Vernacular and Modern Building: Estimating the CO2 emissions from the building materials in Egypt

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Abstract: Buildings are responsible for at least 40% of energy use in most countries. In Egypt, energy use in buildings has grown in the last 20 years mainly due to the increases of population, number of households, as well as increase in service demand, such as more air conditioners, more computers, and larger houses. Therefore, various improved technology, such as energy efficient building shells, appliances, and building designs, are strongly expected to control energy consumption in residence and commercial sectors.

Meanwhile, Low Carbon Building technologies can be classified into three key areas: building materials, renewable energy for buildings and building design. These technologies are relevant for all residential, commercial and industrial buildings. They are relevant for new as well as retrofitted existing buildings.

Under these circumstances, the main goal of this paper is to develop a practical platform for applying the key of building material to improve the building energy efficiency in Egypt. Eventually, the research discusses the following objectives:

- The past experience of vernacular architecture.
- Whether there are significant differences in initial embodied energy of different building material in two residential buildings.

The comparison between the vernacular and the modern examples in their building materials, can achieve a satisfactory result on reducing (59,77%) of the total CO2 emissions. Vernacular buildings require similar amounts of energy and result in similar levels of CO2 emissions, both being much more than the equivalent values for modern building.

Keywords: Low carbon emissions, Construction materials, Residential building, Egypt.

Nomenclature

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TE</td>
<td>Thermal Energy</td>
</tr>
<tr>
<td>mm</td>
<td>Millimeter (Dimension of Building Material)</td>
</tr>
<tr>
<td>MJ</td>
<td>Mega joule per cubic meter</td>
</tr>
<tr>
<td>EI</td>
<td>Energy Intensity</td>
</tr>
<tr>
<td>T</td>
<td>mean temperature</td>
</tr>
<tr>
<td>V</td>
<td>volume of building material used</td>
</tr>
<tr>
<td>D</td>
<td>Density of the building material</td>
</tr>
<tr>
<td>C</td>
<td>Embodied carbon emission</td>
</tr>
</tbody>
</table>

Abbreviations

- LCB: Low carbon Building
- CO2: Carbon Dioxide
- BEE: Building Energy Efficiency
- CH4: Methane
- N2O: Nitrous Oxide
- F-gases: Fluorinated Gases
- HFCs: Hydro Fluorocarbons
- PFCs: Per Fluorocarbons
- SF6: Sulfur Hexafluoride

1. Introduction and Research Problem:

Building energy efficiency (BEE) has come to the forefront of political debates due to high energy prices and climate change concerns. Improving energy efficiency in buildings is considered to be one of the easiest and the lowest cost options to decrease a building’s energy use, owner operating costs, and carbon footprint. [1] In the context of global climate change, “Buildings” as one of the main energy consumers and carbon emitters attract increasing attention. According to IPCC, [2] buildings consumed 40% of energy sources and led to 36% of energy related carbon emission in industrialized countries. As estimated by EIA [3].

Buildings accounted for 30.8% of global energy consumption. Greenhouse gases trap heat and make the planet warmer. Human activities are responsible for almost all of the increase in greenhouse gases in the atmosphere over the last 150 years. The largest source of
greenhouse gas emissions from human activities in the world is from burning fossil fuels for electricity, heat, and transportation. Fig. (1)

Buildings’ construction is a major consumer of land and raw materials. [5] It is also a significant user of nonrenewable energy and an emitter of greenhouse gases and other gaseous wastes [6]. According to data from the World Watch Institute, the construction of buildings consumes 40% of the stone, sand and gravel, 25% of the timber and 16% of the water used annually in the world. [7] The building and construction sector (i.e. including production and transport of building materials) in most of countries consumes from 25% to 40% of the total energy used (as much as 50% in some countries). [8] Buildings through their construction period, use and demolition, consume approximately 50% of the final energy consumption in the members states of the European Union and contribute almost 50% of the CO2 emissions released in the atmosphere, which is considered to be the basic gas responsible for the greenhouse effect. [9]

At the global scale, the key greenhouse gases emitted by human activities are:

- **Carbon dioxide (CO2)** - Fossil fuel use is the primary source of CO2. The way in which people use land is also an important source of CO2 emissions. The human-induced land usage change, such as de-forestation, is also an important source of CO2. Land can remove CO2 from the atmosphere through re-forestation, improvement of soils, and other activities.

- **Methane (CH4)** - Agricultural activities, waste management, and energy use all contribute to CH4 emissions.

- **Nitrous oxide (N2O)** - Agricultural activities, such as fertilizer use, are the primary sources of N2O emissions.

- **Fluorinated gases (F-gases)** - Industrial processes, refrigeration, and the use of a variety of consumer products contribute to emissions of F-gases, which include hydro fluorocarbons (HFCs), per fluorocarbons (PFCs), and sulfur hexafluoride (SF6).

Regarding the Greenhouse Gas Effect in Egypt, The first GHG inventory of Egypt was developed for the year 1990/91 based on the 1995, IPCC guidelines and default emission factors. The inventory was estimated for the main three GHGs, namely CO2, CH4 and N2O. CO2 is the main Greenhouse Gas in Egypt. It represents about 72% of the total GHG emissions in 2005/2007. The second important greenhouse gas is CH4, which represents 19% of the total GHG emissions and lastly N2O at 9%. [10]

In 2005/2007, the total net GHG emissions were about 117000 Gg of CO2 equivalent while the total GHG sinks in the land–use and forestry sector recorded 9900 Gg of CO2 equivalent. With 92% dependence on fossil fuels, the energy sector is the major source of GHG emissions, contributing in 71% of the national total.

Buildings account for nearly a fifth of world final end use energy consumption. This is almost the same amount of greenhouse gas emissions as that produced by the entire transport sector. The buildings
sectors contribution to greenhouse gas emissions is mainly driven by its end use or, or demand for, electricity. Fig. (3) [11]. Figure (3) shows the share of Residential and Commercial buildings in Egypt. The Residential Building Sector was responsible for (21%) of CO2 emissions more than the Commercial Building. Furthermore, the cooling sector in residential building is recorded 28% of all sources of the CO2 emission.

2. Methodology:
The present paper investigates the role of different construction materials and quantifies them in terms of the embodied energy and the equivalent emissions of CO2 in two different buildings (Vernacular and Modern) buildings in Egypt. The aims of the current paper are to:

- Study the past experience of vernacular architecture in Egypt.
- Test the residential buildings made of sun baked mud bricks and straw.
- Whether there are significant differences in initial embodied energy of different building materials in two residential buildings.

3. Scope of the present study:
Energy in buildings can be categorized into two types: (1) energy for the maintenance/servicing of a building during its useful life, (2) energy that goes into production of a building (embodied energy) using various building materials. Study of both the types of energy consumption is required for holistic understanding of building energy needs. Embodied energy of buildings can vary with the choice of building materials and building techniques. RC frames, RC slabs, burnt clay brick masonry, concrete block masonry, tile roofs represent common conventional systems forming the main structure of buildings in Egypt. Similar building systems can be found in many other developed and developing countries. Alternative building technologies such as stabilized mud blocks (SMB’s), prefabricated roofing systems, masonry vaults, filler slab roofs, lime pozzolana (LP) cements, etc. can be used for minimizing the embodied energy of buildings.

Embodied energy can be split into:
1. Energy consumption in building materials.
2. Energy required for transportation of building materials.
3. Energy consumed in different types of buildings and building systems.

4. Energy in building materials

4.1. Basic building materials
Energy consumed during production of basic building materials is given in Table 1. These energy values pertain to the production systems which is employed by the material manufacturers in Egypt. Total energy values of various basic materials which are given in Table 1 have been used in the computations of energy in building materials/systems and buildings. [12]

<table>
<thead>
<tr>
<th>Type of material</th>
<th>Thermal energy (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>5.85</td>
</tr>
<tr>
<td>Lime</td>
<td>5.63</td>
</tr>
<tr>
<td>LP</td>
<td>2.33</td>
</tr>
<tr>
<td>Steel</td>
<td>42.0</td>
</tr>
<tr>
<td>Aluminum</td>
<td>236.8</td>
</tr>
<tr>
<td>Glass</td>
<td>25.8</td>
</tr>
</tbody>
</table>

4.2. Masonry materials
Masonry walls constitute one of the major energy consuming components of the building, especially in case of load bearing masonry structures. Varieties of materials are used for the construction of masonry walls. There are five types of building blocks: “stone, burnt clay brick, soil–
cement block, hollow concrete block and steam cured mud block”. [14]

4.2.1. Stone block
Stone blocks are generally produced by splitting the hard natural stone into convenient sizes. Stone blocks of size approximately about 180 mm × 180 mm × 180 mm are generally termed as size stones in the Egyptian construction practices.

4.2.2. Burnt clay bricks
These are commonly used for building construction. The common brick size is 230 mm × 110 mm × 60–75 mm. They require considerable amount of thermal energy during the burning process. Coal, coal cinder and firewood are the most commonly used fuels for brick burning in Egypt.

4.2.3. Hollow concrete blocks
The basic composition of the blocks consists of cement, sand and coarse aggregates (6 mm size). The energy content of the block will mainly depend upon the cement percentage. Energy spent for crushing of coarse aggregate will also contribute to the block energy.

4.2.4. Soil cement blocks
These are produced by pressing a wetted soil–cement mixture into a solid block using a machine (manually operated or mechanized) and then cured. Soil–cement blocks produced by employing manually operated machines in a highly decentralized fashion have become increasingly popular.

5. Energy in transportation of building materials
Transportation of materials is a major factor in the cost and energy of a building. Most of the building materials in urban and semi-urban centers are transported using trucks. The transportation distance may vary depending upon the location of construction activity. [15]

Natural sand and crushed stone aggregate consume about 1.75 MJ/m3 for every one kilometer of transportation distance. Similarly bricks require about 2.0 MJ/m3 per km travel. Assuming steel and cement are also transported using trucks; diesel energy of 1 MJ/ton/km is spent during transportation. Thermal energy spent for natural sand production is nil, but it requires about 175 MJ of diesel energy/m3 for transporting it over 100 km distance. Crushed aggregate consumes about 20 MJ/m3 during its production and an additional 400–800% more during transportation for distances of 50–100 km. The energy spent during transportation of bricks is about 4–8% of its energy in production, for distances of 50–100 km. Transportation energy required for hauling high-energy materials such as steel and cement is marginal when compared to the energy spent during production.

6. MATERIALS & METHODS
Four major building materials namely cement, steel, glass and timber will be substituted with alternative building materials slag cement, recycled steel, cullet glass and plywood respectively. The amount of CO2 emission is estimated by referring to the total weight of different building materials used; multiplied by the CO2 emission intensity of those which are materials obtained from previous researchers. The study based on some assumptions that the strengths of the traditional and alternative materials are the same. [16]

The formula for calculation is expressed as follows: [17]

\[ V \times D \times C /1000 = \text{Amount of CO2 emission (kg)} \]  

Where as:
\( V = \text{volume of building material used (m3)} \)
\( D = \text{Density of the building material (kg/m3)} \)
\( C = \text{Embodied carbon dioxide emission (kg CO2/ ton)} \)

7. Egyptian climate overview
Annual mean temperatures increase from around 20°C on the Mediterranean coastline to around 24°C on the Red Sea coastline, 25°C at Cairo and 26°C further south at Aswan with a seasonal variation of about ±7°C. Typical daytime in mid-summer
Climate change seems inevitable. According to the IPCC 2007 Synthesis Report, eleven of the twelve years before 2007 (1995-2006) ranked among the twelve warmest years in the instrumental record of global surface temperature (since 1850). Furthermore, to maintain the temperature rise at 2.0–2.4°C, a level to which, in prevailing belief, it is possible to adapt to, the annual greenhouse gas (GHG) emissions which should be reduced by 50 to 85% by 2050, as the decay of the GHGs emitted to the atmosphere is slow. [18]

8. Why Vernacular Buildings are Different

It is important to understand the differences between vernacular and modern buildings so that we can care for older buildings in an appropriate and compatible manner.

8.1. Vernacular buildings are built to 'breath'

Most vernacular buildings are built with stone, soft bricks, timber and earth using earth or lime-based mortars and renders. These materials allow moisture to be absorbed and then to readily evaporate away, we often say it allows the building to 'breath' such as building in figure (4). In such buildings, the levels of dampness in the building are 'controlled' by this process of moisture evaporation.

Externally the porous materials are dried out by the wind and sun. Internally, air movement - through the roof covering, windows and openings - all help the evaporation of moisture from the internal porous surfaces. Where moisture can evaporate freely and the vernacular 'breathing' performance is not impaired, the walls of vernacular buildings will remain relatively dry. [19]

8.2. Modern buildings are built to be waterproofed

The industrial revolution and the increased movement of materials caused very rapid changes in the methods of construction and the building materials available. By the late 19th century, there had been a significant move away from buildings constructed using vernacular materials and methods to those buildings with cavity walls and damp-proof courses built using cement mortars and renders. [20]

Modern building materials (hard dense bricks, cement based mortars and renders, modern masonry paints and external sealants) are generally impermeable and rely on providing physical impervious barriers (cavity walls and cement renders) to the elements to keep out driving rain and physical damp-proof courses to prevent rising dampness.

8.3. Vernacular and the architect in Egypt

Many modern architects have studied vernacular buildings and claimed to be inspired by them, including aspects of the vernacular in their designs. In 1946, the Egyptian architect Hassan Fathy was appointed to design the town of New Gourna near Luxor. Having studied vernacular Nubian settlements and technologies, he incorporated the vernacular mud brick vaults of the Nubian settlements in his designs. The experiment failed, due to a variety of social and economic reasons, however it is the first recorded attempt by an architect to address the social and environmental requirements of building users. [21]
"This house―figure (5)―, and several others that followed it in the same area, were built in local limestone because of a governmental ban on the use of brick following the construction of the high dam, as well as unsatisfactory test results for the structural strength of the soil in this area, first confirmed in the Fouad Riad project. The takhtabush and courtyard area of the house with wooden pergola, recall the latticework notably used in the Moastirli residence in 1930." [22]

8.4. Modern architecture in Egypt
Modern architecture is generally characterized by simplification of form and an absence of applied decoration. It is a term applied to an overarching movement, with its exact definition and scope varying widely.[23] In a broader sense, early modern architecture began at the turn of the 20th century with efforts to reconcile the principles underlying architectural design with rapid technological advancement and the modernization of society. It would take the form of numerous movements, schools of design, and architectural styles, some in tension with one another, and often equally defying such classification such as an Egyptian building in figure (6).

8.5. Comparison between vernacular and modern buildings in Egypt
There is significantly difference between the building material between the two kind buildings; Vernacular and Modern Building. Table (3).

<table>
<thead>
<tr>
<th>Building Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Sun-dried bricks, made of mud and straw. Although these bricks were inexpensive and enabled fast construction.</td>
</tr>
<tr>
<td>- To manufacture the bricks, the mixture of mud and straw was placed into brick molds, and left out in the sun to dry.</td>
</tr>
<tr>
<td>- The wall thickness was about 40 cm, with narrow windows. This helped to keep the house cool by protecting it from the outside heat.</td>
</tr>
<tr>
<td>- Wooden sticks and palm rafters made up the ceilings. [24]</td>
</tr>
</tbody>
</table>
9. Case study
A case study is used in order to demonstrate the differences in initial embodied energy of different construction practices in two residential buildings in Egypt, one is the Modern Building and the other is the Vernacular one.

9.1. The Modern Building

9.1.1. Description
A one storey building with area = 35 m² (5m × 7m). Walls were solid red blocks 25 cm thick for outer walls and 12 cm for partitions. The foundations were: raft foundation with a layer of replacement soil, concrete, and reinforced concrete). Beams were 25×35 cm for slabs. Reinforced concrete slabs were 12 cm. Fig. (7)

9.1.2. Interior finishing
- All floors were finished with porcelain.
- Walls & ceilings: cement stucco, plastic paint.

9.1.3. Exterior finishing
- Granite skirting, 1m above the pavement - anti-solar radiation plastic paint for walls and ceilings.
- Roof floor: cement tiles & heat/moisture insulation layers.

9.1.4. Woodworks
- All woodworks were in fir wood.

9.1.5. Rough Estimate
- Reinforced concrete for foundations & bases = 15 m³
- Reinforced concrete for building ceiling = 10 m³ and Steel: 3 Ton.
- Solid red bricks = 20 m³ (11,250 bricks).
- Ceramic tiles for WCs (walls & floors) = 40 m².
- Porcelain for room & entrance = 25 m².
- Interior paints = 200 m².
- Exterior paints = 150 m².
- Fir wood for doors & windows = 1 m³.
- Doors & windows glass = 5 m².
- Heat & moisture insulation = 95 m².

9.2. The Vernacular Building

9.2.1. Description
A one story building with area = 35 m² (5m × 7m). Bearing walls 40 cm thick with cement plaster made of cement and limestone. Foundations were a riprap, cement, limestone, and dust terrace. The ceiling consisted of 4×3 inch wooden beams, with 1/2 inch hazel wood casing. Fig. (8)
9.2.2. Interior finishing
- All floors were covered with cement tiles.
- All interior and exterior walls and ceilings were plastered with limestone, cement, and dust plaster.

9.2.3. Exterior finishing
- Outer facades were finished with limestone, cement, and dust plaster.
- Roof floor was covered with cement tiles.

9.2.4. Woodworks
- All woodworks were 1 inch thick stacked arrays of wood, in 3×3 inch girders.

9.2.5. Rough estimate
- Foundation and bases terrace = 30 m³.
- Solid red bricks = 55 m³.
- Wood girders for ceiling = 35 m³.
- Cement tiles for floors = 30 m².
- Interior & exterior paints = 150 m².
- Veins for doors & windows = 0.50 m³.
- Doors & windows glass = 2 m².

10. Results and Discussions
Applying eq.1, for all building materials used in the vernacular building and the modern one; the following can be found:
Table (4) shows that the amount of CO₂ emissions of all building materials used in the modern building were 3598.567×10² ton. These materials were: steel, paints (interior & exterior), reinforced concrete, porcelain floors, ceiling insulation materials, solid red bricks, windows glass, and wood respectively (arranged by higher carbon emissions).

<table>
<thead>
<tr>
<th>Building Material</th>
<th>V = (m³)</th>
<th>D = (kg/m³)</th>
<th>C = (kg CO₂/ton)</th>
<th>Amount of CO₂ emission (ton)×10²</th>
</tr>
</thead>
<tbody>
<tr>
<td>R.C</td>
<td>50</td>
<td>2400</td>
<td>333.60</td>
<td>400.32</td>
</tr>
<tr>
<td>Steel</td>
<td>1.5</td>
<td>7860</td>
<td>12207</td>
<td>2439.205</td>
</tr>
<tr>
<td>Brick</td>
<td>20</td>
<td>1580</td>
<td>290.80</td>
<td>91.893</td>
</tr>
<tr>
<td>Tiles</td>
<td>380</td>
<td>17.62</td>
<td>1920</td>
<td>128.556</td>
</tr>
<tr>
<td>Paints</td>
<td>4670</td>
<td>16</td>
<td>186.60</td>
<td>487.996</td>
</tr>
<tr>
<td>Wood</td>
<td>13</td>
<td>530</td>
<td>139</td>
<td>9.5771</td>
</tr>
<tr>
<td>Glass</td>
<td>1</td>
<td>2500</td>
<td>1380.50</td>
<td>34.5125</td>
</tr>
<tr>
<td>Insulation</td>
<td>11</td>
<td>593</td>
<td>1873.50</td>
<td>122.208</td>
</tr>
</tbody>
</table>

Total of CO₂ | 3598.567 |

Table (5) shows that the amount of CO₂ emissions of all building materials used in the vernacular building were 906.241×10² ton. These materials were: floor finishing, glass, soil used in establishing foundations (composed of a riprap, cement, limestone, and dust terrace), wood used in constructing the ceiling of the building with its openings, and paints (interior and exterior) respectively (arranged by higher carbon emissions).
Table 5: The Amount of CO2 emissions in the Vernacular Building

<table>
<thead>
<tr>
<th>Building Material</th>
<th>V = (m³)</th>
<th>D = (kg/m³)</th>
<th>C = (kg CO2/ton)*</th>
<th>Amount of CO2 emission (ton)×10²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td>30</td>
<td>2837</td>
<td>51</td>
<td>43,406</td>
</tr>
<tr>
<td>Tiles</td>
<td>165</td>
<td>350</td>
<td>1220</td>
<td>704,55</td>
</tr>
<tr>
<td>Brick</td>
<td>55</td>
<td>1612</td>
<td>36.40</td>
<td>32,272</td>
</tr>
<tr>
<td>Paints</td>
<td>164.32</td>
<td>16</td>
<td>85.40</td>
<td>2,245</td>
</tr>
<tr>
<td>Paints</td>
<td>4670</td>
<td>16</td>
<td>186.60</td>
<td>487,996</td>
</tr>
<tr>
<td>Wood</td>
<td>35.50</td>
<td>530</td>
<td>139</td>
<td>26,153</td>
</tr>
<tr>
<td>Glass</td>
<td>2.8284</td>
<td>2500</td>
<td>1380.50</td>
<td>97,615</td>
</tr>
</tbody>
</table>

| Total of CO2      | 906,241 |

* The values of the amount of embodied co2 in building materials were taken from: D. Chen, M. Syme, S. Seo, W. Y. Chan, M. Zhou and S. Meddings, Development of an Embodied CO2 Emissions Module for AccuRate, Final report received by FWPA in August, 2010.

In Fig. (9), comparing carbon emissions for both buildings reveals that using steel in construction, and consequently reinforced concrete, is the main cause of increasing carbon emissions from building materials. The common building material is bricks. Carbon emissions from brick in the modern building were higher than those of the vernacular one; due to the difference in manufacturing elements of both types. As for paints, there is a significant difference in carbon emissions between both buildings. This is simply because modern building paints are plastic ones, whereas vernacular building paints are made of limestone, cement, and dust plaster.

11. Conclusion:
The world needs an environmentally friendly construction material because of the desire to reduce CO2 emissions, save nonrenewable energy resources, provide aesthetically pleasing and healthy surroundings and at the same time minimize waste.

This paper concludes that the comparison between the Vernacular and the modern building in their building materials, can achieve a satisfactory result on reducing (59.77%) of the total CO2 emissions.

Vernacular buildings require similar amounts of energy and result in similar levels of CO2 emissions, both being much more than the equivalent values for Reinforced concrete and structural steel buildings (Modern Building). An additional benefit of Mud Brick and the wood construction is the carbon which is 'locked up' in mud brick and wood products for the life of the building.

In order to significantly reduce the emission of carbon dioxide, Mud Brick and wood are placed in high priority to be replaced by alternative building materials. At least, the greenhouse gas, carbon dioxide can be greatly reduced by substitution.

In summary, this study presents a simple but more realistic model on promoting the usage of alternative building materials in constructing buildings.
12. Recommendations:

12.1. Future research
Research should focus on minimizing construction weight and reducing construction material. Reducing cement and steel in reinforced concrete mixtures is another field which could contribute considerably to the environmental problem.

12.2. Producers of construction materials
Companies producing construction materials should research more efficient ways to produce materials. And replace fossil fuels with CO2 neutral fuels (like biodiesel and garbage).

References:


