Sustainable Housing with Low-Consumption Systems for Island Regions

Viviendas sostenibles con redes de bajo consumo para regiones insulares

Casas sustentáveis com redes de baixo consumo para regiões insulares

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Abstract

Introduction: This article highlights the relevant results of the study "Comparative evaluation of technical-economic solutions for internal systems of traditional and sustainable low-energy consumption housing: case study" developed in Pontificia Universidad Javeriana Cali between 2019 and 2021.

Problem: The development corresponds to an applicable prototype, specifically in the community of Buenaventura, in Valle del Cauca (Colombia). This community has the highest multidimensional poverty index represented in the population of strata 1, 2, and 3, that often settle in areas with no urban facilities and where construction is made with no design criteria. As a result, the buildings will not satisfy basic needs, including water supply, the disposal of wastewater, and adequate electrical flow.

Objective: The objective of this study is to show the technical feasibility and economic viability of sustainable social housing, where the end-user benefits from savings in public services such as energy, water supply, and wastewater.

Methodology: The architectural design of the MINGA house, winner of the Solar Decathlon 2019 competition, is used as a platform to include a redesigned residential water supply system, wastewater system and electrical system. The designs of the domestic water supply system, wastewater system and electrical system for the house were developed on top of the original architectural blueprints, allowing for sustainable conditions applicable in low-income housing in the community of Bajamar, Buenaventura.

Results: Alternative elements and equipment are proposed for the implementation of low consumption network systems.

Originality: Feasibility of implementing low consumption system for homes in island regions.

Limitations: System design for one level housing.

Keywords: Housing, sustainable, construction, cost.

Resumen

Introducción: Este artículo destaca los resultados relevantes de la investigación "Evaluación comparativa de soluciones técnico- económicas de redes internas de una vivienda tradicional y una vivienda sostenible de bajo consumo: estudio de caso" desarrollado en la Pontificia Universidad Javeriana Cali entre el 2019 y el 2021.

Problema: El desarrollo corresponde a un prototipo aplicable de manera particular en la comunidad de Buenaventura, en Valle del Cauca (Colombia). Esta comunidad tiene el mayor índice de pobreza multidimensional representada en la población de estratos 1, 2 y 3 que suelen asentarse en áreas en donde construyen sin criterios de diseño. Como resultado, las construcciones no satisfacen las necesidades básicas incluyendo el abastecimiento de agua potable, la disposición de aguas servidas y el adecuado fluido eléctrico.

Objetivo: El objetivo de este estudio es evidenciar la viabilidad técnica y económica de una vivienda de interés social sostenible donde el usuario final reciba el beneficio de ahorros en servicios públicos como energía, acueducto y alcantarillado.

*Metodología***:** El diseño arquitectónico de la casa MINGA ganadora de la competencia Solar Decathlon 2019 fue empleado para el rediseño de las redes de acueducto, alcantarillado y electricidad. Los diseños de las redes domésticas de agua potable, aguas servidas y eléctricas se basaron en los planos arquitectónicos originales, permitiendo condiciones sustentables aplicables en viviendas de interés social en la comunidad de Bajamar, Buenaventura.

Resultados: Se plantean alternativas de elementos y equipos para la puesta en marcha de sistemas de redes de bajo consumo.

Originalidad: Viabilidad de implementación de redes de bajo consumo en viviendas de regiones insulares.

Limitaciones: Diseño de redes para viviendas de un solo piso.

Palabras claves: Vivienda, sostenible, construcción, costo.

Resumo

Introdução: este artigo destaca os resultados relevantes da pesquisa "Avaliação comparativa de soluções técnico-econômicas de redes internas de uma casa tradicional e uma casa sustentável de baixo consumo: estudo de caso" desenvolvida na Pontificia Universidad Javeriana Cali entre 2019 e 2021.

Problema: O desenvolvimento corresponde a um protótipo aplicável de forma particular na comunidade de Buenaventura, no Valle del Cauca (Colômbia). Esta comunidade tem o maior índice de pobreza multidimensional representada na população dos estratos 1, 2 e 3 que tendem a se instalar em áreas onde constroem sem critérios de projeto. Como resultado, os edifícios não satisfazem as necessidades básicas, incluindo o abastecimento de água potável, a eliminação de esgotos e eletricidade adequada.

Objetivo: O objetivo deste estudo é demonstrar a viabilidade técnica e econômica de uma habitação popular sustentável onde o usuário final receba o benefício de economia em serviços públicos como energia, adutora e esgoto.

Metodologia: O projeto de arquitetura da casa MINGA, vencedora do concurso Solar Decathlon 2019, foi utilizado para o redesenho das redes de aqueduto, esgoto e eletricidade. Os projetos das redes domésticas de água potável, esgoto e eletricidade foram baseados nos planos arquitetônicos originais, permitindo condições sustentáveis aplicáveis em habitações populares na comunidade de Bajamar, Buenaventura.

Resultados: São propostos elementos e equipamentos alternativos para a implementação de sistemas de rede de baixo consumo.

Originalidade: Viabilidade de implementação de redes de baixo consumo em habitações em regiões insulares.

Limitações: Projeto de redes para casas térreas.

Palavras-chave: Habitação, sustentável, construção, custo.

1. INTRODUCTION

The construction sector plays an important role in the economy of countries [1]. For this reason, due to rapid population growth, there is a demand for housing, which leads to significant negative environmental impacts generated mostly by the consumption of fossil fuels [2]. Due to energy consumption, which is expected to reach 820 trillion kJ by 2040 [3], as well as the increase in greenhouse gas emissions [4] as a result of wastewater treatment, significant negative environmental impacts are being caused [5]. According to Shrestha y Mulepati [6], the use of air conditioning in buildings has increased by 15% and energy consumption has increased by 2%, in less than a decade [6]. It can be asserted that energy consumption has increased exponentially since the industrial revolution [7].

Numerous studies have been conducted to identify alternative construction materials, including the use of local materials [8] that contribute to mitigating environmental impacts during the construction and operation of housing projects [2], and improve the bioclimatic conditions residential spaces. In this way, as a response to the human right to decent housing [9] with adequate urban facilities and construction of high standards [10], the land on which the project is developed becomes a financial asset [11], satisfying a basic need of individuals [9] [12].

In Latin America, around 60% of the population lives in informal settlements, often in homes built with low-quality materials, where public service coverage is deficient [13]. This situation puts the residents of these homes at risk and has become a problem in which several communities in Colombia are also immersed.

In addition, human-induced global warming is presently increasing [7], making housing solutions aligned with this reality a necessity. Therefore, providing a sustainable housing model that allows users to enjoy a quality life, in a decent home, under conditions of climate comfort, with low energy consumption, is relevant worldwide.

The objective of this study is to show the technical feasibility and economic viability of sustainable homes with the implementation where the end-user benefits from savings in public services such as energy, water supply, and wastewater. The project was developed using the architectural design of the MINGA house prototype, designed and built at the Pontificia Universidad Javeriana, Cali during the 2019 Solar Decathlon for Latin America and the Caribbean [14]. The designs of the domestic water supply system, wastewater system and electrical system for the house were developed on top of the original architectural blueprints, allowing for sustainable conditions applicable in low-income housing in the community of Buenaventura.

1.1 The Solar Decathlon competition

The origin of the competition dates to 2002 as an initiative of the United States Department of Energy to demonstrate the feasibility of using photovoltaic energy as a primary source of energy production. However, it wasn't until 2015 when the first Solar Decathlon of Latin America and the Caribbean took place in Colombia. [15]. The competition has also been held in in the United States, Europe, China, India, Africa, and the Middle East [14] [15].

The competition is meant to be interdisciplinary [16], and the expected outcome is to offer to the community a small, high performance, low-carbon building, powered by solar energy [15]. The most recent competition for Latin America and Caribbean was held in 2019, in the city of Cali, with the team MINGA (Colombia/Brazil) taking first place. The MINGA house was developed by the Pontificia Universidad Javeriana Cali in conjunction with the Federal University of Santa Catarina and the Federal Institute of Santa Catarina. The challenge of the work in this competition was to provide a housing solution for the island region of Buenaventura, specifically on the island of Cascajal.

1.1 Characteristics of the MINGA house

The MINGA house was designed to be implemented in Buenaventura, to promote urban development in the region, as part of the 2050 Partial Plan. It was conceived with 32 m^2 of common areas such as terraces, balconies, and access ramps, and 72 m^2 for private use. So as to facilitate its construction, 12 different modules were proposed to enable the installation of hydraulic, sanitary, electrical, and photovoltaic utilities with consumption meters. The design considerations and the building functionality made the MINGA house worthy of first place in sustainability, energy efficiency, and energy balance, and second place in architectural design.

Considering the sociocultural and demographic characteristics of the Buenaventura region, the cohousing strategy was selected as appropriate, offering spaces that could be occupied by up to eight people. The general design and construction were oriented following the EDGE environmental certification system guidelines, with passive bioclimatic strategies such as double roofing in each room and active strategies such as natural air circulation to respond to climate changes in the sector. The formation of the façade with vertical wooden elements provided shade and allowed for indirect lighting and ventilation, and the transfer of heat from the rooms was controlled with the lightweight structure and wooden sheets [14], favoring the utilization of extreme temperatures and solar radiation in the region [7].

2. METHODOLOGY

This research evaluates the technical feasibility and economic viability of the implementation of greener, low-consumption, sustainable, residential water supply, wastewater, and electricity systems in a proposed sustainable housing for an island region. The steps followed included:

a) Description of the geographical conditions of the study area.
b) Comparison of considerations for the design of electrical, hydro-sanitary, and rainwater systems under the traditional concept, versus the sustainability concept in the MINGA house.
c) Comparison of system specific budget requirements.

3. RESULTS

Improvement of infrastructure in cities and consequently better living conditions for the population in Colombia has been achieved through development policies financed by the national public investment system [17]. However, this is not the case for the municipality of Buenaventura, with the island of Cascajal. Connected to the mainland by the Piñal Bridge, its activity includes mining, hunting, and fishing, as well as fruit production [18]. Although the port has been an essential element in th' city's configuration and its activities from both an economic and socio-cultural perspective, it is recognized that there has been uneven development with respect to the city, in which the latter has not been able to consolidate levels of progress at the same pace as the port, lacking generalized conditions of well-being for the population of Buenaventura [19], where people suffer from high levels of poverty, inequality, violence, and a lack of basic services and infrastructure. In addition, the low institutional capacity does not allow Buenaventura to perceive positive impact in housing matter [19] that does not cover the quantitative or qualitative housing deficit of about 78% of households in the area [20]. Previous studies have shown that spontaneous and informal growth has generated extensive urbanization, located in areas not suitable for construction, on which regularization entails high costs, even higher than any type of formal housing project. As a common practice, there are Palafitic type houses, that are houses build on water, with no design considerations and poor materials, that survive despite the 'egion's weather [21].

3.1 Special architectural considerations of the MINGA house.

The architectural considerations of the MINGA house include the design of common spaces that can adapt to climate changes and promote social cohesion, while maintaining a connection between interior and exterior spaces for rest, work, service, and gathering, as shown in Figure 1. The house also adheres to universal design criteria, such as providing circulation areas with a minimum width of 90 cm and access ramps for people with reduced mobility. Despite the emphasis on social cohesion, the design also prioritizes the'users' needs for privacy, with independent rooms, designated in purple in Figure 1, to allow for a healthier coexistence.

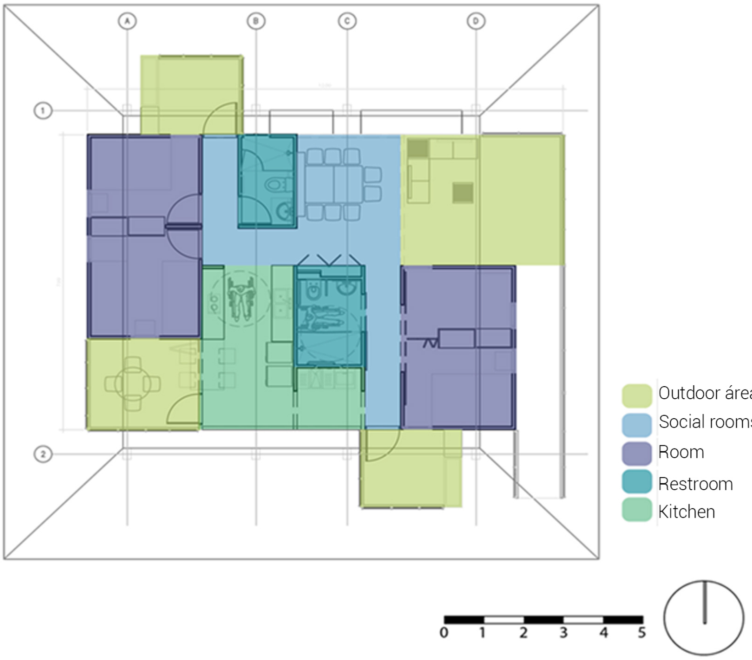


Figure 1. Architectural floor plan of the MINGA house (without dimensions).
Source: [22]

A study was conducted on the effects of shade, solar radiation and wind to identify the bioclimatic strategies that promote sustainable and ecological use of resources. The modeling was made by the MINGA team using Autodesk® Ecotect® Analysis software (Figure 2). The specific strategies derived from the modeling are summarized in Table 1.

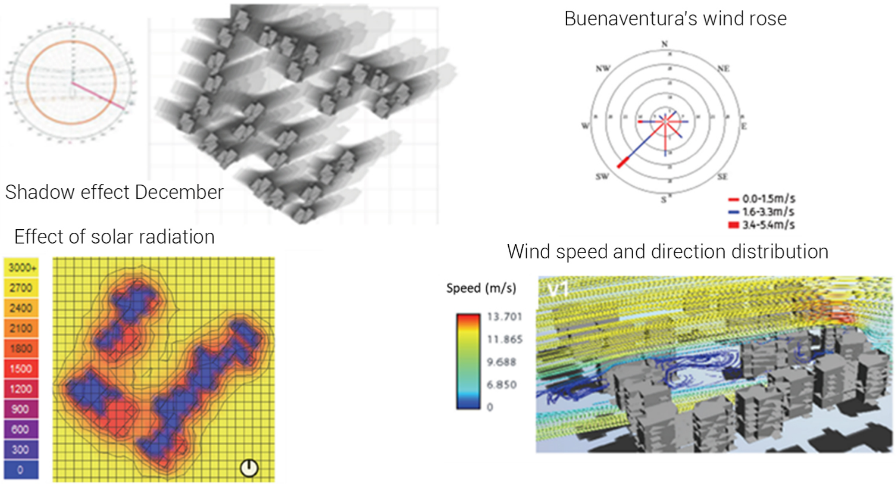
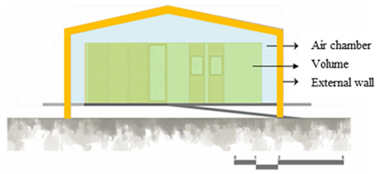
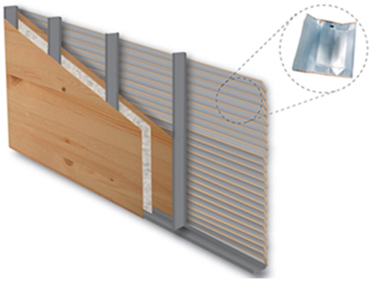
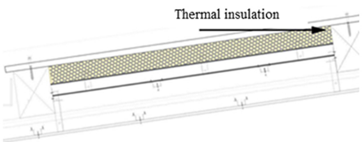
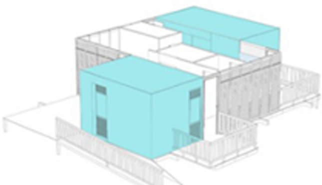
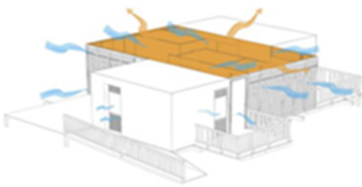


Figure 2. Visualization of modeling results, Autodesk® Ecotect® Analysis software
Source: [22]

Table 1. Design strategies implemented in response to bioclimatic considerations.

Design strategies	Expected result
Envelope with a dfaçadefacade and a roof, covered with thermally insulated multilayer tiles.	Passive heat reduction 
Walls made of lightweight construction with two 15mm wooden panels and a 6mm insulation layer and the insertion of Tetra Pak carton.	Provides thermal comfort, between 22°C and 25°C. 
Roof, composed of a thermally insulated tiles, built at a height that allows for natural ventilation.	Controls the impact of temperature variation on interior spaces. 
Cross-ventilation in communal spaces (passive measure) with sliding windows and proposes extractors in private spaces (active measure) with thick walls constructed of fiberglass.	Provides thermal comfort.  Active  Passive

Source: own work

3.2 Design of electrical system integrating solar production.

The high energy consumption of homes is generating environmental problems because of human activities and overpopulation [23]. Only 24.5% of this energy comes from renewable resources. The primary goal of the electrical and photovoltaic design is to store energy during the day to release it for use at night. Considering that the house has low energy consumption during the day, it is proposed that the surplus (unused energy) be released to the public grid, from which it will be captured again when needed inside the house.

For the design, the installation of nine solar panels that transform light energy into direct current, an inverter, two meters, and surge protector are proposed. A breaker and fuse box are also considered. Table 2 shows the comparison between the systems.

Table 2. Comparison of conventional and low-energy consumption electrical installations.

Traditional system	Low-energy consumption system
One single panel and meter	One electrical panel for each house, maintaining social cohesion without generating conflicts, and one panel for common areas. One main meter and three independent breaker boxes
Multiple circuits	Independent circuits following RETIE regulations

Source: own work

3.3 Design of hydro-sanitary system

Water is an essential resource in human activities [24] and the functionality of any home requires the existence of networks for the supply of potable water and for the management of wastewater and rainwater. Table 3 shows the comparison between a traditional and a low-consumption hydro-sanitary systems. Currently, the use of water is being promoted under the integrated management scheme of water resource, that is, to provide water in the required conditions and quality according to its use [25].

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Table 3. Comparison between a traditional and a low-consumption hydro-sanitary systems

Traditional system	Low-consumption system
It works well with no harvesting of rainwater and the reuse of graywater.	After treatment, the inclusion of rainwater for consumption and the use wastewater from sinks and showers to flush toilets is considered.
Common installation for handling rainwater and wastewater.	Independent systems for the conduction of rainwater, black water, and graywater.
4” pipes for toilets and 2” pipes for showers in compliance with NTC 1500 of 2017.	4” pipes for toilets and 2” pipes for showers in compliance with NTC 1500 of 2017.
Slopes and pipe diameters to facilitate the conduction of rainwater with 4” downspouts.	Slopes and pipe diameters to facilitate the conduction of rainwater with 4” downspouts.
Graywater is not reused.	Collecting graywater from sinks and laundry, in a 1m^3 tank, for reuse in garden irrigation and cleaning of common areas. Water from the kitchen sink passes through a grease trap and can be used in toilets, reducing the use of drinking water in areas and activities that do not require potable water.
Rainwater is disposed of. There is no system for rainwater primary treatment (water filtering)	The collection, storage and purification of rainwater is managed in an underground tank using a 0.5HP pressure pump with an smart pump controller.

Source: own work

3.4 Cost considerations

Construction is an important sector in Colombia, contributing significantly to the country’s economy. It employs many people and has a major impact on infrastructure development, housing, and commercial property, generating tax revenue for the local and national government [26].

To compare the costs of the different alternatives proposed for the MINGA house, an estimate of the cost was developed, based on the government list for unit cost available for Valle del Cauca in 2021. The estimated costs have been broken down into their individual systems, as presented in Table 4.

Table 4. Comparison of total budgets for the construction of hydro-sanitary and energy Systems of the MINGA House (COP 2021)

System	Traditional system	Low-consumption system
Rainwater management	$2.393.110	$3.293.897
Gas network	$1.080.520	$1.080.520
Electricity network	$16.926.708	$29.094.871
Water network	$1.831.939	$11.365.717
Sanitary network	$1.525.977	$3.053.659
Equipment		$9.339.690
Total	$23.758.254	$57.228.354

Source: own work

An increase of about 140.88% in the construction of the low-consumption systems is expected compared with the construction of the traditional system, and the total cost of the MINGA house would increase by $33,470,100 due to the implementation of sustainable low-consumption systems. To calculate the total cost of the house the construction cost per square meter of social interest housing (VIS) must be considered, which is about $1,393,963. Thus, 70 m^2 of the MINGA house would have an approximate direct cost of $97,577,410 to which the amount of $33,470,100 would have to be added because of the implementation of the low-consumption system, resulting in a total cost of $131,047,510 (131.05 SMMLV for 2021). This value is within the limit established in Law 1955 of 2019, which issues the National Development Plan 2018-2022 of Colombia, and which established that VIS housing should not exceed 135 legal monthly minimum wages of the time.

4. DISCUSSION

There are several challenges facing the construction industry today. One of them is adapting to new technological developments [1] and materials [4], as well as the increasing demand for sustainable construction practices [4] [5]. This requires a shift in mindset towards designing buildings with resource scarcity and reducing greenhouse gas emissions [7] [8].

On the other hand, it has been shown that sustainability practices, such as reducing energy consumption [6] or implementing green solutions [8] such as photovoltaic energy, natural ventilation, and wind energy [27] are cost-effective [3], help to improve thermal comfort conditions [3], and contribute to the rational use of water through the reuse of used water [27], thus contributing to the reduction of the water footprint. Additionally, it is evident that interdisciplinary work is required to concretize sustainable housing with low consumption systems [5] to contribute from each field of knowledge to the designs and construction processes that reduce energy consumption [27] and favor energy efficiency [3], minimizing the risks of health problems on the population [7] and offering housing solutions that meet the demands of climate change [7].

The increase in the direct costs of the proposed housing construction does not exceed the established limit for this type of housing in Colombia. Therefore, the implementation of a low-consumption system can be massified without detracting from the profitability of the constructed housing.

5. CONCLUSIONS

The selected prototype is an affordable house designed and built in Colombia by a team of architects and engineers, and it takes into consideration the local climate, building materials, and construction techniques, aiming to provide sustainable and comfortable homes for low-income families. Initially designed to respond to the local condition of Buenaventura, the MINGA house is a single-story house with an open floor plan that allows for flexible use of space. The design includes features such as high ceilings, cross-ventilation, and natural lighting, which help to regulate indoor temperatures and reduce the need for air conditioning. The house is also built to withstand flooding, which is a common occurrence in the area. In addition to its sustainable design features, the MINGA house also incorporates the concept of cohousing, which promotes shared living spaces and communal activities among residents. This approach aims to foster a sense of community and promote social interaction among neighbors.

The use of a solar photovoltaic system to generate electricity from solar energy allows for the storage of excess energy during the day, which can then be used when needed, reducing the reliance on conventional electric power. This contributes to the sustainability of the proposed housing solution and reduces its impact on the environment.

Furthermore, the separation of gray and rainwater systems allows for a more efficient use of water, and the collection and treatment of rainwater for consumption reduces the household potable water supply requirement and enhances the sustainability of the proposed housing.

The proposed solution leads to an increase in the total direct cost of the house. However, the value still falls within the limits set by Colombian legislation to support social interest housing with subsidies. The creation of an economic incentive program for the construction of this type of housing is in the hands of the national government.

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