Layout Design to Remove Barriers to Comfort, Energy Efficiency, and Solar Systems in Housing

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Abstract This chapter analyzes the role of layout patterns and morphological characteristics of land sub-division in social housing to reduce energy demand while promoting comfort, energy efficiency, and the implementation of solar energy. In this context, the project was focused on design factors and scales in different climates and latitudes of Argentina, from 22° to 55 °S. Based on experiences evaluating social housing programmes at a national level and projects by eight provincial housing institutes in different bioclimatic zones, the target was to achieve a reduction of conventional energy, implementing bioclimatic design strategies, energy-efficient measures, and solar systems. Requirements on a layout scale were essential to achieve solar access in façades and solar systems while providing solar protection to avoid overheating and the use of air conditioning. Design alternatives were implemented for wind protection to improve outdoor spaces in cold climates, and breeze and ventilation in humid subtropical areas. Density, solar access, façade orientation, plot size, and vegetation were evaluated, comparing benefits on both planning and building scales. These have successfully contributed to the development of national housing standards which remove barriers and achieve better housing conditions with less energy demand, a result that is relevant for other regions of the Global South.

Keywords Social housing · Bioclimatic strategies · Energy efficiency · Solar energy

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1 Introduction

The integration of layout pattern design for energy efficiency measures and renewable solar systems offers significant economic, social, and environmental benefits, fostering sustainable development, reducing impacts and energy demand while promoting comfort and a better quality of life, according to de Schiller [1].

This chapter aims to show the relevance of a key factor to removing barriers in widely differing environmental conditions in Argentina, shown by de Schiller and Evans [2], potentially useful in the Global South context, according to the IRAM 11603 [3] (See Fig. 1).

To achieve these benefits, the challenge was to promote the implementation of both strategies together within the design resources in the production and use of the built environment, as presented by de Schiller [4]. This required ensuring adequate transfer to policy and legislation to provide support for project development on urban and building scales, with the relevant contribution of professional skills and institutional legal frameworks in the different climatic zones of the country, with possible extensions to other countries of the region, as Jenks [5] points out. Active and solid participation in the social context, from both institutions and future inhabitants,

Locations

N°	Representative locations	Bioclimatic Zone
1	Formosa, Formosa	Ib
2	Tafí Viejo, San Miguel de Tucumán	IIb
3	Salta Capital, Salta	IIIa
4	San Martin, Mendoza	IIIa / IVa
5	San Nicolas, Buenos Aires	IIIb
6	Rawson, Chubut	IVc
7	Zapala, Neuquén	VI
8	Ushuaia, Tierra del Fuego	VI South

Zones: IRAM Standard11.603:2012

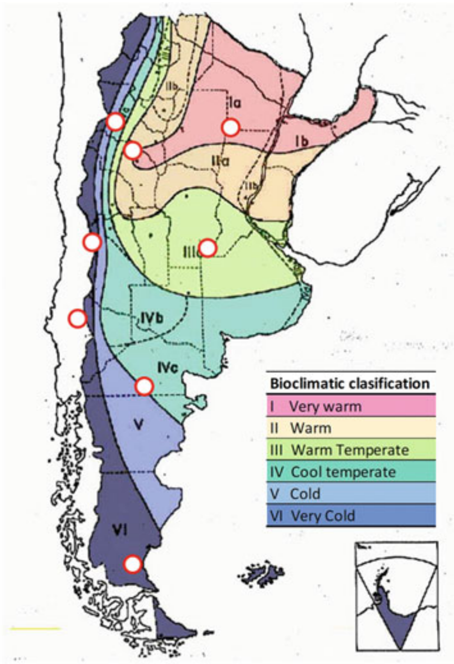

Fig. 1 Location of the eight study projects used to analyze energy efficiency measures to improve thermal comfort, representative of the wide climatic variation and bioclimatic zones found in Argentina, IRAM 11603 [3]

is also required, allowing cooperative actions to achieve positive user control of renewable and passive systems.

In this context, the study presents design strategies for both layout and unit design, with energy reduction measures and the integration of solar energy systems in the development of housing programmes.

Research by de Schiller and Evans [6] shows that these objectives are possible for the implementation of social housing projects at the national level, considering local conditions, and social, environmental, and economic requirements. For this purpose, specific energy-efficient measures at a layout scale are analyzed in the design process of social housing projects. The research is based on the experiences of assessing Provincial Housing Institutes programmes in eight different localities, representative of the broad climatic variation found in Argentina, and relevant for similar conditions in the Global South.

These include major variations from hot and humid sub-tropical climates in the NE, hot and dry climates with large temperature swings in the NW, cold climates at high altitudes with strong solar radiation in the Puna, temperate climates with both high and low-temperature swings at intermediate latitudes, cold and windy climates, extremely low-temperature mountain climates in high latitudes, and cold desert climates in southern Patagonia, as pointed out by Evans and de Schiller [6]. In this framework, examples from the Federal Housing Plan are presented, analyzing the performance achieved with the Minimum Quality Standards of the Secretary of Housing [7], to evaluate results that aim at achieving a 30% reduction of conventional energy use by implementing supplementary measures on the layout scale, considering the efficiency levels required by the programme.

2 Criteria to Implement Sustainable Building Measures

To promote an adequate and effective integration in projects at the house design scale, these measures incorporate the following criteria:

- Improving the thermal performance of the building envelope, with suitable thermal insulation in walls, windows, and roofs, as well as grouping to minimize areas exposed to outdoor air to reduce energy demand with the contribution of efficiency measures, adopting the improved levels established in the IRAM National Standard [8].
- Implementing bioclimatic design strategies in housing units to ensure both solar access in winter and shading in summer. These strategies should be carefully integrated, but not compete with one another, with effective protection from cold and strong winds in cold climates, or to catch breezes in hot climates. This will achieve a better balance between energy demand and supply to promote comfort by improving the environmental performance for users. The IRAM Standard 11603 [3] and other publications from Evans and de Schiller [9] indicate appropriate regional strategies.

- Integrating renewable energy installations on a housing design scale to increase renewable energy supply, and reduce conventional energy use and operating costs in favor of health and well-being. Recent government publications by the Secretary of Housing provide design recommendations [7].

At the layout scale, a series of measures were considered to achieve the project objective: a 30% effective reduction of conventional energy demand and the related environmental impacts in the context of sustainable development for social and economic benefit [4].

3 Design Requirements for Housing Layouts

To complement these measures at the housing design scale, the following requirements were proposed on a layout scale, as they will condition the design of housing projects, in widely varying bioclimatic conditions in different zones of the country.

The following measures played a key role, interacting on both an urban and unit scale: solar access on facades, optimized location and inclination of solar collectors, and potential benefits provided by outdoor spaces on both unit and grouping scales, combined with a local breeze for natural ventilation while ensuring sun and wind protection. According to de Schiller [10], all these measures, implemented at the design decision scale, will also effectively contribute to energy conservation with suitable building envelopes.

As complementary interaction between scales is not always considered in institutional policies for housing project development and production, the professional response also needs technical support to implement integrated criteria. Therefore, this study identifies a vacant niche that needs to be covered to anticipate environmental impacts and avoid conflicting bioclimatic strategies incorporated in the design of housing units without an effective resolution on the layout scale, influencing the environmental and energy performance of housing units.

To clarify the layout design's environmental requirements a research method was developed, applied and structured with specific issues, including solar access on facades and outdoor spaces, while promoting the effective installation of renewable energy systems [11].

4 Research Methodology

The method used in this study focused on solar access, shading, wind protection, and natural ventilation. It considered climatic conditions as the base issues, followed by a selection of key factors, to contribute to removing barriers on the layout scale. This process led to a discussion of conflicting requirements pointing to the relevant results obtained when research is implemented in new legislation for the production of housing projects at a national level with local practical innovation.

4.1 Solar Access and Shading

Energy-efficient and comfortable housing projects require solar radiation incidence in passive systems, by adopting favorable façade orientation and window dimensions in living spaces. To achieve this objective, attention should be paid to the location, latitude, and topography at an urban design scale, along with density, building height, and grouping, while defining compatible house design with form and orientation in individual plots. This helps to define envelope performance and the characteristics of openings by variations between locations. These criteria are essential to achieve winter solar access in cold climates while ensuring summer solar protection in hot and humid climates. The IRAM Standard [3] recommends orientations to achieve the required levels of solar radiation.

Although favorable solar access in both private and communal outdoor areas does not directly affect conventional energy demand, it contributes to improving comfort levels in outdoor and intermediate spaces, as well as the indirect impact on indoor spaces. It also encourages vegetation growth to improve the local microclimate.

At the same time, solar collectors for domestic water heating, considering their limited storage capacity, require effective sun access all year round. According to the Energy Secretary [12], in summer, they can generate more useful energy than needed for hot water supply, while, in winter, solar energy may be insufficient to satisfy demand.

To achieve both, the solar collectors' slope is critical to optimize annual performance while considering the potential impact of partial shading which can significantly affect the effective final energy efficiency result.

Additionally, according to the recommendations of the Energy Secretary [13], grid-connected photovoltaic installations require a similar orientation, but a lower inclination for solar access to optimize total energy generation over the year to obtain the maximum economic benefit for the user.

Special care is needed to avoid partial shading projected by cables, posts, water tanks, and other obstacles from nearby surroundings or housing units.

The impact of possible future extensions of adjacent houses to the north should also be considered to avoid unwanted shading.

In this context, it is relevant to note that solar access and solar protection in building design depends on local climate conditions, such as in hot climates at both humid or dry lower latitudes, and cold and temperate climates at higher latitudes in the south, as the following analysis using IRAM Standards 11603 [3] shows.

- In *hot climates*, sun access design must consider the need for shading with solar protection in summer months, particularly by optimizing north-facing orientations, and allowing access to winter sun compatible with solar protection elements such as overhangs and pergolas with vegetation, while unfavorable west-facing orientations can receive limited sun in winter but suffer excessive summer solar radiation.

- In *cold and temperate climates*, heat conservation requires significant control of surface areas exposed to outdoor conditions, where the form factor, the relation between the external surface and building volume, depends on the volume and grouping of the housing units. The IRAM Standard 11604 [14] shows the importance of the total surface area of walls and roofs in contact with the outdoor environment on the volumetric heat loss coefficient.

4.2 Wind Protection and Natural Ventilation

The impact of wind increases heat losses in winter, an aspect that is critical in cold and temperate climates as a result of two basic mechanisms that promote heat transfer from the external surface of walls and roofs to the outdoor air and the increased heat losses due to higher ventilation rates, as Evans and de Schiller [9] explain. This is due to cold air infiltration through doors, windows, and ventilation vents, a relevant factor in the cold and windy climates of Patagonia and the high Andes region. In this context, design decisions on housing layout play an important role by reducing wind exposure considering density, outdoor space proportions, and distances between buildings.

As de Schiller [15] points out, this can be achieved with favorable width–height relationships, as well as the form and orientation of both housing units and grouping. It should be noted that, in general, a lack of professional knowledge on wind design strongly affects project development. Appropriate tools can be used to overcome this deficiency such as computational fluid dynamics studies or wind tunnel tests during the design process.

On the other hand, in the hot and humid climates of the NE Region of Argentina, improved air movement achieved through cross-ventilation can reduce or even eliminate the demand for artificial conditioning by mechanical means, with the corresponding reduction of costs and environmental and health impacts. This cross-ventilation strategy requires suitable spaces between buildings considering their form and height, windows on opposite sides of the housing units, and interior design to facilitate free indoor air movement. In calm situations, without effective natural air movement, ceiling fans offer comfort with very low energy demand, but this will require a suitable floor-to-ceiling height, which can affect building heights and the eventual length of wind shadows on the layout scale.

4.3 Key Factors on the Layout Scale

Energy savings achieved through insulation and bioclimatic design must be compared with the embodied energy of building materials and construction system components.

At the same time, planning decisions on layout and density affect the demand for urban infrastructure to supply water, electricity, gas, etc., as well as the economy regarding road and transport networks. Thus, these factors generate the following impacts:

Embodied energy. While building materials and manufacturing processes require conventional energy and generate greenhouse gas emissions (GHG), the design and grouping of housing units can help to reduce the volume of materials used. The possibility of sharing party walls is a relevant factor when estimating the environmental and energy performance of the building envelope. However, in seismic zones, double-party walls are required to separate adjoining structures.

Urban infrastructure. The cost of urban infrastructure, with sewer, water, electricity, and gas distribution networks depends on the urban design and density of the housing complex.

Building plots. The lot size substantially affects the ability to implement bioclimatic design strategies on a housing unit scale. In turn, the design of the urban fabric is an important factor that influences the definition of the infrastructure for each unit, in extension and distribution.

Transport. The design of housing projects with increased population density also promotes access to public transport and community facilities, improving both the economy and accessibility, a relevant factor in the design of new settlements in peripheral urban areas.

These factors are linked and strongly affect the design approach to promote sustainable housing, complementing the sun and wind requirements analyzed in the previous section.

The response to all these factors during the initial housing programme and layout planning stage is essential to contribute to an effective design proposal. These will then guide planners and designers, considering project consolidation and further construction, to prevent energy inefficiency and poor comfort levels, avoiding or reducing dependence on artificial conditioning over the housing life cycle.

5 Discussion of Conflicting Requirements

In this context, it is relevant to consider conflicts between requirements to clarify the process of analyzing specific conditions together with the potential contradictions between them, for example:

- Different requirements for the implementation of measures to optimize solar gains in colder seasons or sun protection in warmer months.
- Conflicting requirements between suitable orientations to achieve adequate cross-ventilation or wind protection, and those needed for solar gains in winter and sun protection in summer.
- Higher densities are required to optimize the compactness of the built fabric for wind protection and heat conservation while lower densities improve solar access for the housing units and outdoor spaces.

Other factors that may limit the implementation of the requirements established in the project include the plot size and the orientation of adjacent urban subdivisions within the urban fabric of the city where the new housing complex will be built.

It should be noted that the experimental housing groups studied in the analysis of the R&D project include the development of different alternative designs following the programmed conditions to compare with increasing levels of energy efficiency considered in the study. These housing units, which had to be sited on plots with four different orientations, have a typical land subdivision and a plot size of 10 m wide. Within these conditions, designs were developed for four different cases to be compared and evaluated using the following alternatives:

- Existing conventional housing, designed by the local provincial housing authority, was used as a "reference" case.
- This was compared to units with the same design incorporating improved thermal insulation of the building envelope.
- The next level applied bioclimatic strategies in an improved passive design to achieve the benefits of layout and grouping of housing units.
- The final level included solar systems for water heating and photovoltaic modules for power generation integrated into the improved passive design.

However, it should be noted that the inclusion and integration of these variants in a single project of 16 houses with different designs limited the possibilities of achieving optimal groupings at an urban scale. The different house designs in adjacent plots reduce the benefits of grouping, as the conflicts in the following comparative examples show.

5.1 House Orientation Versus Grouping & Layout

In plots with north and south access, the design of the housing unit achieves good sunlight on the facades of the front or rear, respectively, while also allowing grouping

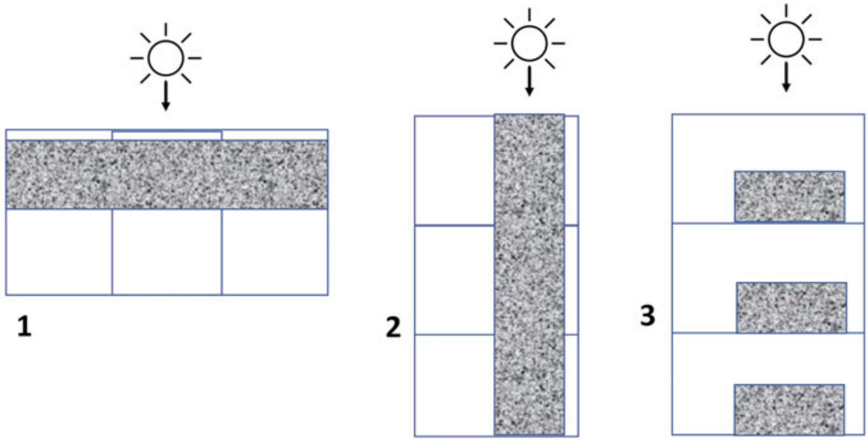

Fig. 2 Orientation and grouping for solar access: 1. Row housing on east–west street; 2. Row housing on north–south street with poor solar access; 3. Separated housing on north–south street with better solar access but increased heat loss

houses with shared party walls, reducing the wall surface in contact with the outside air, thus leading to greater energy efficiency.

On the other hand, in plots with east or west access, house design with favorable solar gains requires north-facing facades to face the lateral party wall. This situation can be compromised by the addition of an upper story in the adjacent unit to the north. So, the building design, to optimize solar gains, also requires separate units without the possibility of shared party walls, increasing energy losses in winter due to a larger surface exposed to wind and outside air (See Fig. 2).

In this case, it is relevant to note that the distance between units is limited by these orientations due to the 10 m standard plot width, reducing the possibility of achieving adequate solar access in mid and high latitudes.

To implement effective cross-ventilation, the main rooms should be orientated towards the prevailing winds with an acceptable variation of 45° in the horizontal plane, preferably avoiding ventilation through two bedrooms, due to the loss of privacy and lower wind speed. With a 10 m standard plot width, good cross-ventilation is achieved in units with two bedrooms on the ground floor, although three-bedroom units require wider plots. As an alternative, a two-story house allows improved exposure to both the breeze and sun with a larger façade surface, but increased height may need more distance between units.

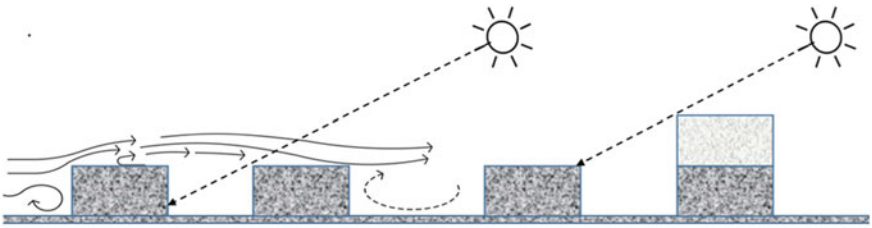

Fig. 3 Spacing for solar access, wind protection, or breeze for cross-ventilation, with an additional story extension producing winter shade

5.2 Layout Density Versus Sun and Wind Protection

Strong Patagonian winds increase energy demand for heating and decrease comfort conditions in outdoor spaces. In this case, cold winds require reduced distances between buildings and a layout to achieve the mutual protection of the units. At the same time, to receive adequate sunlight, more space is needed between built volumes, due to the low angular height of the sun in these higher latitudes from 40 to 55° South (See Fig. 3).

By implementing an environmentally conscious design, it is then possible to achieve favorable access to the winter sun from the north and protection from the strong prevailing winds from the west and southwest, typical of the Patagonian region of the country.

5.3 Layout Density Versus Solar Access

On 10 m wide plots with east or west access, only 4 m remain between the passive solar system and the party wall of the adjacent house, 2.80–3 m high, to the north. According to de Schiller [16], this proportion of outdoor space strongly limits access to the sun for windows or passive solar systems at latitudes above 30°. If the neighboring houses build a second-floor extension at a later stage, the projected shadows reduce further the favorable contribution of winter solar radiation (See Fig. 4).

5.4 Initial Housing Design Versus Subsequent Extensions

According to the Argentine Social Housing Policy and regulations, the initial design of two-bedroom housing units should allow for a future third-bedroom extension. It should be noted that the implementation of effective cross-ventilation and direct winter sun access can be received in all the main rooms of two-bedroom single-story units with conventional 10 m frontage plots.

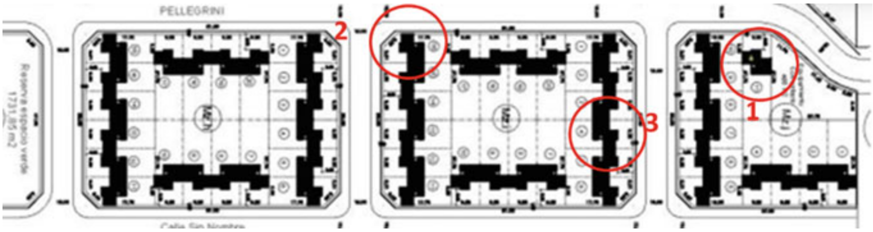

Fig. 4 Housing layout and energy demand for heating, central region Bioclimatic Zone III: 1. Free-standing house; 2. End of terrace House, 5.5% saving; 3. Mid-terrace house, 10.9% saving

However, with a later extension, the third bedroom receives no winter sun in temperate and cool climates, and cross-ventilation could be limited or difficult in hot humid climates. Therefore, better conditions can be achieved on a wider plot of 12.5 m frontage depending on the site available, even though this increases the cost of land, access roads, and urban infrastructure extensions.

Alternatively, two-story houses can be designed, even though the higher units cast longer shadows and reduce air movement on an urban scale. In this framework, the conditions related to land tenure, property law, and land use regulations, typical in Latin-American countries, have to be considered, as a relevant factor that determines the possible future modification and extension of each dwelling. However, weak building control exercised by municipal authorities is another situation that produces informal additions to housing units, exercised without building permits or compliance with local building codes.

6 Achieving Benefits on a Layout Scale

The following relevant benefits can be achieved by using appropriate project design measures, considering orientation and energy performance [11]:

Planned orientation. In existing homes with improved thermal insulation, as in the case of the Zapala housing project, Neuquén Province, 40°S, varying the orientation from NE to SE increased energy demand by approximately 5%, with the same construction cost. However, with an improved passive design, the variation in energy demand was minimal in homes with four different orientations since all the windows and passive solar systems had favorable NE and NW orientations.

Energy performance. A study of the energy demand in the four housing design categories indicates the magnitude of potential reductions. These estimates consider the total conventional energy demand for hot water, heating, cooking, and other uses. Energy inputs include the contribution of conventional energy, the metabolic heat of occupants, direct solar radiation through windows, and indirect radiation provided by passive solar systems. The values depend on variations of the plot subdivisions, the layout design, and the proposals for house plans, as well as the contribution of the construction, and characteristics of materials and the building system. They also vary according to weather conditions, the supply of solar radiation, and latitude, with possible adjustments for location and height above sea level. For example, in very cold climates at high latitudes with limited solar radiation, housing clusters, and compact shapes can offer greater benefits than increasing the north-facing surface area, while in cold and temperate climates at low latitudes, capturing favorable solar resources offers greater benefits than compact forms.

Another factor to consider when evaluating energy benefits in design decisions and setting up the layout is the great variation in the total demand for housing in different bioclimatic regions. The energy demand for heating and hot water in cold climates is more than double that in temperate climates, while solar energy capture can be halved. Thus, the priorities for urban design measures vary considerably in different regions. The performance of solar collectors and photovoltaic panels also varies according to their orientation to the sun.

It should be noted that units are often located parallel or perpendicular to the street frontage, which also affects the performance of passive solar systems as the Energy Secretary [12] warns. As an example, the results of efficiency losses are shown for different solar systems according to orientation in the Buenos Aires Province, 34°S:

- *Photovoltaics:* a PV module in Buenos Aires loses only 2% of its annual generation with a change from the optimal north orientation to 30° to the E or W of N, 5% with a 60° variation, and 9% with east or west orientation.
- *Thermal solar collectors:* the useful energy for heating water decreases from the optimum facing north, decreasing 2.5% as it swings 30° east or west. With a swing of 60° from the north, the decrease is 7%, and at 90° reaches 15%.
- *Passive solar systems:* the reduction in useful solar energy is approximately 22% with a NE or NO orientation, compared to the optimal to the north, although the result may depend on other factors that affect shadow projections. With east and west orientations, the contributions of solar systems are minimal. It should be noted that solar systems can contribute up to 30% of heating energy demand in favorable designs in this temperate climate.
- *Grouping:* houses with a shared party wall reduce heat losses by approximately 1.5–2%, while a terrace house with two party walls in contact with adjacent units reduces losses by 2.5 to 3%.

A favorable urban design with suitable orientations of the units, adding all these factors together, can provide an additional 5.5% saving of conventional energy, with improved comfort at little or no cost, compared to a typical design layout with no consideration of sun and/or wind orientations, based on an average reduction for projects in different climate zones, Table 1.

Table 1 Reduction in conventional energy with efficient building and solar gain

Measures to improve comfort		Without better grouping (%)	With better grouping (%)	Saving (%)
Housing design	Improved wall insulation	6.1	7.5	
	Improved roof insulation	7.8	7.8	
	Reduce thermal bridges	1.5	1.7	
	Improved windows	7.9	7.9	
	Control of ventilation losses	5.1	5.7	
	Insulation of floors	0.7	1.0	
	Reduction in conventional energy demand for heating	29.1	31.5	2.4
Improved solar gains	Better orientation less shading	4.1	6.0	
	Avoidance of winter shading	2.5	3.5	
	Replacement of conventional with solar energy	6.6	9.5	2.9*

* Site orientation, layout, and density reduce optimum solar gains, de Schiller [4]

7 Results of Implementing the Research

The results, although they achieve modest reductions in the conventional energy demand, obtained key environmental benefits at very low cost, and the contributions enhance measures on other design scales, both in architectural design and construction. This saving, estimated at 31%, contributes to a total average conventional energy saving, through improved thermal envelopes and construction details and the application of bioclimatic design strategies on an urban layout and unit scale, together with rational design integration and feasible implementation of both thermal and PV modules solar collectors.

These particular issues integrated into a general overview of the relevance that energy demand must be considered at the project design stage, but as mentioned previously, these solar installations, with higher costs, can then be incorporated after construction, in subsequent improvements and/or extensions, only if the basic conditions for solar access were considered from the very beginning of the layout design process.

The energy and economic benefits are greatest in colder high-latitude or high-altitude locations, while the social value of improved comfort and use of outdoor space are additional advantages in all locations. Design decisions on an urban layout scale have a significant impact on energy demand, complementing measures on architectural and construction scales. In this regard, it should be emphasized that measures such as thermal roof insulation or improved window quality can be incorporated over time but initial design decisions on subdivisions, plot size, access, and orientation, are fixed and cannot be modified once the houses are built.

In this way, the influence of orientation and plot size generates long-term impacts, which last beyond the lifetime of the buildings. Additionally, subsequent extensions, typical of many housing projects, often added to meet the requirements of growing families, increase the useful space but may decrease environmental quality, generating greater dependence on conventional energy supply.

At the same time, densification offers economic benefits in the provision of transport, efficient land use, and access to urban infrastructure, as de Schiller [16] mentions, although it can limit the flexibility and reduce the environmental quality of housing, as explained by the Secretary of Housing [7].

As a result of the studies undertaken, improved thermal standards for social housing were implemented by the National Housing Authority, and the Ministry of Internal Affairs, such as better external envelope performance and solar water installations in all regions of the country, effectively contributing to removing barriers in social housing projects in the context of sustainable development, and promoting innovative legislation for social housing projects, as Evans and de Schiller [17] show.

8 Conclusions

Estimates of potential energy-saving measures on a housing planning scale achieve the modest but significant long-term advantages with a favorable cost–benefit ratio.

The combination of decisions on a project scale with complementary measures at the architectural and construction scale enhances energy efficiency while achieving significant reductions in conventional energy demand and resulting greenhouse gas emissions.

It should be noted that design decisions and energy-conscious measures on a layout scale also offer the benefits of improved comfort in indoor and outdoor spaces.

In multiple ways, removing barriers in the application of bioclimatic design strategies at the scale of housing groups and general layout design decisions in a different and complementary view, integrated with energy efficiency measures and the implementation of solar renewable energy, contribute to the goal of achieving more sustainable social housing development in the Global South.

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