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LA ESCUELA CANTINO

La escuela Cantino obtuvo el *tercer lugar de los Premios CES 2020* (Certificación Edificio Sustentable) *y fue nominada* a los premios ODA 2021 organizado por Archdayli.

La obra cuenta con altos estándares de diseño pasivo y eficiencia energética dado por un contexto de inviernos fríos y veranos calurosos, lo que permitió lograr certificarlo mediante la metodología CES edificio sustentable con la denominación "certificación destacada".

Se aprovechó el potencial de la madera de bosques renovables, como estructura predominante, se utilizó madera estructural de pino radiata y elementos principales de madera laminada. Esta solución estructural fue modelada bajo el software Cadwork y mecanizada con máquina de tecnología CNC para fabricación de piezas, lo que permitió la ejecución de una obra limpia y en menor tiempo.

Se incorporaron sistemas de ventilación y calefacción de alto rendimiento, siendo otra característica el que la obra fue completamente aislada mediante celulosa de papel de diario reciclado.

Toda esta sumatoria de decisiones en su conjunto contribuyeron al desarrollo de un edificio de alto desempeño energético y a la disminución de la huella de carbono, entre otros aspectos.

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EDITORIAL

MORE KNOWLEDGE FOR A NEW ERA

Pandemic and climate change: two events that are mixed and, often, seem to be the same. The events of recent years, and especially 2021, have jeopardized the certainties which up until now, were grounded on that scientific knowledge could lead humanity along a safe path. For a while, we thought that the results of multiple theses, and the accumulated efforts to understand phenomena and solutions based on the concept of sustainability were in vain, given the threats of a ferocious pandemic, along with the frustrated attempts to contain climate change. The goals sought up until now have been greatly challenged.

Facing a new and unexpected reality, architects, urbanists, engineers, and other professionals and researchers connected to the built environment, began to question their certainties. Countless questions arose. For example, how to think about mass-scale public transportation, if this entails crowding, alongside possible unsuitable energy use? And what to do now with urban public spaces, like squares and parks, that were historically considered as meeting places that added quality to cities and their inhabitants? And how to contain -if it has to be contained- the boom of the home office, which has interfered with traditional living spaces, and has emptied commercial and educational buildings? What happens with the increased use of air conditioning and all its environmental consequences, given the growing need to stay in controlled indoor environments? And how to consider spaces for large events, symbols of crowded meetings, and mass-scale events? In this new context, what happens with smart cities? And, after all, what does it mean for a city to be smart when facing this reality?

When the focus turns to the issue of impacts, whether caused by the COVID-19 pandemic or inherent to climate change, it is inevitable to consider the effects these have on the most vulnerable communities, which become even more fragile under this scenario. There is no way to keep a family who lives in a single room apart, nor it is possible to demand that they leave areas at risk of flooding and landslides, on facing the inevitable increase of natural disasters, which have been widely felt in recent years.

The world was shaken in 2021, and from this change, we discover that we have to reinvent ourselves. The individual can no longer achieve well-being, facing the need that the entire community is vaccinated to overcome the pandemic. Thus, it is essential to deal with the social differences, but the formulation of public policy to face this goal cannot be treated as "charity", as the expansion of these differences tends to lead society to a state of barbarism, undesirable for all segments. So that everyone has a dignified quality of life, with greater security, less violence, less environmental impact, better transport conditions, education, and so on., the need to reduce social disparities is evident. Without this, people with better economic conditions will be confined to gated communities and the old citadels may reappear, governed by their own laws, and isolated from urban coexistence.

It is pressing that we keep fighting in the search for an environmental, social, and economic balance. Topics like energy, housing, comfort, and efficiency, which are addressed in this issue of Hábitat Sustentable, will always be among our concerns about what we want to do to make our planet a greener place to live.

The pandemic we have lived through, as well as the 2021 United Nations Conference on Climate Change, held in Glasgow, have made us realize that the world is not just globalized by technology. The planet's survival depends on common comprehensive actions, whether to fight something microscopic like a virus, or something as gargantuan and invisible as the climate. We are all in the same boat, whose course depends on how we use knowledge.

May the works published here be a part of the path towards new, better, and happier times!

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THE ACTIVE ROLE OF THE USER IN THE SEARCH FOR THERMAL COMFORT OF DWELLINGS IN A TEMPERATE ARID CLIMATE

EL ROL ACTIVO DEL USUARIO EN LA BÚSQUEDA DE CONFORT TÉRMICO DE VIVIENDAS EN CLIMA TEMPLADO ÁRIDO

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RESUMEN

El comportamiento del usuario es uno de los principales factores de incertidumbre en el desempeño térmico de una vivienda. El presente estudio contribuye a identificar variables que influyen en la conducta del usuario y, a su vez, en cómo ésta afecta el desempeño térmico de viviendas en la ciudad de Mendoza. En ese sentido, se realizó una auditoría térmica de una vivienda representativa, en verano e invierno, elaborando en forma paralela un registro de uso y gestión de los habitantes. Se concluye que, en verano, una correcta gestión de la envolvente mediante la ventilación nocturna favorece el logro de confort interior en un 89% de los datos registrados; y, en invierno, un correcto aprovechamiento de la ganancia solar directa favorece el logro de confort en un 60% de dichos datos. Se evalúan, finalmente, alternativas de mejora edilicia para la estación más desfavorable.

Palabras clave

uso y gestión, ocupación, comportamiento del usuario, confort térmico, estrategias bioclimáticas

ABSTRACT

User behavior is one of the main factors of uncertainty in the thermal performance of a dwelling. This study contributes to identifying variables that would influence the user behavior and, in turn, how these affect the thermal performance of houses located in the city of Mendoza. For this, a thermal audit of a representative dwelling was made in summer and winter, while also recording occupancy and occupant actions. It was concluded that, in summer, correct management of the envelope through night cooling favors reaching indoor comfort in 89% of the recorded data. In winter, the correct use of direct solar gain favors reaching comfort in 60% of the recorded data. Finally, alternatives for building improvements are evaluated for the most unfavorable season.

Keywords

use and management, occupancy, occupant behavior, thermal comfort, bioclimatic strategies

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INTRODUCTION

The impacts of global warming are affecting both human health and ecosystems. Therefore, reducing greenhouse gas emissions and energy consumption in the building sector is essential. However, these values have been rising in recent years. Buildings are responsible for 36% of the final energy consumption (7% more than 2010) and 39% of the emissions (International Energy Agency – IEA and the United Nations Environment Program – UNEP, 2019). It is estimated that human activities are responsible for a 1°C increase in global warming, above pre-industrial levels (Intergovernmental Panel on Climate Change – IPCC, 2018). The latest IPCC report (2021) has laid out that the global surface temperature will continue increasing at least until the mid- 21st century under all the emissions scenarios studied. Global warming of 1.5°C and 2°C above pre-industrial levels will be exceeded during the 21st century unless major reductions are produced in CO_2 and other greenhouse gas emissions in the coming decades.

In fact,

> The thermal comfort of human beings in the built environment is directly relevant for the main contemporary problems of climate change, being the main cause of disproportionate increases in energy consumption. A relevant phenomenon of climate variability in cities is the presence of heat islands, that is to say, the temperature increase in areas of the city compared to the surrounding peri-urban and rural areas. This leads to an increase in energy consumption to cool homes and service facilities and, as a result, greenhouse gas emissions also increase (Martínez Peralta, 2016, p. 355).

To this, the fact that "the average user demands, as time goes by, better air-conditioned indoor spaces, and is less tolerant to thermal discomfort" is added (Arrieta, 2020, p. 64). The growing demand for thermal comfort in residential settings seeks responses from architecture. Different studies (Roaf, 2018; Invidiata & Ghisi, 2016; Palme, Carrasco & Gálvez, 2016; Silva, Almeida & Ghisi, 2016; Diulio, Netto, Berardi & Czajkowski, 2016) show that the use of passive bioclimatic strategies is essential to increase indoor thermal comfort in homes, also favoring the reduction of energy consumption, although it is important to consider that some passive strategies currently in use will be less efficient in the future, due to global warming (Flores-Larsen, Filippín & Barea, 2019).

In this context, "a future scenario is set out for architects, where a more sustainable architecture is inescapable, which requires a definition of the profile for an architect who is in tune with the environment and with the users" (Pérez, 2016, p. 33). Consequently, this represents the commitment to providing comfort to the users of the projects through adaptation possibilities, conceived from the design. Incorporating opportunities of adaptation in buildings collaborates with the task of increasing their energy efficiency regarding their main role of providing an acceptable, and even pleasant, thermal environment. According to Susan Roaf (2018), achieving thermal comfort, without using air-conditioning equipment that uses auxiliary energy, is the key to the success and resilience of a building.

The balance of cities, in particular those found in a continental temperate arid climate, like the case of Mendoza, Argentina, depends on the suitable and appropriate use of resources and their potentials. The user makes decisions that can positively contribute towards urban sustainability, or impair it since energy consumption is directly related to human activities. Active user behavior has become a key issue to reduce energy consumption and greenhouse gas emissions in the building sector (Andreoin Tretancoste & Ganem Karlen, 2017; D'Amanzo, Mercado & Ganem Karlen, 2020).

The studies on user behavior analysis mainly focus on non-residential typologies (Dueble & de Dear, 2012; Alonso-Frank & Kuchen, 2016; Antoniadou & Papadopoulos, 2017; Ö. Göçer, Candido, Thomas & K. Göçer, 2019). Dwellings are characterized by usage behavior and very varied activities, which leads to a greater complexity when it comes to analyzing user behavior and its impact on building thermal performance. The design of dwellings that have energy efficiency systems and envelopes, that allows the occupant to adapt indoor comfort conditions to their preference, can be perfected based on reliable information taken from the empirical study of user behavior and needs. Different research projects (Hong, Yan, D'Oca & Chen, 2016; Lopes, Antunes, Reis & Martins, 2017; Balvedi, Ghisi & Lamberts, 2018; Li, Yu, Haghighat & Zhang, 2019; Carlucci *et al.*, 2020) show the importance of analyzing user behavior considering the use and management of dwellings to predict building thermal performance through simulation models, understanding by "use", all those practices or habits related to the occupation of the dwelling by the user; both for the number of users and the times in which they use indoor spaces, such as the activities, elements or equipment they use in their daily lives. The notion of "management", however, aims at the management of the active and passive systems and resources of the dwelling, seeking to solve the comfort needs of the user, guaranteeing habitability.

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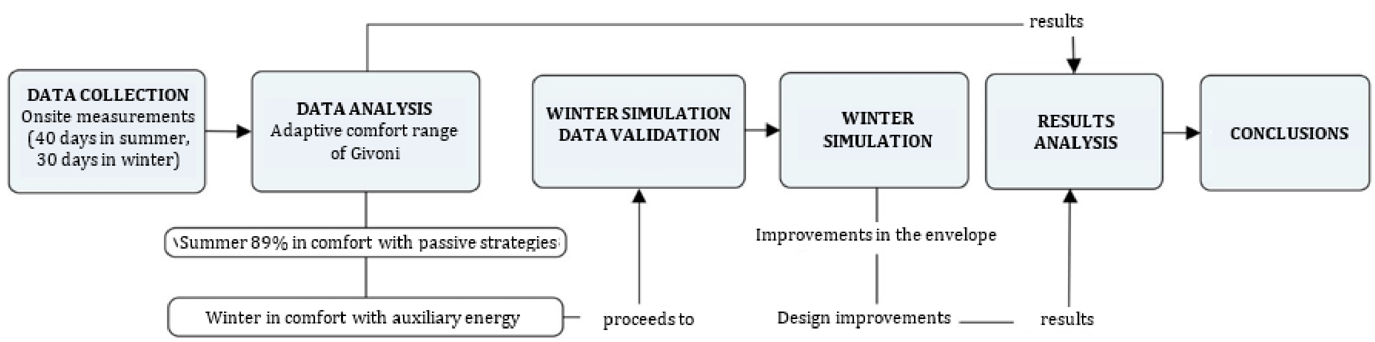

Figure 1. Methodological process flow chart. Source: Preparation by the Authors using the CmapTools software.

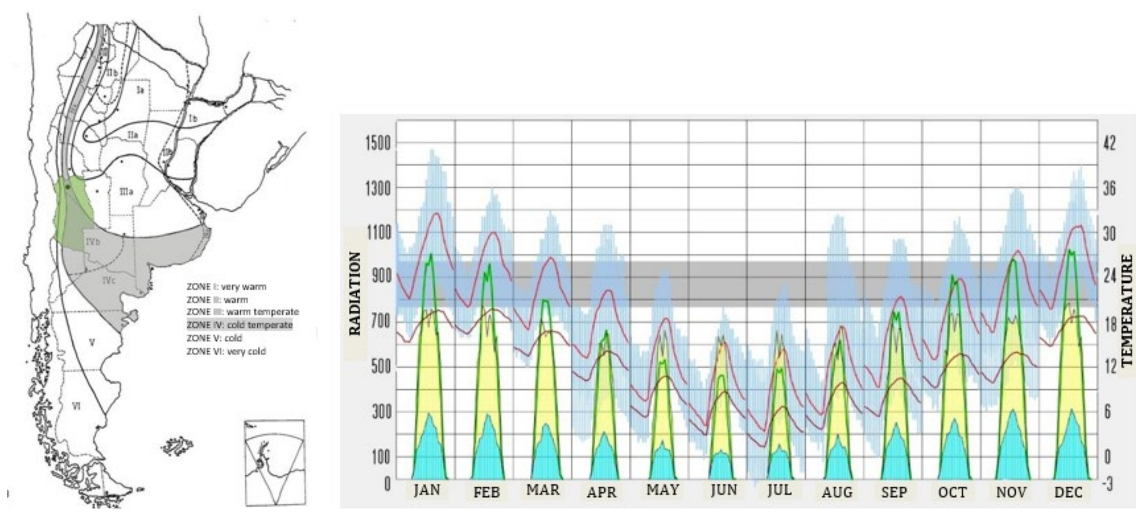

Figure 2. a) Bioenvironmental areas of Argentina, b) Monthly daily averages for temperature and solar radiation in the city of Mendoza. Source: Adaptation by the authors based on IRAM 11603 Standard, and graph made by the authors using Climate Consultant 5.0, EPW, climate file found at http://climate.onebuilding.org/

User behavior is one of the main factors of uncertainty in the thermal performance of a dwelling (Andersen, Fabi & Corgnati, 2016; Cuerda Guerra-Santin & Neila González, 2017; Wagner & O'Brien, 2018), and it varies depending on the climate and the habits of the user. This is why it is essential to analyze the variables that affect their behavior and, at the same time, how said behavior affects the building's thermal performance, to thus be able to layout guidelines to follow in the future, in the design and retrofitting of dwellings in the city of Mendoza.

The purpose of this work is to understand and quantify user behavior and dwelling inhabitant management in the city of Mendoza. It is sought to identify user behavior patterns and their impact on achieving indoor thermal comfort during summer and winter, using bioclimatic design strategies. The relationship of these variables provides the empirical grounds to represent user behavior in building simulation models.

METHODOLOGY

A parallel convergent design of data taking was used in this research, to study occupant behavior of a case study dwelling in the city of Mendoza, Argentina. The convergent designs researched in parallel allowed researchers to quantify the actions of the users and to better understand both cause and effect (Wagner & O'Brien, 2018). A flow chart of the methodological process is shown in Figure 1:

SELECTION OF THE CASE STUDY

The city of Mendoza is located on the western fringe of Argentina, at 32° 40' latitude south and 68° 51' longitude west, at 750 masl. According to the Köppen climate classification (Kottek, Grieser, Beck, Rudolf & Rubel, 2016), the climate characterization is BWk, which is an arid climate with hot summers and cold dry winters.

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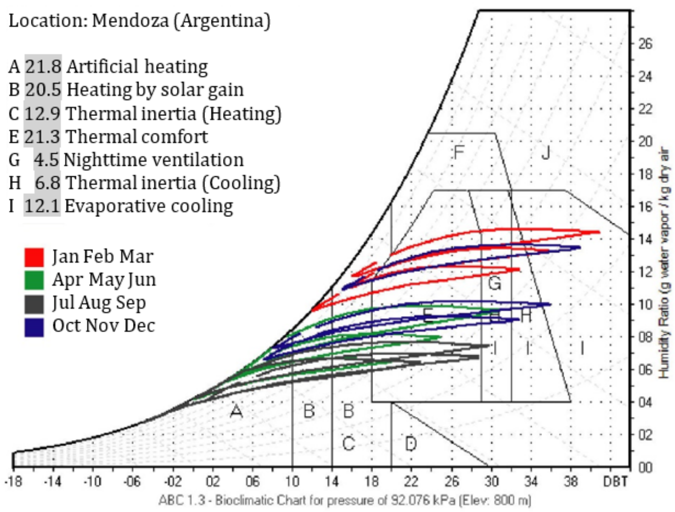

Figure 3. Psychrometric chart for Mendoza. Source: Preparation and adaptation by the authors, based on the graph prepared using the ABC software.

According to the IRAM 11603 Standard (Figure 2a), it belongs to the cold temperate IVa bioenvironmental area. This climate is characterized by large daily and seasonal thermal amplitudes, since it has absolute temperatures that vary between -6°C in winter and 39°C in summer, with daily variations of approximately 10°C to 20°C, and with low relative humidity (annual average of 54.7%). For Mendoza, the heating degree day (base 18°) is 1384°C day/year, and the minimum design temperature is -1.9°C. The city has an annual rainfall of 218 mm, with an elevated solar radiation index and a high heliophany (Figure 2b).

For architecture in this climate, several authors (Olgyay, 1998; Givoni, 1992; Serra Florensa & Coch Roura, 1991) have studied and proposed suitable bioclimatic strategies, all of them including, as a common factor, the principle of being flexible systems, that is to say, elements or sets of elements that can easily change their environmental action using the climatic circumstances. Here, the comfort ranges suggested by Givoni (1992) are used, of 18°C – 25°C, in winter, and 20°C – 27°C in summer. The strategies recommended for the climate of Mendoza, as are analyzed in the psychrometric chart (Figure 3) proposed by the same author, are mainly those of passive solar conditioning, thermal mass effect, and nighttime natural ventilation. It is important to point out that the possible measures to implement in this climate, could only reach comfort in summer by taking advantage of passive strategies. However, in winter, it is seen that passive strategies are insufficient to reach indoor comfort on the coldest days, with auxiliary heating being necessary.

The city of Mendoza is part of the conurbation known as Greater Mendoza or Mendoza Metropolitan Area (AMM, in Spanish), which is the hub with the highest population density in the province, housing 64% of the population. The urban structure is characterized by its checkerboard plotting, with tree-lined streets. Likewise, the lot layout shows a predominance of semi-detached dwellings, with dividing walls (Stocco, Cantón & Correa, 2013; Sosa, Correa & Cantón, 2016). 87.5% of the AMM dwellings are single-family low-rise dwellings (DEIE, 2019). On this being the most representative residential typology, a single-family dwelling was chosen as the case study for this work, located in the heart of the city, built between dividing walls (Figures 4a, 4b, and 4c). Its construction technology is typical of Mendoza, with solid plastered brick walls on both faces, without thermal insulation (K= 2.59W/m^{2}k). The carpentry is metal, with folded sheets, and with single 4mm glazing (K= 5.7W/m^{2}k). It has sloped wooden roofs which have 5 cm thick expanded polystyrene thermal insulation. And, finally, the external finish is made of ceramic tiles (K= 0.93W/m^{2}k). It is worth mentioning that the dwelling does not have cooling systems in any of its rooms; it only has a roof fan in the southern bedroom and a floor fan on the ground floor. The heating system is comprised of two natural gas heaters, one located in the southern bedroom, and the other on the ground floor, in the living-dining room space.

DATA COLLECTION AND PROCESSING

Relative humidity and temperature data were measured onsite, by placing four micro-collection HOBO U10 data loggers: one, outdoors (protected from direct solar radiation), and three in different spaces in the dwelling (Figure 4a). All of them were set up so that they were suspended in the middle of each room, at equivalent heights (approximately 2m from the floor level), to keep them away from the influence of mass constructive elements. This study worked with the living-dining room (Figure 4c), as such, only the data of the micro-collection data logger in said room, and the one outdoors, were considered. The remaining indoor measurements were used to fit the model.

Two measurement periods were considered: one of 40 days in January and February, and another of 30 days between July and August 2017 (summer and winter seasons, respectively, for the southern hemisphere). The data collection interval was set at 15 minutes, and the information was processed using the HOBO ware pro, Excel, and R studio software. In parallel, the recording of the use and management actions was made, using a "diary-like" monitoring survey data collection method (De Simone, Carpino, Mora, Gauthier, Aragon & Harputlugil, 2018), which

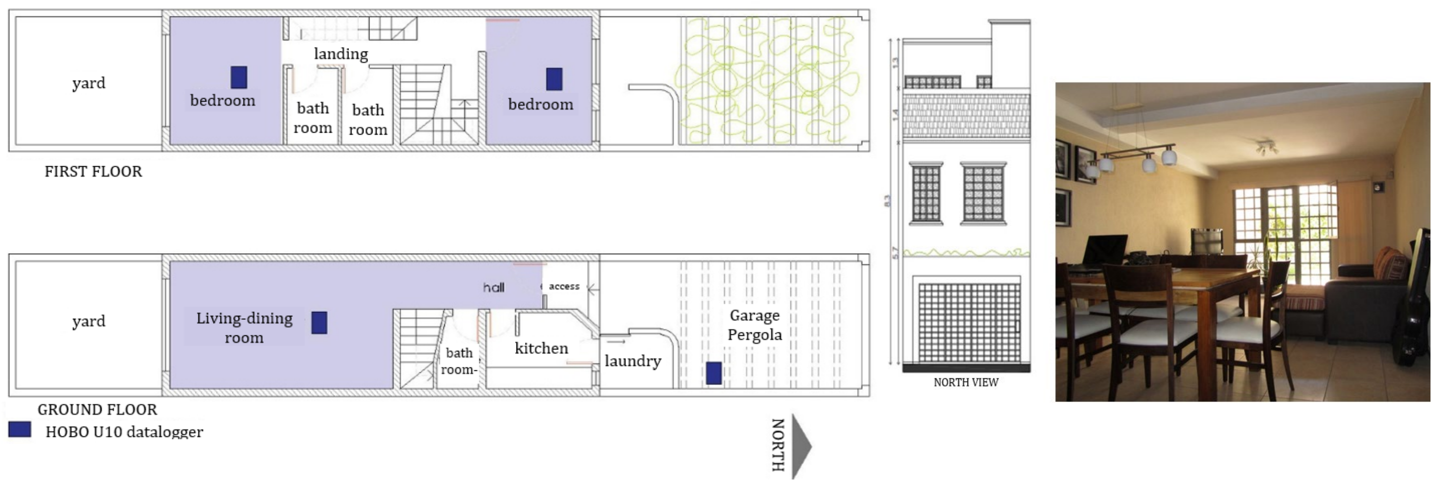

Figure 4. a) Floor plans with the location of the micro-collection HOBO U10 data loggers. b) Front view of the dwelling. c) Photograph of the studied room. Source: Preparation by the authors.

consists of self-filled spreadsheets with structured entries, also called "time use surveys" (TUS). This methodology has the advantage of being comparable and repeatable, as long as the same spreadsheet structure is used. These considered: date, forecast daily temperatures, rainfall, heliophany, controlled use condition, occupation times, closure of openings and their opening, use of fans, daytime, and nighttime sensation of comfort, following the thermal sensation scale of between +3 and -3 (ASHRAE, 2008), outdoor airspeed following the Beaufort Scale (National Meteorological Service [SMN, in Spanish], 2018), and observations.

The TUS spreadsheets were presented to the user as self-completing double-entry fields, where they complete the items requested according to their perception and observation. For their correct execution, a preset scale of the variables considered was established beforehand, which were then checked against the measurements obtained in the research center located less than 2 km away.

Thus, the data were recorded under controlled conditions, testing the different interaction opportunities of the users with the envelope and the dwelling's systems. Within the first 40-day period, data were differentiated in cycles of between 10 to 15 days each. During the first cycle, the users promoted the management of the envelope to make the nighttime ventilation of the dwelling possible. Likewise, during the second cycle, they kept the windows open day and night, keeping this variable fixed, and adapting to the room using the systems (fans). During the two-week period where they went on holiday, records were taken on the days without management of the envelope. Although in the ventilated cases a contribution of ventilation from other rooms could appear, it was considered that the results obtained were valid to analyze user behavior and the relationship with adaption to the indoor summer thermal setting, set out in the goals.

In winter, during the 30 days audited, both the influence of auxiliary heating on days with occupation and the thermal performance of the dwelling during unoccupied days were analyzed. The latter facilitated the fit of the theoretical simulation model, adjusting it to take advantage of direct solar gains.

THERMAL SIMULATION

On reaching this point, a simulation of the reference case was carried out, audited with the Energy Plus version 8.8 software (National Renewable Energy Laboratory [NREL], 2017). A model was built with the plugin for Sketchup, dividing the dwelling into 5 thermal areas in contact with the outside. An .epw climate file was made using the climate data measured in the outdoor micro-climate of the dwelling. The simulation was launched considering 10 days before the chosen dates, to allow the model to enter operation before the dates being evaluated. To reduce the number of variables involved, a measurement period without auxiliary energy and with the dwelling unoccupied was used. In this way, the simulation model was adjusted by fitting the simulated data with the measured data. It was possible to obtain a validated model to study, in later simulations, the thermal performance of the dwelling under scenarios that cannot be monitored onsite.

Figure 5 shows the fit obtained for the studied room: The mean hourly temperatures measured and simulated fit in an average of 1°C, which was

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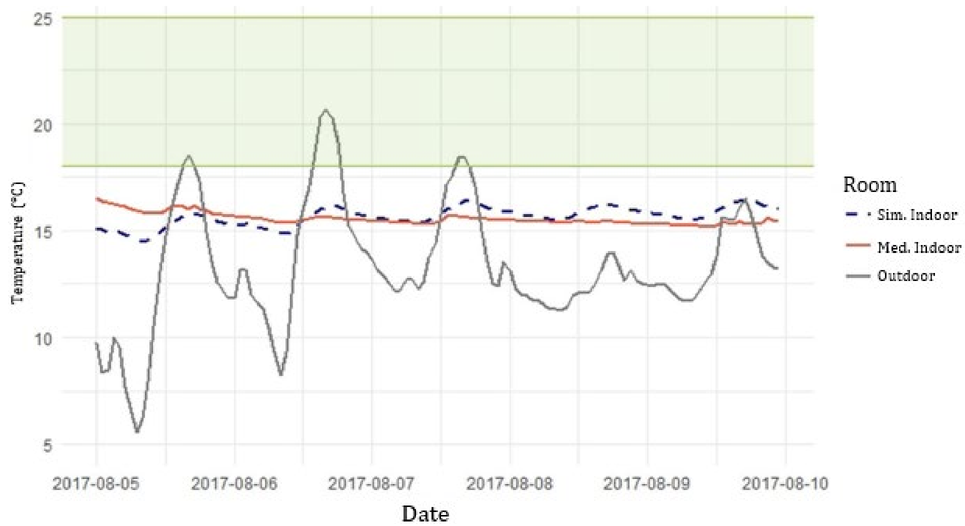

Figure 5. Simulation model fit. Source: Preparation by the authors in R.

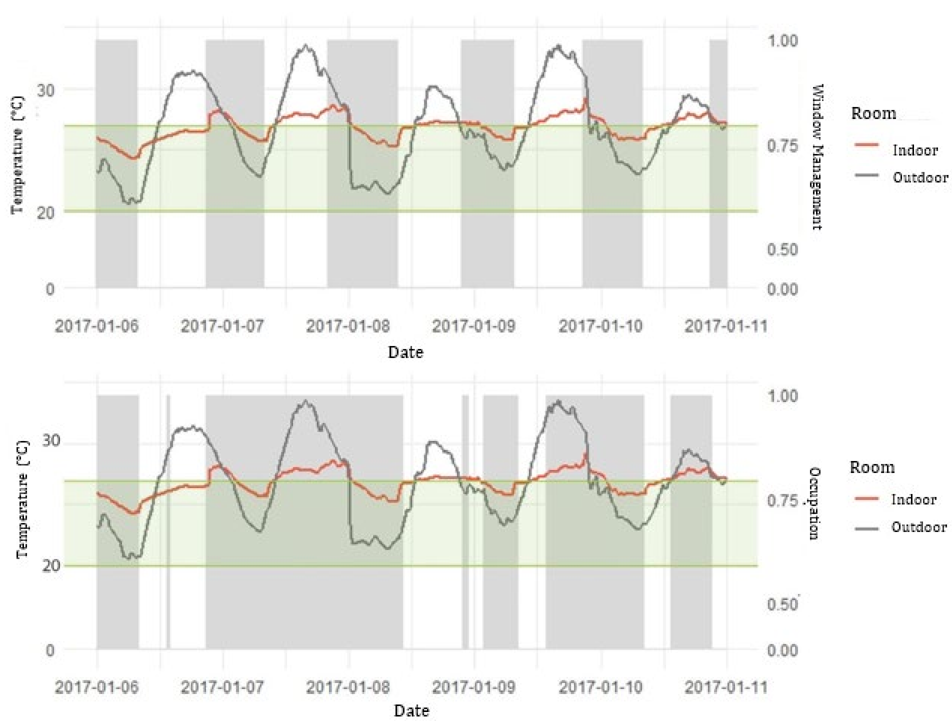

Figure 6. a) Outdoor and indoor summer temperature and window management for nighttime ventilation. b) Summer outdoor and indoor temperature under occupation. Source: Preparation by the authors in R.

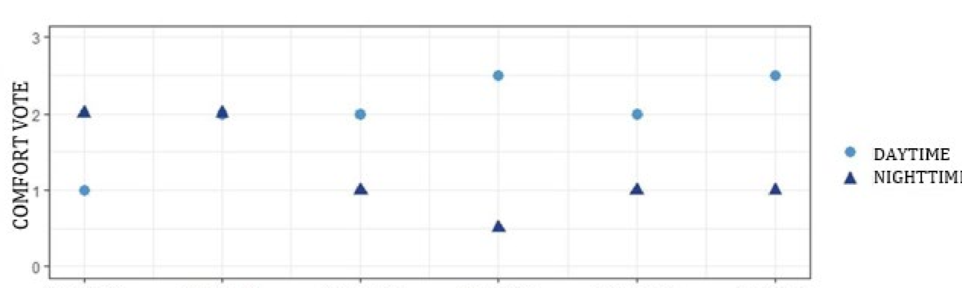

Figure 7. Thermal comfort sensation vote data. Window management period for nighttime natural ventilation. Source: Preparation by the authors in R.

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considered sufficient to obtain a validated model (Filippín & Larsen, 2005).

Once the model was validated, it was possible to make changes in the material of the envelope and its design, achieving, as a result, simulating the thermal performance of the dwelling under scenarios that cannot be monitored onsite.

To know the passive improvement potential in winter, the model was simulated considering the incorporation of improvements to the thermal resistance of the building's envelope. After this, a new simulation was run, adding changes in the orientation of the collector façade of the studied room, which was made to be north-facing (towards the Equator in the southern hemisphere).

RESULTS AND DISCUSSION

The results of the analysis of the data obtained in parallel, both of the humidity and temperature measurements of the case study dwelling, along with the recording of the user behavior on the TUS spreadsheets, are presented below. The data correspond to representative cycles within the study periods made on the "living-dining" room of the case study dwelling, and outside it. Said data are organized in two groups:

Summer:

a. Audit with occupation. Window management to favor nighttime natural ventilation strategy.
b. Audit without occupation. Less committed window management and fan use.

Winter:

a. Audit with occupation and use of auxiliary energy.
b. Audit without auxiliary energy. Validation of simulation model.
c. Simulation without occupation, with improvements on the envelope.
d. Simulation without occupation, with improvements in design and the envelope.

RESULTS OF THE SUMMER ANALYSIS

The results of the first summer analysis cycle are presented in Figure 6. Figure 6a presents the window management, while Figure 6b does so with the occupation patterns. Both graphs were prepared considering the thermal performance of the dwelling.

A relationship is seen in these graphs between the action of opening and closing windows, and the commitment of favoring nighttime natural ventilation, for a better indoor comfort sensation. The window management and occupation data recorded, graphed in gray bars (full bar=open/with occupation; empty bar=closed/without occupation), show a coincidence between the user departure time in the morning, to go to work, and the window closing time in most cases. On the other hand, the window opening record does not coincide with the occupation times, which would indicate that this action is associated, mainly, with a conscious management of the envelope to seek comfort.

It is seen that in graphs 6a and 6b, the outdoor temperature (gray line) varies between 21.5°C and 33.5°C, marking a thermal amplitude of 12°C on average for this period. The indoor temperatures (red line) are within the comfort range in practically the entire period observed, exceeding 27°C by at least 1°C on days 7 and 9.

On comparing the measurement data with the use and management record, it is observed that the days where the temperature exceeds the comfort range correspond to an early opening of the openings (gray bars), which does not coincide with the temperature drop outside. This effect could be clearly seen on day 06/01, when the users returned to the dwelling, at 9 pm, a time when the outdoor temperature exceeded the indoor one by 4°C. On immediately opening the windows, assuming a correct (nighttime) schedule for ventilation, the indoor temperature rose steeply, before starting to drop after midnight. The users, indeed, mentioned that they felt the house was cooler when they arrived.

The comfort vote records (Figure 7) reveal that, although the users were not within the acceptable range (>-5 and <+5) of the thermal comfort sensation scale (ASHRAE, 2008), this value was close, especially at night when windows were opened and fresh air could enter and refresh the thermal mass.

Figure 8 shows the results of the second summer analysis cycle. The fan use and occupation patterns were analyzed regarding the thermal performance of the dwelling. The users kept the windows open during the entire day and night.

Using the graphs, it is possible to identify a variation of the indoor room temperature (between 23°C and 33.5°C), directly affected by the temperature variation outside the dwelling (between 21.5°C and 37°C), on the windows being permanently open. The nighttime ventilation hours are insufficient to climatize the indoor setting, given the temperature accumulation indoors and in the mass materials during the hot air entry times in the day, which cannot be dissipated by nighttime natural ventilation.

The indoor temperatures of the studied room (red line) are found to be above the comfort range in the

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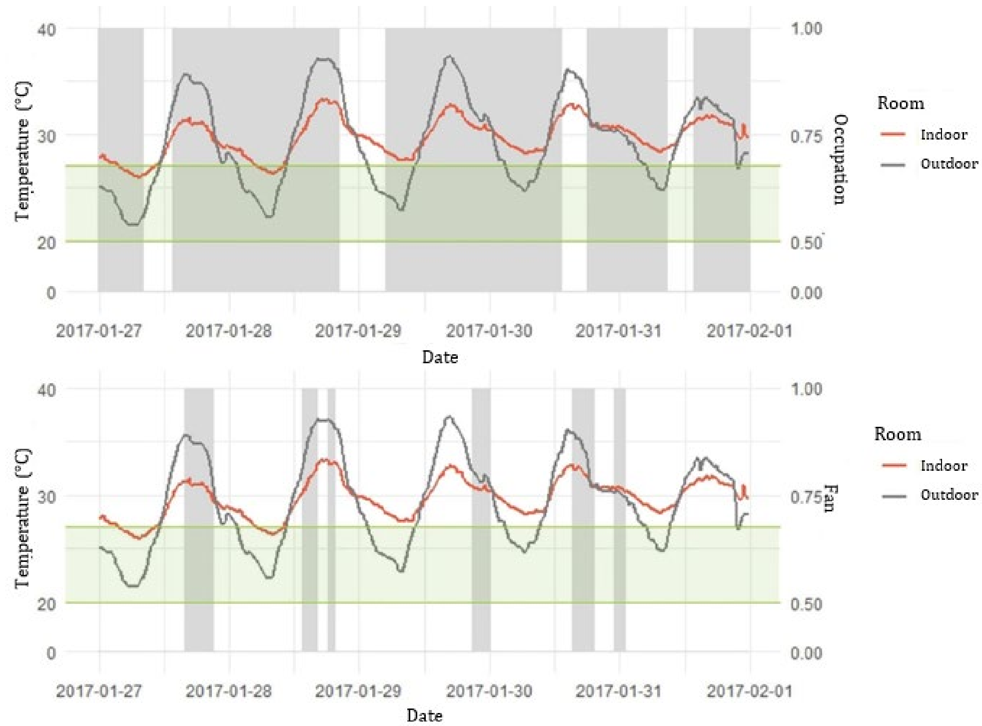

Figure 8. a) Outdoor and indoor temperatures in summer, windows always open, fan management. b) Outdoor and indoor temperatures in summer and occupation record. Source: Preparation by the authors in R.

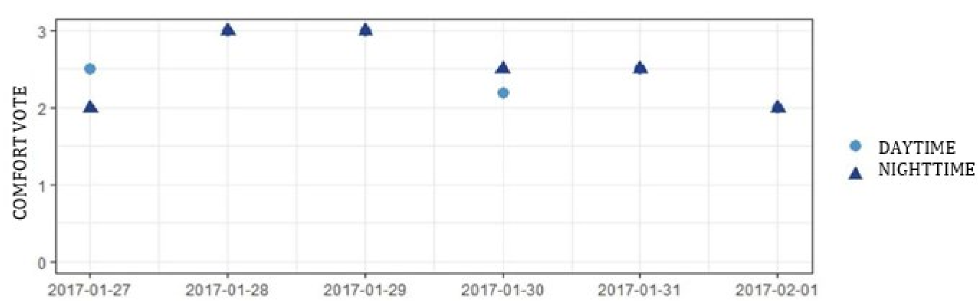

Figure 9. Thermal comfort sensation vote data. Period with windows always open. Source: Preparation by the authors in R.

entire studied period, except for some nighttime hours. It is seen that the fan use pattern coincides with the maximum daytime temperatures and at the start of the afternoon.

In this case, the lack of comfort manifested by users in the entire period is seen (Figure 9), with values that reach +3 (very warm) on the comfort scale (ASHRAE, 2008), and in the case of intensive use of the fan, mainly in the times where the temperature reached the daily peaks (Figure 8b).

RESULTS OF THE WINTER ANALYSIS

The results of the audit made in the winter period, with occupants present and auxiliary energy for heating, are presented below.

Even though the occupation record for the entire dwelling (Figure 10) does not show a relationship with turning on and off the gas heater in the studied space, its use coincides with the occupation of this room. The coincidence of the time the dwelling's occupants go to sleep at night particularly stands out, since, on heading to the master bedroom on the top floor, they turn off the heating of the room on the ground floor (under study), before turning it on in the morning, early, when they get up for breakfast.

The low quality of the envelope, and the limited possibility to make use of the solar resources the dwelling has, are evident, which makes it impossible to use the passive strategies recommended for this climate in winter. The rapid temperature loss on turning off the heater entails important reductions

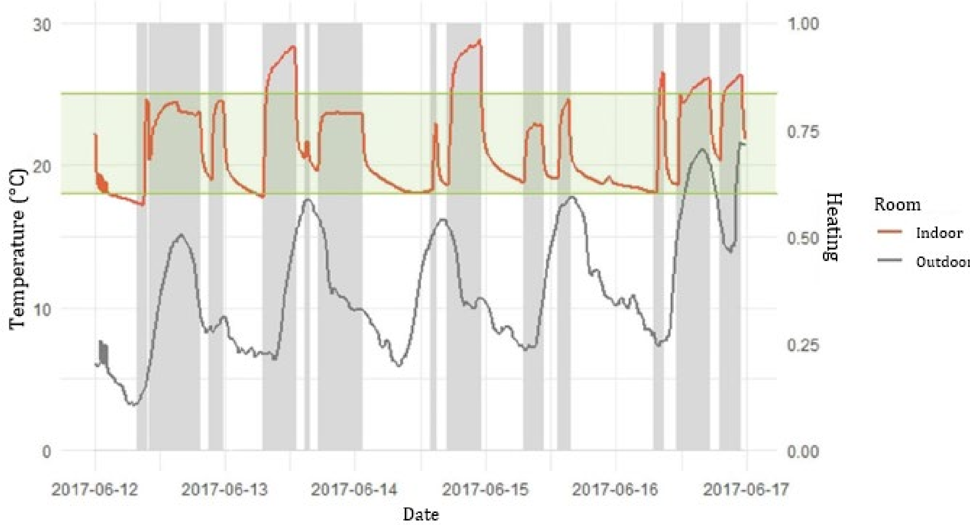

Figure 10. Outdoor and indoor temperature in winter and use of heating. Source: Preparation by the authors in R.

Figure 11. Outdoor and indoor temperatures in winter, without occupation. Source: Preparation by the authors in R.

in the auxiliary energy contribution for heating if improvements are incorporated into the building's envelope.

Figure 11 presents the results of the winter period analyzed, without auxiliary energy, which was previously used to validate the model being simulated. In this graph, it is seen that the indoor temperature of the studied room is well below the comfort zone, losing out on the outdoor thermal amplitude and the solar resources.

Figure 12 illustrates the results of the first winter simulation period. Improvements in the envelope quality are proposed, adding 5 cm of outdoor thermal insulation to the walls (5 cm thick expanded polystyrene), from which a thermal transmittance value of K=0.63W/m^{2}k is obtained, and modifying the existing folded sheet and single glazed carpentry for aluminum ones with 4 mm DHV double glazing (K=4W/m^{2}k). Likewise, the possibility of closing the connection through the staircase from the ground floor to the first floor is suggested, to avoid a temperature exchange between these floors due to stratification. The opening surface of the south façade of the room analyzed is reduced by 38%, so that it ends up measuring 3.36 m^2.

As can be seen, despite the proposed improvements, the simulated indoor temperature (dashed blue line) only rose above the monitored one (continuous red line) by 1°C at night, and 2°C during the day, falling below the comfort range during the entire simulation period.

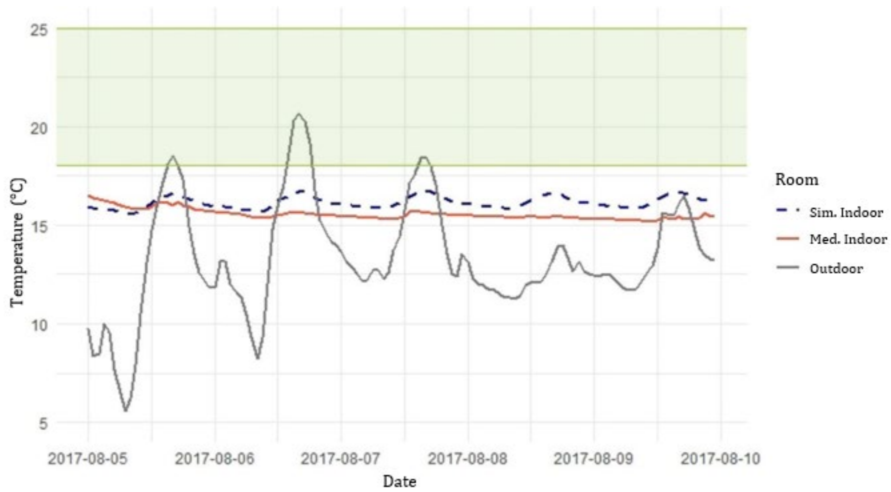

Figure 12. Outdoor and indoor temperatures in winter, simulated, without occupation, with improvements on the envelope.Source: Preparation by the authors in R.

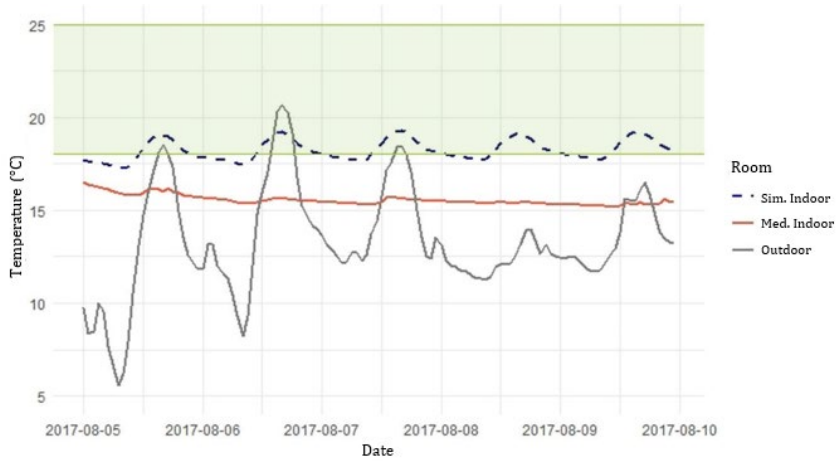

Figure 13. Outdoor and indoor temperatures in winter, simulated, without occupation, with improvements in the envelope and design. Source: Preparation by the authors in R.

Likewise, in the simulated period, the indoor temperatures were close to the comfort range only during a short period, between 2 pm and 6 pm, not managing to exceed 18°C, which shows a limited daytime solar gain.

The results of the same simulation period are shown in Figure 13. In this case, it is proposed to evaluate the result that could be obtained on facing the living-dining room façade towards the north (towards the Equator in the southern hemisphere), allowing for a greater direct solar gain. The original size of the dwelling's openings is maintained in this analysis, as well as the improvements proposed in the simulation mentioned above.

Here, it is possible to note that the simulated indoor temperature increased 2°C above the monitored level during the nighttime hours, and by up to 4.5°C during the day. Thus, on making better use of the direct solar gain, temperatures within the comfort range are attained throughout the analysis period.

The increase of the indoor temperatures during the time band between 12 pm and 6 pm shows a better use of the direct solar gains, compared to the previous simulation. The difference between nighttime indoor and outdoor temperatures is 11°C on average, which shows the effect of a better quality envelope, that prevents thermal losses. The importance of the design based on bioclimatic strategies for better thermal performance is also seen.

CONCLUSION

The detailed study of user behavior patterns in dwellings in the city of Mendoza is addressed in this

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research project. Its results indicate that user behaviors regarding the use and management, as well as the thermal characteristics of the envelope, are parameters that significantly affect the thermal performance of dwellings in cities with a template climate and with a broad daily and seasonal thermal amplitude.

The studied case is considered as representative of the typology and material of dwellings that are either built or being built in Mendoza. This work shows the importance of considering the implementation of improvements in the materials of the dwelling envelope in the city of Mendoza, such as: thermal insulation in walls and roofs; the incorporation of airtight double glazing in openings; solar protections on the northern openings for shading; nighttime protections on south-facing openings; among others.

The comparison of the analysis results in the summer period (Figure 14) shows that good management of the envelope through nighttime ventilation allows the user to adapt the indoor environment to reach suitable comfort conditions without auxiliary energy consumption. It is possible to keep temperatures below 27°C, favoring reaching indoor comfort in 89% of the data recorded, and bearing in mind all the hours audited, independent of the periods, with or without occupation.

The thermal perception of the user is directly related to the actions of opening and closing windows. This is seen on days where the user opens windows before the outdoor temperature has dropped enough in comparison with the indoor temperature, increasing the latter. Likewise, cases are detected where the user closes the windows when outdoor temperatures still favor the ventilation of the thermal mass.

On the other hand, less favorable actions, like the constant opening of windows, lead to a reduction of comfort, experiencing temperatures above 33°C. If there is less committed window management, where these are left open day and night, only 22% of the data recorded has temperatures within the comfort range, which is why auxiliary air conditioning systems are required. Although the user tries to decrease the heat using electrical devices, like fans, the lack of comfort in indoor spaces persists.

The suitable use of the nighttime natural ventilation strategy in the dwelling entails a constant commitment of the user to seek their comfort state. The opening and closing of openings in more favorable times, added to taking advantage of the thermal inertia of the building materials, allows keeping pleasant temperatures in the indoor setting.

Regarding the winter situation, the lack of comfort in the studied room is noticeable. This could be improved by incorporating passive design alternatives like improvements

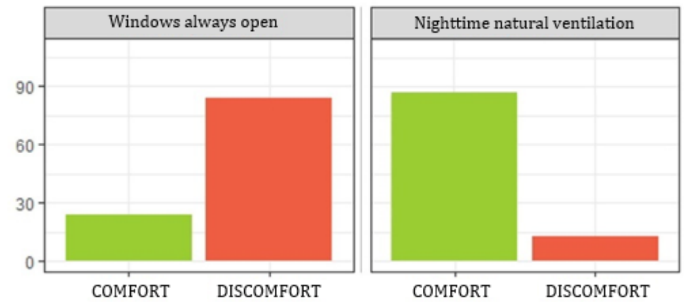

Figure 14. Comfort percentages in summer. Source: Preparation by the authors in R.

in the envelope quality, and a greater direct solar gain surface. On simulating these improvements, indoor temperatures of up to 19.5°C are reached during the day, and differences of 1.5°C between day and night, without using auxiliary heating systems. These measures allow an almost constant comfortable temperature, so a minimal auxiliary heating contribution is required. On comparing the results of the audit data of the reference dwelling with the simulations made, it is concluded (Figure 15) that a good quality building envelope, accompanied by a suitable design of favorable orientations to take advantage of direct solar gain, contribute to achieving indoor comfort in 60% of the data recorded. On the other hand, it is clear in the data collected through onsite measurement, that the reference dwelling has a lower thermal performance in winter, where auxiliary heating does not suffice, given that the low quality of the envelope implies great temperature losses, which at the same time has repercussions on energy consumption.

Bearing this evidence in mind, it is imminent that the local building regulations demand the incorporation of technical aspects that determine the quality of the envelope. Considering these from the start of the design stage and the construction of dwellings is key to avoiding the high costs associated with building retrofitting.

The methodology applied in the analysis presented here, based on the application of time use surveys (qualitative) and onsite data measurement (quantitative), allows quantifying the actions of occupants and obtaining a better understanding of the cause and effect of the phenomenon studied. The use of the aforementioned method, along with statistical analysis methods, would allow integrating data in the user behavior variable in building simulation models, capable of optimizing accuracy in the prediction of the thermal and energy performance in future studies.

In this context, an important potential is identified in single-family dwellings in the city of Mendoza, that allows the user to achieve comfort in summer and winter by correctly managing passive building thermal conditioning

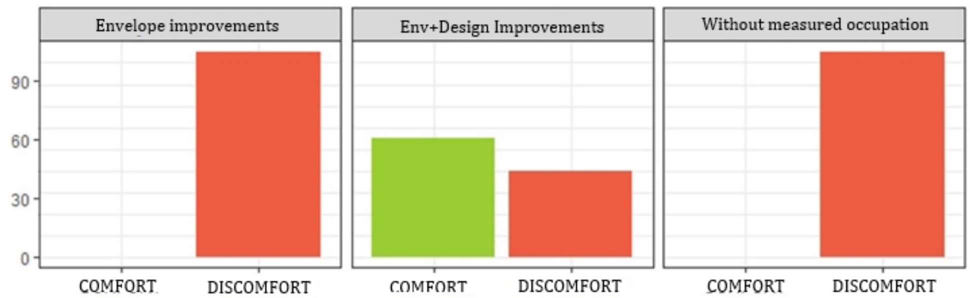

Figure 15. Comfort percentages in winter. Source: Preparation by the authors in R.

strategies. The active role of the user, and their potential regarding achieving indoor thermal comfort and energy consumption savings, is also worth mentioning. Said role is directly linked to the need of understanding the operation of their home and the actions available to them, that are capable of changing its indoor-outdoor relationship, as suits them. This will have a positive result in the reduction of the energy requirements associated with the occupation and management.

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SUSTAINABLE HOSPITALS: CRITICAL ITEMS FOR THEIR CONSTRUCTION AND THE ROLE OF TECHNICAL INSPECTION

HOSPITALES SUSTENTABLES: PARTIDAS CRÍTICAS PARA SU CONSTRUCCIÓN Y EL ROL DE LA INSPECCIÓN TÉCNICA

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RESUMEN

Actualmente, la infraestructura de salud pública en Chile, en sus distintas escalas, presenta avances significativos en la determinación de criterios de diseño en sustentabilidad. Sin embargo, es posible observar que durante su construcción no existen procesos de verificación estandarizados sobre aspectos de sustentabilidad y que la labor de la inspección técnica se centra en el cumplimiento administrativo de los contratos de construcción, más que en la verificación de los aspectos técnicos. La presente investigación propone una lista de partidas y actividades críticas a fiscalizar en la construcción de hospitales para asegurar criterios sustentables en su operación. Luego, se realiza una encuesta a profesionales que participan en el diseño, construcción y fiscalización de obras hospitalarias. Los resultados se jerarquizan con una metodología multicriterio (AHP), a partir de la cual se evidencia una preferencia en la envolvente térmica (20%) e instalaciones térmicas y de ventilación (17%). Finalmente, en base a las debilidades señaladas por los profesionales, se propone un proceso de control y seguimiento a estas partidas y actividades con un rediseño de la labor del Inspector Técnico de Obras.

Palabras clave
infraestructura sanitaria, inspección, sustentabilidad, metodología multicriterio (AHP)

ABSTRACT

Currently, the public health infrastructure in Chile, at its different scales, has made important advances in determining sustainability design criteria. However, it is possible to see that, during its construction, there are no standardized verification processes on sustainability aspects, and that the work of technical inspection focuses on the administrative compliance of construction contracts, rather than on checking technical aspects. This research proposes a list of critical items and activities to supervise hospital construction, to guarantee sustainable criteria in their operation. A survey was also made to professionals involved in the design, construction, and supervision of hospital construction, ranking the results with a multi-criteria methodology (AHP), which showed a preference in the thermal envelope (20%) and thermal and ventilation installations (17%). Finally, based on the weaknesses stated by the professionals, a control and monitoring process of these items and activities is proposed, redesigning the work of the Worksite' Technical Inspector.

Keywords
Health infrastructure, inspection, sustainability, AHP methodology

Hospitales sustentables: partidas críticas para su construcción y el rol de la inspección técnica
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INTRODUCTION

Criteria related to the satisfaction or welfare of professional work teams, patients, and administrators, along with the efficiency of the building's resources, must be considered during all stages of a construction project, especially in hospital buildings (Rodríguez, Svensson & Wood, 2020; Soliman-Junior *et al.*, 2021). In this sense, sustainable standards have been developed in health buildings, through different certifications like LEED, WELL or LBC (Allen *et al.*, 2015), which have the so-called "commissioning" credit, understood as the set of processes which would allow them to carry out project inspection in all its stages (Lord, Noye, Ure, Tennant & Fisk, 2016). In addition, in their application, some authors have shown that a certified building has an additional productivity of 16% (Vasquez *et al.*, 2013), thanks to improvements in lighting, temperature control, improvements in indoor air quality (Xuan, 2015), and a 15% reduction of absenteeism (Vasquez *et al.*, 2013).

Despite this, during the operation of the building, it cannot be confirmed that hospitals certified with the highest score, manage to be more efficient than those that score lower (Golbazi & Aktas, 2016). Together with this, public health infrastructure buildings do not always comply with the sustainability criteria described in the design phase, and few studies further analyze the reasons for this (Balali & Valipour, 2021).

Likewise, during the construction phase of public health infrastructure, there are no standardized verification processes of the project's guidelines in sustainability aspects, which could affect the sustainable life cycle of these buildings. The errors in the execution of critical sections of health infrastructure have different consequences during the operation of a building (Castro, Mateus & Bragança, 2015), from excessive corrective maintenance and an increase of public expense due to the extra energy for energy systems (D'Amanzo, Mercado & Ganem Karlen, 2020), to environmental discomfort for the people who use the building, whether due to overheating, overcooling or poor air quality In constructive terms, said errors can lead to an increase of after-sales costs due to humidity or incorrect waterproofing issues, the incorrect implementation of insulation, or errors in restroom facilities (Carretero-Ayuso & García, 2018).

In this way, the work of the Technical Inspection or the State Inspection of public works in Chile is key to check that what is stipulated in the project is complied with, once implemented. Specifically, the Technical Inspection has two main goals: 1) inspecting the administrative conditions, referring to financial aspects, deadlines, and legal regulations; and 2) inspecting the technical conditions, regarding the execution of the project to safeguard contractual compliance between design and implementation, and thus guarantee the stability, durability, and habitability of the project (Ministry of Housing and Urbanism [MINVU, in Spanish], 2007). However, their work is focused on the administrative compliance of the construction contracts, more than on checking the technical aspects of the projects. The main issues, in this context, are associated with the incompatibility of the blueprints of different areas, differences in criteria between the office and on-site personnel, and the limited feedback about the work methods (Santelices, Herrera & Muñoz, 2019).

A study made by the Chilean General Comptroller of the Republic (Moscoso, 2017) indicates that the most relevant observation in public works contracts for the health area is the non-compliance of technical aspects, while other academic studies confirm that the shortcomings in the design processes are the main factor that influences the problems unleashed on the worksites (Montiel-Santiago, Hermoso-Orzáez & Terrados-Cepeda, 2020). This reflects the need of having construction protocols and standards that are incorporated from the start of the design, and that is accompanied by an effective works technical inspection, focused on the correct operation of the characteristics of the systems and facilities in hospital buildings.

This study identifies the critical sections -set of activities or works of the construction stages of a project (National Standardization Institute [INN, in Spanish], 1999a) – which must be inspected during the execution of a health construction project, and that affect its sustainable life cycle, including, the quality of the indoor environment and the efficiency of water and energy consumption during the operation. In this framework, an analysis of the critical activities of a section was made, to identify sustainable design criteria that should be guaranteed for the operation phase. On the other hand, the information was validated through a survey made to professionals who take part in the design, construction, and supervision of hospital constructions. The results were analyzed with the AHP Prioritization Method to rank the critical sections and activities, and to detect the possible weaknesses that these professionals see in their work. Finally, based on the open questions of the survey, a simplified follow-up process of critical sections and activities was proposed, that could be used throughout the cycle of a public health infrastructure project, with emphasis on the execution stage.

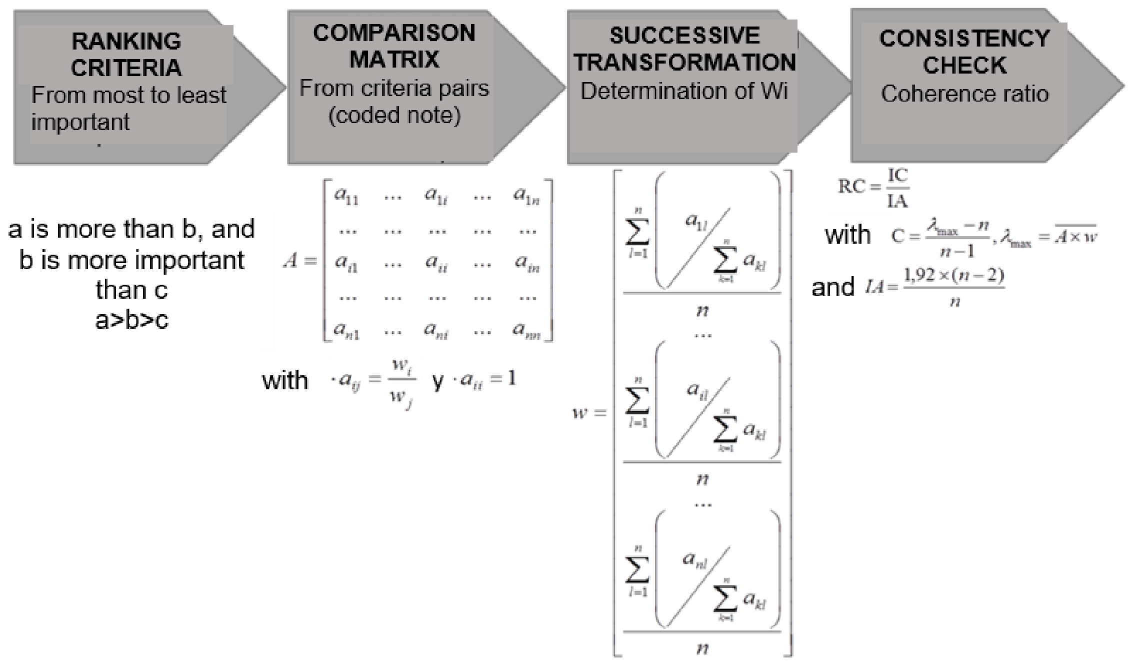

Figure 1. AHP method stages. Source: Preparation by the authors using Saaty (1977; 2008).

METHODOLOGY

This research lays out a simplified hospital inspection process, with emphasis on execution. To present it, the article has been divided into three stages.

In the first phase, a description and analysis of the context of hospital establishments in Chile are presented, for the sake of understanding how their management works and to go further into the technical inspection of the works.

In the second stage, the critical sections and activities that must be supervised in the hospital's construction process are determined. This is a task fed by the requirements that make up the Hospitals Sustainable Building Certification [CES, in Spanish] (Construction Institute [IC, in Spanish], 2017). After this, the critical sections and activities are ranked using a survey applied to professionals who take part in the design, construction, and supervision of hospital works.

The group of professionals was chosen considering experience of at least 5 years in design, monitoring, and direct inspection of health projects. The professionals consulted were 9 architects and 7 engineers, as well as 10 technical inspectors.

The survey was made in three parts. First, the question, "which sections/activities are most important to inspect during the construction of a hospital to ensure that the occupation/operation of the building complies with sustainable standards?" had to be answered. To answer, they were asked to choose, from pairs, the most important critical sections to be evaluated in the execution of hospital projects, and after that, to choose among each critical activity of each section. Second, opinions were sought regarding inspection processes, such as "what difficulties arise on-site to supervise the aforementioned sections or activities? and "what measures could be implemented on-site to guarantee the correct execution of the sections and activities? Finally, they were asked to give their opinion on the need of supporting the technical inspection task with the inclusion of another professional, and they were asked to describe and/or comment on the task the technical inspector performs. The second and third parts of the survey allowed proposing a new monitoring and control process during the construction phase, aiming at guaranteeing the achievement of the sustainable standards defined during the design phase.

The results of the paired comparison of the sections and activities alternatives were prioritized through a multi-criteria prioritization method, where a weight (w_i) is calculated for each alternative presented, making a two-by-two comparison of all the criteria. The method chosen was the Analytic Hierarchy Process (AHP) by Saaty (2008), due to its great popularity to determine priorities in very varied issues like politics, social aspects, personal wishes, education, industry, or engineering (Valderrama-Ulloa & Puiggali, 2014; Darko *et al.*, 2019; Emrouznejad & Marra 2017). The different AHP priority stages are shown in Figure 1.

Here, each alternative is compared with a pair, through 5 levels. For example, it can be seen whether the envelope section is "much more important", "important", "equally important", "less important", or "much less important"

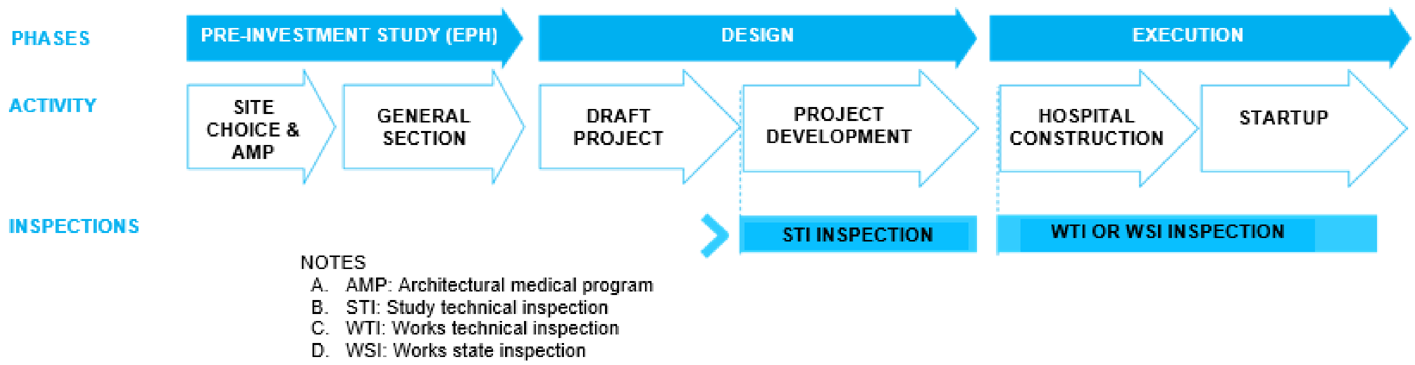

Figure 2. Workflow of a hospital construction process Source: Preparation by the authors.

than the fittings section. The results of the vote lead to the A matrix of paired comparisons of *n* alternatives. Then, successive transformations are made to determine w_i, which will be the prioritization percentage. After this, the consistency level (RC) is determined to confirm whether the result is "rational" or not, with values of between 0.20 and 0.10.

In the third and final stage, based on the comments received in the survey, a simplified hospital inspection process is proposed, with emphasis on the minimum sustainability criteria to be inspected in the sections and activities that are related to these criteria during the construction of the hospital facilities.

BACKGROUND

HOSPITAL ESTABLISHMENTS

The Chilean Ministry of Health (MINSAL, in Spanish) has, among its roles, the setting of the investment regulations and policies in infrastructure and equipment of the public establishments that are part of the healthcare network (MINSAL, 2017). For this purpose, the Undersecretary of Healthcare Networks is in charge of regulating and supervising the operation of the healthcare networks through the design of policies, standards, plans, and programs for their coordination and articulation. In this framework, each project must comply with all the regulatory requirements from MINSAL, regarding healthcare regulations, user satisfaction, and attention quality, as well as the criteria and guidelines the designs will be developed under. In general, the development of hospital projects is divided into the phases of pre-investment or pre-design, design (Figure 2), and execution. Currently, the inspection tasks begin in the design phase, together with the project development by technical studies inspection teams, and once in the execution phase, the works technical inspection takes place.

Hospitals in Chile are closed attention facilities, that provide health care under a continuous attention system, and that must have organized resources of infrastructure, equipment, and personnel necessary for their permanent operation. Currently, these have an outpatient attention area (clinics, outpatient minor surgery rooms, therapeutic and emergency diagnostic support units), that is annexed and complementary to the closed attention where the hospital admissions are mainly found.

In Chile, hospitals are truly relevant to cover the healthcare needs of the population. However, in terms of health infrastructure, the country has shortcomings, which is seen in the lack of hospital beds per number of inhabitants. The average number of hospital beds of member countries of the Organization of Economic Development and Cooperation, OECD, was 5.045 beds per one thousand inhabitants in 2013. In the case of Chile, this is only 2.18 beds per thousand inhabitants (Goyenechea, 2016). This has generated, in the last decade, the preparation of investment plans in hospital infrastructure that manage to strengthen the existing healthcare network. Despite the efforts made, a diagnostic made in 2018 indicates that 80% of hospitals still do not comply with the current infrastructure quality standard, due to the age of their buildings, and that 63% of the premises have buildings from before the 1980s (Sandoval & Leiva, 2018).

In issues related to sustainability, since the mid-2000s, the Chilean Ministry of Health has incorporated sustainability criteria in the designs of health establishments. The first efforts focused on energy efficiency, establishing envelope specifications (walls and windows) with better thermal behavior, which allowed reducing energy demands for the thermal conditioning of premises, as well as the

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incorporation of more efficient active systems (air-conditioning and lighting systems).

In 2017, the Hospitals CES Certification, a voluntary national energy efficiency and environmental quality certification for hospital buildings, came into force. Its purpose is to evaluate, qualify, and certify the capacity of a building to achieve suitable indoor environmental quality, with the efficient use of resources, and low generation of waste and emissions (IC, 2017). The CES certification system is based on the compliance of obligatory requirements, the obtaining of a score, the compliance of each voluntary requirement that it comprises, and verification of the works in the final stage of the evaluation process, which consists of collecting some background information, and at least, making one inspection visit made by an Evaluation Entity. Currently, its use is encouraged as a work method to choose the sustainable criteria that hospital buildings must comply with (MINSAL, 2017).

INSPECTION OF HOSPITAL WORKS

In Chile, there is no detailed procedure to inspect hospital works. Although there is a Works Technical Inspection Manual (Ministry of Housing and Urbanism, 2007), its scope is based on the inspection of social housing, which, as time has gone by, has been extended to paving and green area projects (Moscoso, 2017).

A study on comments and recommendations in the execution of public work contracts, made by the General Comptroller of the Republic between 2012 and 2015, concluded that a large part of these observations is directly related to the role the works technical inspection fulfills, highlighting the non-compliance of the technical standards, which represented 27% of the cases (Moscoso, 2017). It also revealed that 51% of the negative comments were linked to health establishments and that this type of project did not consider a technical inspector in the early design stages, which is why two main problems appeared: 1) Deficient use of time, given that the technical inspector was hired or assigned only at the start of the works, having to invest time in studying the project and all the administrative documents that were part of it; and 2) Not making use of the contribution and experience of the works technical inspector in the early stages of the project, where all modifications have less of an impact on its costs.

Another study on Works Technical Inspection (WTI) indicates that there is an important number of events and situations that lead to conflicts and doubts, not always attributable to a wrong decision by the principal or to the deficient management of the Contractor (Technological Development Corporation [CDT, in Spanish], 2011). These conflicts tend to come from some of the following causes: Projects that do not have a suitable level of detail, which impedes defining, accurately and with objectivity, the demands and standards that must be checked by the WTI; projects that do not have efficient coordination within themselves, or even with the specialties; the roles and responsibilities that the different professionals of the construction processes must take on in their participation in the different stages of the projects, are not seen; both the analyses and the evaluations are based on uncoordinated and almost unreliable background information; and, the lack of definitions, the omissions, and errors that the administrative terms and conditions of the contracts have, lead to an important number of conflicts in the relationship between the parties.

Based on what has been described, a list of relevant critical sections to comply with and check in the construction process (execution phase, construction stage of Figure 2) of hospitals is proposed, to ensure sustainability in their operation.

RESULTS AND DISCUSSION

The main results of the study, including the list and definition of the critical sections and activities that are relevant for the construction of sustainable hospitals, the ranking made by the surveyed professionals, together with recommendations to strengthen technical inspection, and a streamlined control and monitoring process with emphasis on the execution stage, which allows guaranteeing sustainable criteria and variables during the operation, are presented below.

RELEVANT CRITICAL SECTIONS AND ACTIVITIES FOR THE SUSTAINABLE CONSTRUCTION OF PUBLIC HOSPITALS

For the choice of the selected sections, first, each one of the CES variables that had a relationship with the structural or finishings work of a construction project was analyzed (INN, 199b) and, then, the sections where the associated CES variable had the highest scores in the certification were chosen. Finally, each chosen section was subdivided into activities, so that the Works Technical Inspector, during the construction stage, can inspect each section in more detail. Thus, Table 1 shows the CES variable relationship with the associated work section, the list of the selected sections, and the activities that were analyzed in this research.

CES Variable	Associated Works Sections	Chosen sections	Activities involved
Visual comfort - passive	Thermal envelope	Envelope	- verification of the type of material and thickness of the insulation of the: ceiling-roof group, of the envelope wall, of the ventilated floors -verification of the type of glazing and frames in windows - verification of the type of material and continuity of insulation to avoid thermal bridges - verification of the type of material and execution of solar protections - verification of the types of materials of the vapor and humidity barrier
Energy demand	Thermal envelope		
Watertightness of the envelope	Thermal envelope		
Acoustic comfort	Acoustic insulation	Acoustic insulation	- verification of the type of material and thickness of the vertical and horizontal dividing elements - verification of the water-tightness of joints of: vertical and horizontal dividing elements - controlling noise and vibration of: equipment, air injection/extraction ducts of elevators and freight elevators - verification of the acoustic insulation in the sewer network
Equipment noise	Acoustic insulation		
Air quality – passive	Indoor finishings	Finishings	- verification that the vertical indoor covers, ceilings, pavements and paintwork, and varnishing are those specified
Visual comfort – active	Lighting and electrical installations (visual comfort)	Lighting and electrical installations	- verification that the lights are those specified - verification that the lighting sensors and switches are those specified
Energy consumption	Lighting and electrical installations		
Thermal comfort – active	Thermal and ventilation installations (thermal and ventilation comfort)	Thermal and ventilation installations	- verification of the type, characteristics, and operation of the air-conditioning and domestic hot water (DHW) system -verification of the insulation of the air-conditioning and DHW distribution network - verification of the correct installation and operation of the air-conditioning thermostats, of the ventilation airflow, of the type of ventilation and/or forced extraction filters - verification of the location and number of CO2 sensors
Air quality – active	Thermal and ventilation installations		
Energy consumption	Thermal and ventilation installations		
Energy consumption	Non-Conventional Renewable Energy Systems	Non-Conventional Renewable Energy Systems	- verification of the correct installation and operation of photovoltaic panels or thermal solar collectors
NCRE	Non-Conventional Renewable Energy Systems		
Drinking water systems	Sanitary installations	Sanitary installations	-verification of the correct installation of basin and scrub station faucets according to TS - verification of the time in the basin tap timers - verification of the correct installation of WCs - verification of the correct installation of bath and shower taps, as per TS - verification of the type and characteristics of the hard-water treatment system

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Waste management	Waste management	Management of operation waste	- verification of a suitable space to guarantee waste management
Watering	Landscaping	Landscaping	- verification of its existence, and that it has a low water consumption
Landscaping	Landscaping		
Incorporated energy	Structural Works	Structural Works	- verification that the structural materials have an environmental label
Incorporated water	Structural Works	Structural Works	- verification that the structural materials have an environmental label
Comprehensive draft design	-	-	-

Table 1. Detail of sustainable variables and their relationship with the work's sections associated with the chosen sections and activities
Source: Preparation by the authors.

Ranking	E>ITV>T=EnR>IIE>IS>P>AA>R								
Sections	E	AA	T	IS	IIE	ITV	EnR	P	R
wi (%)	20	6	13	10	11	17	13	7	5
λmáx	11.47	IC	0.31	IA	1.54	RC	0.20		

Table 2. Ranking of each section to be supervised in the construction stage, to guarantee that the occupation/operation of the building complies with sustainable standards Source: Preparation by the authors.

RANKING OF CRITICAL SECTIONS AND ACTIVITIES

Regarding the question, "which of the sections is the most important to inspect during the construction of a hospital, to guarantee that the occupation/operation of the building complies with sustainable standards?", a preference of 20% is seen (Table 2) for the Envelope (E), followed by the Thermal and Ventilation Installation (TVI) with 17%, and Finishings (F) and Non-Conventional Renewable Energy Systems (NCRE), with 13%. It is from this that the consistency was 0.20. Finally, the three least voted sections with Landscaping (L), Acoustic Insulation (AI), and Waste Management (W), with 7%, 6%, and 5%, respectively. Sanitary Installations (SI) and Lighting and Electric Installations (LEI) had a very similar valuation, of 10% and 11%, respectively.

Although the AHP method was applied to all sections, here the two most voted sections are graphed. The responses referring to the prioritization of the activities to be supervised on the envelope (the section with the highest priority, 20%) are broken down into two groups -that indicated by the architects, and that indicated by engineers and WTIs (Figure 3)-, as there is a great difference in the priorities indicated by each group, which did not happen in the voting of the other sections or activities. In this way, the 3 most voted activities by the group of engineers and WTIs were the correct installation of: insulation of the envelope wall (26%), vapor and humidity barrier (16%), and ventilated floors with ceiling-roof set insulation (15%). For the group

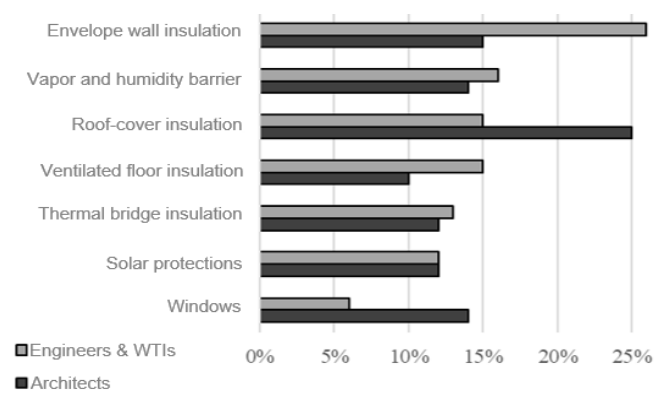

Figure 3. Prioritization by the groups of professionals for the envelope section activities. Source: Preparation by the authors.

of architects, the priorities were: ceiling-roof set insulation (25%), insulation of the envelope wall (15%), and window glazing and frames (14%).

In the case of the activities of the Thermal and Ventilation Installations section (the second most voted, 17%), the 3 most important activities for the professionals were: operation of the air-conditioning and domestic hot water (DHW) (26%), insulation of the air-conditioning and DHW network (22%), and the correct installation of air-conditioning thermostats (18%). The least important to inspect was: ventilation and/or forced extraction filters, with 8% of the responses (Figure 4).

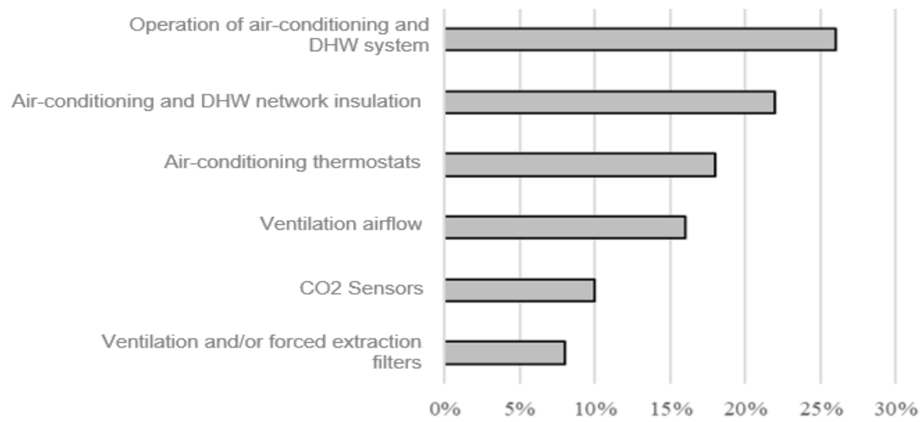

Figure 4. Prioritization by the group of professionals for the Thermal and Ventilation Installations section.
Source: Preparation by the authors.

Opinions were also asked about the technical inspection processes of hospital works. Regarding the difficulties that happen onsite, to inspect the previously prioritized activities or sections, the group of experts indicated that the main two difficulties found onsite are the lack of procedures (33%), and there not being regulatory bodies that provide indications (33%). In third place, a lack of technical knowledge (19%) is acknowledged. Other difficulties mentioned are related to the quality of the projects from the design, and the lack of self-control of the construction companies, sections with contradictory technical specifications, and a lack of coordination meetings; all with 4% of the preferences.

As for the main measures that could be implemented on-site to guarantee the correct execution of sections, creating onsite reception procedures was mentioned (46%), as was creating a regulatory body to provide indications (42%). Other responses indicate the need for having projects inspected by WTIs, standardizing the background information of projects, and having specialized technical support (all with 4%).

When asked about including a new specialized professional that would support the supervision, 100% of those surveyed answered in the affirmative. And some additional comments of the group of experts consulted with, pointed out three main issues that can be improved in the supervision of the sustainable aspects of hospital works, which are detailed below:

The role of the professionals:

- A new specialized professional must not only appear at the start of the work but must accompany even in the design process, coordinating the specialties and informing the principal.
- The collaborative running of the specialties by competent professionals is essential to achieve a high level of energy efficiency and sustainability for the building.
- It is necessary to guarantee, in the design, the incorporation of energy efficiency and sustainability aspects in the specialties.

Verification processes:

- Incorporating better technological tools to control the project and the specialties.
- Making verification processes of the compliance of what is specified a requirement, or previously checking the specified standards.
- Standardizing the checklists, which may be obligatory in the contract, so that the guidelines are not left to the will of the principal or the contractor.
- More frequent visits of the site visitor must take place.
- Checking the performance of the systems in the building startup.
- The installation of the energy systems must have its execution procedures, theoretical explanations, and acceptance checklist with acceptable tolerances.
- Once the works are executed, their compliance must be certified and evaluated through measurements that are part of the site reception process.

Regulatory context:

- there is a lack of a regulatory process that provides indications for the supervision procedures for these critical sustainability sections.
- There is a lack of domestic regulations, especially in the air-conditioning area.
- The international standards are not used, partly because of a language gap.

Based on the ranking of sections and activities presented here, the comments raised about the difficulties that arise on-site that are to be inspected, the measures that could be implemented on-site to guarantee a correct execution, and three topics highlighted in the open questions of the professionals (role of the professionals, verification processes, and regulatory context), a new monitoring and control process of the sections and activities is proposed in the following section, that would allow guaranteeing sustainable standards in the project execution phase (Figure 2), once defined during the design phase.

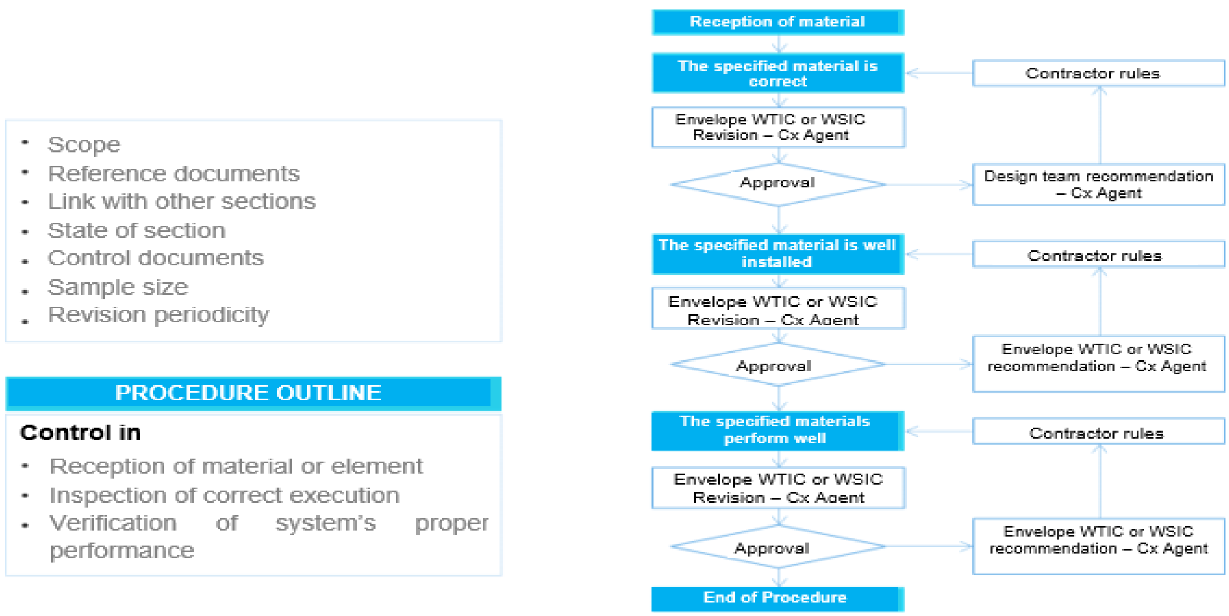

Figure 5. Flow diagram to monitor the execution. Source: Preparation by the authors.

TECHNICAL INSPECTION PROPOSAL

This proposal for a technical inspection control and monitoring process was developed considering any hospital works contract modality. It is recommended that, in these contracts, the technical or state inspection starts from the design and, in this way, facilitate the supervision, in the means that this is done from an early phase by the same specialized team.

This proposal for a monitoring and control process acknowledges the current tasks that the Works Technical Inspection (WTI) and the Works State Inspection (WSI) perform. However, thanks to the feedback from the open questions in the survey applied, it is possible to give new responsibilities and greater participation to these entities in more stages of the project. Likewise, it is foreseen that the teams of Consultants (WTIC or WSIC) would be comprised of specialists with specific knowledge and the capacity to perform support tasks for the monitoring and control process of a construction project since currently these only have the CES certification.

To carry out the aforementioned process, the figure of a coordinator, called Inspection Agent (Cx Agent), is required, who would be present throughout the project, from the pre-design phase to the operation phase, and who would be in charge of checking and documenting that the systems and installations have been planned, designed, installed, tested, operated, and maintained complying with the project requirements, and taking as a priority, the sections and activities revealed in the prioritization survey.

Figure 5 illustrates the flow of this new project control and monitoring process, with an emphasis on the execution phase (Figure 2) and in the checking of the performance and operation of the construction systems and installations. The flow is schematic, given that its specificity will be worked on in each of the sections and activities chosen in the multicriteria analysis. It also comprises a document chart that must be created for each project -or ideally, one that MINSAL uses in all its projects- and a procedure layout that highlights the controls in the execution of the section or activity. It ends with the diagram where the professionals that must be involved in the process are outlined.

CONCLUSIONS

Currently, MINSAL has an extensive plan of investments in health infrastructure, setting a great challenge for this sector, focused on building under sustainability parameters, and on suitably maintaining these new infrastructures during their operation.

Depending on the type of contract for the implementation of a hospital works, the flow of information between the different phases could be blocked, because there are different teams independently making the design, the construction, and the supervisions in each one of these phases, and without suitable monitoring. Because of the complexity that health establishments entail, ongoing verification processes are needed in all stages, which would guarantee the operation of the projected systems and installations.

On the other hand, the information collection process with the experts and, then, their weighting using the AHP method on the choice of critical sections and activities to be inspected in hospital works, allowed checking the relevance of each one. It was seen that the most relevant sections are the Thermal Envelope (20%) and the Thermal and Ventilated Installations (17%).

The results of the surveys show the need of having technical standards the provide system and installation supervision standards and procedures. The development of coordinated, better-quality projects is necessary from the design phase. The contribution of a specialist professional who aids in the supervision, and who is included from the early phases of the design, is acknowledged. In addition, many of the regulations to be applied on the systems and facilities are translations of foreign standards (due to the lack of domestic ones), and their supervision faces a language barrier. In this sense, it is not enough to translate the standards, but moreover, having an institution dedicated to their preparation, applied to the domestic context.

A control and monitoring process would also allow seeing the repercussions that the decisions made on-site, from the design, have, whether due to what is being demanded or to what the market offers. The early inclusion of an official control and monitoring process will lead to having a group of lessons learned in hospital works that could be used. The difficulty in its implementation would be focused both on the need for professional training and qualification for Cx Agents and in the regulations with specific protocols and procedures for each section, in a similar way to what the commissioning credit does in the international environmental certifications, including the energy systems and installations. Based on the systems there are in Chile, this process will likewise allow organizing, supervising, guaranteeing, and complying with the requirements of the current Hospitals CES certification.

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DESIGN OF GREEN OFFICE BUILDINGS TO PROMOTE GREEN OCCUPANTS

DISEÑO DE EDIFICIOS DE OFICINAS SUSTENTABLES PARA PROMOVER OCUPANTES SUSTENTABLES

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RESUMEN
Escasos son los trabajos que se enfocan en investigar el potencial de los edificios sustentables de promover sustentabilidad en sus ocupantes. Por ello, el siguiente estudio tiene como objetivo analizar el uso de créditos LEED para fomentar comportamientos pro-ambientales. La metodología utilizada es de carácter exploratoria y de lógica descriptiva, y analiza comparativamente edificios de oficinas certificados LEED [Argentina (n= 351), Chile (n= 494), Colombia (n= 432), Perú (n= 282)] en el período 2012-2020. Los resultados revelaron que los créditos más empleados fueron: "Acceso a Transporte Público" (99,34%), "Densidad del Entorno" (98,34%) y "Pautas de diseño y construcción para inquilinos" (96,53%); y los menos empleados: "Puesta en servicio mejorada" (44,30%), "Luz diurna" (31,31%) y "Controlabilidad de los sistemas" (7,53%). Se concluye, finalmente, que aquellos que optan por incluir al ocupante en el diseño, eligen intervenir en la cultura, mientras que quienes optan por no hacerlo, eligen la tecnología.

Palabras clave
diseño sustentable, edificios de oficinas, sistemas de certificación en la sustentabilidad, comportamiento pro-ambiental.

ABSTRACT
Few studies focus on researching the potential of sustainable buildings to promote the sustainability of their occupants. Therefore, this study aims at analyzing the use of LEED credits, with the intention of promoting pro-environmental behaviors. The methodology is exploratory in nature, with a descriptive logic, and comparatively analyzes LEED-certified office buildings [Argentina (n = 351); Chile (n = 494); Colombia (n = 432); and Peru (n = 282)], between 2012 and 2020. The results revealed that the most used credits were: "Access to Public Transportation", (99.34%); "Surrounding Density"; (98.34%); and, "Tenant construction and design guidelines", (96.53%); and the least used ones were: "Enhanced commissioning", (44.30%); "Daylight" (31.31%); and, "Controllability of systems", (7.53%). It is concluded that those who choose to include the occupant in the design, choose to intervene in the culture, while those who choose not to include them, choose technology.

Keywords
sustainable design, office buildings, green building rating systems, pro-environmental behavior.

INTRODUCTION

In the early 1990s, one of the most accepted proposals to progress towards meeting green development challenges was the creation of evaluation systems, ratings, and certification for the sustainability of buildings in their design, construction, operation, and maintenance stages (Chwieduk, 2003; R. Cole, 1999; 2002; Ding, 2008). These methods emerged to certify the sustainability of buildings through consensual and measurable indicators, that provided processes and practical guidelines to design and evaluate the building's performance, through an easy-to-use checklist (Gou, 2016). These sustainability certification systems promoted buildings with a low environmental impact (Chwieduk, 2003; R. Cole, 1999; Ding, 2008), but reality has shown that this greatly depends on occupant behavior and that it has been often distorted by construction mistakes, incorrect adjustments of equipment, and the excessive simplification of simulation models (van den Brom, Meijer & Visscher, 2016; Fabi, Andersen & Corgnati, 2011). Several studies have analyzed the gap between the expected performance of the building and the actual performance influenced by human factors (D'Oca, Hong & Langevin, 2018; Hong, Yan, D'Oca & Chen, 2017; Stazi & Naspi, 2018), but few studies have addressed the effect of green design on environmental awareness, attitudes, values, and knowledge, as predictors of pro-environmental behaviors of occupants (Mokhar & Wilkinson, 2015; Deuble & de Dear, 2012; 2009; Kirk, 2010; McCunn & Gifford, 2012; Rashid, Spreckelmeyer & Agrisan, 2012).

For this research, a "Green building" is defined as one designed to be accredited by a green certification system, validated by a third party. The most widely internationally known system is LEED, Leadership in Energy and Environmental Design, developed in the United States in 1998. LEED is prepared to rank all types of buildings based on consensual principles on energy and environmental matters, trying to reach a balance between known established practices and emerging concepts. It is mainly organized into 5 assessment categories: "Green sites"; "Water efficiency"; "Energy and Atmosphere"; "Materials and Resources"; and "Indoor environmental quality". Projects, in each one of their categories, must satisfy given "prerequisites" and earn points or credits. The "Prerequisites" establish the minimum requirements that all buildings must comply with to attain the LEED certification, and the credits, which distinguish the building. Apart from LEED, there are other methods with a global impact, such as BREEAM, HQE, Passivhaus, and so on. (Mattinzioli, Sol-Sánchez, Moreno, Alegre & Martínez, 2020). Each country has progressed in the development of its system, to include local criteria, such as the Green Rating for Integrated Habitat Assessment (GRIHA) in India, Green Building Rating System (SAGRS) in Saudi Arabia, and the Sustainable Building Certification (CES) in Chile, among others (Ahmed, Abul Hasan & Mallick, 2016). The importance of these systems for architectural design should be an aspect to be highlighted, as they affect the way designers think about and settle on their projects (Labartino, 2018). Due to the needs and requirements of occupants, most systems aim at a balance between environmental and social sustainability (Moezzi, 2009). Along this line, Heerwagen (2000) mentions that the benefits of green buildings arise when the building and its occupants are treated as an integrated system, and Lee (2010) argues that green buildings have the greatest chance of success if occupants are taught about sustainable motives and the principles of the organization behind the implementation of a sustainable certification system. There have been different comparative studies between green and conventional buildings, which seek to know the potential of the former to promote sustainability among occupants. Khasha et al (2015) concluded that the knowledge of the building's occupants about environmental problems could improve their behavior in pro of the environment. The work of Steinberg, Patchan, Schunn & Landis (2009) mentioned that a group of occupants that would be moved to green building stated having a greater willingness to change their behavior, than those occupants who would remain in a conventional building. Meanwhile, Mokhtar, Wilkinson & Fassman (2015) made clear that the occupants of green buildings adopt more changes in their behavior than the occupants of conventional buildings, due to the intervention strategies implemented by the organization in green buildings. Hill et al. (2019) explored other factors of the occupants, like environmental awareness, perceptions, and the ease or difficulty perceived about behaviors, to conclude that being in a green building affects occupants in terms of showing pro-environmental behaviors. Tezel and Giritli (2019) found that environmental values, beliefs, and awareness were, statistically, predictors of pro-environmental behavior in the workplace and that the occupants of green offices showed a greater awareness about the sustainable features of the buildings. Now, despite stating a greater awareness, the occupants of green offices showed less evidence of pro-environmental behaviors, compared to those who work in unsustainable office buildings, thus showing the need for greater efforts in training about sustainability issues in society.

In contrast, other studies have shown that green buildings, in general, do not promote pro-environmental behaviors among occupants, when compared to conventional or unsustainable buildings.

For example, Hostetler and Noiseux (2010) concluded that new residents do not show pro-environmental knowledge, attitudes, or behaviors to make sustainable communities work, with the sustainability goals projected in the design. According to McCunn and Gifford (2012), neither environmental commitment nor attitudes are correlated with the green attributes of buildings. According to Rashid et al. (2012), there is no evidence of direct effects of the architectural attributes of a building on environmental awareness and the organizational image of occupants. In this sense, there is research that has looked further into some of the reasons. One of these showed that when recycling was available, people increased their use of free products (office paper, toilet paper, etc.), creating adverse effects on sustainability (Catlin & Wang, 2013). This type of behavior could be explained by the fact that a green building can be considered as a type of offset to relieve negative emotions, like the blame associated with wasteful behavior (Bamberg y Möser, 2007).

A building's sustainability can also look like a rectification, which deteriorates the perceptions of risk of occupants and increases their intentions to use more energy (Bolton, Cohen & Bloom, 2006). In other words, occupying a green building could be considered as compensation for occupants, and give them a license for a less environmentally friendly behavior, as they may perceive and have the feeling that the sustainability strategies in the building offset their environmentally unfriendly behavior. Under this premise, certain authors propose the notion of "Robust Design" (Buso, Fabi, Andersen & Corgnati, 2015; Karjalainen, 2016, O'Brien, 2013; Palme, Isalgue, Coch-Roura, Serra & Coch, 2006), based on the fact that "the occupants do not understand the operation principles of buildings, and use systems in a less-than-optimal way or even, in an unsuitable way from the energy point of view" (Karjalainen, 2016, p. 1,257).

The expression "Green Occupant" (GO) appears for the first time in the work of Browne and Frame (1999), where they conclude that "green buildings need green occupants", starting from the basis that technology in itself is not enough to achieve the sustainability goals proposed in building design, and that the occupants should be included in the process. Later, said conception was considered in other research (Deuble, 2007; Deuble & de Dear, 2012; 2009; Wu, 2016; Wu, Green, Chen, Tang & Yang, 2015; Wu, Greaves, Chen & Grady, 2017; Wu, Kim et al., 2017). Deuble (2007) looked further at the notion of GO, ending up defining this occupant as one that understands green strategies in the building and that, at the same time, one that has a high level of environmental awareness; aspects that can be measured with the "New Ecological Paradigm Scale" (NEP-R) (Dunlap, Van Liere, Mertig & Jones, 2000; Dunlap & Van Liere, 1978). However, some authors describe "gray" occupants in green buildings due to the "Rebound Effect" (Catlin & Wang, 2013; Frondel, 2004; Sorrell, 2007). Under this logic, it could be argued that occupants with high levels of environmental awareness in unsustainable buildings, could offset the absence of green strategies in the building and, therefore, behave in pro of the environment. Starting from this framework, here the GO will be conceived as an occupant with pro-environmental behavior (PEB) in the building, and in parallel, to the "pro-environmental behavior", as one "that consciously looks to minimize the negative impact of oneself in the natural and built world (for example, minimizing energy and resource consumption, the use of non-toxic substances, the reduction of waste production)" (Kollmuss & Agyeman, 2002, p. 240).

Other works have focused on the use of the green building as a promoter of sustainability, through the concept "Teaching Green Building" (L. Cole, 2014; 2018; L. Cole & Hamilton, 2019), which they exemplify with the case of the LEED certification system, that offers credit for planners that use the green school building as a teaching tool (L. Cole, 2013). Likewise, the "communication of sustainability" has been studied through the architectural attributes present in the building (Cranz, Lindsay, Morhayim & Lin, 2014; Wu, 2016; Wu et al, 2015; Wu, Greaves et al., 2017; Wu, Kim et al., 2017), to conclude that the use of educational signage in the design of green buildings must continue being promoted – a measure that ended up being, in one of the cases (Wu, Kim et al., 2017), the most effective communicator of sustainability-, and also to encourage more analyses on the innovative use of green building design, as effective communicators to promote education on sustainability among the building's occupants.

According to what has been said, what has been researched, regarding the design of green buildings and their effect on developing sustainability among the occupants, is not enough. Therefore, the general purpose of this work is to explore the relationship of the green building and the occupant, through the analysis, identification, and ranking of the associated criteria, to promote PEB among said occupants, through a sustainability certification system, based on a theoretical model – which corresponds to Specific Goal 1 (SG1). As a result, a comparative analysis is made about LEED-certified office buildings in Argentina, Chile, Colombia, and Peru, between 2012 and 2020, which corresponds to Specific Goal 2 (SG2).

METHODOLOGY

This research is exploratory (Hernández Sampieri, Fernández & del Pilar, 201), as it entails one of the few approaches to the phenomenon of design strategies in a green building, to promote sustainability (more

Diseño de edificios de oficinas sustentables para promover ocupantes sustentables
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specifically, PEB) among the occupants. Design strategies are represented in the LEED requirements (credits). The selection method of the cases is non-probabilistic and the types of samples (systems and countries) are of the "guided by one or several purposes" type (Hernández Sampieri et al., 2010, p. 396). As this study is part of an ongoing doctoral thesis in Chile, the selection criterion of the certification system is the highest number of projects registered in the country. The same logic is applied for the selection of the version of the system as well as the function of certified buildings. Regarding the choice of countries, these are chosen considering a similar number of projects to those registered in Chile, under the argument of "operational collection capacity" (Hernández Sampieri at al., 2010, p. 402). The assessment by experts was used as a validation method for the analysis, identification, and ranking of credits of the certification system to generate PEB among occupants (Garrote & Rojas, 2015). As for the use of credits in certified buildings in the selected countries, a comparative analysis was made, by describing the averages of LEED credits obtained in each case/country and the standard deviation of LEED credits obtained in each one.

As theoretical support, to analyze, identify, and rank LEED credits that had the potential of promoting PEB among occupants, the LEED credits with the variable "Possibilities of acting in a pro-environmental way" were used, from the "Ecological behavior model" (Fietkau & Kessel [1981], cited in Kollmuss & Agyeman, 2002), where the variable is defined as external factors (infrastructure or economic) that allow or make it difficult for people to live pro-environmentally. The other variables of the theoretical model are: "Attitude and values"; "Behavior incentives"; "Feedback perceived on pro-environmental behavior"; and "Knowledge", - a variable that does not have a direct impact on behavior, but that rather acts as a modifier of attitudes and values.

The specialized literature has identified the relationship between socio-psychological factors and PEB through theoretical conceptualization or empirical case studies, like the Planned Behavior Theory (Ajzen, 1991; Harland, Staats & Wilke, 1999), the Norms Activation Model (NAM) (Lindenberg & Steg, 2007), the Value-Belief Norm (VBN) (Stern, 2000), the New Environmental (or Ecological) Paradigm (Dunlap et al., 2000; Dunlap & Van Liere, 1978), and the Place Attachment Theory (Ramkisson, Weiler & Smith, 2012). Bamberg and Möser (2007) state, in this sense, that pro-environmental behavior is probably best seen as a mix of own interests (for example, to follow a strategy that minimizes one's health risks) and interest towards other people, the next generation, other species or complete ecosystems (for example, preventing air contamination that can cause risks for the health of others and/or the global climate). This combination of own interests and pro-social motives is seen in the formulation of the "Ecological Behavior Model", a complementary criterion for the selection of the model.

The methodological layout of the research is graphed in Figure 1.

SAMPLE:

SG1: Green certification systems in Chile.

SG2: Countries with a similar number of certified projects of the green certification system chosen in SG1.

CLASS:

SG1/SG2: Non-probabilistic or directed

ANALYSIS:

SG1:Descriptive
SG2: Descriptive and comparative.

Figure 1: Methodological layout. Source: Preparation by the authors.

RESULTS AND DISCUSSION

RESULTS

The certification system with the highest number of projects registered in Chile is LEED, with 494 registered projects (Chile GBC, 2020). Other certification systems present in the country are EDGE, Excellence in Design for Greater Efficiencies; WELL, from the International WELL Building Institute; and the national system, CES, Sustainable Building Certification. The countries with a similar number of projects to those registered in Chile, in the LEED certification system are Argentina (n=351), Colombia (n=432), and Peru (n=282) (Chile GBC, 2020). This information, as well as that for the rest of Latin America, can be seen in Table 1.

Country	Registered
Brasil	1589
México	1217
Chile	494
Colombia	432
Argentina	351
Perú	282
Costa Rica	228
Guatemala	91
Ecuador	40
Uruguay	36
Paraguay	14
Bolivia	6

Table 1. LEED registered projects in Latin American countries up to December 2020. Source: Preparation by the authors, based on Chile GBC (2020).

	Argentina	Chile	Colombia	Perú
Office Buildings	84 (100,00)	121 (100)	89 (100)	65 (100)
LEED-CS 1.0 Pilot	0 (0,00)	1 (0,83)	0 (0,00)	0 (0,00)
LEED-CS 2.0	3 (3,57)	8 (6,61)	1 (1,12)	0 (0,00)
LEED-CI 2.0	0 (0,00)	0 (0,00)	2 (2,25)	1 (1,54)
LEED-NC 2.2	0 (0,00)	2 (1,65)	3 (3,37)	0 (0,00)
LEED-CS v2009	24 (28,57)	69 (57,02)	50 (56,18)	38 (58,46)
LEED-NC v2009	24 (28,57)	23 (19,01)	12 (13,48)	3 (4,62)
LEED-CI v2009	15 (17,86)	15 (12,40)	11 (12,36)	7 (10,77)
LEED-EB:OM v2009	13 (15,48)	1 (0,83)	2 (2,25)	7 (10,77)
LEED v4 O+M: EB	0 (0,00)	1 (0,83)	0 (0,00)	0 (0,00)
LEED v4 BD+C: NC	1 (1,19)	0 (0,00)	1 (1,12)	0 (0,00)
LEED v4 ID+C: CI	4 (4,76)	1 (0,83)	6 (6,74)	9 (13,85)
LEED v4.1 O+M: Interiors	0 (0,00)	0 (0,00)	1 (1,12)	0 (0,00)

Table 3. Different versions of LEED in "Office Buildings" Source: Preparation by the authors. (The figures in parenthesis represent the percentage [%]).

	Argentina	Chile	Colombia	Perú
TOTAL LEED Registered	348 (100,00)	490 (100,00)	428 (100,00)	281 (100,00)
NOT Certified + Confidential	206 (59,20)	256 (52,24)	270 (63,08)	184 (65,48)
PT: NOT Office	58 (16,67)	113 (23,06)	69 (16,12)	32 (11,39)
PT: Offices	84 (24,14)	121 (24,69)	89 (20,79)	65 (23,13)

Table 2. LEED projects registered in Argentina, Chile, Colombia, and Peru, classified into: "NOT Certified", "Confidential", and "Project Type (PT)". Source: Preparation by the authors. (The figures in parenthesis represent the percentage [%]).

The public file of the U.S. Green Building Council (https://www.usgbc.org/) was used to filter the information and obtain the certified projects. Table 2 shows a summary of the ranking made from the information by registered projects, filtered by the content: "NOT Certified+ Confidential" projects, to date, registered as confidential and not certified; "NOT Office", projects certified and registered with roles/types different to Office; and "Offices", projects certified and registered with Office role/type in the base file, in the column ProjectTypes.

The version with the highest number of registered projects with the LEED-CS v2009 "Core and Shell" (v3), on being the most used in the database between 2012 and 2020, as expressed in Table 3.

Once the version with the highest number of projects registered was chosen, the credits were ranked in three groups: "Direct", "Indirect", and "Others". "Directs", because, in the description of "Intent" in the manual, the intentionality of promoting PEB among occupants is directly established, as happens, for example, in the alternative transportation credits: SSc4.1; SSc4.2; SSc4.3m SSc4.4: "To reduce pollution and land development impacts from automobile use". "Indirect", because in the description of the "Intent", the intentionality of promoting PEB among occupants is not directly established, but rather in another part of the credit descriptions, like in activities that are requested to obtain scores, for example, that of preparing surveys for the occupants, in the case of the credit "IEQc3: Enhanced Commissioning", or in that of credit "SSc9: Tenant design and construction guidelines", where writing a manual with instructions of the green strategies there are in the building is requested, to instruct future tenants and occupants about the building's green strategies. The category "Others" was considered as justified by the revision

LEED Environmental Category	LEED Code	LEED Identification		Credit Category – LEED / Study (*)		
			Prerequisite	Direct (*)	Indirec (*)	Other (*)
Materiales y Recursos *(Materials and Resources)*	MRp1	Storage and collection of recyclable items.	✓			
Parcelas Sustentables *(Sustainable Sites)*	SSc2	Surrounding density and diverse uses		✓		
	SSc4.1	Alternative transportation: public transportation access		✓		
	SSc4.2	Alternative transportation: bicycle storage and changing rooms.		✓		
	SSc4.3	Alternative transportation: low emitting and fuel-efficient vehicles.		✓		
	SSc4.4	Reduced parking footprint.		✓		
	SSc5.2	Site development. Maximize open space.			✓	
	SSc9	Tenant construction and design guidelines.			✓	
Energía y Atmósfera *(Energy and Atmosphere)*	EAc3	Enhanced commissioning			✓	
Calidad Ambiental Interior *(Indoor Environmental Quality)*	IEQc6	Controllability of systems – thermal comfort			✓	
	IEQc8.1	Daylight and views – Daylight			✓	
	IEQc8.2	Daylight and views – views			✓	
Innovación en el Diseño *(Innovation in Design)*	IDc1	Innovation in Design				✓

Table 4 below, presents the LEED credits with the potential to promote PEB among the occupants, following the LEED Manual CS v 2009 "Core and Shell" (v3) in its English version (USGBC, 2016). Table 4. LEED credits with the potential to promote PEB among occupants.Source: Preparation by the authors. (*) Note. These credits belong to a category different from the "Prerequisites" determined by LEED, which establish the minimum requirements that all buildings must comply with to achieve LEED certification. The former, however, are defined as "those which distinguish (the)

of the literature and the validation of experts, which sees innovation credits in the design as additional opportunities to promote sustainability among the occupants.

To obtain information on the use of LEED-C3 v2009 "Core and Shell" credits in office buildings in Argentina (AR), Chile (CL), Colombia (CO), and Peru (PE), with a potential to promote PEB, the information was collected from the scorecards of each project. Table 5 illustrates the percentage use of each credit with the potential to promote PEB among occupants in the four countries, as well as the average use of each credit by countries, to rank them, and the standard deviation of each credit, to compare them.

The credits that obtained the top three places in use, according to the average, were:

1) "SSc4.1: Access to Quality Public Transportation", with 99.34%;
2) "SSc2: Surrounding Density and Diverse Uses", with 98.34%; and
3) "SSc9: Tenant construction and design guidelines", with 96.53%.

The last three places were:

9) "EAc3: Enhanced commissioning", with 44.30%;
10) "IEQc8.1: Daylight and visits – Daylight", with 31.31%; and

LEED Environmental Category	LEED Credit Code	COUNTRY (%)				Average (%)	Standard Deviation
		AR	CL	CO	PE		
Parcelas Sustentables (Sustainable Sites)	SSc2	100,00	100,00	96,00	97,37	98,34	1,99
	SSc4.1	100,00	100,00	100,00	97,37	99,34	1,32
	SSc4.2	100,00	86,96	88,00	92,11	91,77	5,92
	SSc4.3	83,33	88,41	92,00	94,74	89,62	4,93
	SSc4.4	75,00	56,52	40,00	39,47	52,75	16,81
	SSc5.2	66,67	68,12	88,00	47,37	67,54	16,60
	SSc9	100,00	100,00	94,00	92,11	96,53	4,08
Energía y Atmósfera (Energy and Atmosphere)	EAc3	91,67	14,49	50,00	21,05	44,30	35,15
Calidad Ambiental Interior (Indoor Environmental Quality)	IEQc6	4,17	8,70	12,00	5,26	7,53	3,55
	IEQc8.1	8,33	59,42	18,00	39,47	31,31	22,82
	IEQc8.2	58,33	79,71	70,00	71,05	69,77	8,78

Table 5. Result of the analysis Source: Preparation by the authors.

11) "IEQc6: Controllability of the systems", with 7.53%.

Regarding the result of the standard deviation calculation, the two highest values appeared in the following LEED credits:

- "IEQc8.1: Daylight and visits – Daylight", with a deviation of 22.82 points. Argentina had the lowest average use of this credit (8.33%) and Chile, the highest (59.43%).

- "EAc3: Enhanced commissioning", with a deviation of 35.15 points. Chile had the lowest average use of this credit (14.49%), and Argentina, the highest (91.67%).

DISCUSSION

The first two LEED credits in the use of green office buildings in Argentina, Chile, Colombia, and Peru, between 2012 and 2020, with the potential to promote PEB among occupants, were "SSc4.1: Access to Quality Public Transportation" (99.34%) and "SSc2: Surrounding Density and Diverse Uses" (98.34%). Both look to promote a reduction in vehicle use, a pro-environmental behavior solution at an urban, city scale. In third place was the LEED credit, "SSc9: Tenant construction and design guidelines" (96.53%), whose purpose is educating tenants about the implementation of green construction and design features in the building. These construction and design guidelines look to support the tenants on the design and building of green interiors and so that they also adopt green construction practices, which opt to include the occupant in the design of green buildings, on referring to behavioral and cultural factors, that are crucial for sustainability, and to promote the level of awareness of all stakeholders (clients, designers, contractors, tenants, and occupants) about sustainable development concepts and sustainable buildings (Zuo & Zhao, 2014). This credit also shows the new challenges of including the occupant in the design solution of green buildings since, according to Hoffman & Henn (2008), the new obstacles "are no longer technological and economic, but rather social and psychological" (p. 391). Likewise, a change could be foreseen in the paradigm of occupant-focused certification systems, specifically in the IWBI WLL, Fitwel, and Living Building Challenge (California Polytechnic State University, 2020) systems. In addition, this trend could lead to an interest in studies that identify credits involved in diverse evaluation categories or occupant-focused dimensions (Gou, 2019; Gou, Prasad & Siu-Yu Lau, 2013; Ollankoon, Tam, Le & Shen, 2017), or as Wen et al (2020) suggest, of the considerable increase that, in the last three decades, the weight of the social category has been acquiring in the analyzed systems. Alongside this, a small increase in the weight of the economic category has been noted, and an ongoing reduction of the environmental one. It is worth adding, following Xue, Lau, Gou, Song, and Jiang (2019), that the design of buildings with certification systems should move from the engineering approach, focused on the construction, to a biophilic approach, based on the human being.

The least used LEED credit in the four countries was the "IEQc6: Controllability of the systems" (7.53%). Said figure may be associated with the intention of not including the occupant in the architectural design to comply with the sustainability goals in the building, on minimizing the impact of occupant interaction with the building through personal control. Two terms are linked to this trend, the "Rebound effect" (Frondel, 2004; Grossman, Galvin, Weis, Madlener & Hirschl, 2016; Sorrel, 2007) and the "Robust Design" (Buso et al., 2015; Karjalainen, 2016, O'Brien, 2013; Palme et al., 2006). Research related to occupant interaction with the building through personal control and other topics, like thermal comfort, in the effect on energy savings (Nagy, Yong, Frei & Schlueter, 2015; Wagner, Gossauer, Moosmann, Gropp & Leonhart, 2007), and productivity in labor environments (Leaman & Bordass, 2001), showed that the relation of a greater direct individual control leads to greater thermal comfort (De Dear & Brager, 2002; Karjalainen & Koistinen, 2007), and greater satisfaction (Brager & Baker, 2009; Fountain, Brager & de Dear, 1996). From a psychological point of view, other studies observed that personal control is an important factor to increase the satisfaction and productivity of the occupant (Samani, 2015; Vine, Lee, Clear, DiBartolemeo & Selkowitz, 1998).

As for the figures recorded from the standard deviation calculation -35.15 of the LEED credit "EAc3: Enhanced commissioning", and 22.82 of "IEQc8.1: Daylight and visits – Daylight"-, which showed the spread of the values between the cases of Argentina and Chile, it can be stated that getting to know the possible causes of this represents a valuable research opportunity. From this perspective, as future works, it is foreseen to analyze the cases of Brazil and Mexico, on being the countries with the highest number of LEED-certified buildings in the region, but also the local system of Chile, CES. The methodology proposed can be replicated in both studies, and the results can, therefore, be compared.

CONCLUSION

In the relationship of the green building and the occupant, in the design framework of office buildings that seek to attain sustainable goals, the most used credits in the chosen countries opt to include the occupant in the use and promotion of alternative transportation, which contributes towards reducing the impact on the environment at an urban level, a solution that the three groups proposed in Hopwood, Mellor & O'Brien (2005) would support to face the challenges of sustainable development. Another alternative to include the occupant in the design, referring to the LEED credit that looks to instruct the occupant on the green strategies present in the building, also intervenes in society, but through culture; a term that is associated with the action of cultivating or practicing something. And a final solution, that looks to restrict occupant interaction in the building, to achieve energy efficiency (as a sustainability measurement), contributes to society, this time, through technology, that is to say, from applying science to solve specific problems.

Finally, it has to be stated that identifying criteria, through credits in a certification system to promote sustainability among the occupants -in the PEB-, is in line with the emergence of new certification systems, focused on social sustainability, towards the occupants, instead of focusing on environmental sustainability, energy efficiency, and the use of technologies in buildings. For this reason, this work represents a contribution to the phenomenon of the relationship between green buildings and their occupants.

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ARCHITECTURE RESEARCH TRENDS BETWEEN 2016-2020 IN THE SCOPUS DATABASE, AND THEIR RELATIONSHIP WITH THE CREATION OF RESEARCH GROUPS

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TENDENCIAS DE INVESTIGACIÓN EN ARQUITECTURA ENTRE 2016-2020 EN LA BASE DE DATOS SCOPUS Y SU RELACIÓN CON LA CREACIÓN DE GRUPOS DE INVESTIGACIÓN

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RESUMEN

El interés por dinamizar la investigación dentro de las universidades ha puesto en evidencia la necesidad de creación de grupos de investigación. En este sentido, el objetivo del estudio que aquí se expone es relacionar los datos obtenidos de la bibliometría con el perfil e interés de los investigadores de la Escuela de Arquitectura para identificar nichos de investigación que orienten la labor de dichos grupos de investigación. El trabajo, en concreto, se realizó a través de una revisión sistemática y un uso de herramientas bibliométricas de la producción científica publicada los últimos cinco años dentro del dominio de arquitectura en la base de datos SCOPUS. La investigación se llevó a cabo bajo cinco pasos que direccionan el proceso: búsqueda, evaluación, síntesis, análisis y monitoreo. Con el proceso de búsqueda se obtuvieron 1465 documentos científicos, analizados a través de la aplicación web *Bibliometrix* bajo indicadores que permitieron obtener los resultados para relacionarlos con los intereses y perfiles docentes. El análisis identificó que la sustentabilidad, el diseño y la eficiencia energética son temas de interés y constituyen focos de investigación para motivar el trabajo y la conformación de los grupos de investigación.

Palabras clave
sustentabilidad, arquitectura, bibliometría, tendencia de la investigación.

ABSTRACT

The interest in making research more dynamic within universities has evidenced the need for the creation of research groups. In this sense, the purpose of this article is to establish a relationship between the data obtained from bibliometrics and the profile and interest of Architecture Faculty researchers, to identify research niches that guide their work. This research was carried out through a systematic review and use of scientific production bibliometric tools in the last five years within the architecture domain in the SCOPUS database.
The research made used five steps that guided the process: search; evaluation; synthesis; analysis; and monitoring. Through the search process, 1,465 scientific documents were obtained, analyzed with the Bibliometrix web application using indicators that allowed obtaining the results, to connect them to both teaching interests and profiles. The analysis identified that sustainability, design, and energy efficiency are topics of interest and constitute trending topics to promote the work and the constitution of research groups.

Keywords
Sustainability, architecture, bibliometrics, research trends

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INTRODUCTION

The Department of Research and Postgraduate Courses of the International University of Ecuador (UIDE) proposes the creation of research groups, initially formed by the academic staff of the institution. The goals of these groups are to organize research processes to improve researcher participation and to raise the academic indices related to scientific production.

Facing the need to create a research group in Architecture, it has initially been proposed to apply bibliometric techniques to find research foci that would serve to articulate the interests of the different academic profiles with a macro topic that directs the work of the team.

Regarding research groups, the current demands of the development of scientific knowledge, due to its complexity, have extended beyond specialized individual understanding, as such complementarities and synergies are required from the point of view of different researchers (Smith, Vacca, Krenz & McCarty, 2021).

In this sense, within the context of the UIDE School of Architecture, despite the main members of the future research group mostly having the same professional degree, their specialty differs, with the most common ones being linked to architecture, construction, and architectural projects, so it is necessary to establish an objective selection process of the main research topics, so that their participation, from their specialty fields, becomes a contribution. This would allow developing values and objectives for the research group based on innovation, internal cooperation, belonging, and the quality of academic production, as the bibliography reviewed reports (Agnete, Aina, Svein & Ingvild, 2016).

On the other hand, it is necessary to clarify that within the internal organization of the School of Architecture, there is already a research group that works with urban and territorial issues. Therefore, this research project focuses on topics related to architecture and building. Nevertheless, the members of the current research group were also considered for this study.

The promotion of research within universities has evidenced the need to create research groups and to outline lines of research that allow focusing work on relevant issues for society. Along this line, analyzing research trends within an area or aspect of knowledge is very important and has led to diverse systematic reviews of specialized literature and bibliometric studies that, through indicators, allow evaluating science and scientific productivity (Gallardo, 2016), as well as guiding the scientific and academic community regarding the relevant issues that must be researched.

In this same way, the scientific media has been consolidated through open access and international journals. In this sense, while said production grows exponentially, web interfaces have been created, aiming at providing a set of tools for scienciometric and bibliometric quantitative research. The complexity of scientific production is particularly appreciated thanks to the existence of different communication channels. Not all articles are published in open access journals (Van Raan, 2014). However, this resource brings one closer to a reality that is being built.

In recent years, this type of study has awoken the interest of researchers who analyze the evolution and trends of the most developed topics (Bermeo-Giraldo, Acevedo, Palacios, Benjumea & Arango-Botero, 2020; Ramos-Sanz, 2019; Manterola, Astudillo, Arias & Claros, 2013; among others). However, and despite the fact that these reviews have been made, no study has been made that shows the relationship of the topics under question with the creation of research groups and the profile of researchers.

As Blakeman (2018) reports, bibliometrics offers a variety of quantitative techniques and measurements that are used to measure the number of publications of an author, of research groups, or of entire institutions. Alongside this, author networks and connections between institutions (Blakeman, 2018), are used as search tools to identify updated research. Although bibliometrics and literature reviews are techniques that offer summarized quantitative information from published articles, they may lack rigor and have errors produced by the bias of the researchers. Hence, it is necessary to determine methodological processes that guide research along more objective paths (Snyder, 2019).

In the specific case of architecture and building, bibliometric studies on general research trends are limited. Ramos-Sanz (2019), for example, states that, in the bibliometric analysis of five international journals of the last twenty years, the most common topics are: a) Visual transformation of 2d to 5d; b) The transformation of the architectural object in flows; and c) The transformation of the construction process into information. According to Wen, Ren, Lu, and Wu (2021), the topics covered work on BIM digital technologies, a tool that would be causing the most important changes in architecture and building.

METHODOLOGY

The methodology used in this article looks to provide a descriptive view of what is being researched in the field of architecture in the last five years, using systematic revision techniques, bibliometric tools, and monitoring the research interest of academic staff of the School of Architecture (UIDE), which aid the identification of research trends and their perspectives. The steps for this are determined based on the types of common reviews that a work framework considers, which, at the same time, implies: 1) Search; 2) Evaluation; 3) Synthesis; 4) Analysis, associated with the "SALSA framework" methodology (Grant & Booth, 2009); and 5) The monitoring of bibliographic data with the academic interests and profiles.

All in all, the study is framed within the literature review and cartographic review typologies defined by Grant & Booth (2009), as they work with published documents that have been peer-reviewed, with search criteria that can graph information for its consolidation, analysis, and relationship, and also through its contributions regarding research on architecture issues and the creation of research groups. From this, the characteristics taken from the reviews that guide this work are summarized (Table 1).

The research is done using a bibliometric study of scientific production associated with the topic of architecture in the SCOPUS database, which indexes more than 41,000 scientific journals and that, thanks to its broad database and its impact factor, has earned prestige, becoming a science portal (Aguaded, 2020). To define the search equation, the SCOPUS ASJC (All Science Journal Classification) codes classification is used, which allows limiting the search within the category and classification of the thematic area of architecture (2216, *architecture*), filtering the results.

To refine the search, the following inclusion criteria are applied: last 5 years, Ibero-American countries -to consolidate all Spanish-speaking countries, but also Brazil and Portugal-, and types of related documents (Article-ar / Abstract Report-ab / Book-bk / Book Chapter-ch / Conference Paper-cp / Conference Review-cr / Review-re). As an exclusion criterion, the search is limited to thematic areas associated with urbanism and engineering, as such it is sought to define a group focused on architecture and building. In this way, 1,465 documents are obtained, which are exported in .bib and .csv format, including citations, bibliographic information, abstracts, and keywords, which allow having a clear vision of the study area (Table 2).

Literature review	Review of published material that allows examining the current information on an issue, using a structured search, where an evaluation of the quality of the work is not done. The summary is narrative and the analysis is chronological and thematic.
Cartographic review	Review which maps and categorizes the literature through searches defined in a specific period without a formal evaluation of the information quality. The summary is graphed or tabulated, and the analysis may be quantitative or qualitative, depending on the design of the search.

Table 1. Summary of the review typologies used in the research. Source: Preparation by the authors based on Grant & Booth (2009).

Search equation	Database	Years	Doc types	Countries	Doc. analyzed
Código ASJC2216, architecture	SCOPUS	2016 - 2020	Ar, ab, bk, ch, cp, cr, re	Iberoamericanos	1465

Table 2. Search strategies. Source: Preparation by the authors.

The *Bibliometrix* tool is used for the evaluation. This is an open-code software and facilitates scientific mapping (Duque & Cervantes, 2019; Aria & Cucurrullo, 2017). This tool analyzes the information through production, visibility, impact, and collaboration indicators (Chuquin & Salazar, 2019). The information is shown through scientific cartography and data, which make it possible to perform a synthesis by studying data regarding annual scientific production, productivity by country, impact on journals, keywords, trends of topics, among other factors. The data are extracted as graphs and tables that allow classifying and connecting the information. In the next phase, a descriptive bibliometric analysis is done, examining the information in-depth to identify relevant topics that are being currently researched. Finally, this information is compared with the results obtained in the survey to professors of the School of Architecture (UIDE) to generate the results and the discussion that identify the relationships of the topics with the profile and interests of the researchers (Figure 1).

The *Bibliometrix* indicators (Gallardo, 2016) are classified into three types: the first focuses on scientific production indicators. The second groups impact and author visibility indicators. And the last

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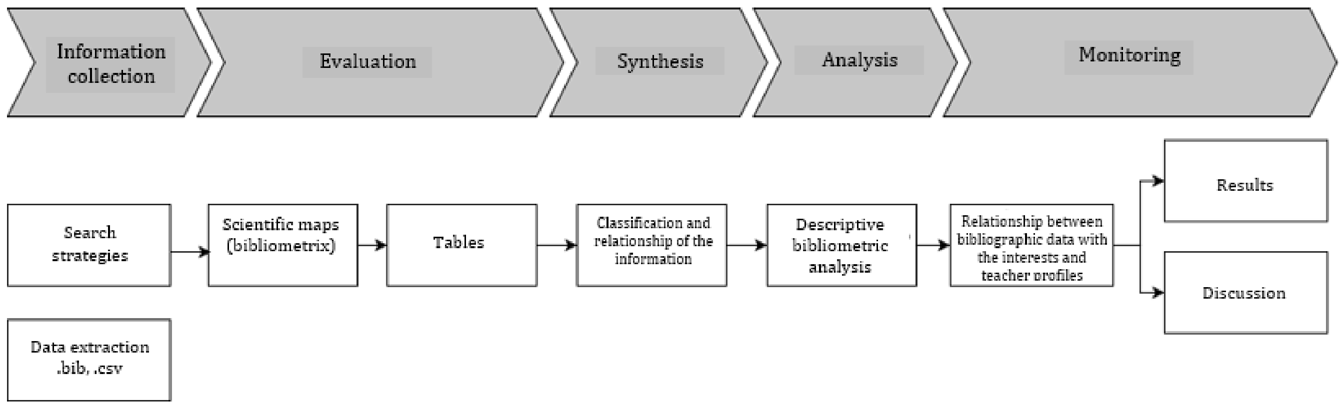

Figure 1. Methodology procedure. Source: Preparation by the authors based on Grant & Booth (2009).

TYPES OF INDICATORS IN BIBLIOMETRIX	INDICATOR	ANALYSIS STRATEGY	PURPOSE OF ANALYSIS	RESULTS
Productivity	H Index in journals	Describe Compare	*H Index:* description and comparison of articles in journals	Identifying the journals with the greatest scientific production on the topic researched.
Impact and Visibility	Lotka's Law Relevance of affiliations Author by country ratio Scientific production by country Most cited countries	Describe Identify Relate	*Lotka's Law:* Identifying whether most authors publish the least number of works, while a few authors publish most of the relevant bibliography on a research topic, and form the most prolific group. *Relevance of affiliations:* Identification of the institutions and universities where the author is from. *Author by country ratio:* Identification of the countries where the most published authors come from. *Scientific production by country:* Identification of the countries with the highest scientific production in the topics of analysis, based on the authors with the highest impact. *Most cited countries:* Identification of the countries with the highest scientific production in the topics of analysis, based on the authors with the highest impact.	Identifying the authors, affiliations, countries, and relevant scientific production that helps to connect data.

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Collaboration	Most cited document by year	Identify Relate Compare Connect	*Most cited document by year:* Identifying the most cited documents that are related to the topic being studied.	Identifying and analyzing the most cited documents.
	Author's keywords		*Author's keywords:* Relates the most frequently used words.	Identifying, through keywords, the trending topics of publication on the issue.
	Conceptual structure		*Conceptual structure:* Identification of the connection among the selection terms.	Relating and analyzing the connection of the selected terms.
	Social structure		*Social structure:* Relation between authors, countries, and institutions.	Identifying the authors, countries, and institutions that are linked to the subject.

Table 3. Types of indicators in Bibliometrix. Source: Preparation by the Authors with data from the guide (Ciencia Unisalle, 2020).

contains collaboration indicators. The scientific productivity indicators record the growth and distribution of scientific production by years, the concentration of the topics in journals, and the geographic distribution of the production. The impact and visibility indicators reveal the influence the content has on the scientific community. Finally, the collaboration indicators can be read through structural maps, that connect several indicators in a single image.

In the framework of this study, the indicators capable of leading to the findings required to give grounds to the purpose of the research were selected (Table 3).

Finally, an analytical survey of closed questions was made to professors from the School of Architecture (UIDE, in Spanish), through which information was obtained on: 1) title of the third level; 2) title of the fourth level; and 3) research preferences according to the bibliometric data. This allowed connecting the professor's profile with the main topics of interest that could be handled by the research group.

RESULTS AND DISCUSSION

The key characteristics of the research process were described above, by which the searches are limited and a focus is put on the revision within the domain of "Architecture", that allowed identifying relevant current topics that contribute towards focusing the work of the research groups on architecture and the establishment of specific lines of research.

Starting from this, a series of results were obtained,

Types of Documents	Result
Papers	998
Book chapters	64
Conference papers	327
Literature revisions	76

Table 4. Types of documents found. Source: Preparation by the authors using Bibliometrix.

which are presented below. Regarding the scientific production of the last 5 years, and considering the 1,465 documents exported from the search, circumscribed within the sphere of architecture, the documents published are those mentioned in Table 4.

Based on an overview of the indicators generated in *Bibliometrix*, and after choosing the indicators that address the subject of the research using qualitative criteria, the search equation was run in the software with the codes presented in the methodology section.

The H index in journals shows that, for this research, the three journals with the greatest relevance, which have the highest production of papers, are the Journal of Building Engineering, ARQ, and the International Journal of Architectural Heritage. From the 1,465 documents published, the first journal has 7.78%; the second, 6.69%; and the third, 6.01%, percentages which, when aggregated, constitute 20.68% of the total production. The ten journals with the highest productivity can be seen in Table 5.

Journals	Documents	Language of publication	Direct University Affiliation	Home Country
Journal of Building Engineering	114	English	No	International
Arq	101	Spanish	Yes	Chile
International Journal of Architectural Heritage	88	English	No	International
Aus	86	Spanish	Yes	Chile
Revista 180	83	Spanish	Yes	Chile
Revista Invi	72	Spanish	Yes	Chile
Structures	59	English	No	International
Advances In Science Technology and Innovation	54	English	No	International
Buildings	45	English	No	International
Architecture City and Environment	43	Spanish	Yes	Spain

Table 5. H Index. Source: Preparation by the authors using Bibliometrix.

Written documents	N° of Authors	Proportion of authors
1	2702	0,829
2	393	0,121
3	97	0,03
4	29	0,009
5	17	0,005
6	4	0,001
7	5	0,002
8	4	0,001
9	2	0,001
10	3	0,001
11	1	0
12	1	0
17	1	0
25	1	0
39	1	0

Table 6. Lotka's Law. Source: Preparation by the authors using Bibliometrix

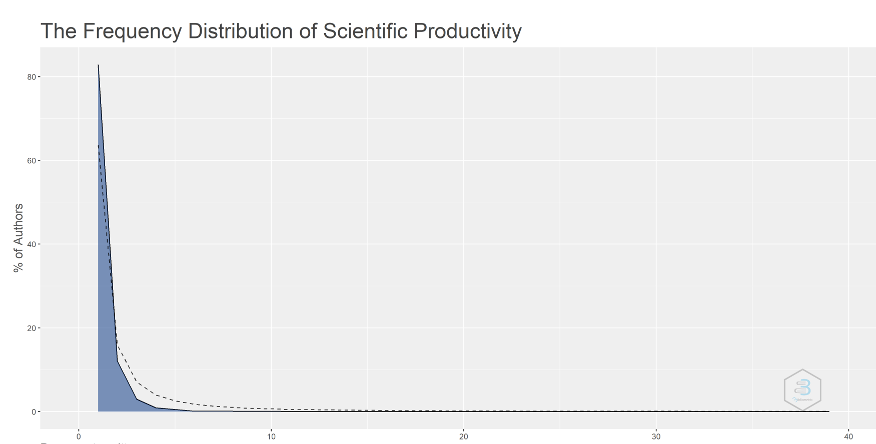

Figure 2. Lotka's Law. Source: Preparation by the a0uthors using Bibliometrix

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Affiliation	Documents	Country
Pontificia Universidad Católica de Chile	148	Chile
Universidad de Lisboa	120	Portugal
Universidad de Minho	90	Portugal
Universidad de Chile	84	Chile
Universidad de Porto	70	Portugal
Universidad de Coimbra	59	Portugal
Universidad de Aveiro	42	Portugal
Universidad del Bío-Bío	39	Chile

Table 7. Relevance of affiliations. Source: Preparation by the authors using Bibliometrix.

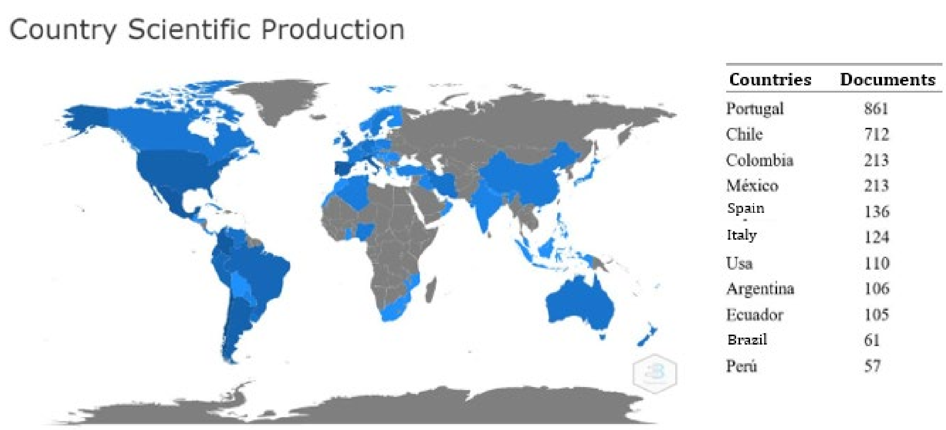

Figure 3. Scientific production indicator by countries. Source: Preparation by the authors using Bibliometrix

From the ten journals identified, it is seen that five often publish papers in Spanish: four universities of Chile, and one in Spain. Once the journals were identified, they become the main material to review trending scientific production.

According to Lotka's Law, during the period of this study, and considering the proportion of authors, it is seen that only 0.5% of the authors publish one article per year, while 82.9% publish approximately one paper in the 5 years studied (Figure 2). Thus. it is seen that the expected curve for the frequency distribution of scientific productivity is below Lotka's law.

As for the index of the relevance of affiliations, the impact of the Pontifical Catholic University of Chile appears first, with 5.11% of the total, followed by the University of Minho, with 3.10%, and in third place, the University of Chile, with 2.90%. The three institutions represent 11.11% of the affiliations corresponding to published papers. The following table shows the top 10 universities which, for the search equation, have the highest impact and visibility. (Table 7).

It is worth adding that other Colombian, Chilean, Portuguese, and Spanish universities appear in this list, like the Nova University Lisbon, the National University of Colombia, the Diego Portales University, the Polytechnical University of Madrid, among others. Likewise, from the total of 1,219 universities analyzed here, 870 register one published paper, that is to say, 71% of the publications.

The main communication platforms that authors use within the architecture area are in Chile and Portugal, which shows that the universities identified are a source of information, both in their publication structure and the topics of interest.

The analysis of the scientific production indicator (Figure 3) reveals the academic capacity of the countries. In particular, the country with the highest scientific production is Portugal, with a total of 861 published documents in the last 5 years, followed by Chile, Colombia, and Mexico. Meanwhile, the authors by country ratio indicator (Figure 4), expresses the MCP (Multiple Countries Publication) and SCP (Single Country Publication) ratios, which allows identifying that Portugal has a higher MCP: from the 296

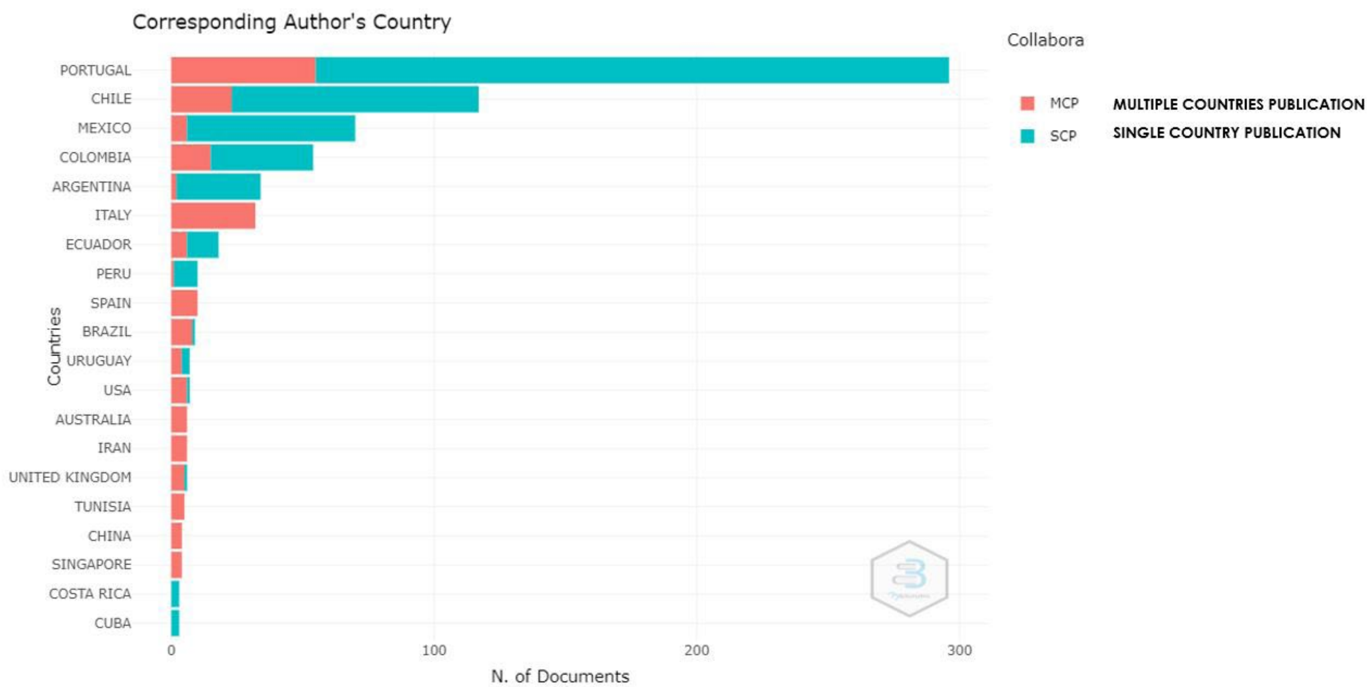

Figure 4. Indicator of the authors by country ratio. Source: Preparation by the authors using Bibliometrix.

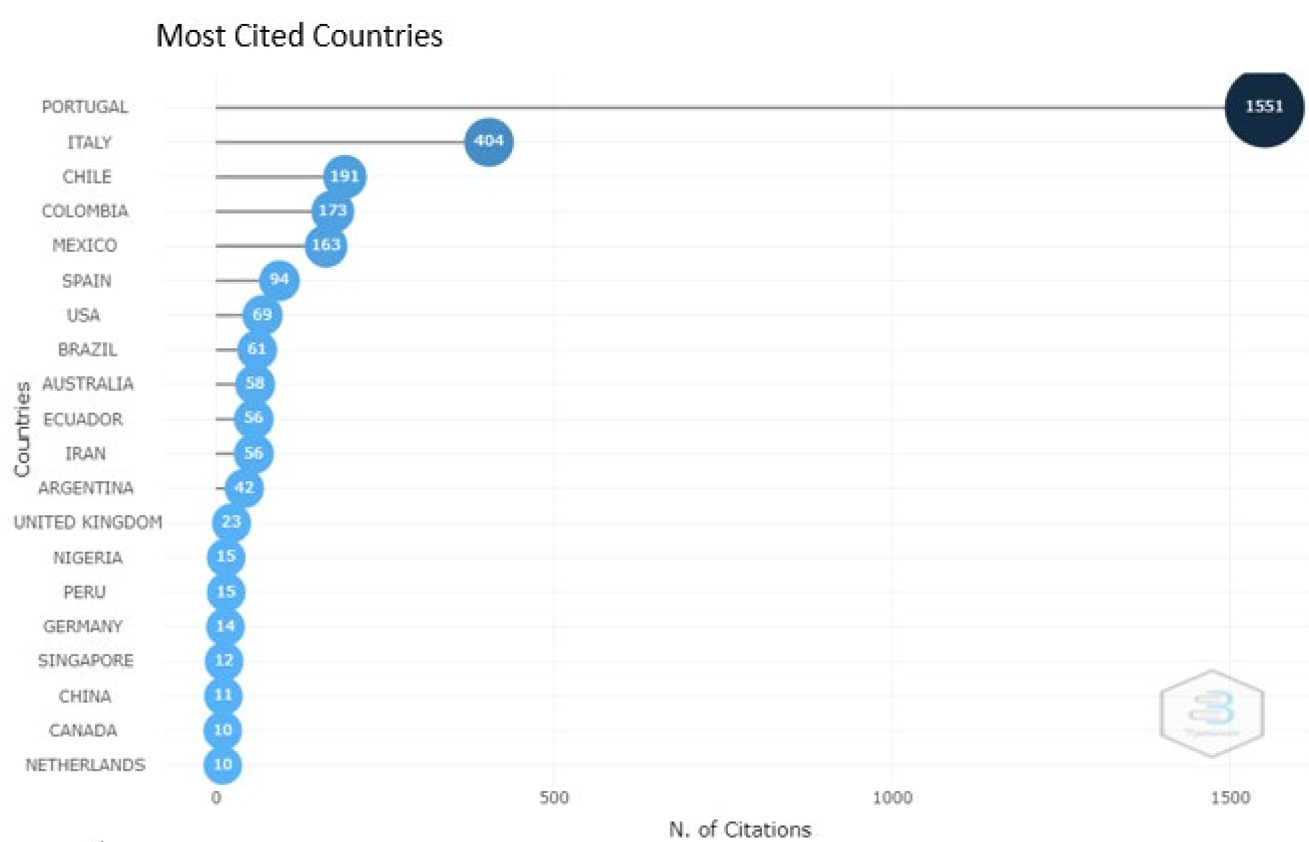

Figure 5. Most cited countries indicator. Source: Preparation by the authors using Bibliometrix

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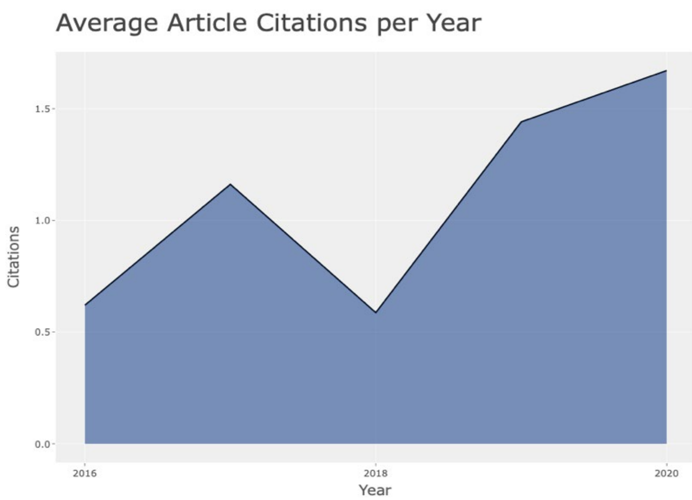

Figure 6. Average paper citations per year. Source: Preparation by the Authors using Bibliometrix.

published papers, 55 have at least one co-author from another country. Italy comes second, with 32 articles published, all of which have international collaboration.

With the most cited countries indicator (Figure 5), it is possible to distinguish that Portugal is at the cutting edge of scientific production and, therefore, is the country with the highest number of citations: in the last 5 years, it got 1,551 citations. But it is important that state that it is relevant to have international collaboration, as it is seen that Italy, Portugal, and Chile have the highest number of citations in their papers.

Considering the collaboration indicator, regarding the most cited document per year (Figure 6), a relationship with the code defined for the search associated with "architecture", and to the exclusion criteria, is noted: one or more documents published in 2020 have the highest average number of citations per year, which implies that the topic has a search incidence.

According to the conceptual structure where the identification of the connection between the filtered topics is made, and following the author keywords fields and the concurrence of these, the topics are grouped into main nodes, and subgroups are established that allow determining the research trends in architecture in the last 5 years.

Considering the data obtained through the thematic map in *Bibliometrix*, the trend of topics related to author keywords found, that are identified in the documents, can be grouped under three terms in said documents: design, construction, and sustainability (Table 8). This information is filtered and analyzed following the aforementioned search criteria, aiming at classifying it in main containers that allow identifying the profiles needed to address the trending topics.

Words	Group label	Relationship with researcher profiles
Test	Project	Construction
Laws	Project	Construction
Wood	Project	Construction
Heritage	Heritage	Construction
Retrofitting	Retrofitting	Construction
Mechanical properties	Retrofitting	Construction
Compression strength	Retrofitting	Construction
Self-compacting concrete	Retrofitting	Construction
Masonry	Masonry	Construction
Reinforced concrete	Masonry	Construction
Seismic evaluation	Masonry	Construction
Seismic vulnerability	Masonry	Construction
Cultural heritage	Masonry	Construction
Numerical modeling	Masonry	Construction
Pressure analysis	Masonry	Construction
Project	Project	Architectural design
Design	Project	Architectural design
Building	Project	Architectural design
Construction	Project	Architectural design
Concrete	Project	Architectural design
Coexistence	Project	Architectural design
Housing	Housing	Architectural design
Modern architecture	Housing	Architectural design
Urban design	Housing	Architectural design
Social housing	Social housing	Architectural design
Sustainability	Sustainability	Sustainability
History	Construction	Sustainability
Energy efficiency	Energy efficiency	Sustainability
Climate change	Energy efficiency	Sustainability
Thermal comfort	Social housing	Sustainability
Stability	Social housing	Sustainability

Table 8. Keywords ranking. Source: Preparation by the authors.

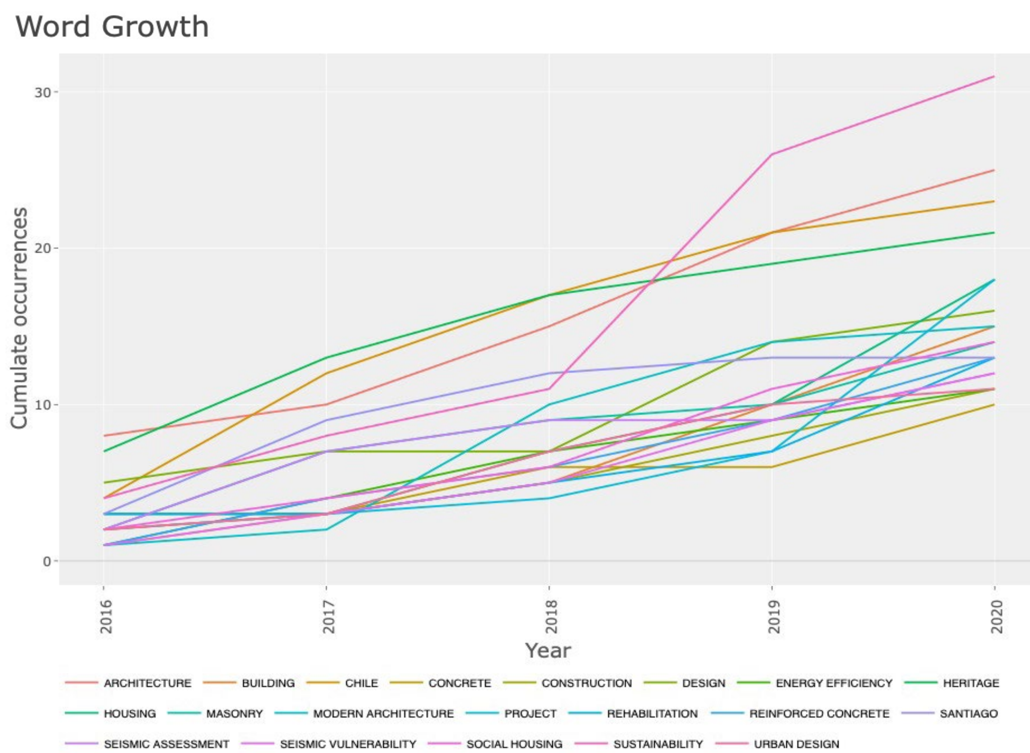

Figure 7. Work trend growth. Source: Preparation by the authors using Bibliometrix.

Thanks to the words dynamic map (Figure 7), it can be seen, through keywords, how the trending topics in architecture publication have been positioned over time. In this case, it is seen that sustainability is a recurring topic in the last 5 years, and reaches its highest peak in 2020, with a clear advantage over the remaining trending topics.

From another point of view, the centrality and density ranges report about the external and internal associations of the groups. In the centrality range, it is seen that sustainability, project, and housing groups tend to be binding and can be addressed in a multi-disciplinary way. On the other hand, the topics related to heritage, masonry, and energy efficiency have a higher frequency of internal associations.

Through the analysis of the social structure, the ties between authors, universities, and countries within architecture research are reviewed, which allows seeking alliances for collaboration in research and creating networks among research groups.

From the 31 universities identified that research topics related to architecture, the Pontifical Catholic University of Chile and the University of Minho have higher intermediation within the University Collaboration Network. Approximately 15 universities collaborate with the former, and 12 with the latter. However, a work connection between them is not seen. Smaller collaboration networks can also be seen in Figure 8, between the Xaverian Pontifical University, the University of Colombia, and the University of Los Andes, and a collaboration network between the University of Cuenca, the University of Azuay, and the Alberto Hurtado University, linked to the network of the Pontifical Catholic University of Chile (Figure 8).

Group	Centrality Range	Density Range
Project	12	7
Heritage	8	12
Retrofitting	10	8
Mexico	6	6
Masonry	9	10
Sustainability	13	3
Housing	11	2
Energy Efficiency	7	9
Social Housing	5	5

Table 9. Centrality and density ranges of the trending topics. Source: Preparation by the authors using *Bibliometrix*.

Likewise, it is clear that, despite there being collaboration among authors within the research, this is minimal, as only eight authors networks are seen among all the analyzed documents. This reflects that, in recent years, to consolidate research within the architecture area,

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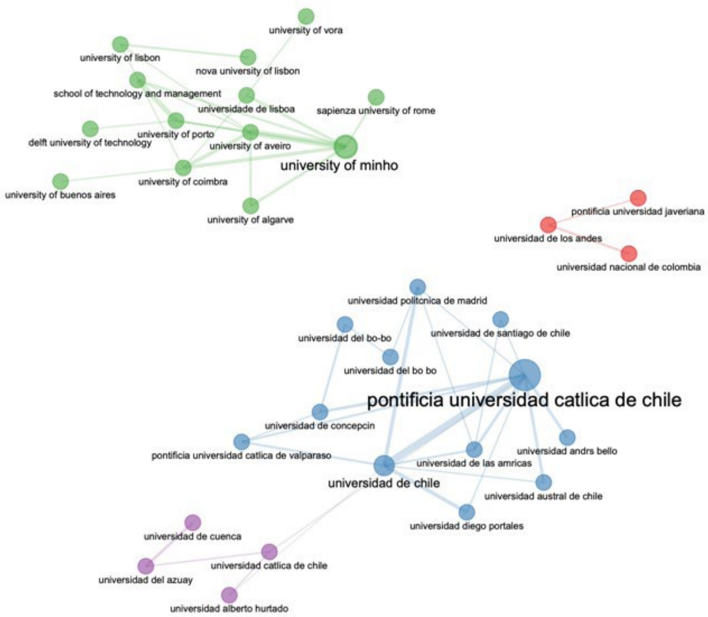

Figure 8. Collaboration network among universities. Source: Preparation by the authors using Bibliometrix.

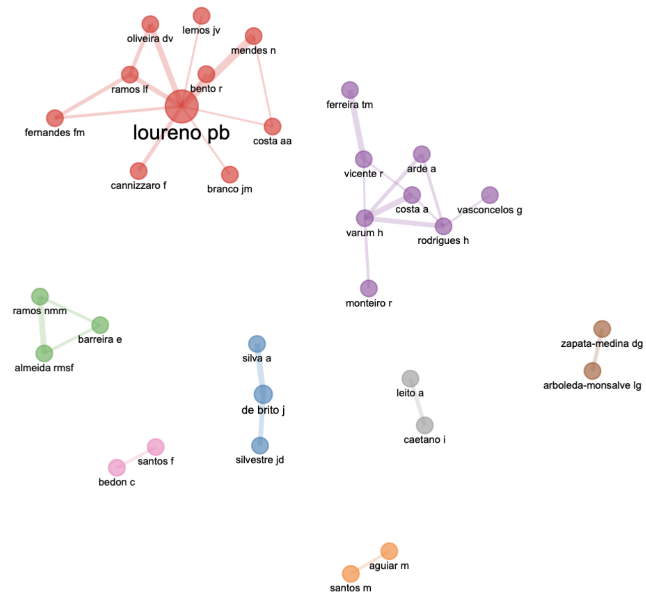

Figure 9. Author collaboration networks. Source: Preparation by the authors using Bibliometrix.

these are done in isolation, leaving aside the creation of networks and research and groups (Figure 9).

On the other hand, connecting specific fields among keywords, countries, and the affiliations of the authors, the trending topics researched during the last 5 years can be determined. Figure 10 shows that sustainability constitutes the most researched topic, which is addressed by different universities in different countries. This field is followed by design, materials, heritage, housing, energy efficiency, and comfort, among others. Thus, it is possible to identify, depending on the research topic, the possibility of generating alliances with other universities to create networks and research groups.

A survey was applied to 19 of the 22 professors of the School (UIDE, in Spanish), to connect the training profile (architecture and projects, constructions, urbanism, and others) with the topics found in bibliometrics. In the results obtained, it was seen that the preferences of the professor profile groups match (Figure 11) in architecture and architectural design. However, sustainability and energy efficiency constitute topics of cross-sectional interest in 3 of the 4 groups monitored.

Given the complementarity between research and teaching in universities, it is worth stating that the trend marked by "sustainability" is also visible in the curriculum for architect training. In fact, González and Trebilcock (2012), for example, mention that 76% of Architecture studies programs in Hispanic-America integrate said concept. In this sense, academic literature has developed the definition of "sustainable design" as a creative process that seeks to reduce expenses in the natural resources used, such as land, air, and water contamination, and indoor comfort in buildings, the economic and financial savings of construction projects, as well as the reduction of the waste generated by construction (D'Amanzo, Mercado & Ganem-Karlen, 2020).

CONCLUSIONS

In the formation of research groups, it is important to connect current research approaches with the profiles of the possible participants. From this perspective, bibliometrics, in general terms, allows seeing the universities with the greatest scientific production and the current topics of potential research. However, it is also necessary to connect these topics with the research interests of the academic staff. This helps to create internal and external collaboration networks to suggest macro topics with different sub-subjects, where the participants work for the same goal, but with different alternatives

The proposed monitoring demonstrates that, despite there being different specialty profiles, cross-sectional topics of interest can be determined. For this case, for example: sustainability, energy efficiency, and architectural design are recurrent preferences in the fields of teaching profiles.

The application of bibliometric techniques in the broad field of architecture is limited, so the search for research niches is difficult. However, bibliometrics is currently being

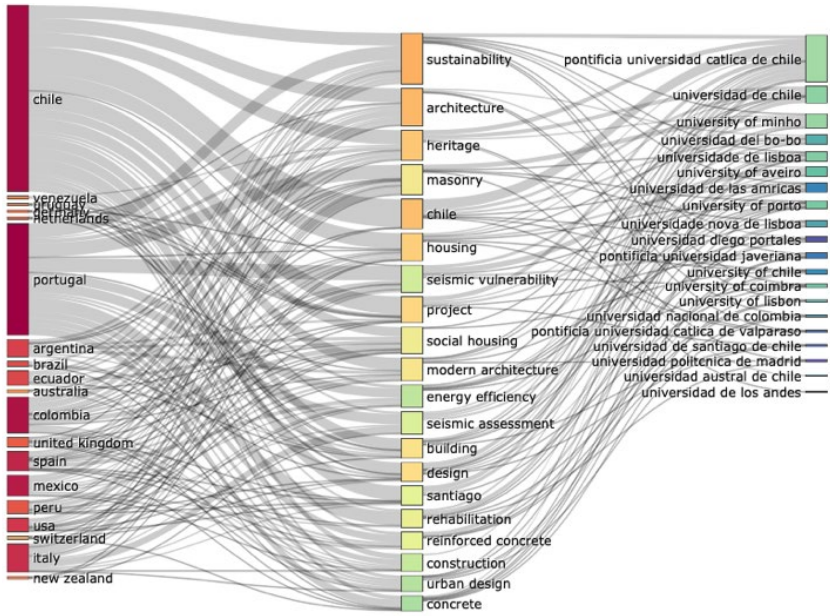

Figure 10. Relationship between topics, countries, and affiliations. Source: Preparation by the authors using Bibliometrix.

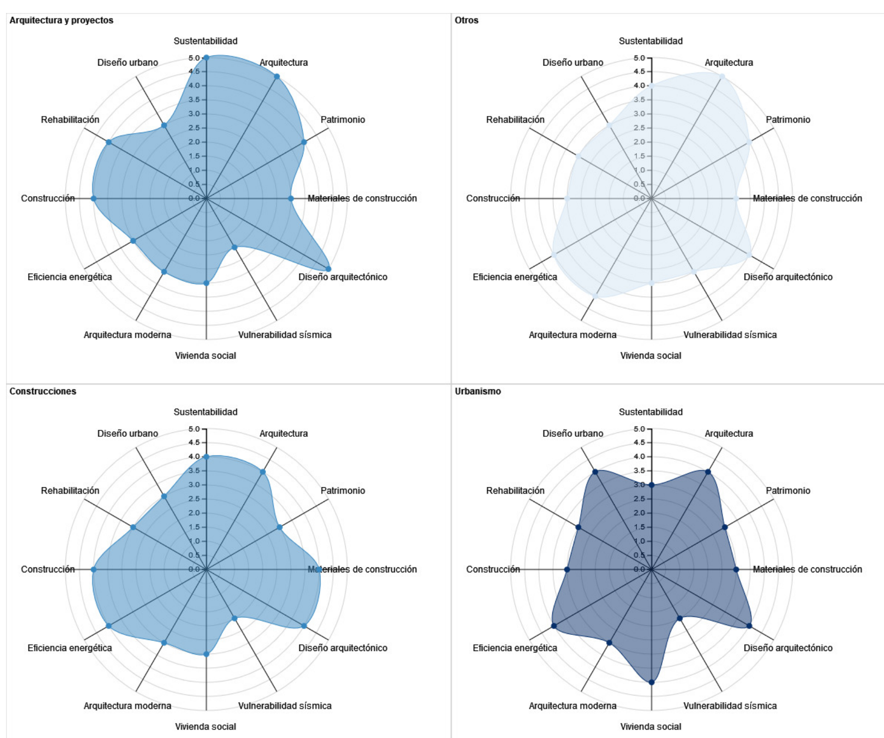

Figure 11. Relationship between research interest and professor profile groups. Source: Preparation by the authors.

widely used to see the evolution of the expansion of digital technologies, referring to BIM. In any case, it is key that other topics are studied to start research on emerging topics that contribute to innovative aspects for academia.

Bibliometric analysis requires an organized revision process, the classification of indices, and data within concrete fields of knowledge. In the case of "architecture", it is seen that the word is widely used in different fields, which is why the decision was made to use the ASJC (2216) code of Scopus, which allowed limiting search processes to topics directly related to the field of Architecture as a discipline. Thus, 1,465 documents were selected: papers, book chapters, conference papers, and literature reviews.

According to the criteria established for the bibliometric search regarding H indices and relevance, it was stated that, in Ibero-America, Chile and Portugal are the countries with the highest scientific production in Architecture, and that Portugal has the highest scientific production in individual and in collaborative publications with multiple countries. It is relevant to also highlight that, in Chile, different universities have their own journals with different indexations based on bibliographical data, which improves the scientific production indices and the development of collaboration networks.

The curve for the frequency distribution of scientific productivity taken from *Bibliometrix* shows that the production index in the last 5 years, for architecture, is below the curve, which shows that it is necessary to change the research approaches. One option would be networking and research groups.

Scientific mapping has managed to identify the dynamics of research in the area of architecture in the last 5 years. Starting from the analysis, it can be determined that research is linked to design, construction, and sustainability, which implies the need for different specializations that allow comprehensively addressing the studies.

Ultimately, it is seen that universities from different Ibero-American countries target their studies towards topics associated with the concept of sustainability, which shows that this can be the guiding line for different research projects, that would encourage the formation and the work of networks and research groups.

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THERMAL AND LIGHTING EVALUATION IN LIGHT ROOF PROTOTYPES, FOR HOT HUMID CLIMATES

EVALUACIÓN TÉRMICA Y LUMÍNICA EN PROTOTIPOS DE CUBIERTAS LIGERAS, PARA CLIMA CÁLIDO HÚMEDO

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RESUMEN

El techo de chapa de zinc es uno de los elementos más populares en la arquitectura latinoamericana, y en muchas otras regiones con climas cálido húmedo. Crear alternativas lumínicas y térmicas enfocadas en esta tipología implicaría profundos beneficios en el campo ambiental y social. El presente estudio, realizado en Manabí-Ecuador, evalúa tres prototipos de cubiertas ligeras, combinando el material Zinc con el PVC, con el fin de determinar la correcta configuración del material translucido para crear ambientes que estén dentro de los parámetros térmicos y lumínicos. Los resultados indican que el modelo de soluciones empíricas presenta la menor variación de temperatura interior, con un 32,63%, a diferencia de los 32,97% del modelo tipo cruz y de los 34,40% del modelo de franjas laterales. Adicionalmente, se evidenció que la mayor influencia de radiación solar sobre la cubierta se registra desde las 13:00 h hasta las 14:00 h aproximadamente.

Palabras clave
Ecuador, vivienda, techos, comportamiento térmico interior

ABSTRACT

The zinc sheet roof is one of the most popular elements in Latin American architecture, and in many other regions with warm humid climates. Creating lighting and thermal alternatives focused on this typology would imply major benefits in the environmental and social fields. This study carried out in Manabí, Ecuador, evaluates three prototypes of light roofs, combining zinc with PVC, in order to determine the correct configuration of translucent material to create environments that are within thermal and lighting parameters. The results indicate that the empirical solutions model has the lowest variation in indoor temperature, with 32.63%, unlike the 32.97% of the cross-type model, and the 34.40% of the side strip model. Additionally, it was seen that the greatest influence of solar radiation on the roof is recorded from 1:00 p.m. to 2 p.m. approximately.

Keywords
Ecuador, housing, roofs, indoor thermal behavior.

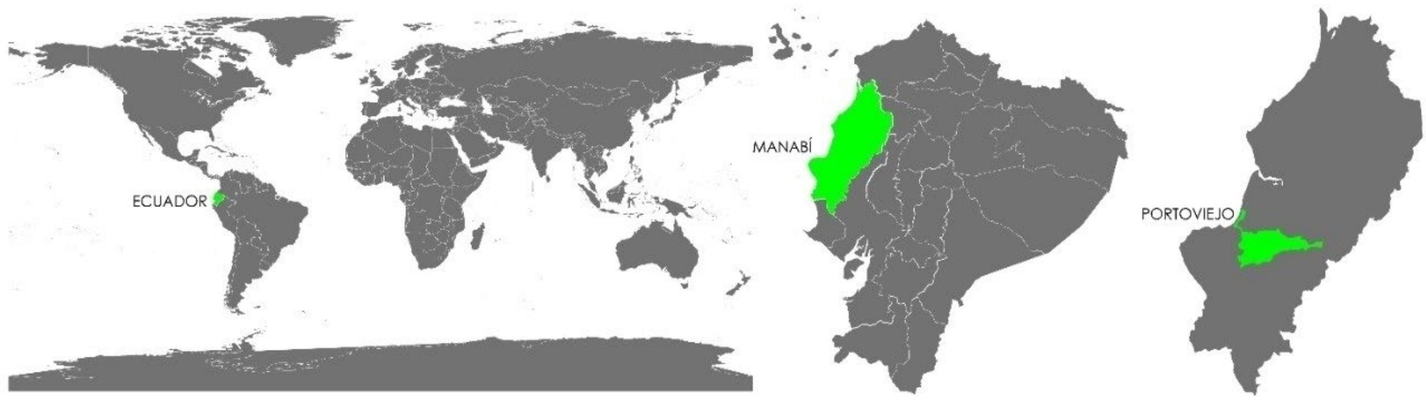

Figure 1. Geographic location of the study area. Source: Prepared by the authors.

INTRODUCTION

The roof is the top part of a building, whose main function is protecting the inside from the weather and external threats. This structural element is classified by its shape, material, and complexity (Hernández-Salomón, Rizo-Aguilera & Frómeta-Salas, 2017). One of the multiple options on the Ecuadorian market, and the most commonly used in the construction of social housing (SH), is the metal roof, characterized on being a corrugated steel sheet coated in zinc and aluminum, known as *Aluzinc* (Véliz-Parraga & González-Couret, 2019). This roof typology stands out as an economic and resistant solution, that is easy to apply and has a good visual appearance. However, due to its simple structural form and low thermal transmittance, it does not provide optimal insulation conditions, which causes a fast passing of the heat flow in buildings, generating uncomfortable indoor environments (Rodríguez, 2017). On certain occasions, a translucent polyvinylchloride (PVC) tile, a salt (57%) and oil (43%) byproduct (plasticseurope, 2021), is used. However, its use is limited on having a high cost, and also because one of its characteristics is letting zenithal light through, which causes an increase in the calorific intensity within the dwelling. Zinc sheets, due to their chemical constitution, have a reflectance quality, which PVC sheets do not have. This feature of reflecting light is one of the most important ones, as it indicates the amount of solar radiant energy that a surface reflects. As such, this is a determining factor in the thermal behavior of roofs (Alchapar, Correa & Cantón, 2012). Likewise, this surface depends greatly on the position of the sun and, thus, on the geographical space where it interacts with the environment, which is due to the angle of inclination of the sunlight, that varies in latitude (0°-90° North and South) and longitude (0° - 180° East and West) of the Earth (Oster, 2021, p. 39). Regions close to latitude 0° have, as a condition, that the roof receives sunlight perpendicularly during the year. This is the case of Ecuador (Torres, Coch & Isalgué, 2019).

The aforementioned country is formed by 24 provinces. Bordering the Pacific Ocean, is the province of Manabí, and within this, the Portoviejo Canton (Figure 1). This province stands out on having annual average temperatures between 21°C and 29°C, divided into two climatic periods, dry and humid (Macías, 2018).

According to the National Meteorology and Hydrology Institute [INAMHI, in Spanish], for October 29th, 2020, at the end of the dry period, absolute maximum temperatures of 32°C were recorded (El Universo, 2020). For March 30th, 2018, the absolute maximum temperatures were 34.9°C (El Diario, 2018), and for July 10th, 2014, at the end of the humid period, absolute maximum temperatures of 35.5°C were reached (INAMHI, 2014). This retrospective longitudinal cutoff indicates the climatic phenomenon that occurs close to 0° latitude. In this context, it must be considered that the solar radiation received by the roof produces more than a third of the thermal gain inside a dwelling (Osuna-Motta, Herrera-Cáceres & López-Bernal, 2017) and that the housing solution typologies of the Portoviejo Canton, where low-rise buildings prevail (Couret & Párraga, 2019), have roofs predominantly made from steel sheets coated in zinc and aluminum (Véliz-Párraga & González-Couret, 2019). It is then clear that it is this construction element that is mainly responsible for the heat contributions inside dwellings.

PASSIVE ROOFING STRATEGIES

Regarding the thermal performance of roofs, different general aspects and strategies have been studied, such as location and orientation; increased loss through convection on using wind direction; shape factor or compactness; useful surface; and total volume of the thermal envelope and the thermal mass of its components (Sisternes, 2019).

All these strategies have been applied to reduce user thermal discomfort without needing to use active systems. Other measures use passive design techniques, focusing on heat reduction or gain through the roof (Torres, Viñachi, Cusquillo, Pazmiñon & Segarra, 2019). The most commonly used ones included: thermal insulation paints, green roofs (Garnica, 2020), and masking through solar protections like trees, buildings, slats, double skins (Rojas, Soto & Díaz, 2020; Balter, Ganem & Discoli, 2016). However, from all this range of strategies focused on solving the comfort of spaces, most only focus on giving a solution to thermal comfort, leaving aside lighting issues. This contrariety has been growing starting from the first industrial revolution (1760-1840), as an effect of technological transformations (Belén & López, 2016), on prioritizing the search for traditional energy alternatives, from the Roman ships that carried wood, to the exploitation of oil wells. Now, as is well-known, fossil fuel supplies will run out, while the sun will continue heating future generations (Izzo, 2017). From this arises the importance of studying solar energy capture.

SOLAR ENERGY: SHAPE AND CAPTURE

The sun is the main axis in the evolution of life on Earth, as it provides suitable conditions for the existence of living beings. This star is involved in all production cycles, and it even determines our progressive activities by the use of time. For this reason, human beings have needed to use and take advantage of the sun to be able to coexist with the environment: as a defense against the cold; to define harvesting times; and even as a promoter of vitamin D (Yépez, 2018). Nowadays, however, our actions are no longer ruled by the sun. Today, artificial light allows the permanent lighting of spaces inside the dwelling, which has caused changes in the biological clock, circadian cycles, eating, working, and resting times; disorders that are also considered agents of the obesity epidemic that society is facing (Iluminet, 2015).

Since the first urban regulations in ancient Greece, in the city of Olynthus, an urban-logic fabric was designed, oriented from east to west, to organize strips and facades so that dwellings would face the south, to guarantee solar access, and to improve the quality of the habitat. It is important to highlight the Hadrian Pantheon in Rome, from 126 AD, as due to its almost perfect orientation of five degrees N-NW, it exposes its entire architectural shape, linked intimately to sunlight, which causes a game of lights and shadows which, for many historians, marked a new indoor spatial conception (Linares, 2015).

Today, there are regulations and ordinances adapted to the needs of each nation about the right to solar access or the continuous availability of unobstructed direct sunlight (Contardo, Cecchi & Lara, 2017).

In international-scale research, done in 10 countries and 34 case studies, about the influence of solar energy on urban planning, it was determined that the selection of technology and the social acceptance of the types of materials play a key role when it comes to designing new urban fabrics, where the basis of environmental impact, the local economy, and the market offer, is found. It was concluded that the formal functional characteristics presented a pattern of straight edges and parallel stripes in the distribution of solar modules; the most suitable shape factor set up for solar energy protection and capture (Lobaccaro et al., 2019). Another study, focusing on the construction of a methodological guide to design economic passive solar buildings and reduce the use of heating, ventilation, and air-conditioning (HVAC) systems, analyzed the normal conditions of a building to then make modifications to its construction components (roof and envelope), to optimize the use of the micro-climate and evaluate the maximum temperature reached by the building during 24 hours of the day, as well as the factors that affect the indoor temperature (Marín, 2012). In research focused on verifying the use of solar energy in the Metropolitan Area of Mendoza, whose climatic conditions are similar to the object of this study, the close ties between urban morphology and solar access were determined: the shape factor, and the land occupation factor, are the agents that most determine urban regulation. From this it is inferred, that the greater the urban density, the lower the solar energy availability there is (Cárdenas & Vásquez, 2017).

One of the core concepts of bioclimatic architecture is the solar approach, which forces further planning of openings, which are responsible for the heat-light contribution (Monroy, 2006) and, on certain occasions, building ventilation, an aspect that, of course, increases the comfort sensation of the user, without needing to turn to the use of HVAC systems. As for lighting, to reach comfort standards, certain design criteria mentioned in the technical guidelines must be met, among which taking advantage of daylight in the lighting of IDAE (2005) buildings stands out: "the choice of the place, orientation, shape, and dimensions of the building, utilizing the contribution of overhead light" (p. 36). For this reason, designing buildings that consider the use of overhead light as a key source of lighting, leads to major benefits for users, from the regulation of melatonin production, to visual comfort (Ramírez & Orozco, 2015), to important energy savings (Villalba, Pattini & Córica, 2012). Therefore, the question arises:

Evaluación térmica y lumínica en prototipos de cubiertas ligeras, para clima cálido húmedo
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If light roof prototypes are designed, combining zinc with PVC, will the level of lighting and thermal comfort rise? To answer the query, prototypes were built with materials from the new vernacular era for areas with warm climates, under the parameters of sustainability and environmental protection. It is sought that these work as a theoretical base for a roof design that is capable of allowing sunlight to pass through with a lower heat contribution, thus contributing towards improving the livability and quality of social housing.

METHODOLOGY

This study was carried out using an experimental approach, with a descriptive scope, and is inserted within the line of research of indoor comfort of the dwelling. It was carried out in the central region of the Ecuadorian coast, in the city of Portoviejo, between the coordinates S1°3'16.49" W80°27'16.02" (Antipodas, 2020). The experimentation was done between January and March 2021, when the maximum temperature was 29°C, and the minimum 23°C, the cloudiness was above 75%, daylight hours were constant, with a value of 12 hours and 9 minutes, and with a westerly wind direction (Table 1). The study was divided into 2 stages.

STAGE 1 (FIELD STUDY)

In the first methodological stage, the structured observation technique was used, where the building characteristics of the geographic setting were revealed (Canton of Portoviejo), and the study was limited to shed-roof dwellings with Aluzinc roofs. A sample of 308 housing solutions of the urban area, and 89 dwellings from the rural area, were analyzed. This analysis showed that, in the urban area, the use of translucent material on the roofs (RTM) represented 7.8% of the sample and, in the rural area, 5.6%; which together total 29 dwellings from the 397 analyzed.

The Canton of Portoviejo is formed by 9 urban and 7 rural parishes (Figure 2), where there are 70,428 dwellings, 51,851 of which are located in the urban area, and 18,577 in the rural area. Of these, 48,744 have an Aluzinc sheet roofing material: 37,855 in the urban area, and 10.889 in the rural area (Table 2) (National Institute of Statistics and Censuses [INEC, in Spanish], 2010).

FORMULA TO CALCULATE THE SAMPLE

To calculate the part of the global total which had the characteristics of the population, the probabilistic formula set out by Flores (2014) was used. This is indicated in equation 1:

Agents / Months	January	February	March
Temperature	Maximum of 29°C and Minimum of 23°C		
Cloudiness	75%-81% cloudy or mainly cloudy 75%-81%		
Rainfall	24%-54%	55%-60%	60%-40%
Daylight	12 hours 9 min.		
Humidity	93%-99%	99%-100%	100% Kte
Wind speed	14.2 to 11.8 km/h	11.7 to 10.3 km/h	10.1 km/h Kte
Wind direction	West 76%	West 76%	West 75%
Short wave radiation	5.6 kWh visible light and ultraviolet radiation.		

Table 1. External climatological factors. Source: Prepared by the authors.

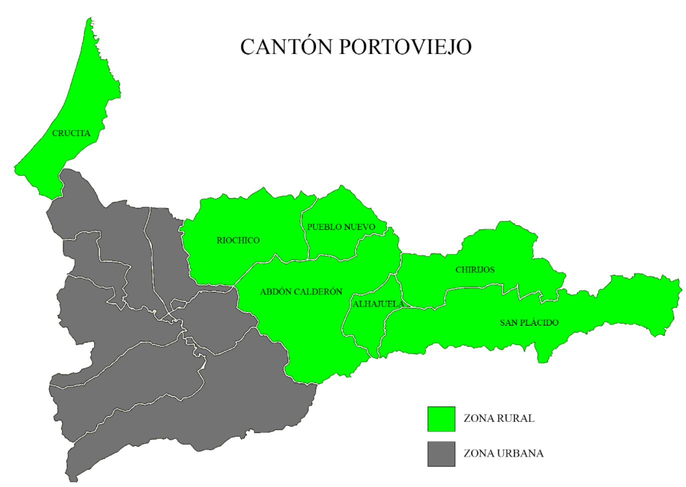

Figure 2. Map of the Canton of Portoviejo.
Source: Prepared by the authors.

$$n = \frac{PQ * N}{(N-1)\frac{E^2}{K^2} + PQ} \qquad (1)$$

Where:

n: Is the size of the probabilistic sample whose value is sought.
N: Is the size of the total population.
PQ: Is a constant of 0.25 of the population variance.
E: Is the maximum admissible error, that varies between 0.01 and 0.09
K: Is the correction coefficient of the error, which is a constant equal to 2.
(N-1): Is a relative constant for samples greater than 30 (Flores, p. 120-121).

CALCULATION OF THE SAMPLE SIZE OF THE PARISHES.

To define the number of parishes to be studied an admissible error of 1.16% of the 16 parishes was used, which resulted in 100% of these, as can be seen in equation 2.

$$n = \frac{PQ * N}{\frac{E^2}{K^2} + PQ} = \frac{0.25 * 16}{\frac{0.016^2}{2^2} + 0.25} = \frac{4}{0.25} = 16. \quad (2)$$

CALCULATION OF THE SAMPLE SIZE BY AREA.

Area	Order	Zinc roof (frequency)
Urban	9	37.855
Rural	7	10.889
Total	16	48.744

Table 2. Number of dwellings by area. Source: Prepared by the authors.

To calculate the number of housing solutions to be assessed, an admissible error of 5% of the 48,744 dwellings was used, which resulted in 397 dwellings (see equation 3). After this, the sample was calculated by share, for the different areas (see Table 3), and a stratified sample was made for the rural area (Table 4), given the geographic spread of this area. To end this first stage, the areas, frequency, sample size, and the RTM were described (Table 5).

$$n = \frac{PQ * N}{(N-1)\frac{E^2}{K^2} + PQ} = \frac{0.25 * 48.744}{(48.744 - 1)\frac{0.05^2}{2^2} + 0.25} = \frac{12.186}{30.71} = 397. \quad (3)$$

Area	Orden	Frequency	%	Cm
Urban	9	37.855	77.66	308
Rural	7	10.889	22.34	89
Total	16	48.744	100	397

Table 3. Number of dwellings to be assessed, by areas. Source: Prepared by the authors.

Rural Area	Orden	Frequency	%	Cm	Mtc
Abdón C.	1	3.104	28.51	25	2
Alhajuela	1	807	7.41	7	0
Chirijos	1	433	3.98	4	1
Crucita	1	1.812	16.64	15	0
Pueblo N.	1	658	6.04	5	1
Riochico	1	2.626	24.12	21	1
San Plácido	1	1.449	13.31	12	0
Total	7	10.889	100	89	5

Table 4. Stratification of the rural area. Source: Prepared by the authors.

Area	Orden	Frequency	%	Cm	Mtc
Urban	9	37.855	77.66	308	24
Rural	7	10.889	22.34	89	5
Total	16	48.744	100	397	29

Table 5. Number of dwellings that use a translucent material in the different areas of the Canton of Portoviejo.
Source: Prepared by the authors.

STAGE 2 (PROBE DESIGN AND ROOF MODELS)

To evaluate the thermal and lighting conditions through the experimental study, 4 model prototypes were built, with 1m x 1m x 1m dimensions, and plywood walls. The variables analyzed were the lighting and temperature characteristics inside the prototypes. The first model (A) is a base model, with a 100% metal roof, and it served to evaluate the environmental conditions and to compare them with the other three prototypes. Model (B) was designed based on the empirical overhead lighting solutions of the 29 dwellings observed, which opted to include PVC-based translucent material on the central upper part of their homes, where PVC represented 2% of the roof element. Model (C) was made from PVC and represented 10% of the total roof (two central strips of 5%, one horizontal and another perpendicular to the solar path), forming a cross on the center of the roof. Model (D) was designed based on recommendations of the IDAE technical guidelines and the overhead lighting methods of the 29 dwellings observed, which opted to include PVC-based translucent material on the outer lateral part of their dwellings (garages, pergolas), where PVC was 16% of the roof, represented in two 8% lateral strips, placed horizontally regarding the solar path. The prototypes were oriented on the East-West axis, with the highest part of the roof facing West, with a 10% slope, and they were positioned equidistant on the North-South axis, with a 1 m separation between them. The parameters measured in these were the indoor air temperature (Tai) and the indoor lighting level (E), for which HTC-2 digital thermo-hygrometers were used, and 2 digital apps: lux light meter Doogo apps and Luxometro: Smart Lux Meter.

RESULTS AND DISCUSSION

ANALYSIS OF PROTOTYPES A & B

The data collection of prototypes A and B was recorded for 15 days in January 2021, in 3 different periods (1-7, 10-14, 29-31), from 8 am to 6 pm, in 60-minute intervals. Figure 3 shows the average results of all the measurements taken at each one

horas	Tai/°C		E/Lux	
	A	B	A	B
8:00	25,76	25,92	0	45,0
9:00	26,07	26,14	0	45,9
10:00	27,38	27,72	0	53,6
11:00	29,85	30,05	0	53,9
12:00	30,78	30,98	0	54,1
13:00	32,23	33,93	0	54,5
14:00	32,45	34,16	0	54,5
15:00	32,27	33,97	0	54,5
16:00	32,09	33,86	0	54,1
17:00	30,15	30,35	0	50,7
18:00	29,19	29,38	0	42,3

Figure 3. Comparative matrix between prototype A and B.Source: Prepared by the authors.

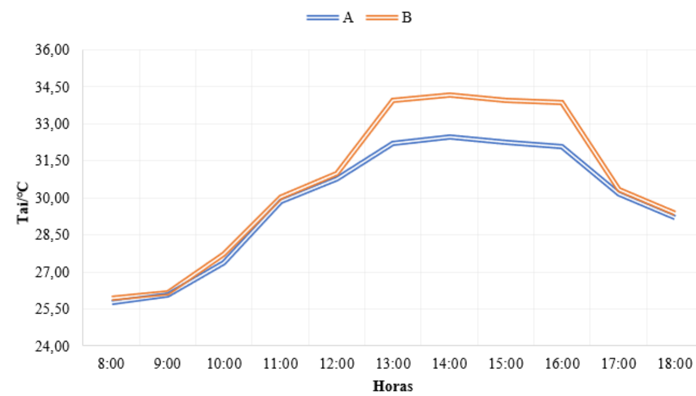

Figure 4. Comparative curves of the indoor temperature between the base model A and prototype B. Source: Prepared by the authors.

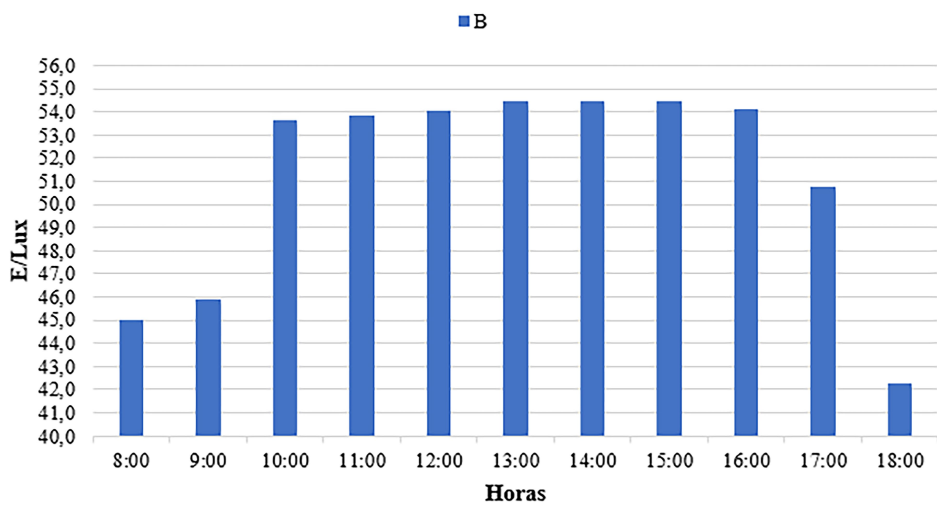

Figure 5. Indoor lighting levels of base model A and prototype B. Source: Prepared by the authors.

of the measurement times, and the structure of the A and B prototypes.

According to the results obtained from the base model A and prototype B, the average daily difference of indoor temperature between them is 0.75°C. The maximum temperature of model B is 34.16°C, recorded around 2 pm, which is 1.71°C higher than the indoor temperature of model (A). The maximum indoor temperature difference at 4 pm was 1.77°C (Figure 4). On the other hand, it was determined that the maximum lux value of prototype B was 54.5 lux, from 1 pm to 3 pm, approximately, and for model (A), the base model, this had a value of 0 lux (Figure 5).

ANALYSIS OF PROTOTYPES A & C

The data collection of prototypes A and C was made for 15 days in February 2021, during 3 periods (5-14, 19-21, 26-28), from 8 am to 6 pm, in 60-minute intervals. Figure 6 shows the average results of all the measurements taken in each one of the measurement times, as well as the structure of prototypes A and C.

Following the results obtained in the base model (A) and prototype C, the average daily indoor temperature difference between them is 1.25°C. The maximum temperature of model C is 36.57°C around 2 pm, which is 4.53°C higher than the indoor temperature of model (A) (Figure 7). Likewise, it was

horas	Tai/°C		E/Lux	
	A	C	A	C
8:00	25,72	25,88	0	64,6
9:00	26,16	26,32	0	67,6
10:00	27,47	28,39	0	69,9
11:00	29,95	30,15	0	70,5
12:00	30,85	31,13	0	70,5
13:00	31,96	34,35	0	71,3
14:00	32,04	36,57	0	71,2
15:00	31,77	34,18	0	70,8
16:00	31,74	33,47	0	69,7
17:00	29,91	30,26	0	69,5
18:00	28,69	29,26	0	57,9

Figure 6. Comparative matrix between prototypes A and C. Source: Prepared by the authors.

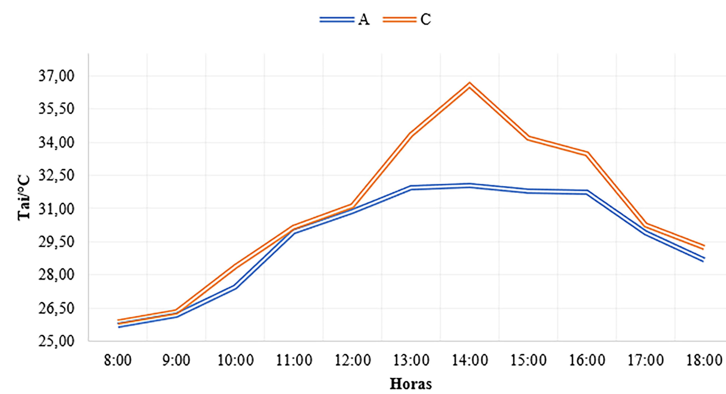

Figure 7. Comparative curves of the indoor temperature between the base model A and prototype C. Source: Prepared by the authors.

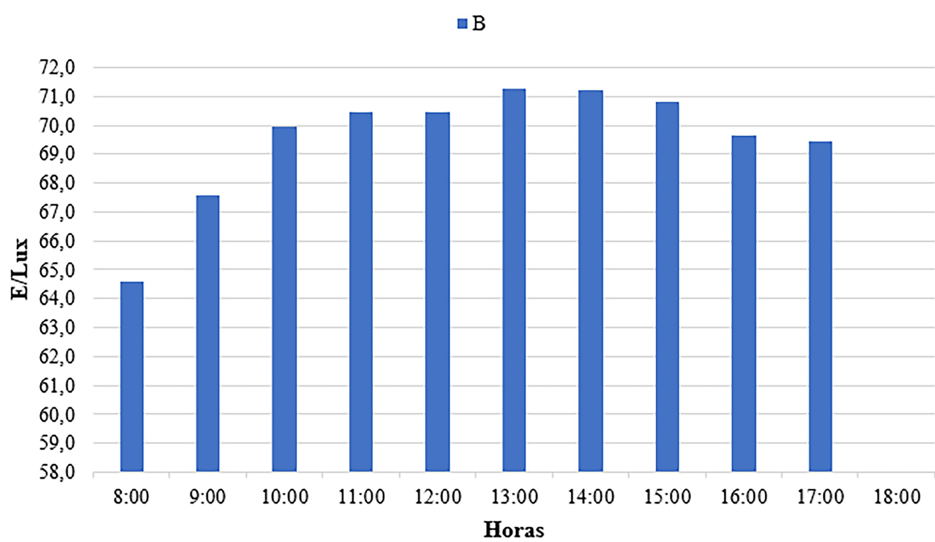

Figure 8. Indoor lighting levels of base model A and prototype C. Source: Prepared by the authors.

determined that the maximum lux value of prototype C was 71.3 lux, at 1 pm approximately, and for model (A), the base model, this had a value of 0 lux (Figure 8).

CALCULATION OF THE VARIATIONS OF PROTOTYPES A & D

The data collection of prototypes A and D was done for 15 days in March 2021, in 2 different periods (6-12, 19-26), from 8 am to 6 pm, in 60-minute intervals. In Figure 9, the average results of all the measurements taken in each one of the measurement times, and the structure of prototypes A and D, can be seen.

According to the results obtained from the comparison between the base model (A) and prototype D, the average daily indoor temperature difference is 1.90°C. The maximum temperature of model D is 38.26°C, recorded around 1 pm, which is 5.07°C higher than the indoor temperature of model (A) (Figure 10). It was also determined that the maximum lux value of prototype D was 118.4 lux, at approximately 1 pm, and that model (A), the base model, had a value of 0 lux (Figure 11).

COMPARISON OF THE DESIGN ALTERNATIVES

Under the analysis of this context, it was determined that, from 1 pm to 2 pm, approximately, there is a greater influence of solar radiation on the roof element, a result that matches Salgado (2012), whose research determined that, under normal conditions, the interphase from midday necessary for those

horas	Tai/°C		E/Lux	
	A	D	A	D
8:00	25,89	26,05	0	87,4
9:00	26,43	26,59	0	90,3
10:00	28,47	30,66	0	101,7
11:00	30,46	32,25	0	103,3
12:00	31,89	35,85	0	109,3
13:00	33,19	38,26	0	118,4
14:00	34,47	37,73	0	114,3
15:00	32,17	34,45	0	114,2
16:00	31,71	33,47	0	109,7
17:00	30,01	30,27	0	104,1
18:00	28,75	29,12	0	83,2

Figure 9: Comparative matrix between sheets A and D. Source: Prepared by the authors.

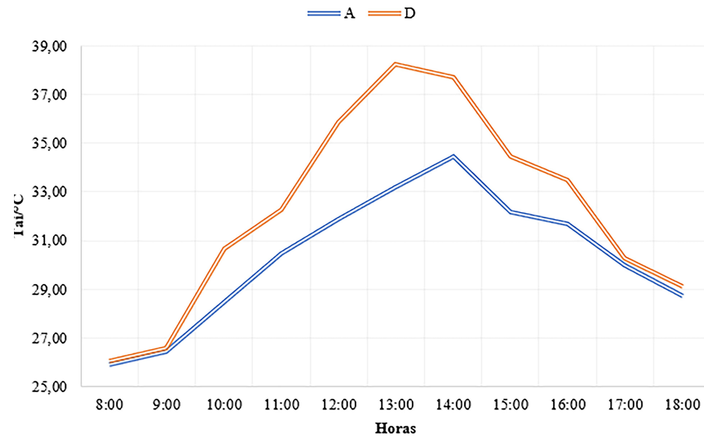

Figure 10. Comparative curves of the indoor temperature between base model A and prototype D. Source: Prepared by the authors.

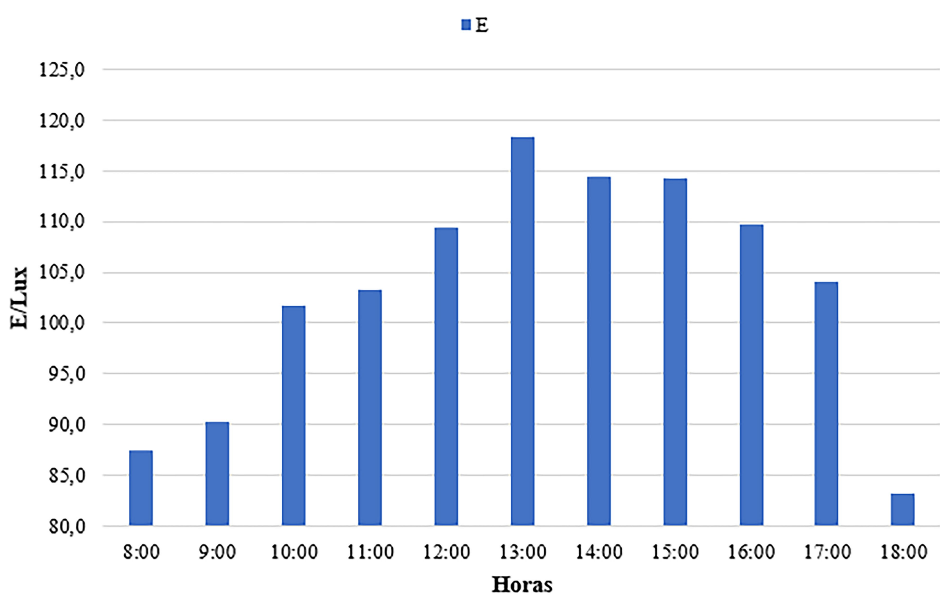

Figure 11. Indoor lighting levels of base model A and prototype D. Source: Prepared by the authors.

buildings to reach their maximum temperature was of 1 hour, 34 minutes and 10 seconds. Based on this study, the following stand out: Model B has the lowest indoor temperature variation, with 32.63%, which contrasts the 32.97% and 34.40% of models C and D, respectively. However, from the moment where the models reach the maximum temperature, model D has drastic temperature drops, reaching a relative balance at 3:30 pm, approximately (Figure 12), compared to the other prototypes. In addition, this model has values that exceed 100 lux from 10 am to 5 pm (Figure 13). This phenomenon is due to the amount of RTM (16%) with which it was designed, a percentage that exceeds the 10% recommended by IDAE (2005, p. 48), and the criterion corroborated by Monroy (2006), who states that the design criteria set out for vertical windows can also be adapted for the design roof hollows (p. 80), specifying that the 1/10 ratio is satisfactory.

In qualitative terms, model C, strictly designed following the setup of the shape factor to the occupied area of 10%, and with a cross shape, does not have good indoor light distribution. The opposite occurs with model D, which does project a suitable light distribution indoors, on having two lateral strips and the peculiarity that the narrowest part forms a perpendicular with the solar path; a measurable and observable aspect that is similar to the spatial distribution of cities of ancient Greece, famous for an orientation that guaranteed continuous access to sunlight. This setup also agrees with Lobaccaro et al. (2019), who analyzed 34 case studies in 10 different countries, determining that, in functional

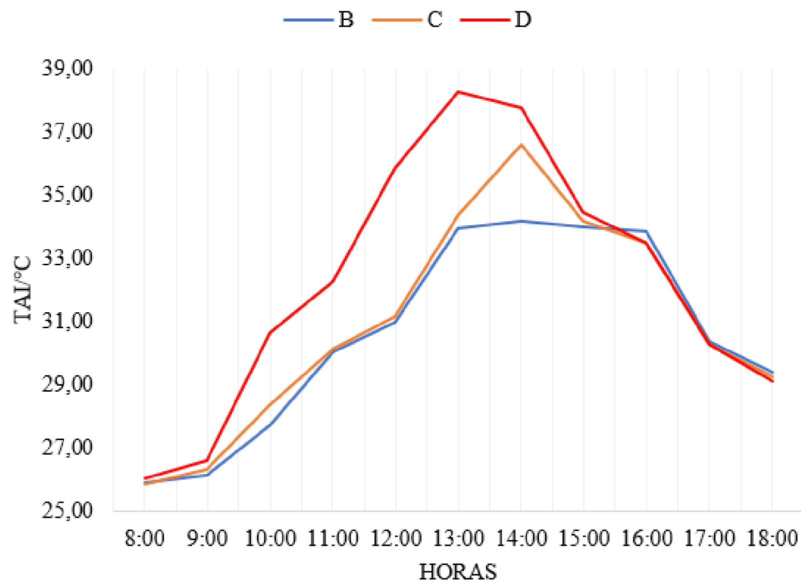

Figure 12. Indoor temperature of models B, C, and D.Source: Prepared by the authors.

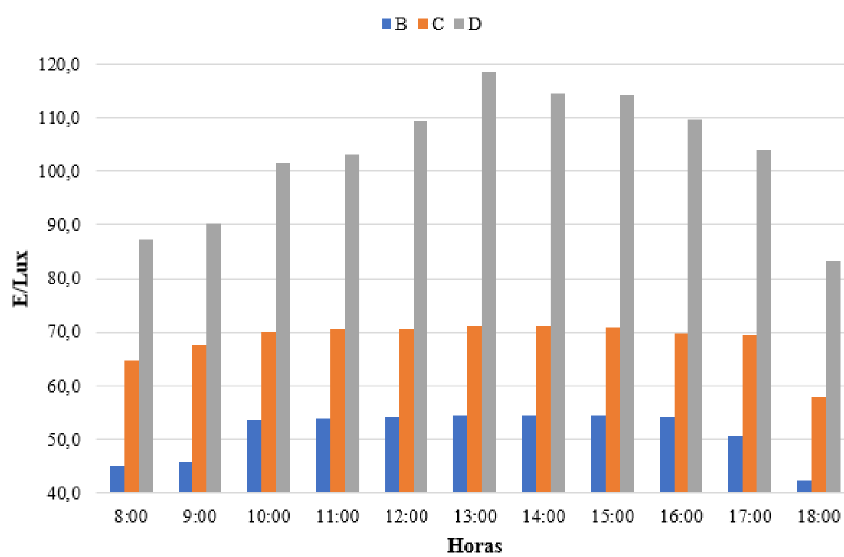

Figure 13. Indoor lighting levels of models B, C, and D. Source: Prepared by the authors.

terms of the shape factor, the distribution on straight edges for solar energy capture has better results. In summary, starting from the criteria mentioned and the experimentation done, this setup shows the best indoor light distribution, although for some authors, like Linares (2015), the play between light and shadow produced by other options will continue being a paradigm.

GENERAL CONSIDERATIONS

On being a developing country, Ecuador does not have regulations or municipal ordinances about the right to solar access, which can be seen in its urban fabric and, particularly, in the 397 housing solutions observed in this research, from which only 13.4% used translucent material on the roofs to capture overhead sunlight. Qualitatively, in the first stage of the study, as part of the systematic observation, in rural areas extremely hot dwellings were seen, with an absence of light, terraced on their side and rear walls, which added to crowding showed a low livability index. As for the needs of the area, the use of prototype D can be implemented. Likewise, it was possible to verify that the dominant roof material in the Canton is Aluzinc, which is even used as a double roof. Regarding the applicability of the prototypes, model B is recommended for specific overhead sunlight

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gains. Model C is not recommended, and model D, for dwellings that have some type of solar protection, and for terraced dwellings attached on their sides and rear.

CONCLUSION

In this work, three light roof prototype alternatives, with the combination of Zinc and PVC materials, were assessed, for warm climate areas under the parameters of sustainability and environmental protection. For this, passive overhead lighting capture strategies were used, such as orientation and the compacity of the shape factor, implementing the solar approach strategy, which would allow designing light roofs that improved the light contribution inside the dwelling, without generating spaces with overheating. The most important discovery of this methodological process, which was based on field measurements using scale models, was the determination of the time of greatest influence of the sun on the roof for this type of areas and the setup that must be given to the RTM, to design spaces that comply with suitable thermal and light characteristics to have healthy dwellings. One of the limitations of this research was the lux data collection, due to its high variability index in space-time.

This allows discarding the hypothesis set out, to a certain degree, as the incorporation of RTM on the roof increases the lighting level, but its shape factor setup does not reduce or maintain the temperature inside the tested models. Now, the results of model D have drastic temperature drops from the moment they reach their peak, and at the same time record a better indoor light distribution, that is to say, a better lux level. As a conclusion, it is important to mention that the question emerges about what would happen if these construction strategies were applied on double-skin roofs and gable roofs. Thus, as the next step to perfect the prototypes presented herein, this study recommends analyzing the incorporation of translucent material on gable roofs.

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CFD SIMULATION OF AN INCLINED ROOF SOLAR CHIMNEY

SIMULACIÓN MEDIANTE CDF DE UNA CHIMENEA SOLAR INCLINADA SOBRE LA CUBIERTA

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RESUMEN
En los últimos años se ha elevado el consumo energético derivado del uso de aparatos eléctricos para promover el movimiento de aire en regiones con climas cálidos, lo que ha traído como consecuencia un impacto negativo en el ambiente. En este trabajo se evalúa el desempeño de una chimenea solar utilizada para inducir la ventilación natural en un espacio cerrado, bajo las condiciones del clima cálido mexicano. Para tal efecto, se desarrollaron simulaciones CFD empleando el modelo de turbulencia RNG k- e y el modelo de radiación DO, y considerando únicamente los fenómenos de convección natural. El desempeño de la chimenea solar se evaluó comparando los resultados de las simulaciones con mediciones experimentales; análisis que reveló una buena concordancia. Se obtuvieron temperaturas de hasta 46.5°C en el aire dentro de la chimenea y de 77.1°C en la placa de absorción; resultados que permiten verificar la influencia del fenómeno de descarga de calor por flotación natural del aire en la chimenea.

Palabras clave
energía solar, ventilación, simulación CFD

ABSTRACT
In recent years, energy consumption from electrical devices to foster air movement in regions with warm climates has risen, with the resulting negative impact on the environment. The purpose of this paper is to evaluate the performance of a solar chimney used to induce natural ventilation in a closed space, under the weather conditions of the hot humid Mexican climate. For this purpose, CFD simulations were run using the RNG k- e turbulence model and the DO radiation model, considering only natural convection phenomena. The solar chimney performance was evaluated, comparing the results of the simulations with experimental measurements, analysis which showed a good match. Temperatures of up to 46.5%°C in the air within the chimney, and of 77.1°C on the absorption plate, were obtained, results that allow verifying the influence of the heat discharge phenomenon by the natural flotation of air in the chimney.

Keywords
solar energy, ventilation, CFD simulation

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INTRODUCTION

Around 30% of residential electricity consumption in Mexico is used to attain thermal comfort in warm climate areas (González & Beele, 2016), a proportion that continues to noticeably increase as the use of air-conditioning equipment rises. The amount of electricity used for artificial climatization in warm climates depends on several factors, specifically the design and elements of the space's envelope, as well as the equipment that provides the three elements that determine thermal comfort: temperature, humidity, and airspeed (de Buen, 2017).

The results of the National Survey on Energy Consumption in Private Housing (National Institute of Statistics and Geography [INEGI, in Spanish], 2018), show there are 14.6 million fans in the country. The ones most commonly used in dwellings, known as ceiling and pedestal fans, total 11.5 million, with a preponderant use, where for 34.4% of the dwellings, they are used between 5 and 9 hours a day.

These data provide a general overview of energy consumption from devices that promote air movement in warm climates, and their resulting economic and environmental impact. From this comes the importance of implementing passive climatization strategies to favor natural ventilation and to provide thermal comfort.

Natural ventilation in buildings comes from two sources: by wind pressure (cross ventilation), and by temperature differences, namely, from the air density between the outside and inside (Stack effect). In warm humid climates, ventilation through the Stack effect is inefficient, since the temperature delta between the outside and inside of naturally ventilated buildings, is limited. In this context, solar chimneys represent an efficient alternative to promote natural ventilation, thanks to their ability to take advantage of solar resources to heat one part of the building, fostering the extraction of warm air by convection.

A solar chimney is basically a solar air heater that is embedded, vertically or horizontally, on a building as part of a wall or roof, and whose classification can vary depending on the different setups or functions (Lal, Kaushik & Bhargav, 2013). Different variations can be found in solar chimney designs. These are affected by several factors, such as the location, climate, orientation, size of the space being ventilated, and internal heat gains. However, the basic elements involved, like the solar collector, the transparent roof, and the entry and exit openings, are part of each design (Khanal & Lei, 2011).

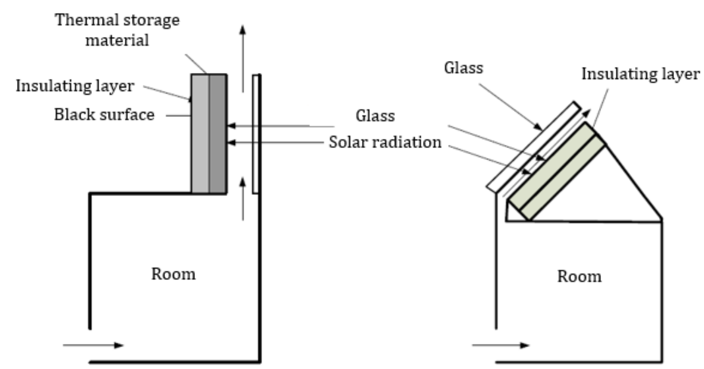

Figure 1. Solar chimney setups. Source: Harris & Helwig (2007, p. 136).

CHARACTERISTICS AND OPERATION OF SOLAR CHIMNEYS ON THE ROOF

To promote natural ventilation, solar chimneys inclined on the roof or cover work with the same principles as vertical chimneys, that is to say, they are assisted by the suction effect on openings located on the lower part of the chimney, and the hot air that is extracted through the upper openings of the flue (Figure 1). Generally, solar chimneys are made up of a transparent cover, and an absorption or thermal storage plate, separated by a cavity or air flue. They have an insulating layer on the back of the plate, to avoid heat losses.

In most cases, the transparent cover of the solar chimney is made of glass, a material that is transparent to short-wave radiation. One part of the incident solar radiation on the surface of the glass is transmitted directly to the internal environment, another is reflected outside, and a third is absorbed by the material. As the glass has low absorption and is exposed to heat exchanges by convection on its two faces, its surface temperature is always close to that of the air it is in contact with.

The absorption plate is commonly made of a metallic material with high emissivity and absorbance values and is heated by absorption from the portion of solar radiation transmitted by the glass. A part of this heat may be lost by conduction towards the external side of the plate, where there is thermal insulation, and another part is ceded to the air in the cavity by thermal convection, and to the glass, by infrared radiation. In this way, with the increase in temperature of the air present in the chimney's cavity, which is heated by the absorption plate and the glass, a rising air movement is generated towards the upper opening.

The strategy of integrating solar chimneys throughout the slope of the roof or cover of the buildings allows having large areas to collect solar irradiance and taking advantage of it when the sun is at its highest. Some disadvantages of these systems are that the effective height is restricted by the angle of inclination of the roof and the possibility of greater pressure losses due to changes of direction, apart from the air's path (Harris & Helwig, 2007).

PREVIOUS RESEARCH PROJECTS

A significant amount of research has been made since the 1990s, through experimental, analytical, and computational methods, focusing especially on finding optimal design solutions to improve natural ventilation using solar chimneys. According to Shi *et al.*, 2018), the performance of these systems is mainly based on eight factors: the angle of inclination; the cavity width; the height; the dimensional ratio between height/cavity; the entry opening area; the exit opening area; the entry/exit ratio, and solar radiation. Zhang, Tan, Yang, and Zhang (2016) also mention the thermal characteristics of the solar radiation absorption material.

The angle of inclination of solar chimneys is one of the most analyzed parameters. Several research projects report that an inclination of 45° is optimal to obtain a maximum airflow (Chen *et al.*, 2003; J. Mathur, Bansal, S. Mathur, Jain & Anupma, 2006; Bassiouny & Korah, 2009; Saifi, Settou, Dokkar, Negrou & Chennouf, 2012; Jianliu & Weihua, 2013; Al-Kayiem, Sreejaya & Gilani, 2014; Saleem, Bady, Ookawara & Abdel-Rahm, 2016; Dhahri & Aouinet, 2020; Kong, Niu & Lei, 2020), an inclination that generates few pressure losses, as it represents a balance between the Stack pressure and the heat transfer by convection (Yusoff, Salleh, Adam, Sapian & Sulaiman, 2010; Mahdavinejad, Fakhari & Alipoor, 2013).

The recommendations for the sizing of the cavity thickness vary between 0.10m and 0.35m. Several studies agree that airflow is reduced with the increase in cavity thickness, due to the presence of inverse flow. In research made by Shi *et al*. (2016), Saifi *et al*. (2012), Yusoff *et al*. (2010) y Zhai, Dai & Wang (2005), no inverse flow is recorded in cavities of 0.20 m. Meanwhile, Bouchair (1994), Li, Jones, Zhao, and Wang (2004), and Liping and Angui (2004) report a 1:10 ratio between the cavity width and the effective height of the chimney, as optimal.

The works done on the increase in length of the solar chimney have shown a lower impact of this geometric characteristic on chimney performance, compared to the increase in the cavity width. The range of chimney lengths analyzed in previous research runs from 0.40 m to 3.00 m. In this sense, Neves (2012) states that after 1.50 m, the variations in length result in progressively lower increases in the airflow.

In general, the range of the setup variables analyzed in previous studies is limited. These focus mainly on cavity width and inclination angle. The optimal values suggested do not apply to all solar chimney setups, as they have reciprocal dependence relationships between two or more variables, so it is necessary to carry out more research to evaluate their performance under different contexts.

DYNAMIC OF COMPUTATIONAL FLUIDS

Computational Fluids Dynamics (CFD), is a branch of fluid mechanics that uses data structures and numerical methods to solve and analyze the equations that govern the flow of fluids, while also allowing quantitatively and qualitatively knowing their behavior.

CFD simulation is one of the most important methods to study natural ventilation and can be used to predict airflow and heat transfer inside and outside buildings. CFD models are capable of providing a detailed spatial distribution of the air temperature, pressure, speed, and turbulence (Sánchez, 2017).

One of the most used numerical techniques to discretize the equations that describe the movement of fluids (Navier-Stokes) is the method of finite volumes, whose starting point is the breakdown of the dominion to be analyzed in a finite number of adjoining control volumes, where the variables are calculated in the nodes located in the centroid of each control volume. The control volumes and the nodes are defined using a numerical mesh, which is essentially a discrete representation of the dominion where the problem is solved.

The description of the CFD simulation model used in this research, to analyze airflow through a solar chimney, is presented in the following section. It is worth mentioning that the boundary conditions were determined based on experimental results obtained from the onsite monitoring of a life-size physical model.

METHODOLOGY

The work presented here has a quantitative approach (using mathematical, statistical, and IT tools). Likewise, the decision was made to run an experimental study and a numerical analysis to collect and analyze the data, seeking causal relationships between the measured variables. The analytical scientific method has been followed regarding the analysis of the simulation results, and the comparison of numerical and experimental results.

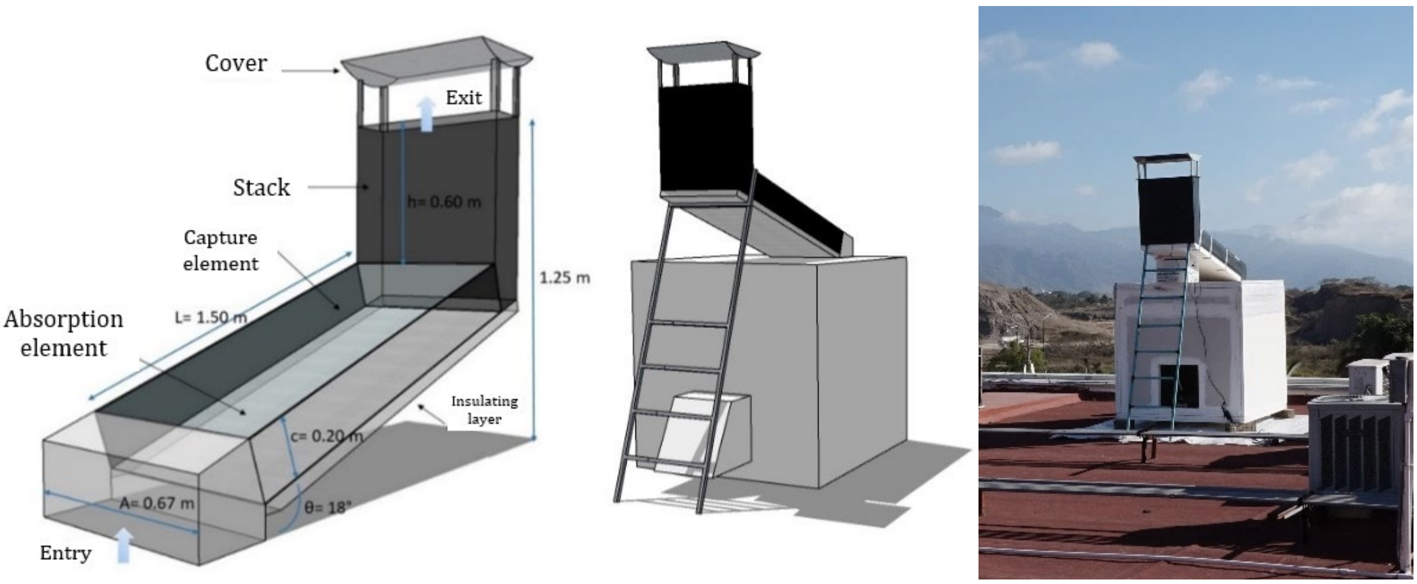

Figure 2. Characteristics of the experimental model. Source: Preparation by the authors.

The design of the research starts from two fundamental phases. The first of these is the design of the solar chimney using the analysis of the existing bibliography, the determination of experimentation periods, and the construction characteristics of the experimental prototype. The second phase consisted in applying the CFD technique to simulate the system, to later validate the CFD model used from the experimental results, and to check whether a coherent solution has been found for the problem.

EXPERIMENTAL STUDY

The experimental study was carried out under the climate conditions of the city of Puerto Vallarta, Mexico, with coordinates 20°C 42’ North and 105° 13’ West, at 10.0 masl. The climatic variables, including the room temperature, relative humidity, wind direction and speed, and global irradiance, were acquired from an automatic meteorological station.

The geometric setup of the solar chimney being analyzed was designed, establishing an inclination of 18° towards the South to obtain suitable solar irradiance conditions throughout the year, at the latitude of the study. A black opaque 22 caliber galvanized steel sheet collector was built, of 1.50 m in length, 0.67 in width, and 0.20 m of cavity thickness. To offset the pressure loss caused by the low inclination angle, a vertical extension or stack of 0.60 m was placed, coupled to the collector.

The space being ventilated consisted of a cubic chamber made of plaster panels of 1.50 per side, where a square opening of 0.50 m per side was placed, on the lower part of the vertical face opposite the collector entry, at a distance of 0.15 m from the base. A simple 4 mm thick clear glass cover was used as a solar radiation capturing element, and a flat 2.0 mm thick black opaque aluminum sheet as an absorption element, insulated on its inside face with a 5 cm thick polystyrene plate. The characteristics of the experimental model are presented in Figure 2.

Sensors were placed on the entrance of the chamber and inside it, inside the collector, on the absorption plate’s surface, and at the exit of the stack. The variables to monitor were the following:

- Airspeed in the chamber entrance.
- Temperature inside the chamber, plate temperature.
- Temperature of the air inside the cavity.
- Airspeed at the collector entrance.
- Speed at the stack exit.

Data were recorded every 5 minutes for three days in different months throughout the year, and hourly averages were then calculated, and statistical analyses were made to determine the data to be used in the simulations.

CFD SIMULATION

The methodology used to run simulations in most CFD codes contains three main stages: pre-processing; solution; and post-processing. Likewise, each one of these stages consisted of the following activities:

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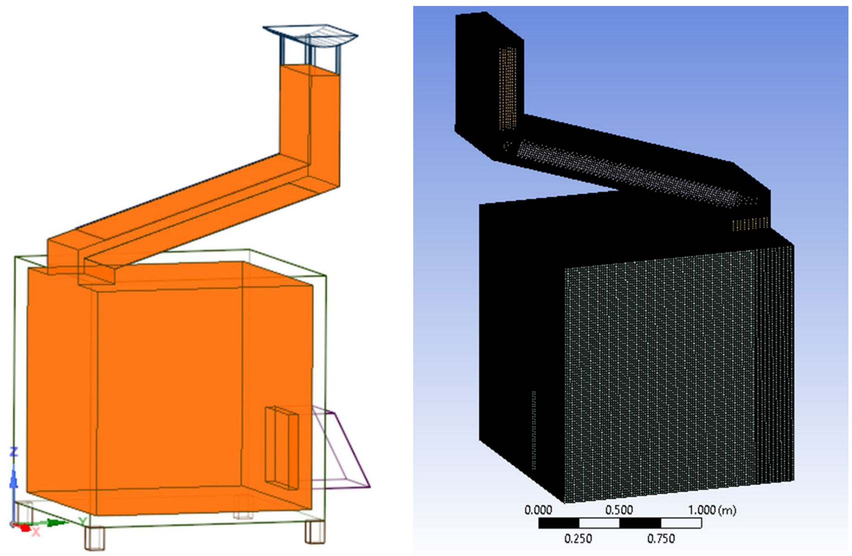

Figure 3. 3D model and analysis mesh. Source: Preparation by the authors.

Pre-processing:

- Choice of the suitable calculation model to solve the specific problem and to determine the target of the simulation.
- Definition of the geometry the problem represents.
- Generation of a suitable mesh, considering its dimensions and topology, as well as the independence of the results of the mesh used.
- Establishing the properties of the fluids.

Processing or solution:

- Determination of the boundary conditions, such as the temperature of the surfaces, the heat flow, the fluid entries and exits, the heat sources and sumps, moisture, etc.
- Definition of the solution's algorithms.
- Selection of the suitable turbulence model.
- Accuracy of the numerical parameters like differentiation schemes, relaxation factors, number of iterations, convergence criteria, etc.

Post-processing:

- Obtaining data, graphs, vectors, flow lines, outlines, etc. of the variables of interest.
- Validation of the model, comparing results with experimental data and other numerical results.

The commercial software ANSYS Fluent was used to develop the model and the numerical analysis. A 3D model was chosen (Figure 3) to make the solar chimney simulations, with the flow in a stationary state, considering only the natural convection phenomena. To simulate the airflow throughout the model, the parameters were adjusted to obtain the same conditions of the experimental test, considering a turbulent, incompressible, and stationary airflow.

Given the setup of the solar chimney's experimental physical model, a structured mesh was chosen, formed by hexahedra, whose sizes were setup considering the dimensions of the chimney, making sure that its shape complied with the requirements, so that the numerical calculations were stable and precise: high orthogonal quality, and low obliqueness of the elements. The mesh was refined in the areas of interest, like the glass cover, the aluminum plate, and the air entry and exit. With the meshing process, seven meshes were obtained, with between 660,711 and 2,376,021 elements, which were configured and tested to determine the suitable number of elements for the model, allowing reducing computational costs without losing information quality. A mesh formed by 1,633,428 elements was chosen for its analysis.

The Energy equation was activated, to allow calculating the parameters related to heat transfer and density variety. The Viscosity model was also activated with the RNG k–e turbulence model, which is described as stable, given that it provides reasonably accurate results for most of the indoor airflows (Rordigues, Frick, Bejat & Garrecht, 2021). The Discrete Ordinates (DO) radiation model, which allows simulating radiation through semitransparent mediums, was chosen, as well as radiation issues with non-participating mediums (like air), where the radiation indirectly affects the flow field, changing the layout conditions on the surfaces. Likewise, the Semi-Implicit Method of Pressure Linked Equations (SIMPLE) was chosen, as the coupling algorithm of pressure and speed.

Finally, the residual value of 10^{-6} was set as a convergence criterion for the energy equation, and of 10^{-3} for the remaining variables, as suggested in

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Material	Density ρ	Specific Heat Cp	Thermal conductivity λ	Absorbance	Emissivity
	kg/m3	J/kg·K	W/m·K	α	E
Glass	2500	750	1.40	0.14	0.85
Aluminum	2719	871	202.40	0.97	0.98

Table 1. Thermal-physical and optical properties of the materials. Source: Preparation by the authors.

the ANSYS user manual.

The system operates at sea-level atmospheric pressure, so the preset value of 101,325 Pa was kept. The operating temperature is the room temperature recorded during different experimentation periods. For all the cases being simulated, it was considered that the air enters the chamber perpendicularly at the entry opening, at a constant speed of 0.15 m/s, and the temperature values obtained during the experimental test were introduced. Table 1 shows the physical properties of the materials of the elements that make up the model, and that take part in the energy exchange.

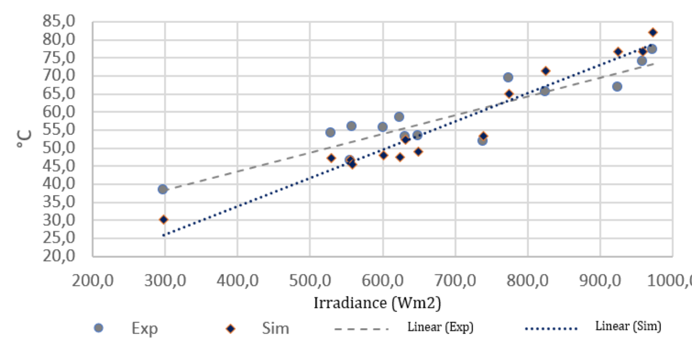

Figure 4. Aluminum plate temperature. Preparation by the authors.

RESULTS AND DISCUSSION

The Pearson linear correlation coefficient was used to analyze the results, to establish similarities between simulated variables and experimental results. Figure 4 shows the spread of the plate temperature data obtained both in experimental monitoring and the simulations. The linear correlation coefficient between the data series equals 0.93, which reveals a high positive correlation. The correlation between irradiance and plate temperature obtained in the simulations is r=0.97, while in the experimental results, this is r=0.91.

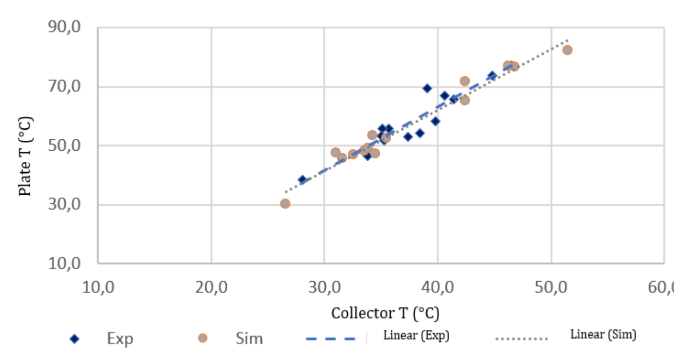

Figure 5. Correlation between air temperature and plate temperature.

The air temperature inside the chimney collector is directly related to the plate temperature, due to the heat transfer by convection (Figure 5); the correlation coefficient between these variables in the experimental measurements is r=0.94, and in the simulations, r=0.98, which indicates a high positive correlation.

In an analysis of the spread of air temperature data inside the collector, it is seen that the temperature obtained in the simulations is higher than the experimental data when irradiance conditions are higher than 750 W/m² (Figure 6). The correlation coefficient between both collector temperature data series (experimental and simulations) is r=0.87.

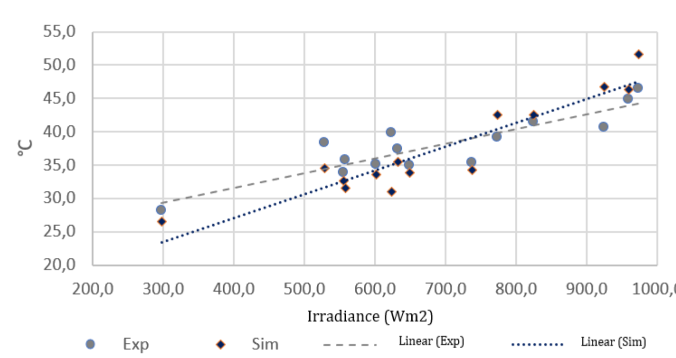

Figure 6. Correlation between air temperature and irradiance. Source: Preparation by the authors.

The results of the comparison of speeds at the slack exit between the experimental and simulation

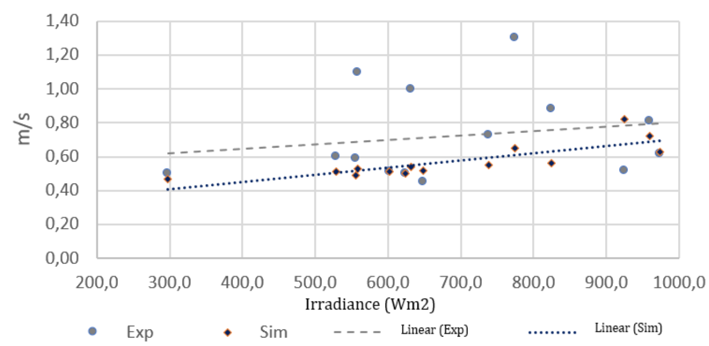

Figure 7. Correlation between air temperature and irradiance. Source: Preparation by the authors.

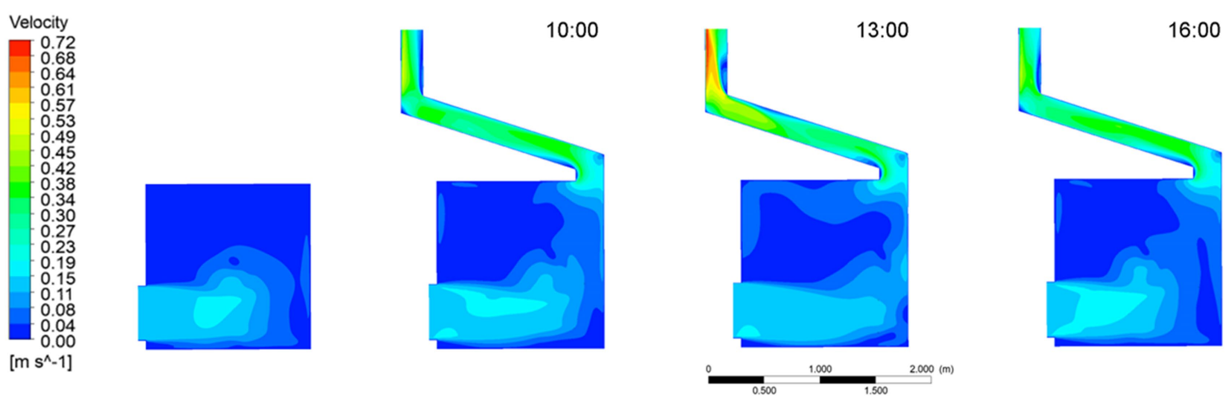

Figure 8. Airspeed layouts in the model's medium plane. Source: Preparation by the authors.

measurements, under different irradiance conditions, are presented in Figure 7, where the difference between the results is noticeable. The correlation coefficient between the experimental measurements and the simulation results is r=0.23.

This is explained because the CFD model does not consider the influence of the wind which, according to that stated in the experimental measurements, has a positive effect on the airspeed at the slack exit.

The internal airspeed is another variable considered when evaluating natural ventilation. The increase of air movement has the potential to change the thermal acceptability at higher operation temperature values (Saadatjoo, Mahdavinejad & Zhang, 2018). To analyze this variable, speed layouts were obtained on the model's medium plane. Figure 8 illustrates the layouts generated by the simulation made with experimental data in October, which had the highest amount of solar irradiance available within the warmest period in the study area. This corresponds to a monthly irradiance average of 363 W/m^2 and a mean temperature of 27.6°C. The changes in the airspeed distribution can be seen in three moments of the day. After comparing the information obtained with the control simulation (the chamber without chimney and exit opening), higher air circulation is seen at 1 pm, close to the solar midday.

CONCLUSION

The results of this research show that it is feasible to use a vertical extension in inclined chimneys to offset the pressure loss caused by the reduction of the inclination angle, and thus optimize solar gains. A smaller inclination would facilitate the incorporation of the system to covers with slopes no greater than 20%, as is the case of most constructions for residential use in the study area.

The data obtained in the simulations showed a good fit with the experimental measurements: the CFD model was capable of suitably predicting the absorption plate temperatures, with a correlation coefficient of r=0.93

with the experimental results. The temperatures inside the collector also showed a high positive correlation with the experimental measurements (r=0.87).

With the CFD simulations, it is possible to verify the importance that the heat discharge phenomenon by natural flotation of hot air has in this system, both for the experimental results and for those obtained by simulation. In fact, a strong correlation of the irradiance with the airflow of the chimney was seen. The CFD analysis allowed studying the airflow patterns within the chimney, by showing the speed layouts.

After comparing the CFD results with the experimental results, the conclusion has been reached that the computational model suitably described the thermo-fluid dynamic behavior of the solar chimney, using the turbulent model k-e RNG complemented with the Discrete Ordinates radiation model.

The seasons and times of the day where natural ventilation is most needed as a thermal comfort strategy in the study area, coincide with the favorable conditions to provide high airflow rates, which states the advantage of using this chimney setup for natural ventilation in low-latitude regions with warm humid climates. It is considered that, by using solar chimneys, it is possible to improve ventilation without economic and energy expenses, as the system does not need conventional energy and does not generate operation or maintenance expenses.

The predictions for speed, temperature, humidity, contaminant concentration, flow patterns, and air exchange rates in buildings are required to design healthy and comfortable indoor environments. The approach proposed in this research contributes to the practical use of the CFD method in architectural design, providing detailed information about the numerical model used. The satisfactory results of these simulations allow concluding that it is possible to simulate and study 3D cases in a stationary state affordably and simply.

Natural ventilation is not only crucial for energy conservation and the reduction of carbon emissions but also to improve the comfort level and the air quality of the built environment. Recently, the importance of providing sufficient ventilation in closed spaces has been pointed out, to promote indoor air renewal with outdoor air, and to reduce the transmission of sicknesses.

From the analyses made, it is concluded that the setup of the proposed solar chimney has significant potential when it comes to increasing natural ventilation in places where cross ventilation cannot be used, bearing in mind that generally rooms of a dwelling are characterized on being ventilated on a single face. It is recommended, for later studies, to make 3D simulations at a life-size scale, and to analyze the temperature distribution in a room of a dwelling with the inclusion of doors, windows, thermal loads, and so on.

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