Comparative Study of Consumption and Life-Cycle Impacts of Water Heating Systems for Residential Multi-familiar Buildings in Rio de Janeiro, Brazil

Arthur B. Silva, Mohammad K. Najjar, Ahmed W. A. Hammad, Assed Haddad, and Elaine Vazquez

Abstract Civil construction, as an integral part of the chain of industrial activities, is one of the various segments responsible for energy consumption and potential greenhouse gas emissions throughout its life cycle. The building materials and their systems have a direct influence on energy consumption and impact assessment. In this context, Hot Water Building Systems (HWBS) are included. The type of installation to be used in a building is defined by technical and/or economic requirements. However, the spectrum of possibilities should consider resource consumption and generation of environmental impacts throughout the life cycle. This research proposes a novel application of an environmental management method to empower the decision-making process of HWBS, insights a Life Cycle Assessment (LCA) methodology to compare the environmental performance of two distinct HWBS (i.e. Natural Gas Heating System and Solar Heating System) for multi-family residential developments. In conclusion to the results obtained, it can be inferred that the HWBS with heating via SHS has better environmental performance than the system with heating via Natural Gas, even though the first one uses an electrical complement for operation appropriate.

Keywords Life cycle assessment · Water heating systems · Residential buildings

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1 Introduction

Population growth and technological development in recent decades have made human activities largely responsible for structural changes in the environmental landscape at regional and global levels [1, 2]. Regarding the aspects of natural resources consumption and the passive impact of human activities, the energy sector is responsible for a major part of greenhouse gas (GHG) emissions [3]. For instance, residential and commercial buildings account for around 41% of total energy consumption in the United States [4]. In these terms, building components have a direct influence on energy consumption and environmental impacts over the entire Life Cycle Assessment (LCA), basically, during the pre-operational phase (i.e. material manufacturing, transportation and construction), as well as at the end-of-life and disposal phase [5].

Buildings are major consumers of energy throughout their life cycle. Generation of energy primarily depends on conventional sources, which is the basic cause of environmental pollution [6]. The materials and their systems have a direct influence on energy consumption and impact generation, in the pre-operational phase (materials manufacturing, transportation and construction), also in the final and discarded life.

Hot Water Building Systems (HWBS) are directly related to energy consumption in residential buildings; performing the second largest energy consumer in buildings and, thus, representing an integral part of the water-energy nexus [3].

The conventional selection of a water heating system in residential buildings focuses on the financial evaluation rather than the sustainability pillars and life cycle consequences (i.e. economic × environmental pillars) [7]. At this level of the analysis, the application of LCA methodology at an early designing phase of residential buildings could empower the decision-making process and sustainability [8], as well as facilitating the selection criteria of HWBS [9], where professional and experts could evaluate the environmental performance of the installed water heating system [10, 11].

A novel application of an environmental management method is presented herein to empower the decision-making process and encourage the selection course of HWBS, taking into consideration the technical and economic aspects at an early designing phase of buildings. The aim of this work is to present a proposal for a method derived from the general LCA methodology in order to compare the environmental performance of two distinct HWBS for multi-family residential developments, through thermal heaters installed on the final roof of buildings, with supplementation of electrical supply, so that accurate information on the environmental performance of the systems can be obtained. However, the installed HWBS considered in this work are NGHS and SHS. In this work, a literature review of the LCA methodology is presented in Sect. 2. The proposed methodology to evaluate the LCA for HWBS is presented in Sect. 3. However, results are discussed in Sect. 4, while the conclusions and final recommendations are presented in the last section.

2 A Literature Review of LCA Methodology

LCA is described by as a scientifically based analysis and assessment of the environmental impacts of product systems [12]. Regarding to ISO standards, this methodology was revised in 2006 and started to be condensed into ISO 14040 and ISO 14044 standards [13]. In Brazil, the Brazilian Association of Technical Standards, published equivalent versions initially translated in 2001 (NBR ISO 14040, NBR ISO 14041, NBR ISO 14042 and NBR ISO 14043) and later in 2009 and 2014 (NBR ISO 14040 and NBR ISO 14044 replacing the previous ones) in a way to support the descriptive text and definitions, as well as facilitate the understanding of the theme [14].

At the level of the energy consumption and impact assessment of products, LCA is characterized as a management methodology that help computing inputs and outputs of a production system to evaluate the environmental performance over their entire lifespan [15]. The application of LCA methodology in the construction sector focuses mainly on the characteristics of the building typology and components [16]. However, such application is facing several challenges that are giving a wide spectrum of related variables and making it necessary and interesting to define a standardized analysis structure in order to increase its accuracy [17]. In this context, HWBS should also be assessed over their entire lifespan, so that the energy incorporated into the biogenic emissions are considered and give greater dimension to the impacts of the systems [18]. The methodology adopted for this study is related to the LCA of HWBS in multifamily residential buildings, taking into consideration comparing the different types of systems in relation to their environmental performance at an early designing step. The general scope of such application will be conducted in four phases based on the LCA methodology: Goal and Scope definition; Life Cycle Inventory analysis (LCI); Life Cycle Impact Assessment (LCIA); and Interpretation of data and results obtained by the partial and final methodological processes [19, 20].

Defining the Goal and Scope of the study means determining the intended application for the analysis and the reason for carrying out the study, the target audience to whom the results are intended to be communicated and, therefore, the means for their dissemination [19]. In these terms, the scope of the study should include the definition of the product system to be studied; the functions of this system or compared systems; the determination of the functional unit/functional equivalent; the system boundary; allocation procedures; selected impact categories and methodology for impact assessment as well as subsequent interpretation to be used; data requirements; assumption; limitations; initial requirements for data analysis; type of critical analysis, if applicable; type and format of report required for study.

The next step is to build up the LCI based on ISO 14044, which demonstrates a definition of the inventory analysis phase that involves the cradle-to-grave character of the method; "life cycle assessment phase involving the compilation and quantification of inputs and outputs of a product system over its lifetime. life cycle". Table 1 illustrates the output results of the LCI step [21], including a list of data of the environmental impacts to be evaluated at the next step of the LCA methodology,

Table 1 Characterization of impact categories commonly demonstrated in studies

Impact categories	Geographic scale		
	Global	Regional	Local
Global warming	×		
Stratospheric ozone depletion	×		
Phoyochemical oxidant formation		×	×
Acidification		×	×
Nutrient enrichment		×	×
Ecotoxicity		×	×
Human toxicty		×	×
Working environment			×
Odour			×
Noise			×
Radiation	×	×	×
Resource consumption	×	×	×
Land use			×
Waste			×

Adapted from Stranddorf and Hoffman [21]

which is LCIA. At this level of the analysis, LCIA aims to give an overview of the significance of the potential impacts of the examined product [22].

There are several methods to evaluate the extracted impacts from the LCI, hence, it is highly important to choose the most appropriate method for each case study [18]. LCIA can be distinguished within two levels: midpoints and endpoints [23]. At the midpoint impact assessment level, indicators are given along the environmental mechanism, while at the endpoint impact assessment level, "*Characterization considers the entire mechanism to its end point, i.e. it refers to a specific damage related to the broader area of protection, which may be human health, natural environment or natural resources*" [24]. Finally, the interpretation level refers to permeate the entire analysis process, where the findings of LCI and LCIA are to be consistently combined with the defined Goal and Scope in order to draw conclusions and recommendations [19].

3 Proposed LCA Methodology for HWBS

The objective of this work is to Present a methodological work flowchart for the comparative application of LCA for HWBS in multi-family residential buildings, as a way to obtain data for analysis regarding the environmental impacts of such systems, taking into consideration the energy consumption during of the operation phase of HWBS and its impact on the living standards, combined with the LCA database of the of the applied materials. The developed method herein is based on nine main phases, which guide the elaboration and evaluation of the projects and their respective analysis and are the organization of the general phases of methodological application of the LCA recommended by ISO Standards. At this level of the analysis, the interpretation phase is divided into four distinct stages; Interpretation (A), Interpretation (B), Interpretation (C) and Interpretation (D), which means that in each phase, I, II, III and IV in the end of it will have an interpretation of the results. Each stage has been oriented and modified to verify the output results collected from the previous steps (LCI and LCIA), as well as evaluating their quality, coherence and importance to the study. Figure 1 describes in detail the steps contained in phases I, II, III, and IV of the study, which are Goal and Scope Definition (A), Interpretation (A), Goal and Scope Definition (B), and Interpretation (B), respectively.

The starting point of the analysis, as presented in Fig. 1 is to determine the environmental profile of a certain HWBS. Phase I, Goal and Scope Definition (A), means to conduct general definitions, function, and functional unit. At this level of the analysis, Item (I.1), presented in Fig. 1, means determining the general purpose of the analysis to be performed. Such an objective must be clear and consistent with the reality of the place of application so that it can be valid and have real importance in the context in which it will be applied. The results of the analysis of the performance of the HWBS during the operation phase can be used to make a decision about the use of a particular type of system still in the design phase, with the general objective being traced, for example, as the definition of the type of system, system to be used for the distribution of water in a specific building type, or if a copper or PVC pipe is defined in the project, given the observed impacts.

Item (I.2), presented in Fig. 1, means determining the target audience. In the case of the building installation project, the target audience can be defined as the end user, who will actually use the system and wants to know which one is most advantageous in this respect, or the builder who will do the work and needs the best cost-benefit, or it may be the own design team that needs the determination of the system that consumes the least environmental resources or generates the least impact in order to have a sustainable building profile that seeks environmental certification. Next, item (I.3) determines the scope of the analysis. At this point, a phase of refinement of objectives is to be included, defining the stages of application, scope, work team involved and other important aspects to the elaboration. Moreover, the evaluated function in the employed method can be traced in item (I.4). The main functions of cold water, hot water and piped gas systems can be analyzed, considering that the functions are closely linked to the uses of systems. The functional unit of the study, presented in item (I.5) in Fig. 1, deals with the quantification of the determined function or product performance characteristic. In these terms, the functional unit must, in the case of building systems, be worked as a performance unit and not a mass or metric unit.

Phase II, Interpretation (A), refers to identify stakeholders, focusing on a more managerial profile of the process. Construction projects involves many stakeholders (i.e. facility owners and users, project managers, project team members, facility managers, designers and architects, allotment companies, shareholders of

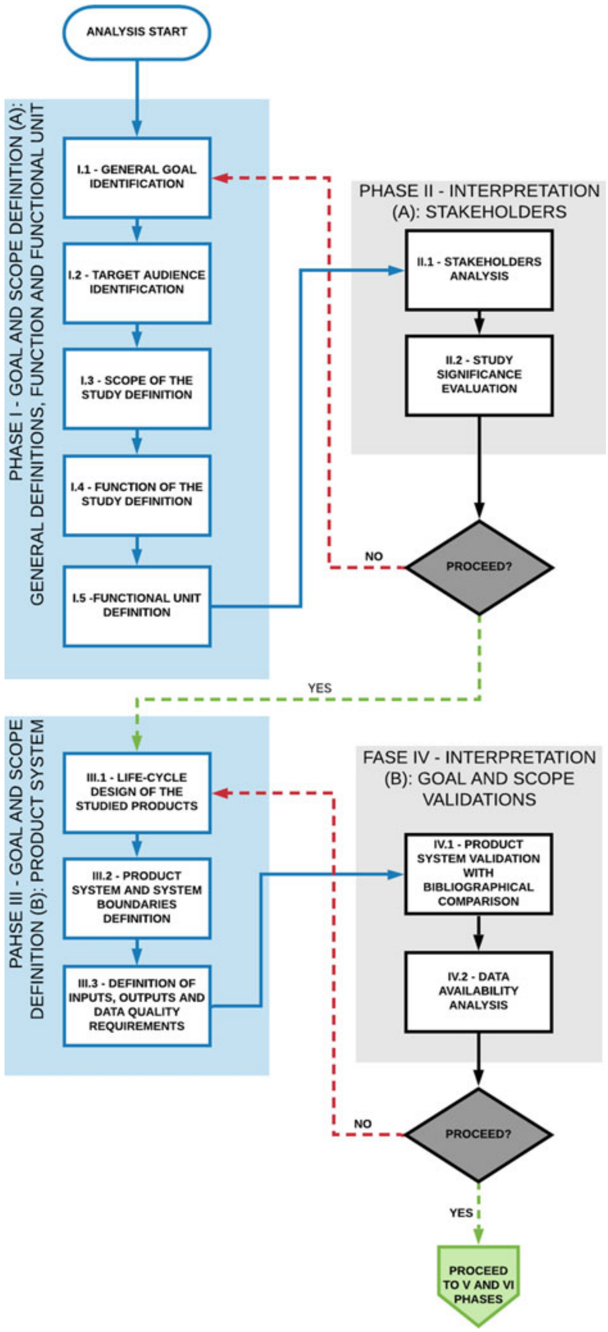

Fig. 1 Detailed flowchart of the proposed methodology of this work—Phases I to IV

the company that develops the enterprise, the public administration, construction workers, subcontractors and outsourced service providers, competitors, banks, insurance companies, representatives of the surrounding community, the general public, and others) [25].

Phase III, Goal and Scope Definition (B) begins by defining the product system, inputs and outputs, which determines the life cycle design of the studied facility systems, as well as the system boundaries. At this level of the analysis, it is necessary to trace the processes and phases involved in the life cycle of the hydraulic installations from the production of the component materials to the final disposal of the system after the operation phase. Conducting the life cycle design of the studied products leads to item (III.2), where the product system and system boundary are to be determined. Item (III.3), presented in Fig. 1, necessitates defining the inputs and outputs of the product system and data requirements. In this work, the most important issue when building up the inventory of database is the quality, relevance, accuracy completeness, and representativeness of the data due to technological and profile changes of the products used to HWBS, taking into account the type and location of installation, consistency and reproducibility of the products.

Phase IV, Interpretation (B), refers to validate the product system. For this, a comparison should be made between the determined life cycle and product system for analysis with other similar related studies and make adjustments that the professional deems necessary to make the system as objective as possible with respect to the results. This factor is extremely important to the legitimacy of the study, since the geographical location and the local social and environmental profile have a direct influence on the quantification and qualification of the impacts of a product system represented by a building installation.

The second sequence of the detailed flowchart of the proposed methodology if this work is illustrated in Fig. 2, represented by Preliminary System Design Development (Phase V), Inventory Analysis (Phase VI), and Interpretation (C) (Phase VII).

Phases V and VI should begin concurrently or sequentially, as the first step in the inventory phase is to define and organize data sources to enable collection, organized according to requirements. In order to obtain these, it is oriented to use an internationally consolidated database, since the exact obtaining of the production processes involved denotes time and resources. However, such a process may lead to variability of results with respect to the actual life cycle of the examined system and compromise the reliability and requirements of the data. Data collection at this level of the analysis may involve the need for bibliographic and market research that fosters the assembly of product system processes and guides the volume of materials consumed for them.

Phase V consists of the preliminary design of building systems for analysis objects for the primary purpose of obtaining the data necessary to foster life cycle inventory analysis, as presented in Fig. 2. Hence, four main sequential activities related to good engineering practices are to be defined, as follows:

An architectural assessment of the needs and demands of the building should be carried out. The project layout should be defined, taking into consideration elements

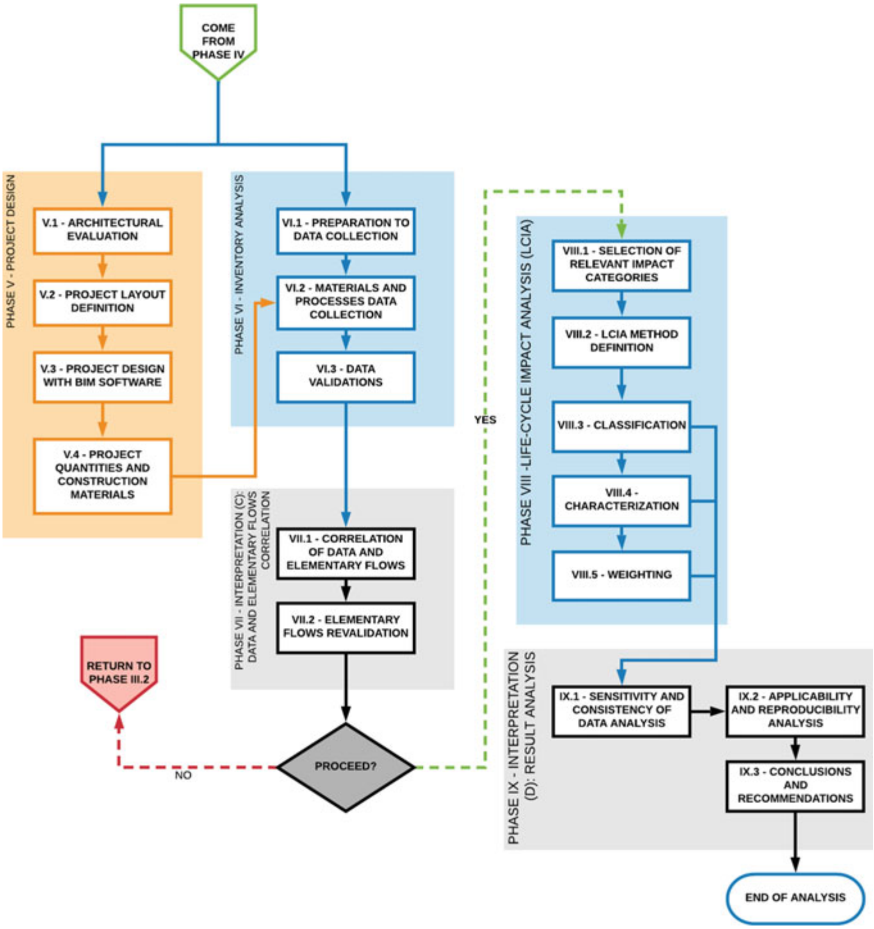

Fig. 2 Detailed flowchart of the proposed methodology of this work—Phases V to IX

such as technical reserve location, water or power inlet leasing, internal distribution pipe division, better leasing of equipment needed for system operation.

The effective elaboration of the projects should be considered based on the current norms and available database. Hence, one should seek to understand the level of details that the project necessitates to meet the requirements of the LCA methodology such as the specifications of buildings components, taking into consideration that the LCA methodology involves processes such as “cradle to grave”, that is, from the extraction and manufacturing phase until the end of life; “cradle to gate”, that is, from the extraction until the end of manufacturing phase; “cradle to cradle”, that is, from the extraction and manufacturing until the end of life and recycling to be reused again [13]. The project materials and construction components should be quantified, considering the use of the products that will actually be installed to increase the reliability and completeness of the data obtained.

Phase VI, inventory analysis, is the elaboration phase of the projects that ends up with obtaining the list of materials that fosters the inventory data. The data collection requires obtaining data related to the life cycle of the components of the HWBS; a factor that is intended to be performed with the help of a database, such as Ecoinvent. This phase necessitates guiding the modeling of the product system with the aid of LCA software, such as OpenLCA. System modeling often involves the combination of basic processes and raw materials in the database to obtain the desired products [26], a factor that can create uncertainties in the process, given the insufficient knowledge obtained about the process. Production or misuse of processes. At this level of the analysis, the data collection stages consider the database collections, materials and processes data collection, and culminate in the data validation. The data collected in the inventory should be evaluated against the data requirements defined at the beginning of the study in a way to determine the relevance or discard of collected data by screening the material.

Phase VII is Interpretation (C), where the correlation of data and elementary flows is ranked in the classification of the collected data according to the defined flows for the studied functional unit [27]. Thus, it is verified whether all flows considered have consistent and sufficient data for the elaboration of the LCIA, if other data are needed or if there is not enough data available for the definition of all flows. At the end of this analysis, a decision should be taken whether to continue the process or to redefine and redo the completed phases to ensure concise results. The carried inventory and the refined product system facilitate proceeding to the LCIA and final interpretations, which are detailed in the figure, Fig. 2, which demonstrates the final phases of the proposed methodology of this work.

Phase VIII, LCIA, means selecting the relevant impact categories to the study, taking into consideration the history of application of LCA for analysis of hydraulic systems. The major impact categories, as previously presented in Table 1, can be exposed to global warming, human toxicity (carcinogenic and non-carcinogenic), shortage of fossil resources and mineral resources and waste, impacts considered directly related to the building systems of employment of the study. The next step after selecting the impact categories, the LCIA step is to be conducted according to the item (VIII.2), illustrated in Fig. 2. Hence, it is important to consider the midpoint impact assessment, which has less data uncertainties [28], using an impact assessment method such as ReCiPe, which combines the Eco-indicator 99 and CML methods, giving them an update regarding the content, deriving characterization factors according to a midpoint approach (with 17 indicators) or endpoint (with 3 indicators) [29]. There is a fundamental relationship between midpoint indicators, direct impacts, and endpoint indicators. The structure overview of ReCiPe impact assessment method is presented in Fig. 3 [30]. Phase IX, Interpretation (D), which necessitates evaluating the completeness, sensitivity and consistency of the data.

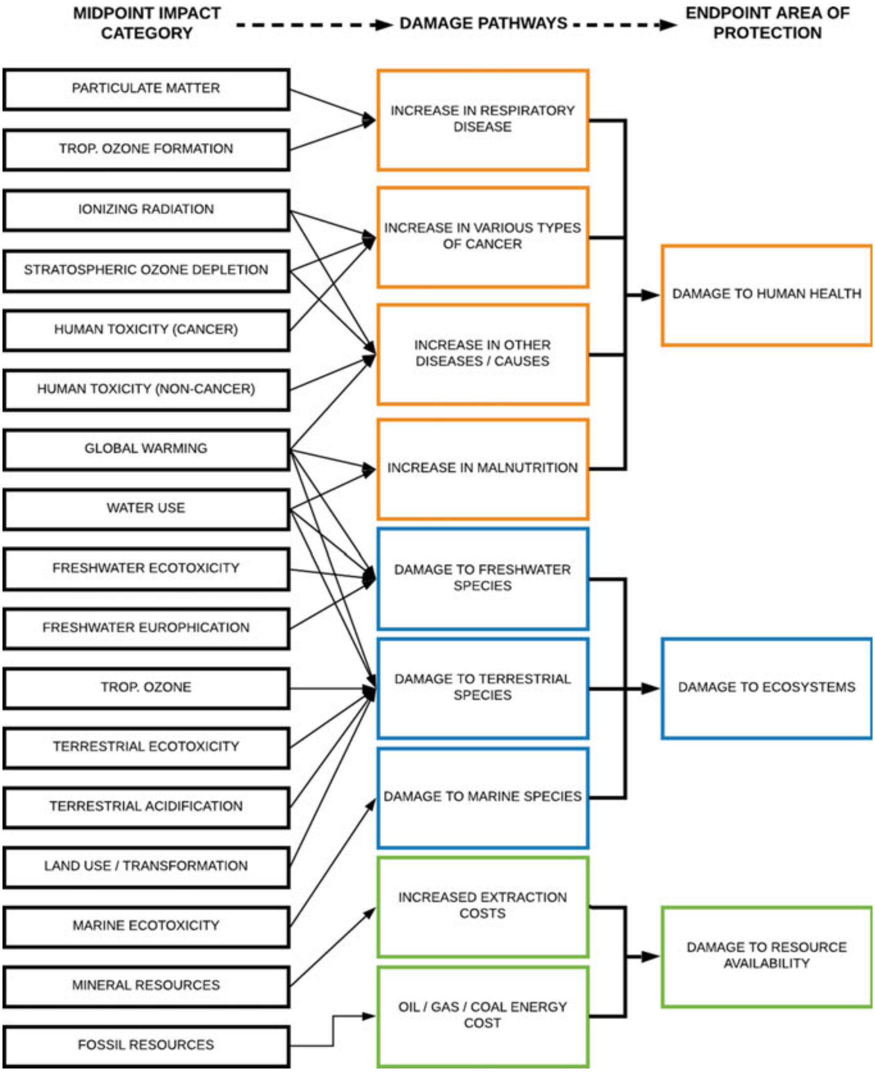

Fig. 3 Structure overview of ReCiPe impact assessment method (Adapted by RIVM [30])

4 Results

A multifamily residential project designed with five buildings interconnected by patio and access corridors, called "Quilombo da Gamboa", was chosen as a case study, which will constitute a housing complex with 116 apartment units.

The main definitions of step (I) are presented, with the objective, scope and functional unit. The general objective was to apply the life cycle assessment method to obtain environmental performance information for a hot water building system with natural gas heating, compared to a hot water building system with a thermal solar heating source, taking into account the executive particularities of the project and the peculiarities of the site. Already the scope of work in relation to the application of LCA methodology for two situations of HWBS's arrangements, considered the relevant equipment installed, the layout and preliminary sizing of pipes, as well as launching the positions of the consumer devices (considering only the showers of bath in each apartment), appliances and heating systems. On the other side, consumption of hot water for cooking, washbasins and other secondary activities was neglected, taking into consideration that it is desired to obtain only the heating performance related to the bath, which is the biggest consumer of water and electricity converted into thermal in homes in the country. The pre-operational and operational phases of the chosen building systems were considered, defining a useful life of 25 years. Finally, the functional unit for the study was configured as a performance unit, fixed according to the parameters necessary for the analysis. In line with the above, the functional unit was defined as the "volume of water at a temperature of 40 °C, necessary for a bath with an average duration of 5 min, in a shower installed in the system, for an estimated lifetime of 25 years". At this level of the analysis, phase (II) was not carried out, taking into consideration that the presented projects were not submitted to an effective decision making by which party should be taken in the case of the hot water installations of the buildings.

The product systems in the pre-operational and manufacturing stage and an operational stage were defined in phase (III). After defining the product systems, the study proceeded with the step of determining the reference flows (building materials of the system and the processes and energy related to its manufacture and transportation; energy and water consumed; environmental interventions), related to the inputs and outputs of the processes involved in the proposed systems. In phase IV, for the validation of the system, it is concluded that for the application of the production processes of the building system component materials, the Brazilian market, there were no databases that sufficiently cover the entire chain. Thus, this work opted for the use of the global market, within Ecoinvent, widely used for LCA studies by the academic community.

In phase V, the projects for the two study systems were elaborated; the installation of the Hot Water System by Gas Heating and via Solar Thermal Heating. For the first system, the design of the bath water heating system was structured so that the supply starts with the connection of the system with the public network of the local concessionaire, installed in the public logotype, and the from the general supply, individualized measurement of gas consumption for heating of each residential unit belonging to the set of buildings is carried out. The gas heating system for the housing complex was made up of individual passage heaters for each unit. For the second system, the project was structured from a solar collection system, with solar collectors, installed in the highest location of the building with water supply for heating through an exclusive branch derived from the upper reservoir of cold water available for each building block. The water will be destined to the collection of solar collectors through copper tubing with thermal insulation, and will be forced to circulate, with a centrifugal circulation pump. For the hot water reserve, a general thermal reservoir located on the roof will be provided, from which the apartments' supply barrel will be derived, which will have columns of exclusive CPVC pipe[1] hot water, with consumption meters. The system was completed with the use of an electric shower.

Phase VI represents the analysis of the inventory in line with the developed project, gathering information on the building materials of the systems, considering a pre-operational stage, which goes back to the extraction of raw materials, manufacturing and transportation of the systems. Components up to the construction of the system and other related to the operation itself, which involves energy consumption during the life of the system, eventual maintenance and other factors. Hence, the OpenLCA software and the Ecoinvent database were used in the modeling of the product system.

For the HWBS inventory with heating via natural gas according to the definitions of the product system and its borders, the components considered were: CPVC piping for the conduction of the heated water from the heater to the point of consumption, copper tubing for conduction of natural gas, passage heating devices (aluminum and copper), shower installed in the bathrooms of the apartments (painted ABS), gas meter installed at the entrance of the branch (aluminum alloy) and closing record of the same (aluminum alloy) copper). In relation to the manufacturing processes associated with the materials, it was considered: for CPVC piping—PVC chlorination, extrusion and injection (for connections), for copper piping and passage heating devices—extrusion and drawing for showers—injection and chrome plating, for gas meters—pressure casting and for registers—casting and machining.

For the HWBS inventory with solar thermal heating and electrical complementation according to the product system definitions and its borders, the components considered were: CPVC pipe for water circulation for heating by solar collectors, PVC pipe for drinking water supply from the heating system, solar collectors, thermal reservoir with different capacities for reserving and reheating water with electrical supply and internal resistances, centrifugal pumps for forced circulation of water by the heating system, hydrometer for measuring the hot water consumption of apartment columns, column closing record and shower for use. Regarding the manufacturing processes associated with the materials, the following considerations have been done as follows: for CPVC piping—PVC chlorination, extrusion and injection (for connections), for PVC piping—PVC chlorination, extrusion, injection (for connections) and chrome plating, for solar collectors, thermal quenching, molding, extrusion, casting, centrifugation, polymerization and molding, extrusion and drawing, for reservoirs—lamination, assembly, casting and centrifugation, for pumps—casting, machining and assembly, for water meters—casting, for records—chlorination of PVC and injection and for showers—injection and chrome plating.

Phase VII was initially determined to define the absolute values applied to the functional unit, which considers only one shower installed in the system consisting

[1]Hot water piping systems in Brazil are usually built with CPVC (Chlorinated Polyvinyl Chloride) pipes, a polymer obtained by the industrial chlorination of PVC (Polyvinyl Chloride), which is used as material in the fabrication of pipes for cold water systems. The chlorination process gives the material high temperature resistance properties.

of 116 units. These data were considered as inputs of the product system modeled within the OpenLCA software. In phase VIII, regarding the calculation of impacts, the ReCiPe midpoint method was considered, which encompasses 18 different impact categories, of which the most important categories were defined for analysis: global warming, human toxicity (carcino-genic and non-carcinogenic), shortage of fossil resources and mineral and waste resources, impacts considered directly related to the building employment systems of the study. However, phase IX presented the midpoint impact categories compared between the two systems, in normalized values. At this level of the analysis, a normalized result for the ReCiPe midpoint impact categories is presented in Fig. 4.

It can be realized that for 14 categories presented in Fig. 4 that the impacts generated by the HWBS with gas heating are higher, for the considerations made in the study. HWBS with solar heating and electric complement only contributes more to the impacts of water consumption, land use, carcinogenic human toxicity and scarcity of fossil resources. The factor corroborates with expected results from the bibliography, insofar as the SHS consists of a source of clean main energy, without consuming fossil resources, for example. Even so, factors related to the production chain of component materials contributed strongly to several categories of impact in both systems. With regard to water consumption, it is noted from the analysis of the results of the category that the greatest contribution to the consumption of this resource by the SHS consists in the use of hydroelectric energy matrix electricity. The result demonstrates that the SHS tends to be less polluting than the gas source, however, in a practical application, in which there is a need to combine it with another energy source so that the system fully meets the demand, performance environmental impact on factors such as water consumption.

The impact category represented by human carcinogenic toxicity consists of another factor in which the SHS has greater influence, a factor associated with the treatment of residues from the production processes of the components, mainly the solar collector, such as red mud residue from bauxite production. With regard to the scarcity of fossil resources, the impacts generated by the HWBS with heating via NGHS represent only (11.49%) of the impacts generated by the system with SHS, a factor directly associated with the pipe used for the heating system via SHS, the HWBS, composed with polymer produced from the cracking of oil. Among other categories of relevance to the systems is global warming, measured by equivalent CO_2 emissions. It is noted that the carbon emission of the SHS represents approximately (82%) of the emission obtained with the heating system via NGHS.

Regarding the impact category represented by the scarcity of mineral resources, the impact analysis shows that the system with heating via NGHS contributes more than twice as much to the impact as the system via SHS, a factor directly associated with the use of the pipe copper for gas supply and distribution. It is shown that the greatest contribution to the impacts generated by the SHS consists of the life cycle of the collectors (60.72%), a factor directly linked to the pre-operational phase, and that the operational phase makes little contribution to the presented impact categories. On the other side, the system with heating via Natural Gas has a strong influence of

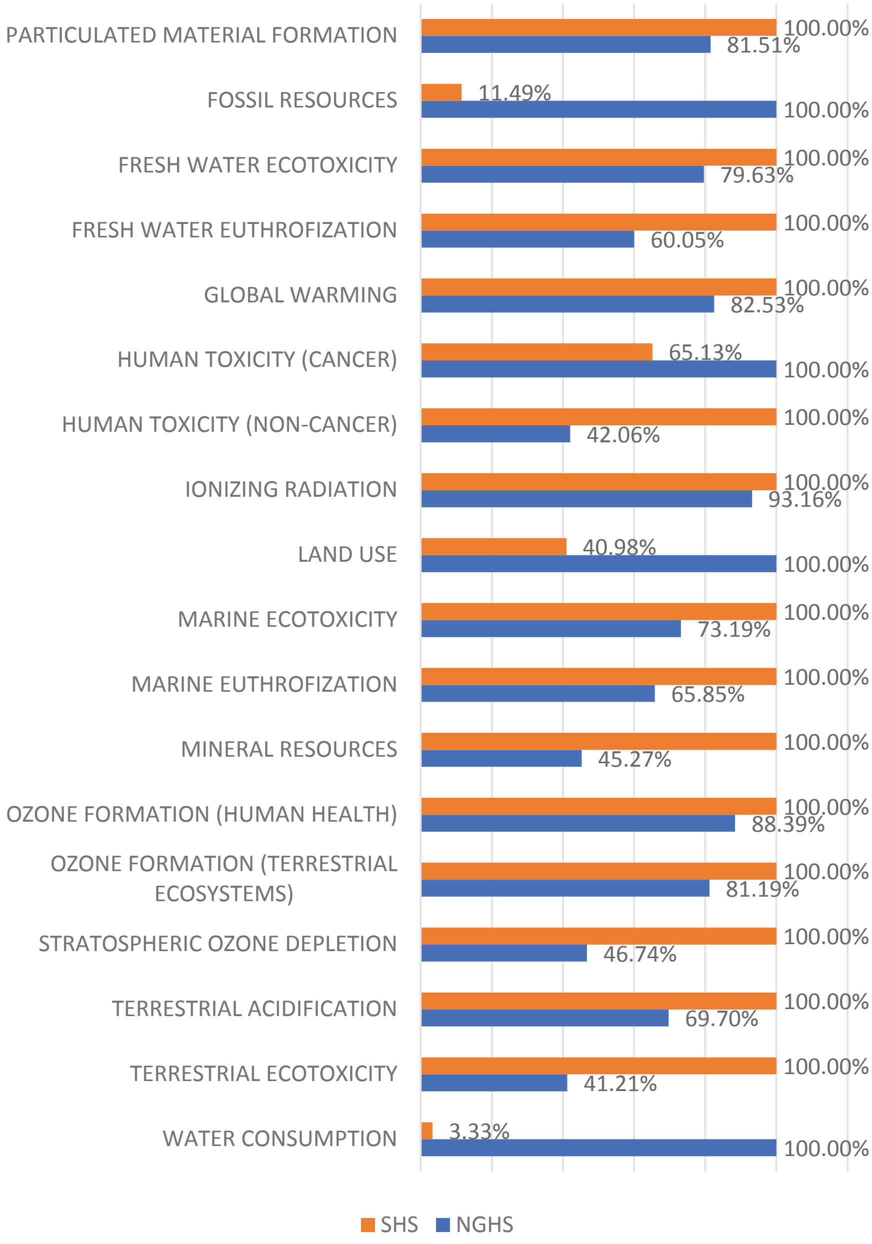

Fig. 4 Normalized results for the ReCiPe midpoint impact categories (H)

the operational phase, considering that, according to the Fig. 4, approximately (73%) of the impacts generated are associated with the supply of natural gas to the system.

In conclusion to the results obtained, it can be inferred that the HWBS with heating via SHS has better environmental performance than the system with heating via Natural Gas, even though the first one uses an electrical complement for operation appropriate. In most of the impact categories analyzed, the system in question is more advantageous than gas, a factor that must be associated mainly with the consumption of energy resources throughout its useful life, considering that the use of irradiation solar contributes a lot to the decrease in energy demand by another source, even if it does not eliminate it entirely. Furthermore, another important factor for performance was the use of CPVC piping for distribution. In the case of the gas system, the use of copper piping has a strong influence on the addition of several analyzed impacts. Finally, it is important to highlight that the SHS has a higher volume of infrastructure applied to the assembly process, causing higher initial resource consumption, however, this factor is balanced, over time, by lower consumption of energy resources for operation.

5 Conclusions

This work aims to present a proposal for a method derived from the general Life Cycle Assessment methodology in order to compare the environmental performance of two distinct Hot Water Building System for multi-family residential developments, through thermal heaters installed on the final roof of buildings, with supplementation of electrical supply, so that accurate information on the environmental performance of the systems can be obtained. However, the installed distinct Hot Water Building System considered in this work are Natural Gas Heating System and Solar Heating System. The novelty of this work is in the application of an environmental management method to empower the decision-making process and encourage the selection course of Hot Water Building System, considering the technical and economic aspects at an early designing phase of buildings.

The proposed method recommends the analysis of the life cycle of Hot Water Building System still in the initial phases of building design, from a cradle-to-gate perspective, including primary extraction of the component materials, processing and production and transportation to the place of execution of the projected installation, so that the energy incorporated into them and their biogenic emissions are considered and give greater dimension to the impacts of the systems, as well as considering information on the use profile of these building systems over its useful life, such as water and energy consumption for heating, bringing to the beginning of the lifecycle of buildings a range of information that allows the designer to make a clearer decision regarding which component system and materials to use in the project and its reflexes to the building and its surroundings.

The proposed method of this work has some limitations regarding its implementation. For example, the results of the application will provide a complex set of numerical values for the environmental impact indicators and a report with all related assumptions elaborated during the analysis, which makes interpretation of results by non-specialists in Life Cycle Assessment difficult, especially if there is no comparative pattern, which is a notable determining factor in the results of the analysis carried out for buildings and building systems, which they still relate to external triggers such as customer demands, government incentives or regulatory obligations acting on the context of formation and installation of building projects. Another limitation refers to the lack of an inventory database for South America, and, for local studies, it is usual to apply Life Cycle Assessment using existing data on global bases, a factor that distances the results from reality application locations. Still on the regionality of the studies, it is necessary to highlight the heterogeneity of the natural, cultural and economic profiles among the localities of the region, a factor that distances even more results based on global databases from a localized reality.

On the other hand, the determination of a methodological standardization regarding the application of Life Cycle Assessment for building systems allows more professionals to be involved in this process, and data can be obtained from the results of applications in buildings, which can be a parameter for other studies on similar buildings and promote an information chain that can bring. The objective of this work is to obtain precise information about the environmental performance of Hot Water Building System as an alternative to the conventional system widely used in Brazil, which consists of heating by electric means, concludes that the System via SHS is the one with the best environmental performance when compared to the system via NGHS. However, as reported, many variants must be taken into account with regard to the data obtained and their reliability.

The size of the Hot Water Building System has a direct influence on the potential environmental impacts, since SHS needs a much more robust installation infrastructure than the heating system via Natural Gas, a factor that can weigh on its performance. The gas system uses a fossil heating source, which has a potentially polluting production chain, while the solar system uses natural radiation available in the atmosphere. In this way, the time of use can counterbalance the installation factor with respect to the potential polluter: an analysis that encompasses the entire useful life tends to favor the application of the solar system to the detriment of gas. Factors of real importance for the data obtained still consist of the regionalization of the application and the uniqueness of the systems, considering that the architectural layout of the buildings is mandatory for the arrangement of the facilities, the place of application and the availability of resources.

The collected results may have significant variability of some magnitude being altered, and may not accurately reflect the local reality, also considering the use of international databases, such as Ecoinvent, to obtain information about the production chain of the building materials for building systems. However, the important value obtained, which consists in guiding the profile of the implementation of the hot water building system for a residential development, is maintained as, with the results, one can have an idea of which system is more advantageous to implement for undertakings of the same size as the one under study, also considering factors external to the environmental issue, such as the availability of installation and maintenance resources throughout the operational life of the installed equipment. Hence, it is suggested that data improvement be carried out with regard to obtain regionalized data for the national market, and even more for regional markets within the scope of the projects, so that a database can be created as a result of applying similar studies to building systems for use by designers and companies in the design decisions of enterprises and their subsystems.

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