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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

Julieta Balter[a,*], Carolina Ganem[a], Carlos Discoli[b]

[a] Instituto de Ambiente, Hábitat y Energía (INAHE), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Avenida Ruiz Leal S/N, Parque General San Martín, Mendoza CP 5500, Argentina

[b] Instituto de Investigaciones y Políticas del Ambiente Construido (IIPAC), Facultad de Arquitectura y Urbanismo (FAU), Universidad Nacional de La Plata (UNLP)/Instituto de Investigaciones en Energía no Convencional (INENCO), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Calle 47 162, La Plata CP 1900, Argentina

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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

* Corresponding author.
E-mail addresses: jbalter@mendoza-conicet.gob.ar (J. Balter), cganem@mendoza-conicet.gob.ar (C. Ganem), discoli@rocketmail.com (C. Discoli).

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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.