ENVIRONMENTALLY FRIENDLY BUILDING MATERIALS

David Rousseau
Archemy Consulting Ltd., Vancouver, B.C, Canada

Keywords: environmentally friendly materials, global trends, resource extraction, material life-cycle, assessment methods.

Contents

Summary

Environmentally friendly building materials are those that make optimal use of resources, produce minimum waste and are safe for the environment and people. Types of materials, environmentally friendly options and rating and certification systems are explored, as well as industry trends. A table of generic environmentally friendly materials is included.

1. Introduction

Building materials, from their resource extraction through manufacturing, use and disposal have become a major component of the total human effects on global ecosystems and the earth's climate, particularly in the two centuries since the advent of the industrial revolution. In the past half-century, with the rapidly advancing pace of urbanization worldwide, finding the raw materials and energy to produce building materials, and absorbing the waste from their production, use and disposal have become pressing global problems. For example, the production of Portland cement alone represents 8% of total global greenhouse gas releases deriving from human sources (WRI). Another highly visible example is the unprecedented degree of deforestation occurring worldwide to produce wood for building construction. The resulting loss of forest diversity, soil stability, water quality and other long-term ecological and economic values are well known.
Because all manufactured building materials industries are raw material and energy consumers, and produce some degree of waste, they are important targets worldwide for efficiency improvements and environmental pollution reductions.

The search for *environmentally friendly* building materials represents a response from the building sector intended to reduce the environmental cost of making and using buildings. Environmentally-friendly building materials may come from traditional sources, such as earth and stone materials, they may come from existing industrial processes, found by *life-cycle-analysis* to be the most environmentally benign, or they may come from new processes or raw material inputs such as industrial waste. Whatever their source, environmentally friendly materials are just one part of the necessary range of responses required to make buildings and cities that are more environmentally responsible. Many other factors such as operating energy efficiency, integrated design, reduction of water consumption and waste, reduction of private automobile use etc. are at least as important as environmentally-friendly materials alone. Furthermore, the way materials are selected and applied in a building is also a very significant component of resource efficiency. For example a floor system may be as complex as a framing layer, a structural sub floor layer, a flooring underlayment, an adhesive or fastening layer and a finish layer. Alternatively, a single material such as a reinforced concrete suspended slab may be finished with a colorant and sealer and serve all these functions.

Some of the important efforts worldwide to mitigate the environmental impact of building materials that will be discussed in this article are:

- *Resource efficient* materials; those that, by good engineering design, use less raw material or more environmentally benign raw material.
- *Reused materials*; those that recapture, by direct reuse, the value in materials being removed from use.
- *Recycled content materials*; those that are made from consumer waste or the waste stream of an industry.
- *Advanced process materials*: those that are made in a highly energy-efficient "closed system" that releases minimal waste.

- *Healthy materials*; those that avoid toxic substances in their manufacture and use, and do not release harmful agents into buildings.
- *Traditional, pre-industrial materials*; those materials such as earth and agricultural waste that are readily available with minimal processing.

Definition:

Environmentally-friendly building materials are those that provide appropriate service and life span, with minimum maintenance, while minimizing the extraction of raw materials, the pollution from, and energy consumed by manufacturing and use, and that have the maximum potential for reuse or resource recovery.

2. The Global Role of Building Materials

2.1 Global scale of resource use

Raw material consumption for building products tends to rise dramatically with a nation's economic development and then stabilize and fall as a growth period is completed. For example per-capita cement use in Europe peaked around 1973 and then fell steadily until 1987 (Ross et al. 1987). In China, on the other hand, national steel consumption approximately doubled from 1990-2000 (IISI-2001) as the country moved into a period of massive urban and industrial expansion.

Globally, over 27% of all wood harvesting is dedicated to lumber (FAO) and large building material industries, such as cement manufacturing, are major users of mined minerals and very large fossil energy users. In the two decades from 1974 to 1994 worldwide consumption of plastics grew by 194%. In the building industry this same period saw the wide acceptance of many plastic building products such as PVC cladding and windows, styrene insulation, and steady growth in the use of plastic-based floor coverings, laminates and roofing. Per-capita steel consumption is the only global indicator of the major building material industries that has declined slightly over that period. The other major building materials industries of interest are brick and masonry products, glass, non-ferrous metals, mineral and cellulose fibre products, asphalt and plastic membrane products, gypsum products and paints and coatings.

As societies industrialize they typically become completely dependent on manufactured building materials; many of them now produced in highly automated plants. Poorer, more traditional societies are more likely to use indigenous materials, waste materials, and highly labour intensive methods for building shelter. Some of these traditional materials and methods, such as stabilized earth walls, straw bale walls, log and pole frame construction, and stone masonry construction are now making a small re-appearance in highly industrialized countries, in part as a reaction against industrialization of building methods.

2.2 Demand created by global urbanization

With the exception of a few periods of recession, demand for building materials has been very strong for most of the post-war period in the expanding economies of the developed world, especially in Western Europe, Japan and North America. However these nations are now highly urbanized, and housing shortages are minimal, so demand has stabilized. Those nations, notably China and, to a smaller extent, India that have been urbanizing rapidly since the 1970's, are expected to become the largest consumers of building materials for the foreseeable future (SABMI). These nations have very large housing shortages to address as their youthful populations begin to demand a higher living standard.

The distribution of urban growth worldwide has large implications for resource demand, environmental degradation, technological development and global trade in building materials. In terms of reducing global environmental impact from building materials production and use, one of the most pressing needs if for the transfer of low pollution and energy efficient production technology and resource management programs to developing countries. For example, China now completes approximately 600 million M2 of construction each year (CCPIT), most of which was until recently of clay brick construction. The brick is largely made by small industries that mine clay on agricultural land and then fire the bricks with agricultural waste burned in open kilns. The damage to agricultural land and the air pollution caused by these industries is so large that the national government has introduced severe restrictions on clay brick use. However adequate supplies of substitutes, such as hollow concrete masonry, are not available yet in China. Therefore low-pollution and energy-efficient industries making masonry products, particularly using available industrial waste such as coal ash, are a pressing need.

Deforestation is an epidemic global problem that cuts across boundaries between rich and poor. It is leading to habitat destruction in the tropical belt, rapid desertification in central Asia, and soil instability contributing to the collapse of fisheries on the coasts of North America. The economic forces driving deforestation tend to be different in the developing world and the industrialized world. In the developing world, subsistence farming and wood fuel gathering are major forces while in the industrialized world mechanized production of wood for building materials and consumer paper is the major one.

3. Material Environmental Life-Cycle: resource extraction; manufacturing; transportation; use

Every building material or system has an "environmental life cycle" which is not the same as its "economic life cycle" since many of the environmental factors are not adequately accounted for by conventional economics. For example resource extraction and release of waste is counted as beneficial economic activity though it is environmentally detrimental.

3.1 Extraction

The environmental life cycle of a product can be said to start when the raw materials to make it are extracted. The most benign raw materials are those that are from recycled sources, particularly post-consumer waste, those that are renewable (and well managed) or those that are readily available with small extraction impacts. The least benign are those that are non-renewable, scarce, and produce large ecological disturbances in their extraction.

Reducing the impact of raw material extraction is typically a matter of effective resource management and pollution prevention. Other factors such as renewability and habitat disturbance are also very important, but are more descriptive and difficult to quantify. Sustainable forestry is a good example of a management practice that addresses all of these factors. Advanced technologies often have a very small role in reducing life cycle impact at the resource extraction stage, unless they are specific pollution or waste reduction systems.

3.2 Manufacturing

The next stage of the life cycle is manufacturing. Three useful measures used to calculate the impact of product manufacturing are:

- the solid waste and toxics produced;
- the air and water pollution produced;
- the energy consumed per unit of raw material.

These factors can also be extended to the raw material extraction stage above. The manufacturing stage is the point at which advanced technologies, such as energy and waste recovery, typically have the most effect on reducing waste and pollution factors associated with materials.

3.3 Transportation

Transportation can account for a large proportion of total energy use for a product, especially for bulky or massive materials like masonry, concrete and steel. Transportation energy efficiency in terms of energy units/mass unit/distance unit (e.g. mj/kg/km) are lowest for marine shipping, followed by rail shipping and trucking. Air freight has the highest energy and pollution cost.

3.4 Installation and use

The installation and use phase of a material life cycle typically has the least energy and waste implications of all stages, unless the material requires a great deal of maintenance or has other operational impacts on the building, such as the case of glazing or insulation that effects energy performance. The installation and use of a material in a manner that allows its removal for reuse or recycling may be the most significant material-related environmental life cycle factor at this stage. The field of design for disassembly is one that requires a great deal of attention, as it has been very poorly defined so far.

3.5 Reuse/recycling or disposal

Once a material is removed from use its fate is also a very significant factor in the overall life cycle. Materials represent investments of environmental and economic cost, so the more directly this can be recaptured (closing the loop) the less the impact. The most direct recapture is the reuse of materials and equipment that are still serviceable after removal. Good examples are doors, timbers, bricks, architectural metalwork, plumbing and lighting fixtures and flooring.

In the developed world there is growing interest in building with used materials salvaged from deconstruction. This may be for environmental reasons or for cost savings, however experience with using salvaged materials indicates that, though the material price may be low, there is nearly always additional labour required to find, handle, clean, adapt and refinish used materials. For the small owner-builder this may be considered a fair trade-off, but for a contractor it is a serious cost and management problem. For this reason, salvaged materials have been slow to be accepted into larger, contract-bid projects. In the developing world, building with salvaged materials is a well-established practice driven by necessity.

Recycling the material's contents is another option that is usually far less preferable in environmental terms to its direct reuse by salvage. To recycle a material's contents it must first be disassembled and separated into recyclable components. This may be a simple and effective process, for example the removal of structural steel from a building frame, or it may be highly complex and ineffective, such as attempts to separate metals, glass and plastics from a window or cladding panel made from composite materials.

Once the material is separated, recycling also enjoys varied degrees of success, depending on the material. Metals are the most easily recycled, and have a high salvage value. Most new metal products today contain some degree of re-melted scrap and quality generally does not suffer compared to all-virgin materials. However recycled plastic products are generally of very poor quality due to difficulty in maintaining purity during separation and recycling. Non- reusable wood demolition debris can, at best, be chipped for fuel or mulch, and concrete and masonry can be crushed for granular fill. These latter two are examples of extreme loss of quality during recycling. For some materials recycling is only done to prevent the material from going to a disposal site for burial. It is not economically viable otherwise.

Today in the developed world the vast majority of construction and demolition waste is buried in landfills simply due to the difficulty of salvage and recycling, or the poor economics of recovery. In the developing world very little reusable material goes to waste.

4. Material Assessment Methods

Work on calculation of the environmental life cycle of *generic* materials has progressed in Europe and North America over the past two decades. Two such software systems in North America are BEES (US, National Institute for Standards and Technology) and ATHENA (Canada, Sustainable Materials Institute). These tools produce a resource use, energy, waste, and pollution profile for building materials. Similar products in Europe are: LCAiT from the Chalmers Industrieteknik, Sweden; IDEMAT from Delft University, the Netherlands; and GaBi3 from the University of Stuttgart, Germany.

Standardized methods for evaluating the life cycle of *trade name* materials and applying "green labeling" have been under development in Western Europe, Japan and North America for more than a decade (Appendix A). The eventual wide availability and high credibility of material labeling will allow accurate purchasing decisions based on environmental impacts, just as energy performance labeling for appliances, HVAC equipment and windows have made responsible energy choices more reliable.

5. Other Economic Factors

Every material represents an environmental debt incurred in its manufacture. This debt is the result of habitat disturbance, raw materials consumed, energy consumed, and waste produced. The usefulness of this material in providing a service is the credit side of the equation. Over time, disturbed habitats can heal, renewable raw materials can be replaced (or non-renewables recycled) and waste can be absorbed, though all of these are highly dependent on the materials, the specifics of the ecosystems, the technology used etc. Once time is added to this equation, it becomes clear that extending the useful life of the material or building is one of the most effective ways of reducing the lifetime environmental debt (GBTool).

For example an asphalt shingle roof may last as little as 15 years, after which it goes for disposal and is replaced. Its contents are non-renewable petroleum and minerals, and it is not effectively recyclable at this time. By comparison, a coated steel roof may last 40 years and is highly recyclable. A cement tile or fibre-cement composite roof may last over 75 years, and though it is not truly recyclable, the demolition waste is benign and may be crushed for clean fill.

6. Material Economic Life Cycle

The greatest difficulty with acceptance of durable materials is the first-time cost. In the above case, the material cost of the more durable roofs is two to five times that of the 15 year asphalt roof. In terms of a simple life cycle cost analysis, given the labour to replace the 15 year roof periodically, and the disposal costs for the waste, the 15 year roof is more expensive than the durable options over a few decades. However to an individual or organization that is very sensitive to first time cost financing, or that won't own the building for the long term, the durable option is hard to justify. This is a strong example of the lack of environmental responsibility and poor long-term investment value that is commonplace in building material choices due to market economics.

The amount that can be spent on a building, and therefore what can be spent on durable, high quality and environmentally friendly materials, is driven by a financing formula called the capitalization rate. The capitalization rate method works backward from the value placed in a building in terms of its market price or rental income potential, and determines what it is economic to spend on it, given certain interest rates, profit margins, and depreciation allowances etc. If the market definition of value can shift slightly to encompass durability, environmental qualities, and security from future shortages of replacement materials or escalations in disposal and replacement costs, then investments in quality, environmentally friendly materials can be better justified. This same trend is beginning to be evident for energy efficient buildings. In an age of unstable and escalating utility rates investors are more willing to spend on efficiency to make their projects more independent of price changes (UEI).

6.1 Building materials and local economies

The manufacture of building materials may provide important employment benefits, tax revenue benefits and other social and economic supports to the local region. An enlightened manufacturing company may also give to environmental, education and culture programs that benefit the local area. Buying locally is a maxim for bioregional economics; it may also be simply good economics. Even if the cost of production of a local product is higher, more of the revenue from purchasing it stays in the local economy and therefore improves the tax base and reduces demand for social support costs compared to an imported product. It also keeps the burden of responsibility for resource management and waste reduction in the local area. Transportation and its environmental effects are also reduced for local products.

-
-
-

Bibliography

1) World Resources Institute (WRI), 2000, Hyperforum on Resources and Sustainability, http://hyperforum.wri.org/

2) Ross, M, E.D. Larson and R.H. Williams, Energy Demand and Materials Flow in the Economy, *Energy*, V.12 #10/11:pp. 953-967, 1987

3) International Institute for the Steel Industries (IISI); http://www.worldsteel.org/trends

4) United Nations Food and Agriculture Organization (FAO) Forest Products Yearbook, 1950-1991, Forestry Series #26, 1992

5) China State Administration of the Building Materials Industries (SABMI), Beijing, 2000

6) China Council for Promotion of International Trade (CCPIT*), ChinaBuilding information Service and The Building Materials Sub-council*, Beijing, China URL: http://www.ccpit.org

7) Building for Environment and Economic Sustainability Software (BEES) US Dept. of Commerce, National Institute of Standards and Technology, Building Fire Research Laboratory http://www.bfrl.nist.gov/oae/bees.html

8) Athena Sustainable Materials Institute (ATHENA Software) Ottawa, Canada http://www.athenasmi.ca

9) Green Building Tool lifecycle assessment method (GBTool), Natural Resource Canada Buildings Group, Ottawa, Canada http://greenbuilding.ca/gbc98cnf/sponsors/gbtool.htm

10) The Urban Environmental Institute (UEI), Mithun Architects + Planners, Sustainability White Paper for Vulcan Northwest's Properties in South Lake Union, Vulcan NW Corp., Seattle WA, USA, 2001

11) CSIRO Built Environment, http://www.dbce.csiro.au/ind-serv/brochures/embodied/embodied.htm

12) Canada Mortgage and Housing Corp. (CMHC), Residential Retrofit Potential in Canada, Research Division, CMHC, Ottawa, Canada, 1996

13) American Institute of Architects (AIA), Environmental Resource Guide, Wiley, New York, 2000

14) Seppanen, Olli & Ilari Aho, *Experience From the Finnish Classification of Indoor Climate, Construction and Finishing Materials for Healthy Indoor Climate*, Proceedings, Sustainable Buildings 1998, October 26-28, Vancouver, Canada, Natural Resources Canada, Ottawa.

15) Environmental Choice, Canada; http://www.environmentalchoice.com/

16)VOC Rules for paints and coatings. USA:http://www.sspc.org/site/regnews.html

EU:http://www.ecosite.co.uk/depart/eubkinfo/paints.htm

17) ISO 14001: See: http://www.iso.ch/

Biographical Sketch

David Rousseau is an environmental building design and urban planning consultant specializing in green systems integration and life cycle analysis. His training is in environmental studies and architecture, including a post-graduate architecture degree combining ecological design, community planning and environmental toxicology. He is the author of three books plus many articles and teaching materials on healthy buildings, sustainable design, and green materials. He lectures widely and has developed and taught *Design With Natural Systems* at the University of British Columbia School of Architecture graduate program.