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On high-rise residential buildings in an oasis-city: Thermal and energy assessment of different envelope materiality above and below tree canopy

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ABSTRACT

Urban foresting can affect high-rise buildings in two ways from an environmentalist point of view because building envelopes are exposed to different conditions above and below the tree canopy. Two buildings were selected as case studies with massive and light envelopes. We performed thermal energy analyses in the apartments above and below treetops along with interviews of the residents in order to calculate the Predicted Mean Vote (PMV). A view of these cases clarifies that these factors greatly influence the occupants and their use of HVAC under normal conditions. Dynamic models are validated by the Energy Plus software and user incidents are excluded in order to evaluate the thermal and energy differences based on variables of materiality and height. These results show that there is variation in energy consumption during winter and summer according to materiality of the building envelope: massive building envelopes require more energy consumption in the winter; while, for the summer their consumption is less. In addition, we find that apartments below the tree canopy take advantage of the benefits of the microclimate in the oasis-city with indoor temperatures closer to comfort ranges as well as lower energy consumption for temperatures in both summer and winter.

1. Introduction

The environmental quality of urban spaces is conditioned by temperature increases in cities, caused by heat island phenomenon and the climate change [1]. In this regard, many international studies have analyzed a number of mitigation technologies for improving comfort in urban areas. The use of cool pavements, reflective, and green roofs applied throughout the city may reduce the average ambient temperature until 3 °C [2,3]. These researches reflect the impact of urban morphology on local temperatures and how urban design can be modified to reduce energy consumption and CO_2 emissions into the atmosphere [4]. In the case of Argentina, local climate change and its impact on energy has been studied, with a focus on promoting the integration of urban climate control in the planning and architectural design process [5]. In the same way, a methodology aimed at evaluating the urban quality of life in an intermediate scale city, analyzes the interactions between basic services, infrastructure and environmental aspects. The results define homogeneous areas and consider the advantages and limitations experienced in implementing the model [6]. Other studies demonstrate that the air quality in urban areas increases contamination problems affecting the not only environment, but also human health [7]. In addition, measurements made in the province of Mendoza, determine that an appropriate selection of urban envelope materials contribute to reducing the negative effects of heat island. Horizontal urban envelopes (more demanding conditions related with solar exposition) offer lower possibilities for improving their thermal behavior than vertical claddings [8]. As a result, it can be concluded that urban morphology, materials, urban forests and the local microclimate must be in balance with the built environment, which promotes the sustainability of the city.

Otherwise, today, many developing countries are renewing their urban centers by building high-rise buildings in consolidated areas. These new buildings, which are mostly based on models in the US

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and Northern Europe, focus mainly on image rather than other factors that are related to interior comfort. This tendency results in the weakening and the simplification of building envelopes through the increased use of glass [9], which leads to a dependence on complex environmental control systems. In Argentina, the compliance on thermal conditioning regulations is mandatory only in the Province of Buenos Aires and is optional for the rest of the country. It is important that energy saving measures be taken because the consumption of resources for air comfort are increasing due to the low prices of mechanical air conditioning equipment and the present accessible energy costs (around 0.05 USD per kWh).

Studies on energy and indoor environmental performance of high-rise residential buildings can be framed in two orientations. On the one hand, for residential buildings, there is a great amount of adaptability and flexibility for thermal requirements when compared to other types of buildings. This is due to the great variation in use as well as the influence of the residents [10]. Consequently, occupants have an important role in the management of interior temperatures and energy consumption [11,12]. On the other hand, the other studies have explored various parameters concerning the materials of the building envelopes and shading devices in search of energy saving measures [13,10,14–16]. With the goal of achieving a rehabilitation of the envelope, some other studies have analyzed energy use in multifamily high-rise buildings by taking measurements, and simulations [17–20]. Also, some buildings have distinguished by their envelope materiality by their massiveness and lightness [21,22]. They indicate that massive buildings have better energy and environmental performances and are a convincing strategy in the fight against climate change in urban areas. The thermo-dynamic analysis of buildings with high thermal inertia mass prevents the phenomena of overheating and ensures good comfort levels in occupied buildings, reducing the needs of HVAC [23]. While the investigations mentioned have certain variables concerning each case, all consider contextual climatic and environmental factors.

Also, urban public and private planted areas in dry regions, to the extent that they can be properly maintained, are a great asset in a hot, dry region because of the scarcity of natural vegetation. The surface temperature of soil that is shaded by vegetation in hot, dry areas is substantially lower than the surface of un-shaded soil [24]. Particularly, the oasis-cities, cities located in arid climates, enjoy unique environmental benefits from the urban forest. These may be defined in two ways: on one side, the situation below the tree canopy benefits low-rise buildings (3–4 stories) in the summer since the incident radiation is moderated and can even be blocked, depending on the density of the foliage [25]. Reductions in the exterior temperature during the summer may fluctuate between 0.3 °C and 3 °C depending on climate and context [26]. On the other hand, the housing units above the tree canopy are directly exposed to the climate of the region and are open to absorbing full solar radiation in the winter (desired incident energy) and in the summer (unwanted incident energy). They are also exposed to convective and radiative energy exchanges in both seasons. Subsequently, this city model presents a microclimate that benefits low-rise buildings, which is in accord with the arid climate located in the region. Despite the differentiation of the microclimates, tall buildings tend to have a single building envelope regardless of these environmental factors of the surroundings.

The studied city, Mendoza, Argentina (32°40′ LS, 68° 51′ W) is located in a semi-desert and arid area, and has a temperate continental climate. It is considered an oasis-city because of the following factors: the urban "checkerboard" structure (a rectangular layout of city blocks), the buildings, an urban forest (a layout of trees that populates the urban frame) and a system of irrigation (canals) that borders the perimeter of the city blocks. These factors result in a sector of the atmosphere that benefit from the environmental effects of the trees and the water. In these ways, Mendoza has reduced the negative effects of the arid climate native to this region [27]. However, it is necessary to encourage a combination of forest structure and urban morphology that benefit nocturnal cooling in order to reduce urban heat island [28]. Fig. 1 shows the articulation of the construction and urban trees in the oasis city of Mendoza, where few buildings stand out on the urban strata.

Table 1
Datum of the city of Mendoza by the Servicio Meteorológico Nacional, Fuerza Aérea Argentina.

Annual values	Average maximum temperature	22.6 °C
	Average minimum temperature	11.0 °C
	Mean temperature	15.9 °C
	Global horizontal irradiance	18 MJ/m^2
	Relative humidity	54.70%
	Mean rainfall	218 mm
July (winter)	Average minimum temperature	3.4 °C
	Mean temperature	7.8 °C
	Average maximum temperature	14.7 °C
	Thermal amplitude	11.3 °C
	Mean wind velocity	7.6 km/h
	Global horizontal irradiance	9.9 MJ/m^2
January (summer)	Average maximum temperature	30.1 °C
	Mean temperature	25.3 °C
	Average minimum temperature	18.4 °C
	Thermal amplitude	11.7 °C
	Mean wind velocity	10.8 km/h
	Global horizontal irradiance	25.7 MJ/m^2
Annual heating degree-days (Tb = 18 °C)		1384
Annual cooling degree-days (Tb = 23 °C)		163

On climate, there are distinct and significant changes throughout the year: cold winters, summers with high temperatures and intermediate seasons where periods of short extreme temperatures may occur. Accordingly, there are considerable differences in the seasons and in their amplitudes. This type of scenario is challenging from a design point of view [29] and it requires a more complex architecture that is able to meet the varying demands of each season. Table 1 shows the climatic characteristics of Mendoza.

This paper presents a study aimed at assessing energy efficiency and its relation to comfort in high-rise residential buildings within oasis cities, with the specific case of Mendoza. This city has high fluctuations in daily temperatures (10–20 °C), which highlights the crucial role of the materiality of the building envelopes and the relationship with interior comfort. For these reasons, this investigation defines two typologies of the exterior building facades – massive and light. These are defined by thermal inertia in terms of density (ρ) and weight (kg/m^2). In order to accomplish this, it is necessary to establish and validate the variables related with audit-diagnostics and then compare the behaviors of thermal simulations. We test and evaluate the trends in building envelope structures in order to generate better proposals that can be transferred to the norms of building architecture regulations.

We propose the following specific objectives: (a) Create a diagnosis for real conditions of use for apartments on different floors (above and below treetops) belonging to two different types of building envelope materiality (massive and light). These apartments are located in highly dense area of the city of Mendoza, Argentina; (b) develop dynamic simulations using the Energy Plus software, which correlates the results of actual thermal measurements of the simulation and validates geometric models; and (c) simulate thermal behavior by excluding resident behavior and analyze the thermo-energetic differences related to the height of the housing units while considering the moderating impact of the urban forest as well as the influence of the materiality of the envelope.

Fig. 1. Aerial view of the city of Mendoza (own source).

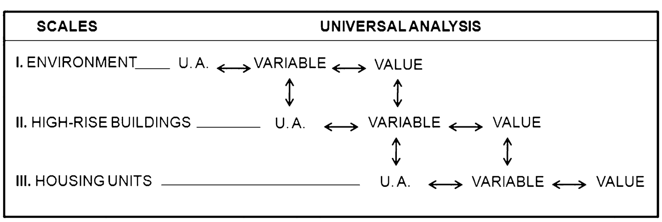

Fig. 2. Cascading Schema from Samaja [19].

2. Choice of the cases studies

Cases were selected following a cascading scheme [30] where the information is structured by the following: Unit of Analysis (UA), Variable and Value, and interchanging roles. Fig. 2 presents the scheme separated into three different approaches: environment, high-rise buildings and housing units. This logistic has been covered in other methodological studies [31,32], and has been applied in different spatial, regional, urban and sectorial scales.

Scale I – Environment: the area concerning the greatest quantity of high-rise buildings, mostly residential, with high population density estimated to be more than 800 habitants/hectare.

Scale II – High-Rise Buildings: Permanent residential buildings were evaluated. Height, Morphology, Materiality and Orientation were set as fixed variables.

Height: This classification was created in relation to one of the distinctive characteristics of the city: urban vegetation. High-rise buildings that rise above the maximum level of treetops, that is, buildings with more than 5 stories (15 m) are considered high. In addition, the selection of case studies includes the same type of trees in order to collect comparable results.

Morphology: high-rise buildings in the city of Mendoza are categorized into three different morphological types according to city building code regulations [33]. The area studied includes a sample of 67 residential buildings. These were classified according to type:

- Towers developed within the land boundaries: buildings up to 10 stories high, developed within land boundaries (there are spaces between the building and the property line).

Table 2
Massive and light building typology description for Mendoza city.

Building typology	Density (ρ) per cubic meter	Weight per square meter
Massive	More than 50% $\rho \geq 1200\,kg/m^3$	$\geq 100\,kg/m^2$
Light	More than 50% $\rho < 1200\,kg/m^3$	$<100\,kg/m^2$

- Base structure and tower: the base is a construction that is developed within the land boundaries with a maximum height of 10 m. Above the base structure, the tower is allowed to expand to a certain distance from the edge of the lot.
- Tower removed from the dividing property lines: towers which do not extend to the limit of the lot. They reach their maximum heights as stipulated by the ratio of the dimensions of the terrain.

Materiality: for all of the buildings in the study, the following exterior elements were calculated: (a) elements of the building envelope that can be considered opaque, translucent or transparent; (b) interior elements that can be considered massive or light; and (c) exterior walls that have exposed surfaces. We determined two building typologies: a massive building envelope refers to constructions with more than 50% of materials with a density (ρ) greater than or equal to 1200 kg/m^3 and a weight greater than or equal to 100 kg/m^2. A light building envelope refers to constructions with more than 50% of materials with a density (ρ) less than 1200 kg/m^3 and a weight less than 100 kg/m^2. Table 2 summarizes these values.

Orientation: in order to assess the effects of the favorable conditions from a bioclimatic point of view (the Southern Hemisphere), cases were evaluated where the principal facade faces north.

Scale III – Housing units: two variables were studied: Height and Orientation.

Height (or relative position of the apartment within the building) was defined by whether the housing unit was located above treetops, which is considered as from the fourth story (12 m) of the building. Height limits are also based on the types of trees [34]: 12 m from street level for mulberry (*Morus alba*) and ash trees (*Fraxinus excelsior*); and a limit of 15 m of height from street level for the plane tree (*Platanus acerifolia*). The following indices were determined:

Fig. 3. Location of the case studies in the city of Mendoza.

- Housing below the tree canopy: up to and including the fourth story (ground floor +3), corresponds to a height up to 12 m.
- Housing above the tree canopy: starting from the fifth story (ground floor +4), corresponds to a height greater than 12 m.

Orientation: Frontal apartments were selected, that is, those oriented toward the street and thus the urban forest. Also, it was considered relevant that a public square is located the area to the immediate north of the building studied to be free of shadow from the surrounding neighborhood.

2.1. The cases studies

From the variables previously raised we selected two buildings: massive and light. Both are located face the main squares of the city, in streets of 20 m wide forested adults *M. alba* tree specimens (Fig. 3). In each building we could measure frontal apartments located below and above the tree canopy.

The massive building studied has 73% of the building envelope made of opaque materials and 27% corresponds to glass. The materiality of the building is made up of 0.30 m of hollow plastered ceramic brick with exterior paint, and it is not insulated. The interior is made of the same material at 0.10 m thick and the slabs are reinforced concrete with wooden floor. Glass windows are simple, 4 mm think. As for shading, there are balconies, 1.20 m wide and sliding wooden shutters with white blinds. The monitored housing units have a roofed area of 122.50 m^2 and a semi-covered balcony of 5.50 m^2 (Fig. 4). They are located on the first and fifth floors.

The building with the light envelope is a Tower removed from the dividing property lines. The building envelope is a light construction with a concrete structure and an exterior layer of glass. The structure is significant because of the seismic activity in the region while the architecture is dominated by a transparent esthetic. 48% of the exterior building envelope is opaque and composed of reinforced concrete walls with a polymer-based textured plaster. However, 22% of this is coated with glass (for esthetic reasons), which varies the thermal transmittance minimally (Table 3). Transparent material makes up 76% of the building envelope. The interior dividing walls are light, made of cardboard and Durlock plasterboard, 10 cm thick and the slabs are reinforced concrete with porcelain floors. The 6 mm (3 + 3) windows are laminated with polyvinyl butyral (PVB). There are varying sections of colorless, artic-blue or mirrored glass. The building has balconies that are 1 m wide without any type of solar protection in the envelope. The housing units have a covered area of 98 m^2 and a semi-roofed balcony of 17 m^2 (Fig. 5). They are located on the third and 16th floors.

A form analysis for both housing units in the study is defined by two factors: Form Factor: FF [35] and exposed envelope area: FAEP [36]. The results show that both apartments have similar factors, for the massive envelope units FF = 1 and FAEP = 0.60 and for the light envelope units FF = 1.20 and FAEP = 0.50, which indicates similar grades of compactness.

Basic data of the massive and light building are presented in Table 3.

3. Monitoring

Thermal audits were performed in four housing units: two in apartments that are equal in design for each selected building (massive and light typologies) located at different heights (above and below the tree canopy). Environmental measurements were performed simultaneously in all four seasons of the year in periods of between 20 and 30 days.

Temperature and relative humidity were taken with HOBO U12 data loggers every 15 min simultaneously on all instruments [37]. Three data loggers were used for each of the housing units placed in different locations: two inside (living room and bedroom) and one outside (balcony), which was protected from solar radiation (see housing units in Figs. 4 and 5). They were located at a height of 2 m, following recommendations [38], and at a sufficient distance from the walls in order to avoid data distortion [39].

Global solar radiation measurements were conducted within a radius of 2 km of the sites, a valid distance for data collection as indicated by the Red Solarimétrica de la República Argentina (Solar Metric Network of the Republic of Argentina) [40]. They were taken with solar meter CM 5 KIPP & ZONEN at the same times and intervals of data collection that were established for temperature and humidity.

Regarding energy audits, bimonthly bills were obtained for a two year period in order to measure natural gas and electricity usage. Energy consumption for HVAC for winter and summer differ by the following:

- Heating in winter: Average natural gas consumption was calculated during periods that gas was not used for heating (from September to May). Then, this data was used to calculate gas consumption for hot water and cooking, allowing us to differentiate from heating the housing unit.
- Cooling in summer: Average electricity consumption was calculated during periods that cooling systems were not used. Then, this data was used to calculate electricity consumption for lighting and electro-domestic needs, allowing us to differentiate from the consumption for cooling the housing unit. In this case, the units differ because the light apartments used their cooling systems for longer periods of time.

3.1. Analysis of use and thermal comfort

Open interviews were conducted with the residents of the apartments about the rooms: the use, schedules, cooling/heating systems, etc. In addition, we included a question that asks about thermal comfort along the 7 points of the ASHRAE scale (+3: hot; +2: warm; +1: slightly warm; 0: neutral; −1: slightly cool; −2: cool; −3: cold) according to the ISO 10551 norm [41].

An extensive survey of environmental parameters was performed during the interviews. In addition to air temperature, we measured: Interior air temperature, relative humidity, and exterior temperature with a micro-brand ONSET data logging device, model HOBO U14; radiant temperature with a micro-brand ONSET model

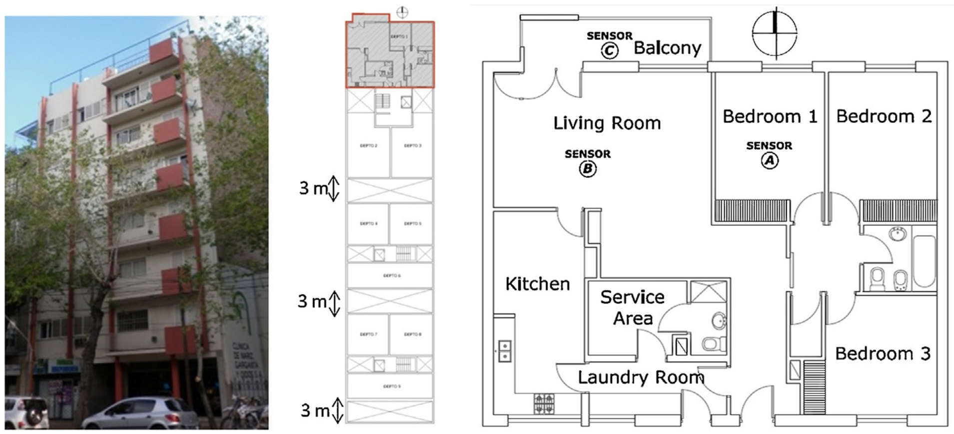

Fig. 4. Massive building. Facade (North), general plans and the housing unit layout.

Table 3
Basic data of the studied buildings.

	Massive building	Light building
U factor		
External walls	$1.36\,W/m^2\,°C$	$2.55\,W/m^2\,°C$ (with glass) $2.54\,W/m^2\,°C$ (without glass)
Vertical internal partitions (internal walls)	$1.97\,W/m^2\,°C$	$5.7\,W/m^2\,°C$
Horizontal internal partitions (floors and roofs)	$1.7\,W/m^2\,°C$	$2.7\,W/m^2\,°C$
Windows	$5.8\,W/m^2\,°C$(solar factor: 0.87)	$5.7\,W/m^2\,°C$(solar factor: 0.07)
Average thermal resistance of the total envelope	$0.49\,m^2\,°C/W$	$0.26\,m^2\,°C/W$

HOBO U12 with a type T thermocouple inside a black balloon; surface temperature with a thermographic FLIR camera, model i3; and indoor air flow and volume with a Testo model 425, hot wire anemometer.

The environment data taken during the interview helps contextualize the answers along with the monthly measurements. This is because people generally only answer about the immediate situation they find themselves in at any given time and not so accurately for other seasons [42].

Furthermore, the evaluation of thermal comfort is complemented by the calculation of the Predicted Mean Vote (PMV) following the ANSI/ASHRAE Standard 55 [43]. The PMV predicts the mean value of the votes for thermal comfort from a large group of people following the previously mentioned 7-point scale. The ANSI/ASHRAE Standard 55 recommends a range of $-0.5 < PMV < +0.5$. The calculation uses the heat balance of the human body in a particular active situation, along with clothing and four environmental parameters to measure the flow of heat required for the highest comfort. This is found using the following equation (1):

$$PMV = (0.303 * e^{-0.036M} + 0.025) * Lo \quad (1)$$

where *Lo*: heat accumulation in the body, *M*: metabolic rate.

For the participants in the case studies, adults were considered to be in a sedentary activity, dressed in classic office clothing with an insulation value equal to 1 clo.

4. Dynamic simulations with Energy Plus

4.1. Model definition and validation

Measurements were taken in order to create dynamic simulation models. The whole building was geometrically defined using Open Studio Plug-in program for Google Sketch Up Version 8, from

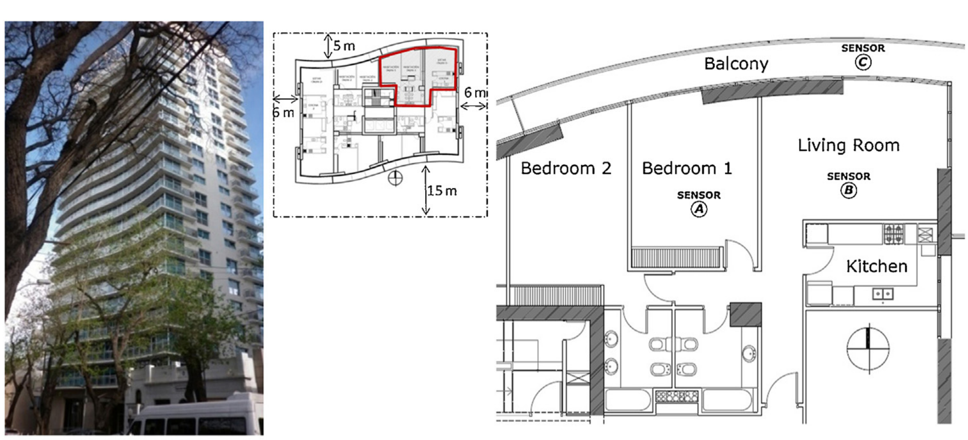

Fig. 5. Light building. Facade (North-West), general plans and the housing unit layout.

which, the data was entered into the *Energy Plus* software version 7.0 [44].

In both buildings was graphed the apartment sector under study. All the apartments were separated into 4 zones because the importance of choosing a suitable division in thermal areas [45]. By incorporating equal apartments (with the same division of zones) below and above the housing units studied, we could control the interchange of heat through the floors and ceilings. Each modeled apartment encompasses a thermal zone for: the living room, bedroom 1, bedroom 2 (oriented to the North in both typologies) and the service area (kitchen, laundry, bathrooms). The ground floor and the staircase were considered as independent thermal areas. In consequence, 26 different thermal areas were defined in the massive building (considering all housing units). In the light building, the housing units studied were entered until the fourth level. Then the levels 15, 16 and 17 were drawn with their real height in order to simplify the simulation. Finally, in this building they were considered the two existing underground levels. In consequence, 32 different thermal areas were defined in the light building.

Thermal and optical properties of the materials of the building envelope were obtained according to local Norms of Thermal Conditionings [46] and the Argentinean glassworks [47]. Floors and ceilings were entered as items composed of four layers (from interior to exterior): an applied ceiling (plaster), concrete slab, concrete subfloor, and hardwood which allowed us to use Conduction Finite Difference in the Heat Balance Algorithm. Detailed description of the construction data assumed in the model is presented in Table 4 for the massive building and Table 5 for the light building.

Furthermore, we considered the following aspects: Building Shading was entered for balconies and blinds; the quantity of people per zone was included in order to determine the purpose of the time of use for each area. Also, Effective Leakage Area models were used to calculate air infiltration, which was done every hour in all thermal zones. This model is based on an investigation [48] and is appropriate for residential buildings. The convective coefficients of the surfaces for the interior walls were set at 6 W/m^2 K. Convective coefficients of the exterior walls are calculated by the software through a detailed model that processes surface orientation, wind speed and direction.

In relation to the validation, simulations were programmed for 10 days before the selected date because it is important that the physical model is entered in advance. Adjustments were made in the living room due to the fact that it is the most occupied room. In addition, in the living room we could know (through the interviews) how the residents influence their environment in the greatest detail. In this case we programmed the number of people and time of space occupation, as well as the schedules in which the people open and close curtains: in the MB housing the living room is occupied by two people eight hours a day (9am–5pm) with blinds and curtains closed 50% throughout the day. In the MB the space is taken up five hours a day (from 1pm to 4pm and from 8pm to 10pm) by two persons, who keep blinds and curtains closed at 100% overnight and 30% open during the day. In the light case, in the LB the living room is occupied by one of the inhabitants six hours a day (2pm–4pm and 7pm–11pm) and by the other person two hours (9pm–11pm); while in the LS the inhabitant occupies the space four hours daily (from 2pm to 4pm and from 9pm to 11pm). In both departments they kept the curtains closed at night and open at 50% during the day.

Regarding the seasons that were selected for the study, it is important to isolate heating and cooling periods. The periods of time where the least use of HVAC were taken into account. This was done by evaluating the areas investigated as well as with interviews of the residents. By measuring the environmental variables

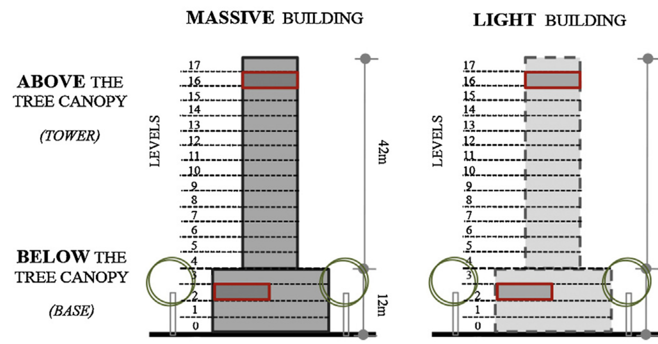

Fig. 6. Thermal and energy comparison in equivalent department story.

during the selected periods, the data was collected for the simulation models. Direct beam and diffuse solar radiation from a horizontal plane were calculated using a Windows application SIMEDIF [49], which takes position and global radiation from a horizontal surface. For this study, two environmental files were created: one concerned the actual condition about the tree canopy from measurements taken regarding temperature and global solar radiation. And a second file shows how the incident radiation changes below the tree canopy in order to understand the circumstances below the treetops. In order to do these studies, we took into account investigations concerning the degrees of permeability of urban trees in central western Argentina [25]. The ratio of permeability to the global radiation at mid-day corresponds to the case study of the *Morus Alba* which is 31.4% in summer and 66.4% in winter. This data was confirmed through a solar radiation audit in the exterior spaces of the housing units using a Lutron SPM-116SD sensor for the days and the times that were selected for the measuring period.

4.2. Simulation by excluding resident behavior and unifying morphological typologies

Once the model was validated, resident behavior was excluded without considering the internal gains from the occupants. Also, as a decision due to the work with equivalent morphological typologies, tower and base characteristics were unified to demonstrate the micro-climatic benefits of the tree canopy in the first floors (up to 12 m high). In the base of the building, the lateral building envelopes – East and West – are protected from exposure to the exterior climate by the surrounding buildings. Therefore, the surface conditions of these envelopes were modified as adiabatic surfaces.

As the energy consumption needed for HVAC were simulated in each zone by the geometric model, we were able to obtain the total consumptions of the housing units analyzed. We studied 5 different scenarios, programming the thermostats for heating at 19 °C, 20 °C, 21 °C, 22 °C and 23 °C; and for cooling at 24 °C, 25 °C, 26 °C, 27 °C and 28 °C.

In order to have clear references for the case studies, the following abbreviations are defined:

MB: Apartment in massive building below the tree canopy.
MA: Apartment in massive building above the tree canopy.
LB: Apartment in light building below the tree canopy.
LA: Apartment in light building above the tree canopy.

Thermal and energy differences were analyzed in equivalent department story: second and 16th levels (see Fig. 6). For this, levels 15, 16 and 17 were drawn in the massive building. With the

Table 4
Detailed construction data of massive building.

Layers	Roughness	Thickness [m]	Conductivity [W/m °C]	Density [kg/m^3]	Specific heat [J/kg °C]
EXT_ WALL (façade)					
Exterior plaster	Very rough	0.025	0.93	1900	1000
Hollow brick	Rough	0.3	0.41	1200	600
Interior plaster	Very rough	0.025	0.93	1900	1000
INT_WALL					
Interior plaster	Very rough	0.025	0.93	1900	1000
Hollow brick	Rough	0.1	0.41	1200	600
Interior plaster	Very rough	0.025	0.93	1900	1000
FLOOR/ROOF					
Gypsum covering	Smooth	0.025	0.48	741.3	836.3
Reinforced concrete	Rough	0.12	1.7	2400	800
Cement mortar	Medium rough	0.1	1.63	2400	800
Wooden floor	Smooth	0.025	0.11	500	2800

Table 5
Detailed construction data of light building.

Layers	Roughness	Thickness [m]	Conductivity [W/m °C]	Density [kg/m^3]	Specific heat [J/kg °C]
EXT_WALL (façade)					
Exterior plaster	Very rough	0.025	0.93	1900	1000
Reinforced concrete	Rough	0.4	1.7	2400	800
Interior plaster	Very rough	0.025	0.93	1900	1000
INT_WALL					
Interior plaster	Very rough	0.025	0.93	1900	1000
Plasterboard	Smooth	0.1	0.44	980	840
Interior plaster	Very rough	0.025	0.93	1900	1000
FLOOR/ROOF					
Gypsum covering	Smooth	0.025	0.48	741.3	836.3
Reinforced concrete	Rough	0.12	1.7	2400	800
Cement mortar	Medium rough	0.1	1.63	2400	800
Porcelain floor	Smooth	0.02	1.3	1800	920
SUBSOIL FLOOR					
Ground	Rough	1	0.87	2000	840
Reinforced concrete	Rough	0.12	1.7	2400	800
Cement mortar	Medium rough	0.1	1.63	2400	800

purpose of compare the main variables in this work, we analyze the following differences:

Height:

Massive building envelope: MA – MB.
Light building envelope: LA – LB.

Materiality:

Apartments below the tree canopy: LB – MB.
Apartment above the tree canopy: LA – MA.

5. Audits results during real conditions

The analysis of the audits shows the thermal and energy habits according to the different types of building envelope and the perceived comfort as expressed by the interviews of the residents for both summer and winter.

The characteristics of the residents and the HVAC systems for each unit are: For the apartment in massive building below the tree canopy (MB) the resident is a retired male over the age of 70. He is practically in the unit at all times (20 h a day). The unit has the following HVAC systems: for cooling, there is an air conditioner (2.55 kW with a consumption of 0.99 kWh) in the living room; and for heating there are two gas wall heaters with a balanced flue: one in the living room (4.48 kW with a consumption of 14.63 kWh) and another in the hall at the entrance of the bedrooms (5.22 kW with a consumption of 21.94 kWh).

In the apartment in massive building above the tree canopy (MA), there is an older couple, still working, living in the apartment between 14 and 16 h a day. The housing unit has the following HVAC systems: a ceiling fan (0.06 kWh consumption) in the main room as the only source of cooling; and for heating, there are three gas wall heaters with a balanced flue – one is 4.64 kW (14.63 kWh consumption) in the living room and two other heaters in the bedroom that are 2.9 kW (12.18 kWh consumption).

In the light building, in the apartment below the tree canopy (LB), the residents are a couple about 40 years old, both working and who occupy the apartment between 16 and 20 a day. In the apartment above the tree canopy (LA), there is a female who works regular business hours from Monday to Saturday.

Concerning the HVAC systems, both apartments have the same equipment: for cooling, there are three air conditioners, one in each room (living room and both bedrooms). The cooling capacity of the two bedroom air conditioners is 4.48 kW (1.32 kWh consumption) and 5.22 kW for the one in the living room (1.98 kWh consumption). There is a central control device in each apartment where the resident can indicate the desired temperature and the system is activated as required. There is radiant floor heating in the apartments and the control system is the same as that for the air conditioning.

5.1. Summer

In the massive building, the temperatures are similar in both apartments with an average difference of 0.30 °C in the living rooms and 0.70 °C in the bedrooms. This is for two reasons: first, in the case

Table 6
Average temperatures, average daily ΔT, energy consumption for HVAC and perceived comfort in summer.

Cases	Living room		Bedroom		Balcony		Cooling energy consumption	Comfort (ASHRAE Scale)
	Average temp. [°C]	Daily ΔT [°C]	Average temp. [°C]	Daily ΔT [°C]	Average temp. [°C]	Daily ΔT [°C]		
MB	28.4	2.2	27.5	1	27.8	6.4	0.3	0 (comfort)
MA	28.1	1.3	28.2	1.2			0.2	0 (comfort)
LB	29.35	2.5	26.5	0.8			2.2	3 (heat)
LA	29.4	3	27.9	1.5			2.2	3 (heat)

Table 7
Average temperatures, average daily ΔT, energy consumption for HVAC and perceived comfort in winter.

Cases	Living room		Bedroom		Balcony		Heating energy consumption [kWh/m^2]	Comfort (ASHRAE Scale)
	Average temp. [°C]	Daily ΔT [°C]	Average temp. [°C]	Daily ΔT [°C]	Average temp. [°C]	Daily ΔT [°C]		
MB	24.5	2.5	20.5	0.8	10.4	13	16.4	1 (slightly cool)
MA	19.85	1	20.1	1			4.9	0 (neutral)
LB	25.05	2	27.2	2			6.5	0 (neutral)
LA	25.9	2.5	26.7	1.8			8	0 (neutral)

of the MO, residents usually closed the curtains during the day to moderate the incident radiation; while in the MB, they normally do not. The urban forests lessened the incident radiation for the MB. This means that if MB correctly manages the building's envelope, indoor temperatures are cooler. As for energy audits, consumption for HVAC is 0.3 kWh/m^2 in MB and 0.2 kWh/m^2 in MO and the residents expressed comfort in both cases (0 in the ASHRAE scale).

In the light building, even though the temperatures are higher in the LA, the average differences are negligible in the living rooms (0.05 °C) and higher in the bedrooms, 1.40 °C. This is because the morphology of the building does not take advantage of the moderation from the trees. LB does not fully benefit from lowered radiation of the tree canopy. Also, LA has higher daily thermal differences because of the atmospheric conditions at that height. Consumption for HVAC is 2.2 kWh/m^2 for both apartments and residents expressed hot (+3 in ASHRAE scale).

It can be seen that in order to achieve similar temperatures (around 29 °C) in the apartments in light buildings, residents consume as much as 10 times the amount of energy than those in massive buildings. There is much greater expenditure for the same levels of comfort. For light buildings, it becomes necessary sometimes to use cooling systems in the autumn due to the direct solar radiation and internal gains [50].

Table 6 shows average temperatures, daily average thermal amplitudes (ΔT) and energy consumption for HVAC in relation to the interviews concerning perceived comfort for the four case studies.

5.2. Winter

In massive buildings, temperatures are higher for the MB with an average difference of 4 °C due to the greater use of heating in this space (see Table 7). However, temperatures in the rooms are similar in both cases with an average difference of 0.40 °C. Energy consumption audits for HVAC show 16.4 kWh/m^2 for the MB and the resident expressed "slightly cool" (ASHRAE scale −1) and 4.9 kWh/m^2 for the MA and the resident expressed neutrality (ASHRAE scale 0). This shows differences in the order of 300% for consumption even though the interviews were done on the same day. This may be due to the cooler winter temperatures in the MB as well as the disparity in the age of the residents.

In light buildings, consumption for air comfort of the apartments is similar. Although the Living room temperatures are higher in the LA, bedroom temperatures are higher in the LB with a mean difference of less than 1 °C. This is due to similar behavior in both cases as well as the tower morphology, which exposes building envelopes in all directions both below and above the tree canopy, and has greater thermal gains but also greater heat loss. Regarding HVAC consumption, LB shows 6.5 kWh/m^2 and for LA 8 kWh/m^2. Residents in both apartments expressed perceived neutrality (ASHRAE scale 0).

Light buildings demonstrate higher energy consumption levels for heating than for cooling even though residents expressed that it is rarely necessary to use central heating in the winter but necessary to have constant air condition in the summer, including spring and autumn use as well in interviews. This is because, in the summer, the air conditioner runs while people are home and then turns off when they leave. While in winter, the use of central heating in these buildings is constant, even when the temperature is set at a minimum level and residents correctly perceive that indoor temperatures are comfortable even without the use of HVAC. This is a result of poorly managed economic subsidies by the state for natural gas causing confusion in the population about medium and high levels of consumption even in state run institutions. This situation masks the reality concerning the complex circumstances about the availability and responsible use of resources. Residential natural gas consumption has great variation in their demands depending on the temperature, and these demands have very high consumption peaks, but short duration. As the outside temperature decreases, consumption increases, and once all the existing heating system in the residence has been turned on, the gas consumption tends to stabilize at its maximum value. This is a fact of great importance in the Argentine system: the specific residential consumptions have very regular temperature dependence, and they are independent of time and economic context [51].

Table 7 shows average temperatures, daily average thermal amplitudes (ΔT) and energy consumption for HVAC in relation to the interviews concerning perceived comfort for the four case studies.

6. Predicted Mean Vote (PMV) calculation

PMV results are analyzed in order to know the value of the predicted mean vote of a large group of people found through resident interviews. Results indicate that for the MB, 64% of people would find the apartment between warm and hot (+0.5 to +3) while 36% of the population would be comfortable (−0.5 to +0.5). Based on the interviews, 36% of people who would reside in the apartment (MB)

Table 8
PMV calculations for the housing units in the study.

Thermic comfort value	MB	MA	LB	LA
+0.5 < PMV ≤ +3	64%	41%	93%	100%
−0.5 ≤ PMV ≤ +0.5	36%	51%	7%	0%
−3 ≤ PMV < −0.5	0%	8%	0%	0%

are not within the greater average percentage of people. Results for the MA show that 51% of people would be comfortable (−0.5 to +0.5), while 41% would be warm/hot (+0.5 to +3) and 8% would be cold (−3 to −0.5). The interviews demonstrate that the behavior of the residents is within the highest percentage of the index. As for light building envelopes, neutrality values are 7% for LB and 0% for LA; the value for warm/heat is 93% for the LB and 100% for the LA. These results put the residents within the highest percentage of responses for the summer as people who would classify their apartments as very hot and stifling (+3). It is seen that in all homes, with the exception of MB, responses from the residents concur with the "type" of residents that the index predicts. This means the MB would be the most comfortable for the highest percentage of people. They would consume less energy for HVAC than the case studied (see Table 8).

7. Adjustments and validations of geometric models

In order to isolate the consumption for HVAC during each selected season, we separated the housing units by materiality. The massive building was adjusted in autumn, from April 6 to 11. The simulated models for MB (Fig. 7) are set up for minor differences of 0.50 °C when compared to the measured data and for the MA (Fig. 8). These differences are less than 1 °C. The comparative analysis of different temperatures demonstrates fluctuations according to the behavior of the resident (opening windows, closing blinds) and more stable values in the simulated cases.

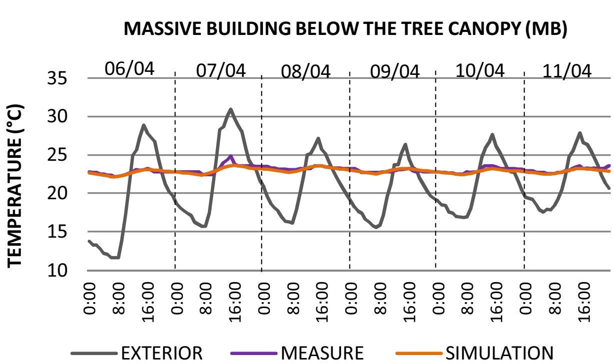

Fig. 7. The relationship of measured and simulated temperatures for the MB.

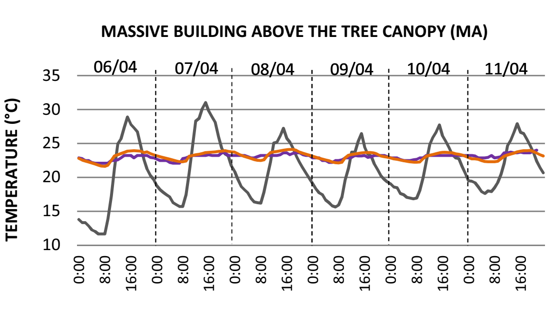

Fig. 8. The relationship of measured and simulated temperatures for the MA.

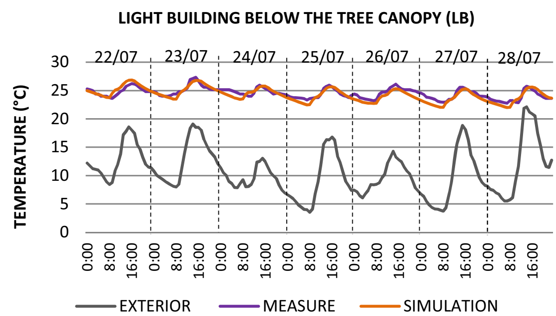

Fig. 9. The relationship of measured and simulated temperatures for the LB.

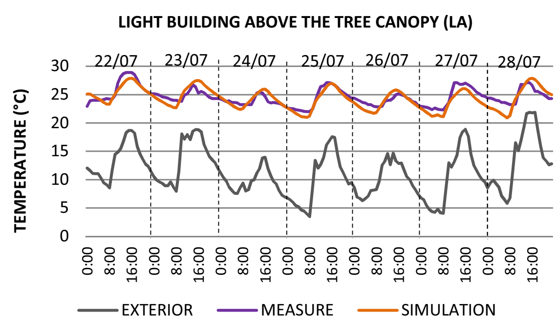

Fig. 10. The relationship of measured and simulated temperatures for the LB.

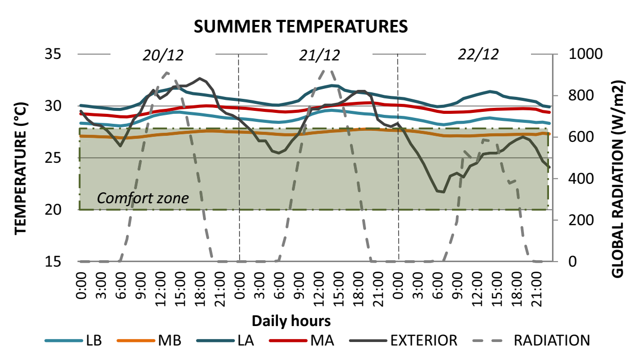

Fig. 11. Thermal behavior of the case studies in summer.

The light building was adjusted in winter, between July 22 and 28. The simulated model of LB (Fig. 9) shows differences when compared to the recorded data of less than 0.90 °C and for the LA (Fig. 10), less than 1.50 °C. In the adjustment made, when simulated temperatures are lower, the differences are due to the moderate use of heating by the actual cases, and when the actual measurements are lower, it is due to the ventilation by the actual resident.

8. Thermal-energy results without resident incidence

Thermal and energy results are shown in equivalent spaces oriented toward the North. In Fig. 11, exterior and interior temperatures for 3 representative days can be seen for the summer and in Fig. 12 for the winter. In Table 9, average, maximum and minimum temperatures can be seen as well as average thermal amplitudes

Table 9
Maximum, minimum and average temperatures of the case studies in summer and winter.

Cases	Summer temperatures [°C]				Winter temperatures [°C]			
	T. Max.	T. Min.	Avg. T.	Daily ΔT	T. Max.	T. Min.	Avg. T.	Daily ΔT
MB	27.6	27.1	27.3	0.5	20.0	18.8	19.4	1.2
MA	30.0	29.3	29.7	0.8	17.7	16.3	17.0	1.4
LB	29.3	28.2	28.8	1.0	27.7	23.3	25.2	4.5
LA	31.7	29.9	30.7	1.8	25.6	20.9	22.9	4.7

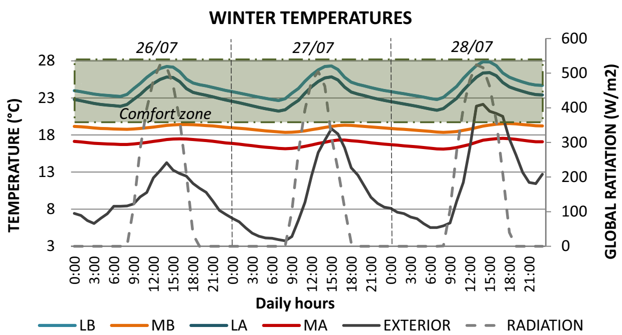

Fig. 12. Thermal behavior of the case studies in winter.

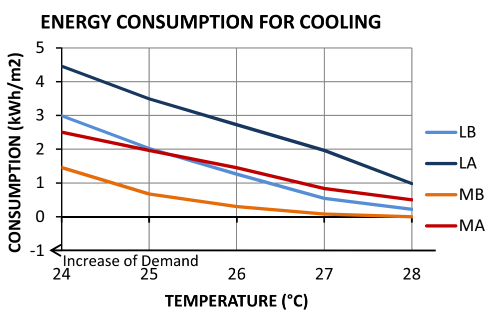

Fig. 13. Energy consumption for cooling in summer for the case studies.

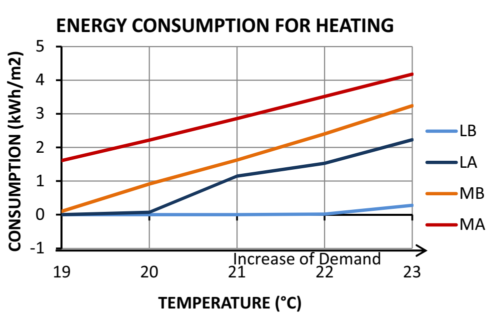

Fig. 14. Energy consumption for heating in winter for the case studies.

of the spaces oriented toward the North in both buildings (living room, and bedrooms 1 and 2).

Housing units are compared according to their variations in height and materiality. Figs. 13 and 14 show consumption graphs for cooling and heating respectively. The energy scenes were analyzed according to thermal requirements: for summer, the most demanding scene is 24 °C and the less demanding is 28 °C. For winter, the most demanding scene is are 23 °C and the less demanding is 19 °C.

8.1. *Height comparison: massive building [MA – MB]*

In summer, the MA housing unit has higher temperatures that reach 2 °C beyond the comfort zone while the MB unit is within the comfort range. The mean difference between the two cases is 2.30 °C. Energy consumption for cooling is higher in the MA with differences of 42% during the scenarios with the most demand while in the scenario with the least demand MB does not require HVAC.

In winter, the MB is warmer and both housing units are below the comfort zone. The thermal average differences between the two cases are 2.40 °C. Energy consumption for heating is greater for the MB with differences reaching 23% during the scenarios with the most demand and 94% in the scenario with the least energy demand.

8.2. *Height comparison: light building [LA – LB]*

In summer, the LA is warmer, but both case studies exceed the limit of 28 °C by 1.30 °C for the LB and 3.70 °C for the LA, which is above the comfort zone [52]. The average difference between the housing units is 1.90 °C. Energy consumption for cooling is greater in the LA with differences of 33% in the scenario with the greatest demand and 78% in the scenario with the least demand.

In winter, the LB is warmer and both apartments are within the comfort ranges. The average difference between the two cases is 2.30 °C. Energy consumption for heating is greater in the LA with differences reaching 87% in the scenario with the most demand. In the scenario with the least demand, neither housing unit required HVAC.

8.3. *Material comparison: below the tree canopy [LB – MB]*

In summer, temperatures are higher in the light building: in the LB, temperatures rise above the comfort zone and in the MB, they fall within a comfortable range. The average thermal difference is 1.40 °C. Energy consumption for cooling is greater in the LB apartment, with differences reaching 51% in the scenario with the greatest demand, while in the scenario of the least demand the MB did not require HVAC.

In winter, temperatures were higher in the Light building: LB was found to be within the comfort range, while in the case of the MB, the findings were below. The differences in this case are in the order of 5.80 °C. Energy consumption for heating is greater in the MB with differences reaching 91% for the scenarios with the greatest demand, while in the scenario with the least demand, the LB did not have any consumption.

8.4. *Material comparison: above the tree canopy [LA – MA]*

In summer, as was with the case with the housing units below the tree canopy; the temperatures were higher in the Light building. However, when comparing these apartments, both exceed comfort ranges. The average thermal difference between the two is 1 °C. Energy consumption for cooling is greater in the LA with differences

Table 10
Maximum, minimum, and average thermal differences for the case studies in summer.

	Thermal differences in summer [°C]			
	Height		Materiality	
	Massive (MA – MB)	Light (LA – LB)	Below (LB – MB)	Above (LS – MS)
Max. T.	2.4	2.4	1.7	1.7
Min. T.	2.2	1.7	1.4	0.6
Avg. T.	2.3	1.9	1.4	1.0

Table 11
Maximum, minimum, and average thermal differences for the case studies in winter.

	Thermal differences in winter [°C]			
	Height		Materiality	
	Massive (MB – MA)	Light (LB – LA)	Below (LB – MB)	Above (LA – MA)
Max. T.	2.3	2.1	7.8	7.9
Min. T.	2.5	2.3	5.8	4.6
Avg. T.	2.4	2.3	5.8	5.9

Table 12
Differences in energy consumption in summer (kWh/m^2) and percentages (%).[a]

Cooling differences					
Cases		Greater demand [24 °C]		Less demanding [28 °C]	
		kWh/m^2	%	kWh/m^2	%
Height	MA – MB	1.0	42	0.5	100
	LA – LB	1.5	33	0.8	78
Materiality	LB – MB	1.5	51	0.2	100
	LA – MA	2.0	44	0.5	49

[a] This table shows differences of 100% for the least demanding scenarios because these situations consume no energy, when the consumption values are 0 kWh/m^2.

Table 13
Differences in energy consumption in the winter (kWh/m^2) and percentages (%).[a]

Heating differences					
Cases		Greater demand [23 °C]		Less demanding [19 °C]	
		kWh/m^2	%	kWh/m^2	%
Height	MB – MA	0.9	23	1.5	94
	LB – LA	1.9	87	0.0	–
Materiality	MB – LB	3.0	91	0.1	100
	MA – LA	2.0	47	1.6	100

[a] This table shows differences of 100% for the least demanding scenarios because these situations consume no energy, when the consumption values are 0 kWh/m^2.

of 44% for the scenario with the greatest requirements and 49% with the least.

In winter, similarly with the previous situation, the temperatures are warmer in the Massive building. The LA showed temperatures that were within the comfort zone, while for the MA, temperature fell below this range. For this comparison, the average thermal differences reach 5.90 °C. Energy consumption for heating is greater in the MA reaching differences of 47% for the scenario with the greatest demand, while for the scenario with the least demand, the LA did not require HVAC. Tables 10 and 11 show maximum, minimal and average thermal differences (°C) for summer and winter, respectively. Tables 12 and 13 show the differences in energy consumption (kWh/m^2) and percentages (%) for cooling and heating respectively.

9. Discussion of the results

The methodology employed in this investigation defines and organizes the principle variables involved in this particular topic, which may also be transferable to other geographic and climatic contexts. This methodology articulates a qualitative analysis (perception of comfort and use of space) influenced by objective conditions (heat and energy assessment from audits, adjustments and simulation). Differences concerning the environments and the energy consumption of high-rise buildings are analyzed by considering the moderating impact of the urban forest and the materiality of the building envelope. The thermal performance and the energy demands of the buildings studied in this investigation show a worrying situation if we consider the increasing trend toward transparent and lightweight materials for building envelopes. If building regulations concerning thermal performance are not made mandatory, we could lose the benefits that massive building constructions bring to cities with arid climates and suffer from high levels of radiation. This study proposes general guidelines for the thermal design of different types of buildings, which hopes to contribute to new policies concerning the distinct components involved in the production of the urban habitat.

The results from the audits demonstrate how much building envelopes can influence the behavior of the residents. In some cases, the influence is positive, but in many others, there is evidence for patterns of use and habits that involve intense reliance on HVAC. By not taking advantage of natural resources for HVAC in the summer, like nocturnal winds, minimal interior temperatures continue to separate further from exterior temperatures. This situation demonstrates the fundamental importance of how building envelope strategies may affect the behavior of the residents. While different measurements depend on various circumstances and variables, one can see that if they are complemented by interviews, a better understanding of the use and occupation of the spaces is achieved. This data can serve to provide methodologies for simulations, which can create solutions for improved design and deeper understandings of the materiality of buildings.

Several ideas are highlighted when assessing these results:

Thermal comparisons by height: this study shows that the housing units analyzed below the tree canopy have better thermal and energetic conditions. In the summer, apartments located in the base of the building have lower temperatures and are therefore within the comfort ranges. This is because, on the one hand, the largest percentage of the building envelope is exposed above the tree canopy, and on the other hand, the microclimate of the city-oasis is influential. There are direct benefits for housing units located below the tree canopy such as moderate protection from incident radiation as well as lower interior temperatures. As for the winter, the apartments below the tree canopy are warmer due to the protection of the surrounding buildings to the east and the west by reducing the loss of heat at night. Since the trees are bare, they allow more solar radiation, up to 66.4% at noon [15]. There is a cooling potential associated with the micro-climate of the oasis city, thus resulting in cooling outdoor air in that environment. So, the housing units above the tree canopy, who have greater exposure to the sun, are exposed to more extreme outdoor weather conditions (high radiation, greater wind speed) and, as they does not benefit of the shadow of the tree canopy, they have greater HVAC consumption.

Thermal comparisons according to materiality: in the summer, even though insulation is lacking for vertical surfaces in the massive case in this study; massive buildings have better thermal performances and show lower energy consumption thanks to the density of the envelope, which limits the solar radiation. The light building envelopes that are analyzed in this investigation (reinforced concrete columns covered with 6 mm of laminated glass) have transparent surfaces of 72%, which does not provide much protection from the extreme conditions from the exterior. In the winter, light buildings have higher temperatures when compared to massive buildings. The higher percentage of glass in the envelope causes daytime temperature to rise because of the direct gains and at night the heat is absorbed by the mass of the walls 0.40 m spread throughout the interior. The high degree of transparency is a trend that is beneficial in winter during the day due to the direct gains (greenhouse effect) within the building.

Concerning energy demands for HVAC, two ideas are highlighted. First, for both types of materiality and heights, as temperature requirements become more demanding, the consumption for HVAC is attenuated (see Figs. 13 and 14). Second, the results are relative to internal temperatures. The simulated scenarios of consumption during the most demanding scenarios (24 °C in summer and 23 °C in winter) show that light buildings require greater energy use in the summer for cooling, with differences reaching 100%. In the winter, massive buildings require higher consumption for heating. In this case, the results differed according to their height. Below the tree canopy, the differences were in the order of 1000% and above the canopy, 100%. Following this, it can be seen that in situations of the greatest demand, higher apartments consume less. Therefore, before the residents of the building start demanding comfort through the use of HVAC, the materiality of the building envelope becomes of vital importance, greater than that of the height of the apartment.

Considering that cities in many developing countries will continue to build high-rise buildings without regulations that aim at reducing energy requirements for HVAC, this methodological approach can be used for future investigations. This methodology allows for the modeling and testing of multiple variables of design and technology, which can contribute to specific improvements to the construction of building envelopes when related to height and preserving the habitability of buildings in oasis-cities.

10. Conclusions

Considering the results obtained in this investigation, it can be asserted that:

- Buildings that rise above the tops of trees should address the situation concerning direct solar exposure. High-rise buildings can take advantage of substantial benefits that the urban forest offers by differentiating the building envelope between lower levels (base of the building) and higher ones (tower).
- The base of high-rise buildings offers compelling advantages from an environmentalist point of view. It may be used as a solid strategy against incident radiation because of lower temperatures in the summer and warmer temperatures in the winter. As a result of these benefits, the need for the reliance on HVAC diminishes.
- Prioritizing typologies for the construction of the Base and the Tower may help maintain urban homogeneity in terms of municipal building codes concerning the protection of the urban forest.
- The Tower typology is a growing trend that marks a break in energy efficient architecture. The perimeters of the buildings and their envelopes are being increasingly exposed to the full amount solar radiation above the tree canopy.
- The materiality of the building envelope becomes more important in the Tower because of its role moderating indoor temperatures. Materiality is essential for the insulation of vertical and horizontal surfaces, which should take advantage of efficient transparent technologies. If the building envelope is constructed with adequate technological and material aspects, the quality of the building will be reflected in the behaviors of the residents.

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References

[1] M. Santamouris, Energy and Climate in the Urban Built Environment, James and James Science Publishers, London, United Kingdom, 2001.
[2] M. Santamouris, Using cool pavements as a mitigation strategy to fight urban heat island – a review of the actual developments, Renew. Sustain. Energy Rev. 26 (2013) 224–240, http://dx.doi.org/10.1016/j.rser.2013.05.047.
[3] M. Santamouris, Cooling the cities – a review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments, Solar Energy 103 (2014) 682–703, http://dx.doi.org/10.1016/j.solener.2012.07.003.
[4] E.J. Gago, J. Roldan, R. Pacheco-Torres, J. Ordóñez, The city and urban heat islands: a review of strategies to mitigate adverse effects, Renew. Sustain. Energy Rev. 25 (2013) 749–758, http://dx.doi.org/10.1016/j.rser.2013.05.057.
[5] S. Schiller, J.M. Evans, Training architects and planners to design with urban microclimates, Atmos. Environ. 30 (1996) 449–454, http://dx.doi.org/10.1016/1352-2310(94)00139-1.
[6] C. Discoli, I. Martini, G. San Juan, D. Barbero, L. Dicroce, C. Ferreyro, J. Esparza, Methodology aimed at evaluating urban life quality levels, Sustain. Cities Soc. 10 (2014) 140–148, http://dx.doi.org/10.1016/j.scs.2013.08.002.
[7] E. Puliafito, M. Guevara, C. Puliafito, Characterization of urban air quality using GIS as a management system, Environ. Pollut. 122 (2003) 105–117, http://dx.doi.org/10.1016/S0269-7491(02)00278-6.
[8] N. Alchapar, E. Correa, A. Cantón, Classification of building materials used in the urban envelopes according to their capacity for mitigation of the urban heat island in semiarid zones, Energy Buildings 69 (2014) 22–32, http://dx.doi.org/10.1016/j.enbuild.2013.10.012.

[9] P. Oldfield, D. Trabucco, A. Wood, Five energy generations of tall buildings: an historical analysis of energy consumption in high-rise buildings, J. Architect. 14 (2009) 591–610, http://dx.doi.org/10.1080/13602360903119405.
[10] E. Juodis, E. Jaraminiene, E. Dudkiewicz, Inherent variability of heat consumption in residential buildings, Energy Buildings 41 (2009) 1188–1194, http://dx.doi.org/10.1016/j.enbuild.2009.06.007.
[11] S. Flores Larsen, C. Filippin, G. Lesino, Incidencia de los usuarios en el comportamiento térmico de una vivienda en el Noroeste Argentino. IV Conferencia Latino Americana de Energía Solar y XVII Simposio Peruano de Energía Solar, 2010.
[12] J. Toftum, R.V. Andersen, K.L. Jensen, Occupant performance and building energy consumption with different philosophies of determining acceptable thermal conditions, Building Environ. 44 (2009) 2009–2016, http://dx.doi.org/10.1016/j.buildenv.2009.02.007.
[13] I. Ballarini, V. Corrado, Application of energy rating methods to the existing building stock: analysis of some residential buildings in Turin, Energy Buildings 41 (2009) 790–800, http://dx.doi.org/10.1016/j.enbuild.2009.02.009.
[14] J. Choa, C. Yoob, Y. Kimc, Viability of exterior shading devices for high-rise residential buildings: case study for cooling energy saving and economic feasibility analysis, Energy Buildings 82 (2014) 771–785, http://dx.doi.org/10.1016/j.enbuild.2014.07.092.
[15] M. Bojic, F. Yic, K. Wan, J. Burnett, Influence of envelope and partition characteristics on the space cooling of high-rise residential buildings in Hong Kong, Energy Buildings 37 (2002) 347–355, http://dx.doi.org/10.1016/S0360-1323(01)00045-2.
[16] M. Bojic, F. Yic, Cooling energy evaluation for high-rise residential buildings in Hong Kong, Energy Buildings 37 (2005) 345–351, http://dx.doi.org/10.1016/j.enbuild.2004.07.003.
[17] J. Terés-Zubiaga, A. Campos-Celador, I. González-Pino, C. Escudero-Revilla, Energy and economic assessment of the envelope retrofitting in residential buildings in Northern Spain, Energy Buildings 86 (2015) 194–202, http://dx.doi.org/10.1016/j.enbuild.2014.10.018.
[18] L. Liu, P. Rohdin, B. Moshfegh, Evaluating indoor environment of a retrofitted multi-family building with improved energy performance in Sweden, Energy Buildings 102 (2015) 32–44, http://dx.doi.org/10.1016/j.enbuild.2015.05.021.
[19] L. Liu, B. Moshfegh, J. Akander, M. Cehlin, Comprehensive investigation on energy retrofits in eleven multi-family buildings in Sweden, Energy Buildings 84 (2014) 704–715, http://dx.doi.org/10.1016/j.enbuild.2014.08.044.
[20] T. Konstantinou, U. Knaack, An approach to integrate energy efficiency upgrade into refurbishment design process, applied in two case-study buildings in Northern European climate, Energy Buildings 59 (2013) 301–309, http://dx.doi.org/10.1016/j.enbuild.2012.12.023.
[21] M. Palme, A. Isalgué, H. Coch, Avoiding the possible impact of climate change on the built environment: the importance of the building's energy robustness, Buildings 3 (2013) 191–204, http://dx.doi.org/10.3390/buildings3010191.
[22] X. Peng, Demand Shifting with Thermal Mass in Light and Heavy Mass Commercial Buildings, Lawrence Berkeley National Laboratory, 2010, Available electronically from: http://escholarship.org/uc/item/9t700887.
[23] A. Gagliano, F. Patania, F. Nocera, C. Signorello, Assessment of the dynamic thermal performance of massive buildings, Energy Buildings 72 (2014) 361–370, http://dx.doi.org/10.1016/j.enbuild.2013.12.060.
[24] B. Givoni, Impact of planted areas on urban environmental quality: a review, Atmos. Environ. 25 (1991) 289–299, http://dx.doi.org/10.1016/0957-1272(91)90001-U.
[25] A. Canton, A. Mesa, J.L. Cortegoso, C. de Rosa, Assessing the solar resource in forested urban environments: results from the use of a photographic-computational method, Architect. Sci. Rev. 46 (2003) 115–123, http://dx.doi.org/10.1080/00038628.2003.9696973.
[26] H. Akbari, M. Pomerantz, H. Taha, Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas, Solar Energy 70 (2001) 295–310, http://dx.doi.org/10.1016/S0038-092X(00)00089-X.
[27] E. Bórmida, Mendoza, una ciudad oasis, Universidad de Mendoza, Mendoza, Argentina, 1984.
[28] E. Correa, A. Ruiz, A. Cantón, L. Lesino, Thermal comfort in forested urban canyons of low building density. An assessment for the city of Mendoza, Argentina, Building Environ. 58 (2012) 219–230, http://dx.doi.org/10.1016/j.buildenv.2012.06.007.
[29] R. Serra, Arquitectura y climas, Gustavo Gili, Barcelona, España, 1999.
[30] J. Samaja, Epistemología y Metodología. Elementos para una teoría de la investigación científica, Universitaria de Buenos Aires, Buenos Aires, Argentina, 1993.
[31] V. Cantón, B. Molina, in: R. Martínez Guarino (Ed.), Cotejo conceptual de la Alta Simplicidad con la Metodología de indicadores territoriales de Sustentabilidad y Gestión Ambiental Institucional de Uruguay, Montevideo, Uruguay, 2005.
[32] C. Discoli, G. San Juan, I. Martí, D. Barbero, L. Dicrocce, L. Ferreyro, G. Viegas, J. Esparza, Calidad de vida en el Sistema Urbano, Universitaria de La Plata, La Plata, Argentina, 2013.
[33] Municipalidad de Mendoza, Código de Edificación, Ordenanza N° 3296/14975/1996, 2000.
[34] M.A. Cantón, J.L. Cortegoso, C. De Rosa, Solar permeability of urban trees in cities of western Argentina, Energy Buildings 20 (1994) 219–230, http://dx.doi.org/10.1016/0378-7788(94)90025-6.
[35] V. Olgyay, Arquitectura y Clima. Manual de diseño bioclimático para arquitectos y urbanistas, Gustavo Gili, Barcelona, España, 1998.
[36] A. Esteves, D. Gelardi, Docencia en Arquitectura Sustentable: Programa de Optimización de Proyectos de Arquitectura basado en el balance térmico, Avances en Energías Renovables y Medioambiente 7 (2003), 10.31–10.34.
[37] M. Longobardi, M. Hancock, Field trip strategies, in: Proceedings of TIA, Oxford, 2000.
[38] N. Kolher, U. Hassler, The building stock as a research object, Building Res. Inform. 30 (4) (2002) 226–236, http://dx.doi.org/10.1080/09613210110102238.
[39] T.R. Oke, Initial Guidance to Obtain Representative Meteorological Observations at Urban Sites. IOM Report, TD, World Meteorological Organization, Geneva, 2004 (in press).
[40] H. Grossi Gallegos, R. Righini, Acerca de la representatividad de los valores de radiación solar global medidos por la Red Solarimétrica en la Pampa Húmeda, Avances en Energías Renovables y Medio Ambiente 15 (2011) 33–40.
[41] ISO 10551, Ergonomics of the Thermal Environment—Assessment of the Influence of the Thermal Environment Using Subjective Judgment Scales, 1995.
[42] I. Marincic, J.M. Ochoa, J. Del Rio, Confort térmico adaptativo dependiente de la temperatura y la humedad, in: ACE: Arquitectura, Ciudad y Entorno, 2012, pp. 27–46.
[43] ANSI/ASHRAE Standard 55-2013, "Thermal Environmental Conditions for Human Occupancy".
[44] Energy Plus. The Official Building Simulation Program of the United States Department of Energy. http://apps1.eere.energy.gov/buildings/energyplus/ (accessed 06/13).
[45] University of Illinois, University of California, Energy Plus, Getting Started, 2013.
[46] Norma IRAM 11601, Acondicionamiento térmico de edificios. Métodos de cálculo. Propiedades térmicas de los componentes y elementos de construcción en régimen estacionario, 1996.
[47] Vidriería Argentina S.A. – VASA, Buenos Aires, Argentina, 2008. www.vasa.com.ar (accessed 03/13).
[48] M.H. Sherman, D.T. Grimsrud, Infiltration-Pressurization Correlation: Simplified Physical Modeling, Lawrence Berkeley Laboratory, Berkeley, CA, 1980, LBL-10163. http://escholarship.org/uc/item/8wd4n2f7 (accessed 10/13).
[49] S. Flores, G. Lesino, L. Saravia, D. Alía, SIMEDIF para Windows, INENCO – unas, Salta, 1984, Versión 2005.
[50] J. Balter, C. Ganem, M.A. Cantón, Evolución morfológica y materialización en edificios en altura en la ciudad de Mendoza. Incidencias en el comportamiento térmico interior, Revista ÁREA 19 (2013) 9–25.
[51] S. Gil, Gas Natural en la Argentina: presente y futuro, Revista Ciencia Hoy (2006) 26–36.
[52] B. Givoni, Comfort, climate analysis and building design guidelines, Energy Building 18 (1991) 11–23, http://dx.doi.org/10.1016/0378-7788(92)90047-K.