Int. Journal for Housing Science, Vol.34, No.1 pp. 37-46, 2010
Published in the United States

LIFE CYCLE ANALYSIS OF CERAMIC VERSUS PAINTING MATERIALS APPLIED TO EXTERNAL WALLS

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ABSTRACT

The environmental impacts of a building are present in diverse stages of its construction and use. They are related to many factors, including the use of energy, emissions and hazardous materials. This paper presents the application of life cycle analysis to study different building facades, comparing the use of painting and ceramic lining technologies. The general objective of this study is to identify and organize the Life Cycle Analysis components of building facades constructed with ceramic tiles and paint, with the purpose of comparing the environmental performance with CO_2 emissions and energy consumption. The study includes definition of LCA objectives, scope, the subsystems and their boundaries, in order to compare emissions and energy consumption for the same durability criteria. The life cycle stages include raw material extraction, materials manufacturing, their use and maintenance. The flow diagrams for the processes and their related emissions are presented.

Key words: Life cycle analysis, Environmental performance of buildings.

Introduction

0146-6518/01/ 37-46, 2010

The significant increase in the emissions of greenhouse gasses has been affecting the world climate [1], with potential impacts to the hydrologic cycle including the frequency and intensity of floods and droughts. The consequences include disruption of local and national economies affected by rise of sea level, reduction in agricultural production, severe flood damages and water scarcity.

A significant amount of CO_2 (carbon dioxide) is emitted to the atmosphere by different phases in the life cycle of the building, starting on production of materials and equipments, construction and use of the building, maintenance and final demolition and disposal [2]. The total energy consumption in the construction industry [2] results in significant CO_2 emissions. These emissions can be quantified for a given set of energy sources available [2]. According to [3], the emissions of greenhouse gasses during the life cycle of the facades of commercial buildings are present during the building construction and operation of its systems.

The facade is a fundamental component of the building's envelope, providing insulation and protection of its users from weather elements such as sunlight, ultraviolet radiation, heat, humidity and wind. The design of the facade also influences the consumption of energy, not only through the materials and processes chosen, but also due to demands for heating and air conditioning during the whole life of the building. In the developed countries, building maintenance is as major aspect considered during its design and the design of its systems. This is corroborated by the existence of specific construction codes.

The general objective of this study is to identify and organize the LCA components of building facades constructed with ceramic tiles and paint, with the purpose of comparing the environmental performance through CO_2 emissions and energy consumption. Environmental inventory data is found in the Brazilian literature of the ceramic tile manufacturing considering the processes of humid milling and single burn. The inventory and processes flow diagrams are fed into the LCA software Umberto.

Life Cycle Analysis and Ceramic tile and Painting

Ceramic facades usually have higher durability comparing to facades finished with paint and ornamental textures. However, this advantage will only be effective if the ceramic covering is executed according to construction codes and manufacturers´ specifications and recommendations for application and use, including also preventive maintenance [4].
In the maintenance process, harmful microorganisms and substances accumulating on the facade are eliminated. However, accurate data on maintenance is usually lacking on literature, especially its direct relationship to CO_2 emissions.

Changes in the construction production chain, including products, suppliers, materials and processes can improve significantly the environmental efficiency and economy during the building usage [5]. For a building to be considered ecologically correct, it is essential to evaluate the environmental impacts of all their constituent parts. The Life Cycle Analysis (LCA) is a systematic approach that allows the evaluation of the building through its components and construction stages. According to [6], the criteria for selection of materials, components and systems for the healthy building site include incorporated energy, socio-economic materials and the use of Life Cycle Analysis as tool for quantification and comparison of results.

The Life Cycle Analysis (LCA) methods allow the analysis of the environmental impacts, inputs and outputs of the whole production chain of a product. A comparative LCA study for different construction materials and processes is useful in identifying and promoting environmental practices of excellence in the project, operation, administration and maintenance of the building, contributing to the reduction of emissions of CO_2 and to increase the energy efficiency.

The LCA basic structure starts with objectives and scope definition, identification of the systems and subsystems that will be modeled, the boundaries, the data specificity, the functional unit and comparison among systems establishing the context in which the evaluation will be made. It is fundamental the elaboration of the inventory that identifies and quantifies the environmental indicators that will be analyzed and interpreted. However, LCA doesn't determine which product process either is the most expensive, cheaper or of better operation. The information produced should be used to support the process of deciding which materials, processes and suppliers will have the least impact in the regional environmental context. The present work used is the LCA software Umberto of the *ifu Institut für Umweltinformatik Hamburg GmbH* (Institute of Environmental Computer science Hamburg Lda) developed with the cooperation of the *Comifeu-Institut für Energie- und Umweltforschung Heidelberg GmbH* (Institute of Energy and Environmental Research Heidelberg Lda.), Germany. The Umberto inventory database was improved with the use of Ecoinvent, an application of expanded inventory data of products which is constantly updated.

Computational Tool

Umberto is a program of environmental administration and analysis of material flow that models a system of processes and calculates the net flow of materials and energy. One of main resources is the ability to create and compare different scenarios in order to investigate processes and products alternatives. With this method, it is possible to identify the interdependence among processes and opportunities of economy of resources and energy in a Company's environmental management plan.
The evaluation Methods available in Umberto are:

a) Dutch - *Centrum voor Milieukunde* (CML), *Center for Environmental Science*, European –

b) Eco-Indicator 99, Swiss - *Environmental Load Factor*
c) The *Valution System Editor* –

The results can be presented through tables, graphs, illustrations or diagrams. The Sankey diagram is a flowchart of materials where the flow quantity is represented by arrows with proportional width to its mass or energy.

LCA Development

The LCA application in this study was based on the following methodology, which defines the analysis scope, purpose and data used.

- Objectives: To present the definition and description of the products and processes involved in the external finishing of buildings, from its production to the application stage in the maintenance phase. To elaborate inventory with identification and quantification of consumption of energy and of emission of CO_2, with the use of the software Umberto. To analyze the result of the inventory of the environmental discharges and of consumption of energy of the facade ceramic and of the paint. To Evaluate the environmental performance of each finishing, based on the generated inventory.
- Destination: To aid professionals in the construction sector in the choice of materials and constructive solutions environmentally sound.
- Subject: The system of ceramic finishing and acrylic painting applied in a facade. These are part of the system delimited in the Figure 1. The functional unit is the durability.
- Scope: Includes the stages of building facade production, use and maintenance, as well as construction materials production cycles. Two scenarios, one with application of ceramic finishing and other with application of acrylic painting are created to compare energy consumption and CO_2 emissions. For each cycle, the time of use of the product before it is discarded, the inputs used in the application process and maintenance, the typical frequency of maintenance and potential of reuse of the material are also considered. The recommendations for the use and maintenance are drawn from [7].
- Data: Most data was gathered through literature review and interviews with industry staff. This information was used to assemble the production chain of the different materials. The data relative to ceramic tile production is based on environmental study of floors, in the period from 2001 to 2003 [8]. This study considered representative companies producing tiles and bricks in the State of Santa Catarina, Brazil. Despite the different applications of the tiles (i.e. facade vs. floor) the production processes are sufficiently similar for the comparison proposed in the present work. Regarding production of the building paint, no

references were found with satisfactory data relative to environmental aspects of production. The latter is currently under further research with the industry.

- Analysis period: The total analysis period is 20 years, considering short-term carbon emissions impact through GWP (global warming potential). This avoids the increasing uncertainties related to GWP as the period becomes longer [9]. The parameter used for determination of the maintenance periods is based in the English norm BS 7543, which is a guide to durability of building and building elements, products and components. Therefore, the maintenance periods will be 20 years for ceramic tiling (8 years for supporting components such as mortar and grout) and 3 years for painting.

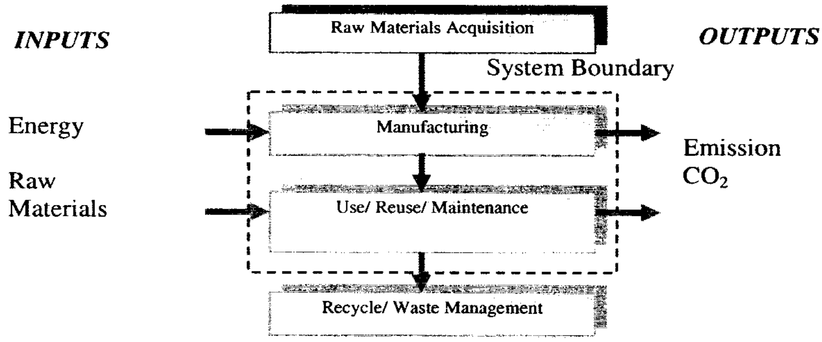

Figure 1 : Life cycle stages

<u>Umberto Application</u>

The material components of the life cycles subject of this study were input in Umberto, declaring the unit and type for each material, separated in groups (folders in Umberto). Different folders were created for energy, natural materials, products and transport (Figure 2).

In the sequence, two separate scenarios were created for ceramic tile cladding and painted facades. A network flow diagram was assembled for each scenario, with all of the processes associated to the study boundaries (Figure 2). In the ceramic production, the glazing process (referred to as T_5) is entered as a production branch joining the flow diagram. Once this branch does not follow the main production sequence, it must be modeled separately in a sub-network (Figure 2).

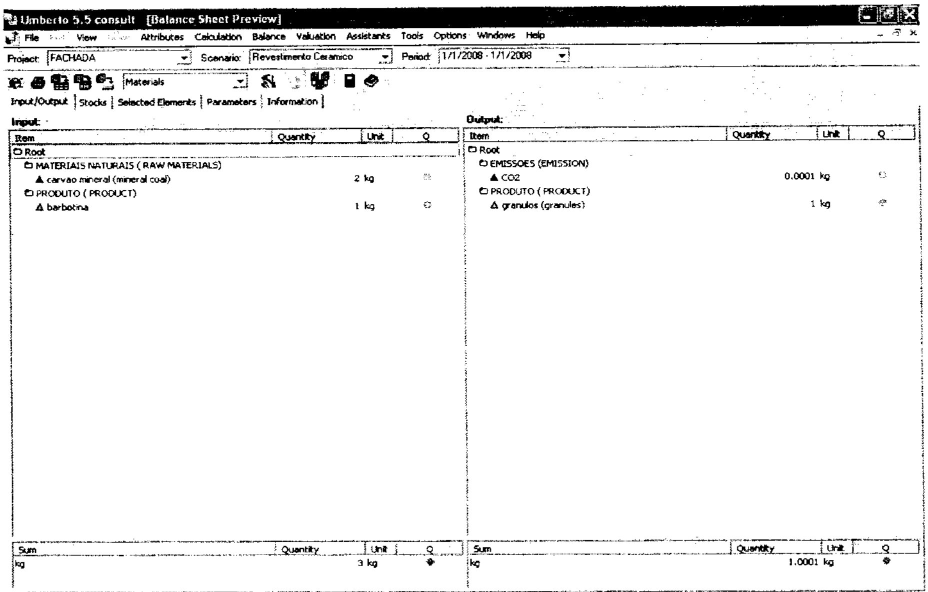

Figure 2 : Inventory of the phase of spray –drying granulation of manufacturing of the tile

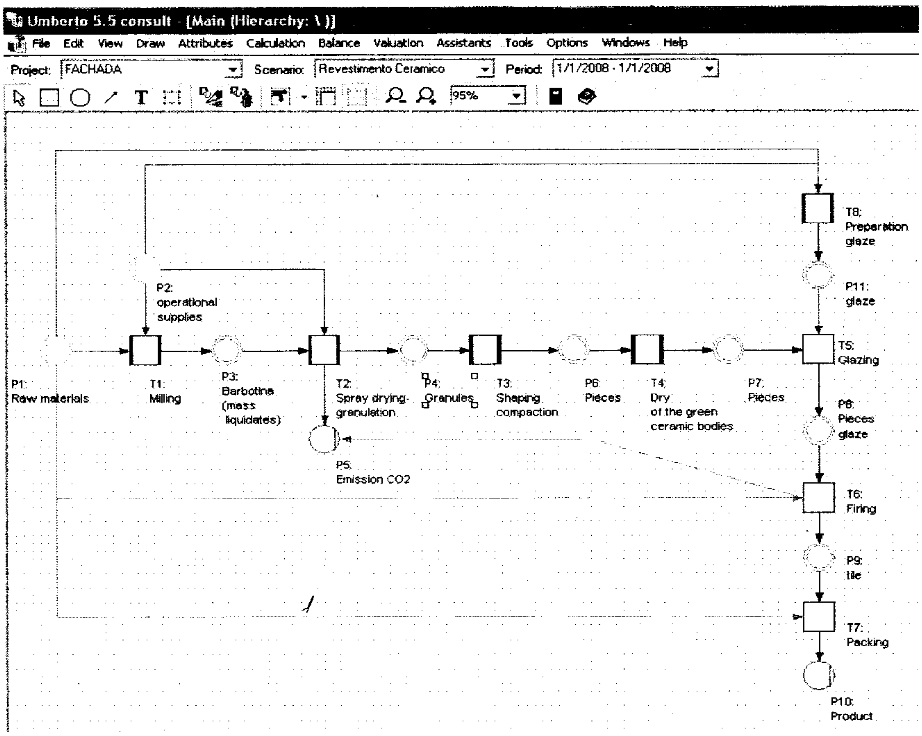

Figure 3 : Net process of manufacturing of the tile

Inventories of the production process, application and maintenance of the tile will be generated, as well as for the paint (Figure 4). The inventory will be shown in the edition window Balances Sheet (Figure 1). For better visualization, a Sankey diagram is used (Figure 5), with one letter represented the flow of materials and the amounts of flow are indicated by arrows with proportional width to their mass or energy.

Two scenarios were developed, one for ceramic tile cladding and other for acrylic painting. Modeling of these scenarios will include the stages of fabrication of components (ceramic tiles, paint, cement and mortar), application of the components in the facade and maintenance procedures. Each stage (subsystem) is represented as a sub-network in the flow diagram. The inventory will include data on CO_2 emissions and energy consumption for specific processes within the subsystems.

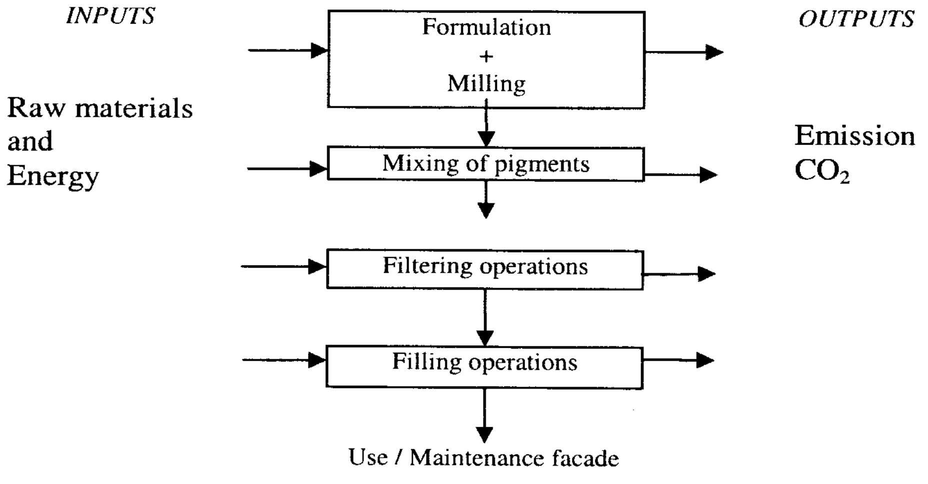

Figure 4 : Process of manufacturing of the paint
Source: Guia Técnico Ambiental – Tintas e Vernizes – CETESB

This set up allows multiple comparisons between and across scenarios, with quantitative evaluation of environmental factors. The scenarios can be compared in terms of global CO_2 emissions and energy consumption to point out which facade construction technology is cleaner regarding the environmental factors. Within each scenario, the stages can be compared to each other to identify the main sources of emissions and energy consumption, which can be targeted in cleaner production initiatives proposed by the construction firm. The scenarios can also be compared to each other to evaluate the emissions produced in the light of the regional environmental context and local susceptibilities to impacts. Finally, one can also evaluate the cost/effectiveness of improving maintenance efforts to reduce materials consumption and the subsequent impacts in the product life cycle.

Data

Inventory data for ceramic tile cladding is presented in Table 1, regarding the emissions of CO_2 and energy of the stage of production of tile. The energy consumption in the stage of production of the ceramic tile, per m², were 2,9 kWh, 1,379 kg of natural gas and 2 kg of mineral coal. The emissions of CO_2 were of 2,8301 kg/m².

Table 1 : Inventory of production of tile

Product: Ceramic	Amount / m^2			
Process: **Milling and Mixing**				
Raw materials	Amount	Energy		Emission CO_2
clay	25,35 Kg/m^2	elétrica	2,9 kW	----
water	5,01 kg	-----	-----	-----
defloculante	0,352 kg	----	----	----
Process: **Spray drying - granulation**				
Raw materials	Amount	Energy		Emission CO_2
mineral coal	2 Kg	-----	-----	0.0001 kg
Process: **Shaping compaction**				
Raw materials	Amount	Energy		Emission CO_2
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Process : **Dry of the green ceramic bodies**				
Raw materials	Amount	Energy		Emission CO_2
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Process: **Glazing**				
Raw materials	Amount	Energy		Emission CO_2
water	0,279 L	------	-----	-----
glaze, paint e solvent	0,335 kg	-----	-----	-----
Process: **Firing**				
Raw materials	Quant.	Energy		Emission CO_2
----------	------	natural gas	1,363 kg	2.83 kg
Process: **Packing**				
Raw materials	Quant.	Energia		Emission CO_2
Cardboard box	0,0848 kg	GLP gas	0,016 kg	-----
glue	0,00036 kg	-----	-----	-----

Source: Soares e Pereira (2004)

Expected Results

This is an on going research. The study proposed will provide quantitative information regarding energy consumption and CO_2 emissions in multiple stages of building facade construction. These results should be useful in identifying construction technology alternatives with reduced environmental impacts, as well as key stages within each alternative that could be improved for cleaner production. It will also be investigated the potential for reduction of emissions of CO_2 and consumption of energy in the stage of maintenance of the building and materials choice.

Conclusion

Given the present context of global warming uncertainties, the construction sector, due to its significant energy consumption and emissions, must thrive to find environmentally efficient solutions and technologies. The source of most problems and inefficiencies lies on the project and design stages, including materials and processes selection. The facade is a key component of the building's envelope. It must endure weather elements while protecting the building inner systems and providing adequate insulation for the users. The facade design, including the technologies, materials and processes chosen will affect the building during all its operational life, and will also generate impacts due to emissions and energy consumed to produce and assemble its components. The Life Cycle Analysis is a systematic method suitable to model and evaluate the facade production chain and the multiple subsystems involved in its construction. This method allows quantitative evaluation of environmental parameters, and it is capable of providing support to decisions involving environmentally sound materials and processes.

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