Recibido 31/08/2020
Aceptado 12/12/2020

IMPROVEMENTS IN THE ENERGY PERFORMANCE OF BUILDINGS IN SUMMER, THROUGH THE INTEGRATION OF VENTILATED ENVELOPES ON NORTH-FACING FACADES AND ROOFS. THE CASE OF MENDOZA, ARGENTINA.

MEJORAS EN EL DESEMPEÑO ENERGÉTICO DE EDIFICIOS EN VERANO MEDIANTE LA INTEGRACIÓN DE ENVOLVENTES VENTILADAS EN FACHADAS NORTE Y CUBIERTAS. EL CASO DE MENDOZA, ARGENTINA.

JULIETA BALTER
Doctora en Arquitectura
Investigadora Asistente
Instituto de Ambiente, Hábitat y Energía (INAHE). Centro Científico Tecnológico Mendoza. Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) Mendoza, Argentina
https://orcid.org/0000-0002-7785-8465
jbalter@mendoza-conicet.gob.ar

CAROLINA GANEM
Doctora en Arquitectura
Investigadora Independiente
Instituto de Ambiente, Hábitat y Energía (INAHE). Centro Científico Tecnológico Mendoza. Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) Mendoza, Argentina
https://orcid.org/0000-0002-1431-1219
cganem@mendoza-conicet.gob.ar

GUSTAVO BAREA
Doctor en Ciencias
Investigador Asistente
Instituto de Ambiente, Hábitat y Energía (INAHE). Centro Científico Tecnológico Mendoza. Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) Mendoza, Argentina
https://orcid.org/0000-0002-5643-3206
gbarea@mendoza-conicet.gob.ar

RESUMEN

La propuesta de medidas de eficiencia energética en el sector residencial de Argentina requiere el análisis de las posibilidades arquitectónicas de rehabilitación edilicia con tecnologías que disminuyan los consumos energéticos, factibles de implementarse a nivel local. En regiones con alto nivel de radiación solar, como es el caso de la ciudad de Mendoza, pueden reducirse los flujos de calor transmitidos al interior mediante la ventilación natural de las capas en la envolvente -tanto en fachadas como en cubiertas-, obteniéndose así importantes ahorros en los consumos para refrigeración. El presente trabajo evalúa el potencial de mejora con la integración de envolventes ventiladas. La metodología del trabajo se estructura en dos etapas: i) relevamiento de edificios residenciales, según la tipología morfológica, y análisis de las posibilidades de rehabilitación con fachada ventilada, de acuerdo a las superficies de envolvente expuesta por orientación; ii) simulación de un caso de estudio -previamente validado con mediciones in situ- con el software EnergyPlus. Al integrar fachadas y cubiertas ventiladas se lograron importantes ahorros energéticos del orden del 32%, considerando al edificio sin usuarios (desocupado). Para el caso de las unidades del último piso, con cubiertas expuestas al exterior se registraron ahorros energéticos del 260%.

Palabras clave
envolvente ventilada, rehabilitación edilicia, eficiencia energética, consumos para refrigeración

ABSTRACT

The proposal of energy efficiency measures in the residential sector in Argentina requires analyzing the architectonic possibilities of building rehabilitation using technologies that reduce energy consumption, that are feasible to implement locally. In regions with high solar radiation levels, as is the case of the city of Mendoza, heat fluxes transmitted inside can be reduced by the natural ventilation of the layers in the envelope, both on facades and roofs, thus obtaining significant savings in consumption for cooling purposes. This work evaluates the potential for improvement with the integration of ventilated envelopes. The work methodology is structured in two stages: i) survey of residential buildings by morphological typology and analysis of rehabilitation possibilities with ventilated facades, considering the exposed envelope surfaces by orientation; ii) simulation of a case study - previously validated with onsite measurements - using the EnergyPlus software. On integrating ventilated facades and roofs important energy savings of around 32% were achieved, considering the building without users (unoccupied). In the case of units on the top floor, with roofs exposed to the outside, energy savings of 260% were recorded.

Keywords
Ventilated envelope, Building rehabilitation, Energy efficiency, Cooling consumption

INTRODUCTION

Facing the context of a continuous growth in energy prices around the world and looking to support global efforts to mitigate global warming, building rehabilitation emerges as a known strategy for improving the energy efficiency of buildings. The rehabilitation of the envelope presents benefits, not just in respect to the energy savings of spaces, the improvement of indoor microclimate and the reduction of contaminating emissions obtained, but also for the technical and economic feasibility of a project (Ascionea, Biancoa, De Masib & Vanolib, 2013). In this regard, valid indicators have been generated starting from the creation of tools, through standards (ISO and ASTM), contributing economic knowledge for the implementation of energy improvements in existing single-family homes (Pérez Fargallo, Calama Rodríguez & Flores Alés, 2016). The results of the cited study indicate that, with respect to walls, the investment in a detached building is three times higher than a dwelling between party walls with interior insulation.

Research on passive strategies in the envelope has increased considerably, offering an important contribution to architecture. Background information, in this sense, includes a series of design and construction recommendations, that cover both those referring to transmittance values, and to the incorporation of weighting factors considering the position of the insulation and thermal mass (Damico *et al*., 2012; Leccese, Salvadori, Asdrubali & Gori, 2018; Albayyaa, Hagare & Saha, 2019; Raimundo, Saraiva & Oliveira, 2020; Cabeza & Gracia, 2021). On the other hand, when considering global warming and climate forecasts, generic adaptation architectonic design strategies have been studied from the passive point of view, determining climate scenarios for 2020, 2050 and 2080 (Rubio-Bellido, Pulido-Arcas, & Ureta-Gragera, 2015; Filippín, Ricard, Flores Larsen & Santamouris, 2017; Haddad *et al*., 2020).

As for the regions with a high level of solar radiation, one of the feasibly applicable strategies to improve the thermo-energy conditions in periods with high temperatures, is reducing the heat flows transmitted inside through the natural ventilation of the envelope's layers, both on façades and roofs, obtaining savings in air-conditioning consumption that can reach up to 80% (Domínguez Delgado, Durand Neyra & Domínguez Torres, 2013; Gagliano, Patania, Nocera, Ferlito & Galesi, 2012). The ventilated envelope system is formed by an air chamber bordered by two opaque sheets, into which the outside air freely accesses. The ventilated chamber creates a "chimney effect" caused by the heating of the outside sheet, which is why a variation of the internal air density of the chamber is produced compared to the ambient temperature outside, with the resulting movement by natural convection. During summer, the external sheet blocks solar radiation, reducing the surface temperature of the inside sheet; meanwhile, in winter, the air movement in the chamber and its resulting fall in temperature, allows the evacuation of water vapor, reducing the possibility of interstitial condensation (Suárez & Molina, 2015). This is due to the increase of the heat flow inside the chamber, generated by direct solar radiation that has a bearing on the outside sheet and the resulting heat transfers through conduction and convection in the air chamber. In addition, this improvement is due to the possibility of continuous thermal insulation on the external face of the interior enclosure and the fact of having a protection to confront the direct solar radiation on the enclosure that limits the inhabitable space.

Ventilated facades, with regard to the vertical envelope, comprise a light or traditional masonry inside sheet, and an outside one, comprising plates that may be made from a great variety of materials, sizes and colors, normally with open joints (see Figure 1). In terms of background information at an academic level, diverse studies have addressed the issue, with different study methods which, at the same time, can be combined with each other. Most of the works are made through dynamic computer simulations (Balocco, 2002; Balocco, 2004; Patania, Gagliano, Nocera, Ferlito & Galesi, 2010; San Juan, Suárez, González, Pistono & Blanco, 2011; Suárez & Molina, 2015; Peci López & Ruiz de Adana Santiago, 2015, Gagliano, Nocera & Aneli, 2016), although in some cases, experimental prototypes have been created (Sandberg & Moshfegh, 1996; Peci López, Jensen, Heiselberg & Ruiz de Adana Santiago, 2012; Sánchez, Giacola, Suárez, Blanco & Heras, 2017) and in others, work has been done by monitoring real buildings in use (Stazi, Tomassoni, Veglio & Di Perna, 2011; Aparicio Fernández, Vivanco, Ferrer Gisbert & Royo Pastor, 2014; Gregorio Atem, 2016). The results of the thermal performance of the system under study in the summer period, show reductions of around 58% of the thermal load obtained on using a ventilated façade in comparison to a façade without ventilation (Fantucci, Marinosci, Serra & Carbonaro, 2017), as well as important reductions in energy consumption for air-conditioning, with energy savings rates for passive cooling of between 35% and 80% (Domínguez Delgado *et al.,* 2013).

The result of experimental studies made in summer, shows that the orientation to the equator has the best performance regarding air flow and speed values in the ventilated chamber (Balter, Pardal, Paricio & Ganem, 2019; Stazi *et al,* 2011). Likewise, a thermodynamic analysis of the performance in the chamber, with maximum air speeds of between 0.45m/s and 1.9m/s,

Revista Hábitat Sustentable Vol. 10, N°. 2. ISSN 0719 - 0700 / Págs. 94 -105
https://doi.org/10.22320/07190700.2020.10.02.07

Figure 1. Different ventilated façade solutions in Barcelona, Spain. Source: Preparation by the Authors[1]

confirms that energy savings for cooling in summer increase as the incident solar radiation also increases (Patania *et al.*, 2010). Said work shows that the thermal and air speed differences in the chamber are mainly due to the thermophysical properties of the outside sheet: a reduction of the heat transfer that enters the building of over 40% is indicated in comparison with the same façade without ventilation.

As for the roofs, the thermal behavior of ventilated roofs, in summer, has been analyzed using computational fluid dynamic (CFD) simulations, and reductions in the heat transfers of around 50% were obtained (Gagliano *et al.*, 2012). The same methodology (CFD), that uses numerical methods and algorithms to resolve and analyze problems about fluid flows, has been used to study the influence of different parameters, thickness of the air chamber, slope of the roof, sizes of the air outlet and absorption coefficient of the external surface, with results that reveal the important influence of the chamber's thickness on the delays of indoor room temperature, which is why a thickness of 100mm is recommended when looking to improve the air flow speed in the ventilated chamber (Li, Zheng, Liu, Qi & Liu, 2016).

Apart from the physical and constructive properties of the system's elements, the air movement in the chamber is an important factor in its efficient performance. In this sense, the background information shows that, although the main variables that affect said movement are solar radiation and external air speed, the width of the chamber is also influential. In the work of Balocco (2002), increases of air flow in respect to this width are obtained, with reductions in summer of the overheating due to radiation of 27% with a 35cm chamber, while reductions with a 7cm chamber are of 7%. In any case, many works agree that it is important to make a detailed analysis of the context before facing a new project or rehabilitation. For this, the local climate, the specific design of the enclosure, the physical and operational differences of the construction (air entry and exit locations, chamber thickness, physical properties of the materials), the desired use and comfort of the building, as well as the primary energy cost and the CO_2 emissions, must be considered (Ibáñez-Puy, Vidaurre-Arbizu, Sacristán-Fernández & Martín-Gómez, 2017; Elarga, De Carli & Zarrella, 2015; Aparicio Fernández *et al.*, 2014; Peci López *et al.*, 2012; San Juan *et al.*, 2011).

1 The images of the buildings were obtained by Cristina Pardal PhD, of the Architecture Technology Department of the Polytechnic University of Catalonia.

In consideration of the study's context, it must be indicated that central-western Argentina has an abundant solar resource. Specifically, Mendoza is located in a continental cold arid area, according to the climate classification of Köppen and Geiger (1936), with considerable differentiations in seasonal and daily temperatures (from 10 to 20°C). With regard to the solar resource, the city has clear skies for 76% of the year, with a mean global radiation in December (summer) on the horizontal surface of 25.4 MJ/m^2 a day and 9.10 MJ/m^2 a day in June (winter). This condition represents an opportunity for the passive conditioning of spaces and, in this framework, the opaque envelope systems with natural ventilation are a feasible alternative to be incorporated, due to their good performance in areas with high radiation.

From the point of view of urban structure, the city of Mendoza (32° 40' LS - 68° 51' LW) is characterized on being an oasis-city (Bórmida, 1984), because of its intense forestation set in an arid area. The city defines, from an environmental approach, two high levels given by said forestation: with and without trees. In this context, indoor spaces located up until the third floor, under the tree canopy, have a moderate micro-climatic situation and are thermally and energetically benefitted. Meanwhile, in spaces on higher floors, from the fourth one up, i.e., above the canopy, the situation is more extreme and the consumption for air-conditioning is higher due to the complete exposure of their envelopes. Even when high-rise constructions of the city, built in the last 15 years, tend to record high percentages of transparent surface on the envelope, most residential buildings in Mendoza, correspond to a mainly opaque material. However, these do not have insulating materials and in rarely have solar control elements on the envelope.

Said situation, which is added to the growing use of ventilated envelope systems in European countries, allows setting questions about the possibility of inserting these systems in our study context: a zone with high solar resources. The comprehensive approach of the topic requires a process that considers analysis from different perspectives: on one hand, from the energy efficiency of the envelope system following the region's climatic conditions, both for building rehabilitation and for new buildings; and, on the other, from the technological availability and the legal possibilities in force to suitably incorporate ventilated systems on their different urban and social scales . In this work, the first of the approaches mentioned is carried out, from which the following objective is defined: Assessing the formal possibilities of rehabilitating residential buildings in the urban-architectonic high density context of the city of Mendoza, in order to reduce energy loads for cooling, through the incorporation of ventilated envelopes on the north façade and roof.

METHODOLOGY

The work methodology is structured in two stages: i) surveying residential buildings by morphological typology and analysis of the possibility of rehabilitation with a ventilated façade, considering the envelope surfaces exposed by orientation; ii) simulation of a case study, previously validated with onsite measurements using the *EnergyPlus* software.

SURVEYING AND ANALYSIS OF BUILDING REHABILITATION WITH VENTILATED FAÇADE BY ORIENTATION

The study area corresponds, according to the Building Code of the city of Mendoza, to Central Zone 2, a zone with a higher high-rise building density of a mainly residential nature. Its population density is estimated at more than 800 inhabit/ha. The zone has three of the main squares in the city's grid plan. There are 14 main roads, 12 of which are 20 meters wide and 2 of them, 30 meters wide. These form a total of 32 blocks. In order to evaluate the possibility of rehabilitating façades considering their exposed orientation, constructions that exceeded the maximum height of the tree's canopy were surveyed (characteristic trait of the "oasis-city" of Mendoza), namely: buildings that have 5 or more floors (starting from GF + 4). According to the morphology of high-rise buildings, in Mendoza there are three typologies, as per the building regulations in force at the time of their construction: 1. High-rise building between party walls; 2. Tower; and 3. Foundation and tower.

Figure 2 shows images of Mendoza and the surveyed building area, with a sample group of 67 residential buildings, 26 of which belong to the building typology of high-rise between party walls; 15 of detached tower; and the other 26, the foundation and tower typology.

2 In the area of Mendoza, new technologies with local innovation levels find limitations to comply with regulatory requirements, as they do not always have the backing of the institutions involved for their definitive approval. In this scenario, only formal technologies, a large part of which, in our case, are foreign in origin, meet these requirements, but in general, these are of a selective implementation given their scale and high costs. The possibilities of including other feasible technologies that can be generated and/or adapted to be implemented on a mid-rise or low-rise building, are limited.

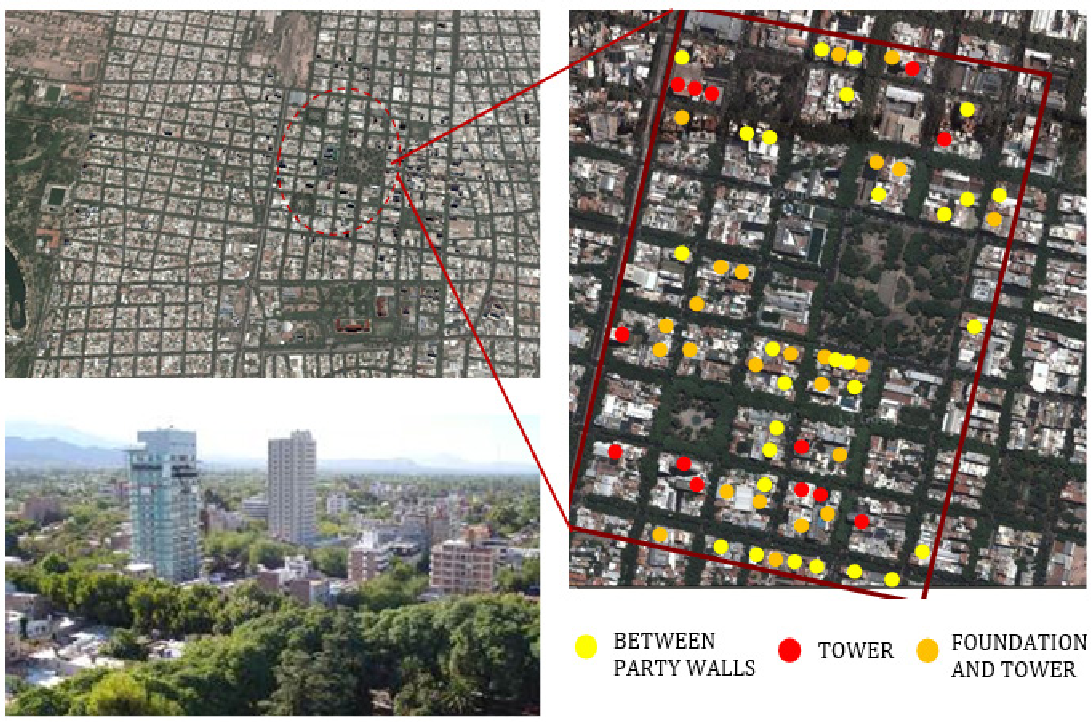


Figure 2. Images of the city of Mendoza. Area of high-rise buildings surveyed. Source: Preparation of the authors.

Starting from the survey of the cases by morphological typology, the following variables were analyzed in each one of the buildings (Table 1): floor height, front façades exposed by orientation, opaque material of the vertical envelope, opaque and transparent envelope surface percentage by façade and orientation and window-to-wall ratio (WWR). It is worth clarifying that some of the cases surveyed are located on corners, so they have front façades on two orientations.

After this, and to diagnose the possibilities of rehabilitation by façade, the envelope's conditions were analyzed by surveying the amount of surface exposed by orientation. From this analysis, the following evaluations emerged: it is considered possible to rehabilitate facades with more than 50% of continuous high-rise surfaces without window openings, given that, on the other hand, the benefit of the ventilated chamber would be lost. However, in cases that have exposed facades with more than 50% of openings or elements that impede the continuity of the chamber (such as balconies), the implementation of the system on these faces could be considered, merely as cladding, to have buildings with a homogeneous and balanced image. In the same way, high-rise buildings belonging the high-rise buildings between party walls typology, built following the pre-1970 regulations, have blind facades on orientations that are next to adjoining land. Today, given that the current building code does not allow constructions above 10 m built side-by-side, these blind facades have the possibility of being intervened and rehabilitated, with the resulting energy benefits. However, there is the risk of having an adjoining tower-block at a minimum distance of 3 meters, with which radiation incidence would be blocked. Therefore, the following conditions are classified, considering each orientation.

- Possible rehabilitation with ventilated façade.
- Possible rehabilitation with ventilated façade on adjoining boundary.
- Intervention impossible.

Figure 3 presents the results given by the survey. In the high-rise between party walls building typology, it is possible to rehabilitate facades in 14 cases, of which only 6 have possibilities to rehabilitate the north-façade; 2 of them can also see the east façade rehabilitated. In the case of the Tower typology, it is possible to rehabilitate 7 buildings, 4 of which allow the north façade's rehabilitation. In those from the foundation and tower typology, none of the cases have possibilities of rehabilitating the north façade. It is important to clarify that the criterion defined to not intervene, is because in some buildings, those with facades of over 50% of glazed surfaces or with balconies across the façade would block the continuous flow of air in the chamber. Now, in other cases, the criterion is based on these being buildings with a marked architectonic trend

Mejoras en el desempeño energético de edificios en verano mediante la integración de envolventes ventiladas en fachadas norte y cubiertas. El caso de Mendoza, Argentina.
Julieta Balter, Carolina Ganem, Gustavo Barea
Revista Hábitat Sustentable Vol. 10, N°. 2. ISSN 0719 - 0700 / Págs. 94 -105
https://doi.org/10.22320/07190700.2020.10.02.07

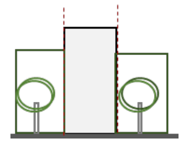
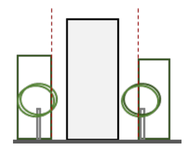
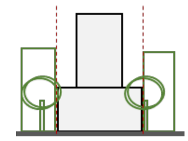
VARIABLES ANALYSIS \ TYPOLOGY		BETWEEN PARTY WALLS				TOWER				FOUNDATION & TOWER			
		 26 buildings (32 front facades)				 15 cases (16 front facades)				 26 cases (33 front facades)			
Height (floors)	> 7	21				11				16			
	7 a 10	5				1				7			
	< 10	-				3				3			
Front facades exposed by orientation	North	13				5				11			
	South	7				6				3			
	East	7				2				6			
	West	5				2				6			
Opaque materiality of vertical envelope	Brick + whitewash	21				11				17			
	Brick + ceramic cladding	1				-				-			
	Brick + stone cladding	2				2				2			
	Visible Brick	-				-				4			
	Reinforced concrete (RC)	1				-				3			
	RC + brick + stone clad.	1				-				-			
	RC + plaster plates	-				2				-			
Window to Wall ratio (WWR)	0 a 0.19	1				1				1			
	0.2 a 0.39	24				11				20			
	0.4 a 0.59	1				2				2			
	0.6 a 0.79	-				-				3			
	0.8 a 1	-				1				-			
% of opaque envelope surf. exposed by facade		N	S	E	W	N	S	E	W	N	S	E	O
	> 40	-	-	-	-	-	-	-	1	1	-	2	-
	40 a 60	-	-	-	-	1	-	-	-	-	1	1	1
	60 a 80	12	6	4	5	4	4	2	1	10	1	5	5
	< 80	1	1	3	-	1	1	-	1	1	1	1	3
% of transp. envelope exposed by facade	> 40	12	7	7	5	3	6	2	2	11	2	6	8
	40 a 60	1	-	-	-	2	-	-	-	-	1	1	1
	60 a 80	-	-	-	-	-	-	-	-	1	-	2	-
	< 80	-	-	-	-	-	-	-	1	-	-	-	-

Table 1. Variables analyzed of the building typologies subject to study.Source: Preparation by the authors.

Revista Hábitat Sustentable Vol. 10, N°. 2. ISSN 0719 - 0700 / Págs. 94 -105
https://doi.org/10.22320/07190700.2020.10.02.07

(brutalism, postmodernism) or material (natural rock cladding). Here, the rehabilitation would remove the architectonic value from the buildings. Likewise, the south façade, in the southern hemisphere, receives only 2.3% direct solar radiation in comparison to the north façade. For this reason, buildings where it is not possible to implement the system being studied, are not considered.

SIMULATION OF THE CASE AUDITED IN ENERGYPLUS

This work takes as a case study, one of the buildings analyzed as possible to be rehabilitated (case 4 in Figure 3), corresponding to the high-rise between party walls building typology (see Figure 4). Although the building analyzed is north-facing, and with possibilities to rehabilitate said façade, the application of the methodology adopted is feasible to be replicated both for other locations, and for other buildings with different orientations.

The building has a total height of 25 m (ground floor + 7). In terms of the envelope's material, it has 0.30m hollow ceramic brick outside wall with paint and whitewash and no insulation, and the roofs comprise reinforced concrete slabs. The windows are simple 4mm glass and wooden carpentry. The dwellings' inside divisions are made with 0.10m thick ceramic brick. The building has, on its front façade, 1.20m deep balconies that form overhangs, and has sliding blinds with white latticework on all the openings. As for the exposed envelope percentage, it has a Window-to-Wall (WWR) ratio of 0.30.

Concretely, hygro-thermal measurements were made on the inside and outside of the building, specifically in the first and fifth floor dwellings. Onsite monitoring was made over a year, in periods of twenty and thirty days, in each of the four seasons. ONSET's HOBO U.12 temperature and humidity dataloggers were used, with recording intervals of every 15 minutes, simultaneous in all the instruments. The global solar radiation measurements were made with a KIPP & ZONEN CM 5 pyranometer in the same periods and with the same data acquisition frequency established for the air and humidity measurements. This allowed making the adjustment and validation of the model with the *EnergyPlus* dynamic simulation software. In this study, two climate files were developed: one, for the condition given by the tree canopy, which contains the measurements made of temperature and global solar radiation (dwellings from the fourth floor up); and a second file in which the incident radiation under the urban tree line was modified, to consider the situation below the tree canopy (dwellings up to the 3rd floor, corresponding to a maximum of 12 m in height). For this, the studies performed on the degree of permeability of trees in

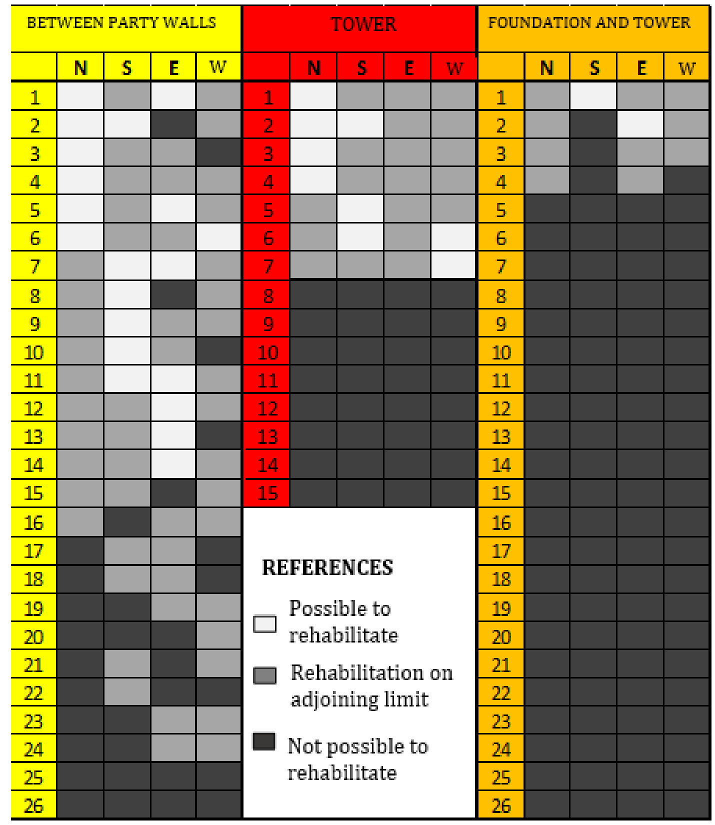


Figure 3. Results of the surveys of facades that can be rehabilitated, by building and orientation. Source: Preparation by the authors.

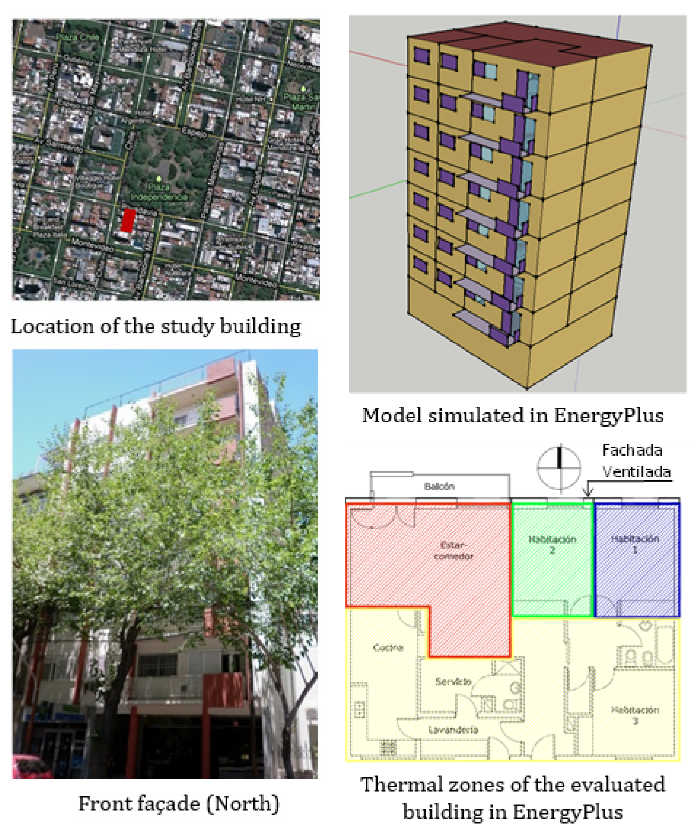


Figure 4. "High-rise building between party walls" building typology assessed. Source: Preparation by the Authors.

Revista Hábitat Sustentable Vol. 10, N°. 2. ISSN 0719 - 0700 / Págs. 94 -105
https://doi.org/10.22320/07190700.2020.10.02.07

Properties of the exterior ventilated cavity	Measurement Unit	Value
Fraction of the openings are	Non-dimensional	1
Thermal emissivity of the exterior plate (cementitious plate type)	Non-dimensional	0.9
Solar absorption of the exterior plate (cementitious plate type)	Non-dimensional	0.1
Thermal insulation (expanded polystyrene)	m	0.05
Height of the ventilated chamber	m	2.7
Thickness of the ventilated chamber	m	0.1
Ratio between the real and projected surface	Non-dimensional	1
Roughness of the exterior surface	Non-dimensional	Soft
Holes with respect to the wind	Non-dimensional	0.25
Discharge coefficient for openings compared to the floatability flow	Non-dimensional	0.65

Table 2. Entry elements for the definition of the ventilated envelope in EnergyPlus.Source: Preparation by the authors.

central-western Argentina (Cantón, Mesa, Cortegoso, De Rosa, 2003) were considered. Said permeability to global radiation at midday corresponding to the urban tree lines there are in the case study (*Morus-Alba)* is 31.4% in summer. The specifications of said monitoring and their adjustment by simulation are found in the cited literature (Balter, Ganem & Discoli, 2016).

The ventilated envelope was incorporated on all front facades of north-facing apartments and on the roof of the top-floor dwelling (seventh). It is considered that one of the starting elements for building energy rehabilitation is the incorporation of insulation on the envelope, so, the cases assessed and compared had 5cm of expanded polystyrene on the outside of the wall. In this way, the rehabilitation under study focused particularly in assessing the effects of incorporating the ventilated chamber and the external layer of the envelope.

With said purpose, the "*Exterior Natural Vented Cavity*" object, used to trace a separate layer of the inside layer, was used inside the advanced constructions module, which allowed defining the characteristics of the cavity and the openings for outside surfaces with natural ventilation (Table 2). This object was used along with the *Other Side Conditions Model*, where the option of *Gap Convection Radiation* was set up, that provides the surrounding conditions for the thermal radiation and convection of the ventilation model modeled independently from the envelope surface.

To analyze cooling energy consumption, thermostats were programmed at 24°C for all the thermal zones being studied.

With regard to the climate file used for simulation, work was done with micro-climate data generated from the validation of data monitored onsite with the ENVI-met dynamic simulation software (Balter, Alchapar, Correa & Ganem, 2018).

RESULTS AND DISCUSSION

In Figure 5, the results of the comparison between the following cases are recorded:

- Without Ventilated Facade (Without VF): 0.30 m ceramic brick + 0.05m expanded polystyrene + exterior whitewashing. Roof: concrete slabs.
- With Ventilated Facade (With VF): 0.30 m ceramic brick + vapor barrier + 0.05m expanded polystyrene + 0.10m ventilated chamber + exterior plate. Roof: concrete slab.
- With Ventilated Roof and Façade (With VF & VR): 0.30m ceramic brick + vapor barrier + 0.05m expanded polystyrene + 0.10m ventilated chamber + exterior plate. Concrete slab + 0.10m ventilated chamber + exterior plate. Roof: concrete slabs.

The dimensional characteristics of the ventilated air chamber and the thermophysical characteristics of the exterior plate are presented in Table 2.

The incorporation of ventilation on the façade implies a reduction of energy loads for cooling, considering 24°C indoors, of around 1% as an average of the building's total. These moderate percentages are due, on one hand, to the fact that the comparison made focuses specifically on the incorporation of the ventilated chamber and the exterior

Revista Hábitat Sustentable Vol. 10, N°. 2. ISSN 0719 - 0700 / Págs. 94 -105
https://doi.org/10.22320/07190700.2020.10.02.07

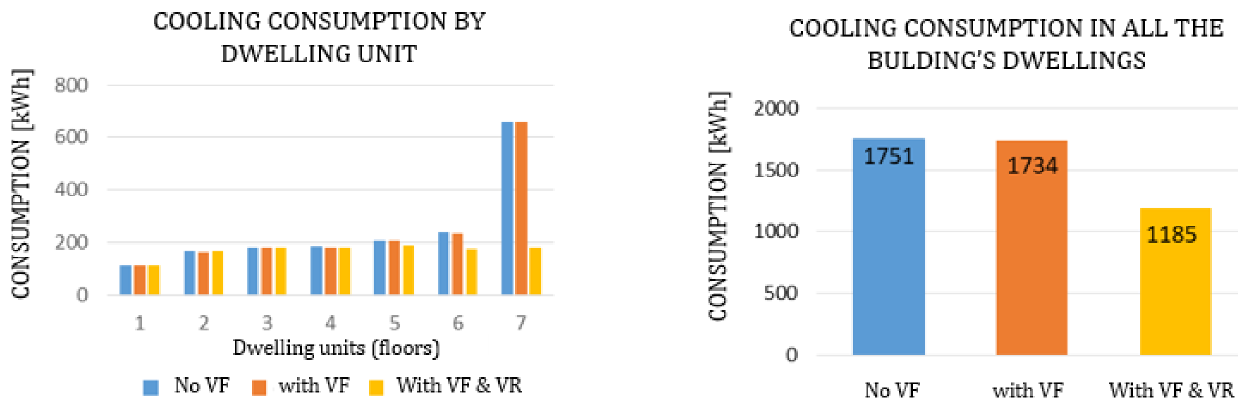


Figure 5. Energy consumption for cooling simulated in EnergyPlus. Source: Preparation by the authors.

layer, that is to say that the base case (without FV) has insulation and whitewashing on the upper part of the envelope. And, on the other hand, these reductions are affected by the compact nature of the dwellings, where only 12% of the entire envelope of each unit is north-facing. Likewise, the north facade receives only 16% of the incident radiation in summer and, in the case of Mendoza, this percentage is greatly reduced (by more than 50%) due to the urban tree lines.

All in all, on incorporating ventilation on the roof of the top-floor dwelling, located on the seventh floor, the average results of the entire building show energy improvements of 32%. In this case, the reduction in consumption of the dwellings on the first four floors is around 1.7%; a percentage that rises as the height of the dwellings goes up: on the sixth floor, this reduction is 34%, and on the top floor, 269%. This is because, above the canopy, the envelope's exposure is greater and, on reducing the heat flow on the horizontal envelope, the behavior of the envelope that has the highest exposure to solar radiation in summer, is optimized.

Regarding the constructive characteristics of the ventilated façade system, it has been shown that the increase of the air opening in the chamber implies greater energy savings for air-conditioning (Patania *et al.*, 2010). Likewise, the survey and monitoring of the air speed of buildings built with ventilated facades in Barcelona, showed that more than 70% of cases had a closed air chamber on their upper and lower openings, making the proper performance of a ventilated envelope system impossible (Balter *et al.*, 2019). The results of this work have been simulated considering interventions on the envelope in operation, which means that, in practice, it must be controlled that the upper and lower openings of the ventilated facades or the side openings of the ventilated roofs, are not closed. This demonstrates the importance of transferring knowledge about the performance of these new envelope systems, both to local building regulations, and to the industrial and construction sector, to achieve an effective guarantee of energy savings.

Another aspect to bear in mind lies in the regulations. The Argentinean IRAM standards (11600 series) work with the thermal quality and energy consumption issues of built buildings, establishing the calculation methods and the minimum values of their hygrothermal conditions. However, for air chambers on the envelope, the standard does not consider the exterior sheet to calculate transmittances. That is to say, it does not consider the resistance of the exterior plate. Anyhow, although the conductivity of the exterior plate's material is not significant for this calculation, it is a variable to be considered, given that the temperature inside the chamber can increase considerably compared to the external air. The IRAM 11600 series is the calculation basis of Standard 11900 (2017) of the Building Energy Certification, which is why the impacts on the envelope of the presence or absence of a ventilated envelope, be this on the façade or roof, are not considered when calculating the Energy Performance Index (IPE in Spanish). The results obtained in this research match those expressed by Fernández, Garzón and Elsinger (2020), who have shown that the thermal insulation increase strategies on the envelope, reduction of glazed surfaces and generation of crossed ventilation do not substantially affect the determination of the energy efficiency label of dwellings. As a result, it is possible to state that the ventilated construction systems are not being considered by the Argentinean regulation.

In consideration of these results, it is foreseen in the future to look further in the studies based on two aspects: on one hand, the evaluation of an effective rehabilitation in economic terms, that foresees integrating into the study, the analysis of materials available in Mendoza that can feasibly be adapted, like ventilated envelope, against the imported ventilated façade systems that can be bought into the country and into the region. And, on the other hand, regarding the regions with seismic risk, like the city of Mendoza, the joint assessment of this condition with the thermal rehabilitation is deemed essential (Manfredi & Masi, 2018). In this sense, the evaluation of the combined loads is considered, for the implementation of the exterior plates of the envelopes.

CONCLUSIONS

Building rehabilitation with energy efficiency criteria is essential in current urban contexts. The passive rehabilitation bioclimatic strategies, like the incorporation of thermal insulation and ventilated envelopes, appear as a valid and effective option in climates with high solar radiation.

The area evaluated for the thermo-energy rehabilitation of residential buildings – Central 2 area of Mendoza, has ten cases with possibilities for intervention on the north-facing facades. The audits made onsite in one of the cases that can be rehabilitated, along with their validation in the *EnergyPlus* model, allowed diagnosing considerable reductions in energy consumption in summer, given by the implementation of ventilation techniques on the envelope, like ventilated roofs and facades.

As for unoccupied buildings in the study, through the incorporation of ventilated envelopes on facades and roofs, important benefits were obtained compared to indoor thermal improvements, which represented energy savings of 32%, in comparison to the same building with insulation. Likewise, the ventilation on the roof implies important reductions in heat transfers, which led to energy reductions of 260% on the units located on the top floor with exposed roofs.

Starting from the study of building rehabilitation possibilities in the high density area of Mendoza, it is concluded that it is possible to achieve an effective thermal-energy performance through the integration of ventilated envelopes. The applicability of the methodology adopted requires monitoring and validation through the dynamic simulation of the indoor thermal performance of the building, through which it will be possible to predict improvements in the thermal-energy performance of existing dwellings, in high-rise, mid-rise and low-rise buildings.

ACKNOWLEDGMENTS

We would like to thank CONICET (National Scientific and Technical Research Council) for their financial support. We would also like to thank Cristina Pardal PhD and Ignacio Paricio PhD, from the Architectural Technology Department of the Polytechnic University of Catalonia, who guided the learning process of the envelope system being studied.

BIBLIOGRAPHICAL REFERENCES

Albayyaa, H., Hagare, D. y Saha, S. (2019). Energy conservation in residential buildings by incorporating Passive Solar and Energy Efficiency Design Strategies and higher thermal mass. *Energy and Buildings*, *182*(1), 205-213. DOI: https://doi.org/10.1016/j.enbuild.2018.09.036

Aparicio-Fernández, C., Vivancos, J.L., Ferrer-Gisbert, P. y Royo-Pastor, R. (2014). Energy performance of a ventilated façade by simulation with experimental validation. *Applied Thermal Engineering*, *66*(1-2), 563-570. DOI: https://doi.org/10.1016/j.applthermaleng.2014.02.041

Ascionea, F., Biancoa, N., De Masib, R. y Vanolib, G. (2013). Rehabilitation of the building envelope of hospitals: Achievable energy savings and microclimatic control on varying the HVAC systems in Mediterranean climates. *Energy and Buildings*, *60*, 125–138. DOI: http://dx.doi.org/10.1016/j.enbuild.2013.01.021

Balocco, C. (2002). A simple model to study ventilated facades energy performance. *Energy and Buildings*, *34*(5), 469-475. DOI: https://doi.org/10.1016/S0378-7788(01)00130-X

Balocco, C. (2004). A non-dimensional analysis of a ventilated double façade energy performance. *Energy* and Buildings, *36*(1), 35-40. DOI: https://doi.org/10.1016/S0378-7788(03)00086-0

Balter, J., Alchapar, N., Correa, E., Ganem, C. (2018). Validación de modelo microclimático calculado con ENVI-met como herramienta para el análisis térmico edilicio de EnegyPlus. En *V Congreso Latinoamericano de Simulación de Edificios. IBPSA (International Building Performance Simulation Association)*. Valparaíso, Chile.

Balter, J., Ganem, C., Discoli, C. (2016). On high-rise residential buildings in an oasis-city: thermal and energy assessment of different envelope materiality above and below tree canopy. *Energy and Buildings*, *113*(1), 61-73. DOI: https://doi.org/10.1016/j.enbuild.2015.11.011

Balter, J., Pardal, C., Paricio, I., Ganem, C (2019). Air cavity performance in Opaque Ventilated Facades in accordance with the Span Technical Building Code. *ACE: Architecture, City and Environment, Arquitectura, Ciudad y Entorno*, *13*(39), 211-232. DOI: 10.5821/ace.13.39.6487

Bórmida, E. (1984). *Mendoza, una ciudad Oasis*. Mendoza: Universidad de Mendoza.

Cabeza, L. y De Gracia. A. (2021). Thermal energy storage systems for cooling in residential buildings. En Cabeza, L. (Ed.), *Advances in Thermal Energy Storage Systems. Methods and Applications* (pp. 595-623). Woodhead Publishing. Universidad de Lleida, Lleida, España.

Cantón, A., Mesa, A., Cortegoso J.L. y De Rosa, C. (2003). Assesssing the solar resource in forested urban environments. *Architectural Science Review*, *46*(2), 115-123.

Damico, F. C., Alvarado, R. G., Bruscato, U., Trebilcock-Kelly, M., Oyola, O. E. y Díaz, M. (2012). Análisis energético de las viviendas del centro-sur de Chile. *Arquitectura Revista*, *8*(1), 62-75.

Domínguez Delgado, A., Durand Neyra, P. y Domínguez Torres, C.A. (2013). Estudio del enfriamiento pasivo por fachadas ventiladas en el sur de España. En *Actas del I Congreso Internacional de Construcción Sostenible y Soluciones Eco-eficientes (20, 21 y 22 de mayo 2013, Sevilla, España)* (pp. 193-205). Sevilla: Universidad de Sevilla.

Elarga, H., De Carli, M. y Zarrella, A. (2015). A simplified mathematical model for transient simulation of thermal performance and energy assessment for active facades. *Energy and Buildings 104*(1), 97-107. DOI: https://doi.org/10.1016/j.enbuild.2015.07.007

Fantucci, S., Marinosci, C., Serra, V. y Carbonaro, C. (2017). Thermal performance assessment of an opaque ventilated façade in the summer period: calibration of a simulation model through in-field measurements. *Energy Procedia*, *111*, 619-628. DOI: https://doi.org/10.1016/j.egypro.2017.03.224

Fernández, A., Garzón, B. y Elsinger, D. (2020). Incidencia de las estrategias pasivas de diseño arquitectónico en la etiqueta de eficiencia energética en Argentina. *Hábitat Sustentable*, *10*(1), 56-67. DOI: https://doi.org/10.22320/07190700.2020.10.01.05

Filippín C., Ricard F., Flores Larsen, S. y Santamouris, M. (2017). Retrospective analysis of the energy consumption of single-family dwellings in central Argentina. Retrofitting and adaptation to the climate change. *Renewable Energy*, *101*, 1226-1241. DOI: https://doi.org/10.1016/j.renene.2016.09.064

Gagliano, A., Patania F., Nocera, F., Ferlito, A. y Galesi, A. (2012). Thermal performance of ventilated roofs during summer period. *Energy and Buildings, 49*, 611–618. DOI: https://doi.org/10.1016/j.enbuild.2012.03.007

Gagliano, A., Nocera, F. y Aneli, S. (2016). Thermodynamic analysis of ventilated façades under different wind conditions in summer period, *Energy and Buildings*, *122*(15), 131-139. DOI: https://doi.org/10.1016/j.enbuild.2016.04.035

Gregorio Atem, C. (2016). *Fachadas ventiladas: hacia un diseño eficiente en Brasil*. Tesis doctoral. Universidad Politécnica de Cataluña.

Haddad, S., Barker, A., Yang, J., Mohan Kumar, D., Garshasbi, S., Paolini, R. y Santamouris, M. (2020). On the potential of building adaptation measures to counterbalance the impact of climatic change in the tropics. *Energy and Buildings*, *229*(15), DOI: https://doi.org/10.1016/j.enbuild.2020.110494

Ibáñez-Puy, M., Vidaurre-Arbizu, M., Sacristán-Fernández, J. y Martín-Gómez, C. (2017). Opaque Ventilated Façades: Thermal and energy performance review*. Renewable and Sustainable Energy Reviews, 79*, 180–191. DOI: https://doi.org/10.1016/j.rser.2017.05.059

IRAM 11601 - Instituto argentino de Normalización y Certificación (2002). *Aislamiento térmico de edificios. Métodos de cálculo*. Buenos Aires: IRAM.

IRAM 11900 - Instituto argentino de Normalización y Certificación (2017). *Prestaciones Energéticas en Viviendas, Método de cálculo*. Buenos Aires: IRAM.

Köppen W. y Geiger R. (1936). *Das geographische system der klimate, Handbuch der klimatologie*. Berlín: Verlag von Gebrüder Borntraeger.

Leccese F., Salvadori, G., Asdrubali, F y Gori, P. (2018). Passive thermal behaviour of buildings: Performance of external multi-layered walls and influence of internal walls. *Applied Energy*, *225*(1), 1078-1089. DOI: https://doi.org/10.1016/j.apenergy.2018.05.090

Li, D., Zheng, Y., Liu, C., Qi, H. y Liu, X. (2016). Numerical analysis on thermal performance of naturally ventilated roofs with different influencing parameters. *Sustainable Cities and Society*, *22*, 86–93. DOI: http://dx.doi.org/10.1016/j.scs.2016.02.004

Manfredi, V. y Masi, A. (2018). Seismic Strengthening and Energy Efficiency: Towards an Integrated Approach for the Rehabilitation of Existing RC Buildings. *Buildings*, *8*(36), 2-19. DOI: https://doi.org/10.3390/buildings8030036

Patania, F., Gagliano, A., Nocera, F., Ferlito, A. y Galesi, A. (2010). Thermofluid-dynamic analysis of ventilated facades. *Energy and Buildings*, *42*(7), 1148-1155. DOI: https://doi.org/10.1016/j.enbuild.2010.02.006

Peci López F., Jensen, R.L., Heiselberg, P. y Ruiz de Adana Santiago, M. (2012). Experimental analysis and model validation of an opaque ventilated façade. *Building and Environment*, *56*, 265-275. DOI: https://doi.org/10.1016/j.buildenv.2012.03.017

Peci López, F. y Ruiz Adana Santiago, M. (2015). Sensitivity study of an opaque ventilated façade in the winter season in different climate zones in Spain. *Renewable Energy*, *75*, 524-533. DOI: https://doi.org/10.1016/j.renene.2014.10.031

Pérez Fargallo, A., Calama Rodríguez, J.M. y Flores Alés, V. (2016). Comparativa de resultados de rehabilitación energética para viviendas en función del grado de mejora. *Informes de la Construcción*, *68*, 1-11. DOI: http://dx.doi.org/10.3989/ic.15.048

Raimundo, A., Saraiva, N. y Oliveira V. (2020). Thermal insulation cost optimality of opaque constructive solutions of buildings under Portuguese temperate climate. *Building and Environment*, *182*, 107-107. DOI: https://doi.org/10.1016/j.buildenv.2020.107107

Rubio-Bellido, C., Pulido-Arcas, J. A. y Ureta-Gragera, M. (2015). Aplicabilidad de estrategias genéricas de diseño pasivo en edificaciones bajo la influencia del cambio climático en Concepción y Santiago, Chile, *Hábitat Sustentable*, *5*(2), 33-41.

San Juan, C., Suárez, M., J., González, M., Pistono, J. y Blanco, E. (2011). Energy performance of an open-joint ventilated façade compared with a conventional sealed cavity façade. *Solar Energy*, *85*(9), 1851-1863. DOI: https://doi.org/10.1016/j.solener.2011.04.028

Sánchez, M.N., Giacola, E., Suárez, M.J., Blanco, E. y Heras, M.R. (2017). Experimental evaluation of the airflow behaviour in horizontal and vertical Open Joint Ventilated Facades using Stereo-PIV. *Renewable Energy*, *109*, 613-623. DOI: https://doi.org/10.1016/j.renene.2017.03.082

Sandberg, M. y Moshfegh, B. (1996). Investigation of fluid flow and heat transfer in a vertical channel heated from one side by PV elements. *Renewable Energy*, *8*(1-4), 248-253. DOI: https://doi.org/10.1016/0960-1481(96)88856-2

Stazi, F., Tomassoni, F., Veglio, A. y Di Perna, C. (2011). Experimental evaluation of ventilated walls with an external clay cladding. *Renewable Energy*, *36*, 3373-3385. DOI: https://doi.org/10.1016/j.renene.2011.05.016

Suárez, C. y Molina, J.L. (2015). Análisis del efecto chimenea en fachadas ventiladas opacas mediante correlaciones del flujo másico inducido. Aplicación para el dimensionado de anchos de cámara. *Informes de la Construcción*, *67*, 1-9.