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COMPARATIVE STUDY OF CO_2 EMISSIONS FROM CERAMIC BRICK AND PLASTER BLOCK VERTICAL SEALS

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Abstract: The objective of this study is to compare the carbon dioxide (CO_2) emissions from materials used in the execution of internal building masonry for construction projects that use plaster blocks and those using ceramic bricks. A total of 20 projects in the city of Recife, Brazil, were analyzed, all of them belonging to a large construction company operating in the Northeast region. The Greenhouse Gas (GHG) emissions were estimated using indexes found in the literature and calculated based on the Energy Life Cycle Assessment (ELCA). The emissions from the transport of materials to the construction site were calculated based on the driving distances between the suppliers and the building sites, taking into account the fuel consumption of the transport vehicles. The construction sites using plaster blocks for the internal masonry seals obtained an average indicator of 19.21 $kgCO_2/m^2$ of constructed area compared to 33.86 $kgCO_2/m^2$ from those using ceramic bricks. Construction sites using plaster blocks for internal masonry had a 43.26% reduction in GHG emissions and there was a strong correlation between costs due to the execution of activities and material emissions.

Keywords: Greenhouse gases, Energy life cycle assessment, Vertical seals, CO_2 emissions

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INTRODUCTION

In order to maintain their socioeconomic development when faced with continued population growth, many nations have exploited the environment as an inexhaustible stock of raw materials, as well as a place to deposit the waste produced. The exaggerated practice of these activities has led to an unrestrained use of natural resources that has damaged the environment and threatened the survival of mankind on the planet. One impact is the increase in the concentration of greenhouse gases (GHG) in the atmosphere, leading to global climate change, a widely-discussed phenomenon whose results have been disseminated by the scientific community. This scenario has created new challenges for companies around the world who must develop new strategies to include sustainable practices in activities that significantly impact the use of these resources. (Silva *et al.*, 2017).

Despite its importance to the economy, the construction industry is the sector most responsible for negative environmental impacts through its intensive use of natural resources, generation of solid waste, and emission of carbon (Kohlman Rabbani *et al.*, 2013; Souza *et al.*, 2015). Construction consumes 60% of the raw materials available, accounts for 39% of greenhouse gas emissions, and consumes 50% of all energy produced (UN/UNEP, 2017; Voskresenskaya *et al.*, 2018).

Some regulatory mechanisms have been put in place to impose limits on countries that emit GHGs, such as the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. In Brazil, Federal Law No. 12,187 of December 29, 2009 establishes a quantitative target for the reduction of emissions by 2020. This law also created the National Policy on Climate Change, which encompasses several sectors of the Brazilian economy (Piaia & Cervi, 2017).

The objective of this study is to compare the emission rates of greenhouse gases from materials used in commercial and residential building masonry. Two methods for constructing internal seals were considered (ceramic brick masonry and plaster block masonry) in order to identify the least polluting materials and procedures.

THEORETICAL FRAMEWORK

Currently, there are several methodologies used for studies that aim to reduce the environmental impacts caused by the construction sector. One of them is the Life Cycle Assessment (LCA). This method requires a detailed qualitative and quantitative survey of the inputs used, energy consumed, production process, transportation, use, reuse, recycling, and final disposal. LCA is an extremely complex tool, considering several instances of interference during the life cycle of a given product (Vieira *et al.*, 2018).

Tavares (2006) found this method to be difficult to carry out and chose to optimize available resources and simplify the methodology. The author developed an energy life cycle analysis (ELCA) that allows one to observe the embedded energy, which is the set of energy inputs for the manufacture and transportation of materials (Tavares, 2006).

Throughout the useful life of a product, an environmental impact is generated for each step of its use process and the LCA is one of the top methods for verifying the best alternative to analyze a productive cycle. It is the ideal system for evaluating environmental issues, defending investment decisions and internal development, identifying priorities, distancing unsustainable actions, and improving marketing on the recyclability of products (Evangelista *et al.*, 2018).

The LCA also contributes by quantifying environmental impacts using previously known data. It is possible to perform a comparative study between service procedures by considering the applicability of certain products, or by evaluating constructive technique options. All of this improves decision making to reduce environmental impacts from buildings and projects (Peuportier *et al.*, 2013).

In order to simplify calculations and obtain a significant environmental impact analysis, an energy life cycle assessment (ELCA) is performed, which, unlike an LCA, does not use all four phases of analysis (objective and scope definition, inventory analysis, impact assessment, and interpretation). Although it is derived from the LCA, an ELCA does not aim to replace the broader environmental analysis method, but to instead prioritize the inventory of direct and indirect energy consumption data for a given product or service (Evangelista *et al.*, 2018). ELCA makes possible the evaluation of certain environmental impacts, such as the emission of greenhouse gases (Azzouz *et al.*, 2017). In addition, it is cheaper and has a shorter execution time than a full LCA.

In Brazil, studies that made use of the LCA include: Tavares (2006); Kulay *et al.* (2010); Lobo (2010); Paulsen & Sposto (2013); Ruschi Mendes Saade *et al.* (2014); Sposto & Paulsen (2014); Bueno & Fabricio (2016); Severo & Sousa (2016); Borges *et al.* (2017); Branco Júnior *et al.* (2018); Vieira *et al.* (2018); and Evangelista *et al.* (2018). Outside Brazil, this subject is discussed by Nässén *et al.* (2012); Park *et al.* (2012); Castellano *et al.* (2014); Zhang & Wang (2015); Seo *et al.* (2016); Roldán-Fontana *et al.* (2017); Lavagna *et al.* (2018); Le *et al.* (2018); and Zhou *et al.* (2018).

Energy life cycle assessment

ELCA is used more frequently in the civil construction industry due to being more viable for study and being optimized in relation to LCA. The impact assessment is reduced to the use of energy as an indicator of environmental impact, as the greatest part of emissions comes from energy production, in addition to the extraction of non-renewable natural resources, such as fuels in general (Sposto & Paulsen, 2014).

All building materials require energy inputs to be produced. If these inputs are consumed within the industry during the processes of manufacturing and obtaining the construction materials, they are called direct inputs. They are considered indirect inputs if they are spent during the following stages: raw material extraction, building material processing, material transportation to factories, and after transportation of finished products to the construction sites, or even during the construction itself. The set of these energy inputs is defined as Embedded Energy (EE).

The energy lifecycle of a building, in a "cradle to grave" approach, consists of the total set of energy requirements needed in all phases of the project: initial energy (energy required for extraction of raw materials, fabrication of materials, and transport services); operating energy (energy required during the useful life, use of equipment, air conditioning, among others); built-in maintenance energy (repairs, renovations, among others); and deconstruction energy (considers total direct inputs for demolition or deconstruction of a building, including the transport of waste) (Tavares, 2006). This study focuses on the calculation of the difference between the impacts from the choice of two construction systems used for the same purpose, taking into account the steps of raw material extraction, transport to industry, manufacturing, and transport to the construction site.

CO_2 emission calculation

The energy sources are important to study, since they deal with two aspects: energy consumption and CO_2 emission during the manufacturing processes. According to Lobo (2010), it is useful to study energy consumption to analyzes the energy efficiency of processes or services, and, in the case of CO_2 emissions, it is important to verify the environmental impacts caused by GHG.

Therefore, the selection of building materials is a very important item for any sustainability study, because the manufacturing process contributes decisively to the generation of greenhouse gases (Carvalho & Sposto, 2012). This ends up enriching discussion about choice of materials and the use of more sustainable technologies as alternatives to existing techniques (Lobo *et al.*, 2010).

The survey of GHG emissions was based on Tavares (2006), on the Intergovernmental Panel on Climate Changes (IPCC) reports, and on the National Energy Balance (BEN) (EPE - Empresa de Pesquisa Energética, 2017). First, primary consumption by industries per specific sources of energy in Brazil (natural gas, petroleum, coal, firewood, electricity, among others) is defined. Afterwards, the percentage of consumption for the various energy sources (cement, steel, mortar, ceramics, among others) used by the industries for producing construction materials is surveyed (Tavares & Bragança, 2016; EPE - Empresa de Pesquisa Energética, 2017).

Subsequently, the emission of carbon dioxide (CO_2) from each energy source used, together with the emissions due to the chemical processes of the materials, is defined. Finally, with embedded energy data, it is possible to quantify GHG emissions for each material manufactured by the industry.

METHODOLOGY

The methodology used to calculate impacts for the materials used in the construction systems consisted of defining the projects for the quantitative survey of materials used, followed by the Embedded Energy and CO_2 emission survey by material for the analyzed buildings, including raw material extraction and material transport. **Figure 1** presents a flowchart with the steps performed to achieve the proposed goal.

Survey of materials and GHG emissions

The buildings chosen belong to a company that has more than 35 years of experience in the market. Its headquarters are located in the city of Recife, in the state of Pernambuco. The company also operates in the states of Alagoas, Bahia, Rio Grande do Norte, and Ceará. The company is considerably large, according to the classification criteria of the Brazilian Service of Support to Micro and Small Companies (SEBRAE - Serviço Brasileiro de Apoio às Micro e Pequenas Empresas, 2010), and has an integrated quality management system with international certificates of quality, health, safety, and the environment.

The survey data were obtained from real quantities of multiple already completed construction projects in the Metropolitan Region of Recife through an ERP (Enterprise Resource Planning) system called SAP (from German: Systeme, Anwendungen und Produkte in der Datenverarbeitung), a system that integrates all data and processes of an organization into a single program, including the purchase and receipt operations of the company.

To acquire a certain resource, whether material or a service, the administration of the construction site must create a purchase requisition, which consists basically of a request for a specific product with the necessary quantity and date that the material must arrive at the construction site. All requested material has a specific code and it must be linked to the budget item corresponding to its service.

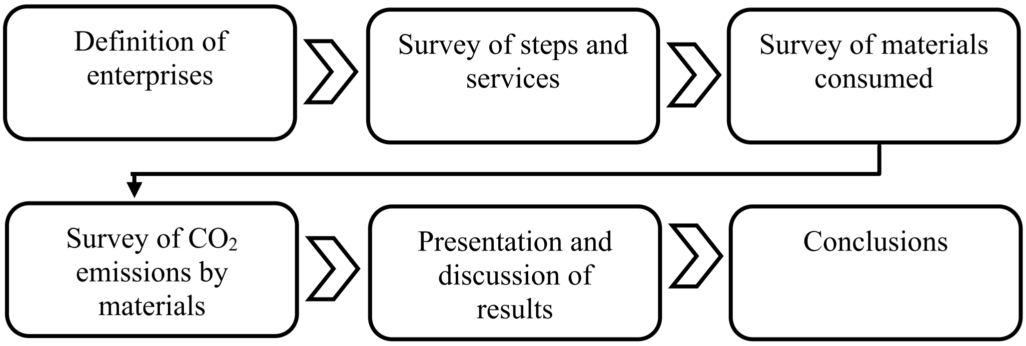


Fig. 1 Stages of information gathering.

The quantities of materials used in this study refers to the actual quantities requested by the construction site administration at the time of material requisition, just before a specific resource was needed onsite. This was made possible, as previously mentioned, because of the use of the SAP enterprise management system at the selected construction sites.

The system enables reports of all purchase orders made by the project management team to be issued with information about each acquisition. **Table 1** gives an example of the main report data that were used in this study, such as: subsystem, supplier name and code, material name and code, unit, quantity, and shipment date. In all, 87 materials were requested in 1,772 purchase orders, considering only the masonry and closing stages from the construction sites in this case study.

All materials registered were indicated with their respective emission factors found in the literature. For inputs that were not measured in kilograms, their values were converted using conversion factors found in the literature and in references from online suppliers.

The number of construction sites analyzed was defined by the availability of complete data from the construction company in an enterprise management system. This system was deployed at the construction company in 2011, limiting the information collection to projects carried out between 2011 and 2017, reaching a total of 20 projects analyzed.

The CO_2 emission factors of the materials were collected from data in the literature, with a considerable amount of information extracted from the studies of Tavares (2006), Lobo (2010), and Tavares & Bragança (2016). These authors have compiled an inventory of emissions according to the methodology of Tavares (2006). With this information, the emissions produced by the materials ordered for the construction sites can be calculated by **Eq. (1)**:

$$CO_2EM = \sum_{m=1}^{n} EF_m \times CF_m \times Q_m \tag{1}$$

where: EF_m: Material CO_2 emission factor ($kgCO_2/kg$), CF_m: Material conversion factor for kilograms, Q_m: Quantity of material ordered, and CO_2EM: CO_2 emissions in material extraction, transportation and manufacture ($kgCO_2$).

Calculation of emissions from transportation

In order to determine the emissions from the transportation of materials, it is necessary to know the distance from the suppliers to the construction site, the emissions of the vehicles responsible for transportation, and the amount of travel necessary to transport all of the material to the site.

The SAP system has a list of suppliers used throughout the company, including contact information such as address and other specific data. This list includes a total of 19,000 companies that provide some type of resource for construction, whether labor or material.

In order to calculate road distances between material suppliers and construction sites, the addresses and postal codes registered in the SAP were used and the distances traveled were calculated using Google Maps, considering that the vehicles make a round trip.

In order to calculate vehicle emissions, data were collected from Costa (2012), who determined the Emission Factor (EF) averages of several vehicles of different brands using data obtained from other surveys conducted in different locations around the world. EF values for the fuel used in the vehicles were also collected (**Table 2**).

Emission factors are expressed in $kgCO_2/t/km$, as the fuel consumption index of a vehicle is directly linked to the load it is carrying. A Conversion Factor (CF) was used to convert the quantities of all materials into kilograms. All 1,772 purchase requests from this case study included the classification of the type of truck used to transport the materials. The calculation of the emissions for each construction site can then be defined by **Eq. (2)**:

Table 1. Example of purchase order report data

Subsystem	Supplier	Material Code	Material	Unit	Qtt	Delivery Date
Masonry	4501493 - Mibra Ltda	100337	Mortar for masonry	kg	20000	03/01/2012
Masonry	4503285 - Lajeiro Gesso Do Nordeste	100720	Plaster block 100mm	m^2	40	01/09/2012
Masonry	4500234 - Abel Eduardo Teixera	100714	Gutter block 19x9x39cm	unit	3000	03/26/2013
Masonry	4503053 - Joseangela Silva De Santana	100307	Sand	m^3	70	07/04/2013
Masonry	4504580 - Cia Industrial De Ceramica	112643	Elet Block 9x19x19cm	unit	500	11/08/2013
Masonry	4500660 - Mario Henrique De Mattos	100694	Cer Block 9x19x19cm	unit	28000	09/17/2016
Masonry	4503000 - Massa Pronta Produtos	100312	Glue mortar ACII ext	kg	6000	07/05/2014
Masonry	4503107 - Gerdau Comercial De Acos	100286	Wire galv bwg 14	kg	60	01/28/2014
Masonry	4503053 - Joseangela Silva	100790	Gravel 12	m^3	60	04/07/2014

Table 2. Average fuel consumption - means of transportation (source: Costa, 2012)

Type of transport	Maximum capacity (t)	Consumption (l/t/km)	EF - Diesel Oil ($kgCO_2/l$)	TEF – Truck Emission Factor ($kgCO_2/t/km$)
Light duty truck	7	0.0446	3.16	0.140936
Medium duty truck	13	0.0347	3.16	0.109652
Semi-heavy duty truck	26	0.0196	3.16	0.061936
Heavy duty truck	45	0.0121	3.16	0.038236

$$CO_2ET = \sum_{m=1}^{n} \frac{Q_m \times CF_m \times TEF_m \times D_m}{1000} \quad (2)$$

where: Q_m: Quantity of material ordered, CF_m: Material conversion factor for kilograms, TEF_m: Truck CO_2 Emission Factor ($kgCO_2/t/km$), D_m: Road distance between supplier and construction site (km), and CO_2ET: CO_2 emissions from transportation of material to the construction site ($kgCO_2$).

The type of truck used, together with data on the weight of materials in each purchase order, defined the amount of travel needed to transport each component and made it possible to calculate the GHG emissions related to transportation, considering the vehicles to have made a round trip.

Characterization of construction sites

The construction sites analyzed are located in the municipality of Recife, capital of the state of Pernambuco, located in the Northeast region of Brazil (**Fig. 2**). Recife occupies a central and prominent position in the region. As previously mentioned, the choice of buildings was limited by the availability of complete purchase requisition data in SAP software, which was implemented by the company in 2011. In total, 20 construction sites were selected, as shown in **Fig. 3**.

In order to analyze possible influences of building properties on GHG emissions, a survey was carried out based on the legal architectural plans of the studied construction sites. First, information such as built area, internal seal type, total masonry area, and building type was collected (**Table 3**).

In order to calculate the final emissions of each construction site, these emissions must be added to those produced from the manufacture and transportation of the materials, as in **Eq. (3)**.

$$ECO_2 = CO_2EM + CO_2ET \quad (3)$$

where: ECO_2 = Total CO_2 emission at the construction site ($kgCO_2$).

After calculating the emissions of each construction site, the activity emission indexes were calculated according to the masonry areas surveyed for each project.

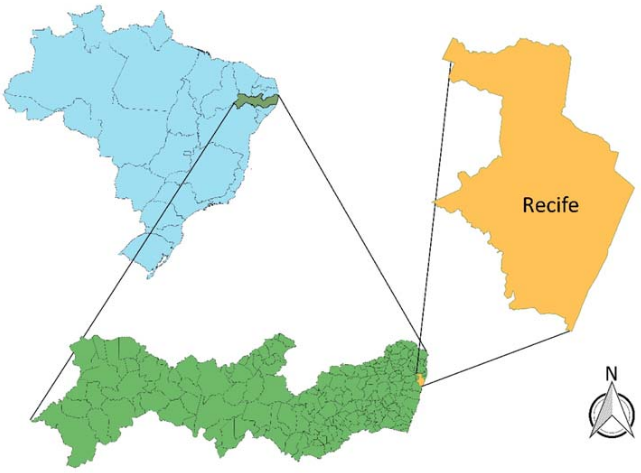


Fig. 2 Location of the city of Recife.

RESULTS AND DISCUSSION

During the masonry and vertical sealing stages of construction, the elements that seal and separate the internal environments are placed. These elements are responsible for ensuring thermal and acoustic comfort, water tightness, and fire resistance, among others. During this phase, the principal materials purchased and used to calculate emissions were: bagged mortar, ceramic blocks, plaster blocks, plaster glue, gypsum powder, gravel, cement, annealed wire, PVC boxes, and conduits for installations. The amount of inputs required represent the actual quantities used in the construction, including losses and waste of materials in stock.

All masonry used at the studied worksites had the sole function of sealing, and conventional ceramic blocks (brick) were used in all of them as periphery closure and to divide the housing unit from the common area and from other units. However, the internal seals within the private units themselves made use of two different constructive techniques: ceramic brick masonry and plaster block masonry.

Taking all sites into consideration, regardless of the type of internal seals chosen, this execution stage had indexes varying from 13.70 $kgCO_2/m^2$ to 42.62 $kgCO_2/m^2$ for constructed masonry, with an average of 27.99 $kgCO_2/m^2$ and 593,206.42 $kgCO_2$ emitted per site into the atmosphere. Emissions from transportation represented an average of 10.54% of the total generated.

Due to the different types of internal seals used, the standard deviation of the indexes was 9.01 $kgCO_2/m^2$, establishing a 32.16% coefficient of variation (CV), which falls within the high data dispersion range (CV > 30%). When considering construction sites using the same constructive method, the variation falls within the average dispersion range (15% > CV > 30%), with a CV of 25.97% for construction sites using plaster and 16.41% for those using ceramic brick.

Table 3. Characteristics of construction sites

Construction Site	Internal Seal Type	Masonry Area (m^2)	Building Type
Site A	Plaster block	19,283.34	Residential
Site B	Brick	27,162.52	Residential
Site C	Plaster block	18,060.94	Hotel/flat
Site D	Plaster block	44,896.18	Hotel/flat
Site E	Brick	22,239.78	Hotel/flat
Site F	Plaster block	18,438.00	Hotel/flat
Site G	Brick	13,162.39	Residential
Site H	Brick	22,111.29	Residential
Site I	Brick	19,011.98	Business
Site J	Plaster block	14,363.68	Residential
Site K	Brick	19,916.34	Residential
Site L	Plaster block	7,836.11	Residential
Site M	Brick	53,610.94	Residential
Site N	Plaster block	29,018.41	Residential
Site O	Plaster block	20,668.14	Residential
Site P	Brick	15,257.52	Residential
Site Q	Brick	10,505.29	Residential
Site R	Brick	12,320.35	Residential
Site S	Brick	8,199.67	Business
Site T	Brick	17,163.20	Residential

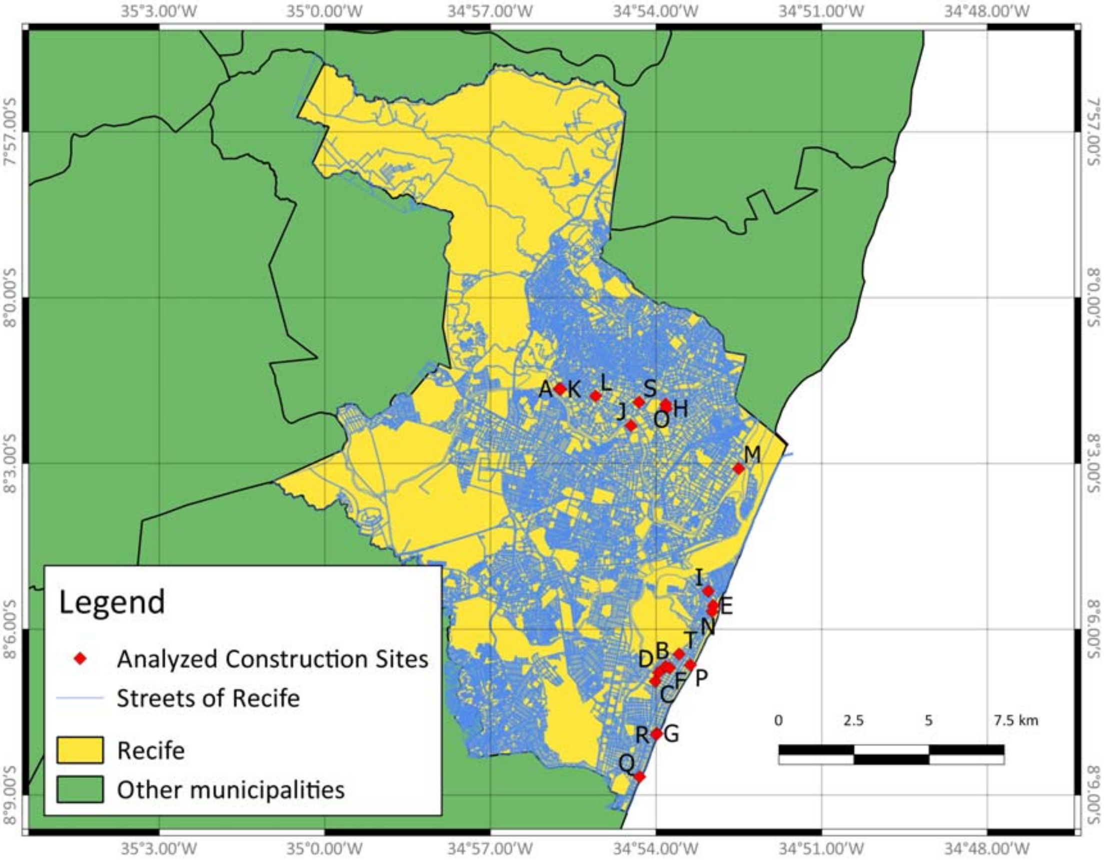


Fig. 3 Location of analyzed construction sites.

In order to calculate the coefficient of determination that shows to what extent the constructed masonry areas determine the total GHG emissions in the masonry phase, two scatter plots were created, one for the construction sites using a ceramic blocks (**Fig. 4**) and the other for sites using plaster blocks for vertical sealing (**Fig. 5**).

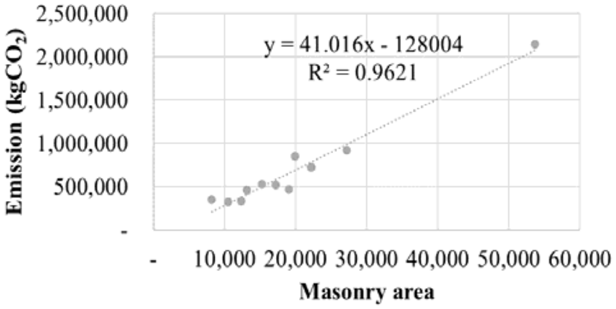


Fig. 4 Influence of masonry area on emissions (construction sites with ceramic brick).

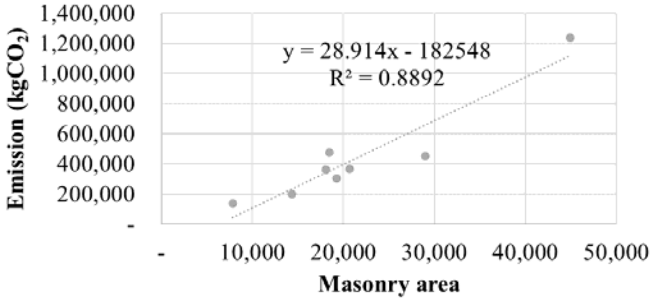


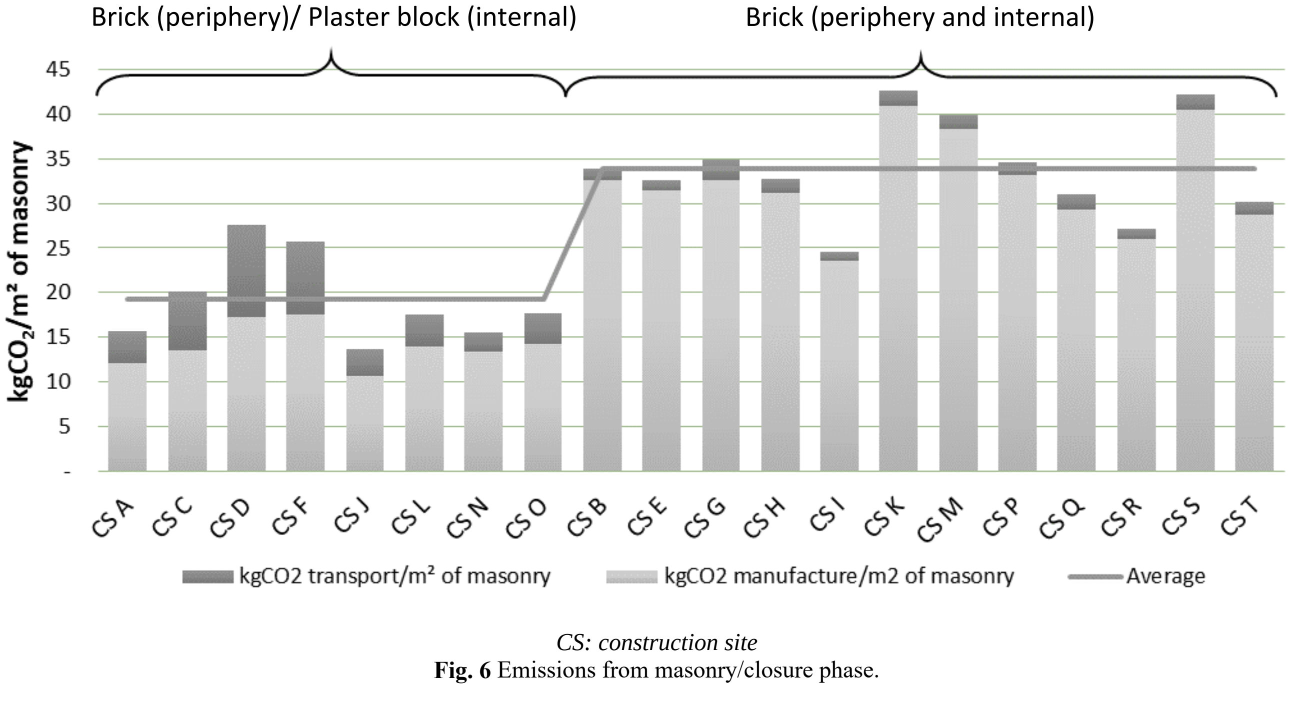
Fig. 5 Influence of masonry area on emissions (construction sites with plaster block).

When placing a linear trend line, a high Determination Coefficient (R²) was found for both types of materials: 96.21% for construction sites using ceramic blocks and 88.92% for buildings using plaster blocks. These percentages represent the extent to which the executed masonry areas determined the total GHG emission values. With this, it can be affirmed that among the analyzed construction sites, the quantity of internal sealing constructed considerably influences GHG emissions, regardless of the masonry type.

In order to verify the influence of each constructive method used for internal sealing, the emission indexes as a function of the masonry areas were separated by type, as shown in **Fig. 6**, with emissions from the manufacturing of materials shown in a light shade and emissions from transportation of materials shown in a dark shade. The mean GHG emission indexes were also calculated (**Table 4**). The construction sites to be compared were separated based on their type of internal sealing, but the periphery sealing has also been included because it is part of subsystem as a whole.

The projects executed using plaster block as internal sealing material have an average area of 42.88% of the total building masonry, varying from 34.99% to 53.69%. This represents, in most cases, less than half of the building masonry area, with the peripheral sealing of the housing units corresponding to a larger percentage of the total masonry.

The peaks in the indexes found for each construction method at construction sites D and F (for plaster block) and sites K, M, and S (for ceramic brick) occur due to specific characteristics of each site. One of them is the index of material losses that can be determined through several factors, such as: internal material logistics,



CS: construction site

Fig. 6 Emissions from masonry/closure phase.

Table 4. Characteristics of construction sites

Internal seal type	Plaster block	Brick
Number of construction sites	8	12
Average emissions ($kgCO_2$)	440,516.74	694,753.56
Average distance traveled by vehicles (km)	167,758.90	26,482.73
Mean distance index (km/m^2)	6.69	1.38
Material emissions index ($kgCO_2/m^2$ of masonry)	14.12	32.33
Transport emissions index ($kgCO_2/m^2$ of masonry)	5.09	1.53
Emissions index ($kgCO_2/m^2$ of masonry)	19.21	33.86

workforce quality, and quality management system efficiency, among others.

Construction sites using plaster block masonry as an internal seal reduced they're in final GHG emission indexes by an average of 43.26%. Looking at the of emissions from the acquired materials, plaster block masonry construction sites had an average of 14.12 $kgCO_2$ per square meter, while ceramic brick masonry sites had 32.33 $kgCO_2/m^2$, representing an average reduction of 56.31% for sites using plaster block.

On the other hand, the percentage of emissions from transportation of material are higher for buildings that used plaster block, with 5.09 $kgCO_2/m^2$, representing 26.50% of the total emissions, while the construction sites that used ceramic brick had emissions of 1.53 $kgCO_2/m^2$ from transportation, representing 4.53% of the total GHG emissions. This represents an increase in the indexes of 231.82% for transportation of materials for constructions sites using plaster block as internal sealing.

This increase in emissions from transportation for construction sites using plaster block occurs because of the greater distance of plaster suppliers from Recife, most of which are located in the Araripe gypsum axis, located at the extreme west of the state of Pernambuco, which concentrates 95% of total gypsum production in Brazil (Melo *et al.*, 2017). In contrast, suppliers of ceramic blocks are located closer to the Recife Metropolitan Area in municipalities such as Paudalho and Lagoa do Carro, both in Pernambuco, as well as Santa Rita, in the state of Paraíba, among others.

The average distance traveled by the vehicles transporting the materials, as a function of the built masonry areas, was 6.69 km/m^2 for the constructions using plaster blocks compared to 1.38 km/m^2 for those using ceramic brick, representing an increase of 383.53%.

FINAL CONSIDERATIONS

Construction systems, which are currently chosen primarily based on technical and economic factors, can also incorporate an environmental impact analysis. One of the most accessible tools for this is ACVE, however, it is necessary to verify that the choice of materials and construction processes meet the minimum requirements demanded by current legislation.

It was found that construction sites using gypsum block masonry as internal sealing obtained an average reduction in GHG emission indexes of 43.26%, representing 19.21 $kgCO_2/m^2$ of constructed masonry, when compared to buildings using ceramic block, which emitted an average index of 33.86 $kgCO_2/m^2$. On the other hand, the percentage of emissions for material transportation is higher for buildings that used plaster block due to the greater distance from the suppliers.

It was also found that the distances from the material suppliers can potentially be decisive for the choice of constructive methods to be used due to the GHG emissions from transportation. This happens especially with materials unique to certain regions, such as plaster, whose production is concentrated in the extreme west of the state of Pernambuco, Brazil. For the construction sites analyzed in this study, the difference between the GHG emission indexes for the two construction methods studied was reduced when considering the emissions from transportation. Although plaster block manufacturers are more distant than ceramic brick producers, the reduced amount of GHG emissions in the manufacturing phase were enough to guarantee the average final emission index.

In addition, a very strong correlation (90.80%) was found between the embedded energy parameters of materials used and the masonry execution costs at the construction sites. A strong correlation (88.29%) was also found between the GHG emissions from masonry, including the transportation of materials, with the expected costs to carry out the activities.

For the construction sites studied in the city of Recife, Pernambuco, it was found that the choice of a plaster block system for internal sealing provides a significant reduction in CO_2 emissions, when compared to ceramic bricks. It can be concluded that the environmental analytical study of the construction systems can determine the choice of methods adopted by construction companies that seek to create new strategies that include sustainable practices in their activities.

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