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ORIGINAL

Environmental impact in low-income housing: Sustainability strategies for impact reduction

Impacto ambiental en viviendas de interés social: Estrategias de sostenibilidad para la reducción del impacto

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ABSTRACT

The research analyzed the environmental impact of Social Interest Housing (VIS) in the Carlos Pizarro neighborhood of Pasto. The study was based on the architectural survey of a typical house, in which the masses of the materials used were calculated and evaluated using Eco-Indicator 99. The results showed that materials such as steel, brick and acrylic paint generated the greatest environmental load, with a total impact estimated at 3 109 076 millipoints. Based on this diagnosis, two improvement proposals were formulated. The first consisted of replacing the internal walls with light structures of wood, fiberglass and gypsum panels. However, the reduction achieved was only 0,6 %, which showed that partial interventions had a limited effect. The second proposal proposed a comprehensive transformation through the use of sustainable and recycled materials, such as PVC, polyaluminum and Tetrapak tiles. This redesign allowed a 92 % reduction in the initial environmental impact, demonstrating that sustainable construction strategies were effective only when applied from the beginning of the construction process. Additionally, the incorporation of photovoltaic and rainwater harvesting systems was evaluated. The solar panels guaranteed the energy supply of the houses, even with the possibility of injecting surpluses into the grid. The rainwater collection system made it possible to replace up to 71,6 % of the monthly potable water consumption, mitigating the pressure on this resource. In conclusion, the study demonstrated that sustainability in VIS was achievable through a comprehensive redesign, the selection of low-impact materials and the implementation of energy and water efficiency technologies.

Keywords: Social Housing; Sustainability; Environmental Impact; Recycled Materials; Energy Efficiency.

RESUMEN

La investigación analizó el impacto ambiental de las Viviendas de Interés Social (VIS) en el barrio Carlos Pizarro de Pasto. El estudio partió del levantamiento arquitectónico de una vivienda tipo, en el cual se calcularon las masas de los materiales empleados y se evaluaron mediante el Eco-Indicador 99. Los resultados mostraron que materiales como el acero, el ladrillo y la pintura acrílica generaban la mayor carga ambiental, con un impacto total estimado en 3 109 076 milipuntos. A partir de este diagnóstico, se formularon dos propuestas de mejora. La primera consistió en sustituir los muros internos por estructuras ligeras de madera, fibra de vidrio y paneles de yeso. Sin embargo, la reducción alcanzada apenas representó un 0,6 %, lo que evidenció que intervenciones parciales tenían un efecto limitado. La segunda propuesta planteó una transformación integral mediante el uso de materiales sostenibles y reciclados, como PVC, polialuminio y tejas Tetrapak. Este rediseño permitió reducir hasta en un 92 % el impacto ambiental inicial, demostrando que las estrategias constructivas sostenibles resultaban efectivas únicamente cuando se aplicaban desde el inicio del proceso constructivo. Adicionalmente, se evaluó la incorporación de sistemas fotovoltaicos y de captación de aguas pluviales. Los paneles solares garantizaron el abastecimiento energético de las viviendas, incluso con posibilidad de inyectar excedentes a la red. El sistema de recolección de aguas lluvias permitió sustituir hasta el 71,6 % del consumo mensual de agua potable, mitigando la presión sobre este recurso. En conclusión, el estudio demostró que la sostenibilidad en VIS era alcanzable mediante un rediseño integral, la selección de materiales de bajo impacto y la implementación de tecnologías de eficiencia energética e hídrica.

Palabras clave: Vivienda Social; Sostenibilidad; Impacto Ambiental; Materiales Reciclados; Eficiencia Energética.

INTRODUCTION

The rapid growth of cities has placed increasing pressure on natural resources and the environment, especially in urban contexts in developing countries. This dynamic, driven by the need to provide affordable housing solutions to a constantly growing population, has led to a significant increase in the environmental impact associated with construction. At the same time, social housing (VIS) is presented as a fundamental alternative to guarantee the right to housing, but its development continues to be linked to conventional construction methods that involve high environmental costs.

In Colombia, the problem is evident. According to Buss[1], the construction sector accounts for 22 % of the country's total energy consumption, with 16,72 % attributed to the residential sector. In addition, buildings consume 79 % of the water supply and are responsible for 10,5 % of greenhouse gas emissions. These figures underscore the need to rethink construction models based on sustainability criteria.

The model formulated by Ehrlich et al.[2] in the 1970s allows us to understand this problem by relating environmental impact (I) to population (P), consumption level (A), and technology used (T). This approach highlights the relationship between population growth, urban lifestyles, and construction practices in environmental degradation, climate change, and resource depletion.

Initiatives such as the National Roadmap for Zero Carbon Buildings (HR-ENCC) propose ambitious goals, such as reducing operational emissions by 30 % by 2030,[3] by promoting more resilient and healthier buildings. In this context, it is essential to incorporate sustainable practices into the construction of VIS, not only to reduce their ecological footprint, but also to ensure better living conditions, energy efficiency, and well-being for their inhabitants.

To this end, the following is an environmental impact study carried out on VIS-type housing in the Carlos Pizarro neighborhood in the city of Pasto, using tools such as Life Cycle Assessment (LCA) and Eco-Indicator 99[4] that allow the environmental burden associated with construction materials and processes to be quantified and compared. In addition, sustainable alternatives are proposed through the use of lower-impact materials, rainwater harvesting systems, and solar energy generation, which contribute to mitigation during the operation of the housing.

The purpose of the research is to contribute to sustainability in VIS with replicable and scalable proposals in Colombia and Latin America, based on architectural strategies with on-site impact reduction.

Calculation of environmental impact using Eco-Indicator 99

To calculate the environmental impact, we began with an architectural survey of the housing using direct measurement tools and three-dimensional modeling with Revit software. This survey provided the planimetry and dimensions needed to estimate the volume of each of the materials used in construction. Based on this data, the mass of the materials was calculated by multiplying the volume by the corresponding density, as stipulated in the Colombian Seismic Resistant Construction Standard NSR-10.[4] The result made it possible to determine the total weight of each material, an essential condition for applying Life Cycle Assessment (LCA). Subsequently, Eco-Indicator 99, a tool developed by Goedkoop et al.[5] that assigns standardized impact values per kilogram of material, was used in the environmental impact assessment. The scale adopted considers that 1 Pt is equivalent to one hundredth of the environmental impact generated annually by an average European citizen. These values, expressed in millipoints (mPt), compare the environmental load of different construction components.

In this regard, the first proposal focused on the use of materials, according to Eco-Indicator 99 values. The following tables show the calculation of the total mass of each material used and the total estimated environmental impact per dwelling, expressed in millipoints (mPt), which allows for the identification of sustainable measures to be adopted to reduce the environmental impact of social housing.

Table 1. Calculation of the total mass of each material

Material	Volume	Density	Mass
Concrete	37,45 m^3	2400 kg/m^3	89 462 kg
Brick	14,24 m^3	1850 kg/m^3	26 340 kg
Iron for doors	0,07 m^3	7200 kg/m^3	498 kg
Iron for door frames	0,02 m^3	7200 kg/m^3	166 kg
Mortar	1,49 m^3	2100 kg/m^3	3120 kg
4 mm glass	0,03 m^3	2600 kg/m^3	101 kg
Acrylic paint	1,48 m^3	1421 kg/m^3	2096 kg
Iron for window frames	0,12 m^3	7200 kg/m^3	385 kg
Wood for window frames	0,07 m^3	750 kg/m^3	29 kg
Wood for doors	0,24 m^3	750 kg/m^3	179 kg
Wood for door frames	0,02 m^3	750 kg/m^3	17,6 kg
Ceramics	0,54 m^3	2400 kg/m^3	1288 kg
Fiber cement for tiles	0,5 m^3	1650 kg/m^3	795 kg
Steel for structural support	0,10 m^3	7800 kg/m^3	1405,8 kg
Superboard for ceilings	0,42 m^3	1440 kg/m^3	619 kg
Concrete for flooring	9,60 m^3	2400 kg/m^3	23 040 kg

Table 2. Total environmental impact calculation for the current home

Material	Name of indicator	Mass	Indicator	Millipoints
Concrete	Unreinforced concrete	89 462,7 kg	3,8	348 907
Brick	Ceramic material	26 340 kg	28	742 190
Iron for doors	Cast iron	498 kg	240	119 578
Iron for door frames	Cast iron	165,6 kg	240	39 744
Mortar	Cement + sand	3120,2 kg	20,8	64 964
Glass	Uncoated glass	100,9 kg	49	4944
Acrylic paint	Acrylic paint	2096 kg	130	272 532
Iron for window frames	Cast iron	385,2 kg	240	92 448
Wood for window frames	Wooden board	29,3 kg	6,6	193,3
Wood for doors	Wooden board	179 kg	6,6	1181,5
Wood for door frames	Wooden board	17,59 kg	6,6	116,08
Ceramic	Ceramic material	1288 kg	28	36 066
Fiber cement for roof tiles	Cement	795 kg	20	15 900
Steel for structural support	High-alloy steel	1405,8 kg	910	1 279 329
Superboard for ceilings	Cement	619 kg	20	12 380
Concrete for flooring	Unreinforced concrete	23 040 kg	3,8	87 552
Total				3 109 076

Table 3. Total calculation of the concrete mass of the house, without reinforcing steel

Total mass of material	Quantities	Percentages
Reinforced concrete	90 868,6 kg	100
Steel	1405,9 kg	1,20
Unreinforced concrete	89 462,7 kg	89,40

In this regard, two improvement proposals were put forward aimed at mitigating the environmental impact of the original house through sustainable construction alternatives and materials with a lower ecological footprint. The first proposal consisted of intervening only on the internal walls of the house. To do this, the traditional brick masonry was replaced with a wooden structure with fiberglass insulation and drywall covering. The other building materials were retained to ensure comparability with the original model. Based on the new construction scheme, the masses and volumes of the modified materials were recalculated, as well as their estimated environmental impact according to Eco-Indicator 99. This procedure is documented in the following tables.

Table 4. Analysis of Low-Impact and Recycled Materials for Environmental Footprint Reduction

Material	Recyclability	Pollution generation	Indicator
Recycled polyaluminum tiles	High	0 %	-240 and -720
Fiberglass	High	25	49 and -15
Recycled PVC for window frames	High	0	-170
Paint	High	35	-240 and -720
Wooden floors	Medium	100	6,6
Gypsum board	Medium	100	6,6
Concrete floor	Medium	100 %	9,9
Cyclopean foundation	Medium	100 %	3,8
4 mm glass	Medium	100 %	3,8
Steel	Low	100 %	49
Wood for doors	Medium	100 %	86
Wood for door frames	Medium	100 %	6,6
Wood laminate for flooring	Medium	100 %	6,6
Superboard sheets	Medium	100 %	6,6

Table 5. Calculation of the mass of materials in the house: first proposal

Material	Volume	Density	Mass
Concrete for structure	37,45 m^3	2400 kg/m^3	89 462,74 kg
Concrete for floor	9,60 m^3	2400 kg/m^3	23 040 kg
Brick masonry	18,56 m^3	1850 kg/m^3	17 172,09 kg
Iron for doors	0,07 m^3	7200 kg/m^3	498,2 kg
Mortar	1,38 m^3	2100 kg/m^3	1445,01 kg
4 mm glass	0,03 m^3	2600 kg/m^3	80,4 kg
Acrylic paint	2,89 m^3	1421 kg/m^3	2054 kg
Wood for interior doors	0,24 m^3	750 kg/m^3	179 kg
Floor tiles	0,54 m^3	2400 kg/m^3	1288 kg
Fiber cement tile	0,5 m^3	1650 kg/m^3	825 kg
Structural steel	0,103 m^3	7800 kg/m^3	1405,86 kg
Iron for window frames	0,12 m^3	7200 kg/m^3	1386 kg
Wood for door frames	0,02 m^3	750 kg/m^3	17,59 kg
Iron for door frames	0,02 m^3	7200 kg/m^3	165,6 kg
Superboard ceiling	0,42 m^3	1440 kg/m3	603,5 kg
Wooden floors	2,07 m^3	600 kg/m^3	1242 kg
Plasterboard	1,09 m^3	800 kg/m^3	872 kg
Fiberglass	1,65 m^3	2600 kg/m^3	4277 kg

By replacing only the internal walls—a common practice in existing homes, with the aim of preserving the structure and most of the materials—the environmental impact is reduced by only 0,6 %. This shows that the mitigation of the impact is minimal, so it is not feasible to intervene on only a limited amount of materials.

The second proposal involved a comprehensive transformation of the home. Most of the original materials were replaced with sustainable options. In addition, elements such as wooden floors, drywall, fiberglass, recycled polyaluminum tiles, and recycled PVC window frames, among others, were introduced.

Table 6. Calculation of the total environmental impact of the renovated home				
Material	**Name of indicator**	**Mass**	**Indicator**	**Millipoints**
Concrete for structure	Unreinforced concrete	89 462,74 kg	3,80	339 958
Concrete for flooring	Unreinforced concrete	23 040 kg	3,80	87 552
Brick masonry	Ceramic material	17 172,09 kg	28	480 819
Iron for doors	Cast iron	498,2 kg	240	119 578
Mortar	Cement + sand	1445,01 kg	20,82	30 085
4 mm glass	Uncoated glass	80,4 kg	49	3939
Acrylic paint	Acrylic paint	2054 kg	130	266 990
Wood for interior doors	Solid wood	179 kg	6,6	1182
Floor tiles	Ceramic material	1288 kg	28	36 066
Fiber cement tile	Cement	825 kg	20	16 500
Structural steel	High-alloy steel	1405,86 kg	910	1 279 329
Iron for window frames	Cast iron	1386 kg	240	332 640
Wood for door frames	Solid wood	17,59 kg	6,6	116
Iron for door frames	Cast iron	165,6 kg	240	39 744
Superboard ceiling	Cement	603,5 kg	20	12 071
Wooden floors	Solid wood	1242 kg	6,6	8197
Plasterboard	Plaster	872 kg	9,9	8633
Fiberglass	Uncoated glass + Recycled glass	4277 kg	49 and -15	33 843
Total				3 097 241

Ceramic floors were replaced with floating laminates, and a cyclopean foundation was included as a low-impact alternative. The new design was evaluated using the same methodology, which showed a substantial reduction in the total environmental impact compared to the original model.

Table 7. Calculation of the mass of materials in the house: second proposal			
Material	**Volume**	**Density**	**Mass**
Wooden floors	4,45 m^3	600 kg/m^3	2671,8 kg
Plasterboard	6,41 m3	800 kg/m^3	4809,6 kg
Fiberglass	7,94 m^3	2600 kg/m^3	20 644 kg
Concrete floor	6,68 m3	2300 kg/m^3	15 364 kg
Cyclopean foundation	10,52 m^3	2200 kg/m^3	23 144 kg
4 mm glass	0,04 m^3	2600 kg/m^3	107 kg
Recycled PVC for window frames	0,07 m3	1420 kg/m^3	106 kg
Steel	0,04 m^3	7800 kg/m^3	0,58 kg
Wood for doors	0,45 m^3	750 kg/m^3	337,5 kg
Wood for door frames	0,07 m^3	750 kg/m^3	50,63 kg
Paint	1,57 m^3	1800 kg/m^3	2217,3 kg
Tetrapak tiles	0,59 m^3	800 kg/m^3	432 kg
Floating laminate flooring	0,40 m^3	600 kg/m^3	240 kg

In the case of this house, it was demonstrated that by replacing all the construction materials from the substructure, it was possible to reduce the environmental impact of the original house by approximately 92 %. This shows that it is possible to achieve a significant reduction in impact, provided that the construction of this type of housing is carried out from scratch.

In addition to the analysis of materials, processes were considered for the valuation of recycling components such as paint, taking into account energy consumption and the efficiency of the industrial recovery process.[6]

Table 8. Total environmental impact of the proposed housing

Material	Name of indicator	Mass	Indicator	Millipoints
Wooden floors	Solid wood	2671,8 kg	6,6	17 634
Plasterboard	Gypsum	4809,6 kg	9,9	47 615
Fiberglass	Uncoated glass + Recycled glass	20 644 kg	49 and -15	33 843
Concrete floor	Unreinforced concrete	15 364 kg	3,8	58 383
Cyclopean foundation	Unreinforced concrete	23 144 kg	3,8	87 947
4 mm glass	Uncoated glass	107 kg	49	5242
Recycled PVC for windows	PVC recycling	106 kg	-170	-17 996
Steel	Steel	0,58 kg	86	50
Wood for doors	Solid wood	337,5 kg	6,6	2228
Wood for door frames	Solid wood	50,63 kg	6,6	334
Paint	Acrylic paint + Paint recycling	2217,3 kg	130 and -64	6210
Tetrapak tiles	PET recycling + Aluminum recycling	432 kg	-240 and -720	-4800
Floating laminate flooring	Solid wood	240 kg	6,6	1585
Total				238 275 mPt

Calculation of the environmental impact of paint recycling

Since recycled paint does not have a specific value in the Eco-Indicator 99 tables, it was necessary to estimate its impact using a complementary procedure based on the indicator's own guidelines. The starting point was the positive impact value assigned to virgin acrylic paint, which is equivalent to 130 millipoints per kilogram, and it was assumed to be negative based on the logic that recycling avoids the production of the original material. Therefore, the starting point was an impact of -130 mPt/kg.

The impact associated with the process of recovering and reintegrating the recycled material into the market must be subtracted from this value. To do this, the energy consumption of the machinery used was considered, as well as its operational efficiency. In this case, a Yalian industrial paint mixer (model YMC-2000) was analyzed, whose technical specifications are related to motor power (5,5 kW), operating time (60 minutes), and production capacity (2000 liters).

The energy efficiency of the process was calculated by considering the use of the machinery per hour of work and applying the machine and operator efficiency factors extracted from Tiktin[6]. Based on these parameters, the total energy consumption required to process the volume of paint used in the proposed housing was estimated. Finally, the energy value was multiplied by the Eco-Indicator 99 coefficient for low-voltage electricity (<1000 V), corresponding to 26 mPt/kWh. The net environmental impact of paint recycling is as follows.

$$\frac{L\ (capacidad\ de\ producción)}{h\ (tiempo\ de\ producción)} =$$

Replacing:

$$\frac{2000\ L}{60\ min} = \frac{2\ m3}{1h} = 2\ m3/h$$

The next step is to determine the production time. To do this, the volume in this equation will be replaced by the total volume of paint used to paint the entire proposed house, which is 1570 liters, equivalent to 1,57 **m³.**

V/(m3/h)

Replacing:

(1,57 m3)/(2m3/h)= 0,78h

The energy consumption of the mixer per hour of work is calculated using the following formula. The equipment efficiency factor was obtained from Zapeter's[7] table of hourly efficiency factors for machinery, which considers the optimal conditions for this machinery. Operator efficiency and machinery conditions were taken from the table of operator and maintenance efficiency factors,[6] under favorable conditions.

Potencia del motor (kW)*Eficiencia del equipo *Tiempo de operación (hora)*Carga de trabajo

Replacing:

5,5 kW*0,78*0,78h*0,80=2,5Kwh

To calculate the paint recycling indicator, the efficiency factor of 2,5 kWh is multiplied by the electricity indicator, 26 BV Europa (UCPTE) for low voltage (<1000 volts), according to Goedkoop et al.[5].

2,5 Kwh*26=65

To obtain the final indicator, the impact of the paint, represented as a negative figure, is added to the machinery indicator.

-130+65=-65

The value obtained corresponds to the environmental impact indicator associated with the use of recycled paint, considering the processes involved in its recovery. This indicator allows us to estimate the impact generated by the number of liters used in painting the proposed house. As it is negative, the impact of using recycled paint is mitigable given its conditions.

Calculation of the environmental impact of using an excavator in the construction of the house

This calculation is made during the energy consumption of the machinery required to begin construction, specifically for the use of the excavator. First, the consumption of the excavator is calculated using the formula indicated in the document: determination of the performance of a 94 HP Caterpillar 420E backhoe loader for earthmoving, by Zapeter[7]. The excavator used for this procedure has the following properties: the 301,5 CAT model is used for trenching, with a filling capacity of 44 liters. Its cycle time is 15 seconds, which is equivalent to 0,25 minutes, allowing 4 cycles per minute, or 240 cycles per hour. The formula applied takes into account the bucket capacity (C), the load factor (Fc), the hourly efficiency (E), the operation and maintenance factor (FO), the filling factor (FG), the spillage factor (FE), and the cycle time in seconds.

Formula:

$$R = C * Fc * E * FO * FG * FE * \frac{1}{CICLO\ (seg)}$$

Substituting:

$$R = 0{,}04 * 0{,}8 * 0{,}83 * 0{,}75 * 0{,}8 * 0{,}8 * \frac{1}{(0{,}004\ seg)} = 3{,}5m3/h$$

The total volume of material to be excavated in the activity is 26,7 m^3. The duration of the activity is obtained by performing the following equation:

$$\frac{V}{m3/h}$$

Substituting:

$$\frac{26{,}7\ m3}{3{,}5m3/h} = 7{,}6h$$

With energy consumption in terms of power, the excavator's energy expenditure per hour of work is calculated using the following formula:

$$Potencia\ del\ motor\ (kW) * Eficiencia\ del\ equipo\ * Tiempo\ de\ operación\ (hora) * Carga\ de\ trabajo$$

Replacing:

$$15,7\ kW * 0,75 * 7,6h * 0,80 = 70,6Kwh$$

Likewise, the fuel consumption of the machinery is determined. This is calculated based on the table provided by Caterpillar[8]. To calculate the impact of the machinery, two factors are taken into account: energy measured in terms of power (kWh) and fuel measured in liters. The units used for the calculation with the indicator are kWh.[9] Therefore, to convert fuel consumption to kWh, the following formula is used:

$$Litro\ \frac{gasoil}{(combustible\ diésel)} = 10,96\ kWh$$

Therefore, fuel consumption is multiplied by this figure to obtain the energy expenditure of the machinery in terms of engine consumption:

$$2,5L * 10,96\frac{kW}{h} = 27,4\ kW/h$$

Now, to calculate the total energy expenditure, the energy expenditure of the machinery process is added to the previous value.

$$Consumo\ energético\ de\ proceso\ + gasto\ energético$$

Replacing:

$$27,4\frac{kW}{h} + 70,6\frac{kW}{h} = 98\ kW/h$$

The total impact generated by the machine is obtained by multiplying the final consumption by the indicator that identifies the impact generated by equipment that requires electricity to operate, according to Goedkoop et al.[5].

$$98\frac{kW}{h} * 26\frac{kW}{h} = 2.550\ mPt$$

Based on the calculation, it was determined that the excavator used in the early stages of construction generates a total environmental impact of approximately 2550 millipoints (mPt), considering both the energy consumption of the process (measured in kWh) and that corresponding to fuel use. This estimate was obtained by converting the total energy consumption into impact units using the Eco-Indicator 99 factor for low-voltage electrical equipment. The results identify the significant contribution of machinery to the overall environmental impact of the house, highlighting the importance of incorporating energy efficiency criteria from the initial stages of the construction project.[10,11]

Implementation of the photovoltaic system

The solar radiation analysis was performed using DrJ Marsh software, which allows three-dimensional simulation of the sun's path throughout the year. The first days of each month at peak radiation time (around midday) were taken as a reference to determine the optimal location of the modules. Subsequently, the photovoltaic systems were designed using the PV*SOL program, which specializes in modeling solar installations connected to the electrical grid.

In assessing the feasibility of incorporating photovoltaic systems, four houses with different orientations with respect to the north were considered, which allowed for the analysis of solar capture based on the position of the property. Each group of houses has a number of solar modules with different capacities and required areas, taking into account the pre-project diagnosis, as follows:

- Homes 1 and 2: five solar modules with a total power of 2,25 kWp, surface area of 12,9 m^2.
- Houses 3 and 4: four solar modules with a total power of 1,80 kWp, surface area of 10,4 m^2.

The projection for the location of the modules is shown in the following figure.

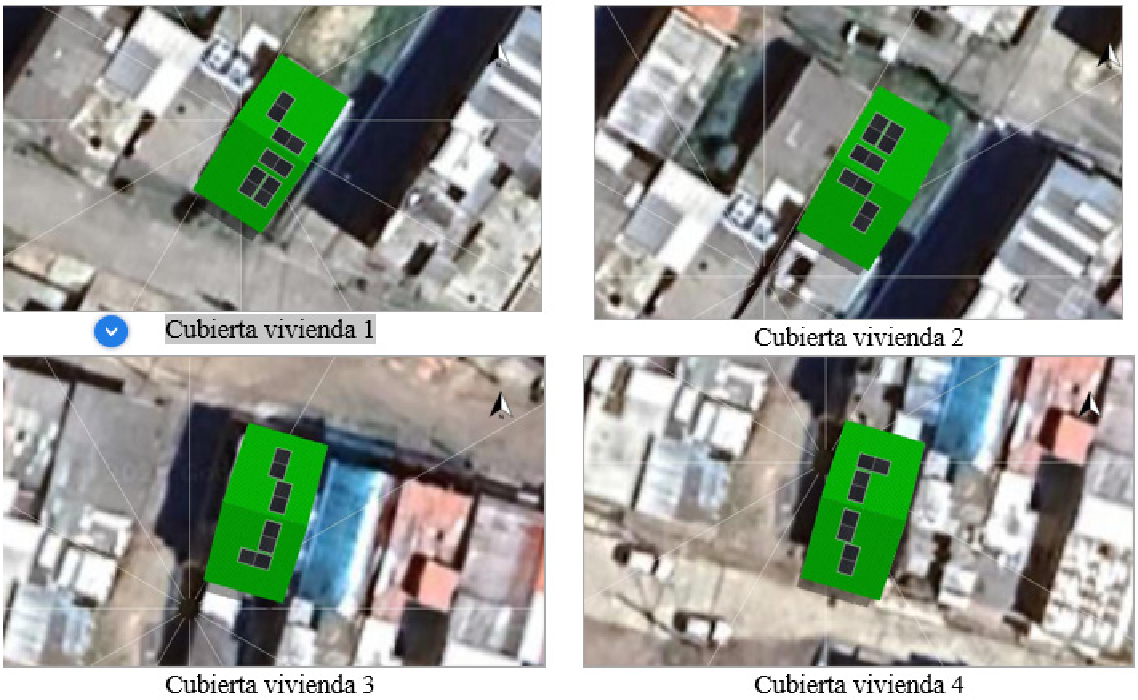

Figure 1. Projection of the roofs with solar panels for the VIS

It is recommended that the solar modules have the following characteristics to ensure efficiency within the VIS: ZNShine PV-Tech (model ZXM6-NH144-450/M), connected in series to Afore New Energy Technology inverters, responsible for transforming the direct current generated by the modules into alternating current that can be used with storage batteries (Example kW, 14,45 kWh).

Rainwater collection and use

In addition to the focus on sustainable materials and energy efficiency, a strategy for the responsible use of water resources was incorporated, centered on rainwater harvesting. This solution responds to the need to reduce drinking water consumption in non-essential domestic activities, while mitigating the environmental impact associated with the water cycle in urban contexts.

The calculation of the amount of rainwater available for collection was based on the roof area of the house and the average annual precipitation data for the city of Pasto. The formula established for this type of system was applied, considering a loss factor of 5 %, which made it possible to determine the potential monthly storage volume.

Table 9. Amount of rainwater collected from the house

	Rainwater collection					
Formula	**Capture (liters) = Roof area (m^2) * Rainfall (mm) * 0,95 (5 % loss)**					
Description	**Roof area**	**Precipitation (mm)/year**	**Losses**	**Liters/year**	**M^3 / year**	**M^3 / month**
Quantity	71,44	1710	0,95	1 106 054,3	116,3	9,67

Based on this estimate, a storage system was designed using underground tanks of different capacities, together with an internal distribution network that allows the collected water to be used for activities such as irrigation, floor washing, and sanitary discharges. To complement this analysis, a balance was made of the typical monthly consumption of a four-person household. The points where it is possible to replace drinking water with rainwater or gray water were identified.

The measures contribute to a significant reduction in the use of drinking water and promote more sustainable management of the resource, in line with the principles of environmentally responsible architecture. In particular, up to 71,6 % of monthly water consumption is mitigated through the use of rainwater, which is equivalent to 8,52 m^3/month that can cover activities such as irrigation, floor washing, cooking, laundry, and toilet flushing.

Table 10. Calculation of consumption throughout the home and percentage of mitigation

Water consumption	m^3 /4 inhabitants/ month	Percentage of consumption %	Consumption mitigation m^3 /month	Percentage of mitigation %
Personal hygiene	4,8	28,4		0
Toilet flushing	4,8	28,4	4,8	28,4
Laundry	1,8	10,6	1,8	10,6
Cooking	3,6	21,3	0,9	21,3
Floor washing	1,2	7,1	1,2	7,1
Watering gardens	0,72	4,3	0,72	4,3
Total	16,92	100	8,52	71,6
Rainwater harvesting	9,67 m^3/month			
Tank capacity 1	8500 liters			
Tank capacity 2	900 liters			

Reduced impact on social housing

The evaluation of the base model of VIS housing showed a significant environmental impact, reflected in a total of 3 109 076 millipoints according to Eco-Indicator 99 (table 3). This value represents the environmental load associated with the materials used in its construction, with components such as steel, ceramic brick, and acrylic paint standing out as those with the highest incidence.

Based on this diagnosis, two intervention proposals were formulated. The first, partial in scope, focused on replacing the internal walls with a lighter structure composed of wood, fiberglass insulation, and drywall. This modification, while retaining the rest of the original materials, allowed for a 0,6 % reduction in environmental impact, with an estimated savings of 11 835 millipoints compared to the initial model. The second proposal, on the other hand, involved a comprehensive redesign of the house with a sustainable approach. By integrating recycled materials with a lower environmental footprint, such as recycled PVC, polyaluminum, laminated wood, and cyclopean foundations, a reduction of 2 870 801 millipoints was achieved, equivalent to 92 % of the total environmental impact of the original model.

The benefits of these transformations become even more significant when projected on a neighborhood scale. If these measures were replicated in the 237 homes in the Carlos Pizarro neighborhood, more than 56 000 tons of waste could be avoided in a six-month period, a considerable figure when compared to the 270 000 tons produced monthly by a city like Bogotá. The following graphs provide a comparative view of the evolution of the environmental impact in each scenario. The curve corresponding to the original home reflects an increasing environmental burden during the construction process. In contrast, the curves for the improved homes show a clear downward trend, demonstrating the effectiveness of the proposed modifications.

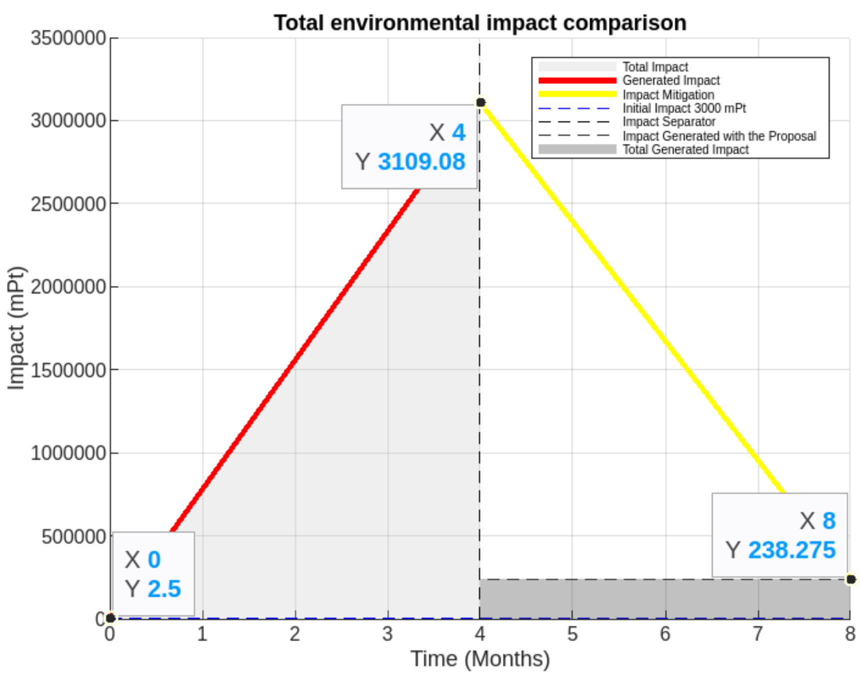

Figure 2. Environmental comparison of the total impact on both houses

On the other hand, the impact of each material is more significant in the current housing. The dotted line indicates the change of materials for those proposed, which demonstrate the mitigation of effects.

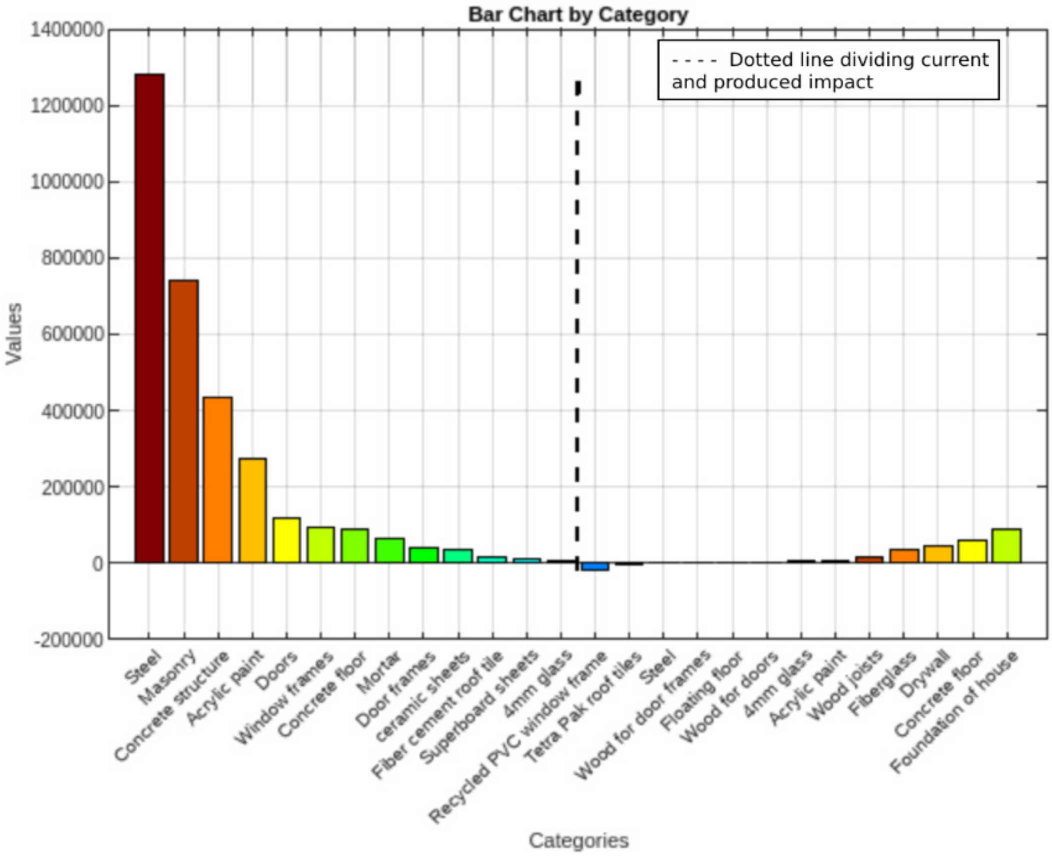

Figure 3. Analysis of the material impact on both houses

CONCLUSIONS

The environmental assessment of the social housing studied shows that it is possible to significantly reduce its impact through wise decisions in the design and selection of materials. Through Life Cycle Assessment (LCA) and the use of Eco-Indicator 99, the construction elements with the highest environmental impact were identified and sustainable alternatives were proposed that preserve the functionality of the living space.

The results obtained show that simply modifying certain components, such as internal walls, already generates measurable benefits, while a complete transformation of the housing can reduce the total environmental impact by up to 90 %. Additionally, the inclusion of systems such as rainwater harvesting and solar energy generation reinforces the comprehensive nature of the proposal. These solutions make it possible to reduce the consumption of conventional resources, generate energy surpluses, and promote more responsible management of the environment.

The implementation of photovoltaic systems yielded significant results in terms of energy efficiency. The capacity of the systems not only covered monthly domestic consumption but also allowed surplus energy to be fed into the electricity grid. This reinforces the added value of combining passive measures (sustainable materials) with active technological solutions (renewable energy).

It is recommended that future social housing initiatives incorporate environmental assessment tools, such as LCA, adapted to local conditions from the early stages. In the case of incorporating inputs not covered by Eco-Indicator 99, it is essential to assess their impact through energy analysis of the recovery and production processes. This approach—implemented in the present study for the case of paint recycling and the use of machinery—offers a reliable way to integrate new solutions.

Finally, this work proposes a replicable roadmap for other urban contexts in Colombia and Latin America, contributing to the evolution of social housing towards more sustainable, resilient models committed to collective well-being.

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