# Life cycle energy assessment of a light steel framing house in Brasilia city

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ABSTRACT: The building sector is responsible for the majority of the energy and materials consumed in the world. Social housing plays a significant responsibility in consumption of resources in Brazil. In this context, this paper aims to evaluate the energy consumption during the life cycle of two social housing for Brazilian context. It was compared a brick masonry house (BM), the most used system in country, with a light steel framing house (LSF). For this, the life cycle energy assessment (LCEA) was used, with a cradle to grave perspective (construction, use and end-of- life were assessed). It was evaluated the relation between the thermal performance of systems and energy in operational phase. It was used the software DesignBuilder with the Energy Plus for thermal and energy simulation. This case study showed that the BM house presented greater energy consumption than LSF house. The wall system presented the biggest participation in terms of mass and embodied energy, for both houses. The operational phase showed the biggest participation in total energy consumption followed by the maintenance and construction phase. The end-of- life phase showed participation lower than 1% in total life cycle. The BM house presented a better thermal performance than the LSF house, however, the final results in operational phase for both houses became very close, with low values of energy savings.

***Keywords*** *LCEA, social housing, light steel framing.*

## 1. INTRODUCTION

The building sector is responsible for great energy and materials consumption worldwide as well as $CO_2$ emissions. Residential buildings play a significant role in consumption of energy and emissions of $CO_2$. The residential buildings in Brazil were responsible for the use of 24.2% of the electricity in the country and the consumption increased by 6.2% between 2013 and 2014 (BEN 2014).

There is a deficit of homes in Brazil and to deal with this problem, the Brazilian government has started up a large program for social housing (Paulsen & Sposto 2013). For this kind of social housing the most used system is brick masonry (BM). However it is necessary to use new building systems, more rational and more productive.

In the last 20 years, there were appeared some new building systems in Brazil, called innovative system, with the promise of increase in the productivity and quality of the residential sector. An example is the light steel framing (LSF) system.

The light steel framing system was imported from the USA and its use is becoming increasingly widespread in the country, because of the higher productivity and less generation of waste of building materials. However, it is necessary to define some environmental criteria to help the designers, architects and engineers to specify more environmental sustainable systems.

In this context, the Life Cycle Assessment (LCA) is an important tool to help the environmental evaluation of building materials, systems and the whole building. LCA evaluates several resources inputs, including energy, water and material consumption, and environmental loads, including $CO_2$ emissions, liquid and solid wastes of a product or a process (ABNT NBR ISO 14001:2009). However, it has been observed that the most of the research about LCA and buildings has focused on the energy consumptions (Cabeza et al. 2014). In this context, more specific tool like Life Cycle Energy Assessment (LCEA) has been developed.

LCEA is a simplified version of LCA which focuses only on the evaluation of energy inputs for different phases of the life cycle of a building (Tavares 2006). The system boundaries include the energy use of: construction, use and demolition. The construction phase includes manufacturing and transportation of building materials and products. The use phase includes the operation and maintenance of the building. The operation phase encompasses all activities related to the use of the buildings, like comfort conditions, water use, and powering appliances. The demolition phase includes demolition/deconstruction of the building and transportation of dismantled materials to landfill sites or reuse, recycling/incineration plants (Chau et al. 2015).

In this context, the aim of this is study was to evaluate the energy consumption, using LCEA methodology, during the life cycle of two social housing in the Brasilia city context. Two alternatives of walls system were compared: Brazilian conventional brick masonry (BM) and light steel framing (LSF), over the entire life cycle of the buildings (construction, use and end-of-life phases).

## 2. METHODOLOGY

### 2.1 Description of the building, scope and functional unit

The building has a living room, 2 bedrooms, a kitchen, a bathroom and an outdoor service area. The building has three internal doors, two external doors and five windows (Fig. 1).

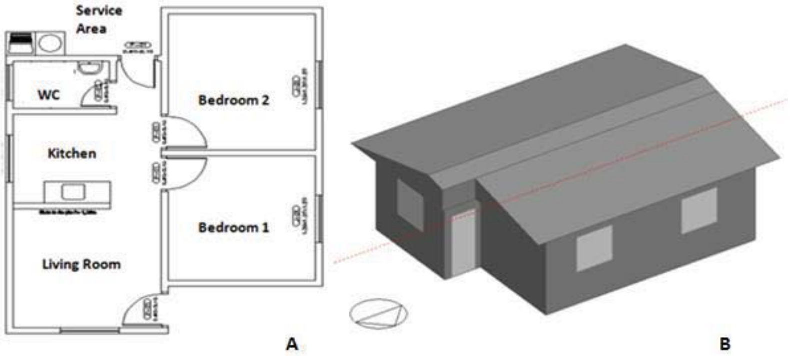

Figure 1. (A) Plant design and (B) DesignBuilder model of the case study. Source: Authors, 2016

The Brazilian conventional wall system (BM) is brick masonry (90 x 190 x 190 mm) with plaster (width 25 mm) and reinforced concrete columns and beams. The wall system with light steel framing (LSF) is galvanized steel frames with 2 OSB boards (width 18.3mm), 1 gypsum fibre board in internal area (width 12.5 mm), 1 Fibre cement board in external area (width 10 mm) and a insulation layer with rock wool (width 50 mm).

The data are cradle to grave data, including: extraction and processing of raw materials, transportation of the building materials from factories to the site location, operation of the building, maintenance and end-of-life, according to Table 1.

Table 1. Phases in the life cycle of the house

| Phase | Stage | Symbols | Description |
|---|---|---|---|
| Construction | Extraction and Process | EE | Embodied energy of building materials |
| | Transport | ET | Energy of transport from factories to site location |
| Use | Operational | EO | Energy of electrical equipments and for cooking |
| | Maintenance | EM | Energy of maintenance |
| End-of –life (post use) | Demolition/Deconstruction | ED | Energy of demolition or deconstruction of house |
| | Waste Transport | ETw | Energy of transport of waste from site location to landfill |
| Whole life cycle | All stages | ETOT | Sum of Energy of all stages of the house life cycle |

The Functional unit (FU) for this study is a standard house located in Brasília – DF, with 4 habitants and an internal floor area of 46 m$^2$ with the service life of 50 years. It was chosen 50 life years because it was observed most of LCEA studies used this period, like observed by (Berggren et al., 2013). The foundation is not included in the study, because it depends of the characteristics of the soil.

## 2.2 Construction phase analysis

Embodied energy (EE), in the stage of extraction and processing of building materials, was found through literature studies (Table 2). Embodied energy for light steel framing was found through Environmental Product Declarations (EPDs). The mean value from values in EPDs was adopted for some components. The hybrid method analysis was used in this study. According to Atmaca & Atmaca (2015), this method is generally considered the preferred approach for LCEA studies due to its systemic completeness and use of reliable data. The spillage of building materials, during the construction process, was considered (Table 2). The energy for the working process was assumed to be mainly performed by hand, so, it was not considered in this study.

In Brazil, the common type of material transports is by truck. Nabut Neto (2011) developed a study with several types of trucks used in Brazil and reached an average value of 0.0137 l diesel/t.km, considering truckloads on the outward path (from factory location to the construction site) and empty on the path back. Knowing one liter of diesel is equivalent to 35.50 MJ (BEN, 2014), the coefficients 0.49 MJ/t.km was found. The transports distances (Table 2) were calculated by Google Maps, considering the shortest distance between the construction site and the building material producers.

Table 2. Data on building materials and content in the studied house (46 m$^2$)

| Building components | Amount (kg/FU) | Embodied energy intensity (MJ/kg) | Source | Spillage (%) | Transport Distances (km) |
|---|---|---|---|---|---|
| | | | Brick Masonry | | |
| Ceramic blocks | 165.3 | 2.9 | Tavares (2006) | 15% | 917 |
| Mortar,plaster | 375.5 | 2.1 | Nabut Neto (2011) | 20% | 29.7 |
| Concrete | 64.1 | 1.2 | Tavares (2006) | 9% | 16.8 |
| Wood | 6.9 | 9 | Tavares (2006) | 10% | 75 |
| Steel | 2.9 | 30 | Tavares (2006) | 10% | 843 |
| | | | Light Steel Framing | | |
| Steel | 14.3 | 30 | Tavares (2006)] | 10% | 16.9 |
| OSB board | 71.2 | 10.6 | Tavares (2006)] | 15% | 1298 |
| Gypsum fibreboards | 49.1 | 4.4 | Tavares (2006)] | 9% | 1195 |
| Fibre cement board | 44.4 | 2.4 | Tavares (2006)] | 9% | 213 |
| Rock wool | 6.4 | 16.5 | Tavares (2006)] | 5% | 1014 |
| | | | Other systems of the house | | |
| Paint (internal and external walls) | 4.9 | 61 | Tavares (2006)] | 15% | 224 |
| PVC (installations) | 3.60 | 80 | Tavares (2006) | 5% | 165 |

| | | | | | |
|---|---|---|---|---|---|
| Ceramic tile (roof) | 67.1 | 5.4 | Tavares (2006) | 10% | 337 |
| Wood (roof) | 17.2 | 0.5 | Tavares (2006) | 4% | 687 |
| PVC (ceiling) | 2.4 | 80 | Tavares (2006) | 5% | 225 |
| Cement (floor) | 14.2 | 3.17 | Tavares (2006) | 20% | 30 |
| Sand (floor) | 69.22 | 0.05 | Tavares (2006) | 20% | 277 |
| Ceramic tile (floor) | 10.9 | 6.2 | Tavares (2006) | 6% | 740 |
| Windows and external doors (steel) | 14.4 | 30 | Tavares (2006) | 2% | 214 |
| Internal doors (wood) | 8.6 | 9 | Tavares (2006) | 1% | 222 |

### 2.3 Use phase analysis

*Operational*

The operational energy (EO) was divided in three parts: electricity used for equipments (excluding air conditioning), gas used for cooking and energy used for air conditioning (calculated with regards to the thermal performance of the building). For the electricity consumption for equipments the value 161 kWh/month was adopted, the same value of [3], or 6.9 GJ per year.

For the simulation of heating/cooling the U-value used for the ceramic block masonry wall was 2.25 W/m$^2$.K and the value 0.29 W/m$^2$.K was used for the light steel framing wall. For Windows the value 5.6 W/m$^2$.K was used. The cooling set-point was set to 24.3°C for the living room, according to the comfort zone, defined by Pereira & Assis (2010), valid for city of Brasília. The machine efficiency (CoP) adopted was 2.8, a common value for this kind of houses in Brazil.

EnergyPlus through DesignBuilder v4.5.0.148 interface was used to evaluate the impact of variations of the external and internal walls on annual energy use of the building related to thermal comfort.

The energy use for air conditioning was 101.63 kWh/year for the BM house and 162.15 kWh/year for the LSF. The final energy use for equipments and air conditioning was 11.9 GJ/year for BM and 12.2 GJ/year for LSF. The energy use for equipments is secondary energy, so, it was converted to primary energy by a conversion factor of 1.62, obtained in (Pedroso 2015). The energy use for cooking comes from liquefied petroleum gas, 47.3 MJ/kg (BEN 2014), and a consumption of 13 kg per month (or 7.4 GJ/year) was assumed. Finally, the total energy for operational phase was 19.3 GJ/year for BM house and 19.6 GJ/year for LSF house. Operating energy was calculated for a 50 years scenario.

*Maintenance stage*

The energy of maintenance (EM) is during the replacement of materials used in the house and depends on the maintenance plan and intervals for maintenance. To estimate the maintenance intervals, data from Brazilian building performance standard is used (ABNT NBR 15575-1:2013). The maintenance intervals were used to estimate the replacement factors (RF) .The same method used by Paulsen & Sposto (2013) and Atmaca & Atmaca (2015).

### 2.4 End-of-life phase analysis

In the end-of-life phase, it was assumed that the building with ceramic block masonry was demolished and the waste generated transported to the nearest landfill, located in a distance of 20 kilometres from the building site. The building with light steel framing was assumed to be deconstructed and the waste generated also transported to the nearest landfill.

The end-of-life phase is divided into two stages, demolition/deconstruction (ED) and waste transport (ETw). A value of 0,0354 MJ/kg was used for demolition of BM house, based on Tavares (2006).The values 0,00257 MJ/kg was used for deconstruction of LSF house, based on Pedroso (2015). For the transport to landfill were used the same energy and emissions data as for truck transport of building materials.

## 3. RESULTS AND DISCUSSION

### 3.1 Construction phase

For the extraction and process s, values of 3.66 and a 3.74 GJ per m$^2$ of embodied energy (EE) are depicted for the BM and LSF houses respectively. Comparing the EE for the two wall systems, the LSF showed higher values, however the differences between the two systems was only 2%.

A comparison of the different parts of the house systems (wall, paint, ceiling, roof, floors, windows and doors) in terms of mass and EE is shown in Figure 2.

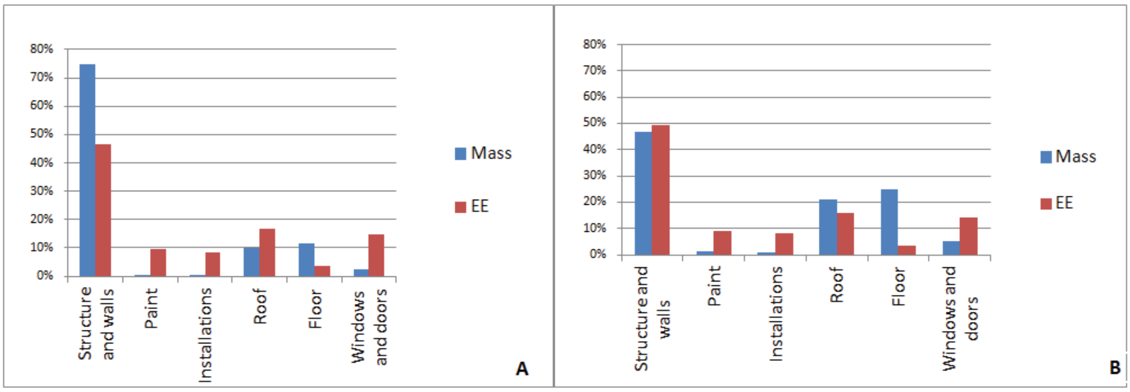

Figure 2. Participation of the house systems in mass, EE for extraction and production stages. (A) BM house. (B) LSF house. Source: Author, 2016

For the BM system, the walls had the highest mass participation (75%), EE (45%) and. These results correspond with the results of Paulsen & Sposto (2013), who verified the significance of the impacts from the ceramic wall system in typical Brazilian social residential buildings.

Comparing the mass of the wall systems, the mass of the LSF was 70% less than the mass of BM. However, the final results of ET for BM and LSF were very close, 0.1306 GJ/m$^2$ and for BM and 0.1302 GJ/m$^2$ for LSF. The longer distances travelled by materials and components of LSF compensate for the mass of the BM system. For both systems, the wall system represents the major participation in the house systems, in embodied and transport energy.

### 3.2 Use phase

The operational energy was estimated to 20.98 GJ/m$^2$ for the BM house and 21.30 GJ/m$^2$ for the LSF house. The better thermal performance of the BM house was due to the larger value of thermal capacity of the walls. This better performance resulted in a smaller energy saving for BM wall system compared to the LSF system. However, in this case study, for Brasília reality, the energy consumption due to use of air conditioning showed a low participation in EO, for both houses (Fig. 3).

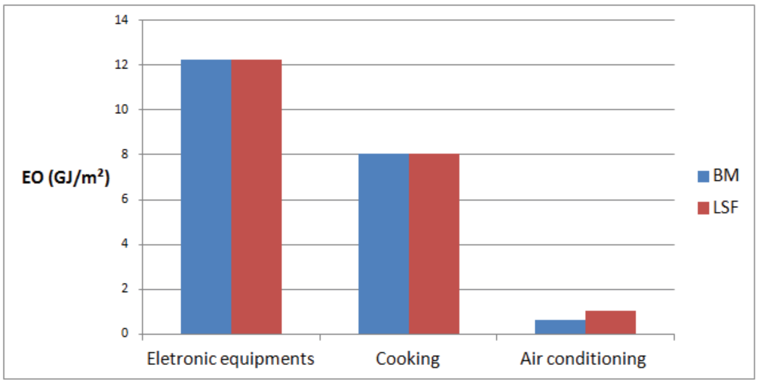

Figure 3. Comparison of operational energy. Source: Author, 2016

In relation to the maintenance phase, the final results of EM for BM and LSF houses were also close, 5.12 GJ/m$^2$ and 5.87 GJ/m$^2$, respectively for LSF. The larger values for the LSF house were due to the gypsum board service life (20 years), while the mortar and plaster have a service life of 40 years. The energy consumption of the maintenance phase showed to be larger than from the construction phase in this case. This indicates the importance of the maintenance phase for this type of Brazilian houses as verified by Paulsen & Sposto (2013). The mass and EM for the houses ware compared, see Figure. 4.

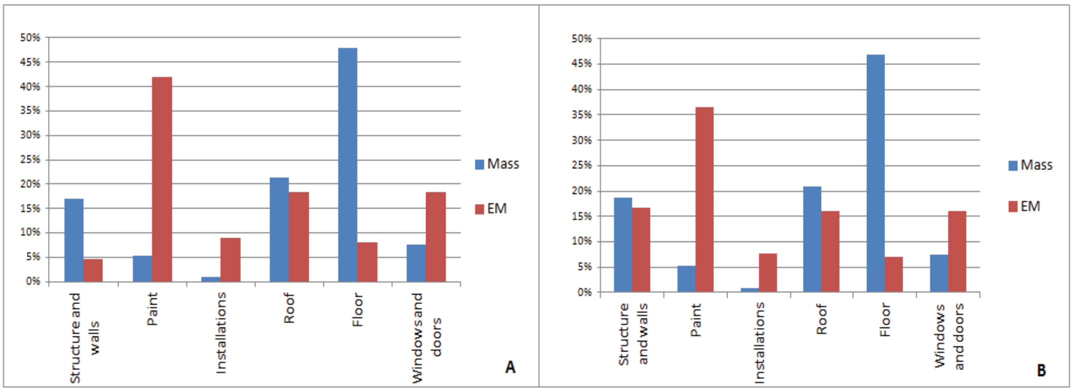

Figure 4. Participation of the house systems in mass, EM for maintenance stage. (A) BM house. (B) LSF house. Source: Author, 2016

The participation of walls in LSF house was greater than BM house. This was consequence of the minor service life of gypsum boards. The paint system showed a great participation in energy because of the low service life and the high value of EE of paints. So, for the maintenance phase it is important to specify, during the design phase, materials and components with low values of embodied energy and high durability.

### 3.3 End-of-life phase

For the end-of-life phase, a 0.24 and a 0.17 GJ per $m^2$ of energy consumption (ED + ETw) were recorded for the BM and LSF respectively. In this case study, the end-of-life phase consists of the demolition or deconstruction of the house and transportation of waste generated. Assuming that transport distances are the same for the BM and LSF houses, the difference in the results was related the mass of the wall systems. So the BM house consumes more energy because the demolition process (instead of the deconstruction in LSF house) and the bigger mass transported to landfill.

### 3.4 Whole life cycle

The final results of ETOT ECO2TOT for BM and LSF houses is summarized in Table 3.

Table 3. Total energy consumption in the houses life cycle

| Energy and $CO_2$ emissions | BM | LSF |
|---|---|---|
| Construction (EE + ET) | 3.79 | 3.87 |
| Operational (EO) | 20.98 | 21.30 |
| Maintenance (EM) | 5.12 | 5.87 |
| End-of-life (ED + ETw) | 0.24 | 0.17 |
| Total energy use (ETOT) (GJ/$m^2$) | 30.13 | 31.21 |

The LSF house presented a larger value of total energy consumption (ETOT) than BM house. However, the difference between the ETOT was only 3%. The values of ETOT are in the same level as found in other Brazilian studies, Tavares (2006), Paulsen & Sposto (2013) and international studies as Huberman & Pearlmutter (2008) and Devi L. & Palaniappan (2014). The share of each phase in the whole life cycle of the houses is shown in Figure 5.

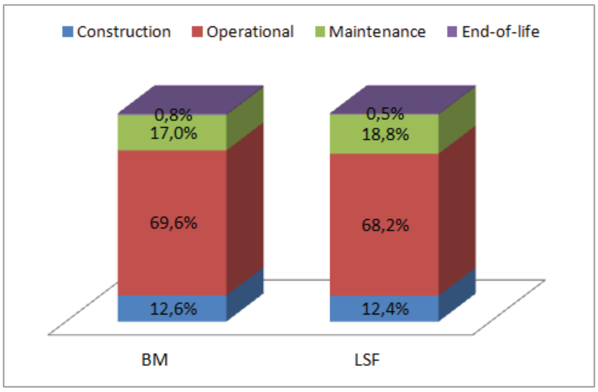

Figure 5. The share of each phases in the life cycle energy assessment. Source: Author, 2016

In both housing systems (BM and LSF), the operational phase generated the largest use of energy (70%). The values found in this case study are in the same range as found in Tavares (2006) and Paulsen & Sposto (2013), but lower than most international studies. According to several authors, like Sartori e Hestnes (2007) and Cabeza et al. (2014) the operational energy it the part that contributes most to the life cycle energy. The end-of-life showed a very low participation.

## 4. CONCLUSIONS

It was evaluated the energy consumption during the life cycle of two Brazilian social housing, one made of light steel framing (LSF) and other of block masonry (BM). The LCEA methodology was applied, considering the construction, use and end-of-life phases of the houses life cycle.

The results showed that the energy in construction was 3.79 GJ/m$^2$ for BM house and 3.87 GJ/m$^2$ for LSF house or 12% of the total energy from the life cycle, the operational energy was approximately 21 GJ/m$^2$ for both systems, with 70% of total energy. The maintenance was 5.1 GJ/m$^2$ for BM and 5.9 GJ/m$^2$ for LSF, around 17-19% of the total energy consumption. The influence from the end-of-life phase was lower than 1%.

Among the different systems of the house, the wall systems presented the biggest share in terms of mass and embodied energy for both houses. The paint system presented the biggest participation in energy consumption for maintenance phase.

The BM wall system presented a better thermal performance. Thus, the difference between air conditioning usages didn’t impact significantly in the total energy consumption of operational phase, only a little potential for energy savings.

In the end, the LSF house presented a higher value of total of energy consumption than the BM house. However, the difference between the two houses was just 3%.

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