Environmental Savings Potential from the Use of Bahareque (Mortar Cement Plastered Bamboo) in Switzerland

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Environmental Savings Potential from the use of bahareque (mortar cement plastered bamboo) in Switzerland

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Abstract. The urgency for energy and material efficiency in the building sector increases every day. In the case of Switzerland, a building's main energy demand occurs during its use/operation phase and is mainly related to heating demands during the winter season. As a means of reducing these demands, current building practice in Switzerland is to insulate with 30cm of foam and to mechanically control indoor environments. Recent research has shown, however, that alternatives to current practice are readily available. With these alternative techniques, natural materials with low embodied energy are used to produce high efficiency building envelopes. The bahareque construction method (bamboo plastered with mortar cement) studied in this paper has been identified as a promising technology both in terms of producing energy efficient building envelopes and also with regards to reducing the environmental impact associated with the construction of buildings in Switzerland. The main objective of the research presented here was to identify the Environmental Savings Potential (ESP) of bahareque in comparison with state of the art technologies in Switzerland. The calculations were geographically limited to Switzerland and the main data sets used for the life cycle assessment models corresponded to this region. Specific datasets were developed for bamboo and bahareque to account for transoceanic transportation. The results showed that bahareque achieves an ESP of 32% compared with clay brick construction and 40% when compared with concrete block construction. It was shown that it is feasible to develop highly efficient building envelopes with low embodied energy that can be used within the Swiss context.

1. Introduction

The building sector is one of the major consumers of both energy and materials. For this very reason it can play a significant role in the quest for energy and material efficiency, the need for which is an undeniable fact[1]. In the case of Switzerland and other countries with seasons, the main energy demand occurs during a building's phase of operation and is mainly related to heating demands during the winter. Figures for energy demand are, however, changing due to the use of highly insulated and airtight building envelopes. Current practice in Switzerland is to insulate buildings using a foam layer 20 to 30cm thick. Other technologies are also employed to produce airtight buildings. However, the use of this kind of highly insulated envelope increases a building's usage of material and consequently its cumulative energy demand. The insulation materials themselves often have a large energy demand associated with their production, adding to their whole life environmental impact.

Goto et al [2] showed the potential in employing alternative techniques in which natural materials with low embodied energy are used to produce highly efficient building envelopes. It was also shown that this kind of building envelope has the potential to improve the economic, environmental and building physics performance of buildings[3]. In parallel to this work, the chair of sustainable construction at the ETH Zurich was developing research on the environmental impact of the use of bamboo as concrete reinforcement [4]. During this study a traditional construction technique in South America was identified as having interesting potential for the European construction industry. Bahareque is a composite construction method that uses bamboo frames, flattened bamboo, chicken wire mesh, and soil-cement or mortar cement plaster to produce lightweight load-bearing walls. The bahareque wall combines a highly renewable material (e.g. bamboo) with a highly durable plaster (e.g. soil-cement). Bahareque has been used in countries such as Colombia, Ecuador and Peru for more than 200 years, keeping the same constructive principles but introducing local variations. Over the past few years, these same countries have revalidated this technique by developing building codes and standards for its use. In order to identify the potential that the bahareque technique has for use in Switzerland, a comparative life cycle assessment study of bahareque and two construction techniques currently used in Switzerland was carried out.

To better understand the possibilities for using bahareque in the Swiss construction context, two main steps were taken. First, the heat transfer coefficients of a bahareque wall and two state of the art construction methods were theoretically calculated. Second, life cycle assessment (LCA) models for the bahareque and comparison construction methods were developed. These models were used to identify the following: the environmental impact of the three construction methods, the main process contributing to those impacts, and their Environmental Savings Potentials (ESP)[4]. To develop these models, datasets from the EcoInvent[5] database were used. SIMApro[6] was used to carry out the impact assessments themselves.

2. Methodology and data

Life cycle assessment has been established as the main tool for assessing environmental impact of products and services over their whole life span [7], including their use/operation and disposal. The methodologies for carrying out an LCA are defined by ISO standard 1440[8]. Four main steps are identified as follows: definition of goal and scope, definition of life cycle inventories (LCI), impact assessment, and interpretation. These steps, as well as how they were defined for this research, are presented in the following sections.

2.1. Definition of Goal and Scope

The main goal of the LCA described in this paper was to establish the feasibility of bahareque as a construction technique in Switzerland by assessing its environmental performance and its ESP when compared with two state of the art construction methods. The research was confined geographically to Switzerland and was limited to the study of the following three methods of construction: bahareque, clay brick, and lightweight concrete block. The LCA models were limited to the production and construction phases of the techniques.

2.2. Functional Unit

The functional unit is used as the main measure of comparison. Theoretically, a functional unit provides the same service or function independent of the materials used. For the LCA presented in this paper the functional unit was defined as one square metre of wall with a heat transfer coefficient of 0.25W/m^{2}K. Heat transfer coefficient calculations were carried out using a programme provided by the canton of Lucerne to support applications for the MINERGIE label for energy efficiency in buildings [9]. The LCIs for the three construction techniques were developed based on these values. The material quantities for each construction method were calculated considering current practice in building construction.

2.3. Life cycle inventories (LCI)

Life cycle inventories can be considered as the recipe for the functional unit. They take into account all energy and material inputs required to produce the functional unit. Tables 1 to 6 present the LCI of the functional units studied as part of this research. The first row of each table describes the functional unit (FU); the following rows present the various inputs required for its production. The life cycle inventories were carried out on two levels: the first describes the production of the material itself; the second describes the construction of one square metre of wall with a heat transfer coefficient of 0.25W/m^{2}K. These models consider the energy, material, and infrastructural demand for the production of one functional unit. The LCIs for the brick and block techniques were developed using existing datasets from EcoInvent[5] v2.2. For bahareque new datasets were created for the production of bamboo poles and flattened bamboo based on De Flander's study of the production of laminated bamboo in Colombia[10]. These new models included inputs to account for the transoceanic transportation of bamboo products. The production of bamboo in Colombia was closely studied by De Flanders[10] and a first attempt to model its LCA was also carried out during previous research[4] at the chair of sustainable construction at the ETH Zurich.

The following tables show the data used to develop the LCA models. Tables 1 and 2 present the energy and material demands for bamboo and bahareque wall. The bahareque wall is considered to be 16cm thick with a layer of cement plaster 1.5cm thick on both sides. The wall has an air pocket of around 7cm. Tables 3 and 4 present the same data for clay brick and clay brick wall. The EcoInvent data set for clay bricks was not modified, as it represents state of the art technology in Switzerland. Tables 5 and 6 present the equivalent data for concrete block and concrete block wall. The use of the datasets for these models follows the same principle as in the case of clay bricks. Figure 1 shows sections of the three walls being studied.

Table 1. LCI for production of 1 kg of bamboo stem

FU	Bamboo stem (dry) transported to Europe	1	kg
Inputs	Bamboo stem	1.093	kg
	Electricity, hydropower, at reservoir power plant, non alpine regions	0.714	kWh
	Freighter oceanic	4.571	tkm
	Truck 40t	7.14E-03	tkm
	Air compressor, screw-type compressor, 300 kW	7.43E-07*	p
	Boric acid, anhydrous, powder,	8.57E-03*	kg

Source: Authors, *[11]

Table 2. LCI for construction of 1 m^2 bahareque wall

FU	Bahareque wall with 1.5cm plaster	1	m2
Inputs	Bamboo stem (dry) transported to Europe	165.5	kg
	Flattened bamboo	135.7	kg
	Bolts and nuts	2.756	kg
	Cement mortar,	132	kg
	Chicken wire mesh	1	kg
	Cement mortar,	120	kg
	Reinforcing steel,	3	kg

Source: Authors

Table 3. LCI for production of 1kg of clay brick

FU	Light clay brick, at plant/DE U ez	1	kg
Inputs	Clay	1.01	kg
	Diesel, burned in building machine	0.0158	MJ
	Electricity, medium voltage,	0.00556	kWh
	Heat, natural gas, at industrial furnace >100kW	1.78	MJ
	Mine, clay	1.67E-10	p
	Packing, clay products	1	kg
	Straw IP, at farm	0.162	kg
	Tap water,	0.113	kg
	Transport, lorry >16t, fleet average	0.0176	tkm

Source: EcoInvent [5]

Table 4. LCI for construction of 1 m^2 clay brick wall

FU	Clay brick wall	1	m2
Inputs	Light clay brick,	458	kg
	Cement mortar,	62.4	kg
	Polystyrene, extruded (XPS) CO2 blown	12.9	kg

Source: Authors

Table 5. LCI for production of 1kg of concrete block

FU	Lightweight concrete block, expanded clay, at plant/CH U ez	1	kg
Inputs	Diesel, burned in building machine	0.0158	MJ
	Electricity, medium voltage	0.0065	kWh
	Expanded clay, at plant	0.9	kg
	Mine, clay	1.67E-10	p
	Packing, clay products	1	kg
	Portland cement, strength class Z 42.5,	0.1	kg
	Tap water,	0.05	kg
	Transport, lorry >16t, fleet average	0.0769	tkm

Source: EcoInvent [5]

Table 6. LCI for construction of 1 m^2 concrete block wall

FU	Lightweight concrete block wall	1	m2
Inputs	Lightweight concrete block, expanded clay,	330	kg
	Cement mortar,	62.4	kg
	Polystyrene, extruded (XPS) CO2 blown	12.9	kg

Source: Authors

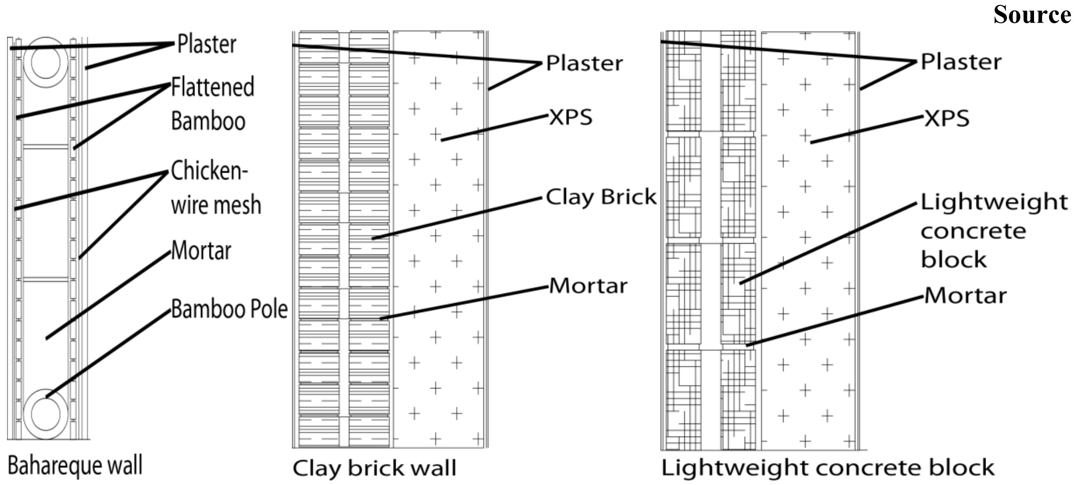

Figure 1. Wall sections

2.4. Impact Assessment

A wide range of evaluation methods exists for calculating the environmental impact of a product. Each has a specific field of application and results vary from one method to the other. In general, results will vary in terms of scale, but with a robust result, using a different calculation method should not change the ranking of the various options studied.

The "Ecological Scarcity 2006" method[12] was selected for this research. This method was developed by the Swiss Federal Office for the Environment[13] and is updated on a regular basis. The Ecological Scarcity method reflects current policy guidelines regarding environment protection in Switzerland. Its results are, therefore, contextualized within the scope of this research, which reduces uncertainty regarding their validity.

The Ecological Scarcity method includes characterisation factors for emissions to air, water and topsoil/groundwater, as well as for the use of energy resources and for some types of waste. All of these factors are calculated with regard to both the present pollution level (current flows) and to the level of pollution considered as critical (critical flows)[12]. The unit used for this method is the EcoPoint or, to use its German abbreviation, UBP (Umweltbelastungspunkt). EcoPoints result from the ratio of current substance flow to critical substance flow. The list of calculations used to assess EcoPoints is very extensive and for this reason the method is implemented in and specialized software. The results of these calculations can be normalized, characterized or weighted, depending on the specific needs of the LCA study. The results presented in this paper are a single score aggregate of all values.

The following three additional evaluation methods were used in this research to assess the robustness of the results: IMPACT 2002+[14], Cumulative Energy Demand (CED)[15], and IPCC100[16]. The results of these calculations are presented in section 4.3. The impact assessment itself was carried out using the software SIMApro.

3. Results

The Environmental Savings Potential (ESP) is defined as the difference between the total environmental impact of a benchmark technology and the total environmental impact of the technology being investigated. For this research, clay brick and concrete block were considered as benchmark technologies.

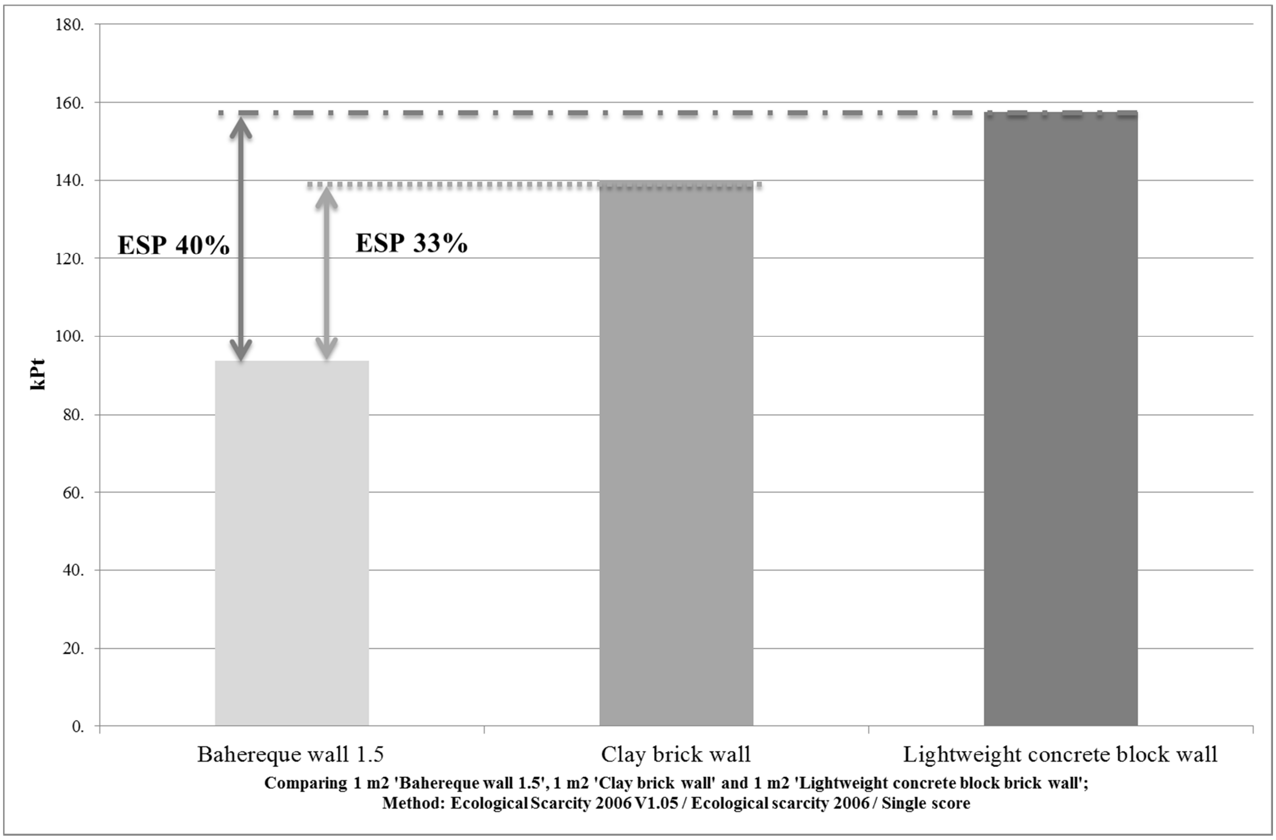

Figure 2. LCA results

Figure 2 shows that bahareque has an ESP of 40% when compared with lightweight concrete wall and 33% when compared with the clay brick wall.

The process contribution analysis showed that the cement mortar was the main contributor to the bahareque technique's environmental impact, with a 39% share of the total, followed by the bamboo products themselves with a 31% share. The item "bamboo products" includes all processes associated with the production and transportation of flattened bamboo and bamboo poles. A detailed analysis of this item showed that the process contributing the most to environmental impact was transoceanic transportation with a 32% share. The bamboo elements themselves contributed less than 1% of the total environmental impact.

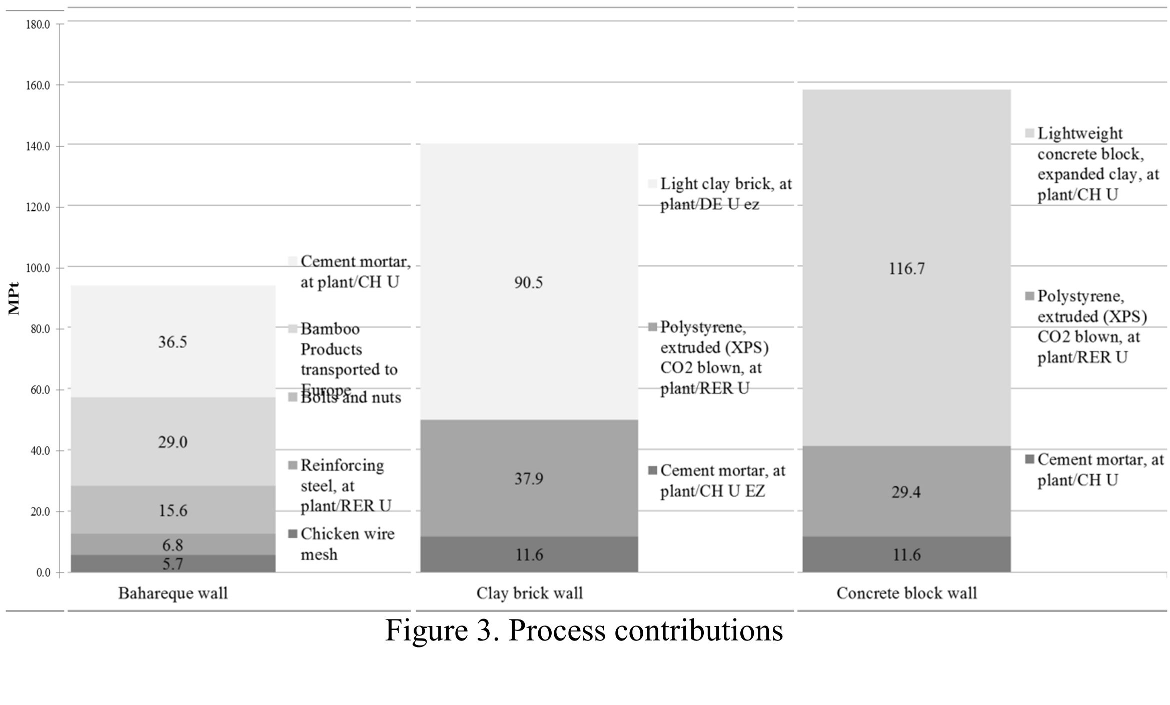

Figure 3. Process contributions

For clay brick and concrete block techniques, the process contribution analysis showed that the main environmental impact was related to the fuels used to produce the construction materials: natural gas in the case of clay bricks and heavy oil fuel for concrete blocks. Extruded polystyrene (XPS), used as an insulation material, also makes a significant contribution to the overall environmental impact of clay brick and concrete block methods, contributing 27% and 19% of the environmental impact for clay brick and concrete block walls respectively. The data sets for brick and block constructions were taken directly from the EcoInvent database and were considered to have the lowest levels of uncertainty.

4. Discussion

In the process of carrying out an LCA certain methodological decisions and assumptions can introduce unexpected variations in the results. These variations can pass unnoticed but can subtly and significantly affect the final interpretation of the LCA results. In the case of the LCA presented in this paper these variations in the results were addressed as uncertainties. Three main sources of uncertainties were identified relating to the following: building physics calculations, life span and maintenance, and evaluation methods. In order to identify the effects of these uncertainties on the final results, new LCA models were developed for each case.

4.1.Uncertainties related to building physics calculations

The method used to calculate the heat transfer coefficients of the studied walls is very simple. However, heat transfer by convection is not considered. This would, in practice, drastically reduce the efficiency of the 7cm layer of air in the bahareque wall. In order to eliminate the uncertainties introduced by this calculation method, the most secure way of carrying out a comparison is to choose the worst-case scenario for the bahareque wall - to consider that the air layer has no effect. In this case, the same insulation material as for the two benchmark wall constructions is used: XPS insulation foam. Table 7 presents the LCI values for this option and figure 4 shows a section of the XPS insulated bahareque wall.

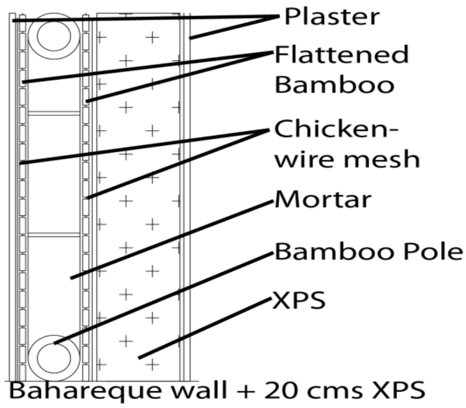

Figure 4. Wall section

Table 7. LCI for construction of 1 m^2 insulated bahareque wall

FU	Bahareque wall	Original	
Inputs	Bamboo stem (dry) transported to Europe	165.5	kg
	Flattened bamboo	135.7	kg
	Bolts and nuts	2.756	kg
	Cement mortar	66	kg
	Chicken wire mesh	1	kg
	Cement mortar	199	kg
	Reinforcing steel	1.8	kg
	Polystyrene, extruded (XPS) CO2 blown	9.6	kg

Source: Authors

The modelled insulated bahareque wall was compared with the clay brick wall and concrete block wall. The results show that the inclusion of insulation foam reduces the ESP of the bahareque wall by between 17 and 22%. Under the studied conditions, however, the bahareque wall still has a significant ESP when compared to state of the art construction techniques.

In order to better understand the effects of the inclusion of a layer of insulation foam, another calculation approach was developed, which considered different thicknesses of foam insulation layer and how they affect the ESP. Figure 5 shows that when compared with the clay brick wall the insulated bahareque wall will still have an ESP if its foam layer is thinner than 32cm. Compared with the concrete block wall the bahareque wall still has an ESP with a foam layer of up to 45cm. This also shows that the bahareque wall can be insulated within practical ranges, 20 to 30cm, while still providing a significant ESP. These are very promising results, but the practicality of building a bahareque wall in Switzerland still needs to be addressed. Moreover, the effects of climatic variation on the ageing behaviour of bahareque walls need to be better understood. These effects also define the expected service life of bahareque walls and their maintenance needs.

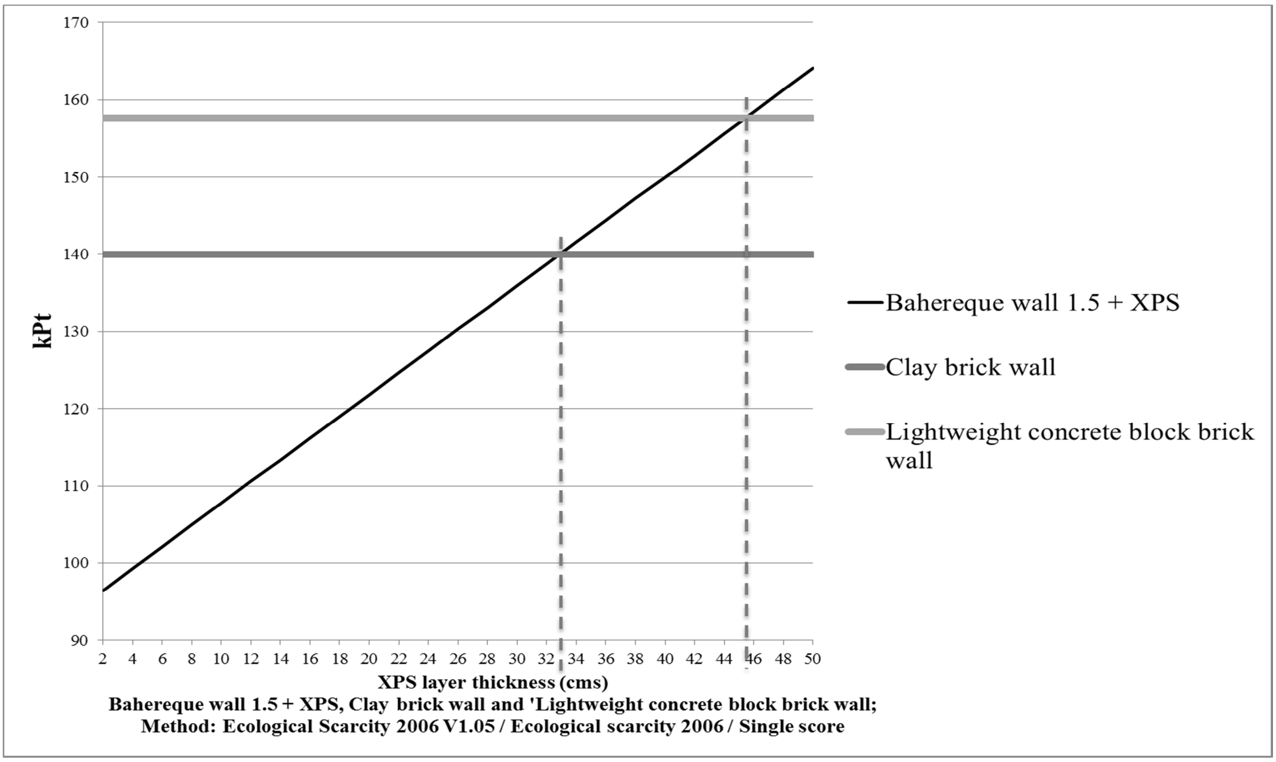

Figure 5. Effect of XPS thickness on bahareque ESP

4.2. Uncertainties related to life span and maintenance needs

The life span of a building and its components is one of the most important factors in an LCA study. At the same time these factors are very sensitive and difficult to model properly. The life span of a building or a given construction technology not only depends on the durability of its materials and how they age, but is also influenced by use, maintenance and even by social and urban dynamics. For the present research we assumed an in-service life span, also known as service life, of 60 years. Maintenance needs were divided into two programmes: one for bahareque and one for brick and block walls.

The maintenance programme for bahareque walls involves replacing the outside layer of the wall (including flattened bamboo, plaster, chicken wire mesh and XPS as shown in table 8). The programme for bahareque was then divided into three levels: high maintenance (every 10 years), mid maintenance (every 20 years), and low maintenance (every 30 years). For brick and block technologies the programme considered the replacement of the XPS insulation layer. The levels of maintenance were defined as high maintenance (every 20 years), mid maintenance (every 30 years), and low maintenance (once after 60 years). These values are presented in tables 9 and 10.

Table 8. Data input for life span and maintenance calculations – bahareque wall

	Bahareque wall	Original		20 years		40 Years		60 Years	
Inputs	Bamboo stem (dry) transported to Europe	165.5	kg	165.5	kg	165.5	kg	165.5	kg
	Flattened bamboo	135.7	kg	203.58	kg	271.4	kg	339.2	kg
	Bolts and nuts	2.756	kg	2.756	kg	2.756	kg	2.756	kg
	Cement mortar	66	kg	99.0	kg	132.0	kg	165.0	kg
	Chicken wire mesh	1	kg	1.5	kg	2.0	kg	2.5	kg
	Cement mortar	199	kg	199	kg	199	kg	199	kg
	Reinforcing steel	1.8	kg	1.8	kg	1.8	kg	1.8	kg
	Polystyrene, extruded (XPS) CO2 blown	9.6	kg	19.2	kg	28.8	kg	38.4	kg

Source: Authors

Table 9. Data input for life span and maintenance calculations – clay brick wall

	Clay brick wall	Original		20 years		40 Years		60 Years	
Inputs	Light clay brick	458	kg	458	kg	458	kg	458	kg
	Cement mortar	62.4	kg	62.4	kg	62.4	kg	62.4	kg
	Polystyrene, extruded (XPS) CO2 blown	12.9	kg	25.9	kg	38.8	kg	51.8	kg

Source: Authors

Table 10. Data input for life span and maintenance calculations – concrete block wall

	Lightweight concrete block brick wall	Original		20 years		40 Years		60 Years	
Inputs	Lightweight concrete block, expanded clay	330	kg	330	kg	330	kg	330	kg
	Cement mortar	62.4	kg	62.4	kg	62.4	kg	62.4	kg
	Polystyrene, extruded (XPS) CO2 blown	12.9	kg	25.9	kg	38.8	kg	51.8	kg

Source: Authors

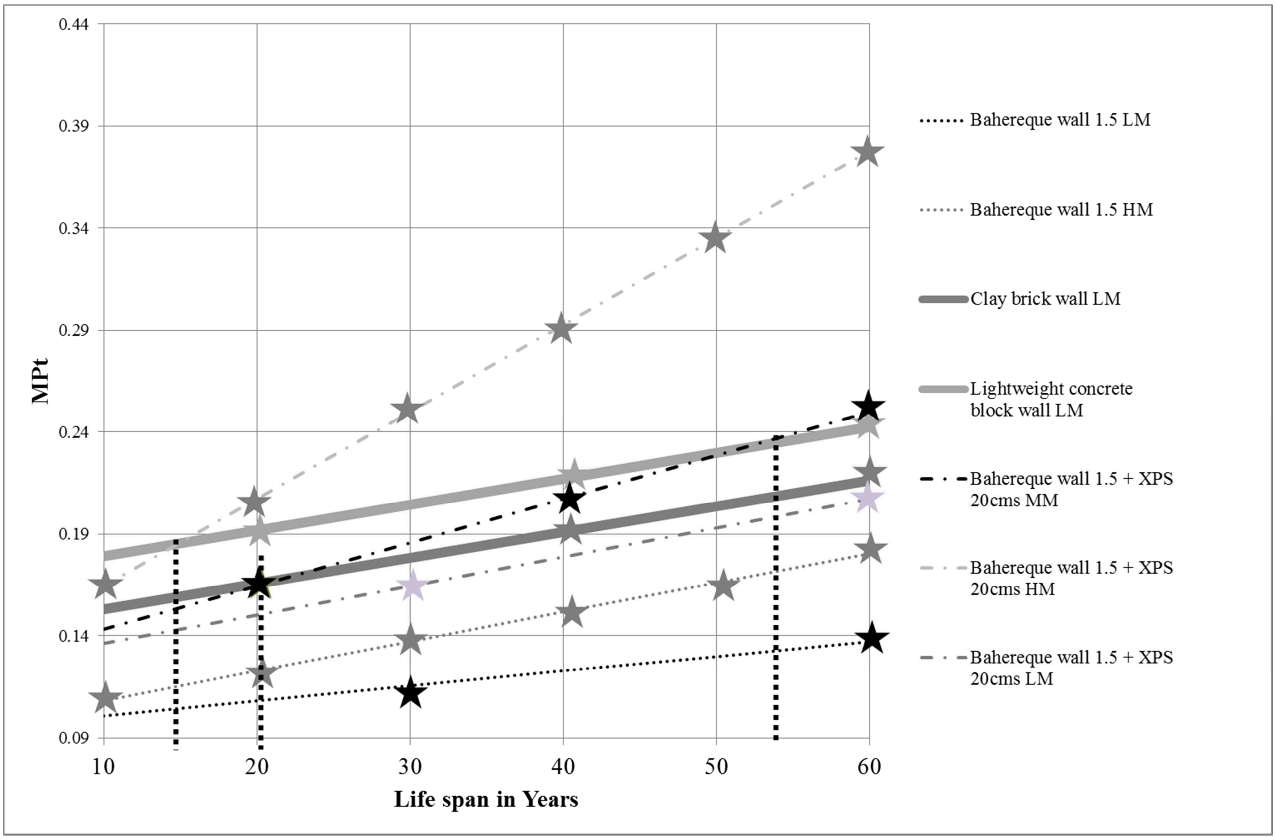

Figure 6. ESP variation for different maintenance programmes and construction methods

Figure 6 presents the results for the maintenance programmes for brick and block technologies and for the bahareque wall with and without insulation. Thicker lines indicate the results for the low maintenance program for brick and block construction methods. Stars mark the instances where a maintenance process is executed. For the case of bahareque without insulation (blue and red lines), it can be seen that under the high maintenance programme (red line, every 10 years) the bahareque wall still presents a significant ESP when compared with brick and block constructions. The ESP for the low maintenance programme is maintained between 34% and 40% over the modelled life span. On the other hand, the ESP for the high maintenance programme presents a variation of 12% over the same period. It is clear that the higher energy and material demands of the high maintenance programme manifest in a reduction of the ESP of the bahareque method.

These calculations were also carried out for the case of an insulated bahareque wall. The same low, mid, and high maintenance programmes were considered as with the bahareque wall without insulation. Under the low maintenance programme (violet line, every 30 years) the insulated bahareque construction method presents a significant ESP over the proposed life span. For the mid maintenance programme (cyan line, every 20 years), insulated bahareque presents an ESP for up to 20 years of its life span when compared to the clay brick wall and for up to 50 years when compared to the concrete block wall. This shows that maintenance needs can play a significant role in the whole life environmental impact of the construction methods studied. Under the high maintenance program (orange line, every 10 years), the insulated bahareque does not present an ESP when compared to the clay brick wall and only presents an ESP for up to 15 years of its life span when compared to the concrete block wall.

4.3. Uncertainties related to the selected evaluation methods (EMs)

Three additional evaluation methods (EMs) (IMPACT 2002+, IPCC 100, and Cumulative Energy Demand (CED)) were used in order to validate the results provided by Ecological Scarcity 2006. The first, IMPACT 2002+, was also developed in Switzerland, but it assesses a different set of mid and endpoint categories. The results from IMPACT2002+ are presented in figure 7. The results show that the bahareque wall has an ESP of 27% when compared with the clay brick wall and 45% in comparison with concrete block. This shows a similar trend to that which was observed from the results produced using Ecological Scarcity. Similar results were also obtained from assessment using the other two EMs.

IPCC100 was developed by the Intergovernmental Panel on Climate Change. This EM assesses the amount in kilograms of CO_2 equivalents related to the production and/or use of the products being investigated. Figure 7 shows that the use of the bahareque construction method could lead to a CO_2 reduction of 50% compared with concrete block and 33% compared with clay brick construction. This is a very interesting result, not only with regard to the potential for reducing CO_2 emissions but also in terms of creating CO_2 credits that could be used as a financial incentive for the use/development of bahareque construction in the Swiss context.

The Cumulative Energy Demand (CeD) EM is, as its name suggests, a method used to assess all the energy needed for the production and use of the products being studied. Figure 7 shows that according to this EM the bahareque technique presents a potential energy demand reductions of 52% and 35% when compared to concrete block and clay brick construction respectively. This result indicates that the bahareque technique has the potential to reduce both material and energy demands.

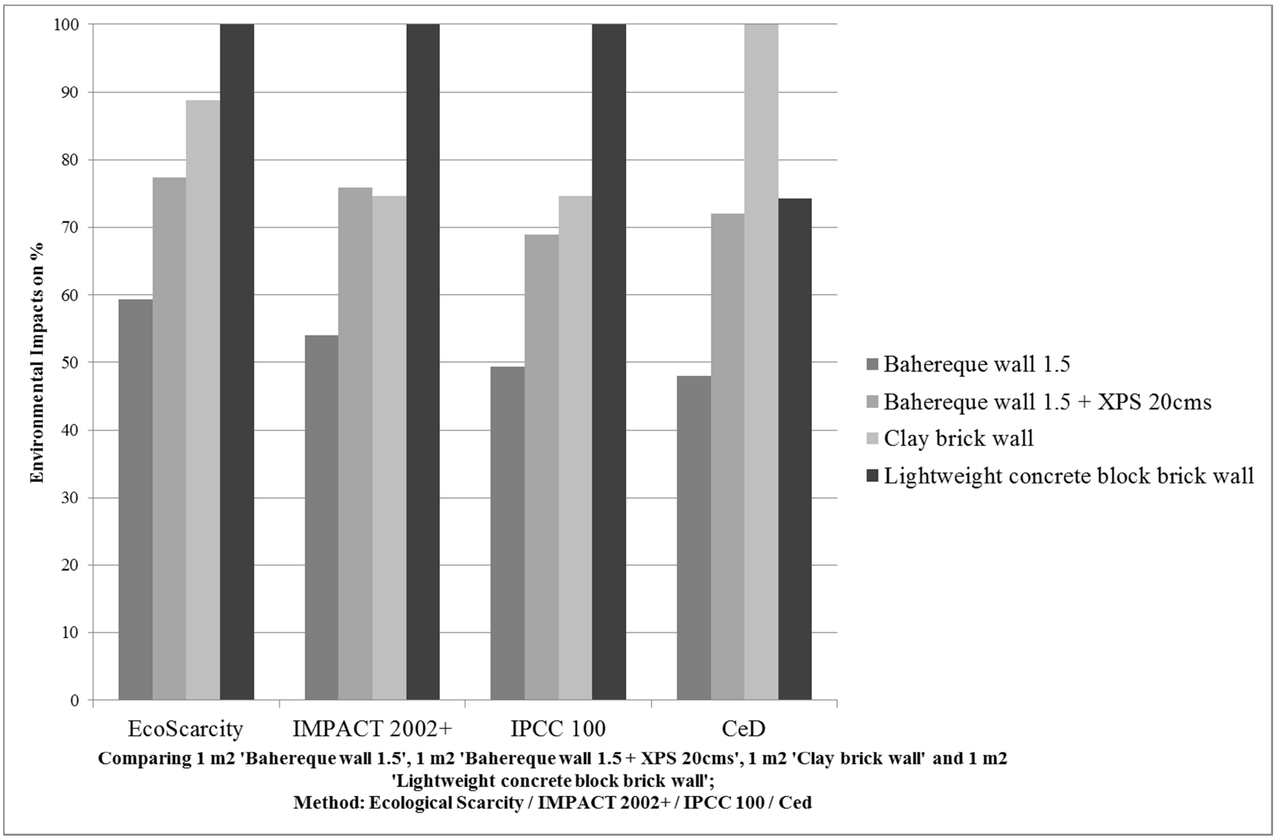

Figure 7. Normalized results comparison for the four EMs

The aggregated results for the four EMs are presented in figure 7. The results from each EM were normalized in order to make comparison possible between them. The normalized results were then benchmarked against the highest score of each EM. The results from this analysis show that the bahareque wall receives the lowest scores of the three constructions, no matter which EM is used. This shows that the results for bahareque are consistent and present low levels of uncertainty. For the cases of concrete block and insulated bahereque the results are consistent for three out of four EMs. Analysis of these construction methods can, therefore, be considered as having a medium uncertainty level. Finally, the clay brick wall presents the highest variation, with the results consistent for only two out of four EMs. From these results it is clear that the processes included in the clay brick datasets are very sensitive to which evaluation method is being used for assessment.

5. Conclusions and recommendations

The research presented showed that the bahareque construction method has the potential to produce building envelopes with low heat transfer coefficients within the Swiss context. The results showed that the factor contributing most to the overall environmental impact of bahareque is the use of cement for plaster and reinforcement. It was also shown that the transoceanic transportation of bamboo products has a larger environmental impact than the products themselves. This means that the ESP of bahareque in bamboo producing countries could be even higher than the results shown in this paper.

It was also shown that, while the use of an extra layer of insulation reduces the ESP of bahareque, under the studied conditions the ESP will still be significant. Nevertheless, it is necessary to carry out physical testing to establish the thermal transfer coefficient of bahareque constructions. It is also necessary to develop models that consider other kinds of insulation materials in order to identify the most efficient building envelope possible. The results also showed that even insulated bahareque will have an ESP after three cycles of maintenance over 60 years of service. However, the ageing behaviour of bahareque still needs to be established, considering exposure not only to precipitation but also to temperature changes similar to those experienced in Switzerland.

The proposed methodological approach proved to be a valid means of reducing the level of uncertainty when dealing with partial datasets. However, this approach still needs further development and consolidation into an established methodology. It is also important to mention that valid local data sets for bamboo production and other alternative construction materials are still needed. It is crucial that these datasets are developed and submitted to LCA databases, both in order to make them available to researchers around the world and also to validate them through databases' peer review processes. It must also be highlighted that the present research focused only on the environmental impacts associated with the construction and use of a functional unit. To understand the economic implications of choosing one technique over another, a life cycle cost assessment is needed.

What the research presented here showed, however, is that alternative construction materials have the potential to be used in highly energy efficient building envelopes, and, moreover, that the material and energy demand of existing tehcniques can be improved even further.

6. Acknowledgments

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