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GLAZED CURTAIN WALLS: THERMAL TRANSMITANCE CALCULATION

FACHADAS VIDRIADAS: CÁLCULO DE TRANSMITANCIA TÉRMICA

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RESUMEN

La piel de vidrio es uno de los elementos dominantes de la arquitectura moderna y contemporánea. Este diseño de envolvente puede influir significativamente en la demanda de energía operativa de los edificios. En este trabajo, se analizan los sistemas de fachada de piel de vidrio disponibles en Argentina, con el objetivo de determinar los rangos de transmitancia térmica asociados, en función del diseño de perfiles, del tipo de vidriado y de las dimensiones de los paños vidriados. Inicialmente, se estudia mediante cálculo numérico bidimensional el impacto de varios parámetros de diseño de los perfiles sobre la transmitancia térmica, destacando la relevancia del modo de fijación del vidriado, para luego calcular la transmitancia térmica de las fachadas completas. Los resultados indican que el valor de transmitancia térmica de las fachadas de piel de vidrio depende principalmente de la transmitancia del vidriado empleado, y supera la misma en un 24%, en promedio.

Palabras clave
fachadas, piel de vidrio, índices, sistemas constructivos.

ABSTRACT

Glazing is one of the dominant features of modern and contemporary architecture. This envelope design may have a great impact on operational energy demand of buildings. In this work, glazed façade systems available in Argentina are analyzed, with the purpose of determining the associated thermal transmittance ranges, in terms of the profiles' design, the type of glazing and the size of glass panes. First, by using bidimensional numerical calculation, the impact of several profile design parameters on thermal transmittance is studied, highlighting the relevance of glazing fixing methods, to then calculate the thermal transmittance of the entire facade. The results indicate that the thermal transmittance value of glazed facades, mainly depends on the transmittance of the glass used, and exceeds this by 24% on average.

Keywords
façades, glazing, indices, construction systems

INTRODUCTION

The way our habitat is built, cannot just be focused on seeking architectural functionality and aesthetics. It must also consider the sustainability of the built space, looking to reduce global final energy consumption and greenhouse gas emissions. The environmental impact of the building sector has been rising in recent decades (Cao, Dai & Liu, 2016), and reversing this trend is a great challenge which numerous countries have already embarked upon. The road to reach this goal, can be classified in three categories: the passive design and energy conservation strategies, the energy efficiency technologies for building operation; and energy production using renewable energies (D'Amanzo, Mercado & Karlen, 2020). Within the first category, one can find the design of the building envelope, which has an impact on the operational energy demand.

One of the envelope characteristics that most affects the heating and cooling energy consumption of buildings is the window-to-wall ratio (WWR) (Lam, Ge & Fazio, 2016; de Gastines & Pattini, 2020). In this sense, Aste, Buzzetti, Del Pero and Leonforte (2018) analyzed heating, cooling and lighting consumption in offices located in cities with different climates (Athens, Stockholm and Milan), and saw that, in the absence of shading elements, the WWR has a noticeable impact on energy demands (up to 60% difference between cases with WWR of 20% and 80%). Hence, fully glazed building envelopes with integrated facades represent a challenge for designers, who have to try to control thermal energy flows through these envelopes. For this, knowledge of the energy indicators of integrated façade systems is essential. Despite the great role of glazing, whose thermal properties are well documented, in these envelopes, the latticework support of the integrated façade can significantly affect the thermal transmittance value (U) of the façade (De Gastines & Pattini, 2019a). This is due to the high conductivity of the aluminum used to manufacture profiles, and the low compactness that they tend to have (De Gastines & Pattini, 2019b), which leads to a higher exposure to the interior and/or exterior film coefficients (convection and radiation). In addition, despite being hidden behind the glazing, the projected surface of the latticework can be important and significantly affect the thermal transmittance of the façade system (Bae, Oh & Kim, 2015).

At an international level, it has been sought to improve the energy performance of integrated façade systems using insulating materials, including the thermal bridge breaker, triple hermetically sealed glazing, thermochromic glazing (Arnesano *et al.,* 2021), polyester reinforced with fiber glass (Cordero, 2015), or through the use of a double envelope, where the glazed façade conceals another low thermal transmittance skin (Bronwyn, 2018), or allows building a ventilated chamber (Saroglou, Meir & Theodosiou, 2020). The main innovation in integrated façade systems is the integration of semi-transparent photovoltaic nodules on parts of the façade that receive more solar radiation (Mocerino, 2020; Wu & Flemmer, 2020). However, these strategies are associated to a high initial cost, that limits their general use in developing countries.

The energy indices of integrated façade systems used in Argentina, have not yet been characterized in detail. The data that is available is limited to the properties of the glazing (IRAM 11601, 2002) and the traditional window systems (de Gastines & Pattini, 2019b), along with the study of a glazing skin façade design (de Gastines & Pattini, 2019b). However, it is possible that the thermal transmittance values of integrated façade systems vary considerably considering the design variants there are.

The glazed skin is an integrated façade system that consists in a latticework comprised by vertical load bearing profiles and horizontal aluminum crossbeams, which once assembled on site, allow inserting aluminum and glass sheets. This is one of the dominant elements of modern contemporary architecture (Viteri, 2020), generally used to achieve a completely glazed outside face, where the metal structure is hidden behind tonal glass, and fixed with glue or through small glazing moldings. It is often used in commercial and medium to large scale office buildings, and to a lesser extent, in the residential sector. This construction system has numerous advantages for buildings with several floors, including its easy assembly, the light weight (especially relevant for seismic areas), the watertightness, as well as a luminous and comfortable indoor environment (Hamida & Alshibani, 2020; Yalaz, Tavil & Celik, 2018; Huang, Chen, Lu & Mosalam, 2017), as long as the control of undesired solar radiation is guaranteed.

The purpose of this work is based on analyzing the glazed skin façade systems available in Argentina, and to determine the associated thermal transmittance value ranges, considering the profile design used, the type of glazing, and the sizes of the glazed panels.

METHODOLOGY

ANALYSIS OF PROFILE DESIGN VARIANTS

A revision of the product catalogs offered by six Argentinean companies for integrated façade profile extruders allowed defining a representative range of glass skin façade construction systems.

There are different parameters to consider to choose the glazed skin system. First, the profiles must adapt

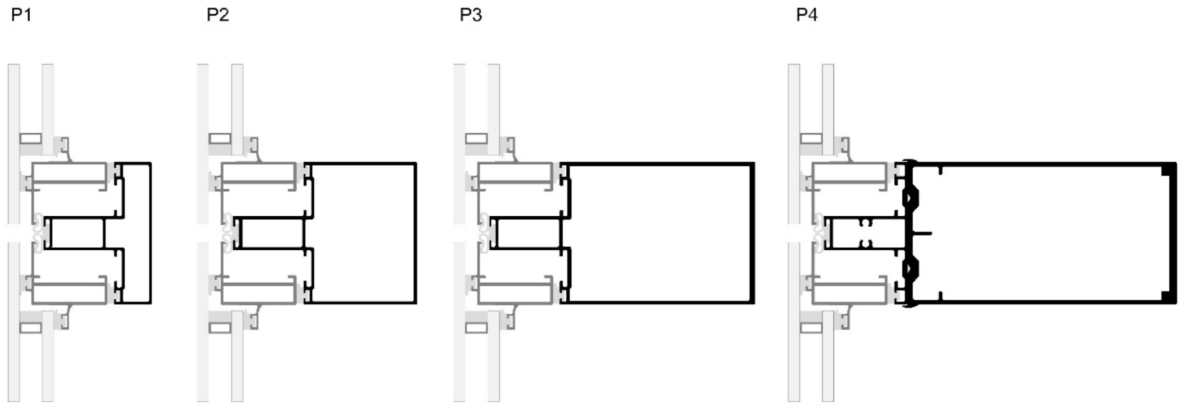


Figure 1. Variation of the column length (from left to right: 57 mm, 97 mm, 140 mm, 186 mm). Source: Preparation by the Authors.

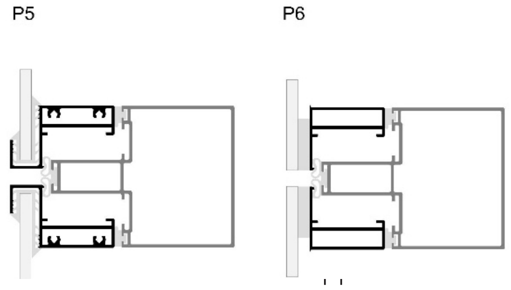


Figure 2. Comparison between the glazing fixtures: contained (section P5) and glued (section P6) Source: Preparation by the Authors.

to the chosen glazing width, which varies greatly depending on whether this is simple glazing (SG), or hermetically sealed double glazing (HDG). These also fit the panel opening (fixed panel (FP) or mobile panel (MP)). Finally, the profiles differ depending on whether the glazing is contained (whether capsulated, or fixed using glazing moldings) or glued (using structural silicon or VHB tape). There is also a sheet variant for the offset HDG. This variant allows installing HDG and SG together in certain parts of the façade (for example, in front of slabs of multi-floor buildings), keeping the same external edges on the entire façade.

Given the great variety of profile options, parameters were highlighted that could significantly affect the thermal transmittance values of the profiles, studying the relevance of each one separately, to select a smaller sample of profiles for the later analysis of the entire façade system. The parameters revealed are detailed below.

Wall supports (horizontal shear)

Parameter 1: Column length. The column profile bears the load of the façade, which is why it must be chosen considering the dimensions of the glazed panels and the weight of the glazing, to achieve the necessary mechanical resistance. The surveying made, allowed highlighting that the column lengths common to most of the manufacturers are 57 mm, 97 mm and 140 mm. There are longer profiles, whose dimensions differ depending on the manufacturer, with the longest being 186 mm (dividing column and supplementary column assembly). It is considered that the column length may be a factor that significantly impacts the thermal transmittance value of the latticework, as it generates different degrees of interior compactness of its vertical sections.

Figure 1 graphically shows the four sections analyzed, where the column profile's length varies depending on the aforementioned measurements.

Parameter 2: Contained or glued glass. Although there are several ways to attach the glazing, from a thermal point of view, two types of sections are distinguished. The first, with contained glass (i.e. encapsulated or fixed using glazing moldings), where a thermal bridge is generated between the inside and outside by the sheet profile; and the second, with glued glass, where the metal profiles are insulated from the outside through the glazing, silicon, and a partly ventilated cavity in the joint between glazed panels.

Figure 2 shows the two sections chosen to compare the impact of the type of glazing fixture on the thermal transmittance value.

Parameter 3: Offset HDG. The offset HDG setup increases the projected width of the wall support,

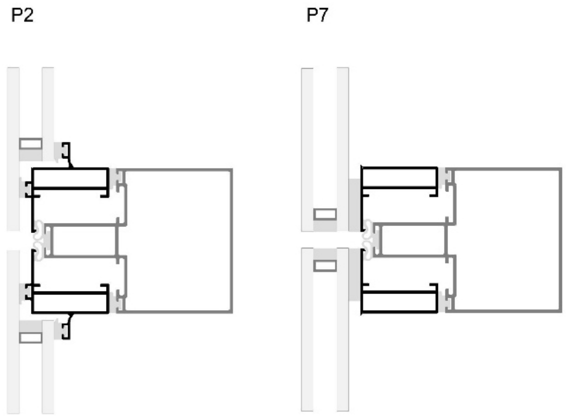


Figure 3. Comparison between wall support with offset (section P2) and glued (section P7) HDG setup. Source: Preparation by the Authors.

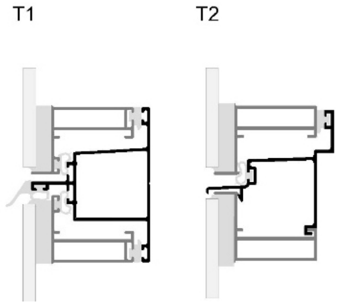


Figure 4. Crossbeam profile design variants: with cavity (left) and with water draining (right). Source: Preparation by the authors.

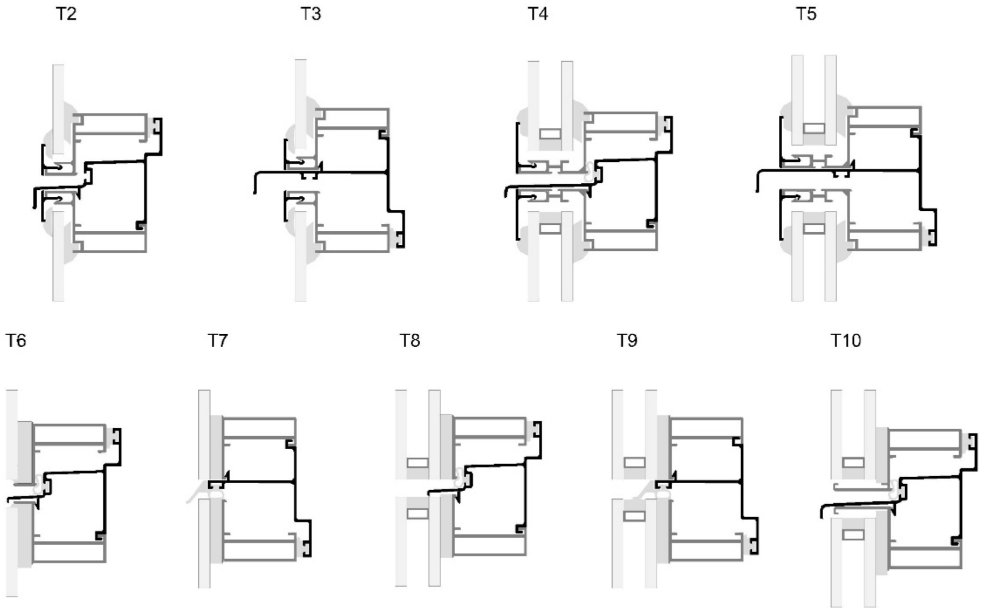


Figure 5. Horizontal interstitial space design variants: setups with contained glazing (above) and glued glazing (below). Options with SG or HDG, and fixed panel (even numbers) or mobile panel (odd numbers) header. T10 is a variant of section T8 with water drains jutting out. Source: Preparation by the authors.

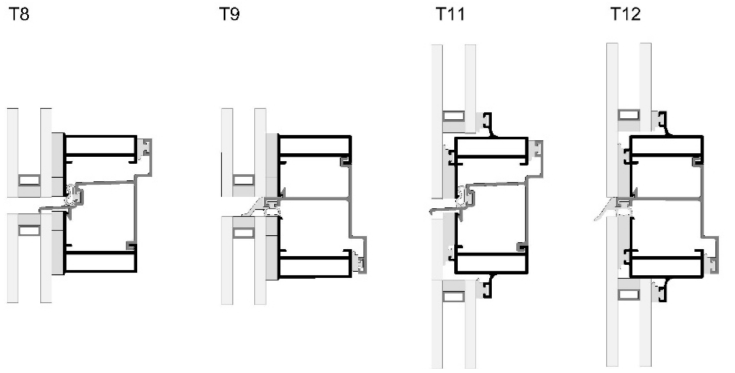


Figure 6. Comparison of the glued (T8: FP variant and T9: MP variant) and offset (T11: FP variant and T12: MP variant) HDG setups. Source: Preparation by the Authors.

as well as slightly reducing the surface of profiles exposed to the interior border conditions. To know the impact of this parameter, section P2 (with median column and offset HDG) is compared with a similar variant, but with glued HDG (P7) (Figure 3)

Crossbeams (vertical sections)

Parameter 4. Crossbeam design. 2 types of crossbeam profiles are seen, one common to two of the catalogs analyzed, with a cavity, and another common to the other four catalogs, called "water draining" (Figure 4). On having different morphologies, in particular different amounts and dimensions of internal cavities, they could also have different thermal transmittance values.

Parameter 5: Horizontal interstitial space. Among the crossbeam profile variants with water draining, 9 similar design options were highlighted regarding their interior profile (same projected width and compactness coefficient), which are different from one another, essentially because of the length of the water drain at the level of the interstitial space between glazed panels, and due to the presence or absence of glazing moldings. Depending on the type of glazing (SG / HDG), the type of opening (FP/MP), and the means of fixing the glazing (contained/glued), the water drain may or may not jut outside the façade, generating or not generating a thermal bridge. Likewise, the variation in length modifies the external compactness coefficient of the profile, thus being able to affect its thermal transmittance value.

Parameter 6. Offset HDG. The offset HDG setup increases the projected width of the crossbeam, as well as slightly reducing the surface of profiles exposed to internal border conditions. Here the crossbeam sections (FP and MP variants) were compared with glued HDG and offset HDG, as can be seen in Figure 6.

Projected section width

Finally, the projected width of the different profiles is compared, which will determine the final thermal transmittance value of the façade system (as this depends on the percentage of the façade surface occupied by the metal latticework).

CASE STUDY SELECTION

Metal profiles

After having isolated the parameters chosen to analyze the impact of each one on the thermal transmittance values, and to identify the most relevant parameters, the study concentrated on the latter.

It is worth clarifying that this work does not consider the analysis of the lower, upper or lateral finishings, nor the corners and swivel joints, as it is assumed that said profiles occupy a small percentage of the façade surface.

Glazing

The glazing generally used on glass skin facades is solar control HDG glued with structural silicon, that allows limiting solar gains, avoiding the overheating of the building and, at the same time, hides the metal latticework, achieving a completely glazed view.

It is proposed to study the following glazing options, that address a broad range of thermal transmittance values:

- G1: Reflective solar control and low emissivity HDG (Eclipse Advantage Evergreen 6 mm / 12 mm air chamber / 6 mm colorless float).
- G2: High reflectance and solar control HDG (Cool Lite STB 120 6 mm / 12 mm air chamber / 6 mm colorless float).
- G3: solar control pyrolytic reflective SV and low emissivity (Eclipse Advantage Evergreen 6 mm).
- G4: Solar control and high reflectance SV (Cool Lite ST136 6 mm).

Panel sizes

The construction system under analysis allows a certain degree of freedom in the sizing of glazed panels, as long as the static use limits are respected, which are related to the distance between columns (panel width), and the distance (height) between the supporting or anchoring points to the building's structure, calculated considering the wind pressure and column profile used. It is also recommended, that panel sizes do not exceed 1.25 m x 1.50 m (width by height).

In practice, and in general, one seeks to optimize glass use, which come in 2.40 m x 3.60 m sheets. Also the incorporation of mobile panels implies horizontal divisions that tend to be a fixed sill panel, an intermediate mobile panel and a fixed lintel panel.

Three glazed panel sizes are compared in this study. The largest comprising panels that are 1.20 wide by 1.50 m high; the intermediate of 1.20 m by 1.00 m; and the smallest, of 0.80m by 1.00 m.

CALCULATION PROCEDURE

In the following stage, the sections chosen were simulated using the WINDOW 7.7 and THERM7.7 programs, developed by LBNL (Lawrence Berkeley National Laboratory). WINDOW allows calculating the thermal transmittance of the glazing (U_g), while the woodwork profile sections are simulated in THERM. This program uses the finite elements method to calculate heat flows in the studied component, considering the indicated environmental conditions. In this way, it produces the transmittance value of the frame (U_f) and of the glazed edge (U_e), which corresponds to a perimetral strip of 63.5 mm, where the border effects between the frame and the glazing appear. Figure 7 indicates the different parts of the integrated façade system (center of the glazing, border, frame/wall support or crossbeam sheet profile).

Representative environmental conditions of a winter day in Buenos Aires (de Gastines & Pattini, 2019b) were considered, as outlined in Table 1. The conductivity values considered for the different materials that the façade system comprises, are shown in Table 2.

The U_g values of the glazing were calculated using WINDOW. Then, the wall support and crossbeam sections were simulated in THERM twice, successively inserting glazing G3 and G4 (sections with SG) or G1 or G2 (sections with HDG), to obtain the corresponding U_f and U_e values. Once the thermal indices of the different parts of the integrated façade system were obtained, the weighted average by their area (U) was calculated, for the different proposed glazing panels sizes.

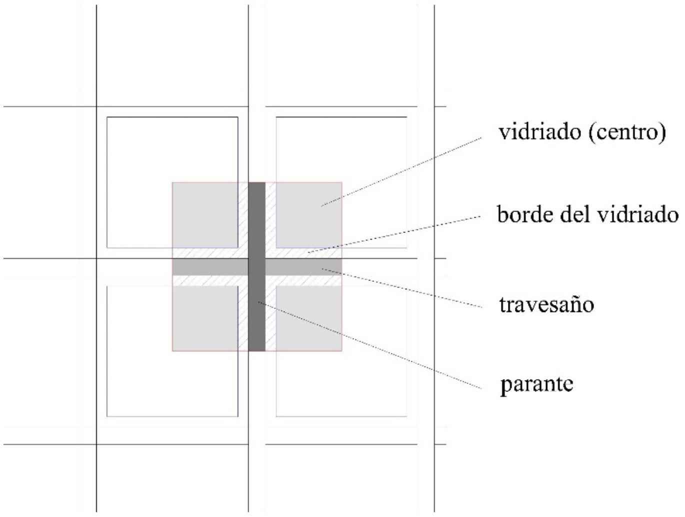


Figure 7. Base module of the integrated façade system, identifying its different parts. Source: Preparation by the Authors.

To	Tro	hco	Ti	Tri	hci
12.9°C	12.9°C	9.33 W/ m2K	21°C	21°C	3.29 W/ m2K

Table 1. Environmental conditions used to calculate thermal transmittance, where Ti and To are the indoor and outdoor air temperatures, respectively; Tri and Tro are respectively, the indoor and outdoor mean radiant temperatures; and hci and hco are the convective indoor and outdoor coefficients, respectively, Source: Preparation by the Authors, 2019b

Material	Conductivity (W(mK)
Aluminum	199
EPDM weather strip	0,25
Silicon	0,35 (Carbary y Kimberlain, 2020)

Table 2. Conductivity values considered in this research. Source: Preparation by the Authors.

RESULTS AND DISCUSSION

PROFILE THERMAL TRANSMITTANCE

The thermal transmittance values, U_f, of the simulated sections are presented in Figure 8. Below, the relevance of the different wall supports, highlighted above, are analyzed.

Parameter 1: Column length. The variation of thermal transmittance values considering the column length is seen in Figure 9, comparing the Uf values of sections P1, P2, P3 and P4. A significant difference is seen between the

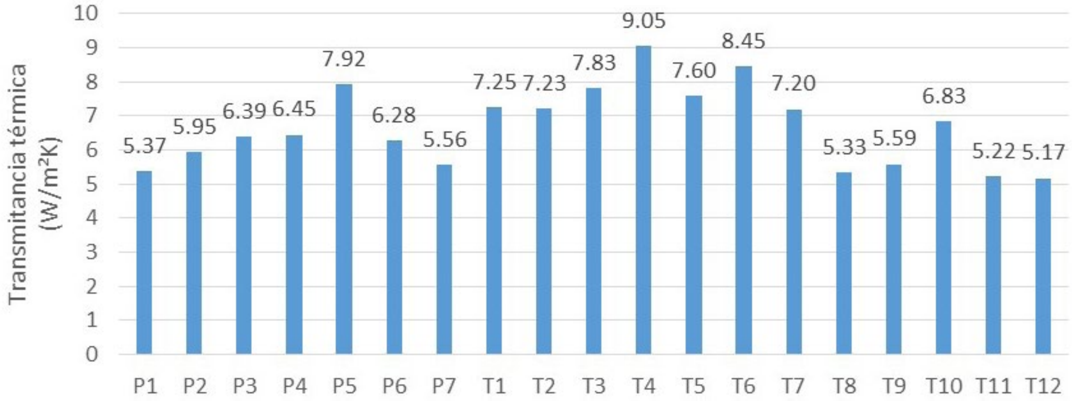
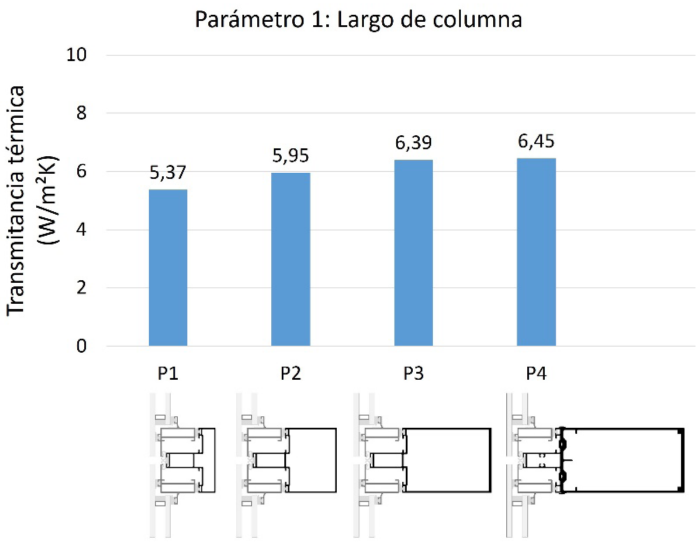


Figure 8. Thermal transmittance values (in W/m2K) of the sections analyzed. Source: Preparation by the Authors.



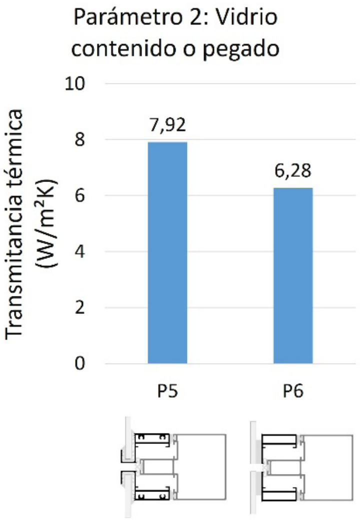
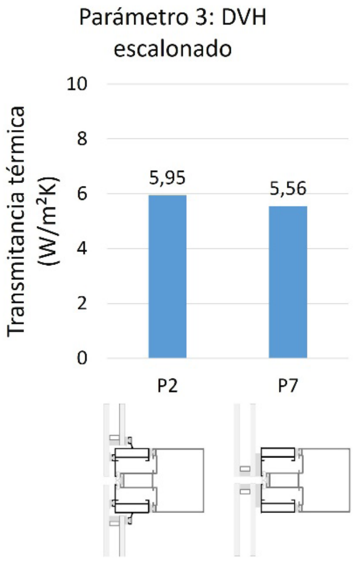


Figure 9. Effect of the column length on the thermal transmittance value.Source: Preparation by the Authors.
Figure 10. Effect of glazing fixture method on the thermal transmittance value. Source: Preparation by the Authors.



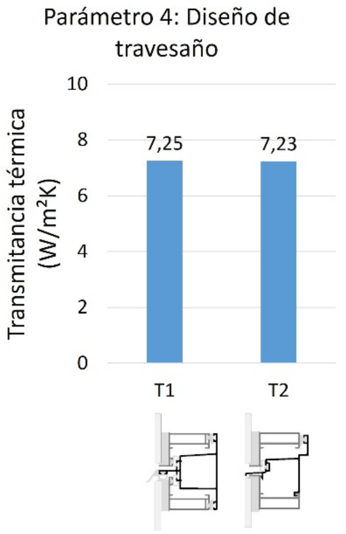


Figure 11. Effect of the offset HDG on the thermal transmittance value of the supporting wall. Source: Preparation by the Authors
Figure 12. Effect of the crossbeam design on the thermal transmittance value. Source: Preparation by the Authors.

thermal transmittance of the first three sections (absolute difference of 1.02 W/m2K between P1 and P3), while the fourth (with reinforced columns) has a Uf value similar to that of section P3.

Parameter 2: Contained or glued glass. Comparing the U_f values obtained through the simulation of sections P5 and P6 (Figure 6), an important difference is seen (1.64 W/m^{2}K) between the thermal transmittance of the supporting wall with contained (section P5) and glued (section P6) setups. The variant with glued glass has a better thermal performance, given that it avoids the thermal bridge associated to glazing moldings or to the sheet profile for encapsulated glass.

Parameter 3: offset HDG. The comparison between the U_f values of sections P2 and P7 (Figure 11), allows analyzing the difference regarding the thermal flow between the offset HDG (P2) and glued HDG (P7) setups on supporting walls. The offset HDG produces a slight increase of the heat transfers (0.39 W/m^{2}K).

Parameter 4: Crossbeam design. As can be seen in Figure 12, the two crossbeam variables, T1 and T2 (with cavity and water drains, respectively), have the same thermal transmittance value (insignificant difference of 0.02 W/m^{2}K). Therefore, this parameter is not relevant

Parameter 5: Horizontal interstitial space. The comparison of the U_f values of sections T2 to T10 (Figure 13) reveal that the design of the horizontal interstitial space between panels has a great impact on the thermal transmittance of the crossbeam (maximum difference of 3.72 W/m^{2}K).

The minimum values are obtained in the setups with glued HDG, T8 and T9 (5.33 and 5.59 W/m^{2}K, respectively), where the HDG and the interstitial cavity act as a thermal bridge breaker between the metal profile and the outside of the façade. The variant, T10 with glued HDG, but with water drain jutting out, obtains a higher U_f value (6.83 W/m^{2}K), due to the thermal bridge that this generates.

Then, in sections T6 and T7 (7.23 and 7.20 W/m^{2}K, respectively), it is seen that these are identical to sections T8 and T9, but with glued single glazing (fixed and mobile). On the glazing being narrower, the water draining profiles jut outside the façade and generate a thermal bridge, as such the thermal transmittance values significantly rise in comparison to sections T8 and T9.

The crossbeam sections with contained glazing (T2 to T5) obtain higher thermal transmittance values than sections with glued glass, as also happens in the wall supports. Comparing the sections with fixed panel, T2 and T4 (7.83 and 7.60 W/m^{2}K, respectively), and the mobile panel sections, T3 and T5 (9.05 and 8.45 W/m^{2}K, respectively), the latter have the highest thermal transmittance values. In a façade setup with fixed sill and lintel and intermediate mobile panel, the two crossbeam variants are used simultaneously, therefore, the U_f values obtained can be averaged, leaving a value of 8.03 W/m^{2}K for the crossbeam with contained HDG, and 8.44 W/m^{2}K for the crossbeam with contained single glazing.

Parameter 6: Offset HDG. In Figure 14, sections T11 and T12 (crossbeams with offset HDG, fixed panel and mobile panel head, respectively), with sections T8 and T9 (identical, but with glued HDG). Their thermal transmittance values differ in 0.11 W/m^{2}K (T8 – T11) and 0.42 W/m^{2}K (T9 – T12). This difference is not very significant, just as with the wall support sections.

Projected width of the section. Figure 15 indicates the projected widths of all the simulated sections, differentiated by the way the glazing is fitted. A correlation is seen between both variables: the width is higher for the offset setup, intermediate for the contained glazing, and lower for the systems with glued glazing. In this way, the differences between these three categories are seen, which also have uneven thermal performances, both in the wall support sections and in crossbeams (parameters 2 and 5).

THERMAL TRANSMITTANCE OF THE FAÇADE

The analysis of the variants of profile designs and their impact on the thermal transmittance values presented in the previous section, allowed determining which parameters are relevant to establish thermal transmittance ranges of glass skin façade systems.

Regarding the column length in wall support sections, the values are kept in a range of around ± 0.6 W/m^{2}K to the value of the setup with a middle column (P2), as such this profiling section is used as follows. The two existing crossbeam design variants (parameter 4) added to this, had the same thermal transmittance values, as such variant T1 was discarded.

It stood out that the sections -both crossbeams and wall supports- with contained glazing, obtain higher thermal transmittance values than sections with glued glazing. Among these categories, whether the glazing is single or double (SG/HDG) and the way of opening the glazed panel (FP/MP), has an impact. In response to this, on one hand, an additional wall support section with contained HDG (P8) is simulated. And, on the other, to simplify analysis, the thermal transmittance values of the variants with FP and MP are averaged, considering that, in a façade setup with fixed sill and lintel and intermediate mobile panel, the two crossbeam variants are used simultaneously.

Although the offset HDG only produces a slight increase of heat transfers (between 0.11 and 0.42 W/m^{2}K) compared to the glued HDG, the 30% increase of the wall support projected width is added to this, all of which

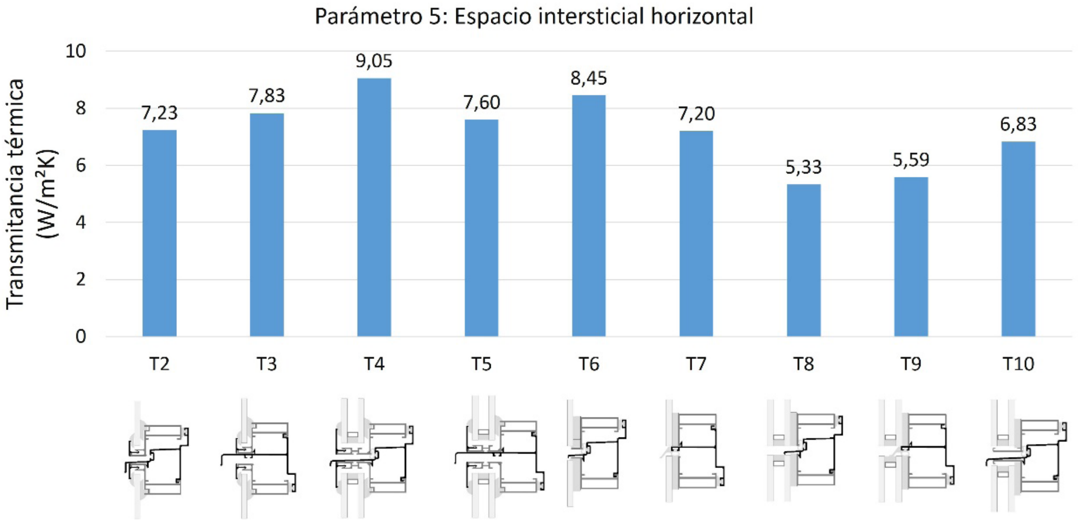


Figure 13. Effect of the horizontal interstitial space on the thermal transmittance value. Source: Preparation by the Authors.

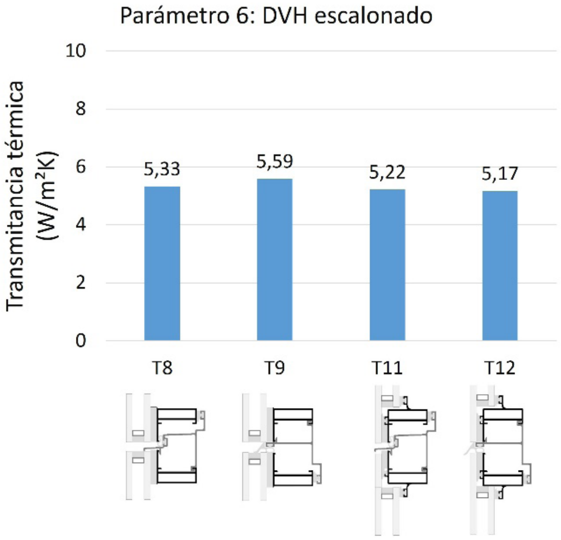


Figure 14. Effect of the offset HDG on the thermal transmittance value of the crossbeam. Source: Preparation by the Authors.

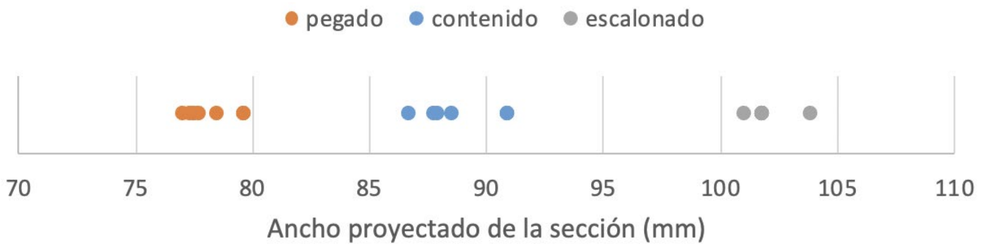


Figure 15. Spread of the projected width values of the sections analyzed, differentiated depending on the type of glazing fitting (glued, contained, and offset). Source: Preparation by the Authors.

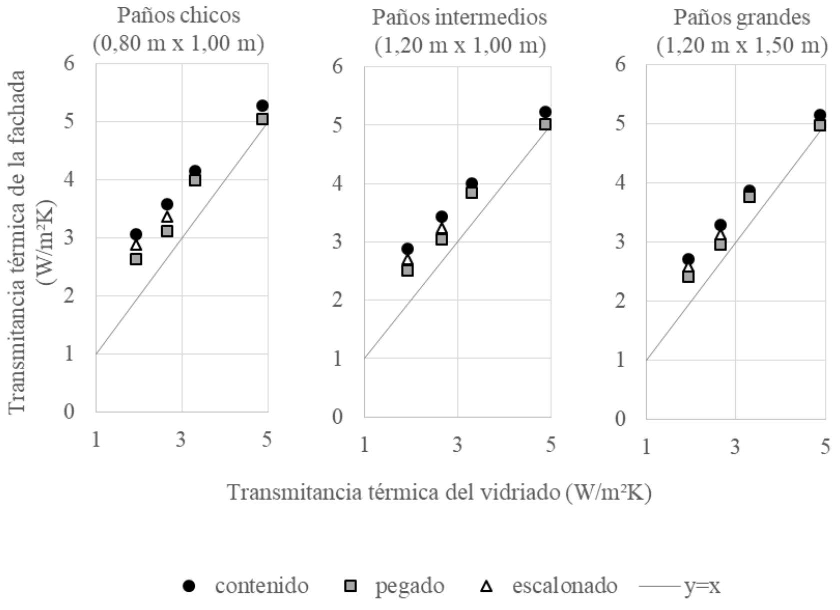


Figure 16. Representation of the thermal transmittance values of façade systems, differentiated by the way of fitting the glazing (glued, contained, and offset) and the sizes of the glazed panels.Source: Preparation by the Authors.

contributes to increase the thermal transmittance value of the whole façade. Therefore, this aspect is analyzed as a separate category.

Figure 16 presents the results of the simulations made, divided into three graphs -one for each façade sizing-, where the thermal transmittance values of the facades are expressed with contained, glued and offset glazing, considering the glazing used. The "identity" function is also graphed, to show the impact of the metal latticework on the total U value of the façade. On average, the U value exceeds the Ug value by 24%.

However, it is seen that the thermal transmittance of the glazing is the most important factor to consider to reach given thermal transmittance value ranges for the entire façade.

The sizing of the glazed panels has a variable impact, with the maximum difference obtained being 13%, which corresponds to the contained G1 glazing, a setup with the highest contrast of thermal transmittances (lowest U_g and highest U_f). On average, a difference of 7% is calculated between the extreme sizes studied.

The means of fitting the glazing has a significant impact in the case of facades with HDG (differences of 11% to 16% between setups with contained and glued glass). The variants with offset HDG have intermediate thermal transmittance values.

CONCLUSIONS

The analysis of the variants of profile designs for glass skin facades allowed isolating several parameters, and then studying the impact of each one on the thermal transmittance values (U_f) of the profiling sections.

The most important parameters identified are the column length and the means of fitting the glazing (contained or glued) in the wall support sections, and the design of the horizontal interstitial space in crossbeam sections, where the type of glazing (SG or HDG) and their means of fitting, as well as the type of opening (FP or MP) are involved.

However, the crossbeam design (Figure 4) is not relevant, and the setup with offset HDG does not significantly change the U_f value compared to the common HDG. However, said setup stands out on having a higher section width than variants with glued or contained HDG, in such a way that it produces a difference in the thermal transmittance of the entire façade system.

Using the information collected in this preliminary study, a more reduced sample of profiles was chosen to make the analysis of entire façade systems. The results indicate that thermal transmittance values of the glass skin facades available in Argentina vary significantly (from 2.42 to 5.28 W/m²K), mainly depending on the thermal transmittance of the glazing, but also in their fitting system (contained, glued, or offset), as well as the sizes of the glazed panels.

The results confirm the importance of having the thermal transmittance data of integrated façade systems, as using an estimate of the thermal transmittance value of the glazing leads to underestimating the thermal flows that will occur through the façade (24% higher on average).

The contributions of this work provide a valuable tool to building designers and constructors, so that decisions can be made not just aiming at economic and constructive criteria, but also from the optic of sustainability.

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BIBLIOGRAPHICAL REFERENCES

Aste, N., Buzzetti, M., Del Pero, C., Leonforte, F. (2018). Glazing's techno-economic performance: A comparison of window features in office buildings in different climates. *Energy Build. 159*, 123–135. DOI: https://doi.org/10.1016/j.enbuild.2017.10.088

Arnesano, M., Pandarese, G., Martarelli, M., Naspi, F., Gurunatha, K. L., Sol, C., ... y Revel, G. M. (2021). Optimization of the thermochromic glazing design for curtain wall buildings based on experimental measurements and dynamic simulation. *Solar Energy*, *216*, 14-25. DOI: https://doi.org/10.1016/j.solener.2021.01.013

Bae, M. J., Oh, J. H. y Kim, S. S. (2015). The effects of the frame ratio and glass on the thermal performance of a curtain wall system. *Energy Procedia*, *78*, 2488-2493. DOI: https://doi.org/10.1016/j.egypro.2015.11.234

Bronwyn, B. (2018). Energy and Design Criticism: Is It Time for a New Measure of Beauty? *Architectural Design, 88*(1), 116-121. DOI: https://doi.org/10.1002/ad.2266

Cao, X., Dai, X. y Liu, J. (2016). Building energy-consumption status worldwide and the state-of-the-art technologies for zero-energy buildings during the past decade. *Energy and buildings*, *128*, 198-213. DOI: https://doi.org/10.1016/j.enbuild.2016.06.089

Carbary, L. D. y Kimberlain, J. H. (2020). Structural silicone glazing: optimizing future designs based on historical performances. *Intelligent Buildings International*, *12*(3), 169-179. DOI: https://doi.org/10.1080/17508975.2018.1544881

Cordero, B. (2020). Thermal performance of novel frame-integrated unitised curtain wall. *Journal of Construction*, *14*(1), 23-31. Recuperado de https://scielo.conicyt.cl/scielo.php?script=sci_abstract&pid=S0718-915X2018000100112&lng=es&nrm=iso

D'Amanzo, M., Mercado, M. V. y Karlen, C. G. (2020). 10 preguntas de los edificios energía cero: revisión del estado del arte. *Hábitat Sustentable*, *10*(2), 24-41. DOI: https://doi.org/10.22320/07190700.2020.10.02.02

De Gastines, M. y Pattini, A. (2019a). Modelización de un sistema de fachada integral en herramienta de simulación energética de edificios. En Villalba, A. y Alchapar, N. (Eds.), *VI Congreso Latinoamericano de Simulación de Edificios - IBPSA LATAM 2019* (pp. 330–339). Recuperado de http://ibpsa.com.ar/wp-content/uploads/2019/12/actas-IBPSA-LATAM-2019.pdf

De Gastines, M. y Pattini, A.E. (2019b). Propiedades energéticas de tecnologías de ventanas en Argentina. *Hábitat Sustentable*, *9*(1), 46–57. DOI: https://doi.org/10.22320/07190700.2019.09.01.04

De Gastines, M. y Pattini, A.E. (2020). Window energy efficiency in Argentina - Determining factors and energy savings strategies. *Journal of Cleaner Production*, *247*. DOI: https://doi.org/10.1016/j.jclepro.2019.119104

Hamida, H. y Alshibani, A. (2020). A multi-criteria decision-making model for selecting curtain wall systems in office buildings. *Journal of Engineering, Design and Technology*. DOI: https://doi.org/10.1108/JEDT-04-2020-0154

Huang, B., Chen, S., Lu, W. y Mosalam, K. M. (2017). Seismic demand and experimental evaluation of the nonstructural building curtain wall: A review. *Soil Dynamics and Earthquake Engineering*, *100*, 16-33. DOI: https://doi.org/10.1016/j.soildyn.2017.05.025

Instituto Argentino de Normalización y Certificación, 2002. IRAM 11601. *Aislamiento térmico de edificios. Método de cálculo--Propiedades térmicas de los componentes y elementos de construcción en régimen estacionario.*

Lam, T. C., Ge, H. y Fazio, P. (2016). Energy positive curtain wall configurations for a cold climate using the Analysis of Variance (ANOVA) approach. *Building simulation*, *9*(3), 297-310. DOI: https://doi.org/10.1007/s12273-016-0275-6

Mocerino, C. (2020). High Performance and Intelligence of Glass Technologies in Architecture. *Journal of Civil Engineering and Architecture*, *14*(4). DOI: https://doi.org/10.17265/1934-7359/2020.04.003

Saroglou, T., Meir, I. A. y Theodosiou, T. (2020). Improving the Energy Efficiency of a Mediterranean High-Rise Envelope. *CTBUH Journal*, (2). Recuperado de https://global.ctbuh.org/resources/papers/download/4301-improving-the-energy-efficiency-of-a-mediterranean-high-rise-envelope.pdf

Viteri, S. L. (2020). *Piel de vidrio en oficinas en altura, hacia una arquitectura Eco-Tech*. Universidad Politécnica de Madrid. Recuperado de http://oa.upm.es/57981/1/TFG_20_Larumbe_Viteri_Sof%C3%ADa.pdf

Wu, Y. y Flemmer, C. (2020). Glass Curtain Wall Technology and Sustainability in Commercial Buildings in Auckland, New Zealand. *International Journal of Built Environment and Sustainability*, *7*(2), 57-65. DOI: https://doi.org/10.11113/ijbes.v7.n2.495

Yalaz, E. T., Tavil, A. U. y Celik, O. C. (2018). Lifetime performance evaluation of stick and panel curtain wall systems by full-scale testing. *Construction and Building Materials*, *170*, 254-271. DOI: https://doi.org/10.1016/j.conbuildmat.2018.03.061