Revista Hábitat Sustentable Vol. 10, N°. 2. ISSN 0719 - 0700 / Págs. 82 - 93
https://doi.org/10.22320/07190700.2020.10.02.06




Recibido 16/06/2020
Aceptado 27/10/2020

# THERMAL PERFORMANCE OF TRADITIONAL EAST FACING GREEN FACADES IN TRACT HOUSING LOCATED IN ARID CLIMATES

## DESEMPEÑO TÉRMICO DE FACHADAS VERDES TRADICIONALES DE ORIENTACIÓN ESTE EN VIVIENDAS SERIADAS EMPLAZADAS EN CLIMAS ÁRIDOS

PABLO ABEL SUAREZ
Arquitecto, Becario Doctoral
Instituto de Ambiente, Hábitat y Energía (INAHE - CCT CONICET), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) Mendoza, Argentina
https://orcid.org/0000-0002-0032-3278
suarezpablo91@gmail.com

MARÍA ALICIA CANTÓN
Diplomada en Estudios Avanzados en Arquitectura
Investigadora principal Instituto de Ambiente, Hábitat y Energía (INAHE - CCT CONICET), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) Mendoza, Argentina
https://orcid.org/0000-0002-8714-9697
macanton@mendoza-conicet.gob.ar

ÉRICA CORREA
Doctora en Ciencias, Investigadora Independiente
Independiente, Instituto de Ambiente, Hábitat y Energía (INAHE - CCT CONICET), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) Mendoza, Argentina
https://orcid.org/0000-0003-1690-076X
ecorrea@mendoza-conicet.gob.ar

RESUMEN

La infraestructura verde constituye una estrategia de mitigación de las temperaturas urbanas y edilicias. El presente trabajo evalúa el impacto de un tipo de Sistema de Enverdecimiento Vertical (SEV), las Fachadas Verdes Tradicionales (FVT), en la condición térmica de viviendas localizadas en el Área Metropolitana de Mendoza, Argentina; cuyo clima es seco desértico (BWk - Köppen-Geiger). Con tal fin, se monitorearon, durante dos veranos consecutivos, dos casos de estudio: una vivienda con FVT, en orientación este, y una vivienda testigo de igual tipología y materialidad. Se registraron datos de temperatura ambiente exterior e interior; superficial exterior e interior y radiación horizontal. Se hallaron disminuciones de hasta 3.1°C en la temperatura ambiente interior de las viviendas con FVT, de hasta 27.4°C en muros exteriores y de 6.5°C en muros interiores. Las magnitudes de los resultados encontrados demuestran el potencial de la aplicación de esta estrategia en un clima árido.

Palabras clave
zonas áridas, arquitectura bioclimática, viviendas unifamiliares, Sistemas de Enverdecimiento Vertical.

**ABSTRACT**

Green infrastructure is a strategy for mitigating urban and building temperatures. This work assesses the impact of a type of Vertical Greenery System (VGS), the Traditional Green Façades (TGF), on the thermal condition of dwellings located in the Metropolitan Area of Mendoza, Argentina, whose climate is dry desert (BWk - Köppen-Geiger). To this end, two case studies were monitored for two consecutive summers: a dwelling with an east-facing TGF and a control dwelling of the same typology and materiality. Outdoor and indoor ambient temperature data were recorded: surface exterior and interior, and horizontal radiation. Decreases of up to 3.1°C in the indoor ambient temperature of FVT dwellings, of up to 27.4°C on exterior walls and 6.5°C on interior walls were found. The magnitudes of the results found show the potential of applying this strategy in an arid climate.

Keywords
arid zones, bioclimatic architecture, single dwellings, Vertical Greenery Systems

Revista Hábitat Sustentable Vol. 10, N°. 2. ISSN 0719 - 0700 / Págs. 82 - 93
https://doi.org/10.22320/07190700.2020.10.02.06



# INTRODUCTION

In densely populated areas, there are negative impacts typical of the advance of urbanity on the environment, from carbon emissions and the increase of average air temperatures, to the laying waste of periphery production areas and the destruction of ecosystems. According to data from the International Energy Agency (OECD / IEA, 2017), cities cover 3% of the planet's surface and, apart from causing the increase in the average air temperature, they are responsible for 67% of global energy consumption. At the same time, the United Nations Environment Program (UNEP) indicates that 75% of the infrastructure there will be in 2030, has not yet been built. This represents an opportunity to create "clean and green cities", that are efficient and resilient. One strategy to reach this goal is urban greenery.

Green infrastructure generates environmental-energy benefits: at an urban scale, it reduces the heat island and increases the comfort of public spaces and, at a building scale, it reduces energy consumption to condition indoor spaces. Recent research has determined that in a template climate, a 10% increase of green infrastructure could reduce average urban air temperatures by 2.5°C (Gill, Handley, Ennos & Pauleit, 2007) and, that in a dry arid climate, the ambient temperature in a tree covered area could fall 3.8°C (Salas & Herrera, 2017). In addition, green spaces generate benefits for peoples' health and welfare (Contesse, Van Vliet & Lenhart, 2018). Given that the city consolidation phenomenon has held back the potential of incorporating traditional green structures like parks, squares and tree-lined streets, new vegetation typologies associated to green walls and roofs have emerged.

The development of knowledge linked to Vertical Greenery Systems (VGS) has grown in terms of its international relevance in the last decade (Bustami, Belusko & Beecham, 2018). They show proven efficiency in reducing temperatures of living spaces and their resulting impact on energy consumption. The results vary in their magnitude, depending on the type of climate where VGS are applied, recording the highest outdoor surface temperature reductions of around 34°C (Suklje, Saso & Arkar, 2016) in Cfa/Cfb type climates (humid warm template, hot summer) and indoor room temperature of around 5°C (Haggag, Hassan & Elmasry, 2014) in BWh type climates (desert arid, hot summer) and outdoor ambient temperature of around 3.3°C (Wong, Kwang Tan, Tan, Chiang & Wong, 2010) in AF type climates (Humid equatorial). Most of the studies have been run in European, Asian and North American countries, in warm template, both humid and dry – Csa, Cfa/Cfb - climates. The results have shown similar or better performance for VGS, regarding temperature reductions, in arid climates compared to humid ones.

The Metropolitan Area of Mendoza, Argentina (AMM, in Spanish), has a desert arid climate (BWk - Köppen-Geiger). From the point of view of the presence of vegetated spaces, it has a relevant number of forested open spaces within its structure. However, the urban densification and growth process has not been accompanied by a densification process of the urban greenery and also, the availability of empty urban spaces that allow incorporating traditional green spaces has also been limited. As a result, increasing green areas implies implementing new vegetation technologies like VGS, among others.

The thermal-energy benefits of VGS are associated to diverse effects. First, the *shading effect*, which places the VGS as interceptors of direct or indirect incident solar radiation. This effect, depending on the wall's orientation, is important in climates with a strong solar incidence (Othman & Sahidin, 2016). Secondly, the *cooling effect* that reduces air temperature and increases humidity, releasing water vapor from plants into the atmosphere (Wong & Baldwin, 2016). It is proven that the reach of this extends up to 60 cm from its surface (Wong et al., 2010). The *insulation effect* also has to be mentioned. This is produced by the layers that the VGS construction package comprises, that interfere in the heat transmission of building envelopes. And finally, the *windbreak effect*, which causes reductions in heat losses or gains through convection due to the ruggedness of foliage that blocks air circulation. Regarding the impact of VGS on energy savings, Coma et al. (2017) have recorded values of around 58.9%. In terms of environmental benefits, carbon emissions absorption values were recorded that range between 0.14 and 0.99 kg/m$^3$ (Marchi, Pulselli R., Marchettini, Pulselli F & Bastianoni, 2015). This, apart from the impact it generates on the degree of noise absorption and the contribution to the preservation of biodiversity. Finally, green façades increase the perception of comfort, relaxation and improve people's moods (Elsadek, Liu & Lian, 2019).

VGS are grouped into two categories: Living Walls (LW) and Green Façades (GF) (Figure 1). GF are those systems where there are climbing and/or hanging plants, covering a given area. They can be divided into three typologies: Traditional Green

Revista Hábitat Sustentable Vol. 10, N°. 2. ISSN 0719 - 0700 / Págs. 82 - 93
https://doi.org/10.22320/07190700.2020.10.02.06

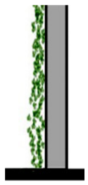
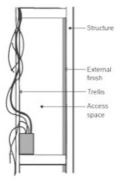
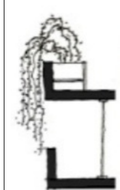

<table>
<tr><th>VGS</th><th colspan="6">TYPOLOGY</th></tr>
<tr><td rowspan="2">Green Façades</td><td></td><td></td><td>
</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Traditional</td><td colspan="2">Double Skin</td><td colspan="2">Perimeter Flowerpots</td></tr>
</table>

Figure 1. GF Typologies. Source: Preparation by the authors.

Façades (TGF), where the plant attaches itself to the building's wall; Double Skin Green Façades (DSGF) or green curtain wall, where there is a supplementary structure that is separated, at a variable distance, from the building's wall; and Green Façades with Perimeter Flowerpots (PFGF), which can house flowerpots with climbing and/or hanging plants to generate a green curtain wall.

TGF are systems whose application is simple, low-cost and have a reduced impact on the existing construction. In the case of Mendoza, this strategy is one of a spontaneous application that is widespread in residential low-density areas. The benefits are classified in two categories: thermal-energy and environmental.

The thermal-energy benefits have been extensively analyzed in international literature. However, the development of knowledge regarding the incidence of TGF on the thermal behavior of indoor spaces in desert type climates is limited, as is the analysis of the differential impact of using the strategy, considering the orientation of the façade.

In this context, Alexandri & Jones (2008) determine for the case of Athens, Greece, whose latitude (32° N) is comparable to that of Mendoza (37° S). that the maximum radiation received in summer on east- and west-facing vertical planes is 1.65 times greater than that received on north and south planes. Meanwhile, Susorova, Angulo, Bahrami & Stephens (2013), measure the effect of TGF on building walls in the four orientations in Chicago, finding greater magnitudes, around 4 to 5 times higher, for east and west orientations. Coma et al. (2017) determine that DSGF type facades are more effective on west and east sides than on the north one. Recent studies assign greater cooling and energy saving magnitudes produced by an east and west-facing GF in summer conditions (Pérez, Coma, Sol & Cabeza, 2017) (Kontoleon & Eumorfopoulou, 2010). From all this, it can be seen that VGS generate the greatest impact on east and west facing positions whose vertical planes are those most demanded by solar radiation.

As a result, the objective of this work is to evaluate the impact of east-facing TGF, on indoor and outdoor surface temperatures, and the thermal condition of indoor spaces in terraced single-family dwellings in AMM, Argentina.

# WORK HYPOTHESIS

In arid climates, new vegetation technologies, in particular Traditional Green Façades, constitute a passive bioclimatic conditioning strategy due to their capacity to attenuate the surface temperatures of the building envelope, and to approach comfort conditions in the inhabitable spaces in the warm season.

# METHODOLOGY

## CASE STUDIES

To carry out this study, two dwellings were chosen, located in a terraced typology neighborhood in Guaymallén, Mendoza. The morphology of both houses is compact, extended and structured on two levels. Figure 2 shows the location of the dwellings in the context of the Mendoza Metropolitan Area (AMM). And, in Figure 3, the morphological type of the buildings is seen along with the hour-by-hour sunlight study of incident solar radiation on the east façade.

Technologically, the cases of analysis show a construction type, typical of seismic areas:

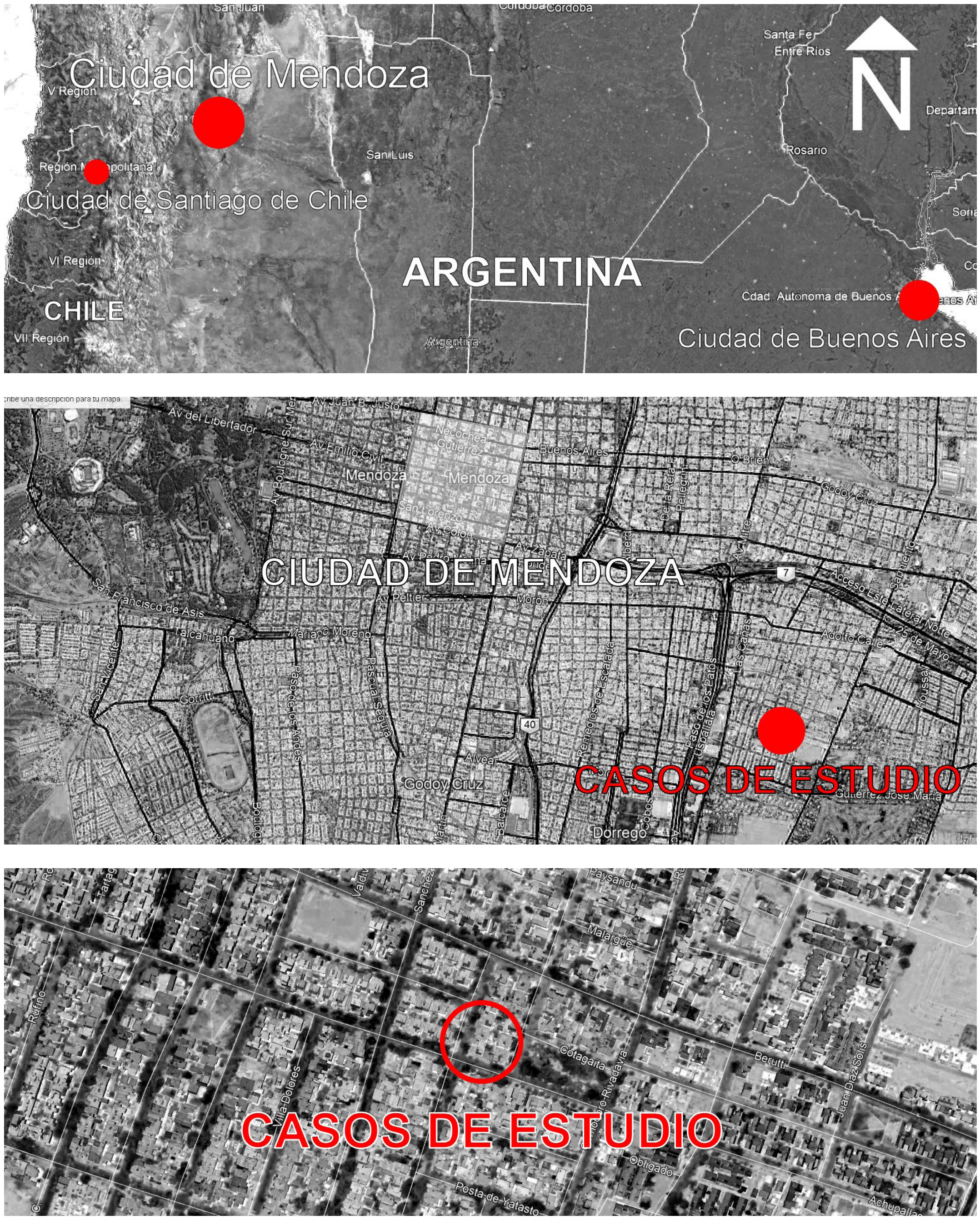



Figure 2: Location of the dwellings in the context of AMM. Source: Preparation by the Authors.

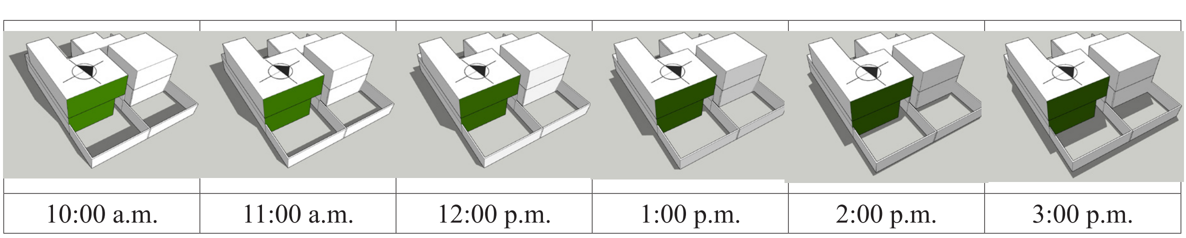



Figure 3. Hour by hour sunlight study of the incident solar radiation on the east façade. Source: Preparation by the Authors.

Revista Hábitat Sustentable Vol. 10, N°. 2. ISSN 0719 - 0700 / Págs. 82 - 93
https://doi.org/10.22320/07190700.2020.10.02.06

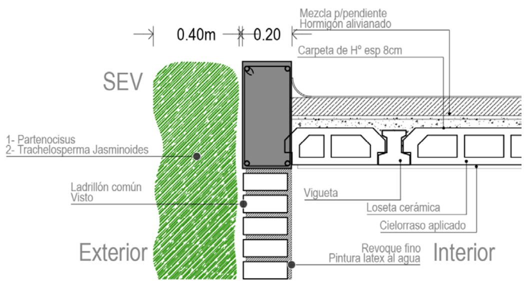
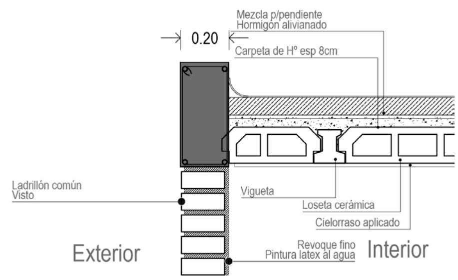

| | |
|---|---|
|  |  |
| Dwelling with TGF | Control dwelling |
|  |  |
| Envelope construction plan | Envelope construction plan |
|  | |
| Climbing species: Parthenocissus Quinquefolia -Virginia Creeper | |

Figure 4. Case studies Source: Preparation by the authors.

reinforced concrete and visible brick masonry structure. The roofs are flat, formed by thermically and hydraulically insulated lightened concrete slabs. One of these has the TGF system on the internal east-facing façade of the dwelling and on the north-facing façade. The TGF is a simple system formed by a climbing plant of the Parthenocissus *Quinquefolia* species, from the Vitaceae family, locally known as the Virginia Creeper, a species originally from North and Central America; woody, deciduous, hardy, fast growing, high foliage density and adaptable (tolerates most soils and climate conditions), low solar permeability and upkeep, it is widely used in the region. It has grown attached to the wall with an average thickness of 40 cm over its whole extension and covers 100% of the masonry wall which forms the east façade of the dwelling (Figure 4).

## CASE STUDY MONITORING

To evaluate the impact of TGF on the thermal behavior of the dwellings' east facing façades, the variables measured were the following: outdoor air humidity and temperature in the open public and private spaces next to the dwellings, indoor air humidity and temperature and indoor and outdoor surface temperature on walls. The sensors used to measure the environmental relative humidity and temperature were a thermistor and thermocouple type, HOBO Onset, UX100-003, UX120. The location of the sensors and equipment used is presented in Figure 5.

The data were recorded in two periods: summer 2019 – 21/01 to 05/02 and 2020 – 30/01 to 14/02, over 15 days, with data being recorded every 15 minutes. The sensors were calibrated beforehand to guarantee reliability of the data obtained.

Desempeño térmico de fachadas verdes tradicionales de orientación este en viviendas seriadas emplazadas en climas áridos
Pablo Abel Suarez, María Alicia Cantón, Érica Correa
Revista Hábitat Sustentable Vol. 10, N°. 2. ISSN 0719 - 0700 / Págs. 82 - 93
https://doi.org/10.22320/07190700.2020.10.02.06



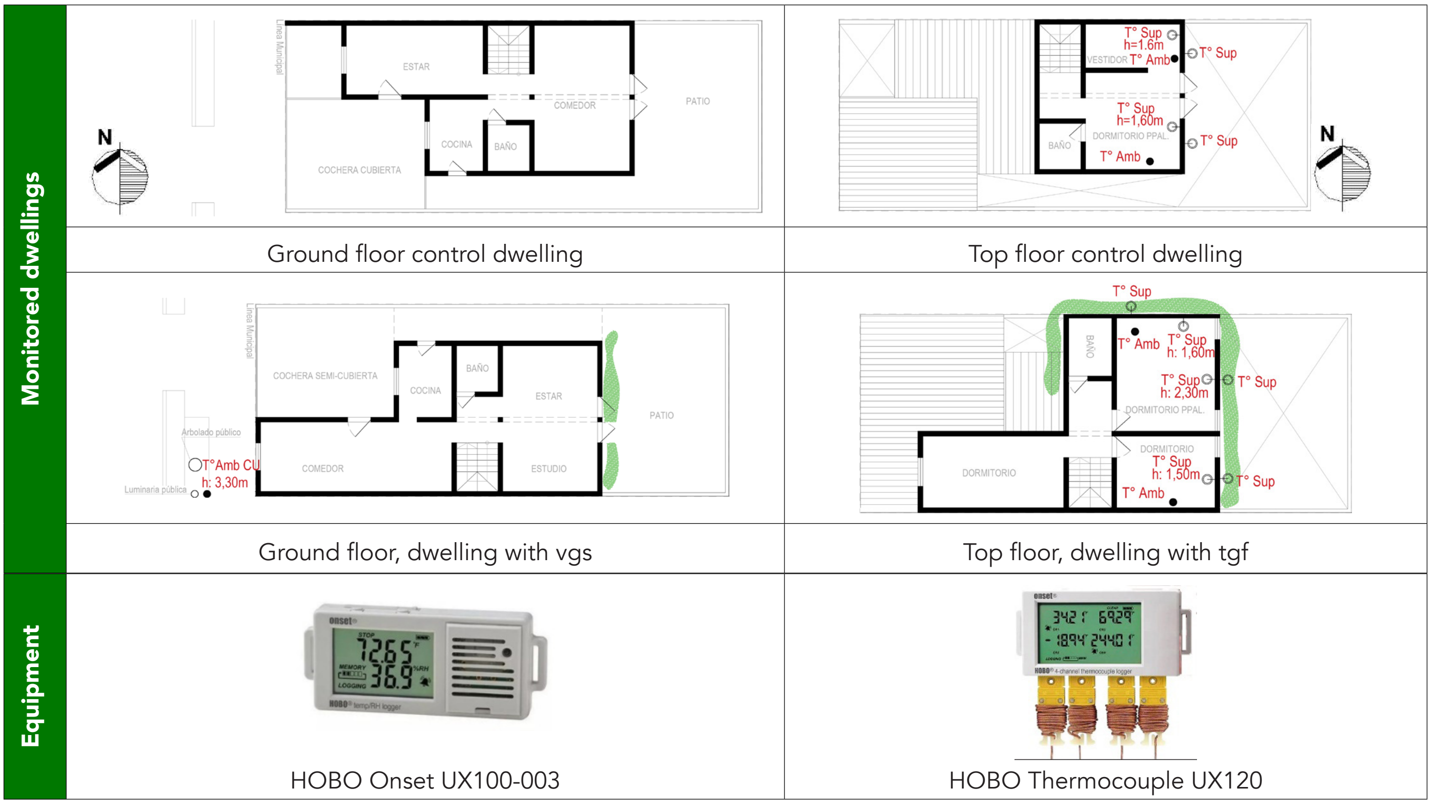



Figure 5. Case studies: location of sensors and equipment used.Fuente: Elaboración de los autores.Source: Preparation by the authors.

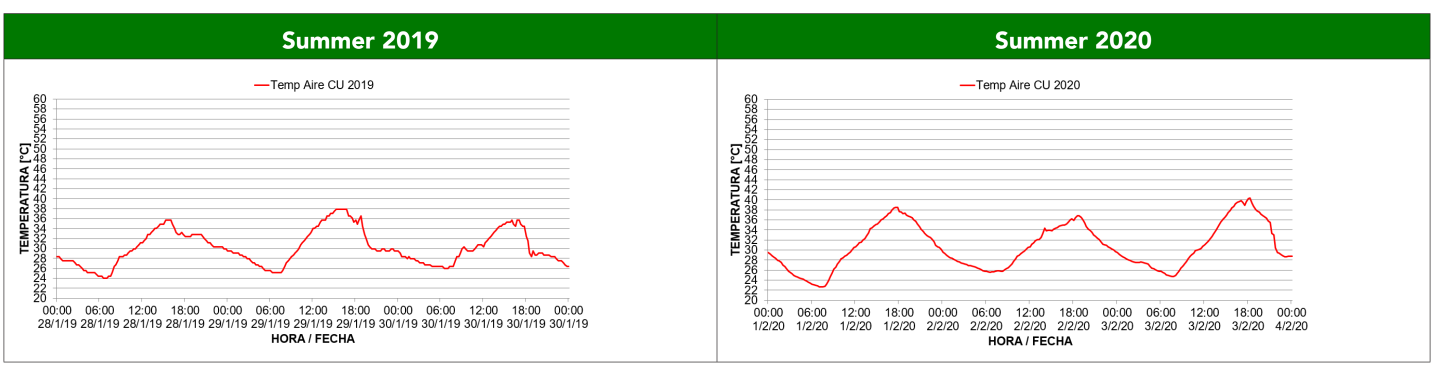



Figure 6. Air temperature in the urban canyon for the chosen days. Source: Preparation by the authors.

## SELECTION OF ANALYSIS DAYS

For the purposes of comparatively analyzing the thermal response of the case studies evaluated with and without TGF, days were chosen, whose characteristics were representative of a typical summer day of the local microclimate, within the 30-day period where the measurements were recorded. As a result of this, the selection criteria were the following: highest and lowest temperatures, high heliophania and low wind speed. The days chosen in each period were: from January 28th to 30th 2019, and from February 1st to 3rd 2020. Figure 6 presents the air temperature behavior in the urban canyon for the days of analysis. The shape of the curve reflects that the analyzed days have a similar behavior regarding the kurtosis of the outdoor air temperature curve as well as its amplitude. It is checked that the maximum and minimum temperature peaks match in magnitude and hourly occurrence over time.

Considering the behavior of the curves and the quantitative analysis of the data for the 2019 period, daily temperature ranges that vary from 35.7°C to 37.9°C are seen for the maximum, and between 24.0°C and 26.0°C for the minimum. In the days corresponding to summer 2020, daily temperature values that oscillate between 36.8°C and 40.4°C are

| | Max. Temp. | Min. Temp | Total av. Temp. | Min. Av. Temp | Max. Av. Tempo | Av. Amplitude |
|---|---|---|---|---|---|---|
| 2019 Period: 28/01 - 30/01 | 37.9 | 24.0 | 30.4 | 25.0 | 36.4 | 11.4 |
| 2020 Period: 01/02 - 03/02 | 404 | 22.7 | 30.9 | 24.3 | 38.6 | 14.2 |

Table 1. Average maximum, mean and minimum temperatures for the analyzed periods.

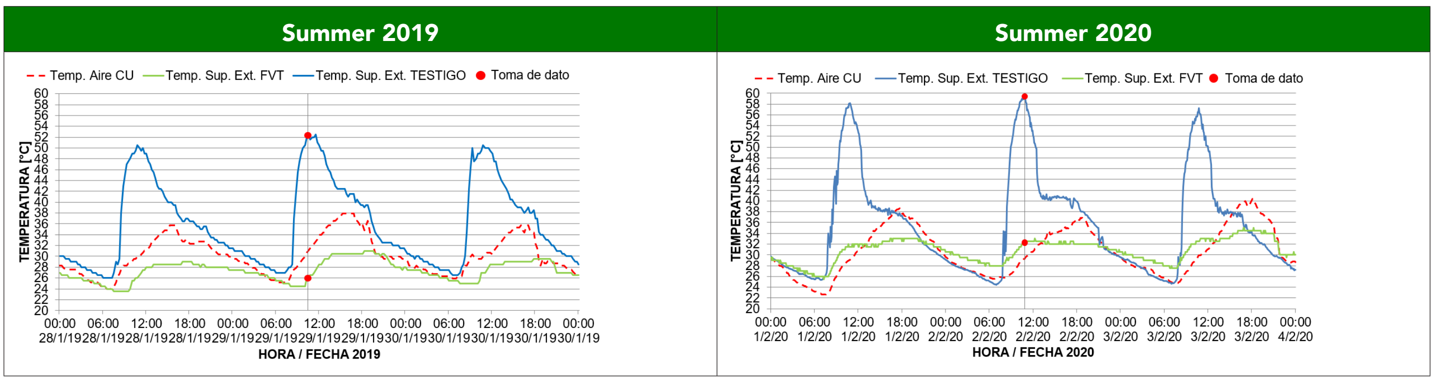



Figure 7. Outdoor surface temperature: control case and case with east-facing TGF. Source: Preparation by the authors.

seen for the maximums, and between 22.7°C and 25.6°C, for the minimums (Table 1).

Taking the average temperature values, magnitudes of 36.4°C in the maximums and 25.0°C in the minimums are seen for the 2019 period, and values of 38.5°C in the maximums and 24.3°C in the minimums, for the 2020 period are seen. Differences of around 2.1°C are confirmed regarding average maximum temperatures, and differences of 0.7°C with respect to the average minimum temperatures between the two periods considered are also confirmed. Finally, using the average mean temperature values, magnitudes of 30.4°C and 30.9°C were found for the time periods of 2019 and 2020, respectively. It is seen that both periods record differences of around 0.5°C (Table 1).

Considering the daily thermal amplitude variable, the temperature range oscillates between 9.8°C and 12.7°C, for the first period, and between 11.2°C and 15.8°C for the second one. On average, the thermal amplitude registers magnitudes of 11.4°C and 14.2°C for the 2019 and 2020 periods, respectively (Table 1).

# RESULTS AND DISCUSSION

Continuing with the study, three variables were chosen, incidence on the thermal-energy performance of the cases being analyzed – from the database collated over the chosen days of summer 2019 and 2020: outdoor surface temperature, indoor surface temperature, and indoor room temperature of homolog spaces. Said variables were analyzed in terms of the temperature difference between both cases: case with TGF and control case. This is outlined below.

## OUTDOOR SURFACE TEMPERATURE: CASE WITH TGF VS. CONTROL CASE

In order to recognize potential impacts of using vegetation on east-facing outdoor masonry walls, the outdoor surface temperatures of the case with TGF (green curve), the control case (blue curve) and the behavior of the outdoor air temperature (red curve) were compared (Figure 7).

The TGF case has lower outdoor surface temperatures than the control case during all daytime hours. The maximum outdoor surface temperature reductions were 26.5°C and 27.4°C, for the first and second period, respectively. The temperature difference peaks are seen, in both periods, between 10:30 am and 10:45 am, on days with clear skies (Figure 8). This shows that the outdoor surface temperature is essentially controlled by the radiation phenomenon, bearing in mind the orientation of the wall, east. The results are higher than magnitudes found by Vox, Blanco and Schettini (2018) and Hoelscher, Nehls, Jänicke and Wessolek (2016), which range between 9.0°C and 15.5°C (North-facing TGF in a Csa Mediterranean hot summer climate type, Northeast-facing TGF in a DFb warm summer climate type, respectively).

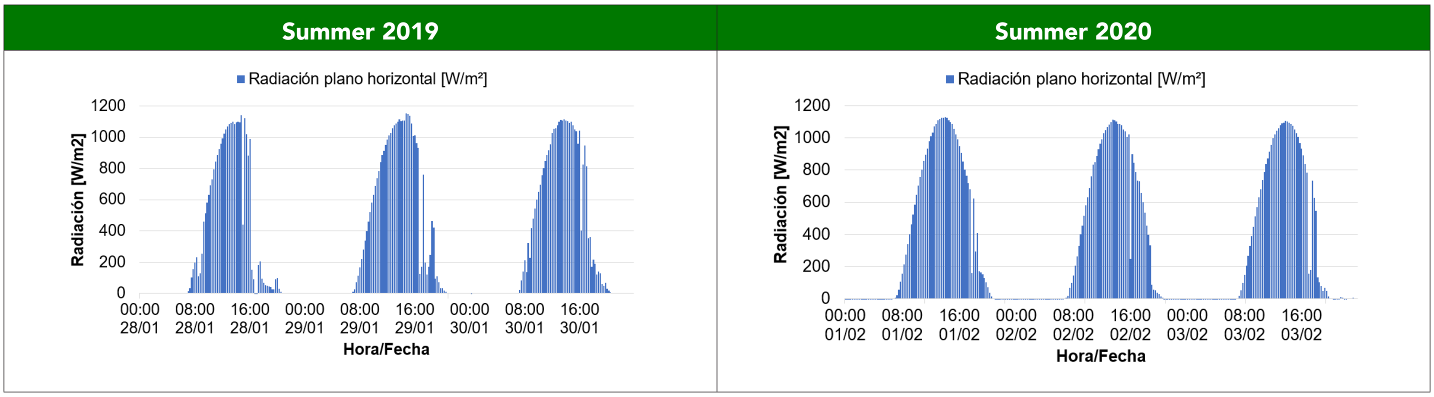



Figure 8. Global irradiance on the horizontal plane for both study periods. Source: Preparation by the authors.

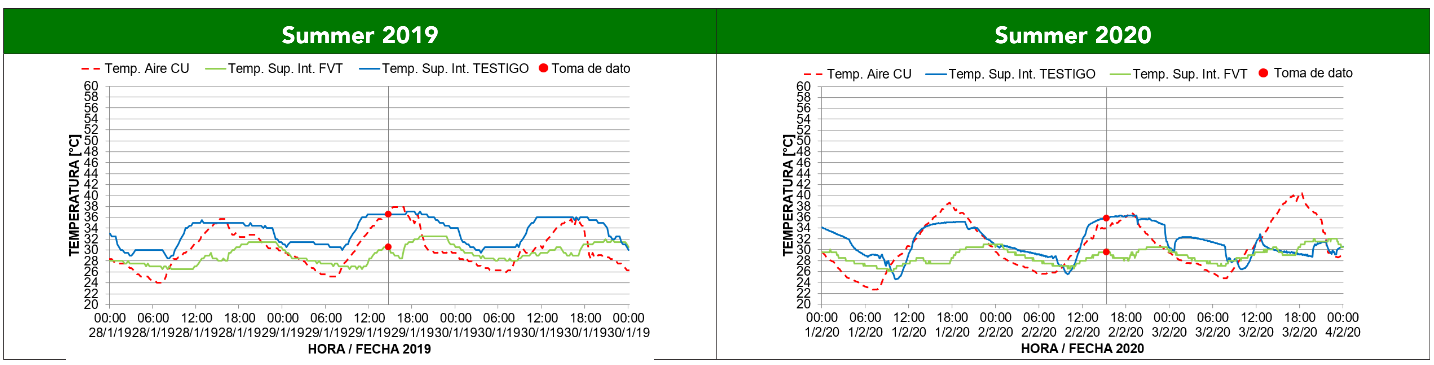



Figure 9. Indoor surface temperature: control case and case with VGS, east facing. Source: Preparation by the authors.

The analysis of the surface temperature curves of the wall with TGF shows a thermal amplitude that oscillates around 6°C on average in both periods measured. On the contrary, the curve corresponding to the control wall registers a thermal amplitude of 24°C on average in the first period and of 31°C in the second period. This is because in the second period measured, 2020, higher temperatures were recorded. The behavior of the wall covered with vegetation shows attenuated maximums and minimums which reflect the conservative capacity of the green wall, compared to the behavior of the insulating material.

In the behavior of the curves of Figure 6, it is seen that the cooling effect produced by the TGF occurs throughout all daytime hours in both periods, where the outdoor surfaces of the walls are always colder than the control case. While, on the other hand, the case with TGF has higher outdoor surface temperatures compared to the control case, during the night of the 2020 period. This magnitude records a maximum of 4.1°C higher on the surface covered with vegetation, compared to the control wall. As a result, the wall with TGF is fresher during the day and warmer during the night, compared to the control in this period. These results are because of the higher thermal amplitude recorded in the summer of 2020, where the insulating effect of the wall with TGF can be perceived during the night. However, it must be considered that the maximum cooling magnitude on the wall with TGF is 6.7 times higher than the maximum heating magnitude of the control case, and it happens at times where the outdoor ambient temperature registers its highest values.

With the purpose of checking the response of the outdoor surface temperatures on control and TGF walls when facing different outdoor climate conditions, and considering that the summer of 2020 has higher average and maximum temperatures than summer 2019, a comparison was made between the averages of the maximum daily magnitudes of this variable. The averages of the maximums recorded on the control wall and the wall with TGF were compared in the two periods. The control wall has, during the entire 2020 period, a 7.3°C increase in the average maximum outdoor surface temperatures, compared to 2019; while the TGF wall has, during the entire 2020 period, a 4.5°C increase in the average maximum outdoor surface temperature compared to 2019. Bearing in mind that the average maximum air temperature increased 2.2°C between the periods, it can be inferred that the harder the summer is, the greater the impact of the TGF is.

Revista Hábitat Sustentable Vol. 10, N°. 2. ISSN 0719 - 0700 / Págs. 82 - 93
https://doi.org/10.22320/07190700.2020.10.02.06

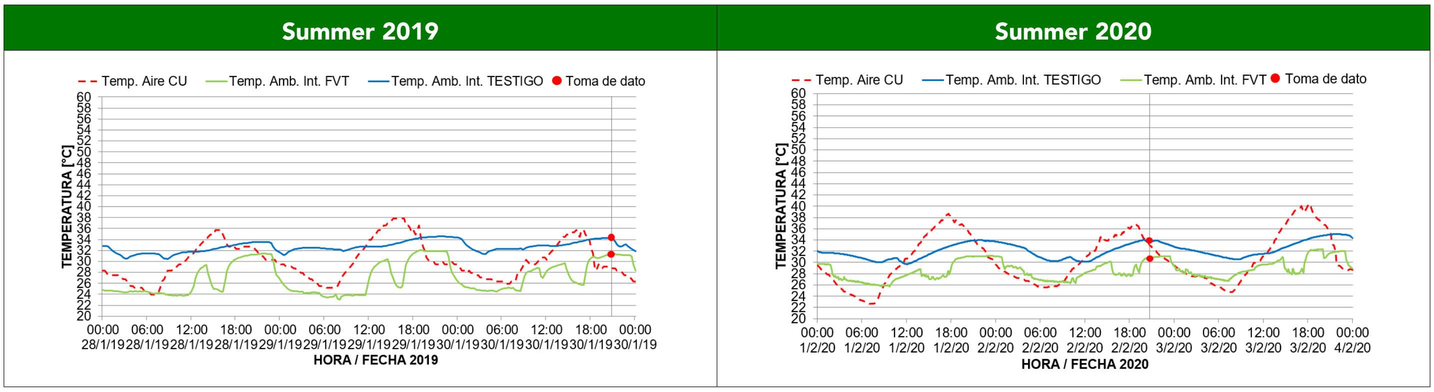




Figure 10. Indoor room temperature: control case and case with VGS, both east-facing.Source: Preparation by the authors.

## INDOOR SURFACE TEMPERATURE: TGF CASE VS. CONTROL CASE

The indoor surface temperatures were measured to determine the thermal impact of using vegetation inside the evaluated dwellings. Figure 9 illustrates the behavior of the indoor surface temperature of the wall with TGF (green curve), the control case (blue curve) and the outdoor air temperature (red curve).

The case with TGF shows the indoor surface temperatures compared to the control case during all daytime hours, with maximum reductions of 6.0°C and 6.5°C for the 2019 and 2020 cycles, respectively. These temperature differences are seen in both periods between 2:45 pm and 3:45pm: one and two hours after the solar midday. This delay found, in respect to the maximum radiation time, can be interpreted as a consequence of the thermal inertia of the construction setup of the walls, which is coherent with the typical behavior of the mass materials of the envelope. This underscores that, just as with the outdoor surface temperature, the indoor surface temperature is greatly conditioned by the radiative phenomenon for this east-facing wall. The results are higher than the magnitudes found by Hoelscher et al. (2016) and Susorova et al (2013), which oscillate between 1.7°C and 2.0°C (West-facing TGF in DFb warm summer climate type, North-facing TGF in Dfa hot summer continental climate type, respectively).

Unlike the analysis of the outdoor surface temperature, the cooling magnitudes on the indoor surfaces of the walls, produced by the presence of vegetation, occur during daytime and nighttime hours in both periods. That is to say, the cooling effects of the TGF have an impact on the inside of the dwellings also during times without solar radiation. Now, it is important to mention that the indoor surface temperatures are affected by the use of air conditioning at times where the outdoor environmental temperature moves away from the comfort temperature. This is the result of monitoring real cases in use conditions in the warm season. It is because of this that, in the interest of considering the objective of this work, the temperature differences were taken in the absence of air conditioning.

## INDOOR ROOM TEMPERATURE: TGF CASE VS. CONTROL CASE

Figure 10 graphically shows the behavior of the indoor room temperature in two homolog spaces between the TGF (green curve), the control (blue curve) and the outdoor air temperature (red curve) cases for the two periods measured.

The analysis of indoor room temperature allows identifying that the temperature of the TGF case is lower than the control one, with maximum differences of between 2.9°C and 3.1°C during all hours of the day in the two measurement cycles. Just as seen in the surface temperature analysis, the differences are greater than those found by Kontoleon and Eumorfopoulou (2010), which were around 0.5°C (east-facing TGF with a Cfb soft summer template oceanic climate type). Meanwhile Hoelscher et al. (2016) and Perini, Ottelé, Fraaij, Haas and Raiteri (2011) did not find effects of the TGF on the air temperature in indoor spaces.

The indoor room temperature in the dwelling with TGF reveals average reductions of 3°C compared to the control case. This result can be interpreted as the magnitude of the TGF use impact on the sensitive heat of a dwelling. Just as in the case of the indoor surface temperature, the use of air-conditioning is seen in the behavior of the indoor temperature curve. It is for this reason that, again in this analysis, the data were taken in periods without artificial air conditioning of the spaces.

# CONCLUSION

The work presented evaluated the impact of east-facing TGF, on the indoor and outdoor temperatures, and the indoor room temperature in dwellings built from baked brick and reinforced concrete structures. The study was performed in the Metropolitan Area of Mendoza, during the summer, on a representative analysis universe, from the morphological and technological point of view, of single-family terraced dwellings in the study area.

Quantitatively, the research shows a potential to reduce outdoor surface temperatures on the envelopes of buildings by up to 27.4°C and by 6.5°C on indoor surface temperatures. These benefits are due to the effect of the green structure on the wall compared to the full exposure of the control wall. Considering the results found in international literature for other climates and the same construction technology – bricks and reinforced concrete – it is seen that the application of TGF, as a strategy to improve the thermal behavior of indoor spaces, is more efficient in arid climates.

In addition, the temperature variations between the two periods measured express that, on facing the harshest outdoor conditions, the impact of TGF is greater in the attenuation of indoor and outdoor surface temperatures.

The comparison of the behavior of the wall surface temperature curves with TGF compared to the control wall, show the attenuation capacities of the maximum and minimum temperatures that result from the conservative nature of the TGF, which is comparable with that of an insulating material. However, the TGF offer additional advantages compared to the application of synthetic materials for thermal conservation, linked to ecosystemic benefits and contributions to people's health. From this conclusion, the need is seen that, in future research, the additional benefits of green strategies are considered to measure their efficiency regarding traditionally used insulation strategies.

Regarding room temperatures, reductions of around 2.9°C and 3.1°C were recorded in the 2020 and 2019 periods, respectively, in the dwelling with TGF compared to the control case. Likewise, it was seen that the average magnitude of the impact on the sensitive heat of the dwelling is around 3°C. The indoor temperature reduction values reached in this work, just like those obtained regarding the reduction of surface temperatures, have a greater magnitude compared to the findings in scientific literature, in similar experiences evaluated in other climates (0.5°C). These results demonstrate the value of using the strategy to decrease indoor temperatures and to approach comfort conditions for inhabitable spaces inside buildings in arid climates.

Summarizing, this research represents a concrete contribution to the development of knowledge about the implementation of VGS in buildings located in desert arid type climate areas (BWk - Köppen-Geiger). In this sense, the results found demonstrate the potential of a suitable greenery technology regarding its efficiency to reduce temperatures and contribute to energy savings, as a result of a lower energy demand for the thermal conditioning of indoor spaces. That is to say, it presents an alternative simple application strategy for building envelopes that tends to not just guarantee the sustainability of the habitat in harsh climatic contexts, but also to improve the quality of life of the built environment within the framework of a sustainable development.

In future stages, it is foreseen to increase the number of case studies, assess the impact associated to other construction technologies and to the use of different species for the TGF. The end goal is to broaden the scope of this research, and to generalize results that contribute towards fostering the use of TGF as a design tool to reduce indoor temperatures in the built setting and their impacts on a building, urban and global scale.

# ACKNOWLEDGMENTS

The authors would like to thank the National Scientific and Technical Research Council (CONICET) and the National Agency for Scientific and Technological Promotion (ANPCYT) for the financing received to carry out this research. They would also like to thank the owners of the dwellings, Miguel Martí and Rodrigo Benítez who allowed the monitoring of the case studies.

# BIBLIOGRAPHICAL REFERENCES

Alexandri, E. y Jones, P. (2008). Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. *Building and Environment*, *43*(4), 480–493. DOI: https://doi.org/10.1016/j.buildenv.2006.10.055

Bustami, R. A., Belusko, M., Ward, J. y Beecham, S. (2018). Vertical greenery systems : A systematic review of research trends. *Building and Environment*, *146*(August), 226–237. Recuperado de https://doi.org/10.1016/j.buildenv.2018.09.045

Coma, J., Pérez, G., De Gracia, A., Burés, S., Urrestarazu, M. y Cabeza, L. F. (2017). Vertical greenery systems for energy savings in buildings: A comparative study between green walls and green facades. *Building and Environment*, *111*, 228–237. DOI: https://doi.org/10.1016/j.buildenv.2016.11.014

Contesse, M., Van Vliet, B. J. M. y Lenhart, J. (2018). Is urban agriculture urban green space? A comparison of policy arrangements for urban green space and urban agriculture in Santiago de Chile. *Land Use Policy*, *71*(October), 566–577. DOI: https://doi.org/10.1016/j.landusepol.2017.11.006

Elsadek, M., Liu, B. y Lian, Z. (2019). Urban Forestry & Urban Greening Green façades : Their contribution to stress recovery and well-being in high- density cities. *Urban Forestry & Urban Greening*, *46*(September). DOI: https://doi.org/10.1016/j.ufug.2019.126446

Gill, S. E., Handley, J. F., Ennos, A. R. y Pauleit, S. (2007). Adapting cities for climate change: The role of the green infrastructure. *Built Environment*, *33*(1), 115–133. DOI: https://doi.org/10.2148/benv.33.1.115

Haggag, M., Hassan, A. y Elmasry, S. (2014). Experimental study on reduced heat gain through green façades in a high heat load climate. *Energy and Buildings*, *82*, 668–674. DOI: https://doi.org/10.1016/j.enbuild.2014.07.087

Hoelscher, M. T., Nehls, T., Jänicke, B. y Wessolek, G. (2016). Quantifying cooling effects of facade greening: Shading, transpiration and insulation. *Energy and Buildings*, *114*, 283–290. Recuperado de https://doi.org/10.1016/j.enbuild.2015.06.047

Kontoleon, K. J. y Eumorfopoulou, E. A. (2010). The effect of the orientation and proportion of a plant-covered wall layer on the thermal performance of a building zone. *Building and Environment*, *45*(5), 1287–1303. DOI: https://doi.org/10.1016/j.buildenv.2009.11.013

Marchi, M., Pulselli, R. M., Marchettini, N., Pulselli, F. M. y Bastianoni, S. (2015). Carbon dioxide sequestration model of a vertical greenery system. *Ecological Modelling*, *306*, 46–56. DOI: https://doi.org/10.1016/j.ecolmodel.2014.08.013

OCED / IEA. (2017). Energy Technology Perspectives 2017. *International Energy Agency (IEA) Publications*. Recuperado de https://webstore.iea.org/download/summary/237?fileName=English-ETP-2017-ES.pdf

Othman, A. R. y Sahidin, N. (2016). Vertical Greening Façade as Passive Approach in Sustainable Design. *Procedia - Social and Behavioral Sciences*, *222*, 845–854. DOI: https://doi.org/10.1016/j.sbspro.2016.05.185

Pérez, G., Coma, J., Sol, S. y Cabeza, L. F. (2017). Green facade for energy savings in buildings: The influence of leaf area index and facade orientation on the shadow effect. *Applied Energy*, *187*, 424–437. DOI: https://doi.org/10.1016/j.apenergy.2016.11.055

Perini, K., Ottelé, M., Fraaij, A. L. A., Haas, E. M. y Raiteri, R. (2011). Vertical greening systems and the effect on air flow and temperature on the building envelope. *Building and Environment*, *46*(11), 2287–2294. DOI: https://doi.org/10.1016/j.buildenv.2011.05.009

Salas-Esparza, M. G. y Herrera-Sosa, L. C. (2017). La vegetación como sistema de control para las Islas de Calor Urbano en Ciudad Juárez, Chihuahua. *Hábitat Sustentable*, *7*(1), 14-23. Recuperado de http://revistas.ubiobio.cl/index.php/RHS/article/view/2737

Suklje, T., Saso, M. y Arkar, C. (2016). On detailed thermal response modeling of vertical greenery systems as cooling measure for buildings and cities in summer conditions. *Energy, 115*, 1055–1068. DOI: https://doi.org/10.1016/j.energy.2016.08.095

Susorova, I., Angulo, M., Bahrami, P. y Stephens, B. (2013). A model of vegetated exterior facades for evaluation of wall thermal performance. *Building and Environment*, *67*, 1–13. DOI: https://doi.org/10.1016/j.buildenv.2013.04.027

Vox, G., Blanco, I. y Schettini, E. (2018). Green façades to control wall surface temperature in buildings. *Building and Environment*, *129*(September 2017), 154–166. DOI: https://doi.org/10.1016/j.buildenv.2017.12.002

Wong, I. y Baldwin, A. N. (2016). Investigating the potential of applying vertical green walls to high-rise residential buildings for energy-saving in sub-tropical region. *Building and Environment*, *97*, 34–39. DOI: https://doi.org/10.1016/j.buildenv.2015.11.028

Wong, N. H., Kwang Tan, A. Y., Tan, P. Y., Chiang, K. y Wong, N. C. (2010). Acoustics evaluation of vertical greenery systems for building walls. *Building and Environment*, *45*(2), 411–420. DOI: https://doi.org/10.1016/j.buildenv.2009.06.017