Analysis of energy saving in a single-family home project

A A Macgregor¹, R J Gallardo¹, and J A Gómez Camperos²
¹ Grupo de Investigación en Construcción, Geotecnia y Medio Ambiente, Universidad Francisco de Paula Santander, Seccional Ocaña, Colombia
² Grupo de Investigación en Nuevas Tecnologías Sostenibilidad e Innovación, Universidad Francisco de Paula Santander, Seccional Ocaña, Colombia
E-mail: aamacgregort@ufpso.edu.co, rjgallardoa@ufpso.edu.co

Abstract. Electric energy is one of the types of energy that is most present in the activities that human beings carry out daily, hence the importance of making efficient consumption of this resource, especially that which is done in homes, since energy savings represent a reduction in carbon dioxide emissions. Given that the construction sector can represent up to 39% of the carbon dioxide emissions emitted into the atmosphere, this research analyzes the impact generated by the construction and use of a single-family home, with the use of DesignBuilder software. Initially, a model was made under traditional conditions, thus determining where the greatest heat gains were concentrated, followed by a second model under adjusted conditions. A life cycle analysis was made under conditions adjusted to a period of 100 years and the submission of the two conditions to the choosing by advantages method. The results showed that the changes can reduce annual energy consumption by up to 66% and recover the investment in 10 years. Finally, the analysis of the life cycle determined that for a period of 100 years the emissions are 18679.67 equivalent tonnes of carbon dioxide.

1. Introduction

At present, there is a concern about the growth model that is being developed around the world, since with the accelerated increase in the world population, the increase in consumption has been directly proportional, leading as a result to significant changes on planet earth such as deforestation, scarcity of water, natural resources and food, extinction of animals and long periods of floods and droughts. The construction industry significantly affects the environmental field since it impacts natural resources and ecosystems, in the same way the social field, because it impacts the health and quality of life of people, likewise the economic field because it provides sources income as well as infrastructure.

The construction sector is one of the sectors that contributes significantly to the carbon footprint generated by humanity, representing up to 39% of the carbon dioxide (CO₂) emissions emitted into the atmosphere [1-3], in order to stop this problem, strategies have been created that seek to use materials that generate less environmental impacts [4]. One way to quantify the impacts on the construction of a project before executing it is the development of specialized software models, in this case through the DesignBuilder software [5,6], which was used to determine the energy-thermal performance of this project a two-level single-family house through an integrated design, where initially an analysis of the geometry of the structure was made, followed by the materials and internal loads defined such as the equipment and occupants, later the evaluation and analysis of results was made to create and implement strategies in a new model with which is expected to obtain favorable results.
At present, the circular economy has taken on great importance and with this, it has begun to speak on a large scale of the life cycles of a product and a project, the first is denoted as the consecutive and interrelated stages of the system of a product, from the acquisition of raw materials or generation from natural resources until their final disposal [7] and the second as the set of phases in which a project is organized from its inception to its closure [8]; in general terms we can say that the life cycle of a project is contained in the life cycle of a product, this is how a life cycle analysis for housing was subsequently carried out [9-11], based on Environmental declarations of products for 100 years of the useful life of the infrastructure, identifying the CO₂ equivalent emissions of each product necessary for the construction of the house and the quantities necessary to quantify the total emissions. Since every project can be developed from multiple alternatives, the evaluation of these can be done from many methods that allow an objective, efficient and effective selection, for this case two alternatives were evaluated using the choosing by advantages (CBA) method [12], complemented with a cost study, analyzing the return period of the investment of the selected alternative.

2. Methodology
For the development of the project, it was necessary to follow the procedure outlined in Figure 1.

![Figure 1. Processes for research development.](image)

Initially, the type of project is defined, as well as the materials and loads for the initial study conditions, this research was carried out taking as a reference a two-level single-family house built with traditional materials, loaded the respective specifications in the DesignBuilder software, we proceed to Execute the model, the results are analyzed in order to identify where the greatest heat gains are concentrated and thus be able to plan the respective strategies that lead to improve the initial conditions, the highest concentrations of heat in this project are found in lighting Therefore, the respective changes are focused on changing the type of luminaires as well as the installation of the ceiling in the slabs of the building, once the respective adjustments have been made, the model is executed for the second time, expecting significant changes in heat losses and gains, later we proceed to do an life cycle analysis (LCA) through the use of materials with their respective environmental product declaration (EPD), this analysis was developed considering a period of life of the property of 100 years. To know another result parallel to the models, the two alternatives were subjected to a selection method by advantage in which it was necessary to define some factors, criteria, and weighting values for each of the factors to be considered. Finally, a cost analysis is carried out to know what the return period of the investment is made by the adjustments of alternative 2.
3. Results
The analysis project was a two-level structure, for single-family residential use, see Figure 2; the model in initial conditions was raised under basic construction conditions using materials that have an environmental declaration, as well as equipment and appliances for general use, to know the behavior of heat gains and losses in this type of structure.

In Figure 3 we can see how the highest heat gains in the home are obtained through lighting, cooling, and operation of equipment with values of 56.76 KW·h/m², 41.84 KW·h/m², and 4.06 KW·h/m² respectively, these variables are those that must be evaluated and improved with significant changes, due to the climate conditions of the region (Temperate). The model in tight condition was executed by adjusting, including installing a drywall ceiling on both levels of the house, in addition to changing the type of lighting in the building, with the aim of optimizing heat gains and losses in the structure.

In Figure 4 you can see the considerable reduction in heat gains due to changes in the structure. The values are 37.84 KW·h/m², 41.08 KW·h/m² and 4.06 KW·h/m² respectively, achieving a 66% reduction in the energy of the luminaires, in the other two aspects they remain constant.

Life cycle analysis (LCA) is a tool that allows quantifying the impacts generated by the manufacture of a product at all times of its useful life [13]. LCA results are used to classify products according to their emissions, thanks to the environmental product declarations (EPD) [14-16]. DAPs are voluntary declarations where environmental information about the life cycle of a product is disseminated, for the
evaluation of the life cycle of the single-family home under study, EPD published in [17] were used, taking into account the emissions of CO\textsubscript{2} equivalent for 100 years of useful life of the house, in Table 1 you will find the list of materials, their EPD registration number, their study unit and the emissions generated in each activity.

Additionally, the emissions generated by electricity consumption of the selected alternative were considered, by means of a greenhouse gas calculator the annual consumption of 83.73 KW·h/m\textsuperscript{2} was transformed into 2326.53 Kg CO\textsubscript{2} equivalent, with this it was possible to determine that the emissions generated by the construction and use of the house for a period of 100 years is 25133.04 Tons of CO\textsubscript{2} equivalent.

### Table 1. Construction materials LCA [17].

| Material          | EDP registration number | Study unit     | CO₂ equivalent * Study unit | Quantity | Total emission |
|-------------------|-------------------------|----------------|-----------------------------|----------|----------------|
| Steel             | S-P-00704               | Ton            | 605.00                      | 3.65     | 2209.53        |
| Concrete          | S-P-00896               | M\textsuperscript{3} | 2.67E+02                    | 30.67    | 8189.90        |
| Ceramics          | S-P-01310               | M\textsuperscript{2} | 25.00                       | 108.27   | 2706.75        |
| Stucco            | S-P-00584               | KG             | 1.13E-01                    | 757.84   | 85.64          |
| Brick             | S-P-00750               | 3731 bricks    | 2.83E+02                    | 0.97     | 273.22         |
| Roof sheet for over roof | S-P-00429          | M\textsuperscript{2} | 3.30E+02                    | 63.77    | 394.23         |
| Mortar            | S-P-00897               | M\textsuperscript{3} | 1.42E+02                    | 4.32     | 613.44         |
| I stick ceramic   | S-P-1677                | KG             | 3.38E-01                    | 360.90   | 122.00         |
| Painting          | S-P-01853               | M\textsuperscript{2} | 4.28E-01                    | 287.98   | 123.26         |
| Wooden door       | S-P-01392               | UND            | 2.00E+02                    | 8.00     | 1600.00        |
| Pressure pvc pipe | S-P-00718               | KG             | 4.54776                     | 11.20    | 50.93          |
| Sanitary pvc pipe | S-P-00716               | KG             | 3.7004818                   | 52.82    | 195.46         |
| Windows           | S-P-01749               | UND (1230 mm×1480 mm) | 352.55180                   | 6.00     | 2115.31        |
| Kg CO\textsubscript{2}eq |                |                |                             |          | 18679.67       |

The different alternatives are generally proposed in order to satisfy the context and the purpose for which they were created. One of the methods used in the market is to choose by advantages or the better-known CBA Method [18-20], which initially consists of in generating factors to which an importance criterion will be assigned later, defining the factors and criteria, the attributes of each of the proposals are compared, indicating the variables of significance for each of them, each of the attributes was initially rated in order of importance, the next step is to assign the rating to each of the proposals.

Table 2 shows the analysis carried out by the CBA method for the selection of the best alternative for the Housing project. The analysis is made from the evaluation of criteria such as innovation, investment of economic resources, duration of each Project, temperature oscillation, the comfort of the property, the losses and gains of heat, and the most important criterion, the consumption of annual energy of each of the alternatives. Alternative 2 exceeds the level of significance to alternative 1 since the highest weighting of the factors was assigned to the annual KW electricity energy consumption factor, which was decisive for the selection, where alternative 2 obtained a value of 250 points versus alternative 1 that only reached a value of 150 points respectively, which confirms the provisions of the previous models made with the DesignBuilder software, but from another perspective.

The respective budgets of each of the alternatives were developed independently, obtaining as a result that the adjustments of alternative 2 had an extra cost in relation to alternative 1 in a value of $7,602,060 Colombian pesos (COP). As indicated in [21,22], Figure 6 shows the analysis of costs and the payback period [23], for the investment made. The initial investment with which it is expected to generate a reduction of 18.92 KW·h/m\textsuperscript{2} has a return period of 10 years, since the income is of a linear type with a value of COP 760,206, achieving a balance in said evaluated time; from year 11 only income is generated. Taking a construction life span of 100 years, income of COP 76,020,600 is achieved.
Table 2. Choosing by advantages method for project.

| Factor / Criterion | Alternative 1 Housing in initial conditions | Alternative 2 Housing in final conditions |
|--------------------|---------------------------------------------|------------------------------------------|
| Innovation         | Greater use in buildings                    | Less use in buildings                     |
| Less is better     | Less frequent use of technology             | More frequent use of technology           |
| Investment ($)     | Lower investment                            | Greater investment                        |
| Less is better     | Investment cost reduction                   | Increased investment costs                |
| Employment (Days)  | Shorter duration of the work                | Longer duration of the work               |
| Less is better     | Shorter duration in activities              | Moderate duration in activities           |
| Oscillation (%)    | Greater oscillation                         | Less oscilliation                         |
| Less is better     | Greater oscillation in the T°               | Less oscillation in the T°                |
| Comfort (%)        | Nonconformity                               | Nonconformity                            |
| Greater is better  | Less comfort                               | Greater comfort                          |
| Loss / Gain (KWh/m²)| Greater losses                             | Lower losses                             |
| Less is better     | Reduction of energy gains                   | Greater energy gains                      |
| Annual consumption of (KWh/m²) | Higher Consumption | Lower consumption |
| Less is better     | Greater consumption of electrical energy    | Reduction in the consumption of electrical energy |
| TOTAL              | 150                                         | 250                                      |

Figure 5. Cost analysis.

4. Conclusions
With the completion of the life cycle analysis, it was possible to see how, in the short term, the emissions generated by the construction of alternative 1 are lower due to the fact that fewer materials are used for its construction, but when analyzing the 100-year useful life of the housing the use of the improvements reduces the emissions of Kg of carbon dioxide equivalent by 17%. Additionally, with the implementation of the changes in alternative 2, it was possible to obtain a reduction of 66% in annual energy consumption in the property.

Applying the choosing by advantages selection method, alternative 2 exceeds alternative 1 by twice the significance value, because in this analysis the reduction in equivalent Kg of carbon dioxide emissions was of greater importance. The results obtained allow us to verify how the implementation of small changes in the construction of the houses manages to significantly reduce the emissions generated and therefore convert a normal construction into a sustainable one. The above indicates the need to promote responsible energy consumption, through the implementation of improvement processes in the construction sector, so that a contribution is made to the environment with the reduction of carbon dioxide emissions and the reduction of costs in the value of electrical energy consumption. Future research is expected to extend the analysis to educational, industrial, and commercial construction projects.
References
[1] García J, Quito J C, Perdomo J 2020 Análisis de la Huella de Carbono en la Construcción y su Impacto Sobre el Ambiente (Villavicencio: Universidad Cooperativa de Colombia)
[2] Guerrero A, Marrero M, Martín J 2016 Incorporación de huella de carbono y huella ecológica en las bases de costes de construcción. Estudio de caso de un proyecto de urbanización en Écija, España Hábitat Sustentable 6(1) 6
[3] Mercader M, Ramírez A, Olivares M 2012 Modelo de cuantificación de las emisiones de CO2 producidas en edificación derivadas de los recursos materiales consumidos en su ejecución Informes de la Construcción 64(527) 401
[4] Bribián I, Usón A, Scarpellini S 2009 Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification Building and Environment 44(12) 2510
[5] García-Alvarado R, González A, Bustamante W, Bobadilla A, Muñoz C 2014. Características relevantes de la simulación energética de viviendas unifamiliares Informes de la Construcción 66(533) e005
[6] Mahmoud A, Asif, M, Hassanain M, Babail M, Sanni-Anibire M 2017 Energy and economic evaluation of green roofs for residential buildings in hot-humid climates Buildings 7(2) 30
[7] International Organization for Standardization (ISO) 2006 Environmental Management-Life Cycle Assessment-Requirements and Guidelines, ISO 14040 (Switzerland: International Organization for Standardization)
[8] Kim C, Kim J, Hong T, Koo C, Jeong K, Park H 2015 A program-level management system for the life cycle environmental and economic assessment of complex building projects Environmental Impact Assessment Review 54 9
[9] Mitchell J, Arena A 2000 Evaluación ambiental comparativa de materiales mampuestos aplicados en muros de viviendas en regiones áridas andinas Avances en Energias Renovables y Medio Ambiente 4 87
[10] Acosta D 2009 Arquitectura y construcción sostenibles: conceptos, problemas y estrategias Dearq Revista de Arquitectura 4 14
[11] García F, Armengot J, Ramirez G 2015 El análisis del coste del ciclo de vida como herramienta para la evaluación económica de la edificación sostenible. Estado de la cuestión Informes de la Construcción 67(537) e056
[12] Arroyo P, Herrera R, Salazar L, Giménez Z, Martínez J, Calahorra M 2018 Un nuevo enfoque para la integración de factores ambientales, sociales y económicos para evaluar mezclas asfálticas con y sin neumáticos de desecho Revista Ingeniería de Construcción 33(3) 301
[13] Ros T, et al. 2011 Impactos ambientales del ciclo de vida de las baldosas cerámicas: análisis sectorial, identificación de estrategias de mejora y comunicación (I) Piscinas XXI 235 62
[14] Sánchez O, Cardona C, Sánchez D 2007 Análisis de ciclo de vida y su aplicación a la producción de bioetanol: una aproximación cualitativa Revista Universidad EAFIT 43(146) 59
[15] Benveniste G, et al. 2011 Análisis de ciclo de vida y reglas de categoría de producto en la construcción. El caso de las baldosas cerámicas Informes de la Construcción 63(522) 71
[16] Ibáñez-Flórez V, et al. 2016 Environmental product declarations: exploring their evolution and the factors affecting their demand in Europe Journal of Cleaner Production 116 157
[17] The International EPD® System 2020 The International EPD® System (Suecia: The International EPD)
[18] Salgin B, Arroyo P, Ballard G 2016 Explorando la relación entre los métodos de diseño lean y la reducción de residuos de construcción y demolición: tres estudios de caso de proyectos hospitalarios en California Revista Ingeniería de Construcción 31(3) 191
[19] Arroyo P, Tonnemelín I, Ballard G 2015 Comparing AHP and CBA as decision methods to resolve the choosing problem in detailed design Journal of Construction Engineering and Management 141(1) 04014063
[20] Briosi X, Calderón-Hernández C 2019 Improving the scoring system with the choosing by advantages (CBA) elements to evaluate construction-flows using BIM and lean construction Advances in Building Education 3(2) 9
[21] Salazar W, Montoya D 2014 Los costos ambientales en la sostenibilidad empresarial. Propuesta para su valoración y revelación contable Contaduría Universidad de Antioquia 65 173
[22] Cordero S, Montenegro R, Maña M, Burgués I, Reid J 2006 Análisis de Costo Beneficio de Cuatro Proyectos Hidroeléctricos en la Cuenca Changuinola-Teribe (Panamá: The Nature Conservancy)
[23] González C 2012 Análisis de Costos de Operación y Mantenimiento en Edificios de Oficinas con Parámetros Leed Implementados (Bogotá: Universidad de los Andes)