ANALYSIS OF SELECTION CRITERIA FOR GREEN BUILDING MATERIALS IN RINKER HALL

By

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To my wonderful and loving parents, Mala Arora and Narinder Arora, who have supported me in innumerable ways throughout my life. Also, I dedicate this thesis to my elder brother, Prashant Arora, without him this thesis would not have been possible.

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Abstract of Thesis Presented to the Graduate School
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ANALYSIS OF SELECTION CRITERIA FOR GREEN BUILDING MATERIALS IN RINKER HALL

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The evaluation and assessment of high performance green buildings is theoretically and practically a complex task and becomes all the more challenging when comparing different products with similar function in projects outlined with the ultimate goal of being recognized as a green building. Although a product/material may be evaluated and selected for use based on different selection criteria, it should embody the principles of reduced resource consumption, reduced environmental impacts and improved contribution to ecosystems function while improving function and aesthetics of a building.

This study attempts to find overall product/material selection criteria of building materials deemed sustainable, their environmental impact and the various advantages associated with them. There is still considerable debate about the validity of green materials in terms of their "embodied energy" or "economic viability". This research attempts to contribute towards the debate by adopting a holistic approach vis-à-vis by taking into account resource efficiency, indoor air quality, energy efficiency, water conservation and affordability. Secondary goal of this study is to explain energy analysis, indoor environment quality (IEQ) and global warming

potential (GWP) in a LEED certified building which incorporates sustainably managed green building materials and techniques which make it a “green building”.

To do so, recommendations and conclusions are made based on theory and research from U.S. Green Building Council (USGBC) and other such nationally recognized institutions, their publications and other publications.

Keywords**:** Building materials; Sustainability; Selection criteria; Indoor air quality; Environmental impact; Efficiency; Material emissions; Recycling; Embodied energy.

CHAPTER 1
INTRODUCTION

Introduction

Sustainability is picking up its pace globally. From recycling to energy efficiency to reducing carbon emissions, there is an urgency to minimize the impact on the environment more than ever. Building renovation and construction is taking a lead in this movement. It not only has a significant impact on the environment and health, but it also promotes long term financial savings and social responsibility in the community. Building green is the construction standard for the future and a smart solution for today's problems.

With the industrialization of construction, a worldwide trend emerged that allowed architects to design modern buildings for investors who built equity at the expense of environment. This blindsided practice has of late been labeled unsustainable but it is still the norm, and building green, a movement once considered peripheral and its features "add-on", is quickly finding acceptance. According to National Association of Home Builders (NAHB) it will be the norm within the next ten years. Already up to 40% of all buildings are projected to have three of the five green criteria built into their plans by next year. A study by the American Institutes of Architects (AIA) shows that homeowner's priorities when selecting housing designs are focused on energy conservation first. They are quickly moving toward sustainable products, water saving products and energy saving products. For the first time builders with green projects have surpassed those builders with less than 15% green projects; estimated growth in green building was anticipated to be up to 60% of all building projects for "green builders" in 2009 (Live Green Live Smart Institute 2008).

However, this growth and the rise in demand have not come without challenges. Currently, the following issues are restricting the number of green projects being built (Articles Base 2005):

- Green products are selling at a premium compared to conventional products.
- Production of green products is still limited and increased demand has lead to long lead times.
- A few building systems and unspecified products are being marketed as green when they are not. Thus, giving rise to "Greenwashing."
- Building officials are struggling with a steep learning curve on how to evaluate new green products and sustainable building techniques.

There are tangible and long-term benefits of incorporating both active and passive sustainable design features when integrated with green products. Per USGBC data, green buildings not only save water and electricity but require fewer raw materials, and divert less waste to the already shrinking landfills. However, despite the gaining popularity of sustainable design there are still some orthodox building professionals and buyers who are skeptic about the economic returns of building green. Studies have suggested that an initial upfront investment of 2% extra will yield over ten times the initial investment over the life cycle of the building. Additional economic payback (mentioned at numerous occasions in this study) may come in the form of employee productivity gains incurred as a result of working in a healthier environment. According to a recent study, the benefit to realty from an unconventional building is equally promising- A LEED certified building commands rent premiums of $11.24 per square foot over non-LEED buildings and have 3.8% higher occupancy. They may be more expensive to finance, plan and execute but people have awakened to the benefit of living and working in a green building that is sensitive to the environment before and even after it was built (USGBC 2008).

Life Cycle Analysis (LCA)

Life cycle analysis (LCA) represents a comprehensive means to judge the environmental impact of a product through the various stages of its life cycle. The various stages/factors assessed for this purpose include material procurement, manufacturing, packaging and shipping,

through installation, indoor air quality, durability and performance, and end-of-use resource recovery. Such stringent evaluation helps selection of such healthy and sustainable materials which have a clear potential of minimizing the undesirable effects on the environment (Down to Earth Design 2000).

LCA differs from embodied energy or life cycle cost (LCC) in a manner that LCA is qualitative in nature while both embodied energy and LCC are primarily quantitative entities. Embodied energy represents the energy required to acquire the necessary raw materials, produce the product, and transport it to the point-of-use; and LCC, on the other hand, quantifies the economic impact of a material on the peak performance of a building. Inspite of the validity of the data being highly dependent on the method of evaluation, LCC can prove to be useful when comparing two different materials (Down to Earth Design 2000).

Statement of Purpose

The purpose of this paper is to draw upon the evolution of the concept of sustainable building materials, forge an understanding of their benefits with regard to a case study, the significance of selection criteria and its impact on the environment. Green building materials are considered environmentally responsible due to the consideration of the fact that just any building material can potentially leave a larger carbon footprint over its entire useful life.

Constructing a building requires enormous quantities of resources and energy. According to Environmental Protection Agency (EPA), buildings in the U.S. itself account for 37% of the nation's total energy use, 12% of potable water consumption, 68% of total electricity consumption, and 136 million tons of construction and demolition debris annually. The HVAC system, lighting (both exterior and interior), landscape irrigation, water heating, and vertical transportation systems- all contribute to making buildings a significant source of greenhouse gas emissions and a leading energy user (Green Energy Ohio 2004). However, by building smaller,

smarter and more efficiently, there is reduction in the resources and energy necessary to make the buildings work. Also, by selecting “green” building materials, one makes a conscious decision to think beyond the project and not consider the building and environment as mutually exclusive. Sustained effort in this direction can ensure that every remodel or addition becomes an opportunity to create a healthier environment and improve employee productivity and satisfaction. When selecting materials, it is important to keep in mind that there are no single correct criteria. The goal should be to make educated choices about products which are resource and process efficient, easy to maintain and when used integrally should optimize the life cycle economic performance of the building.

According to a Green Seal estimate 82% of consumers are still buying green products despite the lingering recession of 2008-09 (Green Seal 2009). Going back in time a little bit, at beginning of 2005, 177 million square feet of buildings were certified by the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) Program as green. An article in the Harvard Business Review stated its prediction that green construction will emerge as a mainstream technology in the coming five to ten years, as a budding market helps to drive down the cost of green building products, and also with the growing awareness among the building owners regarding the economic, health, and environmental advantages of green building (McWilliams 2006).

But even with the aid of today’s modern technology, considerable damage has been and is still been done to the environment as a result of procedures and processes involved with the extraction, transportation, processing, fabrication, installation, recycling and disposal of construction industry related materials. On a global scale construction activities and buildings consume more than 3 billion tons of raw materials annually which amount to roughly 40% of

total worldwide use of raw material (Green Energy Ohio 2004). It cannot be forbidden altogether but the damage so far caused can be contained by integrating green materials and products into not only niche' but mainstream construction projects as well.

Scope of Study

The scope of the study includes the following:

- A review of the current and forthcoming building technology as well as a detailed analysis of impact, benefits, and recycling of different building materials.
- An in-depth discussion focusing on the building materials defined as "green".
- The definition of green building materials and the criteria these materials must meet in order to be called green.
- The consideration of indoor air quality as a life cycle environmental assessment process for building product selection.
- Green material assessment methods such as "embodied energy".

Objectives of the Study

The objective of the research is to collect and analyze the data that help in the determination of the following:

- The Life Cycle Design principles and analysis of building products and the three phases of them: Pre-building, Building and Post-building.
- The evaluation of building materials' environmental impact at each phase.
- The validity of green materials in terms of their "embodied energy".
- "Energy efficiency" in making a building material environmentally sustainable and the ultimate importance of using such materials in reducing the energy consumption in buildings.
- The environmental assessment process for building product selection.
- Resource efficiency accomplished by reuse and recycling of materials.
- The enhancement of indoor air quality with the utilization of different sustainable materials.

Limitations of the Study

A wide variety of green building materials are available in the market and it was out of the scope of this study to deal with every material. Emphasis, however, was given to materials studied in the case study and the criterions of energy efficiency were limited to the case study. After extensive research certain selection criteria were selected which cover various known aspects of the green building materials and due to time constraints only the identified selection criteria were discussed.

Furnishing of information and subsequent analysis, as based on facts, should be considered as a holistic approach towards this study for which additional research is required. It has been the effort of this author to base analysis of the research on competent evidence and use up to date information for the same. Some information, however, may become obsolete due to the evolving nature of the research pertaining to building materials or modifications in green product lines.

A quantitative LCA and detailed embodied energy study of the materials involving the case study are out of scope due to the long time periods involved in conducting one such study, rather simplified life cycle thinking approach was made of the same. The attributes of energy analysis, IEQ and GWP are based on and inspired by the examination of the case study.

CHAPTER 2
LITERATURE REVIEW

Introduction

This literature review is a derivation of different sections which summarize information regarding green building materials and products. It provides information on their benefits, resource and material efficiency and most importantly their impact on the environment and how they benefit sustainable built environment over the life cycle of the building. It illustrates the information collected from various resources, mostly through web pages and other print media.

General Description

It was after the formation of USGBC in 1993, that the awareness in the field of sustainable building materials and green buildings started. The USGBC has been working tirelessly ever since in a manner that puts emphasis on the central idea that buildings and its users affect the environment and lays down steps that minimizes the impact of construction related activities and proven strategies that could improve the efficiency of the built environment.

In the United States, buildings account for 38% of all carbon dioxide emissions and are of the heaviest consumers of natural resources and account for a significant portion of the green house gas emissions that affect our climate (Green Energy Ohio 2004). They contribute up to 50% of chlorofluorocarbons (CFCs) production; consume 70% of current U.S. electricity, 16% of total U.S. water and produce 40% of the waste that lands up in landfills (Karolides 2002). The process of getting the materials to construction sites and constructing the buildings alone accounts for 40% of total energy flows (Green Energy Ohio 2004). However, by incorporating sound principles of sustainable architecture, a smarter and more efficient system of construction can be put in place which can result in significant reduction in the resources and energy necessary to make the buildings work. The utilization of green building materials and products,

in this case, carries the potential to promote the conservation of non-renewable resources internationally. In addition, integrating green building materials and products into construction projects can minimize the hazardous effects on environment that occur as a result of various procedures involved with the extraction, transportation, processing, fabrication, installation, recycling, and disposal of these construction industry source materials.

What is a Green Building Material?

A green building material is one that uses the earth's natural resources in an ecologically sensitive manner and is composed of renewable, rather than non-renewable, elements. Such materials do not attempt to disturb the inherent pattern of nature's cycles and the interrelationships of various ecosystems, as is the case with many artificial man-made materials. They are prepared from recycled materials and are themselves recyclable as well. Green materials are non-toxic, energy efficient and water efficient. The way they are manufactured, used, and reclaimed, with a sensitive consideration of their environmental imprint over the complete life of the product, makes them green in the true sense. They also positively influence other key parameters such as resource management, IEQ, and performance based on energy and water efficiency (Spiegel and Meadows 2006).

Three Phases of Building Materials

In reference to an article by Jong Kim and Brenda Rigdon (December 1998), the Life Cycle Design principles and analysis of building products provide important guidelines for the selection of building materials. A "cradle-to-grave" analysis of building products, from the gathering of raw materials to their ultimate disposal, provides a better understanding of their life cycle. A material's life cycle can be organized into three phases: Pre-Building, Building, and Post-Building (Kim and Rigdon 1998).

The Pre-Building Phase is about the delivery and manufacturing of a material, up to, but excluding the process of installation. This includes the unearthing of raw materials in nature as well as extracting, manufacturing, packing, and transportation to a construction site. This phase is bound to carry the maximum potential for causing environmental damage. The Building Phase refers to the material's useful life. This phase starts from the point where the material is assembled to give shape or applied to a structure, including the repair and maintenance and extends throughout the material's shelf life. The Post- Building Phase refers to the building materials when their usefulness in a building has expired. This is the time when the components of these materials can be recycled back into other products, reused or be discarded (Kim and Rigdon 1998).

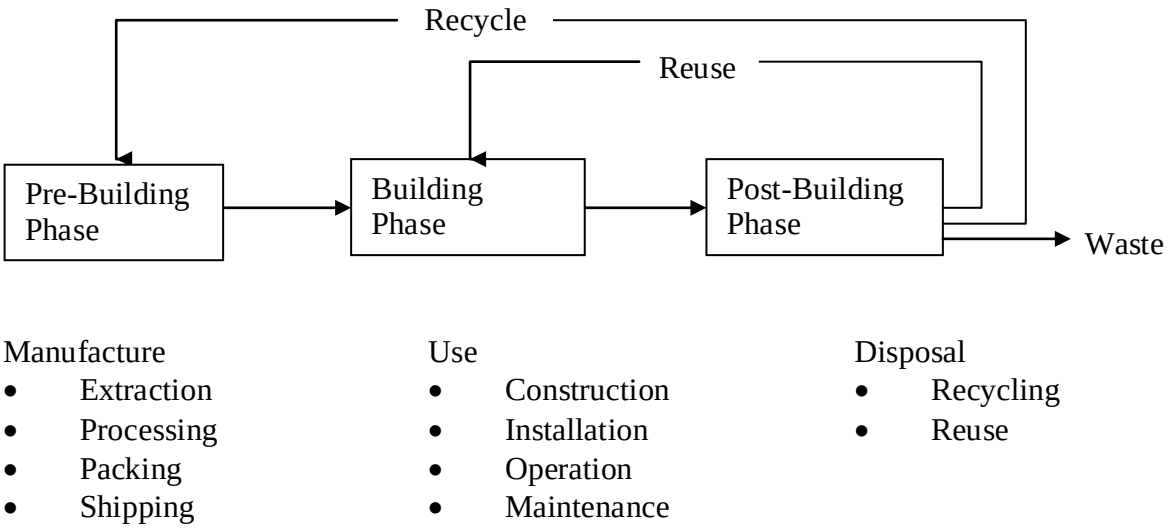

Figure 2-1. Three phases of the building material life cycle (Source: Kim and Rigdon 1998).

Life Cycle Assessment

Life cycle assessment (LCA) is the environmental impact or financial cost of a building throughout its lifespan. Typically, "green" buildings have a higher initial cost than a conventional building but the cost is lower over their lifespan (Shepard 2001).

To determine the embodied environmental effects of materials, rather than emphasizing on particular material properties such as recycled content or transportation of materials after they are manufactured, LCA is used for performance based outcomes. It is a methodology for assessing the environmental performance of a material over its full life cycle, which includes all stages of raw material extraction, production, manufacturing, distribution, use, maintenance, reuse, or recycling, disposal, and all transportation. Figure 2-2 shows all stages of a material's life cycle. The energy required to operate a building can outweigh the inherent energy of the materials and products to a large amount. The importance of LCA is to apprehend all the applicable effects of a process or material over its entire life cycle. It is also significant to learn that LCA of a product takes into account the maintenance and use of any other products required for cleaning and maintaining during its useful stage (Carmody and Trusty 2002).

It is essential to note that LCA is not same as LCC. The two methodologies complement each other, while LCA focuses on environmental performance; LCC is the dollar costs of building and its maintenance over its life cycle. Environmental performance is generally measured in relation to a wide range of potential effects, such as:

- Global warming potential
- Use of non-renewable resources such as fossil fuel
- Ozone layer depletion
- Smog creation
- Water usage
- Emission of toxic substances to air, water, and land

All of these measures are results from the manufacture, use and disposal of materials which are indicators of environmental performance, and which make a significant impact on the natural environment (Carmody and Trusty 2002).

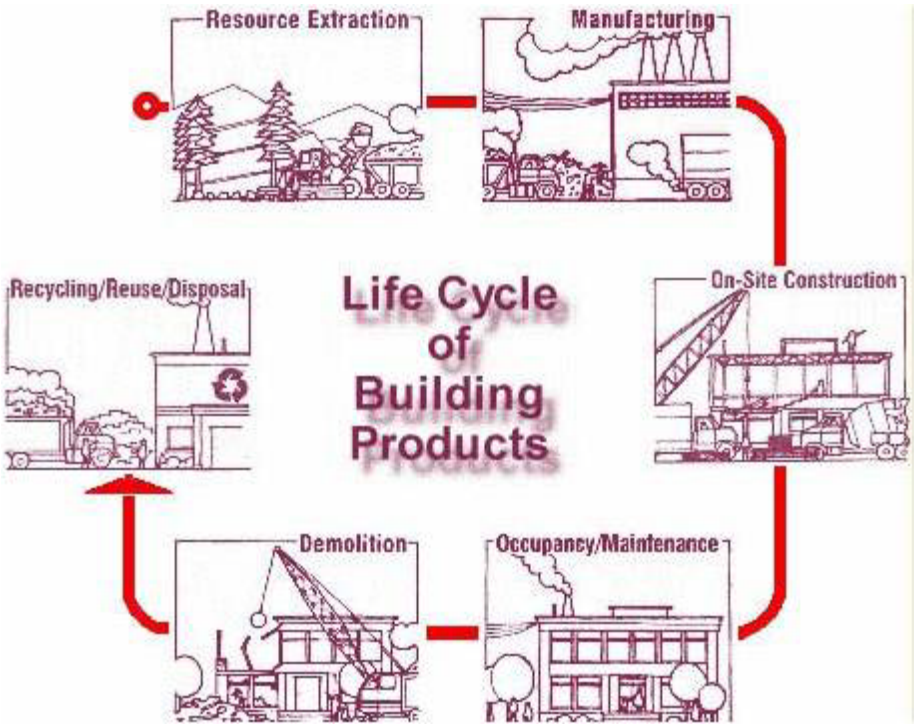

Figure 2-2. Life cycle of materials based on LCA (Source: Carmody 2002).

Criteria for Selecting Sustainable Building Materials

Literature was reviewed, and seventeen different sources of material selection criteria were identified (see Table 2-5). The unique criteria are defined and discussed in the following sections.

In a survey conducted by University of Michigan about a decade ago, of the building material manufacturers, it revealed environmentally sustainable replacements for use in every type of building system. The different types of materials and products selected from this survey highlighted the wide range of available materials that are manufactured and designed with consideration to environment. The selection criteria included sustainability in regard to a large range of environmental issues: raw material extraction, manufacturing processes, construction techniques, and disposal of demolition waste (Kim and Rigdon 1998).

Table 2-1 shows the different criteria, grouped as per the affected phase of the building life cycle. This table helps compare different materials on the basis of their sustainable qualities. Their relative sustainability is established on the basis of presence of such "green features" in the building material or product.

Table 2-1. Key to the green features of sustainable building materials (Source: Kim and Rigdon 1998).

	Green features	
Manufacturing process	Building operations	Waste management
Waste reduction	Energy efficiency	Biodegradable
Pollution prevention	Water treatment and conservation	Recyclable
Recycled	Non-toxic	Reusable
Embodied energy reduction	Renewable energy source	Others
Natural material	Longer life	

Features of Sustainable Building Materials

The features of the materials were identified into three groups: manufacture, use, and disposal. These groups based on the material life cycle were used in evaluating the environmental sustainability of building materials. The presence of one or more of the features in materials makes it environmentally sustainable (Kim and Rigdon 1998).

Pre-Building phase: Manufacture

- Waste reduction
- Pollution prevention
- Recycled content
- Embodied energy reduction
- Use of natural materials

Building Phase: Use

- Reduction in construction waste
- Energy efficiency
- Water treatment/conservation
- Use of non-toxic or less-toxic materials
- Renewable energy systems
- Longer life

Post-Building Phase: Disposal

- Reusability
- Recyclability
- Biodegradability

These were the criteria adopted to evaluate the building materials. More and more research in the subject came up with new results and better understanding of the selection criteria which helped in choosing and determining environmentally preferred materials and products.

Evaluation of Green Building Materials

In the current market an important goal for the building sector is to produce buildings with minimum impact on environment and to take on the challenge of besting the process of selecting both responsible and responsive materials for a building project. The purpose of this section is to characterize the evaluation of products and to offer environmentally preferable options to traditional building materials and techniques (Burnett 2001).

There is no single solution for selecting the right material. The evaluation and assessment of green building becomes increasingly complex when comparing different products with the similar function. A product/material may be evaluated and selected for a use based on many different criteria, for example recycled content, recyclable, energy efficiency, indoor air quality, reusability, resource efficiency, low-toxicity, and low embodied energy (Froeschle 1999).

The significance of selection criteria is in determining the materials' impact on the environment over the life of the product. A material may be evaluated using more than one criterion to minimize the overall environmental impact. A LCA of the product is very important; it addresses the impacts of a product through all of its life stages. LCA principles are used for evaluating and comparing various green building materials and systems. Inspite of being simple in principle, this approach has proved to be quite expensive and difficult to implement in actual practice. Conditions vary from project to project and the goal should be to make intelligent and

educated choices (Santa Barbara County Green Building Guidelines 2001; Spiegel and Meadows 2006).

Three Basic Steps of Product Selection

The environmental assessment and analysis of green building materials is divided into three phases and product selection begins after the establishment of project-specific environmental goals. The environmental assessment process involves three basic steps (Froeschle 1999).

- Research
- Evaluation
- Selection

Research

This step is involved with the gathering of technical information to be evaluated, raw material characteristics whether they are virgin, renewable or recycled content data, manufacturing process and location, transportation, maintenance, and durability requirements of the finished products, costs, disposal strategy, indoor air quality (IAQ) test data, product warranties, manufacturers' information such as material safety data sheets (MSDS), and lastly environmental statements (Froeschle 1999).

Evaluation

The research process is followed by evaluation stage and this step implies confirmation of the technical information, as well as filling in information gaps. Evaluation and assessment is relatively simple when similar types of building materials are compared using the environmental criteria. It becomes more complex when different products with the same function are compared. In this stage, the environmental burdens associated with the product, process and activity are identified and quantified. This includes the impact on the environment, whether in a positive or negative way, associated with energy and materials used and waste generated. The evaluation

stage involves the use of LCA. It is an evaluation of the relative "greenness" of building materials and products covering the whole life of the component from cradle to grave, which includes the use of the component in buildings and its final end life disposal (Froeschle 1999).

Selection

The selection stage involves a simpler approach to a fully quantitative LCA in terms of environmental assessment matrix. The key to material selection is the identification of the goals such as aesthetics, durability, recycled content, maintenance, and recyclability. The goals are prioritized and weight ages are assigned to them. An evaluation matrix for scoring the project-specific environmental criteria is included in this phase. The product with the total score of evaluation indicates the maximum environmental attributes. It is a semi quantitative method and best used for comparing different types of materials. It can be easily executed in a project and allows for a more comprehensible approach towards an environmental assessment (Froeschle 1999).

Table 2-2. Environmental material assessment matrix (Source: Froeschle 1999).

Environmental criteria	Product “A”	Product “B”	Product “C”
Resource efficiency			
Durable materials			
Local product			
Recyclable materials			
Recycled content			
Reusable components			
Sustainable sources			
Improved IAQ			
Healthful maintenance			
Low-toxicity			
Low-VOC assembly			
Minimal emissions			
Moisture resistant			
Energy efficiency			
Water conserving			
Affordable material			
Environmental score			

Over All Material/Product Selection Criteria

When evaluating materials, the "cradle-to-grave" approach should be followed. Materials should be chosen that minimize environmental and health impacts during resource extraction, manufacturing, packaging, transportation, installation, operation, and disposal (Santa Barbara County Green Building Guidelines 2001). The overall method for selecting building materials can be broadly divided into five main categories (Froeschle 1999).

- Resource efficiency
- Indoor air quality
- Energy efficiency
- Water conservation
- Affordability

Resource Efficiency

It is accomplished by the usage of materials that meets the following criteria and the importance of each criterion varies with the environmental goals of a project. The different factors help in determining environmentally preferred materials and products. Resource efficiency of building materials is also increased by reducing waste in the manufacturing process.

Durable

The durability of materials is an important factor in analyzing a building's life cycle costs. Durable products are long lasting or are comparable to conventional products and need little maintenance with long life expectancies (Spiegel and Meadows 2006).

Local/regional materials

Other criteria which can be combined with the objective of low embodied energy and reduced air pollution and consumption of fossil resources is the use of locally manufactured building materials which helps in reducing the environmental impact resulting from the transportation distances. The construction of buildings requires transportation of large quantities of materials over great distances. Material mass and transportation to manufacturing facility or

site are the key factors contributing to transportation related environmental impacts. The key parameters are (i) Distances traveled from place of extraction to manufacturing facility (ii) Distances traveled from manufacturing facility to site (iii) Mass of materials. The fuel required to transport a material to a site or to a manufacturing facility refers to a significant part of embodied energy. Lower the distance, lesser the fuel used and lesser the embodied energy (Scheuer and Keoleian 2002).

Low embodied energy

Embodied energy is a term used to describe the total amount of energy contained in a product or material. It is the energy required to process and extract the raw materials, manufacture and packaging of a product, distributing it to retail outlets, wholesalers and finally to the job site. It refers to the total energy that has been put in to producing a particular material to the final installation at the site, which includes the collection and transportation of raw materials (Shepard 2001).

This energy typically comes from the burning of fossil fuels and non-renewable resources which are a limited in nature. The greater a material's embodied energy, the greater will be the amount of energy required to produce it, and hence resulting in the heavy ecological consequences. Recycling of materials preserves the embodied energy they contain. The energy used in the manufacturing of new materials or products is far more than the energy required in the recycling process. Generally, natural materials are lower in embodied energy. They require less processing and are less damaging to the environment. Many, like wood, are theoretically renewable and when these kind of natural materials are put to practical use by blending and integrating into building products, the products become even more sustainable (Kim and Rigdon 1998).

The energy used in transportation of the materials also becomes a part of building's embodied energy. It is therefore advisable to use local materials which further lessen the embodied energy embedded in a building (Buchanan 2000). Typical embodied energy units used are MJ/kg (mega joules of energy needed to make a kilogram of product) (CSIRO 2003).

Table 2-3. Estimated embodied energy of common building materials (Source: Karolides 2003).

Common building materials	Embodied energy (in MJ/Kg)
Baled straw	0.2
Kiln-dried hardwood	2.0
Cement	7.8
Float glass	15.9
Fiberglass	30.3
Virgin steel	32.0
Recycled steel	10.1
Expanded polystyrene plastic (EPS)	117.0
Virgin aluminum	191.0
Recycled aluminum	8.1

Natural or minimally processed

Products that are natural or minimally processed can be green because of low energy use and low risk of chemical releases during manufacture. Materials harvested from sustainably managed sources and preferably have an independent certification (e.g., certified wood by Forest Stewardship Council) and are certified by an independent third party (Wilson 2006).

Recyclable materials

Materials that are recyclable or reusable at the end of their useful life save the cost of new materials and leave a lower impact on the natural resources (Froeschle 1999). After the useful life, they can be reprocessed into other materials that would have otherwise ended in landfills (Shannon et al. 2005).

Recycled materials

Recycling of materials is one component of a larger holistic practice called sustainable or green building construction. One of the most important criteria which define that product or

material should be used with recycled content with a preference for postconsumer content. The use of recycled materials reduces landfill burdens. It also displaces the use of virgin or primary resources of materials. In addition, it provides the opportunity to reduce the embodied energy of a material by eliminating the process of extraction and processing. Hence, energy burden for the primary resources is reduced. To an extent, recycling helps eliminate the process of extraction and processing thus encouraging reduction in the use of fossil fuel consumption; it cuts air pollution and saves transportation costs over great distances as well (Scheuer and Keoleian 2002).

Renewable resources

Products manufactured using renewable sources over non-renewable resources of energy helps reduce the environmental impact. By utilizing renewable energies, such as wind, solar, tidal, as well as renewable products, such as wood, grasses or soil, natural paints, organic cotton, cork, and jute lessen the strain ecosystems and helps preserve biodiversity. The aforementioned products are less energy-intensive to produce, though transportation and processing energy use must be considered. They are biodegradable, often (but not always) low in VOC emissions, and are generally produced from agricultural crops. Components that encourage daylighting, passive and active solar heating, and on-site power generation are also included in this category. Apart from this, the key building materials include limestone, aluminum, steel, bricks and tile, petrochemicals and wood (Shannon et al. 2005; Wilson 2006).

Reusable/salvageable products

Deconstruction methods and demolition waste, if used efficiently, can help save consumption of green materials/products. Many products can be reused or recycled at the end of their useful life. Materials can be easily dismantled and can be reused as they are or can be altered and used as a post-consumer product thereby saving a lot of energy which goes in to

manufacturing new products from raw materials. The fundamental tenet of green building construction is the efficient use of resources. This means reducing, reusing, and recycling most, if not all materials that are remnants of a construction or renovation project (Wilson and Malin 2006).

Indoor Air Quality (IAQ)

Materials used in the interior of a building can be a significant source of pollutants and can affect the indoor air quality which can adversely affect the health and comfort of building occupants. Incidentally with the popularity of sustainable development, understanding and awareness about the quality of air we breathe inside the building has gained considerable attention as well over the past one decade (Burnett 2001). IAQ can be enhanced with the selection of materials that meets the following criteria:

Healthfully maintained

Materials, components and systems which require little maintenance and are maintained healthfully should be the ideal approach. The method for cleaning should be simple, non-toxic, or low-VOC (Froeschle 1999).

Low or non-toxic

Materials that emit few or no carcinogens, reproductive toxicants, or irritants as demonstrated by the manufacturer, help in maintaining a healthy indoor environment. They should be manufactured from non-toxic components that cause minimum pollution. Non-toxic methods of cleaning should also be adopted (Ecology Action 2007).

Low-VOC assembly

The significant indoor pollutant sources are not limited to radon or formaldehyde. Many other materials like carpet, resilient flooring, and wall covering emit a variety of VOCs. Among

others include insulation, acoustical ceiling tile, and furnishing which emit VOCs and particulate contaminants (Burnett and Niu 2001).

Materials installed with minimal VOC-producing compounds, or no-VOC mechanical attachment methods should be used, which are less hazardous (Froeschle 1999).

Minimal chemical emissions

Volatile organic compounds (VOCs) are found to be major contributors to sick building syndrome and in the general indoor environments are typically at the concentration level of parts-per-billion (Burnett and Niu 2001). Table 2-4 shows the pollutant emissions of various materials and the health concerns associated with them.

Table 2-4. Interior materials, their pollutant emissions and the health concerns (Source: Burnett and Niu 2001).

Materials	Pollutant emitted	Contribution indoor concentrations	Health effects
Earth – derived materials – brick, concrete and tiles	Radon	Ventilation rate-dependent, up to 1000 Bq/m^3	Lung cancer, particularly for smokers
Asbestos – fire proofing materials	Asbestos fibers Variety of VOCs	Usually at parts-per-billion levels, unusually high concentrations occur	Lung disease: asbestosis, cancer Species-dependent, likely causes of SBS
Particleboard and plywood	Formaldehyde		Membrane irritation, suspected carcinogens
Carpet, resilient flooring, and wall covering	Variety of VOCs	Usually at parts-per-billion levels	Species dependent, likely causes of SBS
Insulation, acoustical ceiling tile, and furnishing	VOCs and particulate contaminants		

Products that do not contain VOCs or having low amount should be used whenever possible. A volatile substance is one that evaporates readily at normal temperatures and pressures. Paint is made of three components: solvent, pigment, and binder. Pigment and binder are non-volatile while solvent is volatile. They are hazardous to the ozone and contribute to smog

formation. Indoor VOCs can contribute to poor indoor air quality and multiple chemical sensitivities (PPG 2008).

The use of paints and other materials, for example, in flooring should have low or no VOCs and should avoid the use of chlorofluorocarbons (CFCs). The other materials which are sources of a variety of VOCs include adhesives, sealants, and architectural coatings. A few other indoor pollutants include radon and formaldehyde. Radon comes from soil, but is also released from any earth crust-derived building materials, including bricks and concrete. Formaldehyde is a colorless gas that sometimes has a noticeable odor and can be found in the adhesives used for the production of plywood and particleboard (Burnett and Niu 2001). These materials can release the gas into the air and can cause nausea, headaches, allergic sensitization, asthma, and eye, nose, throat, and skin irritation depending on people's sensitivity to formaldehyde (USEPA 2009). High levels of formaldehyde exposures are associated with more serious cardiovascular and pulmonary effects, neurological effects, and even cancer (Burnett and Niu 2001).

Moisture resistant

The materials used should be moisture resistant and also, resist mold growth. Those products and systems should be used which inhibit the growth of biological contaminants (Froeschle 1999).

Energy Efficiency

Energy efficiency is a significant feature in making a building material environmentally sustainable. The ultimate aim of using such energy-efficient materials is to minimize the amount of generated energy that is required at a building site. The long-term energy costs of operating a building are heavily dependent on the materials utilized in its construction. Depending on type, the energy-efficiency of building materials can be measured using factors such as R-value, shading coefficient, luminous efficiency, or fuel efficiency (Kim and Rigdon 1998).

R-value

R-value is a measure of thermal resistance and building envelopes are generally rated by their insulating value, known as the R-value. Materials with higher R-values are better insulators and increasing the thickness of an insulating layer increases the thermal resistance (Kim and Rigdon 1998).

System efficiency

Electrical and mechanical systems are responsible for a significant amount of a building's annual energy cost. Heating, ventilation, and air-conditioning (HVAC) systems should be selected for the greatest efficiency. Regular maintenance programs are also necessary to keep equipment operating at highest level of efficiency (Kim and Rigdon 1998).

Energy efficiency strategies

The following strategies contribute to the goal of gaining energy efficiency, which are as follows (CIWMB 2008):

- Passive design strategies include building shape and orientation, solar design and the use of natural lighting, which significantly affects a building energy performance. Natural lighting on the other hand, increases productivity and well being of the occupants.
- High-efficiency lighting systems with advanced lighting controls should be installed, which includes motion and other sensors to control the amount of light required.
- Electric loads from lighting, equipment, and appliances should be minimized.
- Alternative energy sources such as photovoltaic and fuel cells should be used.
- A thermally efficient building envelope with energy efficient heating and cooling system helps in saving energy.
- Use of light colors for roofing and wall finish materials should be maximized.
- Wall and ceiling insulation systems with higher R-value should be installed.
- Technologies using renewable energy sources such as geothermal heat pumps, trombe wall should be used.

Using energy efficient methods and materials reduces the energy consumption during construction as well as through the building's life cycle operation. Use of proper insulation methods for construction, efficient use of daylighting, high performance glazing and windows, building orientation, eliminating or lessening the need for air conditioning and heating helps in reducing energy consumption in buildings and facilities. Consideration of renewable sources of energy can help alleviate reliance on traditional fossil fuel sources (Shannon et al. 2005).

Water Conservation

Products with water conservation features reduce the amount of water used on site. This is generally accomplished in two ways: by restricting the amount of water through a fixture, e.g. faucet, water closet, showerhead or by recycling the water that has already reached the site or being used. The gray water from showers, bathroom sink, laundry, and kitchen may be recycled by channeling to flush toilets. Other strategy includes using stored rainwater or captured water runoff which may be used for irrigation (Kim and Rigdon 1998).

Efficient use of water and overall reduction in the volume consumed helps in conservation of freshwater. With the exception of using well-water and septic systems utilized in buildings, all water that leaves or enter a building must be treated. Producing less waste is another goal which is achieved by vacuum-assisted or composting toilets which use less water. The advantages of composting toilets are that no waste enters the already burdened waste stream, and the resulting compost can be used as fertilizer. The policy adopted in Japan to flush toilets, is by connecting the sink drain to the toilet water tank (flushing system uses dual flush system, also very popular in Australia). For flushing toilets and landscape irrigation, rainwater collected from roofs and paved parking lots or pathways can be utilized. The building can be designed to accommodate a tank for collection of rainwater which can be used at a later stage (Kim and Rigdon 1998).

Storm water pollution

Methods should be adopted to minimize storm water pollution and to conserve storm water as well. Storm water treatment system helps in reducing the pollutants level and the treated water can be utilized to flush toilets and for irrigation purposes. Water from the impervious surfaces can be collected and stored for future use. Porous paving products and green (vegetated) roofing systems also reduce storm water runoff and prevent water pollution (Wilson 2006).

Water efficiency strategies

Some of the basic techniques for achieving water efficiency are as follows (CIWMB 2008):

- Recirculation systems for centralized hot water distribution should be used.
- Point-of-use hot water heating systems for more distant locations should be installed.
- Waste of water can be minimized by using low flow shower heads, low-flush toilets, dual-flush toilets and other water conserving fixtures like water less urinals.
- Dual plumbing design features should be adopted to use recycled water for flushing toilets or a gray water system that recovers rainwater for site irrigation.
- Irrigation controlling methods should be used and self-closing nozzles on hoses.

Affordability

Green building materials are not significantly more costly than their counterpart conventional building materials. The long term operating and maintenance costs are lower as compared to the initial costs. The consideration of LCC is very important and with the utilization of green construction techniques, cost associated with energy, replacement and maintenance costs are greatly reduced (Shannon et al. 2005).

The LCC analysis is an economic method for evaluating a project or project alternatives over a specified period of time. This method helps comparing LCC for alternative building designs or system of a project having the same purpose to determine which has the lowest LCC over a period of time. The LCC method is particularly applicable in determining the cost of a

building which is economically justified with future reductions when compared with an alternative building which has lower initial cost but higher future costs in terms of maintenance, operating, replacement, and repair. If a building has both lower initial cost and lower future costs, relative to an alternative, the LCC analysis is not required to show the former is an economically preferable choice (ASTM 1999).

Benefits of Green Building Materials

The build environment has a deep impact on the natural environment, health, productivity and economy. Sustainable building practices go beyond energy and water conservation to incorporate environmentally sensitive site planning, resource efficient building materials and superior indoor environmental quality. Some of the key benefits of the materials are as follows (USGBC 2006):

Environmental Benefits

- Green building materials help in enhancing and protecting the ecosystems and biodiversity.
- Natural resources and renewable sources of energy are conserved.
- Recycling and reusing of materials help reduce solid waste, thus lessening landfill burden and saving on the virgin resources.
- They assist in improving the environment and indoor air quality.
- They help in minimizing ozone layer depletion and reduce air pollution.
- Green building products and practices help in conversation of water and reducing storm water pollution.

Economic Benefits

- They reduce operating, maintenance and replacement costs.
- Asset value and profits are enhanced with their usage.
- They optimize life cycle economic performance.
- They improve and maximize the performance, productivity, and comfort of occupants.

Health and Community Benefits

- They improve air, thermal, and acoustic environments and provide a healthier living environment.
- They minimize strain on local infrastructure.
- They contribute to overall quality of life and enhance community well-being.

Summary

A sustainable material or product is one the environmental impact of whose manufacturing has been factored in, and has the capability to reduce the overall carbon footprint of a building. The longevity and durability of the materials help save natural resources and the associated long term cost of maintaining their performance and appearance. The use of evaluation and selection criteria of materials even before the construction process begins helps in determining their life cycle benefits and with appropriate choices of materials better indoor environment quality can be achieved.

However, the main objective in trying to achieve a sustainable built environment is matching of the materials to the design at hand and in meeting the owners' environmental, social and financial goals while at the same time minimizing the overall impact on the environment.

This study identified and enumerated 38 selection criteria from fifteen organizations and two published articles. The criteria matrix in Table 2-5 was listed by frequency .This study helped in understanding various attributes of selection criteria by evaluating the materials and their contribution in a LEED certified building, which is discussed in Chapter 4.

Table 2-5. Summary of selection criteria from seventeen different sources.

Criteria	Frequency	Source 1	2	3	4	5	6	7	8
Recycled content	14	X	X	X	X	X	X	X	X
Recyclable	14	X	X	X	X	X	X	X	X
Energy efficient	14	X	X	X	X	X	X	X	
Renewable products	14	X	X	X	X	X	X	X	X
Improves IAQ	14	X	X	X	X	X	X	X	X
Reusable	13	X	X	X	X	X		X	X
Resource efficiency	12	X	X	X	X	X			
Water conserving	12	X	X	X	X	X		X	
Low-toxicity	11	X		X		X		X	X
Durable	11	X	X	X	X	X	X		
Minimum waste	11	X	X		X		X	X	
Low-VOC assembly	11	X		X		X			X
Local product	10	X		X		X	X		X
Non-ozone depleting products	10	X	X	X	X				X
Salvaged products	9	X	X	X	X	X			X
Natural or minimally processed	9	X	X	X	X	X			X
Minimal emissions	7	X		X		X		X	
Healthfully maintained	7	X	X	X	X				
Sustainable	7	X		X				X	X
Low embodied energy	7						X	X	X
Moisture	5	X		X		X			
Affordable	5	X		X		X	X		
Non-hazardous products	5	X	X	X	X				
Products with low maintenance requirements	5		X		X				
Products that reduce storm water pollution	5		X		X			X	
Certified wood products	5		X		X				
Low environmental impact	4						X	X	
Products made with waste agricultural material	4		X		X				
Products that remove indoor pollutants	3		X			X		X	
Products that enhance community well-being	3	X	X	X	X	X	X	X	X
Products that reduce material use	3		X		X				
Biodegradable	3								X
Products that reduce or eliminate pesticide	2								
treatments	2		X		X				
Products that improve light quality	2		X		X				
Products that help noise control	2		X		X				
Waste material	2								
Long lasting	2								
Bio-based materials	1								X

Table 2-5. Continued

Criteria	Source 9	10	11	12	13	14	15	16	17
Recycled content	X	X			X	X	X	X	X
Recyclable	X	X			X	X		X	X
Energy efficient	X	X	X	X	X	X	X	X	X
Renewable products	X	X		X		X	X	X	X
Improves IAQ	X	X		X	X	X	X	X	X
Reusable	X	X			X	X		X	X
Resource efficiency	X	X	X	X		X	X	X	X
Water conserving		X		X		X	X	X	X
Low-toxicity	X	X		X	X	X			X
Durable	X	X				X	X		X
Minimum waste		X		X		X	X	X	X
Low-VOC assembly	X	X			X	X	X	X	X
Local product	X	X		X		X			X
Non-ozone depleting products		X		X	X	X	X	X	
Salvaged products		X			X	X			
Natural or minimally processed	X					X			X
Minimal emissions	X	X			X				
Healthfully maintained	X	X				X			
Sustainable		X				X			X
Low embodied energy		X			X	X			X
Moisture	X	X							
Affordable			X						
Non-hazardous products									X
Products with low maintenance requirements		X				X			X
Products that reduce storm water pollution							X		X
Certified wood products							X	X	X
Low environmental impact				X		X			
Products made with waste agricultural material					X	X			
Products that remove indoor pollutants		X							
Products that enhance community well-being									
Products that reduce material use						X			
Biodegradable						X			X
Products that reduce or eliminate pesticide treatments									
Products that improve light quality									
Products that help noise control									
Waste material					X	X			
Long lasting						X			X
Bio-based materials									

Table 2-6. Sources corresponding to the numbers denoted in Table 2-5 (Source: Pranav Arora).

Number	Source Name
1	Froeschle, Lynn M. (October, 1999). *Environmental Assessment and Specification of Green Building Materials*, The Construction Specifier, 53-57.
2	Port, Darren. (September, 2007). *Creating Sustainable Communities: A Guide for Developers and Communities*, NJ Department of Community Affairs, 1-3.
3	CIWMB (California Integrated Waste Management Board. (January, 2008). "Green Building Materials." <http://www.ciwmb.ca.gov/greenbuilding/Materials/>
4	Wilson, Alex. (January, 2006). "Environmental Building News." *Newsletter on Green Building Materials*, 9(1), 1-6.
5	Calfinder. (2008). "Criteria for Green Building Materials." <http://www.calfinder.com/blog/green-remodeling/criteria-for-green-building-materials/>
6	Criss, Shannon et al. (April, 2005). "10 Criteria for Evaluating Green Building Materials." Heartland Green Sheets, School of Architecture and Urban Design, University of Kansas, KS. <http://www.heartlandgreensheets.org/10criteria.html#1>
7	USEPA (United States Environmental Protection Agency). (2007). "Buildings and Construction." <http://www.epa.gov/epp/pubs/products/construction.htm>
8	Amatruda, John. (2007). "Evaluating and Selecting Green Products." Whole Building Design Guide, <http://www.wbdg.org/resources/greenproducts.php>
9	Indiabizclub. (n.d.). "Green Building Materials." <http://buildingmaterial.indiabizclub.com/info/types/green_building_material>
10	Ecology Action. (2007). "Green Building Materials Guide." <http://www.ecoact.org/Programs/Green_Building/green_Materials/material_selection.htm>
11	Ireland, Elaine et al. (March, 2008). "A Green Sage Guide to Green Material." <http://www.greensage.com/ezine/08zines/03Mar08/ezine03-08GrnMatrls.html>
12	Saskatchewan's Green Directory. (2007). "Product selection criteria used in the Green Directory." <http://www.saskatchewangreendirectory.org/category-index/product-selection-criteria-used-green-directory>
13	Austin Energy Green Building. (2006). "Sustainable Building Sourcebook." <http://www.austinenergy.com/Energy%20Efficiency/Programs/Green%20Building/Sourcebook/materials.htm>
14	Down to Earth Design. (2000). "Natural, Healthy & Sustainable Building Materials." <http://www.buildnaturally.com/EDucate/Articles/LCA.htm>
15	Contra Costa County. (2006). "Green Building Materials." <http://www.co.contra-costa.ca.us/index.aspx?NID=2074>
16	California Green Builder. (2009). "Components." <http://www.cagreenbuilder.org/components.html>
17	Kim, Jong-Jin, and Rigdon, Brenda. (December, 1998). *Qualities, Use, and Examples of Sustainable Building Materials*, National Pollution Prevention Center for Higher Education, University of Michigan, Ann Arbor, MI.

CHAPTER 3
RESEARCH METHODOLOGY

Introduction

The evaluation of selection criteria aids in determining the importance of various attributes in a selection criteria that in turn helps in material selection and in determining the carbon footprint of a building. The comprehensible approach towards an environmental assessment was made by identifying different selection criteria of green building materials from nationally recognized organizations and published articles and thereafter, combining the recommendations in a “selection criteria matrix”.

Importance of Selection Criteria

The identified selection criteria were listed by the frequency. The summarized information of all the criteria helped in recognizing the importance of each criterion by their frequency number. The significance of each criterion differs from one another, depending upon the building, the quantities and use of materials, and their environmental impact. The identified selection criteria were thoroughly examined in order to establish the importance and magnitude of each and how a building achieves the same through the use of selected building materials and green construction practices.

Analysis of the selection criteria based on energy analysis, GWP and IEQ was a qualitative representation. This helped in lying out the benefits and importance associated with selection criteria. Each criterion has unique benefits and impact in respect to the environment. Therefore, examination of criteria in terms of pollution remittances, energy savings and indoor environmental affect was based on energy analysis, GWP and IEQ.

Magnitude of Selection Criteria

Materials and various systems act as the building block of a building and are used in various shapes, sizes and quantities. In laying down the hierarchy of selection criteria, magnitude of savings over the life of the building dictates which material or what aspect of building operation will take precedence. In an office building, for example, compared to wheat board panels for cabinetry, structural and non structural steel is used in large quantities. If the steel is recycled and locally processed it will have a greater impact on energy savings and will cause less pollution, compared to the advantage in using wheat board panels.

Also, energy efficiency thus achieved helps in electricity savings and reduced global warming over the life of the building. The magnitude of energy efficiency, when compared with criteria like recycled content and minimizing waste, clearly dominates as the latter have lesser impact because they mainly contribute to resource efficiency alone.

Another example which demonstrates the impact of a decision made on the basis of what comes first is that of occupant comfort. Indoor environment, which is of great significance to the health, well being and productivity of the occupants, can be achieved through effective ventilation, good daylighting, noise control, and less VOC emissions. All these features have their benefits but some are relative and can be discounted. For example, noise control in a building is important but health of the occupants and clear indoor quality always gets higher marks over the acoustic comfort of a space. Therefore, a case study was used to analyze the variables.

The case study met or exceeded all criteria identified from different organizations. It presented itself to be like a palimpsest with layers of information and intertwined systems which when put together embellished the selected criteria used as a template. As all the layers of this complex information were peeled and then compared to the already set mold of criteria

previously selected, the true nature of the complex inner workings of a green building, its impact over the life of the building and the current benefits it is having and how it was achieved, was revealed.

Qualitative Combination of Criteria Based on Energy Analysis, GWP and IEQ

The various selection criteria have interdependence in terms of energy efficiency, low embodied energy, local materials, recycled content, resource efficiency, and IEQ. The necessity to explain the impact and magnitude of selection criteria in terms of energy savings and pollution remittances was to analyze them, and finally rank and combine them for energy analysis and GWP. In the same manner, various selection criteria identified for indoor environment have interdependence in terms of daylighting, ventilation, material emissions, energy efficiency, and healthy environment. The importance of criteria under IEQ helped to determine which criteria has the maximum potential to benefit occupants and has a reduced environmental impact. Some of them help in energy savings as well.

The combination of selection criteria based on energy savings, GWP and IEQ was by the maximum amount of energy saved. Firstly, energy savings with the life cycle of the building and secondly, less pollution leading to reduced global warming potential. For IEQ, the criteria were based, on energy savings combined with the healthy environment for the occupants. The criterion was grouped based on the examination of the case study which helped to analyze the energy savings, contribution to the global warming and the necessity for a better IEQ. The qualitative analysis of selection criteria assisted in coming up with a solution for ranking the criteria from a maximum amount to the lowest as discussed in Chapter 5.

CHAPTER 4
RESULTS

Introduction

This study attempts to do a critical analysis of the material/product selection criteria of sustainable building materials and a brief study of their environmental impact on a LEED certified building. The concept of sustainable building incorporates and integrates a variety of strategies during the design, construction, and operation of building projects. “Building Materials” focuses on the environmental impact of the manufacture, use, and disposal of building materials; it also examines how the choice of a material affects the overall sustainability of a building.

The case study was Rinker Hall at University of Florida, also known as M.E. Rinker, Sr. School of Building Construction. This chapter describes the attainment of different selection criteria for the green building materials and explains in detail the effect of selection criteria on Rinker Hall and how it achieves the same. The reasons this building was selected are as follows:

- The author had spent two years in this building and was more familiar than any other building on the University of Florida campus.
- This building holds the honor of being the first LEED Gold building in the State of Florida.
- A high-performance design (LEED Gold) was completed within the constraints of the State of Florida budget scale ($137.50 per square feet) (USGBC 2006).
- With 74°F groundwater in an area defined by American Society for Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) as a humid climate belt, major benefits could be obtained from energy innovation compared to conventional practice (USGBC 2006).
- Nine out of ten possible LEED energy points were attained in the case of Rinker Hall and it gained compensating economics under a rigorous “materials minimization” approach that also earned an innovation point in LEED (USGBC 2006).

Rinker Hall

Figure 4-1 shows Rinker Hall's north entrance located at the intersection of Newell Drive and Inner Road.

Figure 4-1. Rinker Hall (Source: Pranav Arora).

Rinker Hall was designed by Croxton Collaborative Architects and Gould Evans Associates and was built by Centex Rooney Construction Company. It was occupied in April 2003 and houses the Rinker School of Building Construction. Rinker Hall is approximately 47,300 gross sq feet.

Rinker Hall is situated at Newell Drive on the east side of the University of Florida, Gainesville campus. This three storied building provides a productive and healthy environment for students, faculty and, staff of the School of Building Construction, the nation's oldest and most recognized program of this type through its unique building design and construction. Accommodating 450 students, the building includes a mix of classrooms, teaching labs, construction labs, faculty and administrative offices, and student facilities.

Rinker Hall is a one of a kind building on the University of Florida campus and yet it blends seamlessly with the rest of the built environment. It was the first LEED Gold certified building at the University of Florida and as well as in the State of Florida. It incorporates various green building features. The three-way process of planning, design and cost analysis by the

designers and the users resulted in a building that is responsive, integrated and in the end achieved the goal of leaving a smaller carbon footprint.

Selection Criteria

Site Description and Building Orientation

Reflecting the belief that sustainable design embodies not only environmental concerns, but social and economic ones as well, the design team chose to orient the building along north-south axis out of respect for existing landmarks, and to use patterns identified during a three-day site-planning charrette with students, faculty and staff. Rinker Hall was designed to have a minimum impact on the surroundings. It is situated on a 1.70 acre lot and the building footprint is 22,200 sq ft. Site was selected to make maximum use of the existing infrastructure and to provide more vegetated and open space and also to provide optimum space for outdoor activities. The old trees were preserved and Rinker Hall has been maintaining a healthy environment both inside and outside for the users. Low-maintenance landscaping using native plants has a positive effect on the site by reducing irrigation. The “cabbage palm” which are 42 in number need no watering expect Gainesville’s average 56 inches of annual rainfall. The rest of the vegetation including trees used on Rinker Hall’s site is native and require no ongoing watering (2006).

Figure 4-2. Building’s north-south orientation (Source: USGBC 2006).

A

B

Figure 4-3. Sustainable site. A) Existing trees preserved. B) Palms at the west side of the building. (Source: Pranav Arora).

Land Use and Water Conservation

Contrary to university tradition, an existing parking lot was chosen as the site for Rinker Hall which gives it the credit of not having disturbed a green site. The conservation on site is done through rainwater harvesting, storm water reuse, reduced irrigation requirements, and reduced water usage for interior needs and reclamation of wastewater for irrigation. The features for rain water harvesting includes roof drains, rainwater leaders, overflow lines to storm system, hatch access for cleaning and membrane waterproofing inside and out. Adding to the list is an 8,000 gallon concrete storage tank under the exterior staircase on the south side which is used for irrigation and toilet flushing (Kibert 2004; Brow 2008).

Also, the site was selected to take advantage of the adjacent university wastewater treatment system, which treats all of the building's wastewater before returning it to the site as irrigation water. The main outdoor areas were surfaced with compacted gravel to allow groundwater systems to recharge while providing durable surfaces for gatherings and student projects. Storm water that falls on the site's impervious surfaces is captured and directed to the campus storm water system, which uses the water for irrigation. The other key features include low flow fixtures such as water closets, water free urinals and electronic faucets. According to

“Falcon water free technologies”, a water free urinal saves 40,000 gallons of fresh water per urinal per year. It is hygienic and touch-free too. As a result water free urinals installed on the two floors save approximately 160,000 gallons of fresh water annually. The remaining fixtures use at least 20% less water. Rinker Hall uses 30% less water as compared to a conventional building. The saved water can be used for upcoming buildings in the campus, thus balancing the amount of consumption (USGBC 2006; Brow 2008).

A

B

C

Figure 4-4. Water efficiency. A) Electronic faucets. B) Waterless urinal. C) Low-flow fixture. (Source: Pranav Arora).

Figure 4-5. Rainwater harvesting system. A) South side of the building. B) Reclaimed water system for irrigation. C) Concrete storage tank-under exterior staircase. D) Access hatch. (Source: Pranav Arora).

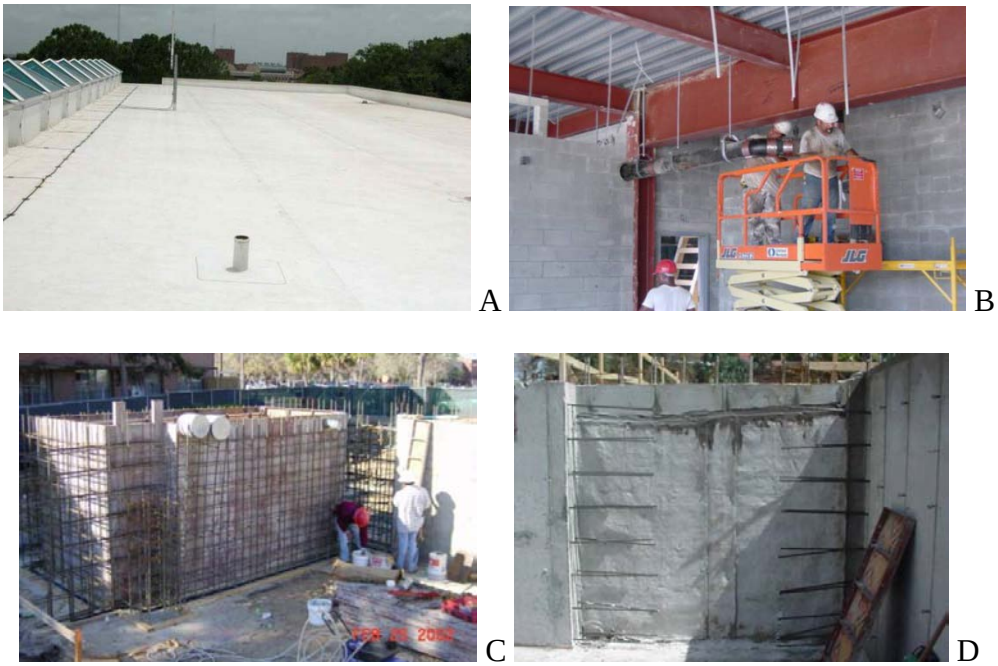

Figure 4-6. Rainwater harvesting system-continued. A) Roof drains. B) Rainwater leaders. C) Overflow lines to storm system. D) Membrane waterproofing-inside and out. (Source: Kibert 2004).

Waste Materials/Recycled Materials

During construction a construction waste management plan was also adopted to recycle the waste materials. The plan required the contractor to record all construction waste and components that were reused, recycled, and sent to a landfill. Over 50% of the construction waste was recycled or reused. Through the University of Florida recycling program, plastic and glass were recycled. Scrap steel and lumber were recycled through local agencies and drywall debris was hauled to Apollo Beach (returned to plant), so that it can be reused on other projects. Designated recycle areas throughout the site were created and self sorting, breakdown and consolidation of materials was encouraged to eliminate contamination and possibility of rejection by the recycling agency (Kibert 2004).

The benefit of recycling was used to a larger extent and it helped in reducing the burden on landfills. In addition, it provided the opportunity to reduce the embodied energy of a material by eliminating the process of extraction and processing. However, recycling can also have negative environmental impacts such as noise, dust generation and vibrations (Thormark 2001).

A

B

Figure 4-7. Recycling of waste materials. A) Bins for recycling at site. B) Hauling of drywall waste. (Source: Kibert 2004).

Energy Efficiency

Operation of buildings consumes a great amount of energy. Commercial, institutional and residential buildings account for approximately 68% of U.S. electricity consumption (for

operation alone). Using energy efficient methods and materials, energy consumption during construction and through the building's life cycle operation is greatly reduced (Olgyay and Herdt 2004). Rinker Hall is anticipated to use 57% less energy than a comparable, baseline building designed in minimal compliance with ASHRAE 90.1-1999 (USGBC 2006).

The north-south orientation of Rinker Hall has proven to be beneficial for superior net direct solar exposure and its ability to utilize low-angle sunlight. Energy conserving measures include (Kibert 2004):

- Shade walls on the west and south facades as shading devices.
- The Energy-Star-rated white thermoplastic polyolefin (TPO) mechanically fastened roof membrane. This roofing material produces fewer harmful chemicals than other low sloping roof options, and its light color reflects sunlight, thus reducing the amount of heat absorbed by the building (Puchall 2005).
- 14 pyramids skylights with high performance glazing were installed along the longer axis providing daylight, thus reducing the energy requirement by artificial means.
- Large exterior windows on the east and west sides and high ceilings provide increased daylight to all the rooms.
- At night, low-energy fluorescent lights illuminate the interior. Motion detectors and day lighting sensors keep electric light use to a minimum (Puchall 2005).
- Interior mechanical louvers filter the strong Florida sun and control heat gain and glare.
- Light reflecting wall surfaces.
- Building envelope- a high performance wall which constitutes "Rainscreen" metal wall panels, thermally broken curtain wall and storefront doors, spectrally selective low-e insulated glass panels, cellulose and rigid insulation supported by wood strips.

Adding to the list is north side staircase which has an entirely glazed wall and the elevator, in which the glazed cab is facing the full-height glass wall, having the maximized advantage of natural light all day long (USGBC 2006). An efficient HVAC system maintains a comfortable indoor environment using an enthalpy wheel that takes advantage of air that has already been cooled or heated (Puchall 2005).

A

B

C

Figure 4-8. Energy efficiency. A) West facade wall shading. B) Motion detector. C) Glazed wall-elevator and staircase. (Source: Pranav Arora).

A

B

C

Figure 4-9. High performance wall. A) Cellulose and rigid insulation supported by wood strips. (Source: Kibert 2004). B) “Rainscreen” metal wall panels. C) Thermally broken storefront doors. (Source: Pranav Arora).

Renewable Products: Durable Products Made with Waste Agricultural Material

Products manufactured using renewable sources over non-renewable resources of energy helps reduce depletion of natural resources. The rapidly renewable materials used were linoleum flooring and agriboard or wheatboard for cabinetry. Linoleum is made from natural, raw materials. Linseed oil, which comes from the flax plant, is the primary ingredient. Other ingredients include wood or cork powder, resins, and ground limestone. When installed using a low-VOC adhesive, linoleum emits much lower levels of contaminants than vinyl. In manufacturing and disposal, linoleum is environmentally kind, biodegradable, and creates no toxins. Linoleum is extremely durable and has a life expectancy of decades with minimal maintenance, which makes it ideal for high traffic areas (Demesne 2005). Agriboard or wheatboard was used for cabinetry in labs. It is made of compressed wheat and rice straw and it is a 100% recycle material. It is good for insulation and it can be recycled into mulch at the end of building useful life cycle. It eliminates job site work as everything is pre-engineered. It can be fire resistant, provides insect control, mold resistance and sound control. The other important advantage of wheatboard is that no greenhouse gases or ozone-depleting gages are emitted. With the various advantages associated with it, it is highly useful and contributes to a sustainable environment (Green Building Pages 2002).

A

B

Figure 4-10. Renewable products. A) Linoleum flooring-atrium. B) Agriboard cabinetry. (Source: Pranav Arora).

Indoor Air Quality (IAQ)/Minimal Emissions

Computer modeling for Rinker Hall demonstrated that when designed correctly, a building oriented along the north-south axis can actually benefit, in terms of both energy efficiency and indoor environmental quality, from its more abundant and varied daylighting. Add zero VOC products to this equation and you have a building that will not only be healthy but will support productive user behavior. “Pure Performance Paints” by Pittsburgh Paints, in this case, did the job. They have zero volatile organic compounds (VOC) and confirm to Green Seal Standard GS-11. Another material used having low toxicity were adhesives which confirmed to the VOC limits set by South Coast Air Quality Management District (SCAQMD). Better ventilation techniques were used in the building as well like the enthalpy wheel and large operable windows along the west and east facades with large exterior windows fitted with spectrally selective glazing to admit abundant visible light while blocking solar heat gain. No smoking policy further enhanced the indoor air quality (Kibert 2004).

During the construction phase, importance was given to maintaining quality of air. This included elimination of dust, dirt, and moisture from ducts before installing and doing the ductwork. No smoking policy was adopted during the construction work as well. The drywall and insulation materials were kept off floor and windows were protected by the use of plastic sheets to hinder the entry of dust particles (Kibert 2004). Flooring is made of linoleum which helps to control microbial growth because of the ongoing process of linoleic acid oxidation (Wilson 2006). Radon protection system was also used. In addition to this a complete building flush-out was performed prior to occupancy and filtration media of MERV 13 was installed for regularly occupied building areas. An efficient ventilation system, operable windows and advanced mechanical system- all come together to create healthy indoor air quality and has helped reduce absenteeism from workplace (Kibert 2004).

A

B

C

Figure 4-11. Role of windows. A) Windows in a classroom on the west side. B) Spectrally selective glazing on the south side in computer lab. C) Large windows on the east side. (Source: Pranav Arora).

A

B

Figure 4-12. Indoor air quality during construction. A) Cleaning of ducts. B) Temporary window protection. (Source: Kibert 2004).

Figure 4-13. Linoleum flooring. (Source: Pranav Arora).

Reused/Salvaged Materials

Demolition waste if used effectively can help in saving on new materials/products. A building by the name of Hume Hall on University of Florida campus was demolished in 2001 and the salvaged bricks were reused in Rinker Hall. They were cleaned and palletized by students and stored for use. Other materials included irrigation PVC for brick weeps, asphalt and limestone from the former parking lot. Reuse of materials helped minimize waste from the demolition which in turn helped reduce burden on landfills and the tipping costs associated with it (Kibert 2004).

A

B

Figure 4-14. Reused/Salvaged Materials. A) Bricks used on the east side. B) West-facade wall. (Source: Pranav Arora).

Resource Efficiency

There are no singular criteria for selection of green building materials. It heavily depends upon a specific project and the goal is to make intelligent and educated choices, highlighting the natural and efficient features of a product. “Typical” buildings consume more resources than necessary which leave a negative impact on the environment and generate a large amount of waste. Resource extraction is a significant factor when evaluating the green building materials,

as it plays an important part in reducing energy consumption, minimizing waste, and reducing green house gases.

Criterion under resource efficiency

- Materials with post-consumer and pre-consumer content. Materials used: Structural and nonstructural steel products, aluminum wall panels and glazing systems, railings, cellulose wall insulation, plastic bathroom partitions, drywall, concrete with fly ash, vitreous tile, and ceiling tile.
- Salvaged products. Materials used: Bricks, irrigation PVC for brick weeps, asphalt and limestone.
- Rapidly renewable products. Materials used: Linoleum flooring and wheatboard for cabinetry.
- Certified wood products from sustainably managed forests as approved by the Forest Stewardship Council. Materials used: Wood doors and for cabinetry.
- Products made from agricultural waste. Materials used: Wheatboard for cabinetry.
- Products extracted and processed locally or regionally. Materials used: Structural steel, metal wall panels, railings, stairs, concrete slabs, foundation and walls, drywall, brick/block and curtain wall.
- Products which are durable and long lasting with low maintenance requirements. Materials used: Bricks, linoleum, waterless urinals, thermoplastic polyolefin roof and agriboard materials.

Resource efficient manufacturing process

- Products manufactured with resource-efficient processes including reducing energy consumption, minimizing waste, and reducing greenhouse gases.
- Products having low embodied energy, including all processes.
- Easily recyclable or reusable when no longer needed.
- Products enhancing water and energy efficiency.
- Products which are biodegradable.

All of the above features help in determining environment friendly materials and products and Rinker Hall exhibits every facet of these factors, accomplishing a green building in terms of resource efficiency.

Durability of Products

Some building materials are considered green because they are durable. Durable products are long lasting and need little maintenance (Real Goods Solar).

Linoleum flooring is used in Rinker Hall. It is extremely durable and has a good life expectancy of decades with minimal maintenance (Demesne 2005). Agriborad is used for cabinetry, which is stronger, environmentally sound, cheaper and more durable than most construction materials of its class (Green Building pages 2002). Metals like steel and aluminum are the most widely used construction material and in Rinker Hall the designers have used them economically and effectively. The mining, manufacture, and transportation of metals result in some of the highest embodied energy of all construction materials. However, metals also have properties that make them environmentally desirable, including: easy recycling, strength, durability, malleability, and negligible out-gassing. The key to using metals in an environmentally responsible way is to make certain that metals are the most appropriate material for the application (Karolides 2003).

Minimum Waste

During the construction of Rinker Hall, steps were taken to recycle waste materials not only through waste management plan but also reduce waste at the design table by the use of effective specification for materials and their installation. For example, drywall clips allow the elimination of corner studs, engineered stair stringers reduce lumber waste, and sealed concrete floor slabs eliminate the need for conventional finish flooring (Wilson 2006).

Local/Regional Materials

Selection of materials for Rinker Hall were reviewed for concurrence in manufacturing, recycled content, renewable-resource content, sustainable harvesting, durability, low maintenance requirements, low toxicity, healthy indoor and outdoor environment and ability to

be recycled or reused at the end of their useful life. Building materials which are manufactured locally helps in reducing the environmental impact resulting from the transportation distances and help boost the local economy. Using building products that are harvested, extracted and manufactured within a 500-mile radius can help lessen air pollution from transport vehicles. In case of Rinker Hall, many of the building materials were transported and manufactured within a radius of 500 miles. While designing, emphasis and preference had been given to important aspects like reduction in energy and the materials which were sourced and manufactured locally e.g. structural steel, metal wall panels, railings, stairs, concrete slabs, foundation and walls, drywall, brick/block and curtain wall (Puchall 2005).

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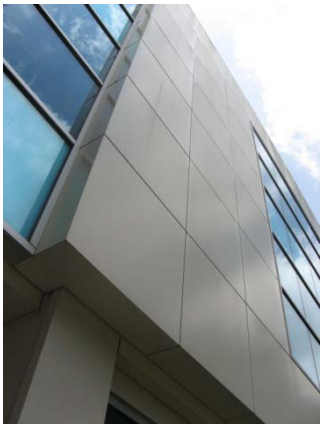
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D

Figure 4-15. Local/Regional Materials. A) Structural steel. B) Metal wall panels. C) Stairs and railings. (Source: Pranav Arora). D) CMU blocks. (Source: Kibert 2004).

Non-Ozone Depleting Products

Some chemicals can damage the earth's protective ozone layer. Ozone depleting substances (ODS), including chlorofluorocarbons (CFCs), hydrocholoroflurocarbons (HCFCs), and several other chemicals, are responsible for thinning the stratospheric ozone layer. Volatile organic compounds are also responsible for depleting ozone layer and contribute to smog formation. Methane is the most common VOC, a green house gas (ESPERE Climate Encyclopedia 2007). Rinker Hall does not use any product or system that uses or emits any of the ozone depleting substances.

Sustainability

The construction of buildings, both in design and choice of materials is one of the significant ways that affect the future generations. A material is considered renewable or sustainable if it can be grown at a rate that meets or exceeds the rate of human consumption. The important factor is to use materials efficiently and emphasis should be given to ‘resource efficiency’.

With the diligent planning and designing involved in constructing the Rinker Hall, many techniques, methods and strategies were used for attaining maximum energy efficiency, water conservation, resource efficiency, and enhanced indoor air quality, thus making it the first LEED Gold building in the State of Florida.

Low Embodied Energy

For a product to be truly sustainable the total amount of energy required to manufacture a product should be as little as possible. The embodied energy, which is the energy required to extract, manufacture, assemble, install, disassemble, deconstruct and/or decompose a building's materials as well as that required to 'finish' it. It is a methodology which aims to find the sum total of the energy necessary for an entire product life cycle (Thormark 2001).

In Rinker Hall, emphasis had been given to minimize the energy consumption as well as to use materials having low embodied energy and through different ways, the requirement of energy from the manufacturing and extraction stage was kept as little as possible. For example, a material like aluminum requires a lot of energy to extract and manufacture. It uses 126 times the energy as compared to wood (from sustainably managed forests) (Buchanan 2000).

Some of the regionally obtained materials were structural steel, metal wall panels, railings, stairs, concrete slabs, foundation and walls, drywall, brick/block and curtain wall. A range of materials with recycled content also helped in reducing embodied energy e.g. structural and nonstructural steel products, aluminum wall panels and glazing systems, railings, cellulose wall insulation, plastic bathroom partitions made from recycled plastic, drywall, concrete with fly ash, vitreous tile, and ceiling tile (Kibert 2004).

Figure 4-16. Recycled bathroom partition. (Source: Pranav Arora).

Moisture Penetration

Moisture can enter a building envelope in three ways—rain transport from outside, diffusion of water vapor through the envelope materials, and transport of water vapor in air that leaks through cracks in the envelope (RS Means 2008). It is the key to succeed in at least two ways, firstly, health (in terms of avoiding mold) and durability (in terms of avoiding premature deterioration of materials).

The important consideration in selection of green building materials is to resist moisture and to inhibit growth of biological contaminants (Wilson 2006). One of the features of the high performance wall at Rinker hall is “Rainscreen” metal wall panels. This system was carefully designed to control moisture, thermal loading, and daylight. Brick masonry on the other hand is resistant to deterioration from moisture and insects (USGBC 2006).

Affordability

Affordability is another criterion for evaluating green building materials and can be considered when building product life cycle costs comparable to conventional materials or as a whole, is within a project-defined percentage of the overall budget (Froeschle 1999).

Consideration of life cycle costs against first-costs is very important. The heedfulness of cost benefits of green building materials in terms of energy savings, worker productivity, safer indoor air quality, longevity of the building, environmental and health factors help in financial savings in the long run, even if the initial cost is more for green products and materials. Besides life cycle costs, there are other ways which help making materials more affordable. For example, finding local recycled materials for flooring or countertops can be much more cost effective than ordering them through a manufacturer. Minimizing construction waste and recycling the rest saves on hauling costs and landfill tipping fees (Green Building Supply 2009).

While Rinker Hall cost more than a comparable conventional structure, the owner expects to recover the additional costs within a span of six years through energy savings (Puchall 2005).

Non-Hazardous Products

Hazardous products are danger to human health. Some materials provide a better alternative in an application dominated by products for which there are concerns about toxic constituents, intermediaries, or by-products. Non- or less-toxic materials are less hazardous to construction workers and a building’s occupants. Environmentally friendly products like

fluorescent lights are energy efficient and non-hazardous. The fluorescent lights and other products used in Rinker Hall are non-hazardous. Products which emit low or no VOCs usually have minimal hazards.

When natural or artificial ventilation is inadequate to remove odors and chemicals emitted by certain building materials, these substances tend to be hazardous or even carcinogenic (Kim and Rigdon 1998).

Products with Low Maintenance Requirements

Manufacturing of building materials is very energy-intensive; a product that lasts longer or requires less maintenance usually saves energy. The choice of materials which are durable and require low maintenance leads to cost saving in the long run (Kibert 2004). A few examples of low maintenance products and materials from Rinker Hall are as follows:

- Bricks used for the façade wall are durable and requires less maintenance and are aesthetically pleasing as well.
- Linoleum, an environment friendly flooring improves air quality in several ways, requires low maintenance, and it is easy to clean which makes it ideal for high traffic areas like a school building.
- Waterless urinals having many advantages are easy to clean and eliminate the costs and repair for flush valves, handles, sensors, or water supply piping.
- The Energy-Star-rated white thermoplastic polyolefin (TPO) mechanically fastened roof membrane requires low maintenance.
- No toxic or carcinogenic materials required for maintenance of Agriboard materials.

Certified Wood Products

Wood materials used for doors and cabinetry were specified to originate from certified, sustainably managed forests as approved by the Forest Stewardship Council (Kibert 2004).

A

B

Figure 4-17. Certified wood products. A) Cabinetry. B) Wood doors. (Source: Pranav Arora).

Indoor Pollutant Control

Many factors were taken into consideration in maintaining healthy indoor environment such as:

- Materials with low or no VOCs, toxins and irritating chemicals (Kibert 2004).
- Mold and moisture resistant – Building's indoor environment is free of moisture due to the "Rainscreen" system used in designing the high performance wall. Efficient HVAC techniques also contribute to this (Kibert 2004).
- Permanently installed grates to capture and remove dirt and particulates from the entering the building at main entryways directly connected to the outdoors.
- Large windows in the building help in providing good ventilation and help in flushing out indoor pollutants (Kibert 2004).
- Carbon dioxide and carbon monoxide monitors in densely occupied spaces help in monitoring indoor pollutants and poor ventilation.

All these systems and materials help in maintaining a comfortable and healthy space for the occupants and have a far lesser impact on the environment.

Reduction in Material Use

Many times large performance and financial gains can be made by minimizing material use and with simple method of construction. Optimizing design to make use of smaller spaces and utilizing materials efficiently boosts the concept of "Reduce Material Use". To cite an example- Sealed concrete floors used in classrooms are extremely durable and are easy to maintain. It eliminates the further covering of floor with wood, tiles, vinyl or epoxy. Concrete floors have

great impact resistance and are ideal for high traffic areas such as classrooms, labs and outdoor areas. Also, it does not succumb to mold growth or other allergens.

Figure 4-18. Concrete floor in classrooms. (Source: Pranav Arora).

Biodegradable

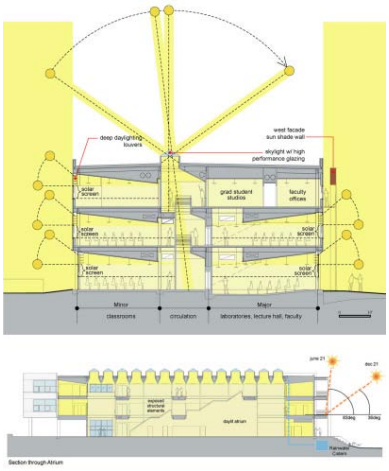
The biodegradability of a material refers to its potential to naturally decompose when discarded. Incorporating biodegradable building materials in a project can reduce waste, pollution, and energy use. Commonly used building materials that are biodegradable are wood, materials made from earthen materials and gypsum/drywall. The extraction, manufacture and transport, and disposal of virgin building materials pollute air and water, depletes resources, and damages natural habitats (Ecology Action 2009).

According to Agriboard Industries, Agriboard products are up to 59% biodegradable and can be reused (Green Building Pages 2002). In manufacturing and disposal, linoleum is biodegradable too. Several biodegradable materials have been used in Rinker Hall, and as a result provided benefits like reduced landfill waste, reduced embodied energy, pleasing aesthetics, and reduced impacts from harvest or mining of virgin materials.

Products that Improve Light Quality

There is a growing body of evidence that daylight is beneficial to health and productivity. With this view, diligent planning and designing was done for Rinker Hall at design phase. There

are numerous factors which contribute to Rinker's Hall's appealing indoor environment and are helpful in minimizing its energy requirements. The factors are as follows: the building has a central three level atrium space which is covered by 14 pyramid skylights with high performance glazing providing the open public stairways with dynamic daylight. For further penetration of light in the building, sloped "lightwells" in center-core have been provided. Building elements like sloped acoustical ceiling in classrooms and upper daylight louvers/light sleeves have also been provided for deeper penetration of light in the classrooms and also to control glare. This manipulation of natural light saves a significant amount of energy by greatly reducing the need for electrical illumination. Level 5 drywall finishes have been done to maximize the reflectance of light (Kibert 2004).



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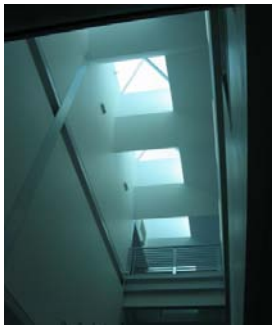

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Figure 4-19. Daylighting strategies. A) Building sections highlight daylighting. (Source: USGBC 2006). B) Pyramid skylights. (Source: Kibert 2004). C) Skylights above the staircase. (Source: Pranav Arora).

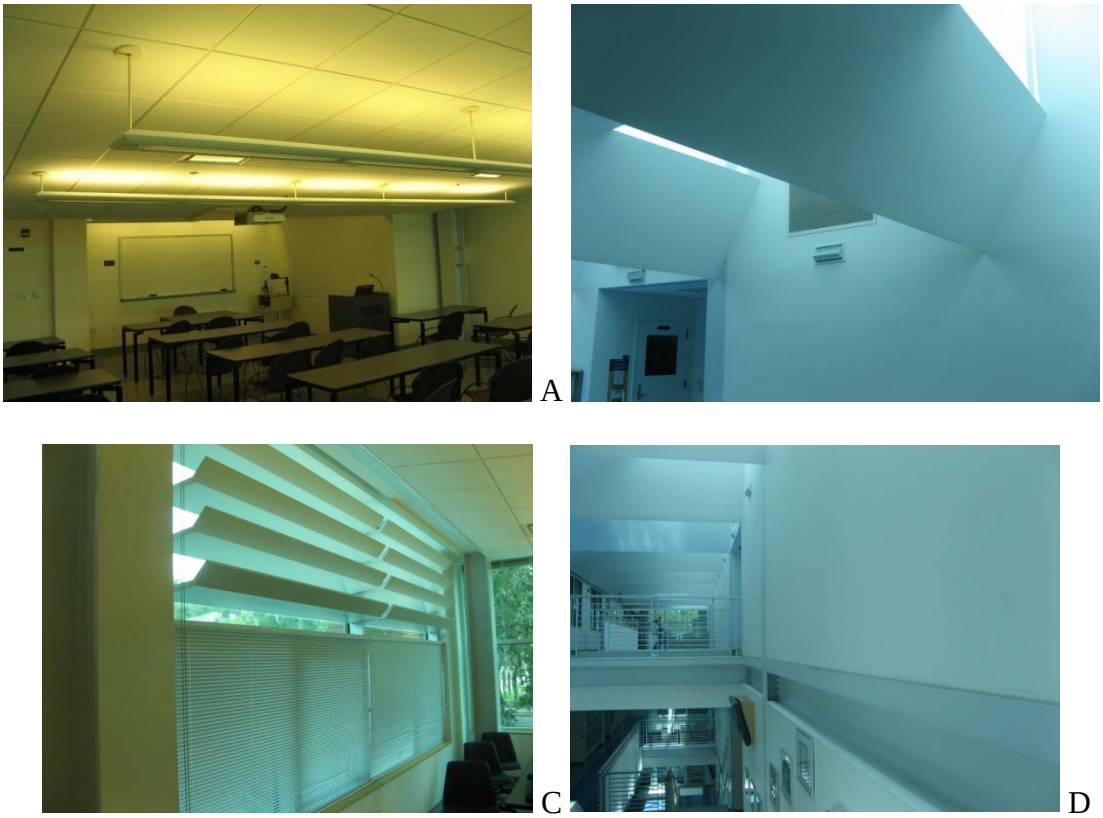

Figure 4-20. Products that improve light quality. A) Sloped acoustical ceiling in classrooms. B) Sloped lightwells. C) Light sleeves and daylight louvers. D) Level 5 drywall finish. (Source: Pranav Arora).

Bio-Based Materials

Bio-based building materials are produced from plant fiber waste and by their nature, they are rapidly renewable materials. They generate low embodied energy products and have several advantages, which are as follows (Olgyay and Herdt 2004):

They reduce reliance on petrochemicals, therefore fewer emissions into the air and water. They increase environmental benefits like saving forests, minimizing emissions of carbon dioxide and other gases associated with climate change, and reduce reliance on petroleum and other fossil fuels. Most bio-based chemicals and solvents emit fewer toxic fumes. They require less maintenance and are easy to clean. They further reduce the environmental impact of burning or otherwise disposing of agricultural waste (Green Biz 2004). These are non-food, non-feed

resources, which are factory pressed and molded into panels, bricks and building products (Olgyay and Herdt 2004). Linoleum flooring and Agriboard are made from bio-based materials and having so many benefits, they have been a success in Rinker Hall.

Summary

The use and manufacture of green building products strive to lessen the environmental impact by increasing the efficiency of resource use– energy, water and materials during the building's life cycle. The integration of these materials in building projects help reduce the environmental impact associated with extraction, transport, installation, fabrication, recycling, indoor air quality, reuse, minimal emissions, low maintenance, minimizing waste, resource efficiency and disposal of the source materials. Materials with low embodied energy and non-ozone depleting materials help too. To examine the total environmental impact of a material from its pre building phase to post building phase, a LCA is reviewed. By evaluating products and materials through it, healthy and sustainable materials can be selected, minimizing the detrimental impacts on the environment.

The selection criteria for products and building systems vary from project to project and several agencies like EPA, Green Building Resource Guide, Building Green, Inc., FSC, ASHRAE, Green Seal and USGBC and many more have exhaustive information both in print and online on achieving excellence in green building design and construction.

Material choices on the Rinker Hall project were the result of information gathering on multiple environmental attributes. They were reviewed for proximity in manufacturing, recycled content, renewable-resource content, sustainable harvesting, longevity, maintenance requirements, and ability to be recycled or reused at the end of a useful life. The significant factor in review of materials was to lessen the health hazards for the workers and building occupants.

CHAPTER 5
QUALITATIVE ANALYSIS OF SELECTION CRITERIA

Introduction

The analysis of selection criteria plays a vital role in determining the environmental impact of a building. The energy analysis, global warming potential and indoor environmental quality explains the marked effect in construction of a building and over its life cycle, taking into account the various attributes of selection criteria and the choice of materials. The criteria identified for Rinker Hall exhibited the reduced impact on the environment and a healthier indoor environment quality. It is of great significance to analyze the selection criteria of Rinker Hall and in giving the output from the maximum achieved criteria to the lowest in terms of quality analyzed and benefits to the environment.

Energy Analysis

A lot of energy goes into manufacturing, production and transportation of materials; day to day operation of buildings itself consumes an enormous amount of energy. The main purpose of energy analysis is to identify the energy saved through recycling, reusing, resource efficiency, reduction in the amount of materials used and waste generated thereof. Other factors considered are use of low embodied energy materials and energy efficiency of the Rinker Hall achieved and saving through its life cycle.

Global Warming Potential

Global warming potential is a measure of the climate warming effect caused by a given mass of greenhouse gases resulting from the manufacture and use of materials or products compared to that of carbon dioxide, which has a GWP of 1.0. Green building materials having many advantages and with the manner they are used and manufactured/processed, helps to minimize carbon emissions and global warming (Austin Energy 2006).

Indoor Environmental Quality

Healthy IEQ is of vital interest for an institutional building like Rinker Hall. Beneficial and healthy construction practices, good design and well commissioned operating and maintenance practices led to good indoor air quality and productive occupants. Various factors contributed in making Rinker Hall a safe, healthier and comfortable environment for the users.

Qualitative Analysis of Selection Criteria Based on Energy Analysis and GWP

Many green practices showed a marked effect during the construction of Rinker Hall and the various advantages associated with it over its useful life. Qualitative analysis helps in determining which criteria were achieved to a maximum amount and to what effect.

Energy Efficiency

Electricity is mainly generated through coal-powered plants in United States. These plants account for a mammoth amount of carbon dioxide emissions. Energy efficiency of a building exhibits minimum use of electricity and conservation of coal consumption, a non-renewable source of energy. Rinker Hall is anticipated to use 57% less energy comparable to a baseline building, thus producing limited pollution. The energy thus saved with the life cycle of the building reduces the carbon dioxide emission significantly and enhances the natural environment.

Recycled Content

A wide variety of recycled materials were used in Rinker Hall which included structural and nonstructural steel, aluminum wall panels, glazing system and cellulose wall insulation. Both recycled steel and aluminum have been used in large quantities at Rinker Hall. The usage of these materials had a very low environmental impact because of reduced energy consumption, reduced carbon dioxide emission and other greenhouse gases.

The estimated embodied energy of virgin steel is 32.0 MJ/kg and of recycled steel is 10.1 MJ/kg. Hence, recycled steel has approximately three times less embodied energy. Recycling of steel saves the usage of other materials like iron ore, coal, and limestone also. Steel recycling drastically reduces the energy and materials requirements and further reduces the energy consumption of the steel industry to manufacture new steel. Steel beams and columns were manufactured to standardized dimensions, thereafter, waste produced was less (Waste Cap).

Virgin aluminum on the other hand has an estimated embodied energy of 191.0 MJ/kg and of recycled aluminum is only 8.1 MJ/kg and hence, energy savings are up to 24 times. Only a small quantity of carbon dioxide is produced to recycle aluminum as compared to producing raw aluminum. Energy savings were further increased by recycling the waste materials produced during the construction. All the recycled materials together helped in saving energy, reducing landfill burden and in the overall scheme of things helped reduce global warming.

Resource Efficiency

Resource efficiency criteria include many other criteria which help in saving energy, minimizing waste and contributing less to the global warming. The transportation and energy used in manufacturing, however, does affect the environment. The entire criterion under resource efficiency have been combined and ranked according to the volume of the materials used and through their various advantages. All the selection criteria identified have been met by Rinker Hall and are as follows:

- Local/Regionally extracted and processed products
- Recyclable, reusable, and salvaged products
- Renewable products, bio-based materials, and products from agriculture waste
- Products with low maintenance requirements
- Durable materials
- Biodegradable materials
- Certified wood products

Resource efficient manufacturing process helps in reducing energy consumption and greenhouse gases. Resource efficient methods like products made from agriculture waste, salvaged products and local/regional products help save on embodied energy and in turn save virgin resources. Not all criteria are similar or weigh equally in a project or a collection of buildings. However, collectively, every criterion achieved has importance at some level and each makes a unique contribution in achieving a sustainable built environment and minimized global warming.

Water Conservation

Rinker Hall uses 30% less water as compared to a conventional building and conservation of water saves energy. Using less water puts less pressure on sewage treatment facilities and less energy is required for water heating. Conservation of water helps reduce energy required to treat and distribute water as well.

Low Embodied Energy

Large bodies of materials used in Rinker Hall were of recycled quality and regionally obtained. Salvaged materials were used as well. On the flip side, energy required for manufacturing new materials is enormous as compared to the recycled materials. Producing and processing new materials cause pollution, emission of carbon dioxide and greenhouse gases. Use of products with low embodied energies reduces the harmful effects of industrial production, conserves energy and reduces global warming.

Minimum Waste

Generating less waste and further recycling the waste from a construction project conserves the need for new raw materials. This concept reduces the energy consumption for the production of new products and directly lessens the amount of pollution. During the construction of Rinker Hall, steps were taken to recycle the waste materials. Time and effort of additional

manpower required for consolidation, breakdown and sorting of materials and pollution emissions by transporting the waste materials should be considered as well.

Products that Reduce Material Use

Simple and practical ways of using materials and construction systems usually minimize the use of materials. Low maintenance, durability and material minimization further reduce the need for more materials even if they are recycled, thus conserving the energy required in manufacturing new materials. For example sealed concrete floors were used in classrooms at Rinker Hall, which eliminated the use of other materials like wooden flooring or carpets for covering it.

Another instance would be the use of concrete with fly ash. Cement used in concrete can be replaced with fly ash up to 70%. A high percentage of cement replaced with fly ash reduces energy consumption and solid waste, and even makes the concrete stronger and durable. On the other hand, energy required to make cement comes from coal-powered plants and manufacturing process of cement releases carbon dioxide and this process is a major source of green house gases. Fly ash reduces the usage of cement and has significant benefits for the environment. Furthermore, fly ash use partially displaces production of other concrete ingredients, resulting in significant energy savings and reductions in greenhouse gas emissions (Karolides 2003; Headwaters Resources).

Non-Ozone Depleting Products

Rinker Hall does not use any product or system that uses or emits any of the greenhouse gases. The flooring and interior paints used are free of any harmful substances or VOCs which contribute to ozone depletion. Though the connection between global warming and ozone depletion is weak, the use of non-ozone depleting substances does not contribute towards global warming.

Qualitative Analysis of Selection Criteria Based on Indoor Environmental Quality

The qualitative analysis of selection criteria for IEQ is based on the fact, a criteria establishing and demonstrating the maximum impact over the life of a building. The significance to analyze qualitatively is from a view witnessing the usefulness, importance, and healthy environment for the occupants combined with the reduction in energy usage.

Products that Improve Light Quality

Ample and good quality of light is of immense importance for a school building. One of the significant features is daylighting and it plays an economical role as well. It helps create a visually stimulating and productive environment for building occupants while reducing the energy costs and overall benefits the indoor environment. The priority is to achieve a comfortable living space without any undesirable side effects (Ander 2008). Many factors contributed towards achieving a good quality of light in Rinker Hall and some of the benefits are as follows:

Increased user productivity

Natural light increases the user satisfaction and visual comfort leading to improved performance (Ander 2008). It also enlivens spaces and is beneficial to health leading to increased productivity (Wilson 2006).

Reduced emissions

Daylight reduces greenhouse gases and slows down fossil fuel depletion by minimizing the energy consumption for lighting and lessening the need for air conditioning (Ander 2008). Reduced emissions, therefore lead to minimized global warming.

Reduced operating cost

Electrical illumination accounts for 35 to 50% of the total electricity consumption in commercial and institutional buildings. The artificial means of lighting also add to the load on

the building mechanical equipment system. The energy savings from reduced electric lighting through the use of daylighting strategies directly reduce building cooling energy usage by an addition of 10 to 20%. Consequently, for many institutional and commercial buildings, total energy costs can be reduced by as much as one third through the optimal integration of daylighting strategies (Ander 2008).

Glare and distribution

The daylighting concept also involves avoiding glare and effective distribution to maintain a comfortable and pleasing atmosphere. The daylighting strategies in Rinker Hall provide better lighting quality which arrives directly from a natural or artificial source with no glare and is distributed evenly.

Products that Remove Indoor Pollutants

Natural ventilation is a useful method for reducing energy use and cost. It also helps in maintaining an acceptable IAQ and a healthy, comfortable, and productive indoor climate. The savings in energy consumption through natural ventilation can be from 10% to 30% and with the life cycle of a building, reduced energy consumption lessens the environmental impact. Natural ventilation delivers fresh air in the buildings and this alleviates odors, pollutants and provides oxygen for respiration (Walker 2008). The dual advantage of the criteria is well achieved in Rinker Hall.

Minimal Emissions/ Low-Toxicity/ Low-VOC Assembly

Building materials used at Rinker Hall were evaluated and selected based on performance and aesthetics. The health of the occupants is of a major concern and indoor environments have strong effects on occupants' well being and functioning. Indoor air contamination can lead to absenteeism, poor health and increased health costs. Enhanced and better IAQ reduces respiratory illness, allergies and chances of sick building syndrome (Smith 2003). The IAQ at

Rinker Hall is of the highest standard and provides a safer and comfortable space for the students, staff, and faculty.

Moisture

Moisture in buildings is a major source of mold growth, poor IAQ, and unhealthy indoor environment and can lead to serious health problems. The prevention of mold and fungi is dependent upon effective HVAC and building envelope design. Rinker Hall's high performance wall with "rainscreen" metal wall metals and efficient HVAC system prohibits the moisture generation, providing a safe and healthy indoor environment.

Noise Control

Workspace comfort is a combination of many factors which includes but not limited to temperature, daylighting, artificial lighting, IAQ, and acoustics. A building with poor acoustical treatment can affect the productivity of employees. Careful planning of Rinker Hall with proper segregation of different rooms like classrooms, toilets, administrative office, and mechanical equipment room helps in maintaining the noise levels at acceptable levels. The door locations were offset to extend the sound level path from one classroom to the next, reducing noise from adjoining classrooms. Acoustical products like ceiling tiles, insulation, and carpeting, among others, help meet the project's sustainability goals since many of them are recyclable or are manufactured from recycled content (Paradis 2008).

The sloped suspended acoustical ceiling in Rinker Hall does an excellent job in absorbing sound and at the same time, in combination with light sleeves and daylight louvers, improves daylighting conditions as well. This building with its planning provides a better and enhanced learning environment for the students.

Non-Hazardous Products/ Healthfully Maintained

Many factors are taken into consideration for maintaining a healthy environment. At Rinker Hall no products or materials have been used which pose a danger to human health or are hazardous. Also, the cleaning and maintenance does not require toxic or VOC methods of cleaning. All the systems and materials used help in maintaining a comfortable, safe, and healthy atmosphere for the occupants and eventually, do not produce a negative impact on the IEQ.

Summary

The primary intent with qualitative analysis of selection criteria was to analyze the energy savings, GWP and IEQ. Energy efficiency with the life cycle of the building helps to reduce the pollution emissions for decades. With the use of recycled materials, energy was reduced to a considerable amount and this helped in the recovery of embodied energy as well. Many of the materials used will be able to recycle at the end of their useful life cycle, again reducing the use of natural resources and the need to be dumped in a landfill. Resource efficiency with the association of the aforementioned criteria helps in energy savings and reduced global warming. However, their effect is reduced to an extent when initial construction of the building is taken into account.

Under IEQ, criteria of “products that improve light quality” and “products that remove indoor air pollutants” boost energy efficiency of the building over the life cycle, along with providing a better environment for the occupants. Compared to overall energy consumption of the building, far less energy is expended on water usage as well, and as such Rinker Hall uses far less water compared to a baseline building. As a result, the highest priority is of energy efficiency, followed by recycled content, resource efficiency, and water conservation. The other criteria help in energy savings too but their magnitude of savings is less when compared to the

selected top criteria. Table 5-1 shows the combination of selection criteria and summarized ranking based on energy analysis, GWP and IEQ.

Table 5-1. Combination and ranking of selection criteria based on energy analysis, GWP and IEQ of Rinker Hall (Source: Pranav Arora).

Energy analysis and GWP	IEQ
Energy efficiency	Products that improve light quality
Recycled content	Products that remove indoor pollutants
Resource efficiency	Minimal emission/ Low toxicity/ Low-VOC assembly
Local/Regionally extracted and processed products	Moisture
Recyclable, reusable, and salvaged products	Noise control
Renewable products, bio-based materials, and products from agriculture waste	Non-hazardous products/ Healthfully maintained
Product with low maintenance requirements	
Durable materials	
Biodegradable materials	
Certified wood products	
Water conservation	
Low embodied energy	
Minimum waste	
Product that reduce material use	
Non-ozone depleting products	

The comparison between the frequency of selection criteria from Table 2-5 and ranking of selection criteria based on energy analysis, GWP and IEQ is shown in Table 5-2. This table signifies the two sets of ranking and shows the similarity and difference of the criteria ranking achieved.

Table 5-2. Comparison of selection criteria from Table 2-5 to selection criteria based on energy analysis, GWP and IEQ (Source: Pranav Arora).

Criteria	Frequency	Energy analysis and GWP
Energy efficient	14	Energy efficiency
Recycled content	14	Recycled content
Resource efficiency	12	Resource efficiency
Local product	10	Local/Regionally extracted and processed products
Recyclable	14	Recyclable, reusable, and salvaged products
Reusable	13	
Salvaged products	9	
Renewable products	14	Renewable products, bio-based materials, and products from agriculture waste
Bio-based materials	1	
Products made with waste agricultural material	4	
Products with low maintenance requirements	5	Product with low maintenance requirements
Durable	11	Durable materials
Biodegradable	3	Biodegradable materials
Certified wood product	5	Certified wood products
Water conserving	12	Water conservation
Low embodied energy	7	Low embodied energy
Minimum waste	11	Minimum waste
Products that reduce material use	3	Product that reduce material use
Non-ozone depleting products	10	Non-ozone depleting products
		IEQ
Products that improve light quality	2	Products that improve light quality
Products that remove indoor pollutants	3	Products that remove indoor pollutants
Minimal emissions	7	Minimal emission/ Low-toxicity/ Low-VOC assembly
Low-toxicity	11	
Low-VOC assembly	11	
Moisture	5	Moisture
Products that help noise control	2	Noise control
Non-hazardous products	5	Non-hazardous products/ Healthfully maintained
Healthfully maintained	7	

CHAPTER 6
CONCLUSIONS

The complexity involved in the evaluation and selection processes of materials is often misguided by their simple definitions. A specific product may not be “green” or certified as green but when it embodies the reduced negative environmental impact of a green building it may be viewed as green. On the other hand a chosen green product, when not used efficiently, can result in reduced durability, poor technical performance, and high maintenance, and is certainly not sustainable. However, in quest to extract the maximum benefit out of a green material, it would be unwise and impractical to be expecting a material to perform at par on all projects. The “standards” for green materials will continually change with new information, research data, design concepts and performance requirements. It is up to the architect, contractor and last but not least the owner to interpret the greenness of a material and use it to their advantage.

As per Rinker Hall’s analysis of selection criteria, the criteria evaluated at the top are energy efficiency, followed by recycled content. Both have the same frequency as indicated in Table 2-5, but energy efficiency has more importance due to the savings over the life cycle. Resource efficiency and water conservation appear next in the evaluation; again both have the same frequency, but the former when combined with other criteria has played an important role in reducing energy consumption and made less of an impact to the environment. Table 5-2 indicates that in terms of frequency, the mentioned criterion match with their ranking achieved with Rinker Hall’s analysis. Thus demonstrating the achievement of same importance as attained with collective importance from different sources**.** The other criteria have different rankings as compared to the ones evaluated with the frequency of criterion as shown in Table 5-2. These rankings depend upon the amount and kinds of materials used, energy savings, and their relative

importance and impact to the environment. Unlikely to be ascertained from the analysis of the case study, others factors contributing to the difference in rankings could be location, climate, size, and type of building. Furthermore, the design of the building and choice of materials weigh heavily over them as well.

Much like the manufacturing process of a material, the approach for this study involved extraction of information, identifying connections and interdependencies, laying out groundwork, building up analysis, and finally documenting the findings. It was found that just building a sustainable building is not enough; a smart building with smart systems and materials that respond to its needs requires vigorous filtering of selection criteria which aid in the selection of materials in the first place. The process is not one way but of evolving nature much like the savings which are not static but cyclic. And this happens only once the hierarchy of systems or criteria are pre determined at the planning stage. The study of Rinker Hall clearly demonstrated that energy efficiency played a vital role in reducing its carbon footprint and in theory can, in fact, in conjunction with other pertinent systems, make it sustainable too. Resource efficiency, water conservation, indoor air quality, reduced emissions, and controlled global warming potential, all weigh heavily in making the right decisions but a sustained confirmation of their contribution can only be determined by continually documenting the efficiency with which the building is operating and it can be most efficiently documented by quantifying its energy requirements.

Energy efficiency and the effort that goes in to achieving its potential can only go so far in achieving a building's targeted goal. In this post modern world of architecture, architects have to deal with the weighty issue of being morally and politically correct by designing green and continually struggle to achieve this delicate balance between conservation and creation.

However, when this balance is struck, be it a design breakthrough or a rare collaboration, the philosophy behind designing a sustainable building through the utilization of green materials and technology can pave way for a creation that may inspire posterity.

CHAPTER 7
RECOMMENDATIONS

In order to get more specific results in terms of selecting cost effective and environment friendly materials, a LCA study should be done. A detailed and quantitative analysis using the LCA for calculating energy savings and GWP would be the ideal approach for quantifying sustainability.

Recommendations for architects, engineers and contractors would be to better understand the green building material selection process and to take extra measures in using and promoting the green building strategies. The members of the construction industry should greatly encourage the use of green building materials to lessen the environmental impact and for a better indoor/outdoor environment.

Last but not least, education is the thrust the industry needs for consumers to look beyond the financial gains and risks involved in investing in real estate. Besides aiming for profitability, industry leaders need to incorporate programs in their real estate endeavors that encourage public participation early on so that they are in sync with what went into the product that they are buying. This is turn will encourage designers, builders and contractors to invest in green technologies, green building materials and a host of other sustainable features.

U.S. Department of Energy's biennially held Solar Decathlon in Washington D.C. is a great example of the leveling of playing field in sustainable architecture. It is an educational project that challenges college teams from around the globe in ten contests to design, build, and operate the most livable, energy-efficient, and completely solar-powered house (Solar Decathlon 2009). Events like these should be held throughout the country to raise public awareness and to induce corporate establishments to fund future research in this field.

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BIOGRAPHICAL SKETCH

Pranav Arora was born in 1980 in the city of Jalandhar, Northern India. His initiation into architecture and construction, unbeknownst to him, started at home. His father, an architect himself, influenced his interests and helped him develop a keen sense of aesthetics and an eye for building technique since early childhood. After completing his bachelor's in architecture from Pune University, India in 2004, his curiosity for learning more about the built environment propelled him to pursue master's degree in building construction at the University of Florida in the United States.

Before starting his graduate studies, he worked as an intern architect for two years in India and one year in Atlanta, Georgia with Smallwood Reynolds, Stewart & Stewart Architects. His appetite for learning and aptitude for design and construction oriented challenges helped him establish himself as a competent professional. While pursuing his graduate studies, he was a graduate assistant and then a teaching assistant for structures course in the Building Construction Department (2008-09). He completed his Masters of Science degree in the summer of 2009 and upon completion he will work in the field of construction to apply his knowledge of architecture and building construction.