Life cycle energy (LCEA) and carbon dioxide emissions (LCCO2A) assessment of roofing systems: conventional system and green roof

Júlia Santiago de Matos Monteiro Lira

University of Brasília, Department of Civil and Environmental Engineering, Brasília (DF), Brazil
juliasanttiago@gmail.com

Rosa Maria Sposto

University of Brasília, Department of Civil and Environmental Engineering, Brasília (DF), Brazil
rmsposto@unb.br

ABSTRACT: With the increase of urban occupation and therefore the constant need of new buildings, the concern about its environmental impacts grows recently. Thus, is demanded the research on the concept of buildings considering the economy of resources, especially energy. Green roof is an ancient alternative to reduce the effects of heat islands and global warming, providing architectural, construction, aesthetic and environmental benefits. The efficiency of thermal performance of this system is already known, however, aspects related to energy and environmental sustainable, including CO2 emissions, are still poorly studied. Therefore, the study of sustainability of this alternative of roof is necessary, considering the full life cycle of it to evaluate the energy consumption and CO2 emissions. The aim of this study is to evaluate the sustainability of a green roof compared to the conventional system made of concrete slab with ceramic tile. Green roof system used in the research is the modulate type with structure in solid wood beams and closure in structural plywood sheets. The comparison will be done through the life cycle energy (LCEA) and carbon dioxide emissions (LCCO2A) analysis in the extraction and processing of raw materials, transport, construction and maintenance phases. With the research results, the green roof confirmed the reduction of CO2 emissions the life cycle, but it has a higher embodied energy than the conventional system.

Keywords *Green roof, Sustainable, Life cycle assessment, Life cycle energy, CO2 emissions.*

ISBN: 978-85-92631-00-0

1. INTRODUCTION

The building sector consumes an estimated 30 to 40% energy worldwide and it is responsible for 40% of total primary energy consumption in European Union (Contarini et al. 2015; Coma et al. 2016). Greenhouse gas emissions totaled in 2014 an average of 2.4 tCO_2 per capita in Brazil (Brazil 2015). The data are alarming and the responsibility of countries to reduce environmental impacts by human activities is growing. The COP 21 (ONU Climate Conference), that took place in December 2015, was a global framework to reduce carbon emissions and to mitigate the effects of global warming.

According Coma et al. (2016), the construction sector is an effective way to achieve the reduction of energy consumption and CO_2 emissions, aiming sustainable buildings with more energy-efficient. Some technologies have been employed to help mitigate the high energy consumption in buildings and the recurrence of floods in urban centers, i.e. green roofs (Savi, 2012). Sainz et al. (2006) stated that green roof is among several technologies for the development of environmentally sustainable buildings and the creation of urban environments visually appealing.

Brazilian laws are still insufficient about the use of this system. The state of Santa Catarina created a program to encourage the adoption of green roofs by Law Nº14243 (December 11, 2007). But the only law that establishes the obligation of the green roof use is Nº18112/2015 of Recife which provides the improvement of environmental quality of buildings obliging also the construction of accumulation reservoirs or the flow delay of rainwater to the urban drainage. This law establishes the mandatory use of green roofs for multifamily residential buildings with more than four floors and non-housing with more than 400 m^2 of area covered, under penalty of non-approval of the building.

A green roof differs from a conventional roof by having a substrate (soil or growing media) with vegetation (Peri et al. 2012). The addition of a green layer in building coverage causes many advantages, including: increased water retention, contributing to drainage and reuse of rainwater, reduced urban heat island by reducing of CO_2, sound absorption, aesthetic improvement of cities, increased biodiversity and reduction of habitat loss (Kosareo & Ries, 2007; Savi, 2012; Bianchini et al. 2012; Coma et al. 2016).

The benefits of this system are obvious, but the real potential to environmental sustainability should be measured, since the material impacts are also important because of its emissions and the use of raw materials during production and waste disposal (Contarini & Meijer, 2015).

The most appropriate tool to assess the overall environmental performance of a building and the quantification of its impacts, considering a wide range of categories of damage, is the Life Cycle Assessment (LCA). According to ABNT NBR ISO 14040 (2006), LCA is a method in which the product or process is evaluated in the life cycle's phases: extraction and production of raw materials, use, maintenance and demolition.

The choice for the quantification of energy consumption in the building life cycle (life cycle energy assessment - LCEA) is because prioritizes data inventory of energy consumption (direct and indirect). Although not use the concept of multi-analysis, characteristic of

ISBN: 978-85-92631-00-0

LCAs, a LCEA gives conditions for the evaluation of significant environmental impacts (Tavares, 2006).

In this work will be used a type of LCA to quantify two categories: the total energy consumption (LCEA) and CO_2 emissions (LCCO_2A) related with stages of the life cycle of the systems. They are simplified versions of the LCA that focus only on the evaluation of energy inputs and CO_2 emissions for the different stages of the life cycle and are already being widely used by researchers of construction as Atmaca & Atmaca (2015) and Chau et al. (2015).

1.1 Goal and scope definition

The aim of this research is to analyze the energy consumption and CO_2 emissions in the phases of life cycle of green roof compared to the conventional system of roof. The functional unit used was 1 m^2 of roofing for 50 years of housing life service.

The system boundaries including the phases for the two systems were: extraction and processing of materials and components, transport, construction and maintenance. Carbon sequestration that vegetation of the green roof promotes was not recorded because this operation phase was not analyzed.

2. DESCRIPTION OF THE SYSTEMS

2.1 Conventional system

The choice of the conventional system was the widespread used in Brazilians houses. The system consists of massive reinforced concrete slab with closure made by wooden structure with ceramic tile type Plan. The view of the housing roofing is shown in Figure 1.

Figure 1. Conventional system. Source: Pedroso, 2015.

2.2 Green roof system

There are two main types of green roof: the extensive and the intensive. Extensive roofs are lighter and are ideal for small vegetation because the system thickness is between 8 and 12 cm (Tavares et al. 2014). According to Céron-Palma et al. (2013), it requires low maintenance and a water retaining layer (Pereira, 2014). Intensive roofs are also known

ISBN: 978-85-92631-00-0

as vertical gardens by having larger plants. They have substrate thickness ranging from 15 to 50 cm and they can't be run on sloping roof (Pereira, 2014).

A green roof usually has the following layers: structural support, waterproof membrane, root barrier, drainage, filter, substrate and vegetation (Pereira, 2014). Although it is common to find green roofs on slabs, green roof is a building system that allows variations and application to different surfaces and structures (Tavares et al. 2014).

Looking for more sustainable and energy-efficient alternatives, in this research a system with structure in solid wood beams with closure in structural plywood sheets of the type Oriented Strand Board (OSB) was proposed as the basis for extensive green roof. The geomembrane of high density polyethylene (HDPE) has been used for waterproofing and under it lightweight cellular modules were composed by HDPE too. The choice of this modular system was due to the decrease in the total weight of the roofing and operational simplicity in maintenance phase.

A geotextile blanket was placed in the substrate layer within the module to facilitate storage and filtration of water in the modules ribbed. To reduce the need for frequent irrigation, the vegetation chosen were Cacto Margarida (Lampranthus productus). The green roof scheme is shown in Figure 2.

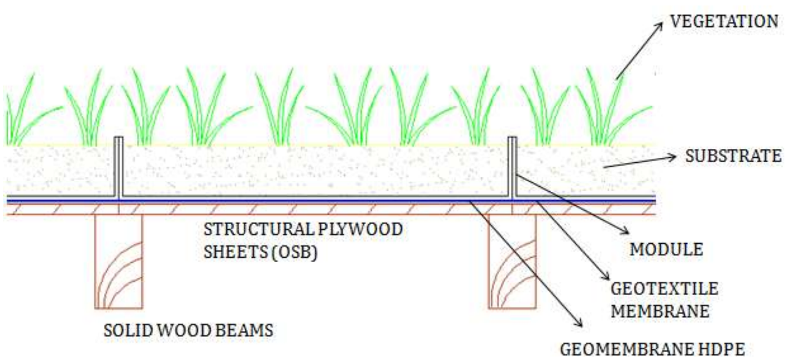

Figure 2. Green roof system. Source: Authors, 2016

3. METHODOLOGY

The study was applied in a housing unit approved by the Brazilian bank Caixa Econômica Federal used in the program "My House, My Life" representing the reality of social housing in the country. The same design was analyzed by Pedroso (2015) with the ground floor shown in Figure 3. The housing has 45.64 m²of built area distributed in two bedrooms, living room, kitchen, bathroom and an outside service area. The life service adopted was 50 years and the functional unit was 1 m² of roofing.

To standardize the transport distance, the building were located at the University of Brasilia (UnB) in Brasilia (DF).

ISBN: 978-85-92631-00-0

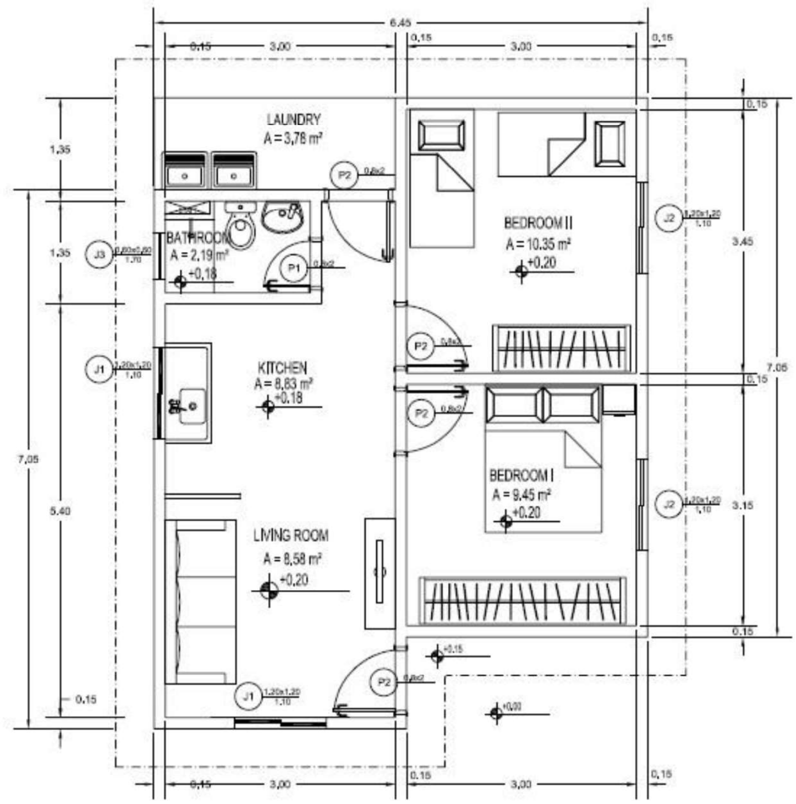

Figure 3. Social housing project for the deployment of systems. Source: Pedroso, 2015

The elementary concept of LCA is to calculate the environmental impacts of product over different life cycle stages: extraction, manufacture, construction, operation, demolition, recycling and disposal (Atmaca & Atmaca, 2015). To calculate the LCA and $LCCO_2A$, all energy inputs and CO_2 equivalent emissions released from a system in the pre-use and maintenance phase were quantified, respecting the ABNT NBR ISO 14040 series of standards. The calculation derived from a survey in national literature for the extraction of secondary data. They were used preferably from Brazilian documents to better adapt the production process and characteristics of the materials.

3.1 Pre-use phase

Based on the detailed architectural design of the Figure 3, materials and components used in the roofing of the two systems were raised. The pre-use phase was divided into three stages shown in Table 1:

Table 1. Stages of pre-use phase.

1	Extraction and processing of materials	Energy consumption (EE) CO_2 emissions (CO_2E)
2	Transport of materials and components	Energy consumption (ET) CO_2 emissions (CO_2T)
3	System construction	Energy consumption (EC) CO_2 emissions (CO_2C)

To calculate the energy consumption and CO_2 emissions from the extraction and processing of materials and components phase equations 1 and 2 were used. When necessary, used the coefficient of 0.036 $kgCO_2/MJ$ for energy conversion in CO_2 emissions

ISBN: 978-85-92631-00-0

was used. This value is the result of an average of the latest values from the National Energy Balance (BEN), if the FCO_2 coefficient in the studied sources did not exist.

$$EE = Q \times FE \tag{1}$$

$$CO_2E = Q \times FCO_2eq \tag{2}$$

Q – quantity of materials used in housing (Unit of measure - UM: kg or m^3);

FE – energy embodied factor (MJ/UM);

FCO_2 – emissions factor ($kgCO_{2eq}$/kg or $kgCO_{2eq}/m^3$);

EE – embodied energy of the extraction and processing of materials stage (MJ);

CO_2E – emissions of the extraction and processing of materials stage ($kgCO_{2eq}$);

In transport stage of materials and components to the construction site, the coefficients for the calculation of CO_2 emissions used by NaBut Neto (2011) were: average consumption of diesel equal to 0.0136 L/T.km and liter diesel emitting 3.15 $kgCO_2$/km. Throughout the transport phase, only CO_2 emissions will be quantified.

Table 2. Quantity of materials for 1 m^2 of roofing.

	MATERIALS AND COMPONENTS	QUANTITY		FE (MJ/UM)	FCO_2 ($KgCO_2eq$/UM)	TRANSPORT (Km)
CONVENTIONAL	CONCRETE (slab 10cm)	0.10	m^3	1002.40[1]	151.08[1]	14
	STEEL	0.14	kg	10.27[1]	1.55[1]	18
	WOOD STRUCTURE	0.04	m^3	9469.28[1]	58.55[1]	19
	ROOF TILES	86.20	kg	2.52[1]	0.63[1]	25
	PVC TROUGH AND COLLECTOR	1.76	kg	65.24[1]	5.92[1]	13
GREEN ROOF	OSB	0.02	m^3	23377.34[1]	501.95[1]	28.3
	BEAMS STONE ANGELIM 7x15 cm	0.02	m^3	9469.28[1]	58.55[1]	19
	BLANKET HDPE	5.25	kg	79.67[2]	2.87	1399
	MODULE PLASTIC (HDPE)	5.80	kg	79.67[2]	2.87	2131
	GEOTEXTILE BLANKET	0.20	kg	95[2]	3.42	758
	SUBSTRATE	60	kg	3.904[2]	0.14	11
	VEGETATION CACTO MARGARIDA	1.00	m^2	-	-	17
	PVC COLLECTOR	0.88	kg	65.24[1]	5.92[1]	13

[1] Saade et al. (2014)

[2] Lopes (2014)

For the systems' construction, formwork of wood and metal shoring were used for of concrete slab and vibrating equipment was used for thickening of the concrete, but only the material consumption has been recorded.

3.2 Maintenance Phase

In systems maintenance phase, each material or component that has a smaller service life than the service life of the system has a replacement factor (RF) which means how many changes will be needed throughout the building life cycle. The values were found in the scientific literature and technical (Table 3).

ISBN: 978-85-92631-00-0

Table 3. Replacement factor in the maintenance phase for 1 m^2 of roofing.

	MATERIALS AND COMPONENTS	QUANTITY		RF
CONVENTIONAL	CONCRETE	0.10	m^3	-
	STEEL	0.14	kg	-
	WOOD STRUCTURE	0.04	m^3	-
	ROOF TILES	86.20	kg	2.5(1)
	PVC TROUGH AND COLLECTOR	1.76	kg	-
GREEN ROOF	OSB	0.02	m^3	-
	BEAMS STONE ANGELIM	0.02	m^3	-
	BLANKET HDPE	5.25	kg	-
	MODULE PLASTIC (HDPE)	5.80	kg	-
	GEOTEXTILE BLANKET	0.20	kg	-
	SUBSTRATE	60	kg	9.8(2)
	VEGETATION CACTO MARGARIDA	1.00	m^2	-
	PVC COLLECTOR	0.88	kg	-

(1) Bengoa (2011)

(2) Lamnatou and Chemisana (2014)

4. RESULTS ANALYSIS

The comparison of each life cycle phase analyzed in this study between the two roofing systems. This allowed the observation of the environmental impacts of the green roof over the conventional system (used in large-scale in social housing) in relation to energy indicators and CO_2 emissions. The result of the stages of extraction and processing and transport of the pre-use phase transport is gathered in Table 4.

Table 4. Result of LCAE and LCCO2A in the pre-use phase to 1 m^2 of roofing.

	MATERIALS AND COMPONENTS	QUANTITY		EE (MJ)	CO_2E (kg CO_{2eq})	CO_2T (kgCO_{2eq})
CONVENTIONAL	CONCRETE	0.10	m^3	100.24	15.11	0.045696
	STEEL	0.14	kg	1.42	0.21	0.000034
	WOOD STRUCTURE	0.04	m^3	352.83	2.18	0.005295
	ROOF TILES	86.20	kg	217.22	54.31	0.029308
	PVC TROUGH AND COLLECTOR	1.76	kg	114.82	10.42	0.000311
	TOTAL			786.53	82.23	0.080644
GREEN ROOF	OSB	0.02	m^3	427.81	9.19	0.004226
	BEAMS STONE ANGELIM	0.02	m^3	180.96	1.12	0.002716
	BLANKET HDPE	5.25	kg	418.33	15.06	0.099905
	MODULE PLASTIC (HDPE)	5.80	kg	462.07	16.63	0.168087
	GEOTEXTILE BLANKET	0.20	kg	19.38	0.70	0.002103
	SUBSTRATE	60.00	kg	234.24	8.43	0.008976
	VEGETATION	1.00	m^2	-	-	0.000231
	PVC COLLECTOR	0.88	kg	57.41	5.21	0.000156
	TOTAL			1800.20	56.34	0.286399

In the construction phase, the use of materials such as wood and steel, occurs in the conventional system. The amount, with the total embodied energy and CO_2 emissions are shown in Table 5. The energy and CO_2 factors were extracted from Table 1, considering a metal shoring with cross pieces on wooden boards and closing in plywood.

ISBN: 978-85-92631-00-0

Table 5. Result of LCAE and $LCCO_2A$ in the construction phase to 1 m^2 of roofing.

MATERIALS AND COMPONENTS	QUANTITY		EC (MJ)	CO_2T ($kgCO_{2eq}$)
PLYWOOD FORM	0.01	m^3	187.02	0.001847
METAL SHORING	23.22	kg	238.47	0.000034
WOOD PARTS	0.01	m^3	121.56	0.000739
TOTAL			547.05	0.002620

The maintenance phase of two systems is presented in Table 6, with the total amount of energy consumption (EM) and CO_2 emissions (CO_2M) for the tiles (conventional system) and the substrate (green roof).

Table 6. Result of LCAE and $LCCO_2A$ in the maintenance phase to 1 m^2 of roofing.

MATERIALS AND COMPONENTS	QUANTITY		RF	EM (MJ)	CO_2M ($kgCO_{2eq}$)	CO_2T ($kgCO_{2eq}$)
TILES	86.20	kg	2.5	543.06	54.31	0.07
SUBSTRATE	60.00	kg	9.8	2295.55	8.43	0.09

The total values are shown in Figure 4 (in MJ/kg or MJ/m^3). It were obtained for both systems studied, correlated to the analyzed phases. The transport phase included all shifts: the material transport of plants or sale point to the building site in the maintenance phase.

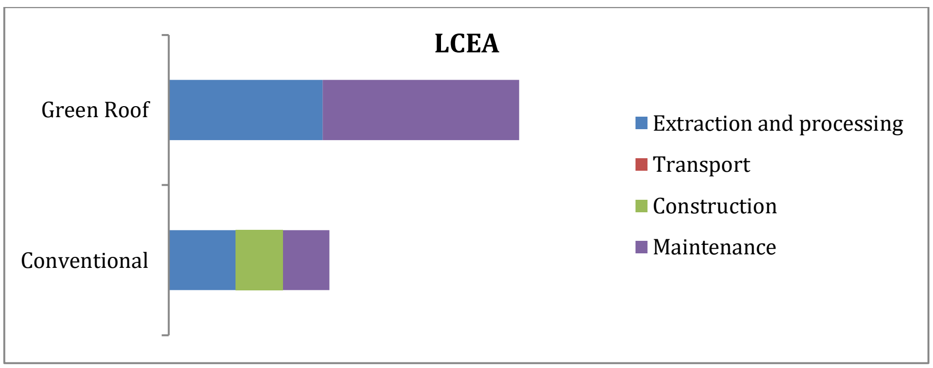

Figure 4. Result of life cycle energy to the two systems. Source: Authors, 2016

In Figure 5, the same results are presented for CO_2 emissions quantified in $LCCO_2A$. The results are in $kgCO_2eq/kg$ or $kgCO_2eq/m^3$ depending on the unit of measure of the analyzed material.

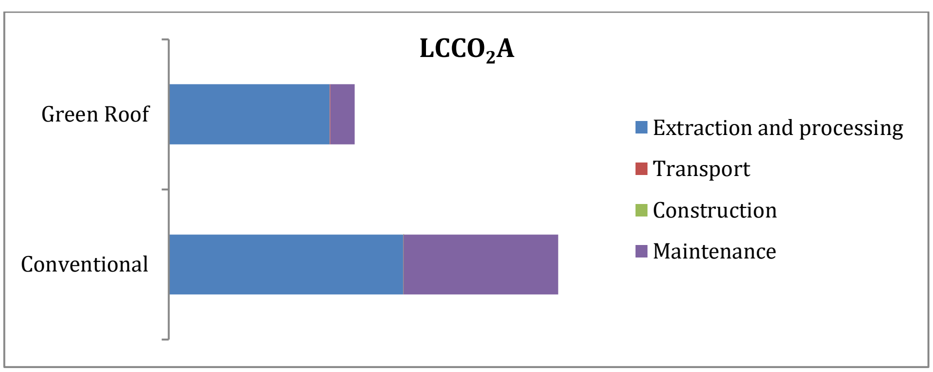

Figure 5. Result of life cycle CO_2 emissions to the two systems. Source: Authors, 2016

ISBN: 978-85-92631-00-0

With the results, it is observed that the higher energy consumption achieved by the green roof system was in the phases of extraction and processing and maintenance, because it has a frequent replacement of the substrate layer. However, in assessing the life cycle CO_2 emissions, the conventional system has a disadvantage. All total values of the phases of LCEA and $LCCO_2A$ are shown in Table 7.

Table 7. Result of all values of LCAE and $LCCO_2A$ in the phases to 1 m^2 of roofing.

	LCEA (MJ)		$LCCO_2A$ ($kgCO_{2eq}$)	
	Conventional	Green roof	Conventional	Green roof
Extraction and processing	786.53	1800.20	82.23	56.34
Transport	0	0	0.16	0.37
Construction	547.05	0	0.0026	0
Maintenance	543.06	2295.55	54.31	8.43

5. CONCLUSION

Two roofing systems were analyzed: conventional and green roof system. The first one is already used in large scale in Brazilian social housing. The second one is still not broadcast, offers numerous aesthetic, environmental, thermal advantages, among others. The methodology focused on the search for secondary data, especially national, to composition of the life cycle assessment.

It is noted by the results that the isolated energy analysis doesn't indicate the best solution, and neither the CO_2 analysis. The evaluation of the two combined of LCA seems to be more suitable to compose the environmental profile of the systems.

The conventional system has proved better in LCEA, but became worse in $LCCO_2A$. In the maintenance phase, the necessity for replacement of material in the conventional system has a high emission levels embedded, which is ceramic tile. the green roof replacement is the substrate, which is an organic material.

To confirm these values and extract other observations, it's necessary that in future work should be use primary dates or other databases used in Brazil. Other indicators should also be raised, such as the CO_2 equivalent, water footprint, among others, selected according to their importance in Brazil.

REFERENCES

Associação Brasileira de Normas Técnicas (ABNT). NBR ISO 14040. Gestão ambiental – Avaliação do ciclo de vida – Princípios e estrutura. Rio de Janeiro, 2009.
Atmaca, A.; Atmaca, N. Life cycle energy (LCEA) and carbon dioxide emissions ($LCCO_2A$)assessment of two residential buildings in Gaziantep, Turkey. *Energy and Building*, v. 102, p. 417-437, 2015.
Bianchini, F. & Hewage, K. 2012 How "green" are the green roofs? Lifecycle analysis of green roof materials. *Building and Environment* 48: 57-65.
Bengoa, X. Quantis Internacional. *Análise comparativa do ciclo de vida das Telhas cerâmicas versus Telhas de concreto.* Montreal: Anicer, 2011. 77 p. Disponível em: <http://anicer.com.br/acv/ACV Telhas Cerâmicas.pdf>. Acesso em: 18 maio 2016.
BRASIL. Empresa de Pesquisa Energética EPE. Balanço Energético Nacional 2015 ano base 2014. Brasil, 2015.

ISBN: 978-85-92631-00-0

Cerón-Palma, I. & Sanyé-Mengual, E.; Oliver-Solà, J; Montero, J.; Ponce-Caballero, C.; Rieradevall, J. Towards a green sustainable strategy for social neighbourhoods in Latin America: Case from social housing in Merida, Yucatan, Mexico. *Habitat International*, v. 38, p.47-56, abr. 2013.
Chau, C. K.; Leung, T. M.; Ng, W. Y. A review on Life Cycle Assessment, Life Cycle Energy Assessment and Life Cycle Carbon Emissions Assessment on buildings. *Applied Energy*, v. 143, p.395-413, 2015.
Coma, J.; Pérez. G.; Solé, C.; Castell, A.; Cabeza, L. Thermal assessment of extensive green roofs as passive tool for energy savings in buildings. *Renewable Energy*, v. 85, p.1106-1115, 2016.
Contarini, A.; Meijer, A. LCA comparison of roofing materials for flat roofs. *Smart and Sustainable Built Environment*, vol. 4, p.97 - 109, 2015.
Estado De Santa Catarina (Estado). *Lei Nº 14.243*. Santa Catarina, 2007.
Kosareo, L.; Ries, R. Comparative environmental life cycle assessment of green roofs. *Building and Environment*, v. 42, p.2606-2613, 2007.
Lamnatou, C.; Chemisana, D. Photovoltaic-green roofs: a life cycle assessment approach with emphasis on warm months of Mediterranean climate. *Journal of Cleaner Production*, v. 72, p.57-75, 2014.
Lopes, Thais Vieira. *Telhado verde, energia embutida e emissão de CO_2: uma análise comparativa a sistemas de cobertura convencionais*. 2014. 92 f. Monografia (Especialização) - Curso de Construção Civil, Universidade Tecnológica Federal do Paraná, Curitiba, 2014.
Nabut Neto, A. C. *Energia Incorporada e emissões de CO_2 de fachadas. Estudo de caso do steel frame para utilização em Brasília, DF*. Dissertação de Mestrado em Estruturas e Construção Civil, Publicação E.DM-009A/11, Departamento de Engenharia Civil e Ambiental, Universidade de Brasília, Brasília, DF, 117 p. 2011.
Pedroso, G. M. *Avaliação de ciclo de vida energético (ACVE) de sistemas de vedação de habitações*. Tese de Doutorado em Estruturas e Construção Civil, Departamento de Engenharia Civil e Ambiental, Universidade de Brasília, DF, 226p, 2015.
Pereira, M. F. B. *Conteúdo energético e emissões de CO_2 em coberturas verdes, de telha cerâmica e de fibrocimento: estudo de caso*. 2014. 148 f. Dissertação (Mestrado) - Curso de Engenharia Civil, Universidade Federal de Santa Maria, Santa Maria, 2014.
Peri, G.; Traverso, M.; Finkbeiner, M.; Rizzo, G. Embedding "substrate" in environmental assessment of green roofs life cycle: evidences from an application to the whole chain in a Mediterranean site. *Journal of Cleaner Production*, v. 35, p.274-287, 2012.
Prefeitura do Recife. Lei Nº 18.112. Recife, 2015.
Saade, M.; Silva, M.; Silva, V.; Franco, H. G.; Schwamback, D.; Lavor, B. Material eco-efficiency indicators for Brazilian buildings. *Smart and Sustainable Built Environment*, v. 3, p.54-71, 2014.
Saiz, S.; Kennedy, C.; Bass, B.; Pressnall, K. Comparative Life Cycle Assessment of Standard and Green Roofs. *Environmental Science & Technology*, v. 40, p.4312-4316, 2006.
Savi, A. C**.** *Telhados verdes: uma análise da influência das espécies vegetais no seu desempenho na cidade de Curitiba***.** 2015. 179 f. Dissertação (Mestrado) - Programa de pós-graduação em Engenharia de Construção, Setor de Tecnologia, Universidade Federal do Paraná, Curitiba, 2015.
TAVARES, S. F. *Metodologia de análise do ciclo de vida energético de edificações residenciais brasileiras*. Tese de doutorado, PPGEC, UFSC, Florianópolis, SC, 2006.
Tavares, S.; Lopes, T.; Savi, A; Oliveira, E. Telhado verde, energia embutida e emissão de CO2: análise comparativa a coberturas convencionais. In: ENCONTRO NACIONAL DE TECNOLOGIA DO AMBIENTE CONSTRUÍDO, 15, 2014, Maceió. Anais do XIV ENTAC. Maceió: ANTAC, 2014. P. 1-10.