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A Multi-Criteria Decision Analysis based assessment of walling materials in India

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ABSTRACT

Building construction in India is estimated to grow at a rate of 6.6% per year between 2005 and 2030 resulting in a continuous increase in demand for building materials. Fired clay bricks are the most widely-used walling materials in the country. However, over the past few decades, the development of other materials such as concrete blocks, fly ash bricks, stabilized mud blocks, etc., has created viable alternatives to bricks. There is limited understanding of the broader environmental consequences of these building materials addressing natural resource depletion, energy, environment and socio-economic impacts.

The main objective of this paper is to present a comprehensive assessment of materials used for wall construction by comparing one square meter of constructed wall for each of the materials. A composite Environmental Index was developed by weighting and aggregating normalized numerical scores of several parameters making use of a Multi-Criteria Decision Analysis (MCDA) framework. The Environmental Index was then ranked to determine walling systems that are best suited in the context of India.

Our analysis shows that wall assemblies that use non-fired products as masonry units are ranked higher compared to fired masonry unit wall assemblies. Clay fired masonry wall assemblies exhibit poorer environmental performance compared to non-fired masonry wall assemblies. When a more efficient form of construction such as the Rat-trap bond wall construction is considered, the environmental performance of clay fired brick walls is significantly improved.

1. Introduction

1.1. Building material demand in India

The Indian economy has been growing at a rate of between 7 and 8% since 2001. The growth in the economy and population coupled with urbanization has resulted in an increasing demand for residential, commercial, industrial and public buildings as well as other physical infrastructure. Building construction in India is estimated to grow at a rate of 6.6% per year from 8.0 billion square meters in 2005 to 41.0 billion square meters in 2030 [1]. The building stock is expected to multiply five times during this period, resulting in a continuous increase in demand for building materials.

The bulk of building material is presently derived from locally available clay, soil, sand and gravel. Solid fired clay bricks are the most widely-used walling materials in the country. However, over the past few decades, the development of other materials such as solid/hollow concrete blocks, fly ash bricks, Cement Stabilized Soil Blocks (CSSB), Fly Ash–Lime–Gypsum (FaL-G) blocks, Autoclaved Aerated Concrete (AAC) blocks, etc., has created viable alternatives to bricks that have also penetrated the market.

1.2. Issues related to building material use

1.2.1. Raw materials and water

The built environment is a significant consumer of land and resources in the production of material required for construction, second only to the food industry [2]. Raw materials used in the construction of buildings consume 40% of the stone, sand and gravel, 25% of the timber and 16% of the water used annually in the world according to data from the Worldwatch Institute [3]. Behrens et al. [4] have shown that annual resource consumption of the world economy increased by about one-third between 1980 and 2002. The rate of exploitation of vital fertile soils is now so rapid that there is a danger that critical thresholds will be crossed [2].

In the context of the projected demand for construction material in India over the next few decades and in particular the use of

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bricks as the major walling material, it is likely that natural resources, including water, will come under tremendous pressure if adequate and timely measures are not taken to ensure more sustainable management of resources and more responsible consumption.

1.2.2. Energy

Apart from having a large environmental footprint in terms of raw material use, the production of building materials also requires an enormous amount of energy. The amount of energy embodied in the extraction of raw material, the manufacturing processes to produce a finished product, the associated transportation energy as well as the energy for construction and ultimate demolition, accounts for 10–20% of a building's life-cycle energy, while 80–90% of the energy a building uses during its entire life-cycle is consumed for heating, cooling, lighting, and other appliances [5]. With buildings accounting for 30–40% of energy use worldwide, reducing embodied energy as well as operational energy in buildings assumes enormous importance. This is very relevant in the context of the current power shortage facing India, and where demand for power is likely to increase more than five-fold from 700 terawatt hours (TWh) in 2005 to 3870 TWh by 2030 [1].

1.2.3. Pollution

Pollution relates closely to the amount and source of energy used in the production of materials. Transport both of raw materials and finished products could be a major factor in materials that are not locally produced or for materials that source raw materials from large distances. Energy pollution from combustion of fuels and electricity use in the manufacturing process and from transportation refers to regional air pollutant emissions as well as greenhouse gas emissions.

In India, the use of coal and other biomass for brick production results in regional environmental pollution through emissions of particulate matter (PM) including Black Carbon (BC), sulphur dioxide (SO_2), oxides of nitrogen (NO_x) and carbon monoxide (CO). BC emissions and carbon dioxide (CO_2) emitted from brick kilns are global pollutants affecting climate change.

1.2.4. Occupational risks and safety

The production of building materials also has a socio-economic dimension. In India, the building materials production industry is largely an informal sector employing a very large number of workers. Although the sector is a major source of employment, especially for poor families, the working conditions endured by workers of this unregulated sector impact health and compromise safety and are a cause for concern. This calls for attention and intervention by policy makers.

1.3. Assessment of building materials

Building materials have so far been assessed largely in terms of energy consumption during the manufacture of materials or in terms of thermal behavior of wall elements. For example, Buchanan and Honey [6], Suzuki and Oka [7], Reddy and Jagadish [8], etc., focus on the embodied energy of building materials. Vijayalakshmi et al. [9] have assessed the thermal properties of different opaque wall materials in India. Other case studies have estimated life-cycle energy use that includes embodied energy and operational energy, e.g., Keoleian et al. [10], Kofoworola and Gheewala [11], Scheuer et al. [12], Utama and Gheewala [13], etc. A few of these studies have also estimated CO_2 emissions resulting from such energy use.

While assessments of embodied energy and operational energy have been carried out for certain building materials in India, there is limited literature available on the relative impacts of building material use on natural resource depletion or on environmental emissions. Literature on the social and economic impacts of building material use, particularly in the material production stage, is also limited.

The building materials production industry in India, particularly when seen in the light of future demand for building materials, could have long lasting implications in terms of natural resource depletion, future energy demand, local pollution, contributions to greenhouse gas emissions as well as socio-economic conditions of a significant number of low-income workers. There is limited understanding of the broader environmental consequences of building materials that address all these aspects together. There is a need to have a comprehensive plan for development of walling materials production in India.

This paper is limited to walling materials since various alternatives to brick as walling materials have been introduced over the past few decades and the relative energy, environmental and social merits of these materials have so far not been assessed.

2. Methodology and data

2.1. Analysis framework

A wide range of methods and tools to assess materials has been used in the literature. Life-Cycle Assessments (LCA) have commonly been used for assessing materials using economic, energy and/or environmental data (e.g., Frenette et al. [14]; Blengini and DeCarlo [15]; De Meester et al. [16]; etc.). These have found to be valuable for building databases or making comparisons for simple systems and are appropriate when comparing materials when quantitative evaluation parameters are used. However, the use of LCA using both quantitative and qualitative parameters in a multi-criteria analysis is limited.

An Environmental Suitability Index (ESI) based on embodied energy, life-cycle cost and re-usability of five of the most commonly used walling materials in Sri Lanka has been developed in an analysis to rank environmental performance of each of the five materials [17]. Esin [18] has used a points-based system to analyze the environmental aspects and ecological criteria of the building materials production process that involves allocation of points for previously defined endorsements.

The methodology used in this study compares one square meter of constructed wall for each of the materials considered by deriving an Environmental Index from performance criteria discussed in Section 2.2. In this study, the Environmental Index and ranking have made use of a Multi-Criteria Decision Analysis (MCDA) framework. This approach employs numerical scores on a single normalized scale developed from the performance of each wall option with respect to an individual criterion. These scores have then been aggregated into a composite Environmental Index by a summation of weighted scores.

The final Environmental Index (EI) for each walling material M_i is given as:

$$EI(M_i) = \sum_{k=1}^{C} Z_k(M_i) \cdot w(C_k) \quad (1)$$

where $Z_k(M_i)$ is the normalized score of option M_i under criterion C and $w(C_k)$ is the weight for criterion C_k.

This provides a systematic analytical approach for an integrated evaluation and ranking of alternatives.

The quantity of mortar required to construct one square meter of wall would vary depending on the size of the masonry unit. This unit of analysis therefore adequately captures this variation and