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Neighborhood designs for low-density social housing energy efficiency: Case study of an arid city in Argentina

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ABSTRACT

Neighborhood planning and design strategies that reduce outdoor air temperatures would improve the thermal and energy performance of cities in arid regions. This study presents the thermal behavior and energy consumption of different urban scenarios for low-density social housing neighborhoods in Mendoza, Argentina. The microclimates of three representative urban canyons located in three different social housing neighborhoods were monitored. These neighborhoods have different layouts but share other similar features, which allow the behavior of their microclimates to be compared. Thus, 48 simulations were conducted using ENVI-met software to test neighborhood-level scenarios with the following features: two street widths (16 and 20 m), three layout grids (multi-azimuthal, Cul-de-Sac, and rectangular), and four street orientations (E-W, N-S, NE-SW, and NW-SE). The energy consumption of each urban scenario was then estimated and compared. The results show that, in a house constructed without following bioclimatic design strategies, at least 21% of the auxiliary energy required to achieve a comfortable indoor temperature (25 °C) during summer can be saved. Energy savings depend on a suitable layout and street orientation, urban trees, and the albedo of the building materials. This study highlights the importance of planning and design decisions, especially for social housing settlements in arid cities.

1. Introduction

By 2030, the global energy demand is expected to grow by 40–50% [52]. Providing electricity to the global population would require an annual investment of $52 billion per year by 2030, which exceeds twice the level mobilized under current and planned policies [12]. Energy usage in residential buildings accounts for a significant portion of global energy consumption. The U.S. Energy Information Administration estimates that the country's electricity usage in 2016 exceeded that in 1950 by more than 13-fold, and space cooling by the residential sector (i.e., air conditioning) accounted for the highest electricity consumptions [9].

The amount of energy used by the residential sector depends on the climate, building characteristics, the number and characteristics of energy-consuming devices, and the inhabitantś socioeconomic level [5,36]. Cities in arid zones must survive in an environment that is characterized by extreme climatic conditions, with high solar radiation and air temperatures. In this climate, the urban heat island (UHI) effect and warming are most noticeable during the summer and affect energy consumption via air conditioning as well as the health of city dwellers.

The main causes of these phenomena are the modification of land surfaces and waste heat generated by energy usage [24,44]. Regarding energy consumption, Lin et al. [25] determined that a 1 °C increase in temperature increases peak electricity demand by 2–4%, and Salamanca et al. [40] demonstrated that extended use of air conditioning increases the air temperature of arid cities by 1 °C at night. As outdoor temperatures rise, more energy will be required for cooling system operation. Increased energy demand will increase its price, rendering it unaffordable to low-income households. This generates a cycle that negatively affects urban sustainability [56]. The high cost of energy will detriment the indoor habitability of social housing [4]. Therefore, designing energy efficient dwellings will reduce electricity bills for residents [34].

One of the most important aspects of urban planning is the creation of sustainable urban environments. The planning process is closely related to the climate [57]. The LEED-ND rating system recommends that an energy-efficient building is good, but an energy-efficient neighborhood is better. A well-planned neighborhood that considers the layout, street and block proportions and orientations, urban trees, and cooler materials can reduce the impacts of the

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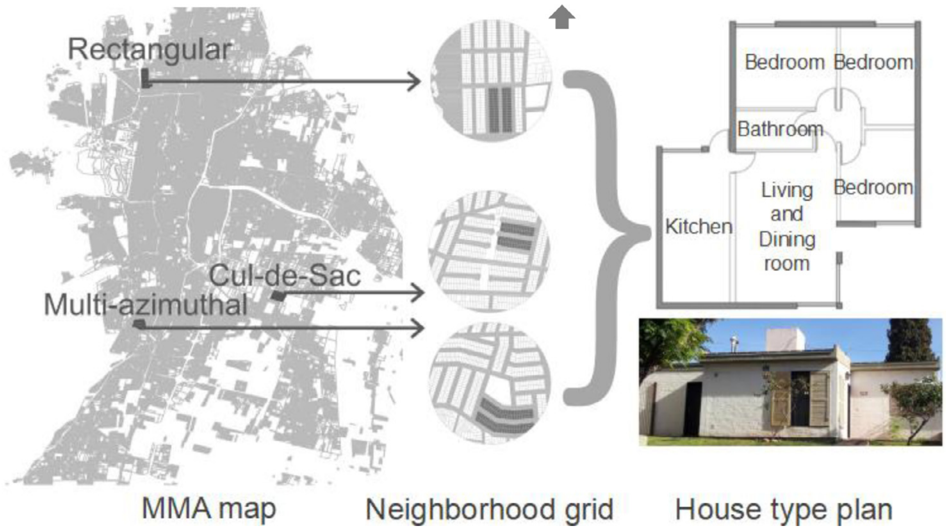

Fig. 1. Selected study sites: MMA location, neighborhood grid layouts, monitored streets, and house typology.

microclimate generated by the urban form [16,27,30,45]. While there is evidence that indicates that the urban form, or some of its attributes, affects energy demand, characterizing the effect of the urban form remains a major challenge [21,42,43]. The implications on operational energy use in buildings are not always explored, and there are few studies that have focused on this. Thus, it is important to evaluate how elements of the urban form affect building energy consumption [19]. Comprehensively understanding the relationship between urban form and energy use is important to formulate city-level climate change mitigation policies [23]. Rosenthal, Kinney, and Metzgerd [38] suggested that low-income neighborhoods should be prioritized in the climate adaptation planning of cities, and that disparities in accessing residential air conditioning are associated with heat-related mortality rates in New York. Therefore, socioeconomically weak communities are more vulnerable to the impacts of climate change [10,31,37,46]. Research in this area would aid the planning of energy-efficient social housing neighborhoods that considers microclimatic variables in the design stage.

1.1. Objectives

This study aims to:

- evaluate the impact of different social housing neighborhood designs on outdoor air temperatures and the energy consumption for cooling during summertime.
- improve energy efficiency at the neighborhood scale by providing planning and design strategies for social housing settlements in cities with arid climates.

2. Methodology

The following methodology was undertaken to conduct this study: (i) study site characterization and selection, (ii) microclimate monitoring, (iii) computational fluid dynamics (CFD) simulations, and (iv) estimation of energy consumption.

2.1. Study site characterization and selection process

This study was conducted in the Mendoza Metropolitan Area, Argentina (MMA), a region with a hot-dry climate (BSk) according to the Köppen Climate Classification. The MMA contains 62.8% of the population of Mendoza [13]. The energy demand faces a maximum increase of 18% during the summer months (December and January). By relating the UHI and urban warming impacts to the energy demand for air conditioning, previous studies have observed an energy consumption increase of up to 20% in the MMA [7]. This is characterized by low building density, mainly constituting of single-family attached houses [14]. Currently, there is a housing deficit of 65 thousand homes in the MMA [53]. To improve the deficit, a National Housing Plan with two specific programs, "Social Housing" and "Housing = Work", is being developed by the government. These housing programs provide the same house type regardless of context within the MMA, and no energy efficiency strategies have been considered (Fig. 1).

Table 1
Features of the selected urban canyons.

Neighborhood grid	Multi-azimuthal	Cul-de-Sac	Rectangular
Street length (m)	255	145	192
Street width (m)	20	20	16
H/W	0.15	0.15	0.19
Street orientation	E-W	E-W	N-S
Sky view factor	0.69	0.57	0.35
Quantity of trees (u)	53	36	53
Tree species	*Morus alba*	*Ulmus umbraculifera*	*Morus alba*

To select the most representative cases within the MMA, the study site selection process was categorized into three urban levels:

- Urban districts: The MMA contains six districts, namely, Mendoza Capital, Guaymallén, Las Heras, Godoy Cruz, Maipú, and Luján. The most populated districts were selected and they share borders with the Capital (Guaymallén: 16%, Las Heras: 12%, and Godoy Cruz: 11%). A graphic survey was conducted in the selected districts to identify the most representative urban block forms. The results of the survey show that 31% of the blocks in Godoy Cruz are rectangular, 48% in Guaymallén are irregular, and 33% of those in Las Heras are irregular while 30% are rectangular blocks with a North-South orientation. One neighborhood in each urban district was selected based on these results.
- Urban neighborhood: The selected neighborhoods have different layouts and block orientations but share some features that allow us to compare their microclimatic behaviors. For this study, urban neighborhoods with similar house types were selected to prevent the incidence of built-up characteristics. Ad-