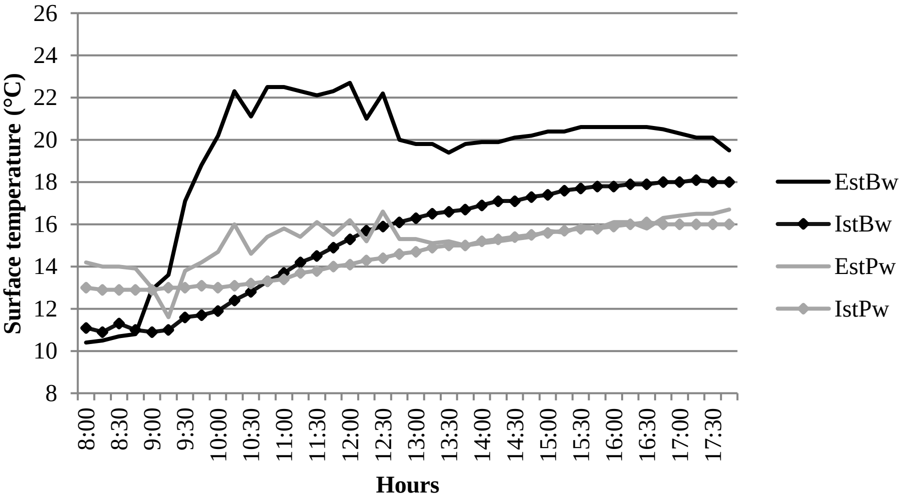
The results are presented in two parts: 1- The influence of the shading mechanism on variations in surface temperatures of the plot protected by the garden; 2- the temperature gradient formed along the “garden-protected plot” system.

During the monitoring period, incident solar radiation always recorded maximum values at 9:15 am, in the three days of monitoring and with a maximum value of 905 W/m². While the air temperature ranged from 7.4 °C to 24.3 °C and the relative humidity from 24.9% to 97.9%.

The shading mechanism on the variations on surface temperatures of the protected wall

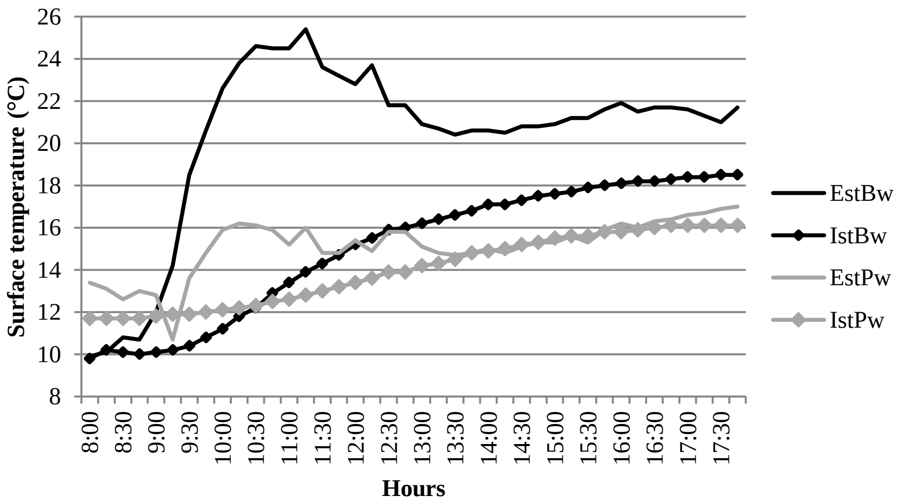
Figures 8, 9 and 10 show the behavior of the plots' external and internal surface temperatures in the three days of monitoring, and it is possible to see that the variables showed the same general pattern of variation, including in the thermal inversions. At the beginning of monitoring (8:00 am to 9:00 am), the protected plot always presented the highest internal (Ist) and external (Est) surface temperatures compared to the control plot. During this period, maximum differences were registered between the 3.8 °C (Est) and 1.9 °C (Ist) plots.

Figure 8 - Surface temperatures of plots with and without vertical garden on the first day of monitoring



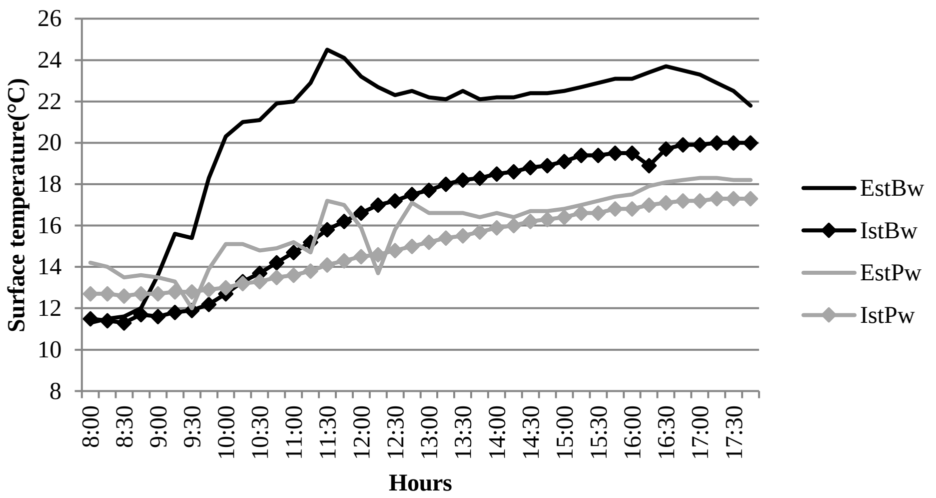
Source: the authors.

Figure 9 - Surface temperatures of plots with and without vertical garden on the second day of monitoring



Source: the authors.

Figure 10 - Surface temperatures of plots with and without vertical garden on the third day of monitoring



Source: The Authors.

These differences suggest that, with the colder room temperature, the garden worked as a thermal insulator, making it difficult for the protected plot to lose heat at night and keep the protected plot's indoor and outdoor surface temperatures higher than in the control plot. From 9:15 am, when there was already an incidence of direct solar radiation in the plots, there was an inversion, and the external surface temperature of the control plot (EstBw) increased rapidly and always recorded the highest values until the end of the monitoring period.

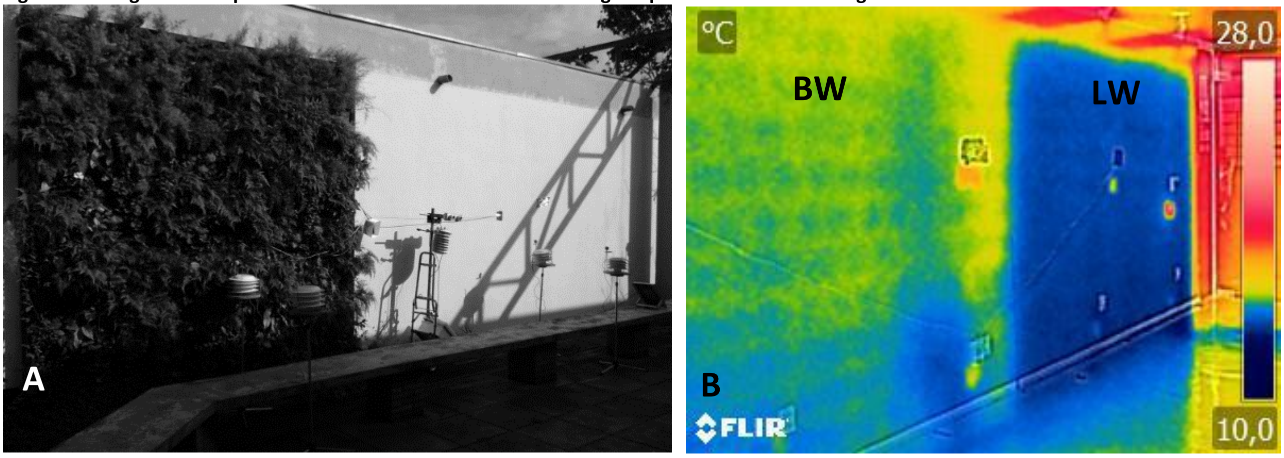
This inversion coincided with when the peak of direct solar radiation occurred, and this increase in EstBw happened even with the high reflectance of the control plot, which is painted white. In other words, the control parcel absorbed more radiation, while the living wall system (composed of vegetation and construction structure) acted as a shield against radiation for the protected parcel.

The inversion between the internal surface temperatures occurred between 10:15 am and 10:45 am, which reinforces the occurrence of a slower heat loss by the inner surface of the protected plot concerning the control, but also that there is less heat transfer into the building through the protected parcel. While EstPw still decreases until 9:15 am and then increases in value more sharply, IstPw has a more stable behavior, different from the behavior of surface temperatures in the control plot, in the same period. After 11 am, IstBw always reached values above all surface temperatures of the protected plot and remained so until the end of the monitoring period.

Figure 11 qualitatively illustrates the difference in internal surface temperature of the sample plots at 11:45 am, and it is clear the thermal influence of the vertical garden shading on the protected plot, which dampens heat input to the internal environment and reduces its superficial temperatures.

The garden maintained the minimum values of surface temperatures (external and internal) of the protected plot higher than those of the control plot, while the maximum values remained smaller. The protected plot's average surface temperatures (external and internal) were also consistently lower than those of the control plot (Table 2). In addition, the living wall also influenced the reduction of the variation in surface temperatures of the protected plot (Table 2), which recorded an average deviation of 5,9 °C (Est) and 4.1 °C (Ist). In contrast, in the control plot, this variation was 13.7 °C (Est) and 8.2 °C (Ist). It maintained an average difference of around 7.8 °C (Est) and 4.1 ° C (Ist) between the protected and control plots.

Figure 11 -Image of the experimental field and internal thermal image of plots with and without garden



Notes: A- Experimental field at 9:15 am with solar incidence in the plots. B- Internal surfaces of the plots with and without garden at 11:45 am. LW: living wall; BW: bare wall. Source: The Authors.

Table 2 - Descriptive analysis of external and internal surface temperatures

		Average (°C)	CV (%)	Interval (°C)		Daily variation (° C)	Minimum value (° C)	Maximum value (° C)
				Lower limit	Upper limit			
Est	EstBw 1	19,2	18,2	18,1	20,4	12,3	10,4	22,7
	EstBw 2	20,3	20,2	19,0	21,6	15,5	9,9	25,4
	EstBw 3	20,8	18,4	19,6	22,0	13,2	11,3	24,5
	EstPw 1	15,3	6,9	14,9	15,6	5,1	11,6	16,7
	EstPw 2	15,1	8,7	14,7	15,5	6,3	10,7	17,0
	EstPw 3	16,0	10,5	15,5	16,5	6,3	12,0	18,3
Ist	IstBw 1	15,2	17,2	14,4	16,1	7,2	10,9	18,1
	IstBw 2	15,0	20,7	14,0	16,0	8,7	9,8	18,5
	IstBw 3	16,5	18,8	15,5	17,5	8,7	11,3	20,0
	IstPw 1	14,5	8,3	14,1	14,9	3,2	12,9	16,1
	IstPw 2	14,0	11,7	13,4	14,5	4,4	11,7	16,1
	IstPw 3	15,0	11,3	14,4	15,5	4,7	12,6	17,3

Notes: 1- First Day; 2- Second day; 3- Third day. Source: The Authors.

The maximum reductions found for the external surface temperature always occurred in the morning (10:45 – 12:15). The maximum internal reductions only occurred after 3:30 pm. This hourly pattern was repeated in the three days of monitoring, and the garden provided a maximum decrease of 9.4 °C for the external surface temperature and 2.8 °C for the internal surface (Table 3), with the protected plot always recording the smallest values.

Table 3 - Reductions in external and internal surface temperatures between walls every monitored day

Monitored days	Maximum daily reductions		Average daily reductions	
	Est (°C)	Ist (°C)	Est (°C)	Ist °C
1º dia	7,1	2,1	4,0	0,7
2º dia	9,4	2,4	5,2	1,1
3º dia	8,2	2,8	4,8	1,5

Notes: Est: External surface temperature; Ist: Internal surfaace temperature

From these results, the external and internal surface temperature data of both plots (control and protected) were submitted to analysis of variance (ANOVA) and the Tukey test. For ANOVA, the data sets from the three days of monitoring showed that there was homogeneity of variance and normal distribution, which resulted in a p-value = 0.000 and indicated a difference between the means.

Tukey's test showed that the external surface temperatures showed a significant difference between treatments (control and protected) on all monitored days. In contrast, the internal surface temperatures showed a significant difference between the values of the protected plot of the first two days (lowest recorded IstPw) concerning the values of the control plot of the third day (highest registered IstBw). When comparing these days, there was an average difference of 2.0 - 2.5 °C in the Tsi of the protected plot compared to the control.

The living wall also reduced external surface temperature peaks by up to 8.4 °C compared to the control plot, with a maximum thermal delay of 06h30min.The same happened with the internal surface temperatures, with a difference of 2.7 °C, but with an anticipation of 45 minutes before the control plot (Table 4).

Table 4 - Impact of the living wall on the surface temperature peaks of the protected wall

Monitored days	Est (°C)			Ist(°C)		
	Pw	Bw	Difference between the peaks	Pw	Bw	Difference between the peaks
1º day	16,7 (05:45 pm)	22,7 (12 pm)	6,0	16,1 (04:30 pm)	18,1 (05:15 pm)	2,0
2º day	17,0 (05:45 pm)	25,4 (11:15 am)	8,4	16,7 (04:45 pm)	18,5 (05:30 pm)	2,4
3º day	18,3 (05:45 pm)	24,5 (11:30 am)	6,2	17,3 (05:15 pm)	20,0 (05:15 pm)	2,7
Averages	Average thermal delay 06h		Mean difference 6,9			Mean difference 2,4

Notes: EST: External surface temperature; IST: Internal surface temperature; Pw: Protected wall; Bw: Bare wall. Source: the authors.

When comparing the results obtained here with the few studies that investigated living walls in the winter period and presented the results as temperature variation (PERINI *et al.*, 2011; LIMA JÚNIOR, 2014; DJEDJIG; BELARBI; BOZONNET, 2017; CHAROENKIT; YIEMWATTANA, 2017), note- it appears that the thermal influence of the living wall is repeated, with a reduction in surface temperatures throughout the day (Table 5), as well as a reduction in thermal variation, even in different climates.

Table 5 - Comparison of the literature on the thermal influence of the living wall in different climates

Authors	Living Wall Type	Set up/ Size	Local	Climate	Façade orientation	Maximum temperature reduction	
						Est (°C)	Ist (°C)
Perini et al. (2011)	Plastic planter boxes	Existing LW/ -	Netherlands	-	West	5	-
Lima Júnior (2014)	Continuous living wall	Test cell/ 1,20 x -	Brazil	Temperate oceanic	East	11,9	7,2
Djedjig; Belarbi; Bozonnet, (2017)	Trays with sphagnum	Test cell/ 5,00 x 1,24	France	Oceanic	West	5	-
Charoenkit; Yemwattana (2017)	Modular with polypropylene planters	Test cell/ 1,00 x 1,00	Thailand	Tropical	South	2,1	1,6
Present work	Continuous living wall	Life size LW/ 2,80 x 2,80	Brazil	Humid subtropical	East	9,4	2,8

Notes: Size: length x hight; -: missing information; LW: living wall; EST: External surface temperature; IST: Internal surface temperature. Source: the authors.

In Brazil, Lima Júnior (2014) found a reduction in thermal amplitude of 5.4 °C and 18.8 °C for indoor and outdoor surface temperature, respectively, between treatments with and without a garden. It is noticed that the values differ in magnitude from those found by this study, probably due to the characteristics of the experiment, in which the author worked with smaller, independent test cells finished in concrete, with an internal heat source and with a living wall without side finish that could seal the air cavity and prevent convective exchanges.

While this work built an experiment in a full-size building, with a continuous façade painted in white (which can generate differences in surface temperature due to the reflectance and internal conduction of the wall) and without internal heat production on the monitoring days. In addition, this experimental garden was laterally sealed, which prevented the entry of heat by convection into the air cavity.

In climates with more severe winters (PERINI *et al*., 2011; DJEDJIG; BELARBI; BOZONNET, 2017), the reduction in daytime outdoor surface temperatures was lower than those recorded in this study, and indoor surface temperature was not monitored. In comparison, the only work in a tropical climate (CHAROENKIT; YIEMWATTANA, 2017) recorded reductions much smaller than this one and with a difference between them of 7.3 °C (Tse) and 1.2 °C (Tsi).

When considering the climatic conditions of the winter period in the city of Bauru, the findings of this work are in line with the initial hypothesis, as from high temperatures throughout the day, it was expected that the living wall would protect the facade and reduce temperatures external and internal surface of the protected parcel. However, in addition to these reductions, it was identified that the continuous living wall also influenced the reduction of thermal variation, surface temperature peak values and thermal delay.

Thus, the thermal influence of the living wall on the surface temperatures of the protected plot is desirable for this type of climate, as it demonstrates a decrease in the thermal load absorbed by the building throughout the day. The consequence of this is a tendency to reduce: 1- the internal ambient temperatures and 2- the use of active techniques of ambient conditioning, which can increase the building's thermal and energy efficiency.

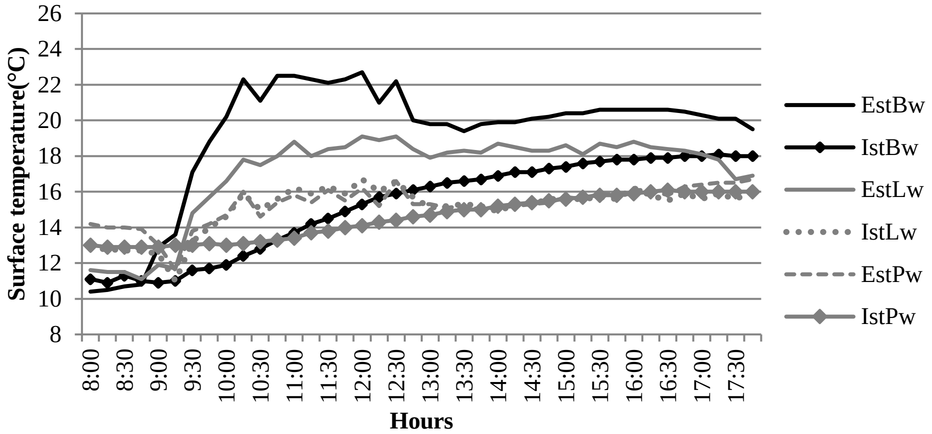
In addition, the behavior identified at the beginning of the measurement period indicates that, during the night, when outdoor ambient temperatures are lower, the garden prevents the building from losing heat and maintains higher internal surface temperatures than the control plot. This energy balance was identified by Bianco *et al*. (2017), who found, on sunny winter days, that the continuous living wall structure contributes to an approximately 63% reduction in thermal energy loss compared to a control wall.

"Living wall- Protected wall" system

Figures 11, 12 and 13 show the behavior of surface temperatures along the structure of the living wall, the external and internal surfaces of the protected plot and the control plot for the following variables: external surface temperature of the control plot (EstBw), surface temperature internal surface temperature of the control plot (IstBw), the external surface temperature of the garden (EstLw), the internal surface temperature of the garden (IstLw), the external surface temperature of the protected plot (EstPw) and internal surface temperature of the protected plot (IstPw).

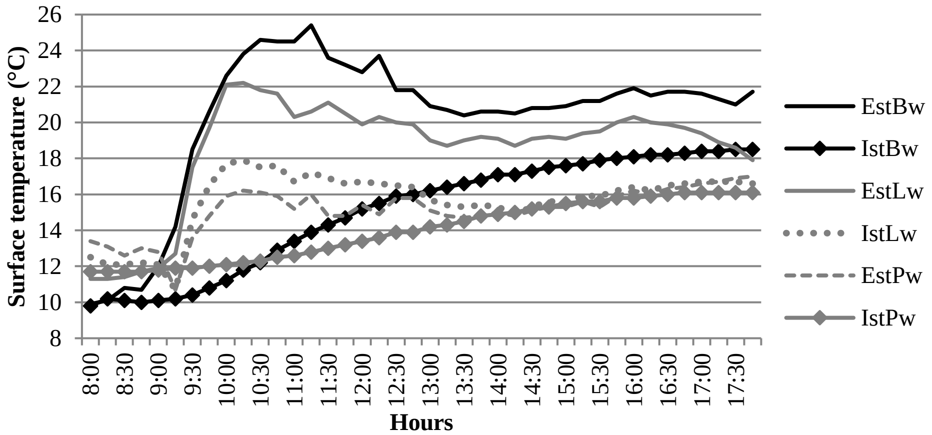
The surface temperatures of the "garden-protected plot" system were higher than those of the control plot only at the beginning of the monitoring period (8 am-9 am). From the incidence of direct solar radiation, the results showed a gradient of temperature values (external surface temperature of the garden, internal surface temperature of the garden, external surface temperature of the protected plot and the internal surface temperature of the protected plot) that was repeated in the three days of measurement.

Figure 11 - Surface temperatures along the garden-facade system on the first day of monitoring



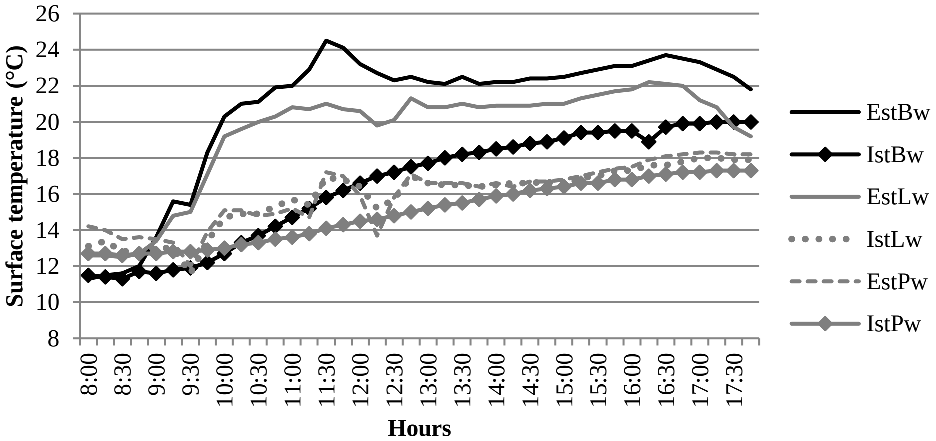
Source: the authors

Figure 12 - Surface temperatures along the garden-facade system on the second day of monitoring



Source: the authors

Figure 13 - Surface temperatures along the garden-facade system on the third day of monitoring



Source: the authors.

The EstLw showed maximum reductions of 3.5 - 4.8 °C in relation to EstBw, as a function of the vegetation that forms the first shading layer of the system. By analyzing only the differences between the peaks of external surface temperatures (EstLw x EstBw), the vegetation contributed to an average difference of 3 °C.

Thus, when considering the total average difference between the external surface temperature peaks (6.9 °C) provided by the living wall system (structure + vegetation), the shading of the vegetation contributed to almost 50% of this value, which demonstrates the importance of vegetation in the thermal influence of the system on the protected plot. It is noteworthy, however, that a pattern of time was not observed in the occurrence of peaks in the external surface temperature of the garden. Bianco *et al.* (2017) found that the surface temperature of the planting modules shaded by vegetation was eight °C lower than the external surface temperature of the unprotected wall under Italian winter conditions in the humid subtropical climate.

The maximum difference between the garden structure's external and internal surface temperatures was up to 5.1 °C. Whereas between the surface temperatures outside the garden and outside the protected plot it was 6.1 °C. This value was higher than that found by Perini *et al*. (2011), who also found that the external surface temperature of the garden structure, shaded by the foliage, is, on average, two °C higher than the external surface temperature of the protected wall.

The external surface temperature of the garden was lower than the internal surface temperature of the control plot from 5 pm onwards, which can be explained by the absence of direct radiation and the transfer of heat accumulated through the garden structure, as can be seen by the increase in internal surface temperatures of the living wall and external and internal temperatures of the protected portion.

The external surface temperature of the garden presented a pattern of variation similar to the external surface temperature of the control plot; similarly, the internal surface temperature of the garden also varied along with the external surface of the protected plot and, finally, the internal surface temperatures showed a similar pattern of variation. These patterns demonstrate how the constructive layers of the living wall increase the system's thermal resistance, insulating and preventing the direct influence of solar radiation on the internal surfaces of the garden and the external surfaces of the protected plot.

The internal surface temperatures of the garden (IstLw) had generally higher values in relation to the external surfaces of the protected plot (EstPw), with a maximum difference of 2.1 °C. The external surface temperatures of the protected plot were higher than its internal ones during hours of direct sunlight in the garden (until noon). From that time onwards, this plot's surface temperatures (indoor and outdoor) approached, with average differences of 0.3 °C until the end of the afternoon.

From 17:00 onwards, the external surface temperature of the protected plot showed a slight tendency to increase, probably due to the heat flow from the vertical garden and the thermal exchanges existing in the air cavity. The direction of this heat flux (visible by the reductions in the garden's external and internal surface temperatures) allows for identifying the heat loss to the air cavity. At the same time, there is a simultaneous increase in the external surface temperature of the protected plot.

Conclusion

From a scenario of the popularization of living walls and, concomitantly, the complete lack of scientific studies that evaluate the benefits that these technologies can add to the built environment, in the Brazilian reality, the present work aimed to identify and quantify the influence of a "continuous living wall" in the variations of surface temperatures (internal and external) of an East facade, in the winter period of a city with a Cfa climate.

To achieve this objective, an approach was used with the construction of an experimental vertical garden, the establishment of sample plots on the east facade (control plot and wall plot protected by the garden) and the monitoring of its external and internal surface temperatures, along and after the period of direct sunlight.

For the climatic conditions of the city of Bauru, the results show that, throughout the day, the living wall significantly influenced the reductions in surface temperatures of the protected plot (9.4 °C for Tse and 2.8 °C for Tsi), in the damping of the thermal variation and kept the minimum temperatures higher and the maximum temperatures lower than those of the control plot. In addition, the living wall was able to reduce, on average, 6.9 °C in external surface temperature peaks, with an average thermal delay of 6 hours.

Vegetation plays a fundamental role in this dynamic, as it forms the first shading layer of the system and contributes almost 50% to the average reduction of the external surface temperature peaks of the protected plot, in addition to reducing the external surface temperature of the garden by 3 °C, average.

These results demonstrate that the living wall has a significant thermal influence on the built environment due to the action of the different constructive layers that shade and provide resistance to entry and heat loss by the protected part of the building. This effect is very positive for the winter conditions of the climate studied, as it is characterized as a dry climate, with very high daytime temperatures and little cloud cover (which leads to intense solar radiation incidents on buildings during the day, at the same time when there is a sudden drop in ambient temperature, at night), different from the European climates already studied by the literature in the area.

Thus, the findings of this work contribute to quantitatively highlighting the significant thermal influence of the living wall on the building, even on a small scale. And it expands the knowledge of the thermal behavior of this technology in the Brazilian climate reality to guide future architects and landscapers in using these vertical gardens beyond the aesthetic issue.

It is essential to point out that the internal thermal environment is also influenced by the activities carried out by the envelope and cover materials. However, the objective of this work was to identify the thermal environment between the "protected garden-plot" system, which opens space for future work with this theme in the reality of national science. Be it for the measurement protocol, equipment types, vertical garden system model, experimental size, and maintenance of the prototype.

For future works, it is necessary to investigate the transfer of heat to the internal environment, the quantification of heat flux between plots with and without a garden, the use of measurement data for the calibration of computational simulations and the comparison between a living wall and other classic shading and isolation elements.

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