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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

SOLEDAD ELISA ANDREONI-TRENTACOSTE
Magíster en Energías Renovables
Becaria Doctoral
Instituto de Ambiente, Hábitat y Energía (INAHE) - Centro Científico Tecnológico (CCT) - Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET)
Mendoza, Argentina
https://orcid.org/0000-0002-2298-7649
sandreoni@mendoza-conicet.gob.ar

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

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

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- 21^{st} 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 21^{st} 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.

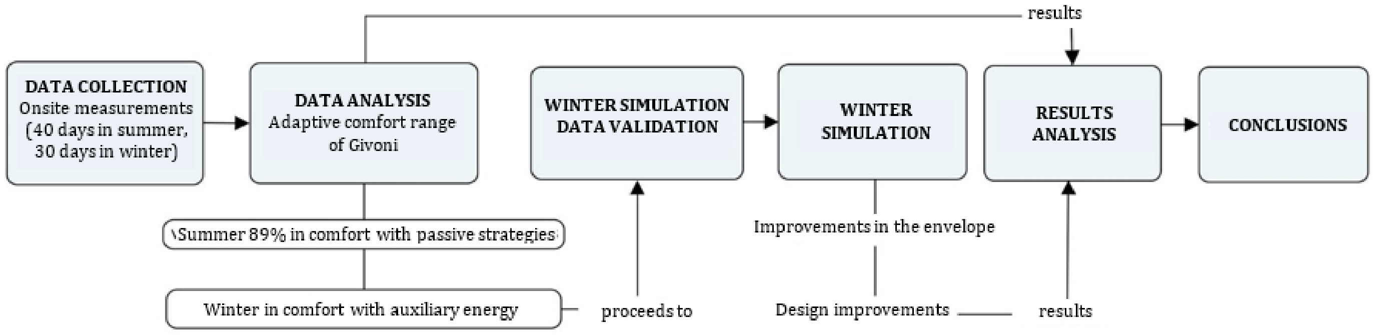

Figure 1. Methodological process flow chart. Source: Preparation by the Authors using the CmapTools software.

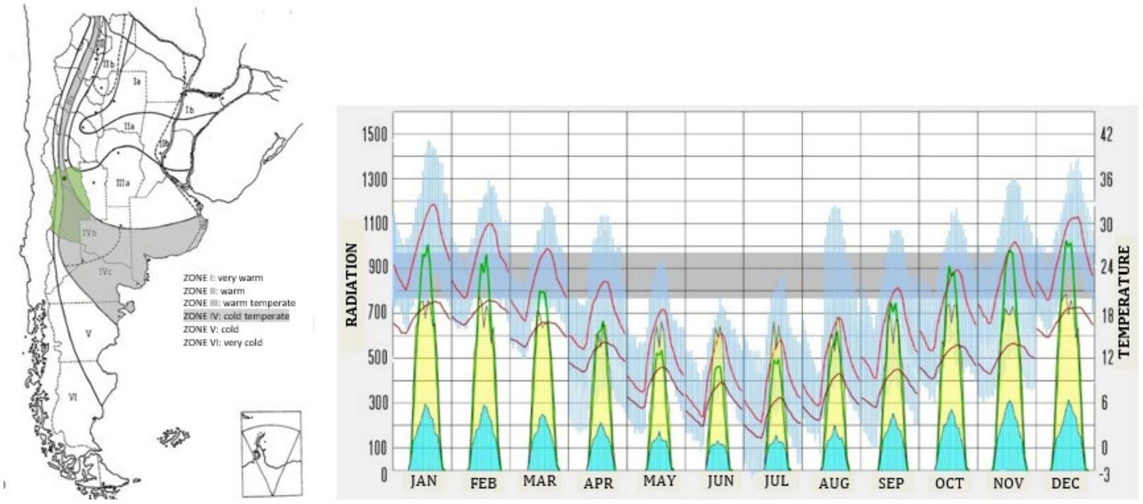

Figure 2. a) Bioenvironmental areas of Argentina, b) Monthly daily averages for temperature and solar radiation in the city of Mendoza. Source: Adaptation by the authors based on IRAM 11603 Standard, and graph made by the authors using Climate Consultant 5.0, EPW, climate file found at http://climate.onebuilding.org/

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.

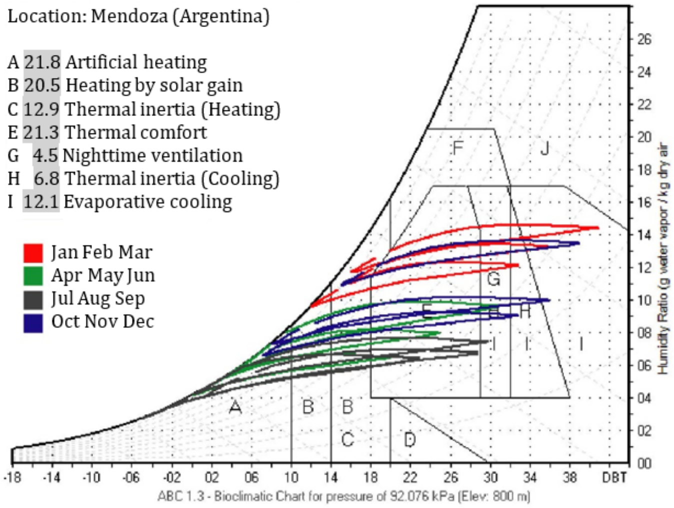

Figure 3. Psychrometric chart for Mendoza. Source: Preparation and adaptation by the authors, based on the graph prepared using the ABC software.

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

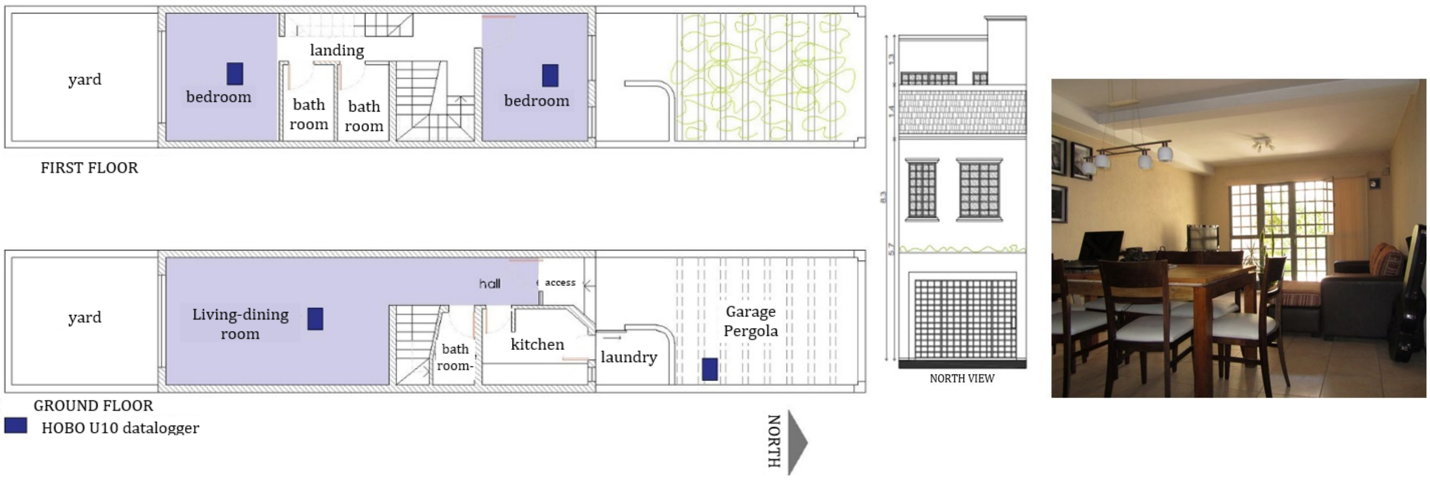

Figure 4. a) Floor plans with the location of the micro-collection HOBO U10 data loggers. b) Front view of the dwelling. c) Photograph of the studied room. Source: Preparation by the authors.

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

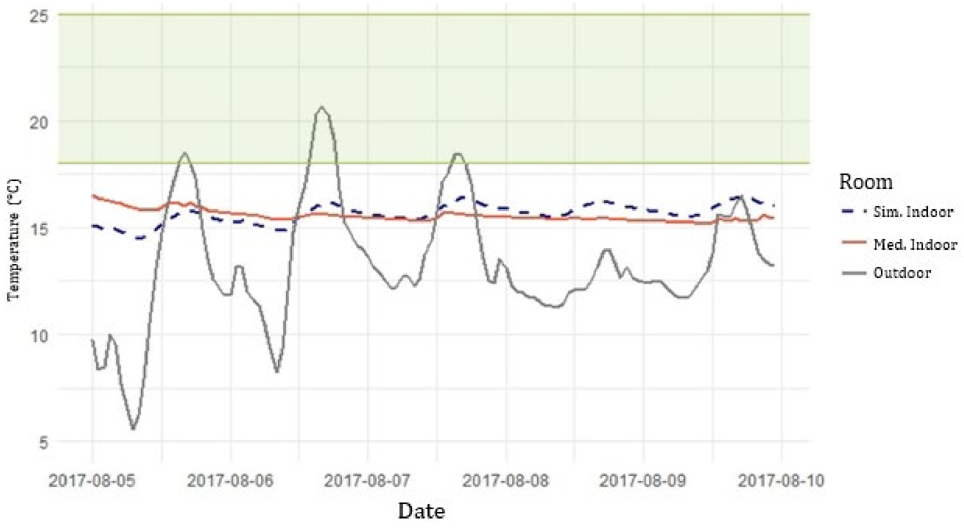

Figure 5. Simulation model fit. Source: Preparation by the authors in R.

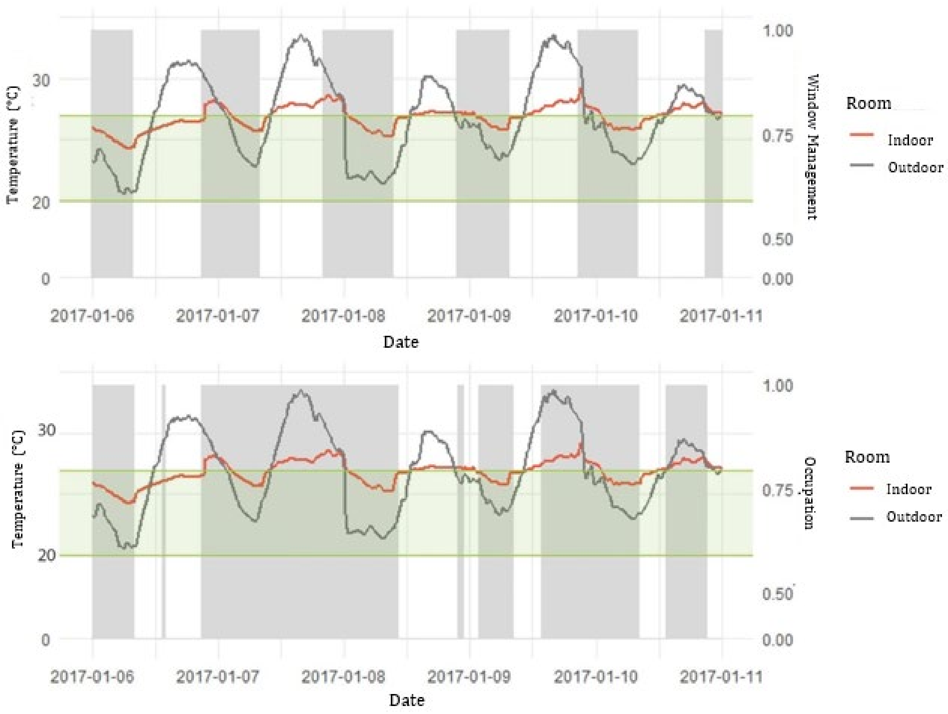

Figure 6. a) Outdoor and indoor summer temperature and window management for nighttime ventilation. b) Summer outdoor and indoor temperature under occupation. Source: Preparation by the authors in R.

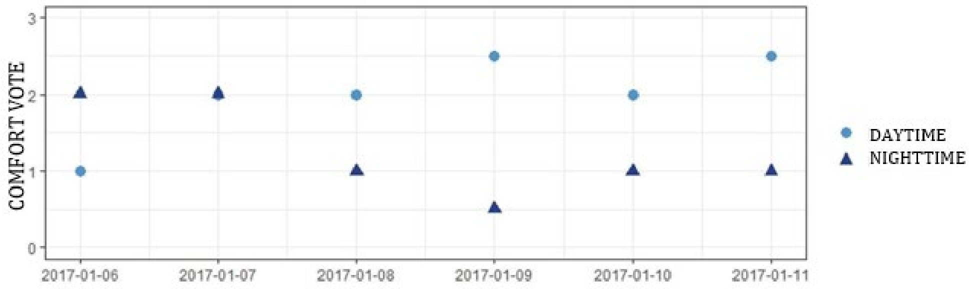

Figure 7. Thermal comfort sensation vote data. Window management period for nighttime natural ventilation. Source: Preparation by the authors in R.

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

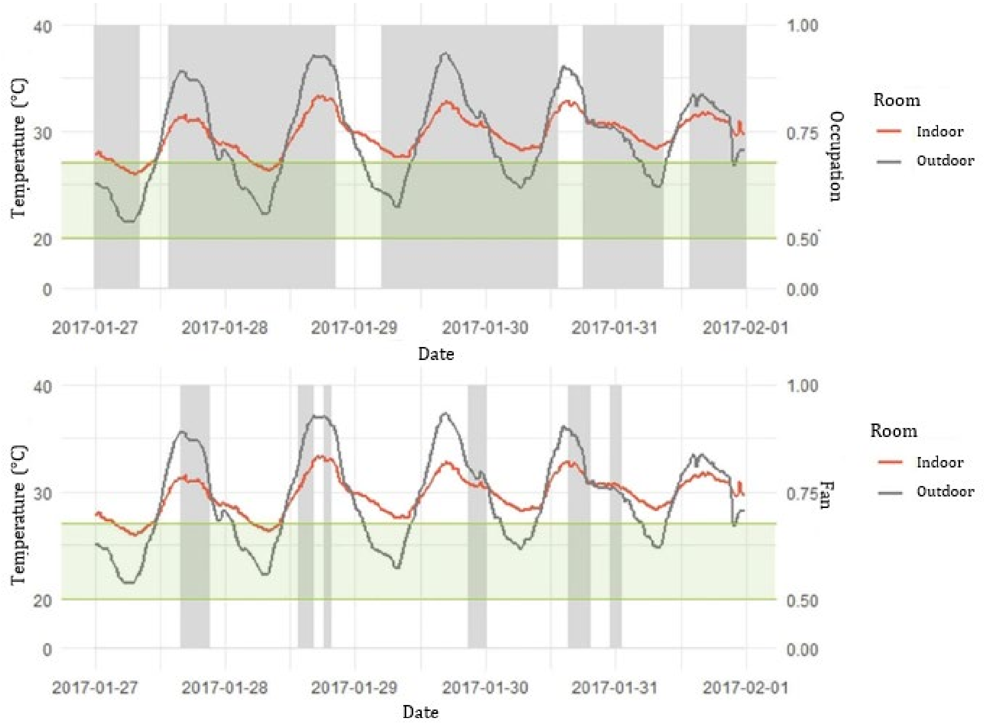

Figure 8. a) Outdoor and indoor temperatures in summer, windows always open, fan management. b) Outdoor and indoor temperatures in summer and occupation record. Source: Preparation by the authors in R.

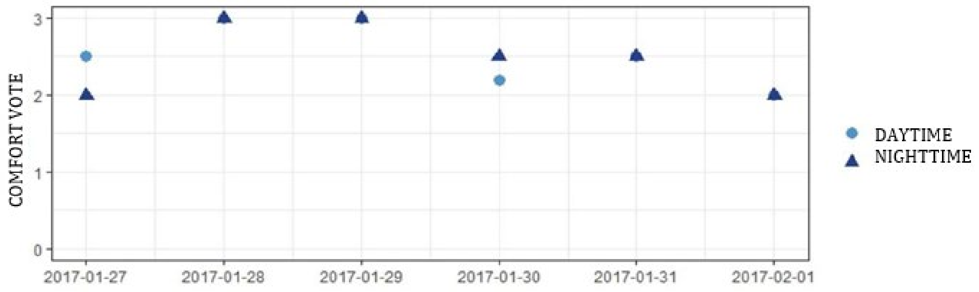

Figure 9. Thermal comfort sensation vote data. Period with windows always open. Source: Preparation by the authors in R.

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

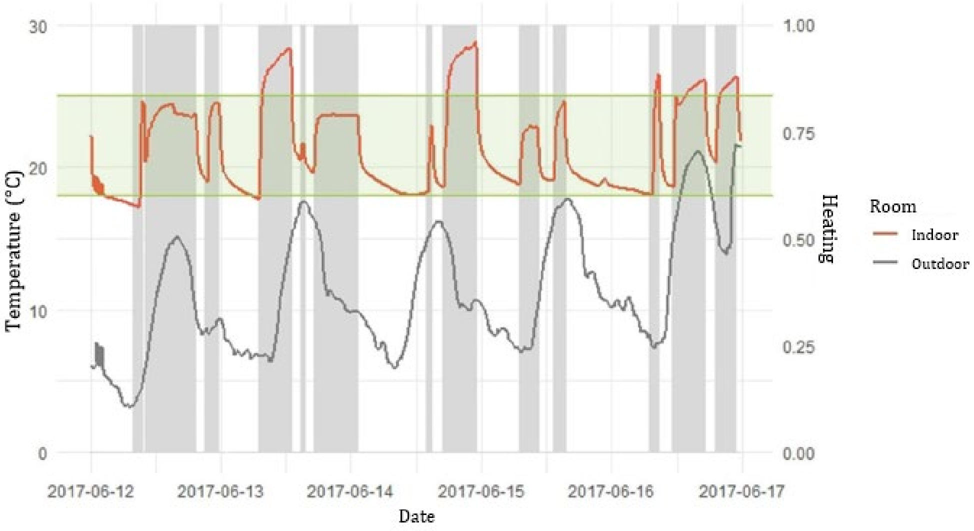

Figure 10. Outdoor and indoor temperature in winter and use of heating. Source: Preparation by the authors in R.

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^2k is obtained, and modifying the existing folded sheet and single glazed carpentry for aluminum ones with 4 mm DHV double glazing (K=4W/m^2k). 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.

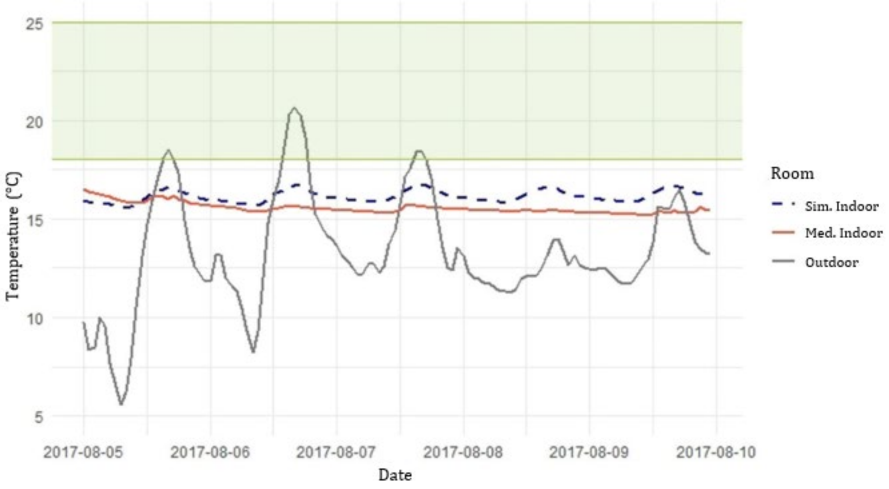

Figure 12. Outdoor and indoor temperatures in winter, simulated, without occupation, with improvements on the envelope.Source: Preparation by the authors in R.

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 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 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.

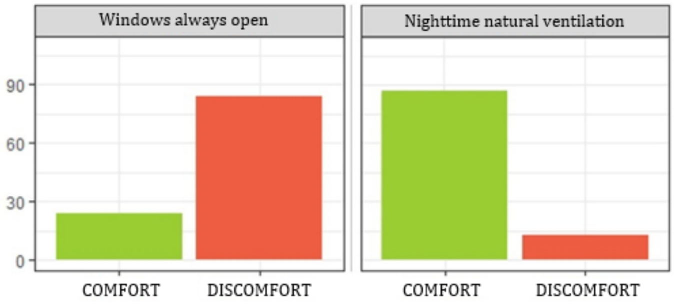

Figure 14. Comfort percentages in summer. Source: Preparation by the authors in R.

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

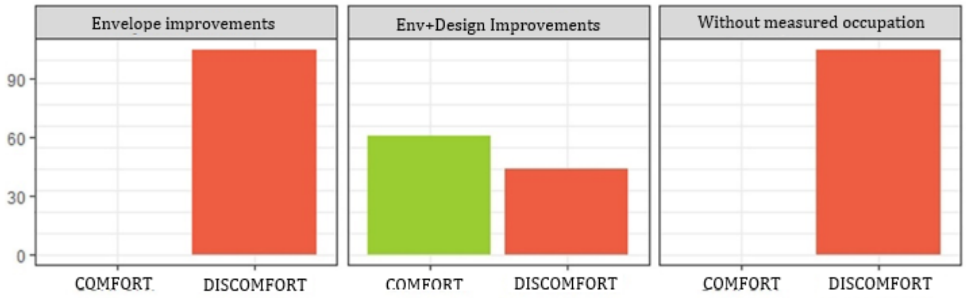

Figure 15. Comfort percentages in winter. Source: Preparation by the authors in R.

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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