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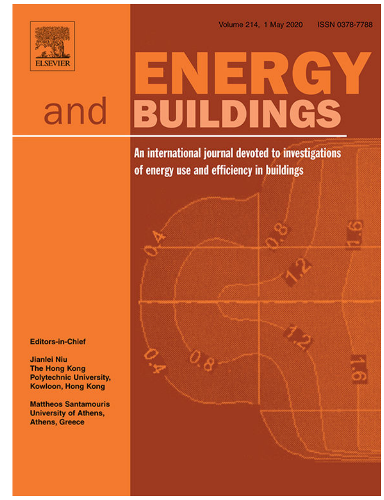

New paradigms in bioclimatic design toward climatic change in arid environments

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PII:	S0378-7788(22)00271-7
DOI:	https://doi.org/10.1016/j.enbuild.2022.112100
Reference:	ENB 112100
To appear in:	*Energy & Buildings*
Received Date:	19 January 2022
Revised Date:	1 April 2022
Accepted Date:	11 April 2022

Please cite this article as: G. Barea, M. Victoria Mercado, C. Filippín, J. Manuel Monteoliva, A. Villalba, New paradigms in bioclimatic design toward climatic change in arid environments, *Energy & Buildings* (2022), doi: https://doi.org/10.1016/j.enbuild.2022.112100

NEW PARADIGMS IN BIOCLIMATIC DESIGN TOWARD CLIMATIC CHANGE IN ARID ENVIRONMENTS

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Abstract

Energy consumption in buildings has increased exponentially since the industrial revolution. Given this scenario, the Argentinian government has proposed to implement energy efficiency measures in the public and private sectors with the aim of reducing energy demand by 10.3% by 2030 [72]. The Rational and Efficient Energy Use Program (PROUREE) aims to reduce consumption levels in buildings of the National Public Administration (NPA), assuming an exemplary role before the rest of the society [73]. In this context and, as a first instance, this study aims to know the performance of a bioclimatic building of the NPA currently constructed in an arid climate with high irradiance, when exposed to the consequences of CC. After validation in Energy Plus with data measured in situ, and considering that these types of buildings are replicated in the region, a simple design strategy is proposed to increase thermal, daylighting, and energy performance by 2099, without changing the project: the building was rotated 180º (case B), allowing to reduce direct solar gain, increase exposure to the strongest summer breezes and homogenize daylighting. The findings suggest that the implementation of these passive design parameters through an integrated analysis (energy, daylighting, and thermal comfort), can reduce energy consumption by 33.82 Kwh/m2, which represents 51.82% of the total energy consumption of the building in arid climates with high solar irradiance (Measured case=65.26kwh/m2. Improved case=31.44kwh/m2). These obtained reference values will serve as a source of reference for designers and policymakers to anticipate climate change and counteract the effects of CC through energy efficiency.

Keywords: Bioclimatic architecture. Natural ventilation. Daylighting. Climate change.

1. Introduction

Buildings are examples of technical innovation; they provide shelter, adapt to people's living and working needs, express desires, and represent cultures. And energy consumption depends, to a large extent, on the technology used during the design, construction, and maintenance of a building [1].

The residential and commercial building sector is responsible for approximately 30% to 40% of total global energy demand and one-third of global GHG emissions [2]. Energy use and related emissions are expected to double or even triple by mid-century due to several key trends, such as population growth and rising living standards. This dangerous trend could be partially reversed if better available building practices and technologies were widely disseminated. If this were the case, total energy use could remain constant or even decrease by mid-century compared to current levels [3]. Within this framework, there is a fundamental challenge; to consider energy systems holistically to address their inherent complexity.

Bioclimatic design strategies are well known, and through the use of globally accessible technology, serve to reduce the energy consumption of buildings. Numerous papers focus on specific issues of environmentally conscious design, opening up a niche of study regarding the holistic approach to this type of design. Harputjlugil and Wilde [4] caution that more attention should be paid to interdisciplinary research.

In pursuing environmental comfort, it is evident that a large number of randomly interacting variables are involved in determining the energy performance of a building [5]. Tianzhen Hong, Sarah C. et al [6] and V. Fabi et al. [7] state that, in addition to the properties of a building, building controls are closely related to occupant behavior, which in turn affects the energy consumption of the building. In this context, the final realization of the construction, the technical installations and the actual use of the systems operated by the occupants can have a large effect on the energy consumption and this results in huge differences between the actual and the predicted energy performance of the buildings. Nordford et al. [8] state that computer simulation models of building energy use, if calibrated with measured data, provide a means of assessing savings from retrofits, optimizing the operation of HVAC systems, and presenting energy consumption information to building operators. In their article, [5], summarize a number of recommendations: calibration should be performed over an annual cycle using hourly energy data; when this is not possible, primary hourly data should be collected over shorter cycles (weekly or monthly) to validate simulation results; and for a model to be considered calibrated, local weather archives should be obtained and used.

It is also a challenge to design a built environment that integrates thermal and lighting comfort to minimize the risk to sensory organs. Alan Pino et al. [9] state that overheating, high cooling energy demand and glare are recurrent problems in office buildings in Santiago, Chile. The authors analyzed energy consumption as a function of the ratio of glazed surface area to opaque surface area (WWR) in 288 office buildings in Santiago during spring and summer, under climatic conditions characterized by high irradiance. The authors concluded that, on the one hand, for these climatic conditions the most influential factor in energy demand (heating and cooling) is glazed surface area and that a ratio of 20% is adequate. On the other hand, they concluded that night ventilation proved to be an effective operational strategy to reduce the cooling energy demand, since 8-hour night ventilation (from 10 am to 7 pm) during weekdays reduces up to 37% of the total annual energy demand required for air conditioning. In addition, solar shading improves daylighting performance by preventing glare.

The randomness of variables in the prediction of building energy performance, defined by V. Fabi et al. [7] as a complex process, is added to climate uncertainty and the urgent need to study the effects of CC on the built habitat. Numerous studies have investigated trends in building energy demand in different parts of the world. Elias [10] and G.S. Brager et al. [11] have suggested that in order to design buildings and optimize their thermal comfort in the coming years without burdening the ecosystem with further environmental degradation, predictions of future climate conditions in different cities should be made. In this way, any changes can be anticipated and their effects counteracted through energy efficiency, better design, and, ultimately, energy savings [12]. In recent years, studies have predicted an increase in global air temperature due to climate change: one of the consequences of this temperature increase could be its effect on the indoor comfort of buildings, leading to higher energy consumption. Cellura et al. [61] studied the energy demand of office building typologies in southern Europe. The results reveal that, by 2090, energy consumption for cooling will increase between 50% and 119.7%. Similar studies has been done by Ciancio et al. [62] in Europe, Zou et al. [63] in China, Flores-Larsen et al. [3] in Argentina, Invidiata et al. [64] in Brasil, Pérez et al. [65] in España, Wang et al. [66], Shen [67] and Wang et al. [68] in América, among others.

In Argentina, the Center for Marine and Atmospheric Research (CIMA) prepared a report on climate trends in the recent past (second half of the 20th century) and a projection of the future climate (21st century) as part of the baseline studies for the third National Communication to the United Nations Framework Convention on Climate Change. The study focuses on observed and projected trends in surface temperature and precipitation and on some of the extreme indices that may cause relevant impacts. The climate scenarios were developed for two RCPs (Representative Concentration Pathway), 4.5 and 8.5, which correspond to the extreme case in which emissions will continue to grow according to current trends until the end of the century, so that the temperature will rise and consequently the energy consumption for cooling. Given this situation, and considering that the Argentine energy matrix is 90% based on fossil fuels and that the building stock represents 40% of national energy consumption, it is essential to recognize that buildings play a critical role in a low-emission future and as such their integration with sustainable development represents a global challenge [3-13].

Gholam Reza Roshan et al. [14], also endorse that to ensure thermal comfort in the near future it is necessary to review and adapt the design criteria of our buildings to climate change. The same authors compared bioclimatic design recommendations with climate data for two periods, 1986-2015 and 2020-2050, using RCPs 2.6, 4.5 and 8.5 of the IPCC fifth report. The results showed that, for all climates studied, the trend is for temperatures to increase in the coming decades; as a result, the use of heating strategies will decrease, and the use of cooling strategies, will increase. Andric et al. [15] concur with these results. The International Energy Agency (IEA), projects that energy demand for space cooling will triple by 2050 ("Future of Cooling" by the International Energy Agency-IEA.

According to Ines Camilloni [85], the countries of the global South face the greatest risks regarding climate change, despite being the least responsible historically for greenhouse gas emissions, they have few resources to mitigate or prepare for climate risks. Climate change adaptation measures and policies should aim to address changes that have already occurred and changes projected for the near future. However, for the adaptation strategies to be truly effective, it is essential to reduce uncertainties with respect to projected changes. This can only be done by prioritizing research in climate science to assess observed changes and future prospects in detail and accurately.

The number of publications about the effects of climate change on the energy consumption of buildings is increasing, promoted by the urgency to implement adaptation measures. In this regard, Campagna et al. [69] conducts a survey of the last 71 papers on the influence of climate change on buildings. In these papers, the greatest emphasis is placed on residential buildings, which represent the 40% of the studies, followed by office buildings with 26% of the papers. On the other hand, less attention is paid to other types of buildings: commercial buildings (9%), schools (6%), hospitals (6%), hotels (4%), warehouses (4%), restaurants (3%) and universities (3%). Governmental building typology does not appear among the studies/authors analyzed.

Argentina and other countries in the Global South are underrepresented in the literature. There is very little bibliography with reference values of energy consumption of public sector government buildings in South America. Obligatory standards and codes in other regions of the world provide accurate data to advance with Energy Efficiency studies. In Argentina there are many standards and codes, but they are recommendations. These should be obligatory. The "energy efficiency building codes" are the key policy instrument used by governments to reduce the energy consumption of buildings [4]. Precisely the largest availability of data and information comes from countries where codes and standards are obligatory and/or mixed, see figure below:

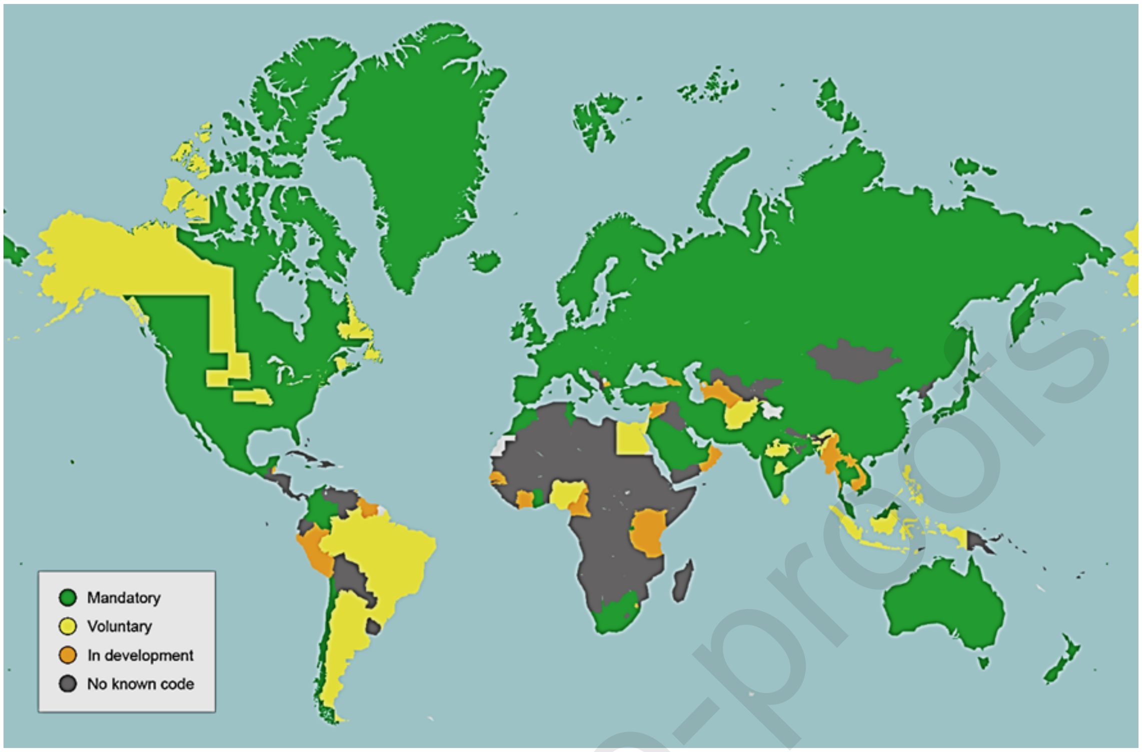


Figure 1. Coverage of energy codes for new buildings, 2021 [74]

As we have seen, in recent years the integration of energy simulation in the building design development process has been increasing. According to Godoy et al. [75] we are in the fourth generation of energy simulation tools development, however, the number of variables to be defined in the model has increased 200 times compared to the first decade of work in this field. This increase in the amount of data required increases the possibilities of errors, added to the lack of information and/or erroneous information, resulting in an increase in the uncertainty of the results.

According to Wilde et al [78], the uncertainties in building performance simulation can be categorized into four types: modeling uncertainty, numerical uncertainty, specification uncertainty (system definition, building geometry, material properties), and scenario uncertainty (occupant behaviour, facility management and renovation scenarios, and climate conditions).

When it comes to rehabilitation or built case studies, part of the uncertainties of these models can be adjusted thanks to a calibration with real data measured in situ. This required adequate technical documentation and data from an audit and monitoring over a long period. This monitoring should involve the active participation of the users.

Concerning to climate change. Warming of the climate system is unequivocal. Since 1950, changes in the climate system have been observed that are unprecedented, both when compared to historical observational records, dating back to the mid-19th century, and to paleoclimatic records referring to the last millennia. Projections for the coming decades of many magnitudes show changes similar to those already observed. Nevertheless, the uncertainty of the projections is high. More importantly, however, despite the enormous increase in effort and knowledge since 1980, the mid-range estimate has changed just a little, and the uncertainty in climate sensitivity has not decreased at all. As well as the uncertainty of the IPCC estimates of net warming from all sources by 2100.

This uncertainty is due, in part, to social factors, i.e. the different possible paths that global society may take, emitting more or less pollutants. The uncertainty arising from the modeling of the physical climate system is also a very important factor.

The probability that the increase in global average temperature is a consequence of human activity has been increasing in successive IPCC reports. The Third and Fourth Assessment Reports stated, respectively, that the probability of human influence was greater than 66% and 90%. The Fifth Assessment Report considers that there is a greater than 95% probability that human influence on climate has caused more than half of the observed increase in global mean surface temperature in the period 1951-2010, which has led to ocean warming, melting of ice and snow, sea level rise and changes in some climatic extremes in the second half of the 20th century.

To substantially reduce uncertainty, sustained observations, unequivocally attributable to anthropogenic forcing, will be necessary. In other words, improved prediction will only occur when climate change actually begins to affect. Since the response of the climate system occurs when greenhouse gases increase, if we wait for this improvement in the models without acting to avoid substantial climate change, we will act too late.

It is also known, and agreed with Wilde [78], that user behavior has a significant impact on building energy use and therefore plays a key role in predictions [79]. Many of the current building energy simulation software treat the user as "deterministic" by setting schedules for variables related to building usage, setting thermostats, lighting, etc. However, this simplification does not represent the complex stochastic nature of human behavior inside buildings. In the work of Wei [80], new approaches to adequately present variations in occupant behavior are presented by classifying them into two types: implicit and explicit [81, 82]. However, the authors conclude that progress is needed in this area to better understand occupant behavior and to find appropriate ways to simulate and calculate the associated uncertainty. According to M. Eguaras [83] occupant behavior can explain up to 30% of the variation in building energy performance.

The facility management and renovation scenarios introduce more uncertainties. Deterioration of building elements over the lifetime of the building will lead to a further reduction in the thermal performance of the building over time [78], but if replacement were to exist, these systems would increase efficiency going forward [84]. For energy demand calculation, HVAC systems are often assumed to operate under ideal conditions. However, in reality, the performance of HVAC systems is affected by a number of factors, such as oversizing, aging, maintenance, and normal deterioration. Contemplating these variables, the results suggest that the uncertainty in annual energy use can range from -28.7 to 79.2% [80].

In this context, the general objective of this research is to study and predict the thermal-energetic performance of a recently constructed bioclimatic building of the national public administration, exposed to the consequences of climate change. This case study allows discussing strategies appropriate to arid climates, in order to improve the performance of similar typologies in the future.

As specific objectives, the following are proposed:

- To simulate and calibrate a physical model in Energy Plus with thermal and energy data measured in situ.

- To re-think design strategies and estimate energy consumption in the current climate (thermal and light).
- To generate future climate scenarios and, to assess future energy consumption.
- To outline and discuss immediate and future assumptions for building design in high irradiance climates, regarding users and management, HVAC technology and design decisions.

The building chosen as a case study (case A) belongs to the National Institute of Agricultural Technology of Argentina, which was designed to save energy and achieve high levels of comfort in an arid climate with high solar irradiation. However, it has not been studied to adapt to the consequences of climate change.

Considering that these types of buildings are replicated in the region, simple strategies are proposed to increase their energy efficiency, considering CC, but without influencing the original project too much: the building was rotated 180º (case B) allowing to reduce direct solar gain, increase exposure to the strongest summer breezes and homogenize natural lighting (Annex A2 explains why the building was rotated 180º).

Consequently, the results of this integrated analysis (energy, lighting and thermal comfort) will be directly applicable to public buildings in arid climates. Reference values will be obtained so that designers can anticipate climatic changes and counteract their effects through energy efficiency. It should be noted that the values obtained are not intended to be deterministic, as the circumstances established for this particular study may change due to multiple uncertainties in the models.

2. Methodology

To respond to the objectives, the manuscript is organized as follows:

A) Presentation of the case study, geographic location analysis and in-situ monitoring. B) Dynamic simulation of thermal-energetic behavior with Energy Plus, calibration of the model and simulation of scenarios for study. C) Dynamic simulation of daylighting behavior. D) Generation of future scenarios 2075 and 2099 and E) Comparison of the results of the thermal-energetic testing of the situations studied.

Subsequently, the results are presented in three blocks: Case study as a "Case A"; Rotated 180 degrees to the south as "Case B and Climate Change".

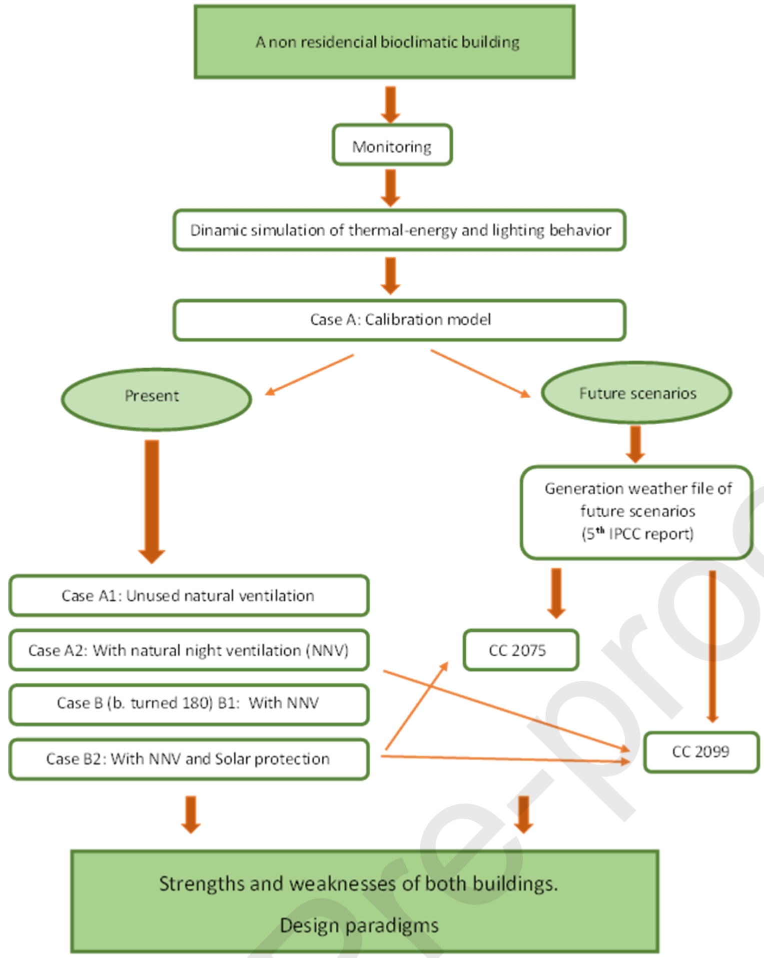
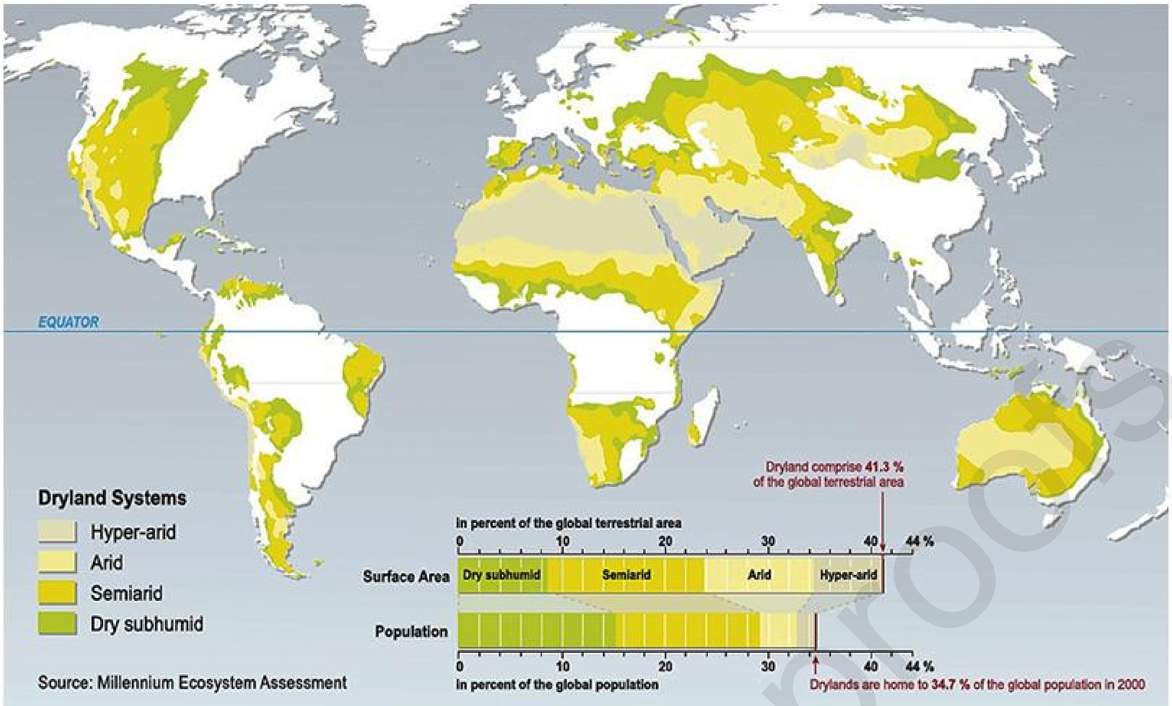


Figure 2: General scheme of the methodology

2.1. Case study and geographical location

Semi-arid areas represent 15.2% of the global land surface, making up 41.1% of drylands (Figure 2). These areas are of key importance for global carbon regulation, as well as being crucial for hosting 38% of the human population and areas of rapid growth [16]. The case study is located in Victorica, in the NW of the province of La Pampa, Argentina (37º38'S, 63º34'W, 175m above sea level) and was constructed in 2016. According to the climatic classification of Köppen-Geiger [60], it is a steppe climate, semi-arid temperate cold (BSk), characteristic of the dry Pampa. The denomination corresponds to B=dry climate, S=steppe and k=cold.



It is located on the border between the bioenvironmental zones IIIa (warm temperate dry) and IVb (cold temperate of maximum irradiance), which according to IRAM 11603 (2011) (Figure 3), [17].As the Norm recommends that cities located on border settings should reflect the most unfavorable conditions, suggested practices include: to use thermal insulation in the whole envelope, to avoid thermal bridges, and to minimize the risk condensation in walls and roofs. The annual average temperature, maximum average and minimum average are 16.0°C, 23.3 °C and 8.7°C respectively, and the relative humidity is 64% (National Weather Service – Air Force, Argentina, 2000)[18]. Annual mean solar irradiance on a horizontal surface is 18.8 MJ/m^2[19]. Table 1 shows the climate conditions.

Figure 3: Arid and semi-arid regions [20]

The case study was chosen because it is a building of the National Public Administration (NPA) built with bioclimatic guidelines. In order to take a building as a case study, it is necessary to have complete technical documentation and, above all, to have appropriate monitoring data of its operation for long periods of time. The users of the building were very committed and helped us to record the variation in consumption three times a day for a year.

On the other hand, article 3 of Decree 134/20151 of the Argentine National Executive Power, invites all scientists to initiate concrete actions to make NPA buildings more efficient.

Non-residential buildings offer great potential for the use of daylighting and also for solar heating and passive cooling due to their essentially daytime occupation. The design assumptions emphasized that the building should accommodate users with a working day divided into activities inside and outside the building. They carry out outreach and advisory activities to agricultural producers in the area of influence, which is why they are not always at their desks during working hours. In this context, the design of the building prioritized the natural conditioning of the spaces as well as a clear zoning of the different functional areas to provide comfortable and well-lit workspaces and low operation and maintenance costs. The building layout is shown in Figure 4. The entrance to the building is defined as an independent area with a double door from which the functional areas are distributed along an E-W axis. The technical office and meeting room face north and have clear glazing for direct solar gain in winter, with protection eaves and pergolas for summer. The multipurpose room is dedicated to training, entertainment and social activities (it is also used as a garage) and is located on the northwest side, facing north. The director's office is located on the south side, with small windows that help visual expansion and provide indirect natural light coming from the circulation area. The service sector is located to the west of this office. A key element in this design is the technical-thermal plenum, which has windows facing the equator. It is located between the northern and southern areas, at a height of 2.40m above the circulation and conceived as a 'thermal steering wheel', heats the building's southern area when the windows located between both areas are open, as well as optimizing natural cross-ventilation during summer. Thus, the plenum allows the building to operate in accordance with the different seasons. This strategy is replicated in the administration area where high windows can be opened from a walkway (a continuation of the plenum) (see Figure 5).

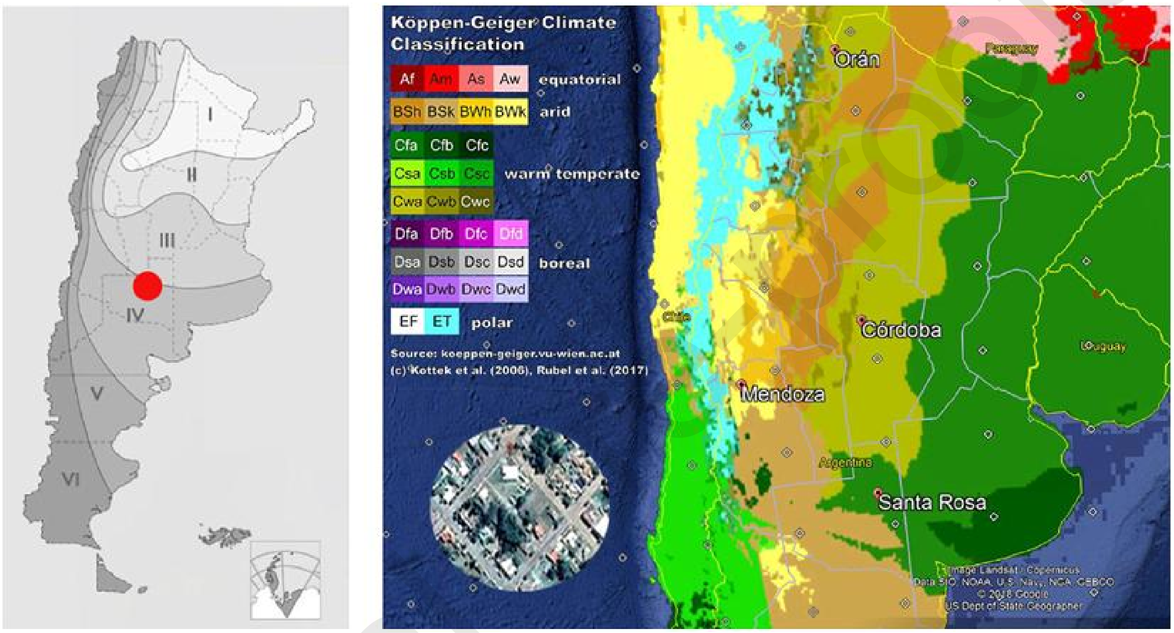
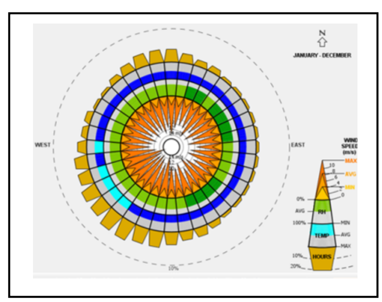


Figure 4: Argentinean bioclimatic regions (IRAM Norm 11603) (left) and view on Google Earth of the Koppen climate classification (right, Rubel et al., 2017) together with a magnification of the neighborhood where the building is located [20].

Table 1: Historical climatic data of Victorica

Mean temperature Tm (ºC)		Mean Relative Humidity (%)		Annual HDD (baseline 18ºC)	Annual CDD (baseline 23ºC)	Mean solar Irradiance on horizontal surface (Wh/m²)	
July	January	July	January			July	January
7.5	23.9	76	55	1538	593	2179	5785



Regarding the area of direct solar gain, it is worth mentioning the results of previous experiences of experimental public buildings built with limited budget availability. Filippín et al., [21] show the results of the thermal and energy performance of residential and non-residential buildings built and measured in the central region of Argentina between 1995 and 2005 with a glazed area to the north between 11 and 17% with respect to the useful area. In the design stage of the building, energy saving, through the solar contribution, was calculated by the Thermal Load-Collector Ratio method [22]. The authors concluded that the values satisfy the requirements of the winter period, but the summer still represents a challenge to meet and overcome in future research. During 2006, the National Institute of Agricultural Technology of Argentina (INTA La Pampa-San Luis Regional Center) endorsed and supported the construction of a bioclimatic building in a semi-arid continental region of central Argentina in a transitional cold temperate climate with 379 DDC base 23ºC. The design applied the previous experience of 10 years (1995-2005). Filippín et al. [23] describe the design and post-occupation evaluation. The effective glass area to the north is approximately 12% of the usable area of the building. In this context, the building is replicated in Victorica with 593 DDC base 23ºC, the glazed area to the north was reduced to 7%.

Energy conservation and storage is achieved through the envelope's technology. The walls are three-layered: solid brick as the thermal mass in the inner part (0.17m thick), expanded polystyrene thermal insulation (0.05m thick) and outer mechanical protection (solid brick, 0.07m thick). The sloping roof are made of pre-painted white sheet metal and 0.10m expanded polystyrene. The joinery for doors and windows consists of pre-painted aluminium, thermal bridge breakers and hardwood pre-frames. The windows are single-glazed and have mechanical roller shutters with adjustable slats (Annex A.3 explains the cost-benefit ratio of improving the building envelope according to Iram Standard 11604). As seen in Table 2, the building has a compact layout and a suitable FAEP (Factor of Exposition, defined as the envelope's surface divided by the covered surface [24]. A FAEP value lower than 2.0 is considered an indicator of energy efficiency in a building's design. The G-value (Volumetric Loss Coefficient) meets the requirements of IRAM Norm 11604-2011 [25]. As a result of the vertical envelope's indoor massive brick walls and use of massive indoor walls, the building has high inertia (400 kg/m2, area density) [26].

Table 2: Dimensional, morphological and thermophysical metrics

Perimeter (m)	Useful area (m^2) -1-	I_c (%)	Volumen (m^3)	Envelope (m^2) -2-			FAEP (2/1)	G (W/m2°C)
				Vertical	Roof	Total		
64	298	95	977	206	274	480	1.61	0.4

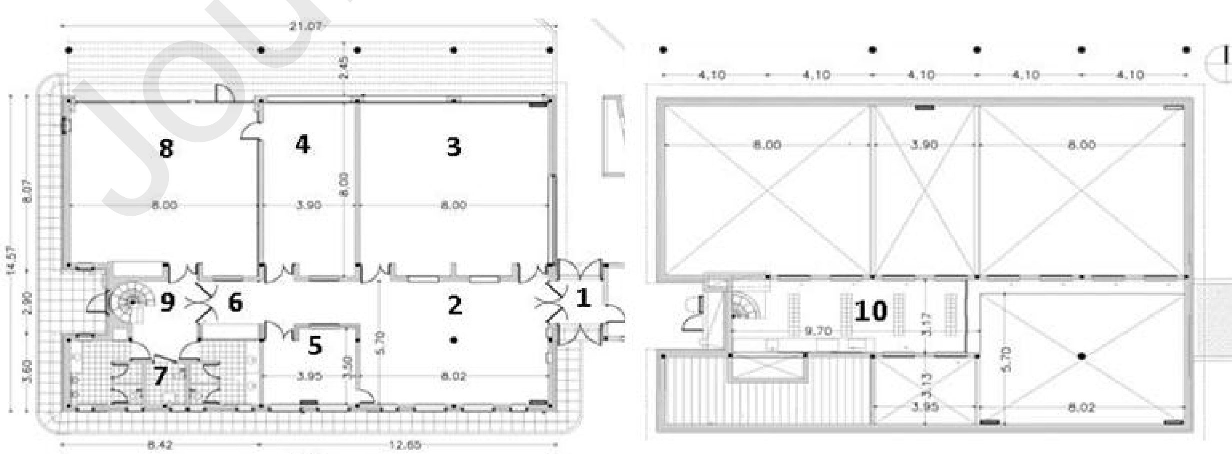


Figure 5: Plant and volumetric configuration. References: 1- Entrance, 2- Administration, 3- Technical office, 4-Meeting room, 5- Director's office, 6- Circulation, 7- Service, 8- Multipurpose room, 9- Access to technical-thermal plenum, 10- technical-thermal plenum. North- facing and passive solar heating; Administration, Technical plenum, and corridor between areas with and without direct solar gains. The photos were taken on July 15 between 14hs and 15hs.

2.2. Dynamic simulation of thermal-energetic behavior with Energy Plus

Building Energy Simulation (BES) programs are able to predict the energy performance of buildings in detail in a dynamic model: these models should ensure that new buildings adapt to future conditions, prior to adjustment and calibration of these models. Calibration was possible because there is detailed technical documentation and specifications, information on the construction process and thermal-energy monitoring under real conditions of use.

A correct dynamic building model requires a proper definition of all parameters, which can affect the model outputs [27].

Table 3: Construction elements of the building envelope of the case study

	Layers (from outdoor)	Finishing painting/color	Thermal transmittance K (W/m2 K)
Exterior walls	Plaster (0.02 m) Massive ceramic brick (0.18 m) Expanded polystyrene (0.05m)	Beige (exterior)	0.63

The entire building was simulated in a dynamic state with Energy Plus v9.3 software. The general guidelines were:

- The building was divided into 8 thermal zones, 7 on the first floor (Hall, Administration, Technical Offices, Conference Room, Management, Services and Circulation) and one on the second floor, the Technical Plenum.
- The envelope data are presented in Table 3.
- Thermal relationships were established between air masses (with an impact on energy balance).
- In the Plenum zone a wind extractor was incorporated by means of the object “ZoneAirBalance:OutdoorAir” which calculates the outdoor air flow in the combined selected zones including interactions between infiltration and leakage in the duct.

With the model measured, we proceeded to the simulation of the improved case.
For the design of the strategies of the case to be simulated, it was taken into account that this is a national public-sector building, which governments usually replicate, so an important premise is to intervene as little as possible in the current design.

a) Thermal performance with natural night ventilation (NCV)
b) Thermal behavior with NCV operation in the building rotated 180 degrees to the south.
c) Energy consumption to reach comfort temperatures in Case A and Case B (building rotated 180 degrees to the south).
d) Energy consumption to reach comfort temperatures in Case A and Case B for the climate change scenarios for 2075 and 2099 (CC'75 and CC'99 respectively).

Natural night ventilation is one of the climate correction strategies suitable for the location of the building due to the high thermal gradient between day and night. Natural ventilation was simulated with the "AirFlowNetwork" calculation module (AIRNET algorithm) of the Energy Plus software. For natural ventilation, the program is based on air movement by natural forces inside the building; this movement will depend on indoor-outdoor temperature differences, height differences between air inlet and outlet, upward convection and wind speed and direction [28]. For the surface pressure flux data (Cp), the program option selected calculates the average per surface area, while factoring into the averages recommended by Swami et al. [29], being analytical models calibrated with experimental measurements. For the airflow control the AirflowNetwork:MultiZone:Component:DetailedOpening object was used, which requires specification of the different properties of windows and doors when closed and when open. The air mass flow coefficient when the opening is closed (AirMassFlowCoefficientWhenOpeningisClosed) makes provision for four cracks around the perimeter of the window or door which area function of the dimensions of the opening. The data proposed by the program were adopted from the work of Liddament [30], as shown in Table 4.

Table 4: Values adopted for simulation in EnergyPlus. DocumentationEnergyPlus v.9.3 [31].

Adopted values	Doors	Windows
Air flow-mass flow coefficient when the opening is closed [Kg/s-m]	0.00124	0.00058
Air-mass flow exponent when the opening is closed (dimensionless)	0.65	0.65
Opening-number factor (dimensionless)	2	2
Maximum value of opening factor (dimensionless)	1	0.5

The windows connecting the interior areas (Technical Offices, Meeting Room Administration, Multipurpose Room and Plenum) are taken as being open 24 hours a day. On the other hand, a night ventilation model was used for the windows that connect interior-exterior areas, simulating their openings during a 10-hour period at night, from 9 pm to 7 am. In section 3.2, the validation of the model is shown, comparing the simulated data with the measurements.

Next, the building rotated 180 degrees is simulated. The choice of the degrees of rotation responds to an urban grid organized in the form of a checkerboard with the possibility of a 90-degree rotation. In this way, we obtain a model that simulates the building when the façade with more glazing is facing south. This allows us to evaluate the hypothesis that a reduction in cooling costs in the face of CC is possible by examining the performance of a building that emphasizes passive cooling rather than passive solar heating as the axis of bioclimatic design in the locality in question. Lastly, solar protection is incorporated into the fenestration (which in the rotated building is oriented towards the equator). (See Annex A2).

2.3. Dynamic simulation of daylighting behavior

The virtual model was built in Google SketchUp Make 2015 software and exported to RADIANCE v.5.0 (Ward et al., 1998) [32] through the Groundhog v.0.9.1 extension [33]. The simulation parameters selected correspond to those proposed by McNeil [34]: -ab 5 -ad 2048 -as 512 -aa 0.08 -ar 512 -dt 0 -ds 0. The photometric characterization of the materials used in the interior space of the room is shown in Table 5. The optical characteristics of the glass were imported by means of a rad. file generated by the OPTICS software as an output while a description of the material follows the parameters requested by the RADIANCE software (Table 5).

Table 5: Visible reflectance (VR) and RGB color coordinates of interior surfaces.

Material	RV	R	G	B
Wall	0.77	0.81	0.80	0.72
Interior floor	0.35	0.35	0.36	0.34
Ceiling	0.8	0.85	0.82	0.73
Exterior block	0.38	0.38	0.39	0.38
Exterior floor	0.28	0.356	0.269	0.225
Grass	0.2	0.053	0.356	0.180

Table 6: Optical properties of 3mm clear glass.

Visible Transmittance	Visible Reflectance$_{front}$	Visible Reflectance$_{back}$
0.899	0.083	0.083

In order to measure horizontal illuminance values, four grids were arranged in the virtual model, each one corresponds to one analyzed space (Administration, Multipurpose room, Offices and Conference room). The sensors were placed at one-meter intervals and at 0.80m off the floor. The distance between the walls and the edge points in the grid was 0.5 m, and the one between consecutive points in both directions was 1 m, as proposed by Nail & Mardaljevic [70]. An occupancy file (*.cvs) was created for the calculation of dynamic daylighting metrics focusing on the use of the space during the week, excluding weekends, from 8 am to 6 pm (solar time). Different dynamic daylighting metrics were considered in the analysis. The standard dynamic metric, Useful Daylight Illuminance (UDI) [35] which establishes that an acceptable illuminance range falls between 100 and 2000 lx; and the Adjustable Useful Daylight Illuminance (aUDI)[36], a metric based on the UDI and its limitations in adjusting the lower and upper limits of the useful illuminance range. In this case, the lower limit of 100 lx was modified and raised to 300 lx, a value indicated for tasks on the work plane [37]. Also, the Spatial Daylight Autonomy (sDA) was considered. The sDA is a measure of daylight illuminance sufficiency for a given area, reporting a percentage of floor area that exceeds a specified illuminance level (300 lx) for a specified amount of annual hours [38]. The time period considered in the analysis was confined to those hours that solar radiation is available as a resource for lighting in the specific location (2871) [39].

2.4. Generation of future scenarios

Future greenhouse gas emissions and concentrations depend on future developments, such as population growth, economic growth, energy use, renewable energy uptake, technological change, deforestation and land use. The IPCC Fifth Assessment Report has defined four new emission scenarios; the so-called Representative Concentration Pathways (RCPs), which take into account the effects of 20th century policies in mitigating climate change, as opposed to the scenarios in the IPCC Fourth Assessment Report: Climate Change 2007 (AR4) (called SRES), which did not take into account the effects of viable policies or international agreements in mitigating emissions. The four RCPs not only cover a wide range of future global warming scenarios but also quantify future greenhouse gas concentrations and radiative forcing (additional energy absorbed by the Earth's system) due to increased pollution from climate change.

The total radiative forcing (RF) predicted for the year 2100 ranges from between 2.6 to 8.5 W/m^2. The four RCPs comprise a scenario in which mitigation efforts lead to a very low level of forcing (RCP 2.6), two stabilization scenarios (RCP 4.5 and RCP 6.0) and a scenario with a very high level of GHG emissions (RCP 8.5), Figure 5. It is important to note that until the mid-21st century the differences in the results between the RCPs are very small, the reason being that the climate system responds relatively slowly to changes in GHG concentration [40]. Therefore, a value of RCP 8.5 has been taken for the subsequent analyses as it provides much faster warming and more pronounced changes in important indicators such as river flow, temperature and precipitation. The methodology used to generate the future data is known as morphing [41], a method that uses both a real-time weather file and future mean monthly data predictions of the variable of interest. Through 'shifting' and 'stretching' mathematical transformations based on the present and future monthly averages of the variables, a present time weather file is transformed into a future weather file. The nature of the transformations ensures that the relationship between the meteorological variables is maintained in the future weather file. In this article, the present time hourly data was the Typical Meteorological Year (TMY) based on averages for the period 1961-2010 (Meteonorm8.0) [42].

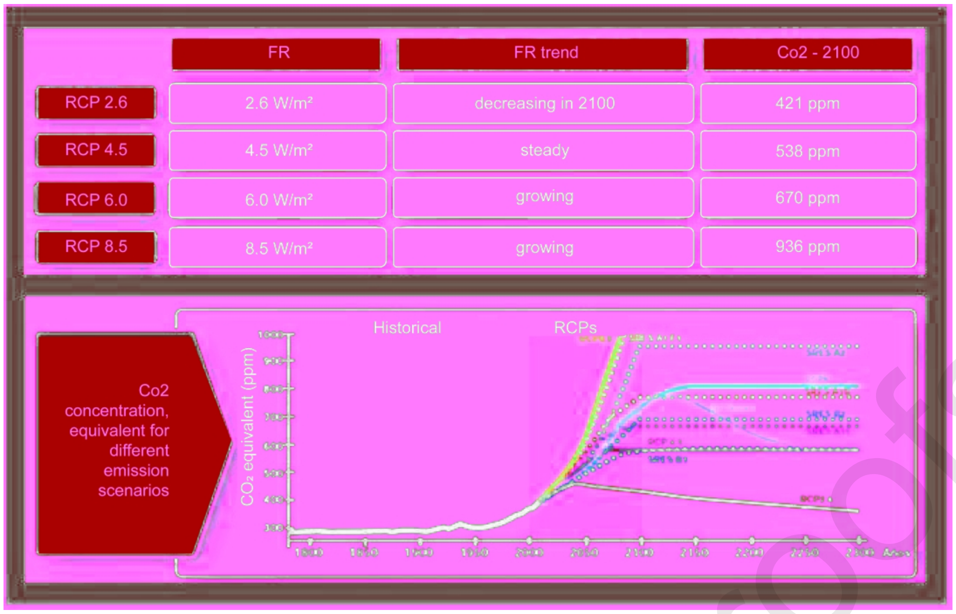


Figure 6. Source: from the summary guide of the 5th evaluation report of the IPCC. "Climate Change: Physical Bases", 2013 [42].

For the future predictions of Victorica, central Argentina, the bases developed by the researchers of the Center for Marine and Atmospheric Research (CIMA) [43] were adopted. The global model "CNRM-CM5 RCP8.5" was selected. The data were downloaded from the CIMA database of 3CN (http://3cn.cima.fcen.uba.ar/) and the World Research Climate Program (WRCP, 2021) [43] for the periods 2015-2039 and 2075-2099. These data are based on CMIP5 models, which can be accessed for 20th century simulations and projections of 21st century climate scenarios from 42 GCM experiments (Figure 6). For the central region of Argentina, 4 regional models are available with the necessary variables to prepare the EPW climate files for Energy Plus. This is because for the validation of the models, the researchers established two criteria for the selection, (1) availability of RCP 8.5 concentration scenarios and (2) daily departures in their projections.

The 4 models behave similarly. However, the CNRM-CM5 model has higher average minimum temperatures during summer (1.6ºC on average). And during winter the average maximum temperature is higher than the rest of the models (4.3ºC on average). This more extreme behavior puts the proposed bioclimatic strategies to the limit, which is why it was selected.

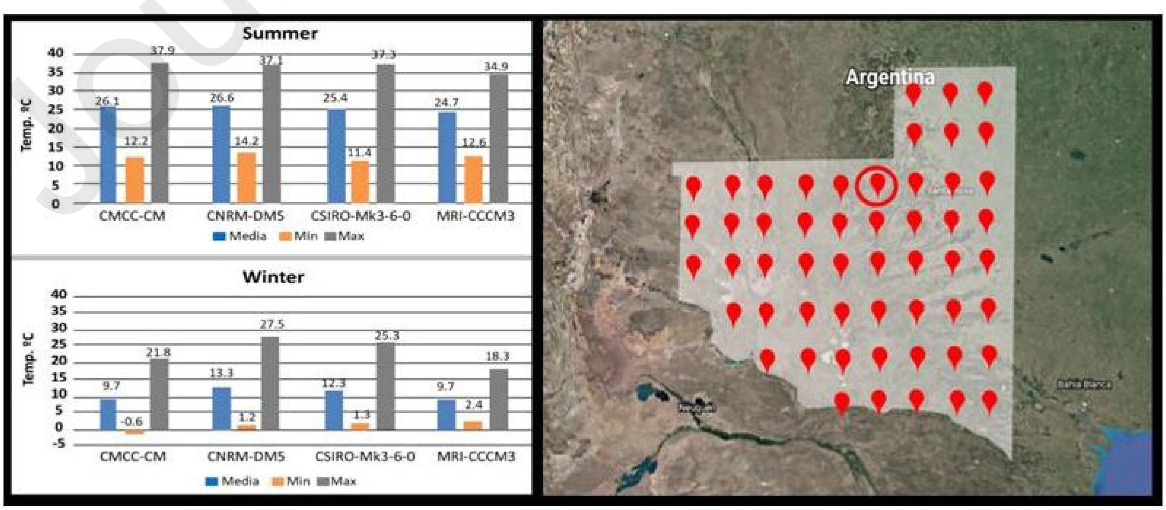


Figure 7. Average temperatures of available models. Grid of simulated points for the province of La Pampa. References: CMCC-CM: 2009. Centro Euro-Mediterraneo per I Cambiamente Climatici, Italia. Resolution 0.9°x1.23°; CNRM-CM5: 2010. Centre National de RecherchesMeteologiques, Francia. Resolution1.41°x1.41°;CSIRO-MK3-6-0: 2009. CSIRO, Australia. Resolution 1.875°x1.875°,MRI-CGCM3: 2011. Meteorological Research Institute, Japon. 1.1°x 1.2°

According to climatological researchers from the Sea and Atmosphere Research Center of Argentina, the sources of uncertainty about future regional climate scenarios come from the lack of ability of climate models to accurately represent the regional climate, emissions scenarios and interdecadal climate variability. In the distant future, as the change due to increased GHG concentrations is large, it can be assumed that interdecadal variability will be smaller than that; and therefore, for this future, the uncertainty is confined to model errors and possible emissions scenarios [43].

Figure 8 presents the quantification of the relative weight of the three different sources of uncertainty in the projections made for South America by the CMIP5 GCMs throughout the 21st century.

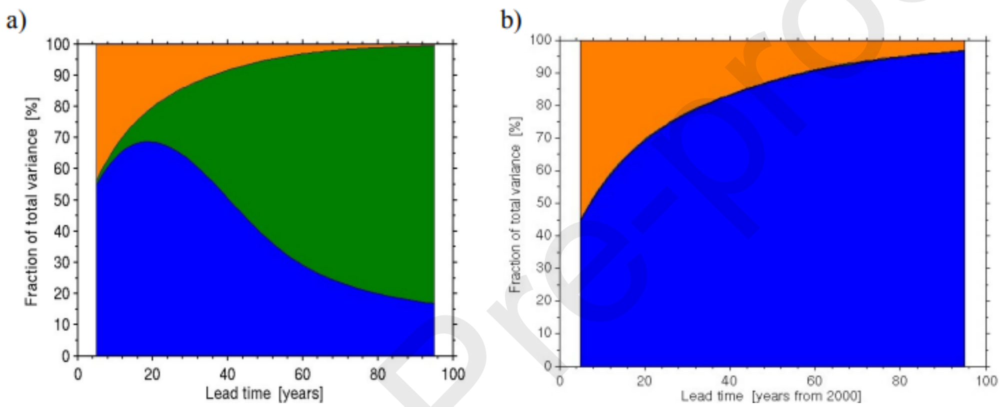


Figure 8. Relative percentage explained by each source of uncertainty of CMIP5 model projections of decadal averages over South America of a) annual mean temperature and b) annual cumulative precipitation. Orange: uncertainty of natural climate variability, green: uncertainty of GHG scenarios, blue: uncertainty of models [86, 87]. (http://climate.ncas.ac.uk/research/uncertainty/)

For both, rainfall and surface temperature, the percentage of uncertainty associated with interdecadal climate variability is significant in the early years, but then it decreases. Similarly, for surface temperature projections, the percentage of uncertainty associated with model errors increases by the middle of the 21st century and then it decreases. However, their contribution to the uncertainty of rainfall projections continues to increase, being the most important towards the end of the 21st century.

In addition, in absolute and not only relative terms, in the near future (i.e. within the first half of the 21st century), the uncertainty caused by different possible GHG concentration scenarios is then very small, while the contributions of the other two sources of uncertainty are large. Over time, although the contribution of natural climate variability may remain constant, its relative weight decreases compared to the uncertainty in the climate change signal due to increased GHG concentrations.

In this study, we work with the RCP8.5 scenario, which is a scenario of extreme warming that would be reached if there were no restrictions on global emissions.

3. Results in a base building

The results of the base case study are described according to; thermal-energy monitoring, thermal-energy simulation and light simulation.

3.1. Monitoring during transition period to warm weather under real conditions of use (November 1 - 21)

The post-occupancy monitoring of the building was carried out between July 17, 2017 and February 5, 2018, however, this work focuses only on the transition period towards warm climatic conditions. HOBO data loggers were installed in each functional area to detect indoor temperature and relative humidity, at a height of 1.8 m, away from heat sources and for not disturb the user. Measurements were recorded every 15 minutes. The external meteorological variables (solar radiation, wind speed, relative humidity and external ambient temperature) were recorded by a meteorological station installed near the building. Three daily readings of the natural gas and electricity meters were taken simultaneously at the beginning, at noon and at the end of the daily activity (period: 7 am - 4 pm).

The monitoring period was extended from November 1 to 21, 2017. Saturday the 11th and Sunday the 12th mark a change in terms of charging and discharging energy to heat and cool the indoor environment. The daily consumption of natural gas for heating falls from 7.3 to 0.9m3. It goes from an alternate period of clear and cloudy days to a period of predominantly clear skies and maximum values of solar irradiance on the horizontal surface of 900 and 1000 W/m2.

Day 12 (Sunday) and days 13 and 14 show a maximum outdoor temperature between 37.8 and 35ºC. Around 6 pm on the 14th the outside temperature drops 7ºC. Regarding the use of air conditioning in the director's office and after the weekend, on the 13th it was turned on between 2:00 p.m. and 3:00 p.m. (27.1ºC to 22.1ºC). On the 14th it is lit from 11 in the morning (25.8ºC) until 1 in the afternoon (17.7ºC). The director turns it off at noon at lunchtime. The drop in the outside temperature (7ºC) from 6:00 p.m. on the 14th and the switching on of the equipment (two hours in the administration and in the office and 1 hour in the director's office and in the meeting room) with a daily consumption of 6 kWh during the working day, it allowed the interior temperature of the building to oscillate between 20 and 23 ºC the rest of the days of the period under analysis.

These days identified in the annual in situ measurements are a transition period: from heating to cooling. This allowed us to adjust and calibrate the simulation models with the building in free float.

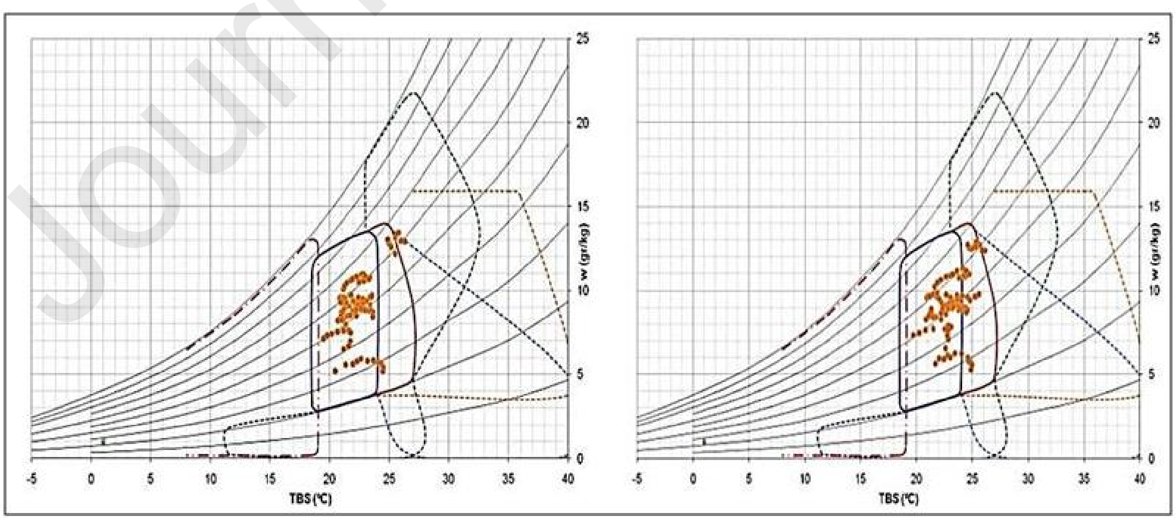


Figure 9: Comfort diagram for the period between November 1 - 21, 2017 in the administration area (left) technical office (right) under real conditions of use.

Table 8 shows that a 0.8ºC difference is recorded in the average indoor air temperature during the analysis period and during the working day. It can be seen that the ΔT between the average indoor and outdoor temperature is 2.1°C for the entire period and 1.8 °C during the period of use. The behavior of the building was adequate during the transition period and shows the suitability of the users' habits. In addition, Figure 7 shows a comfortable environment in the administration area and the technicians' office.

Table 8: Outdoor and indoor air temperature average between November 1 - 21, 2017.

Period	Outdoor and indoor air temperature averages (°C)							
Between November 1st and 21st, 2017	Outdoors	Administration	Technical office	Conference room	Corridor	Director´s office	Multipurposer oom	Technical
	19.1	22.2	22.7	22.5	22.1	21.9	21.4	22.9
During period of use (between 7 am and 4 pm)	20.6	22.4	23.0	22.6	22.1	22.1	21.4	23.1

3.2. Validation of the simulation model (Case A), thermal-energy performance with natural night ventilation(NNV) and light simulation

The building model was calibrated in two instances. First, the indoor temperatures were calibrated in the transition period (described in section 3.1) and then the annual consumption of the model was corroborated by comparing it with the annual consumptions measured in situ.

Figure 10 shows the comparative graphs of the thermal adjustment of four areas of the building (Technical Plenum Room, Technical Office, Director's Office and Administration).

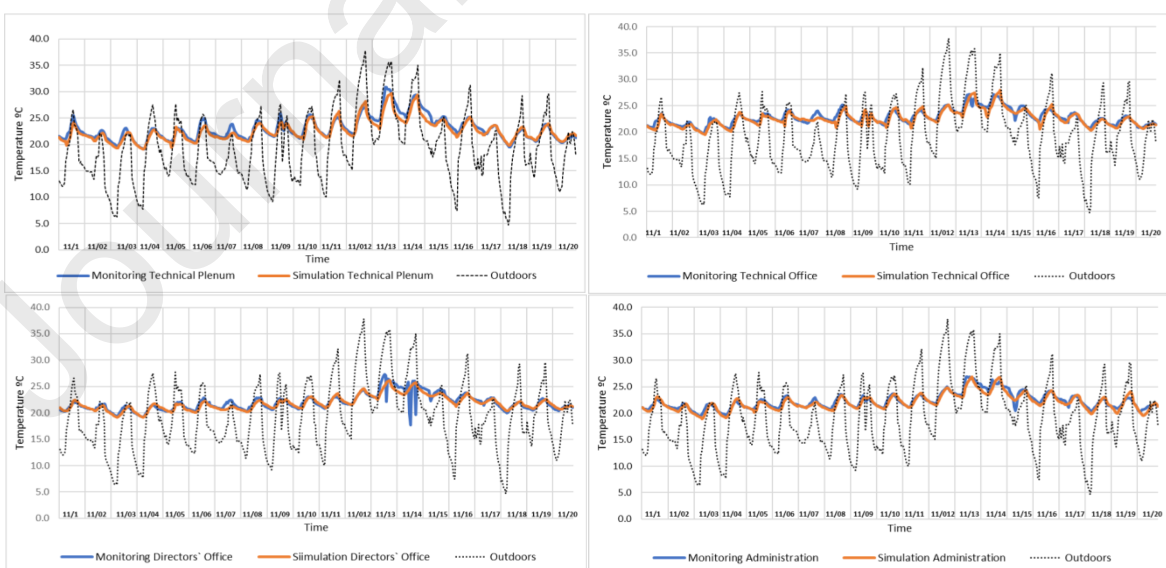


Figure 10. Monitoring and simulated indoor air temperature.

Alfonso Godoy Muñoz [75] describes in his research and bibliographical review, some methods to validate the calibration performance: Mean Bias Error (MBE) (%), Root Mean Square Error (RMSE) (%) and Coefficient of Variation of Root Mean Square Error CV(RMSE) (%).

Table 9. Analysis of equality of means between simulated and monitored temperatures in each room

	Two-sample t-test (α=0,05)			
	t-statistic	**P(T<=t) two tails**	**Critical value for a two-tailed t-test**	**Equality of means**
Administration(1)	1,428	0,1536	1,962	Yes
Technical office(2)	0,559	0,5766	1,962	Yes
Direction(2)	1,736	0,0829	1,962	Yes
Hallway(2)	5,182	0,0000	1,962	No
Meeting room(2)	2,518	0,0120	1,962	No
Bathroom(1)	-0,114	0,9091	1,962	Yes
Multipurpose room(2)	0,344	0,7307	1,962	Yes
PLENUM(2)	0,628	0,5300	1,962	Yes
Building average (2)	**1,423**	**0,1551**	**1,962**	**Yes**

Atwo-tailed t-test [76], which arises from a relationship between the MBE and the CVRMRS, allows us to compare the average values of simulated and monitored temperatures, testing the null hypothesis that the means between both groups are equal. The assumed null hypothesis was accepted when the t-statistic obtain was less than the critical value. It occurred in most of the rooms analyzed and in the average of the building, allowing us to accept the criterion of equality between the simulated and monitored temperatures in general (Table). Previously, we used an one-tailed F-test [77] to test the null hypothesis that simulated and monitored temperatures come from two independent populations having the equal variances. F-Test results were useful in deciding what type of t-test to perform (assuming equal or unequal variances). All tests were applied with a significance level (α) of 0.05.

With the calibrated thermal model, the annual consumptions were compared between the model and the data measured in situ. The consumption data measured in the period from August 1, 2017 to August 1, 2018 were taken. The actual consumption measured on-site was: 64.9 kWh/m2 (total), divided into 46.0 kWh/m2 for heating and 18.9 kWh/m2 for cooling.

Thermostats were set at 18°C for heating and 24°C for cooling according to IRAM 11605 [45]. The results obtained were corrected according to the values of the mechanical conditioning equipment, establishing an efficiency of 0.7 for heating and an EER=2.3 for cooling [46]. The consumptions resulting from the simulation model were 64.2 kWh/m2 (total), 46.0 kWh/m2 (heating) and 18.2 kWh/m2 (cooling) respectively. The analysis of the monitored consumption data and the simulation data reflects a Pearson correlation of 0.99.

With the adjusted model, the base case with natural night ventilation (NNV) was simulated. As mentioned above, it was expected that the incidence of NNV would reduce both the building load and temperatures inside the building. The results are presented for four zones: The Technical Plenum room, responsible for causing a chimney effect with the other zones; the Technical Office, a high-capacity room with a northern orientation; the Director’s Office, a normalized use zone facing south; and Administration room. Figure 11 shows that the Indoor Air Temperature (IAT) decreases when NNV is used.

The Technical Plenum room has a lower temperature drop, however, this space is where all the building’s hot air currents meet when NNV is activated, making it a very important space as a heat sink while at the same time allowing hot air to dissipate due to the design of its openings. In the case of the north-facing Technical Office, without south-facing windows for effective cross ventilation the temperature decreases at peak minimums; this is considered a consequence of a reduction in the overall interior temperature of the building and the interior air movement to which the building design responds. Finally, in the Director's Office the openings face south, so they are directly exposed to the cool breezes of the locality. This situation means that this area experiences the greatest decrease in IAT not only at night, but also during the day; evidence that the thermal mass is functioning correctly.

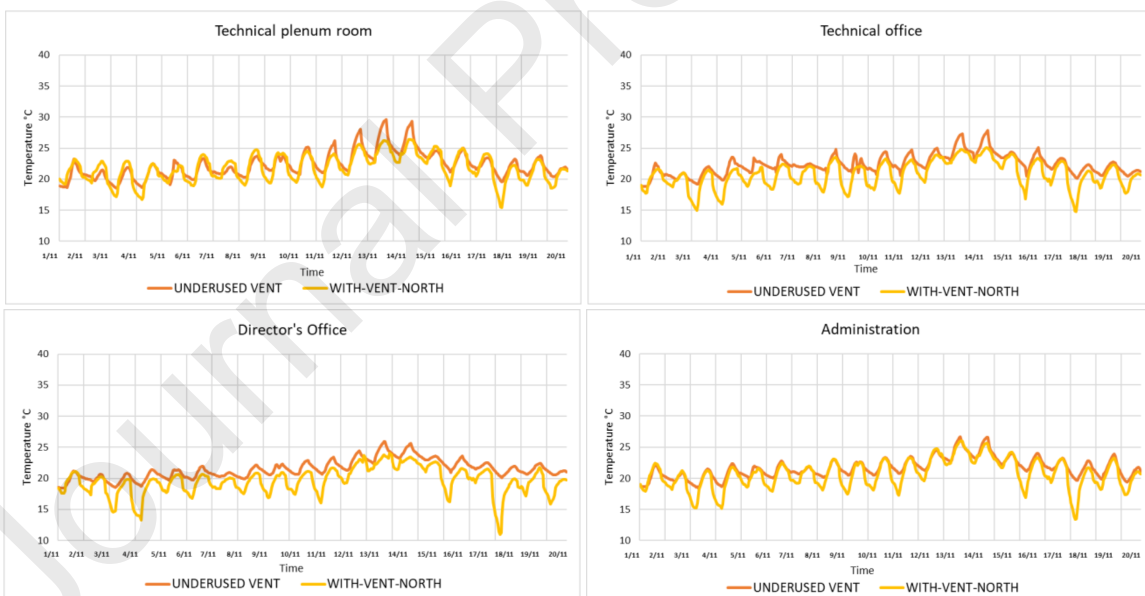


Figure 11: indoor air temperatures of the Technical Plenum room, Technical Office, Director´s Office and Administration, with and without night ventilation.

In terms of energy consumption, the benefits of promoting natural night ventilation are more obvious. Table *10* shows the results for two scenarios analyzed; with underused natural ventilation (Case A1: the wind extractor was not used during the monitoring) and with -NNV- (Case A2).

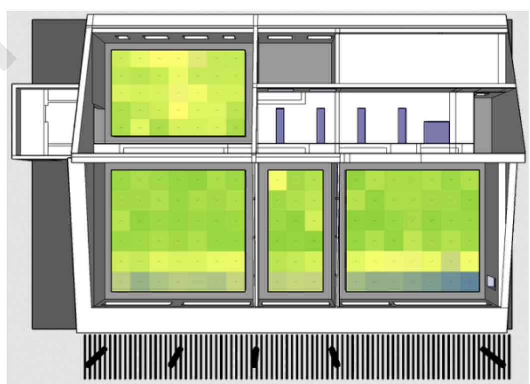
Table10: Measured and simulated energy consumption

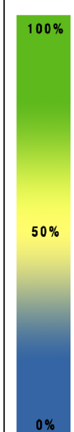
	Year [Kwh/m2]	Heating [Kwh/m2]	Cooling [Kwh/m2]
CASES	Total	Heating	Cooling
CASE A - MONITORING	64.90	46.00	18.90
CASE A1 - UNUSED NATURAL VENTILATION	64.22	46.01	18.21
CASE A2 - WITH NNV	51.23	46.01	5.22

The situations of the on-site measurements and the building underused ventilation are similar. However, in the building with night ventilation, with a better use of the design resources implemented (among them the aeolian extractor in the plenum), summer consumption decreases by 13.68kWh/m^2, i.e. a saving of 72.4% is achieved in summer. In winter, consumption is maintained at 46 kWh/m^2 and total energy (cooling and heating) decreases by 21%. The percentage of energy cooling consumption drops to 10.2% of total consumption. In Argentina, the Secretariat of Energy [48] determined that the annual energy consumption of public buildings ranges from 52 KWh/m^2 (for warm climates) to 170 KWh/m^2 (for colder climates), giving an average of 106 KWh/m^2 for temperate climates. For the case study under control, the energy savings is 38.7% and grows to 51.7% with the use of natural ventilation. For subsequent comparisons of energy consumption, Case A with Natural Night Ventilation is taken as a reference as it is the one with the best energy performance.

Table 11: UDI, aUDI and sDA values for each of the spaces analyzed with the original layout of the building.

		Original	
Administration	UDI%	$UDI_{100-2000}$	$UDI_{300-2000}$
		65	62
	sDA_{300}	100	
	DS	2695	
Multipourpose room	UDI%	$UDI_{100-2000}$	$UDI_{300-2000}$
		68	64
	sDA_{300}	83.3	
	DS	2200	
Conference room	UDI%	$UDI_{100-2000}$	$UDI_{300-2000}$
		75	67
	sDA_{300}	100	
	DS	1881	
Offices	UDI%	$UDI_{100-2000}$	$UDI_{300-2000}$
		72	68
	sDA_{300}	100	
	DS	2108	


$UDI_{300-2000}$



Regarding the light simulation, $UDI_{100-2000}$ values between 65% and 75% (Table 10) were recorded, with the conference room showing the most favorable behavior. The administration area, with a south façade and lower percentage of façade openings, presents lower $UDI_{100-2000}$ values. With respect to $aUDI_{300-2000}$ it is observed that the values decrease slightly with respect to those of UDI, due to the higher requirements established, with a minimum value of 62% and a maximum of 68%. In general, we can say that the space presents acceptable $UDI_{100\text{-}2000}$ and $aUDI_{300\text{-}2000}$ values above 60%. Regarding the sDA300 values, it is observed that the administration, the conference room and the offices reach 100%. This indicates that 100% of the area of these spaces meets or exceeds 300 lx more than 50% of the hours analyzed. This percentage is reduced in the case of the multipourpose room to 83.3%.

4. Results in a rotated building (Case B)

Harputlugil et al. [4] say in some of the conclusions of their work that more attention should be paid to interdisciplinary research since most of the research does not use holistic approaches and focuses on specific technical topics, among others, lighting systems, systems heating etc. Mercado et al.[49] analyze the design parameters that influence energy load, conclude, among other statements, that when the shape is an already determined variable, the most influential parameter in the building's energy consumption is the orientation in a cold temperate climate. In this context, after the analysis of the base building, the orientation is investigated and the case study is rotated 180 degrees. The following analysis aims to reduce the number of north-facing windows, increase the incidence of summer breezes to allow passive cooling, and improve daylight uniformity (see Annex A2).

4.1. Orientation in the bioclimatic design

Good building orientation has been identified as a strategy with high impact on energy consumption savings and very easy to implement because of its low cost [50]. Other studies address the orientation-energy efficiency binomial from the perspective of building cooling. They show that the correct location of openings and their solar protection to take advantage of natural ventilation and avoid solar radiation gain respectively decrease the energy demand of HVAC equipment [51]. In the case of the study, the new layout of the rotated building favors the reduction of the openings to the greater incidence of direct solar radiation and the orientation of the larger openings to the predominance of the direction and frequency of cooling winds. The modular metal structure of the building allows a change of functional areas. Among them, the administration with the greatest requirement for visual comfort would occupy the space of the technicians' office.

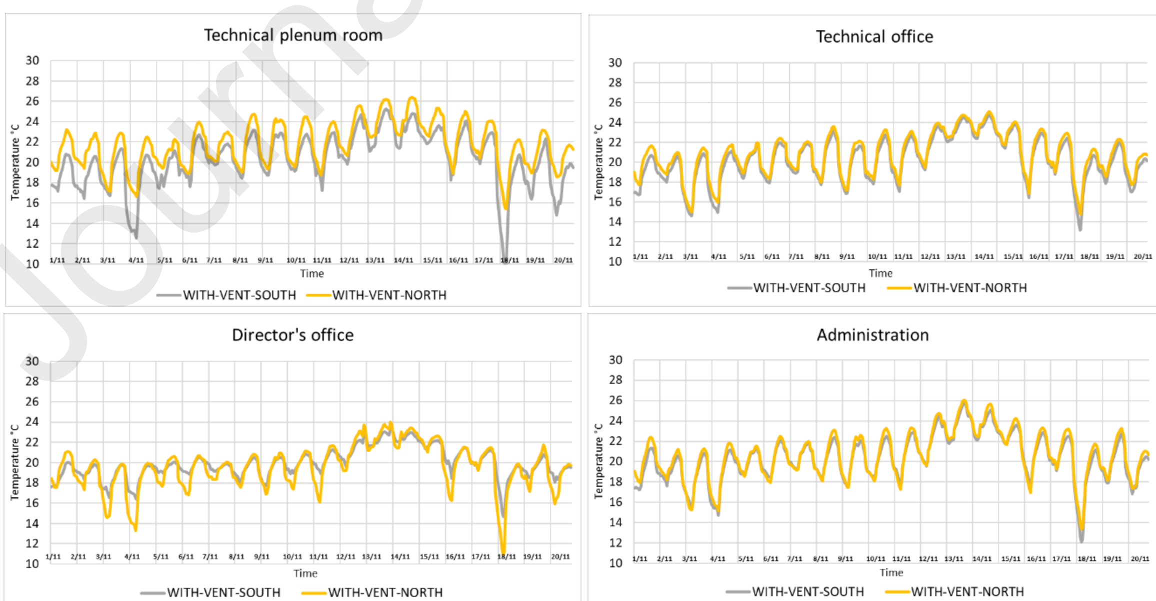


Figure 12: indoor air temperatures of the Technical Plenum room, Technical Office, Director´s Office and Administration with north and south night ventilation.

The four zones observed in section 2.2 are presented in Figure 12. The Technical Plenum room shows a decrease of up to 6°C on cooler nights. The important difference in this space is a sustained temperature decrease of 2.5°C during the hours of highest temperature. The results are relevant because, as detailed in the building description, it is a functional area, designed to promote natural ventilation through internal air currents. In the other spaces, the change of orientation of their openings is evident. The Technical Office (with its openings facing south), presents a decrease of up to 1°C on cooler nights, while the daytime situation reaches a maximum difference of 0.3°C. The Director's Office (with its north-facing openings) shows an increase in minimum temperatures due to the lack of an appropriate design for good natural ventilation

By rotating the building, the WWR for the north and south facades change to the reverse as shown in Table 11. This directly influences the reduction of the direct solar gain surface for heating the building as well as the exposed surface for the entry of cool breezes. Therefore, it is noted that in the case study the WWR for the rotated building is 50% less than that defined for offices by Alan Pino [9].

Table12: Comparison of annual consumption for both cases

	Area façade (m^2)		Area windows (m^2)		**WWR**	
Façade	Case A	Case B	Case A	Case B	**Case A**	**Case B**
North	113	82.4	32	8.44	38	10.2
South	82.4	113	8.44	32	10.2	38

Table13: Comparison of annual consumption for both cases

	Year [Kwh/m2]	**Heating [Kwh/m2]**	**Cooling [Kwh/m2]**
CASES	**Total**	**Heating**	**Cooling**
CASE A2 - WITH NNV	51.23	46.01	5.22
CASE B1 - WITH NNV	60.5	56.0	4.4
CASE B2 - WITH NNV AND SOLAR PROTECTION	58.9	56.8	2.0

Table *13* shows the energy consumption in heating and cooling according to the annual scenarios studied for Case A and Cases B. This implies that cooling energy consumption represents savings of 15.7% and 61.7% for Cases B1 and B2 respectively with respect to Case A2. For heating, an increase of 21.7% and 23.4% is observed. As for the balance between reductions and increases in cooling and heating energy consumption, the final result represents an increase of 18.1% and 15%.

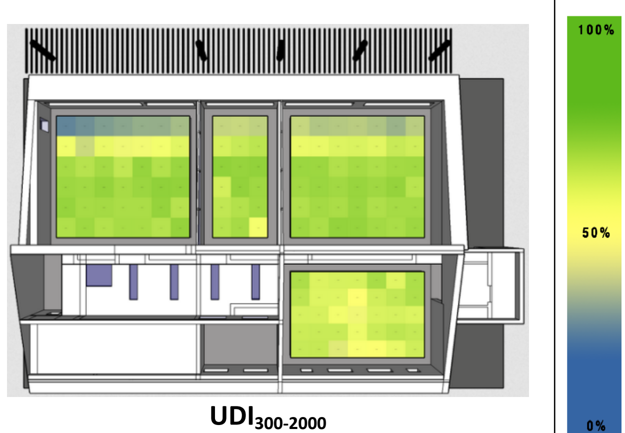
Regarding natural lighting, the analysis in Table *14* shows us that both $UDI_{100-2000}$ and $aUDI_{300-2000}$ values increased under the new building layout. Administration continues to be the space with the lowest $UDI_{100-2000}$, however, under the new layout it increased by 6%. The multipurpose room increased its $UDI_{100-2000}$ by 16%, the conference room by 14% and offices by 16%. With respect to $aUDI_{300-2000}$ we also detected increases under the new building layout. Administration increased it's a $UDI_{100-2000}$ by 6%, the multipurpose room by 12%, the conference room by 5% and offices by 11%. It is interesting to note the increased homogeneity of daylight in the spaces that, according to this layout, would be oriented to the north. This is illustrated in the significant decrease, averaging 60%, in the standard deviations (SD) of the new proposal with respect to the original. As regards the sDA, it is observed that the percentages in the administration and multipurpose room remain the same as those detected in the original proposal. However, in the conference room and offices there is a reduction in the percentage of the area with values equal to or greater than 300 lx, over 50% of the analyzed period, of 11.2% and 2.68%, respectively. This is due to the reduction in the contribution of direct sunlight in this condition with respect to the original condition where these spaces had their openings facing north.

In general, in the new building layout, an improvement in the visual quality of the space from the perspective of daylight availability was detected, in an illuminance range suitable for human vision, and from the perspective of uniform daylight distribution. This improvement in the lighting conditions of the rotated model is due to the fact that the shading element located on the north façade in the original model is not effective in controlling direct solar radiation in the winter period when the solar incidence angles on the north orientation are low. While this is partly due to the discontinuous shape of this shading device, it is also important to stress that north-facing openings in the southern hemisphere require complementary shading strategies to consolidate good daylighting conditions. That is to say, when using fixed devices for mid-latitudes (25° to 50°), it is necessary to complement them with movable devices (roller blinds, venetian blinds, etc.) that allow effective daylight control in winter. This can be clearly seen in Figure 11 where we observe the incidence of direct solar radiation at 12 noon on June 26 for the original layout of the building in the north-facing spaces

The calculated energy consumption for lighting corresponds to a manual electric lighting control system [71]. The total power of the lighting fixtures is 1368W and corresponds to 19 illumination artifacts of two tubes T8 of 36W each, without diffuser screen, located in the different spaces. The horizontal illuminance established for the calculation was 300 [lux]. The energy saving in lighting in the proposed building layouts was 61.02%, obtaining 109.16Kw/h (0.36kwh/m^2) in the original layout (Case A) and 42.55 Kw/h (0.14kwh/m^2) in the proposed building layout, changing to led technology (Case B).

Table14: UDI aUDIandsDAvalues for each of the spaces analyzed with the proposed building layout.

		Submission	
Administration	**UDI%**	**$UDI_{100-2000}$**	**$UDI_{300-2000}$**
		72	69
	sDA_{300}	100	
	DS	2485	
Multipourpose room	**UDI%**	**$UDI_{100-2000}$**	**$UDI_{300-2000}$**
		86	77
	sDA_{300}	83.3	
	DS	960	
Conference room	**UDI%**	**$UDI_{100-2000}$**	**$UDI_{300-2000}$**
		89	72
	sDA_{300}	88.88	
	DS	667	
Offices	**UDI%**	**$UDI_{100-2000}$**	**$UDI_{300-2000}$**
		89	79
	sDA_{300}	97.32	
	DS	757	



$UDI_{300-2000}$

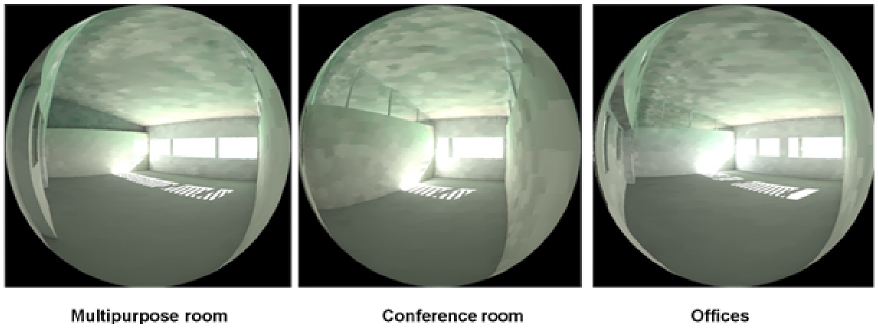


Figure 13: Daylighting conditions at 12 noon on June 26 for the original layout of the building in the spaces located to the north

In terms of energy, the building with the current design and orientation shows better performance as long as natural night ventilation is used correctly for passive cooling. The reduction in cooling consumption is not enough to compensate for the increase in heating consumption. This is understood as a consequence of the reduction of the surface due to solar gain in the rotated building.

5. Results of morphing for RCP 8.5 until 2099 for Victorica

Many authors have predicted that the influence of climate change on buildings will generate an increase in the energy required for cooling and a decrease in the energy required for heating. In the work of Flores Larsen et al. [3], for every 1°C change in average monthly outdoor temperatures, an increase in energy consumption of approximately 2.2 kWh/m2 (for summer) and a decrease of 3.0 kWh/m2 (for winter) was predicted for different locations in Argentina. For Victorica, between TMY2075 and 2099 the mean annual air temperature will increase by 3.2°C and 5.5°C (annual average). These results are in line with the findings of the regional climate models for Argentina [52]. Changes in solar irradiance and wind speed are minor in proportion to the reference TMY. The annual averages for changes in relative humidity are also insignificant (see table *15*).

Table 15: Annual mean values of some climatic parameters for the CNRM-CM5 model, RCP 8.5 scenario. TMY (1961-2010) is included for reference

	TMY	2075	2099
Dry-bulb temperature (°C)	15.1	18.3	20.6
Solar irradiance (W/m^2)	178	179	179
RH (%)	66	66	65
Wind speed (m/s)	3.3	3.3	3.3
Degree days HDD (basline 18°C)	1538	1374	720
Degree days CDD (basline 23°C)	593	720	1041

Figures 14 and 15 show the monthly temperatures for the mean, maximum and minimum air temperatures calculated between 2075-2099 and the TMY reference period 1961-2010. The model predicts that in summer the average temperature will increase 3.3°C for 2075 and 6.8°C for 2099. In July, the increases are between 4°C and 4.5°Cfor the years 2075 and 2099.

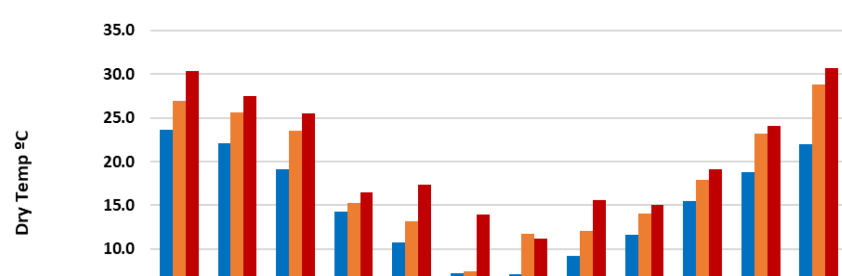
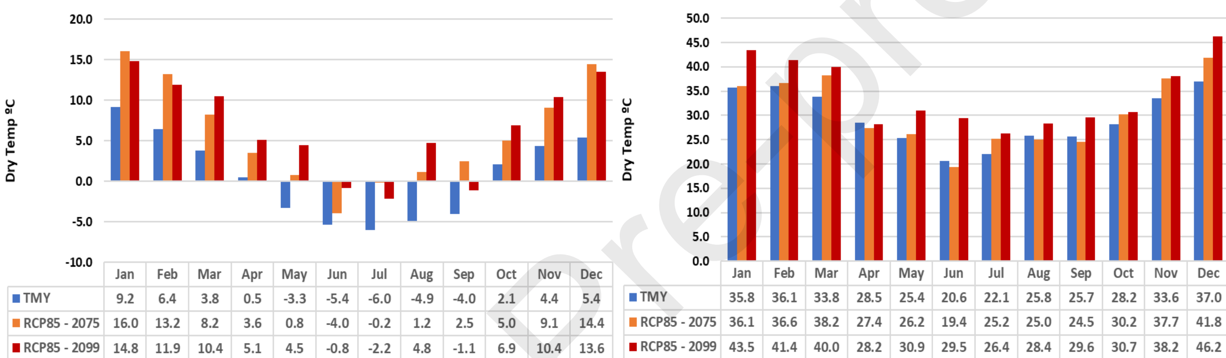


Figure 14: Average air temperature, for the RCP8.5 scenario, 2075-2099 and the TMY reference period 1961-2010, for Victorica

Figure 13 shows that the minimum air temperature will also increase, so warmer nights are expected in winter and summer. In January, TMY registered a temperature of 9.2°C, whereas for 2075 it is 16°C and 2099, 14.8°C. The maximum temperatures in summer could reach 41.8°C by 2075, and 46.2°C by 2099. In winter, an increase in maximum temperatures is also expected.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TMY	9.2	6.4	3.8	0.5	-3.3	-5.4	-6.0	-4.9	-4.0	2.1	4.4	5.4
RCP85 - 2075	16.0	13.2	8.2	3.6	0.8	-4.0	-0.2	1.2	2.5	5.0	9.1	14.4
RCP85 - 2099	14.8	11.9	10.4	5.1	4.5	-0.8	-2.2	4.8	-1.1	6.9	10.4	13.6

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TMY	35.8	36.1	33.8	28.5	25.4	20.6	22.1	25.8	25.7	28.2	33.6	37.0
RCP85 - 2075	36.1	36.6	38.2	27.4	26.2	19.4	25.2	25.0	24.5	30.2	37.7	41.8
RCP85 - 2099	43.5	41.4	40.0	28.2	30.9	29.5	26.4	28.4	29.6	30.7	38.2	46.2

Figure 15: Minimal and Maximum air temperature, for the RCP8.5 scenario, 2075-2099 and the TMY reference period 1961-2010, for Victorica.

5.1. Energy consumption for the case study building

The results of the simulated annual energy consumption (air heating and cooling) for the years 2075 and 2099 are shown in Table 15 and Figure 16.

The results of the A2CC'75 case and the A2 CC'99 case show an increase in annual consumption of 17% for 2075 and 1.8% for 2099. The increase is observed with greater intensity for the year 2075, while the reduction in consumption for heating is 5.8%, the increase for cooling is 220%. For the year 2099, there is also a reduction in heating consumption and an extreme increase in consumption for cooling, with values of 39.9% and 370%, respectively.

When the analysis is performed between Case A2 in relation to cases B2 CC'75 and B2 CC'99, the situation changes. The energy allocated to heating achieves savings of 32.9% and 51.8% by 2075 and 2099. In the case of cooling, savings of 11.5% are observed for 2075 and an increase of 75% for 2099. Analyzing annual consumption, the B CC'75 and B CC'99 cases show a reduction in consumption of 30.7% and 38.9%, respectively. This is considered a consequence of the fact that the decrease in heating needs will be greater than the increase in cooling needs.

Table 16: Simulated annual energy consumption (air heating and cooling) for the years 2075 and 2099

	Year [Kwh/m2]	Heating [Kwh/m2]	Cooling [Kwh/m2]
CASES	**Total**	**Heating**	**Cooling**
CASE A2 - WITH NNV	51.2	46.0	5.2
CASE A2 CC'75- WITH NNV	60.04	43.3	16.7
CASE A2 CC'99- WITH NNV	52.11	27.6	24.5
CASE B2 CC'75 - WITH NNV AND SOLAR PROTECTION	35.5	30.9	4.6
CASE B2 CC'99 - WITH NNV AND SOLAR PROTECTION	31.3	22.2	9.1

As presented in point 5, the future climate situation for the 2075 and 2099 scenarios shows warmer temperatures, which leads to an increase in energy for cooling and a decrease in energy for heating. In other words, in Victorica there will be a lower relative share of heating energy in total consumption.

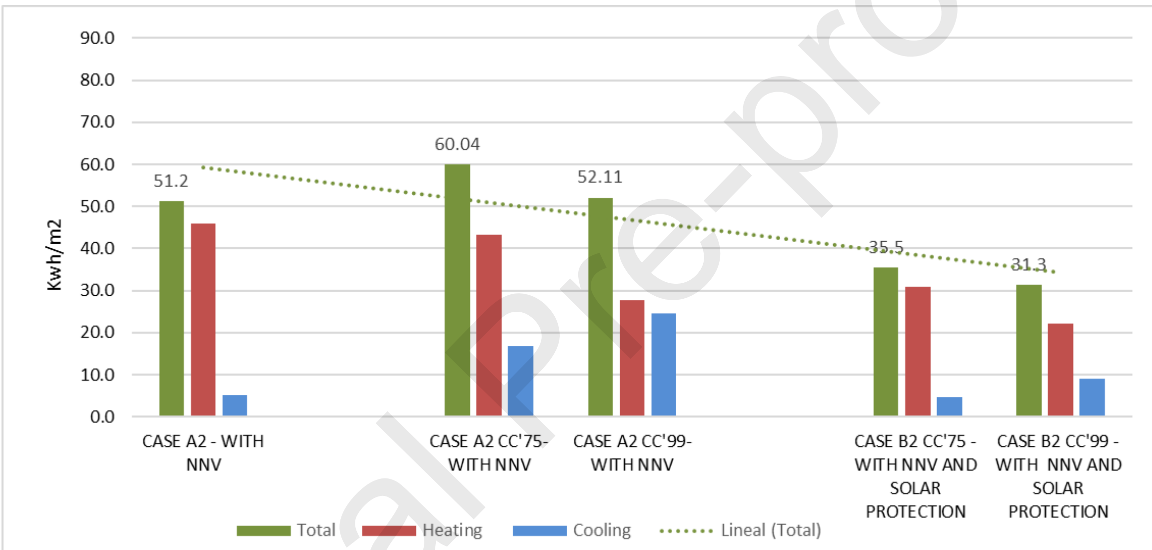


Figure 16: Energy consumption for the Cases A2, A2 CC'75, A2 CC'99, B2 CC'75 andB2 CC'99.

Taking into account the uncertainty of technological progress of refrigeration equipment, according to Santamouris [84], by 2099 will double the efficiency of current equipment.

Table 17 compares the summer consumption for three periods: current, 2075 and 2099; for a COP of 2.3, 2.5 and 4.4 respectively. It can be seen that cooling consumption will decrease, even more than calculated, if we consider more efficient equipment than the current ones.

Table 17: Consumption calculation for refrigeration with more efficient equipment into the future

CASES	Cooling (kwh/m2)		
	COP 2.3 (2020)	**COP 3.5 (2075)**	**COP 4.4 (2099)**
CASE A2-WITH NNV	5.2	3.4	2.7
CASE A2 CC75 WITH NNV	16.7	11.0	8.7
CASE A2 CC99 WITH NNV	24.5	16.1	12.8
CASE B2 CC75 - WITH NNV AND SOLAR PROTECTION	4.6	3.0	2.4
CASE B2 CC99 - WITH NNV AND SOLAR PROTECTION	9.1	6.0	4.8

7. Conclusion

The following conclusions can be drawn from what has been presented in this paper:

Climate change will affect the energy consumption behavior of buildings. A decrease in heating energy needs and an increase in cooling energy needs are expected. For the chosen site, Victorica, between 2075 and 2099, the predicted increases in mean annual air temperature will range from 15.1°C to 20.6°C (5.5°C higher) according to the RCP 8.5 scenario. Monthly increases in average air temperatures will range from 2.2°C to 8.7°C, while average maximum temperatures will increase by 4.3°C to 4.2°C, depending on the month.

A public building was audited for one year. Consumption was recorded three times a day and the other variables described in the manuscript were recorded every 15 minutes. This was made possible by the compromise of the users. The difficulty of studying public buildings has been mentioned before, especially when bibliographic material with reference values for the study region is not available. In the introductory paragraphs it is emphasized that the building was constructed with a limited official budget, a common practice in public institutions in the region.

A physical computational model was calibrated with measured data. This made it possible to model the proposed improvements (with the hypothesis of minimum intervention) and to subject it to the effects of climate change, considering that this type of building is replicated in the region. The results were encouraging, achieving a decrease in consumption for the year 2099, considering the inclemencies of climate change.

Good natural ventilation (NV) performance is essential in all the scenarios studied. With the use of natural ventilation it is feasible to achieve savings of up to 72% of the energy required for cooling. The results confirm the effectiveness of incorporating the "technical plenum" as a functional area that optimizes the passive cooling of the building.

It was also noted that the heating situation should not be neglected if an increase in energy consumption is to be avoided. In relation to the openings that would allow solar gain for heating, it is important that they are always protected for the summer season, this reduces by 46% the consumption for cooling, affecting with an increase of only 1.8% of the energy required for heating.

Another important point is that daylighting requirements have been successfully integrated with thermal and energy requirements. By rotating the building, the benefits of facing south (southern hemisphere) to preserve visual quality (reduction of glare and light uniformity) and energy quality (38.9% savings in annual consumption by 2099) become evident. However, in terms of cooling energy, an increase of 74.3% is observed, leading to a warning that the increase in ventilation openings should not be deliberate, as the number of warm nights in 2099 will increase, leading to a decrease in the effectiveness of natural night ventilation as a passive cooling strategy.

Most significant for the future (RCP 8.5 - 2099) is that the rotated building, with its reduction in direct solar gain (73.1% less than the original case), optimization of natural ventilation and solar shading represents a 51.82% savings in total energy, heating, cooling and lighting for each compared to the monitored building (Measured case= 65.26kwh/m2. Improved case=31.44kwh/m2). If replicated in another geographic location, it would represent a paradigm shift in energy efficient building design.

In general, we can say that the current results are promising at the time of this study. In the near future, the management of the institution may change, and certainly the users as well. In addition, there may be some deterioration of the building itself, which sometimes cannot be repaired without the availability of economic resources. These, among other aspects, generate uncertainty and unpredictability. Therefore, these data are not intended to be deterministic, but on the contrary, indicative data for institutional decision making for the same building typology under an arid climate with high irradiance.

These results allow us to establish guidelines and a new way of thinking about architecture in the context of climate change in arid climates. These can be summarized as follows:

- Design for a warm rather than temperate climate,
- Consider reducing direct solar gain towards the equator to avoid overheating,
- Increase the efficiency of air conditioning systems,
- Advance and incorporate new materials tending to increase their durability without losing physical characteristics over time,
- At the governmental level, promote appropriate mandatory legislation in search of energy efficiency based on bioclimatic design.

8. Prospective

To continue with this research progress will be made in the comprehensive development of uncertain variables using a Monte Carlo approach, with the objective of obtaining results that allow us to obtain a probable distribution of the energy performance, instead of unique deterministic values. These studies will require significant computational power to handle multiple simulations.

Acknowledgements

Promotors: INTA Regional Center, La Pampa-San Luis. Responsible for the architectural project: Arch. León Marek, independent professional. Monitoring users and collaborators: Breit Milton, Molina María José, Poey Maria Sol, Stefanazzi Ivana Noemí (INTA - National Institute of Agricultural Technology - technicians).

The morphing method was applied through a Python code developed by Dr. Silvana Flores Larsen (INENCO-CONICET). The resulting files were transformed into the EPW format through the WeatherConverter application of EnergyPlus. The two-tailed t-test to compare the mean values of simulated and monitored temperatures was developed by Dra. Florencia Ricard (INCITAP-CONICET).

ANNEX I

A.1. Climate Change

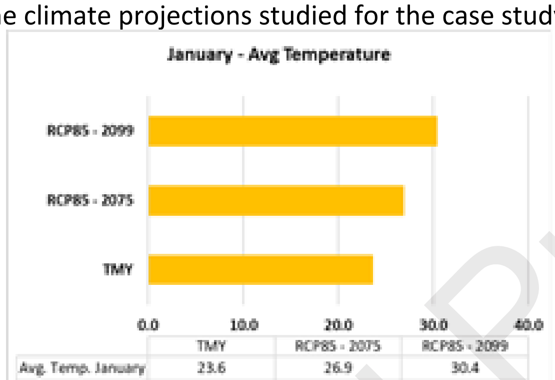
Warming of the climate system is unequivocal. Since 1950, changes in the climate system have been observed that are unprecedented, both when compared to historical observational records, dating back to the mid-19th century, and to paleoclimatic records referring to the last millennia (citation). Projections for the coming decades of many magnitudes show changes similar to those already observed, see Figure 5 of the manuscript. Nevertheless, the uncertainty of the projections is high. The most important issue, despite the enormous increase in effort and knowledge since 1980, is that the mid-range estimate has changed just a little, and the uncertainty in climate sensitivity has not decreased at all. Nor has the uncertainty of the IPCC estimates of net warming from all sources by 2100 decreased.

This uncertainty is due, in part, to social factors, i.e. the different possible paths that global society may take, emitting more or less pollutants. The uncertainty arising from the modeling of the physical climate system is also a very important factor.

The probability that the increase in global average temperature is a consequence of human activity has been increasing in successive IPCC reports. The Third and Fourth Assessment Reports stated, respectively, that the probability of human influence was greater than 66% and 90%. The Fifth Assessment Report considers that there is a greater than 95% probability that human influence on climate has caused more than half of the observed increase in global mean surface temperature in the period 1951-2010, which has led to ocean warming, melting of ice and snow, sea level rise and changes in some climatic extremes in the second half of the 20th century.

To reduce the uncertainty substantially, sustained observations and, unequivocally attributable to anthropogenic forcing, will be necessary. In other words, improved prediction will only occur when climate change actually begins to affect. The response of the climate system happens when greenhouse gases increase, but if we wait for this improvement in the models without acting to avoid substantial climate change, we will be acting too late.

The climate projections studied for the case study are shown below:



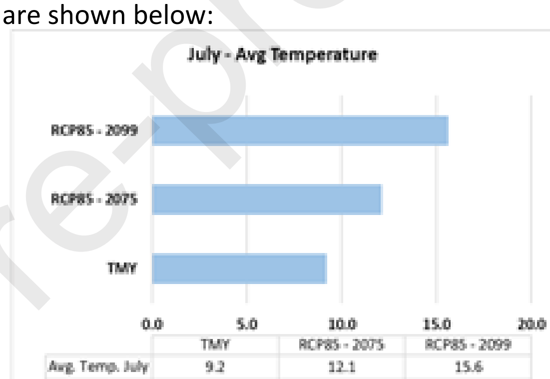
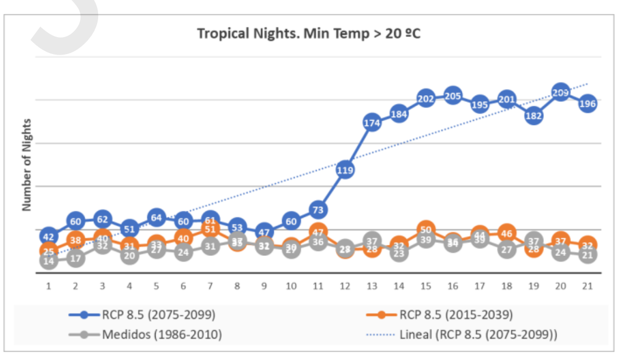


Figure AI-1. Tropical nights, with temperatures higher than 20 °C

The projections show an increase in warm or tropical nights (when the minimum temperature exceeds 20°C [53, 54]). In the near future, (orange line), there will be only two more tropical nights per year than the reference period, whereas in the distant future, (blue line), an increase of 76 more tropical nights per year, 223% more than the measured period, is predicted (see Figure AI-1). This situation will demand a significant increase in cooling loads and energy consumption for air cooling. In winter, the increase in air temperature for all sites indicates that energy consumption for heating will decrease. By comparing the Heating Degree Days (HDD) and Cooling Degree Days (CDD), the trend towards increasing cooling requirements and decreasing heating requirements can be clearly observed. Figure AI-2 and Table AI-1 chart this trend.



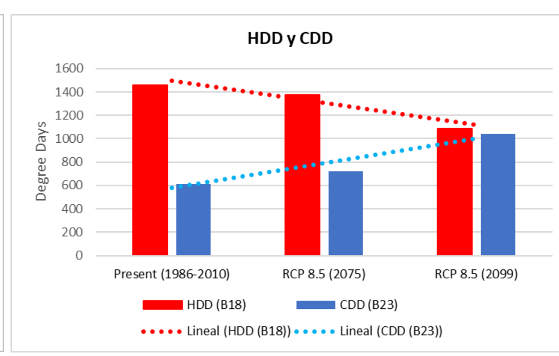


Figure AI-2. Tropical nights, with temperatures higher than 20°C and Heating Degree Days (HDD) and Cooling Degree Days (CDD), for 2075 and 2099 compared to TMY

Table AI-1. Design days with their respective percentiles. Heating Degree Days (HDD) and Cooling Degree Days (CDD), for TMY, 2075 and 2099.

Period	Heating DB		Cooling DB/MCWB			Degree Days	
						HDD	CDD
	99.60%	99%	0.40%	1%	2%	Base 18	Base 23
Present (1986-2010)	-2.85	-1.1	36.4	34	32.5	1461	614
RCP 8.5 (2075)	-2.6	-0.9	37.8	35.7	33.4	1374	720
RCP 8.5 (2099)	0.2	2.1	40.1	37.1	34.9	1087	1041

A.2. Orientation

The rotation of the building was aimed at orienting the largest area of openings to the predominant cooling breezes. From the analysis of the wind rose, it was observed that the cooling breezes, in the summer season, came from the quadrant formed by the south-west. Therefore, an approximation of the energetic performance was made between representative azimuth angles: Case B=180 (South), Case C= 225 (South-West) and Case D=270 (West).

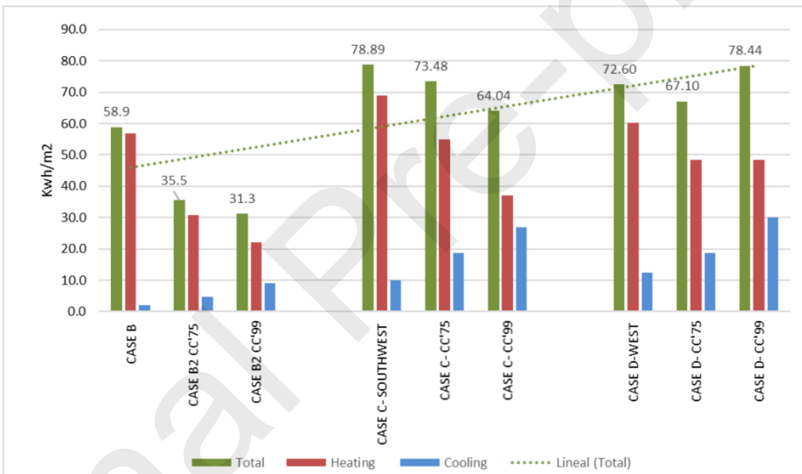


Figure AI-3. Tropical nights, with temperatures higher than 20°C and Heating Degree Days (HDD) and Cooling Degree Days (CDD), for 2075 and 2099 compared to TMY

The results obtained are shown in Figure AI-3. It is observed that the optimal orientation, among those analyzed at this point, is the one presented by Case B, Case D, the most unfavorable, presents differences of up to 511% between the consumptions that refer to cooling, and Case C reaches 394%. As for heating, the values report increases, a strange situation in relation to the other results, this is considered to be directly related to the decrease and lack of windows oriented frankly to the north for solar gain. In terms of total consumption, the values show increases of 34% and 23.3% (Case C and D present), 107% and 89% (Case C and D 2075) and 105% and 151% (Case C and D 2099).

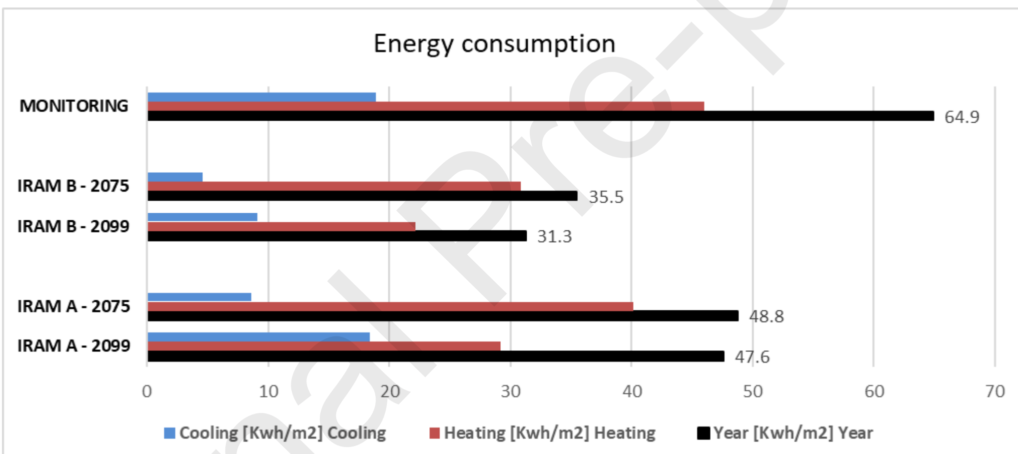
From this study, it was assumed that the building's orientation should respond to the South orientation, providing also, although in a smaller area, direct solar gain to collaborate with the necessary consumption to achieve comfort in winter.

A.3. Envelope, IRAM standards and future design decisions.

The quality of the building envelope studied (Walls: U 0.53 W/m2.ºC; Roofs: U 0.41 W/m2.ºC and glazing U: 3.2 W/m2.ºC) corresponds to level B of the IRAM standard, considering the local climate. Also, the current envelope has an overall loss coefficient (G) value of 0.40 W/m2.ºC, meets the recommendation of IRAM Standard 11604.

If the envelope were to be further improved, it would have to be certified at level A of the mentioned standard. This means increasing the walls' thermal insulation from 7cm to 12.5cm (U, from 0.53 to 0.29 W/m2.ºC), and would imply a 34% increase in the cost per m^2 of the walls (from USD 20.4/m^2 to USD 23.90/m^2). The same would apply to roofs. Improving the roofs insulation levels would imply increasing the insulation thickness from 10cm to 24cm (U, from 0.41 to 0.25 W/m2.ºC), which results in high costs. For the transparent envelope, the north glasses would have to be changed and a low emissivity sheet would have to be added, improving the U values from 3.2 to 1.75 W/m^2.ºC, but increasing the costs of the glass by 100%.

Figure AI-4 show the impact of the potential envelope improvement.It can be observed that the higher insulation levels in the envelope (IRAM A), increase the consumption with respect to the base building (IRAM B). This is due to an overheating of the building, considering climate change predictions.



FigureAI-4: Bar chart of energy consumption for levels A and B of the IRAM standard.

It is also important to state that these results agree with the conclusions of the works of Coscollano et al., Filippin et al. and Mercado et al. [55, 56, 57], where it is distinguished that, from 12 cm of insulation in walls, the U stabilizes and the costs increase, for continental temperate climates. Therefore, we consider it appropriate in this work not to focus on decreasing the U values in the envelope and to propose strategies of natural ventilation and solar gain reduction only by rotating the building. Other regional studies show that thicker insulation thicknesses in non-residential buildings lead to increased energy consumption for cooling due to a lack of heat dissipation from buildings [58, 59].

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