# Diagnosis and Analysis of the Economic and Socio-environmental Viability of Technologies and Alternatives for Sustainable Housing Construction

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**Abstract.** The work presents existing technologies/alternatives of materials, energy and water management that can be used for more sustainable buildings, helping to reduce costs and environmental impacts. The aim was to encourage the reduction of energy consumption, adequate water management and more sustainable material choices in new or existing buildings. For this, a diagnosis of existing technologies and alternatives in the mentioned themes and tested in fictitious studies was carried out in the first stage of the work. The second stage of the study consisted of analyzing among the technologies and/or alternatives diagnosed from the methodology which can be applied in a fictitious case study of housing, its implementation and/or maintenance and viability analyzing, finally, environmental indicators, social and economic. The results showed that the best evaluated technologies/alternatives were in Energy: ventilation and natural light; in water management: double-action sanitary basin, flow restrictors, aerators with constant flow, and minicistern systems; and in Materials: bamboo, wood, soil-cement brick, earth, steel frame and wood frame, aggregate with ash from rice husks, aggregate with ash from sugarcane bagasse, glass, phase change materials, aggregate with residues of construction and demolition, Portland cement and cement with blast furnace slag; which can be used in the civil construction sector, and provide socio-environmental and economic benefits, encouraging new studies and its for public/private buildings, aid in the elaboration of public policies to reduce costs and improve the quality of buildings.

**Keywords:** Sustainable construction · Technologies and alternatives · Socio-environmental viability · Economic viability · Housing

## 1 Introduction

Civil construction is one of the sectors that generates significant negative impacts on the environment. With the population growth and consequent increase in the demand of this sector, it is imperative that actions be taken that seek to minimize such


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environmental impacts and optimize processes. From this concern arises the sustainable construction, that is, the search for the adequate management of the built environment. Less shocking practices and greater responsibility for socio-environmental issues and even lower economic costs are initiated.

In this new panorama, several technologies and/or alternatives that seek to use the concept of sustainable in practice in civil construction apply. Some of these technologies are often are technically optimal, but with high cost, making it a work with a high cost and unfeasible. Others may be technically viable, but environmentally replacing them will not compensate for the extra expenses they may have, with an unfavorable payback time.

In this way, the study aims to diagnose and analyze existing/alternative technologies and materials, energy and water management that can be used for more sustainable buildings, helping to reduce costs and environmental impacts. The specific objectives are: to analyze the technologies in the mentioned themes (energy, water and materials management) and their application in the context of sustainable construction in dwellings and; analyze the costs of implementation and/or maintenance of the diagnosed technologies, their effectiveness and viability through economic, environmental and social indicators aimed at sustainable construction.

## 2 Methodology

A collection of data on existing technologies and/or alternatives in energy, water management and materials considered more sustainable was carried out. Subsequently, we analyzed the recurring difficulties among the several authors mentioned in this methodology, thus giving a list of parameters with items in each theme to be checked which are more suitable for application in buildings (existing and/or under construction). In this data collection, bibliographical, market research and technical visits were carried out, being registered and tested in sub-projects linked to this work that portray the results by survey themes. For each theme (energy, water and material management), specific calculations were used to select the most effective and feasible technologies for use and adaptation in single family homes, aiming at the application of the concept of sustainable construction, cost reduction and socio-environmental impacts. These calculations are described by theme, in following topics. After the application of the test methodology in each theme, a simulation of a single-family residence (fictitious case) was performed, using economic and socio-environmental indicators in each context, investment calculation and time of return, presenting the three themes in a single context which can be applied to a residence. As a case study, a fictitious residence was simulated that falls under the MCMV Program – My home, my life Program of the Federal Government of Brazil. The data of the fictitious residence, its characteristics, location and other details are described in the results of this work. It should be emphasized that this methodology can be adapted and its use directed and applied to other types of buildings since the exact dimensions and appropriate technologies for their simulation in each case, in Brazil and for other countries, are used.

### 2.1 Specific Calculations Used in Stage 01 of This Work in the Themes of Energy, Water and Materials for Sustainable Construction in Housing

**Energy.** From the theoretical reference, the selected energy alternatives to be analyzed were: natural lighting, natural ventilation, vegetation cover and photovoltaic system. The passive strategies (natural lighting and ventilation and vegetation cover) were selected due to the fact that they are important bioclimatic factors that should be considered in a Brazilian housing project, as well as the active strategy, the photovoltaic system, which has a great energy potential in throughout the territory. It was evaluated each of the alternatives, observing which would be more advantageous economically considering previously the following conditions:

**Wage Allocation:** In order to evaluate the energy savings by the residence, a simulation was performed assuming that the family would choose only one of the technologies in their dwelling, earmarking 5% of the salary for discharge of the implementation made and the energy consumed in the residence.

**Calculations:** The formulas used to evaluate the costs were:

$$Q = COST/(SM) \quad (1)$$

$$RE = (CEE \times M \times RCE)/100 \quad (2)$$

$$R = COST/RE \quad (3)$$

With: Q: Discharge time (month); COST: Cost of the evaluated alternative (R$); SM: Value referring to the percentage of the salary destined for the discharge of the alternative per month; RE: Energy bill reduction (R $/year); EEC: Value of the family's monthly electricity bill; M: Number of months during the year, 12 (months); CERs: Reduction of energy consumption (%); A: Return time (years). Source: Prepared by the authors. Based [7, 12–14].

**Water Management.** In order to determine which technologies would be most cost-benefit ratio - considering the costs of implementation, maintenance, time of return on investment (reduction of water consumption) and reuse of water, analyzes were carried out based on indicators of economic, social and environmental benefits. Economic feasibility calculations were performed only for equipment or alternatives whose market values could be determined or did not require highly qualified technical knowledge for their implementation. In order to do so, we considered the cost of acquisition of the equipment and the time of return of the investment, using the equation proposed by Hafner (2007):

$$TR = G/(C \, x \, E \, x \, p - G \, x \, r) \quad (4)$$

Where:
TR - return time (years); G - total costs of acquisition of equipment and installation (R$); C - total consumption by use of conventional equipment (Liters/month); E - water

savings rate generated by substitution; p - cost of drinking one liter of water; r - simple interest rate.

For the calculation of tanks systems, the analysis was performed in a different way, because for systems of use of gray and rainwater, it should be used to determine the time of return of the investment:

$$\mathrm{CMEE} = (\mathrm{PE} \times \mathrm{T} \times \mathrm{D} \times \mathrm{V}) \tag{5}$$

In which:
CMEE: cost of electric energy for the operation of the tank pump (R \$/month); PE - equipment power (kW); T - equipment operating time (h/day); D - number of days of operation of the equipment in the month; V - value of electric energy tariff consumed (R \$/kWh).

In this specific case, to calculate the time of return of tanks, hypothetical budgets have been made and the value of Cost of Maintenance of the Tank System (CMOM) has been defined, and the effective monthly economy (EE) can be calculated according to equation:

$$\mathrm{EE} = \mathrm{ER} - \mathrm{CMOM} \tag{6}$$

Where:
EE = Monthly Effective Economy; ER = Maintenance Costs of the Water Distribution Network; CMOM = Cost of Maintenance of the Tank System.

When considering that the cost of maintenance of the tanks will be negligible (the equipment will not need maintenance), we can consider CMOM = CMEE. Considering the effective monthly economy multiplied by 12 months, we obtained the annual effective savings (U), used to calculate the time of return. Finally, the equation proposed by Sella was used [15].

$$\mathrm{n} = \mathrm{P}/\mathrm{U} \tag{7}$$

In which:
n - return time (years); P - the value of the initial investment (R\$); U - the value of the annual savings portion (R\$).

In order to carry out the final analysis of the alternatives, a system of indicators (social, economic and environmental) was used to identify the best alternatives. Source: Prepared by the authors. Based [2, 9–11, 15].

**Materials.** Elaboration of a spreadsheet with the following parameters: 1. The durability of the material is reflected in the life and price, 2. The recycling is more expensive than the correct disposal and transport, 3. High availability, 4. Low maintenance, 5. 6. It consumes a lot of water, 7. It consumes a lot of energy, 8. It is renewable, 9. It is recycled or reused, 10. Easy to handle, 11. It works as a thermal and/or acoustic insulation, 12. It generates little residue, 13 14. The material has some specific environmental seal, 16. There may be a partnership with NGO's, cooperatives, non-profit associations, etc. 7. It needs a different material that can contaminate the construction site. Can be reused, 18. Possess some hazardous material in the composition, 19. Possess reverse logistics, 20. Requires more and/or other materials for the finish, 21. Visually pleasing when installed. These parameters were chosen in order to simplify the analysis of materials. Each response has a different value and, consequently, can result in a ranking that will be the result of the simple arithmetic mean of the scores assigned to each parameter contained in the table, with the values of each parameter being as follows; 5 (five) for excellent, 3 (three) for good, 1 (one) for regular, −1 (minus one) for bad and −3 (minus three) for does not exist.

$$M = \frac{\sum Parâmetros}{21} \tag{8}$$

Source: Prepared by the authors. Based [1, 3, 4, 6, 12–14, 16].

## 3 Results Obtained

The selection of a fictitious single-family residence in a home rather than an apartment type is due to the fact that it facilitates the application of technologies and/or alternatives, not only for the construction company, but also for its residents, respecting the technical and permissible security of the work, with the advantages presented by the technologies in this project in energy, water and materials management. The chosen residence of the MCMV Program used for this project was Band 2 - families with income of up to R$ 4,000.00 (four thousand reais). This selection aims to give effect to the project, since in the proposed methodology, families will be able to use 5% of their income to apply the technologies, if such improvements are made after family housing.

The fictional residence has 44.04 $m^2$, two bedrooms, living room, kitchen, bathroom and laundry. Aluminum frames, ceramic tile roof over metal structure, ceramic floor and space for enlargement of the work (land with an average of 160 $m^2$).

### 3.1 Applicable Energy Technologies

For a residence to have passive and active alternatives of energy, it is necessary to observe the variables important for its use and for its better use. In this sense, the selected and interesting strategies have the following parameters, maintenance and costs [8, 10, 12, 14]:

(a) Side windows (natural lighting and ventilation): it is necessary to check the latitude of the city, quantity and place of opening for the entrance of natural light and air exchange. Maintenance is poor when the design is done properly (cleaning or painting). There is no additional cost if correctly positioned in the design of a common residence;
(b) Extensive coverage (vegetation cover): it is necessary to observe the climate of the region, soil thickness, type of vegetation and other factors of the residence, as the type of cover. Irrigation and periodic trimming need to be carried out and their purchase and installation cost is measured in $m^2$, due care must be taken to avoid infiltration and mold creation;

(c) *Grid-tie* system for residence connected to the grid (photovoltaic system): Local climate check, the amount of energy to be saved, monthly residence consumption and energy tariff. It is not necessary to maintain it during its useful life (20 years) and the cost involves the purchase and installation of the system, which will depend on the amount of energy to be produced.

It is observed that the use of natural lighting and ventilation can be realized through the side windows, since even the simplest, contribute to the reduction of energy costs, increasing the thermo-energetic performance of the building. Installation of this component should be well planned in the design phase of the house. Thus, with the correct arrangement of these windows, it is possible to improve the environmental comfort of the users, providing better lighting, a healthier environment, and saving themselves with artificial mechanisms of ventilation, cooling and artificial lighting. For the fictitious residence hypothetically located in a city in the interior of the state of São Paulo, Brazil, the best guidelines regarding natural lighting are north and east, for the environments of greater permanence, being necessary a solar protection to the north and avoiding to be avoided the west side being very hot, and the south, for not very cold, while the direction of the prevailing winds are east and southeast [15], and it is interesting to place the window openings also close to this orientation.

The other passive strategy, the vegetal cover, is a structure that helps in the microclimate of the local region, promoting a greater integration of the residence with the natural environment. The cost of this technology was verified through two existing companies, one in Limeira (1) and the other located in São Paulo (2), the data are presented in Table 1.

**Table 1.** Assumed variables for plant cover.[a]

| Company | System components[a] | Value (R$/m$^2$) | Total (R$) |
|---|---|---|---|
| 1 | Complete component (module + substrate + plants + installation) | 200,00 | 8.804,00 |
| 2 | Component with manual for installation and without plants (module + substrate) | 100,78 | 4.436,33 |

[a]Variables - vegetation cover: City: Fake residence, State of São Paulo, Brazil. Type of Coverage: Slab. Dimension of the cover: 44, 04 m$^2$.
Source: Prepared by the authors. Based on [8, 14].

Finally, the active strategy chosen, the photovoltaic system, can achieve to economize of integral form the conventional electrical energy. In the Brazilian market there are companies that manufacture photovoltaic panels, but most of them only with a higher generation of kWh/month. The budget acquired through four Brazilian companies is presented in Table 2.

**Table 2.** Assumed variables for photovoltaic system.[a]

| Company | System components | Total (R$) |
|---|---|---|
| 1 | Generation of 150 kWh/month + installation | 17.000,00 |
| 2 | Generation of 210 kWh/month + installation | 21.300,00 |
| 3 | Generation of 250 kWh/month + installation | 35.780,88 |
| 4 | Generation of 245 kWh/month + installation | 25.290,00 |

[a]Variables - photovoltaic system: City: State of São Paulo, Brazil. Average consumption: 159 kWh/month. Average tariff: $ 0.37/kWh. Network: 127 V. System: single phase

Source: Prepared by the authors. Based [8, 14]

For the possible implantation of the vegetal cover the company budget was chosen of smaller cost, being that the family would follow the installation manual and could choose the vegetation to be planted, being able to even cultivate a small garden that would help in the complement of the feeding, generating a reduction in energy consumption of 2% (considering a residence with only fans, which use less energy). And the other deployment would be the photovoltaic system, being chosen the budget of

**Table 3.** Comparison of costs between the photovoltaic system and plant cover.

| Technology/power alternative | Cost (R$) | Approx. discharge time (Q) | Reducing power consumption (RCE) | Approx. return time (R) |
|---|---|---|---|---|
| Plant cover | 4.436,33 | 5,5 months | 2% | 272 years |
| Photovoltaic system | 17.000,00 | 21 months | 90% | 23 years |

Fonte: Elaborado pelos autores. Baseado [8, 14].

lower cost, which generates the power of 150 kWh/month, practically the family also consumes (159 kWh/month), considering a reduction in energy consumption of 90%. Considering the family income of R$ 4,000.00, the light bill for this consumption being R$ 67.96, and the allocation of the salary for discharge of the alternative of 20% over the months, one alternative at a time, the cost comparison between the photovoltaic system and vegetation cover is presented in Table 3.

**Indicators of Socio-environmental and Economic Feasibility of Energy Technologies.** Qualitative indicators were used to analyze energy technologies and alternatives, such as: (A) Reduction of the use of electric energy; (B) Reduction of expenses; (C) Reduction of greenhouse gas emissions; (D) Reduction of natural resources; (E) Passive use of natural resources; (F) Harmonization with the environment; (G) Better thermal comfort; (H) Better air quality and environment; (I) Health improvement; (J) Improvement in quality of life; (K) Increased energy efficiency; (L) Moderation of urban temperature; (M) Increase in the value of the property; (N) Low cost/maintenance technologies [8, 12, 14]. From these data it is possible to characterize them according to the economic, social and environmental benefits related to each energy alternative, as indicated in Table 4.

**Table 4.** Benefits of each technology and alternative in energy.

| Technology/power alternative | Benefits | | |
|---|---|---|---|
| | Economic | Social | Environmental |
| Natural lighting | A B K M N | G I J | C D E F H L |
| Natural ventilation | A B M N | G I J | C D E F H L |
| Plant cover | A B K M | G I J | C D F H L |
| Photovoltaic system | A B K M | – | C D E |

Source: Prepared by the authors. Based [8, 12, 14].

In this way, it can be observed that, in relation to general economic, social and environmental benefits, Natural Lighting and Natural Ventilation are the most advantageous alternatives, followed by the Plant Cover, serving most of the indicators.

### 3.2 Applicable Water Management Technologies

Among the equipment for water management, the following technologies can be excluded for application in this specific case of housing: vacuum sanitary basins, electric faucet with proximity sensor, reuse of gray water and reuse of rainwater by conventional cisterns [10].

Thus, in addition to the initial costs of construction, it is necessary to calculate the costs in its useful life and the return of the initial investment, according to the economy potential of the technologies and alternatives recommended [1]. Therefore, for each selected technology, we observed different variables such as market cost, water rate savings and time of return for each of them.

It is estimated that the implementation of the technologies and alternatives addressed in this work in homes will immediately reflect on their water consumption, consequently reducing the monthly expenses related to water and sewage.

The time period of return differs from a building constructed for one still under planning. For new buildings, this time of return is calculated by considering: the cost of acquisition and the consumption of conventional equipment, the cost of acquisition and the consumption of the saving equipment, the cost of possible adaptations needed in the project, the water savings generated by technologies and economizing alternatives, water/sewage tariffs and interest rates [17].

In the case of buildings already built, the economic benefit of replacing conventional equipment with economizers depends on local conditions. Thus, before applying this measure, it is recommended a technical and economic evaluation of the interventions necessary to change the system [17]. In the case of existing buildings, to analyze the advantages and feasibility of replacing sanitary equipment, it would be necessary to match the expected water saving and replacement cost [8]. This correspondence is also estimated by the time of return of the investment, that is, the time required for the cost of replacing the equipment to be offset by the reduction in collection due to the water savings generated by the new equipment [17,18]. To make a comparison between the equipment and technologies that allow to verify its economic viability, a calculation was made as explained in the methodology of water management [2]. In order to carry out the calculations, we will take the following considerations: the total gain of R$ 4,000.00 and a monthly allocation of 20% for purchase and installation of saving equipment, will be R$ 800.00 expenses for discharge of these expenses, being one equipment at a time.

Water consumption in the residence: for the water and sewage tariffs used, it will be considered the values will be R$ 22.38/month each, for consumptions of up to 10 $m^3$/month, according to SABESP (2018). A family of four people has water consumption of around 22 $m^3$. According to SABESP, water consumption between 20 and 30 $m^3$ per month adds R$ 8.75/month to residential tariffs. Therefore, we can consider that both families have a monthly total of R$ 62.26 with water and sewage tariffs.

For practicality of calculations, multiplication factor will be 2.20 [2], and the interest rate will be disregarded (null value of multiplication). The calculations will use the higher flow rate of the economizer equipment; sanitary basins with a total of 8 uses per day; taps with a total of 12 uses per day. Once these considerations have been made, it is possible to elaborate Table 5 which presents some comparative results.

**Table 5.** Comparison of technologies and equipment available in the water management market for fictitious residence.

| Comparative data | | | | | | |
|---|---|---|---|---|---|---|
| Equipment | Cost (R$) | | Economic consumption (L/use) | Convencional consumption (L/use) | Consumption savings (%) | Return time |
| | Unity | Total[a] | | | | |
| Double activated sanitary box | 151,90 | 151,90 | 3,5/6 | 12 | 50 | 1,675 months |
| Sanitary basin with gravity washbasin | 18.800,90 | 18.800,90 | 7,2 | 12 | 40 | Equation not applicable |
| Hydromechanical Faucet | 277,90 | 833,70 | 2,4 | 12 | 80 | 1,42 months |
| Flow restrictor | 26,90 | 80,70 | 7,2 | 12 | 40 | 0,082 months |
| Constant flow aerator | 15,79 | 63,16 | 4,8 | 12 | 60 | 0,047 months |

[a]The "Total" cost is the sum of values to replace all the equipment of the house by the models of lower consumption listed.

Source: Prepared by the authors. Based [2, 8, 10].

The equipment and technologies that are not included in the table are those for which no values were available in the market or whose characteristics are already present in other equipment (such as aerators for aerators of constant flow).

From Table 6 we can deduce, therefore, that in the case of hydrosanitary equipment or technologies that apply to them, almost all can be found at relatively affordable costs, with excellent rates of reduction of water consumption and with a very low turnaround time.

In the case of the sanitary basin coupled to the lavatory by gravity, the equation was not applicable, due to the high cost of purchasing the product, which led to a negative result.

To estimate the monthly water saving after the implantation of the rainwater harvesting system, we will consider the "Ready Tank" model. Considering the total area of the single-family dwelling of this project, 02 models of different volumes/values were suggested, being the KCP models of 3,000 and 5,000 L. Using the equations proposed in the project methodology, in the item water management, an effective annual savings of R$ 377.00 was achieved. For an approximation of the return time of the investment, the equation proposed by Sella [15] was used, as explained in the Methodology. Considering the estimated values in the market we have a return time of 20 to 26 years for the suggested models. It is evident, therefore, that a conventional tanker project takes too long a time for a return on investment. And this period can be higher or lower based on the rainfall regime and the accumulation of water in the reservoirs. On the other hand, mini-tank projects do not require complex works, nor materials of high costs, besides being constructed without needing some specific technical knowledge. Although the volume produced by a mini cistern is much smaller than that of a conventional design, it is enough to meet some needs, which gives it a low return time.

**Indicators of Socio-environmental and Economic Viability in Water Management Technologies.** The following qualitative indicators were presented that allow an analysis of water saving equipment and technologies: Reduction of Water Consumption (A); Reduction of Expenses (B); Water Utilization (C); Harmonization with Environment (D); Equipment/Low Cost Technology (E); Equipment/Low Maintenance Technology (F); Equipment/Technology Available in the Market (G); Equipment/Easy Installation Technology (H); Low Return Time (I). Having these indicators, one can then characterize the technologies and equipment according to their economic, social and environmental benefits, as shown in Table 6, below.

**Table 6.** Characterization of technologies, alternatives and equipment selected by qualitative indicators in water management with advantages/best return.

| Technology/Equipment water economizer | Benefits | | |
|---|---|---|---|
| | Environmental | Social | Economic |
| Double activation sanitary basin | A | D, G, H | B, E, F, G, I |
| Flow restrictor | A | D, G, H, I | B, E, F |
| Constant flow aerator | A | D, G, H, I | B, E, F |
| Rainwater reuse (Minicistern) | A, C | D, G, H, I | B, E, F |

Source: Prepared by the authors. Based [8, 10, 12, 13].

### 3.3 Applicable Materials Technologies

In order to assist in the best choice of materials to be used in the project we created a general ranking based on the items of the methodology to assist in the selection of more sustainable materials. Being: Bamboo: 3,57. Wood: 3.19. Soil-cement brick: 2,9. Earth: 2.71. Steel Frame and Wood Frame: 2.33. Aggregate with ash from rice husks: 2.14. Aggregate with ash from sugarcane bagasse: 2,14. Glasses: 2,14. Phase change materials: 2,05. Aggregate with Construction and Demolition Waste (RCD): 1.95. Portland cement: 1.86. Cement with blast furnace slag: 1,76. Cement with construction and demolition wastes: 1,76. Cement limestone powder: 1,76. Aggregate with unserviceable tire: 1.67. Mineral Inks: 1,57. Aggregate with red ceramic: 1,29. Aggregate with fly ash: 1.29. Aggregate with glass: 1,29. Steel or steel slag aggregate: 1.29. Plaster: 1,29.

**Indicators of Social-Environmental and Economic Viability of Materials Technologies.** Regarding the socio-environmental and economic feasibility indicators of the presented materials technologies, it is emphasized that it does not use the same energy and water management tables, but the table with parameters analyzed elaborated by Lima and Moraes [6].

The analyzed residence has a constructed area of 36.36 $m^2$, with a room with a width of 3.3 m and a length of 2.8 m; a kitchen with a width of 2.32 m and a length of 3.25 m; a room with a width of 3.3 m and a length of 2.8 m and another room with a width of 2.8 m and a length of 3.03 m and a bathroom with a width of 1.35 m and a length of 2.2 m; right foot of 2.50 m high.

The assumed amount of materials used in the residency was calculated based on the estimates applied by the sector together with the steps of the construction with the use of the materials raised according to the table in the sequence. However, because the finishes have a great variety, because they depend directly on the design project and the quality of the selected products, they are out of the scope of calculation. The fictitious residence consists of a total wall footage of 2.50 m high with 20 cm wide for traditional materials and 15 cm for sustainable materials, the total wall footage to be built in the residence has the total of 38.15 m, in this way it is also possible to define that the total amount of mortar required to perform the wall covering has a total of 52.36 $m^3$ of mortar. Another fixed value for both materials is the reinforced concrete for the floor, because for the construction of the same one must own 36.36 $m^2$ of reinforced concrete. Table 7 presents the survey of the quantity of sustainable materials needed for the execution of the work together with the probable values to be spent for the acquisition of the materials.

**Table 7.** Quantity of sustainable material for the execution of the work and its costs.

| Reinforced concrete 1:2 5:4 | | |
|---|---|---|
| Material | Quantity for work | Cost |
| Concrete | 3,52 $m^3$ | R$ 5.662,07 |
| Construction Iron | 7 bars | R$ 32,00 |
| **Concrete composition** | | |
| Material | Quantity for work | Cost |
| Cement | 221 Bags/$m^3$ | R$ 5.525,00 |
| Aggregate with ash form sugarcane bagasse | 19,9 $m^3$ | R$ 1,79 |
| Aggregate with Construction and Demolition Waste (RCD) | 23,9 $m^3$ | R$ 135,27 |
| **Cement and sand in trace 1:4** | | |
| Material | Quantity for work | Cost |
| Cement | 4,2 Bags/$m^3$ | R$ 105,00 |
| Aggregate with ash form sugarcane bagasse | 0,81 $m^3$ | R$ 0,07 |
| **Brick of 15 × 30 × 14 – Wall of 15 cm** | | |
| Material | Quantity for work | Cost |
| Soil-cement brick | 2.133 Units | R$ 2.133,00 |
| Mortar | 0,64 $m^3$ | R$ 3,20 |
| **1,5 cm thick wallcovering** | | |
| Material | Quantity for work | Cost |
| Mortar | 72,72 $m^3$ | R$ 363,60 |

Source: Prepared by the authors. Based [5, 6, 8].

The material list to which the methodology was applied does not contemplate all stages of execution of a work; the analyzed materials contemplate the stages of foundation, structure, closings and a small part of the finish. So it's not possible to fully stipulate the cost of a work. Therefore, to calculate the percentage of reduction of cost of the work were used standard values of construction costs and the reduction consistent with the steps in which the materials were analyzed.

Using the cost quantification method proposed by Tognetti (2018), which considers the basic unit cost (CUB) in the single-family category (R1) and the Indirect Benefits and Expanses (BDI), it qas possible to stipulate the value of the work in the low, medium and high standards.

In this way, the inputs required to calculate the value of the work are the CUB of State of São Paulo, Brazil, in category R1 for low standard R$ 1,318.10/$m^2$; for the average standard, R$ 1,635.01/$m^2$; for the high standard, R$ 1,953.31/$m^2$ and the BDI with the value of 20.11%, in possession of such information the values of the cost of the work with traditional and sustainable materials are represented in Table 8.

**Table 8.** Average costs of traditional and sustainable materials.

| Formula used | | |
|---|---|---|
| [(CUB * Construction Area) + items not included] * (1 + DBI) = Final Cost | | |
| Cost of traditional materials | | |
| Low | Medium | High |
| R$ 1.011.720,31 | R$ 1.254.967,62 | R$ 1.499.281,84 |
| Cost of sustainable materials | | |
| Low | Medium | High |
| R$ 946.687,94 | R$ 1.174.274,46 | R$ 1.402.879,52 |

Source: Prepared by the authors. Based [6].

The cost of the sustainable material work was increased and reduced according to the table below, based on the list of materials previously analyzed and the final cost of Table 9.

**Table 9.** Reduction values and additions and equivalence of the work.

| | Foundation | Structure | Coating |
|---|---|---|---|
| | Low | | |
| Equivalent percentage of construction cost | R$ 50.586,02 | R$ 161.875,25 | R$ 146.699,44 |
| Reduction value (Green) Addition value (red) | R$ 12.570,62 | R$ 28.457,67 | R$ 80.919,41 |
| | Medium | | |
| Equivalent percentage of construction cost | R$ 62.748,38 | R$ 200.794,82 | R$ 181.970,31 |
| Reduction value (Green) Addition value (red) | R$ 15.618,07 | R$ 35.299,73 | R$ 100.374,82 |
| | High | | |
| Equivalent percentage of construction cost | R$ 74.964,09 | R$ 239.885,09 | R$ 217.395,87 |
| Reduction value (Green) Addition value (red) | R$ 18.658,56 | R$ 42.171,80 | R$ 119.915,56 |

Based on a 20% investment, a family income of up to R$ 4.000,00 and with the subsidy of R$ 29.000,00 from the Minha Casa Minha Vida program, the payback calculation was performed for all the scenarios mentioned above in Table 9 and are presented in Table 10.

**Table 10.** Payback values of sustainable materials technologies.

| | Foundation | Structure | Coating |
|---|---|---|---|
| | Low | | |
| Equivalent percentage of construction cost | R$ 50.586,02 | R$ 161.875,25 | R$ 146.699,44 |
| Payback with maximum allowance Minha Casa Minha Vida (years) | 2,25 | 13,84 | 12,26 |
| | Medium | | |
| Equivalent percentage of construction cost | R$ 62.748,38 | R$ 200.784,82 | R$ 181.970,31 |
| Payback with maximum allowance Minha Casa Minha Vida (years) | 3,52 | 17,90 | 15,93 |
| | High | | |
| Equivalent percentage of construction cost | R$ 74.964,09 | R$ 239.885,09 | R$ 217.395,87 |
| Payback with maximum allowance Minha Casa Minha Vida (years) | 4,79 | 21,97 | 19,62 |

Source: Prepared by the authors. Based [6].

## 4 Conclusions

With respect to energy technologies, comparing the results of the proposed technologies with the social, environmental and economic benefits, it is possible to observe that for a Brazilian family the most viable technologies are natural lighting and ventilation. Vegetable cover is still a process that does not have a tangible financial return, but it should be noted that it provides greater thermal comfort, improved ambient air quality and population. Finally, photovoltaic energy can be considered an expensive process in Brazil, which may be more feasible in other countries, and that needs more studies and financing, seeking to be more developed and used, but can be used depending on income family.

With regard to water management technologies, this work has demonstrated several technologies and equipment to reduce water consumption in buildings, as well as alternatives to provide water from other sources for non-potable uses. Thus, it can be concluded that the equipment/alternatives that present the most benefits are: double-action sanitary basin, equipment with flow restrictors, aerators (conventional and with constant flow) and mini-tank system, presents the same characteristics of a conventional cistern and more comfortable dimensions for the urban environment.

With respect to material technologies the methodology has shown that it can be applied with ease. In this theme the most advantageous technologies/alternatives were: bamboo, wood, soil-cement brick, earth, steel frame and wood frame, aggregate with ash from rice husks, aggregate with ash from sugarcane bagasse, glass, phase, aggregate with construction and demolition waste, Portland cement and blast furnace slag cement. The analysis of the use of sustainable materials can be performed by stage of the work and thus benefit the three pillars of sustainability.

The adoption of more sustainable constructions is somewhat increasing. Many of the construction companies in Brazil have adhered to several more sustainable practices, either for awareness or even for the benefits they have noticed in this new phase of the construction industry. Another trend is environmental certifications for sustainable buildings, which shows that such a change in the sector is a path that tends to consolidate, thus helping the application of energy technologies, water and materials management, as well as other themes, bringing opportunities for the emergence of new technologies and/or enhancement of existing ones, and still add value.

It should be emphasized that the work also sought to assist the reflection of the civil construction sector with a view to more sustainable actions and practices linked to the UN Sustainable Development Objectives, Agenda 2030, which we can exemplify in this sector: ODS6 - Water and Sanitation for all; ODS 7 - Accessible and clean energy; ODS 9 - Industry, innovation and infrastructure, ODS 11 - Sustainable cities and community and ODS 12 - responsible consumption and production.

Finally, this work aims to encourage new studies and the use of more sustainable technologies and/or alternatives, which can be applied in addition to housing in other public/private buildings and in the aid of the elaboration of public policies to reduce costs and improve quality of buildings with a view to more sustainable construction.

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