CONCRETE'S CONTRIBUTION TO SUSTAINABLE DEVELOPMENT

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INTRODUCTION

Concrete is the most widely used building material on earth. It has a 2,000 year track record of helping build the Roman Empire to building today's modern societies. As a result of its versatility, beauty, strength, and durability, concrete is used in most types of construction, including homes, buildings, roads, bridges, airports, subways, and water resource structures. And with today's heightened awareness and demand for sustainable construction, concrete performs well when compared to other building materials.

Concrete is a sustainable building material due to its many eco-friendly features. The production of concrete is resource efficient and the ingredients require little processing. Most materials for concrete are acquired and manufactured locally which minimizes transportation energy. Concrete building systems combine insulation with high thermal mass and low air infiltration to make homes and buildings more energy efficient. Concrete has a long service life for buildings and transportation infrastructure, thereby increasing the period between reconstruction, repair, and maintenance and the associated environmental impact. Concrete, when used as pavement or exterior cladding, helps minimize the urban heat island effect, thus reducing the energy required to heat and cool our homes and buildings. Concrete incorporates recycled industrial byproducts such as fly ash, slag, and silica fume that helps reduce embodied energy, carbon footprint, and waste.

EMBODIED ENERGY

Embodied energy is an accounting methodology that aims to find the sum total of non-renewable energy necessary to produce a product or service from raw material extraction, transport, manufacturing, assembly, installation, operations, and, finally, its disassembly, deconstruction, and/or decomposition. There are two aspects to embodied energy: the initial embodied energy of a material or system and the recurring embodied energy. The initial embodied energy is the energy necessary to acquire raw materials and to process, manufacture, transport, and install these materials for a project. For concrete, the initial embodied energy includes the energy required to extract limestone and other raw materials for cement, extract aggregates for concrete, manufacture cement, produce concrete, transport concrete to the site, and place concrete for the project. Recurring embodied energy is the energy required to maintain, repair, restore, refurbish, or replace materials during the life of a project. Since concrete is a durable material that requires minimal maintenance over time, the recurring embodied energy is limited.

Typically, embodied energy is measured as a quantity of non-renewable energy per unit of building material, component, or system. Embodied energy may be expressed as mega Joules (MJ) or giga Joules (GJ) per unit of mass (kg or tonne) or area (m^2). Choices of material and design principles have a significant impact on energy required to construct and operate a building. The discussion of embodied energy is relevant to sustainability because embodied energy is often associated with raw material depletion, greenhouse gas emissions, and general degradation of the natural environment. Embodied energy is a recognized quantifiable and comparative indicator of a project's or material's sustainable performance.

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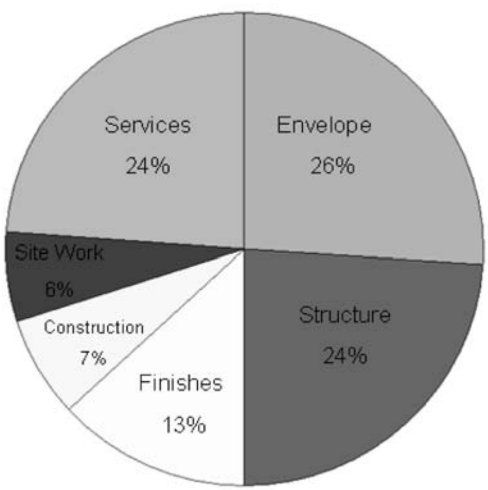
Cole and Kernan conducted research estimating the embodied energy of a typical 50,000 square foot office building with underground parking. The study considered three construction types: wood, concrete, and steel. The research attempted to estimate the impact of the building envelope, the interior structure, and the ongoing services on embodied energy. The building services, structure, and envelope had fairly equivalent embodied energy values ranging from 24–26%, as shown in Figure 1. The building finishes were found to have an embodied energy of 13% and the site work and construction had the least effect on the embodied energy with values of 6% and 7%, respectively. The finishes, which initially represented only 13% of the embodied energy, typically account for the highest increase in recurring embodied energy. When comparing the various building materials, there was little difference found in the initial embodied energy between wood, steel, and concrete construction types (Cole, 1996).

According to the American Institute of Architects' Sustainable Design Resource Guide, the embodied energy of 17.5 MPa (2540 psi) concrete has been estimated at 1.0 MJ/kg (858000 Btu/ton). Of the vast majority of the embodied energy, 90% is attributable to the production of Portland cement. The embodied energy of virgin imported structural steel is 35.0 MJ/kg (30 million Btu/ton), while recycled steel has an embodied energy of 10.1 MJ/kg (8.7 million Btu/ton). When we compare the embodied energy of various building systems, we find that the embodied energy of concrete in its basic form is much less than that of steel but greater than timber. However, when we compare the quantity of steel and quantity of concrete required to construct a structurally similar building, the embodied energy differential between the two materials disappears (Sustainable Design Resource Guide, 2008).

FIGURE 1. Embodied energy of building systems.



Another research study compared the energy of production for concrete and other common building materials for raw material extraction, transportation, and manufacturing. The study concludes that the energy required to produce one metric ton of reinforced concrete was 2.5 GJ/t (2.2 million BTU/ton) compared to 30 GJ/t (25.8 million BTU/ton) for steel and 2.0 GJ/t (1.7 million BTU/ton) for wood. (Pentalla, 1997).

Embodied energy is not limited to buildings. Infrastructure, including highways and roadways, plays an integral role in our country's economic well-being. A New Zealand study compared the embodied energy of concrete and asphalt pavements and found that the embodied energy of asphalt was 3.4 times greater than the embodied energy of concrete (Baird, 1997).

In another study, the Athena Institute compared the embodied energy and global warming potential over a 50-year life cycle for the construction, maintenance, and operation of asphalt and concrete pavements. The results indicate that the embodied primary energy is significantly lower for the concrete pavement as compared to an equivalent asphalt pavement. For a typical concrete roadway, the primary embodied energy ranged from 2.3 to 3.9 times less for the comparable asphalt option. With over 4 million miles of roadways in the U.S., the reduction of embodied energy through the use of concrete paving is significant (Athena Institute, 2006).

THERMAL MASS

Thermal mass is the term used to describe a material that absorbs and stores heat energy. In a building system, it is the mass of the building elements that stores heat during the hottest periods of the day and releases the heat during the cooler evening hours. Concrete is one of several building materials that possess thermal mass properties. In the winter sea-

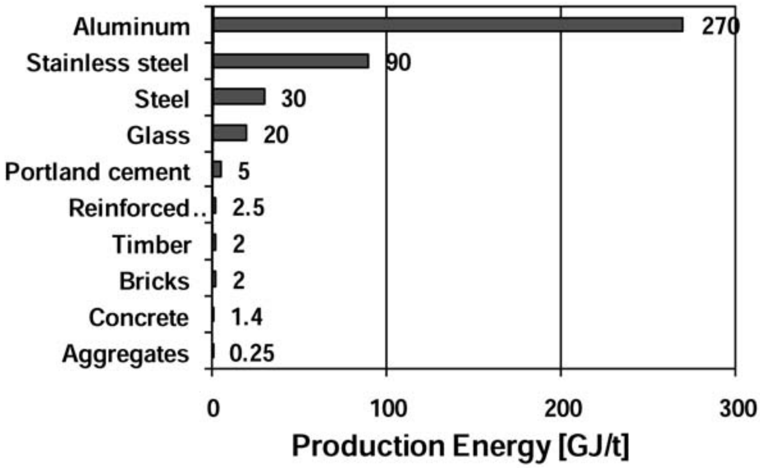


FIGURE 2. Energy of production for common building materials.

son, high thermal mass concrete walls and floors absorb radiant heat from the sun and gradually release it back into the occupied space during the night when the outdoor temperature drops. Concrete is an ideal building material for commercial and residential structures due to its high specific heat, high density, and low thermal conductivity.

The distinct benefits of high thermal mass buildings are:

- Moderate shifts in peak loads of energy requirements due to the reduction in high fluctuations between indoor and outdoor temperatures.
- Heat transfer through a high thermal mass wall is reduced. Therefore, less energy is used to heat and cool the interior space.
- The thermal mass of concrete delays peak temperatures, and reduces and spaces out peak energy loads, therefore shifting the energy demand to off-peak periods when utility rates may be lower. The damping and lag effects of a high thermal mass building are shown in Figure 3.

The Oak Ridge National Laboratory (ORNL) published a study comparing the energy performance of high thermal mass wall technologies with typical residential lightweight wood-framed technologies (Kosny, 2001). The ORNL report detailed a house constructed of Insulated Concrete Form (ICF) construction. ICFs are polystyrene forms that are filled with ready mixed concrete at the site. The ICF walls provide a high thermal mass when compared to a typical wood framed house. The results of the study indicated that the average potential energy savings (ICF house vs. conventional wood-framed house) for all U.S. locations is approximately 8%. Figure 4, reproduced from the ORNL report, shows the energy savings for various U.S. cities.

Another research study compared the energy cost of a 5-story office building, one built using structural steel with lightly framed exterior walls and the other built using reinforced concrete with concrete exterior walls, to determine the benefit of thermal mass. The analysis was conducted for six different cities in the U.S. Energy cost savings for the concrete frame building were 5% in Miami, 10% in Phoenix, 16% in Memphis, TN, 18% in Chicago, 21% in Denver, and 23% in Salem, OR (Marceau, 2007).

CARBON FOOTPRINT

Carbon dioxide (CO_2) is one of several greenhouse gases that are believed to contribute to global warming by trapping the sun's radiant energy in our atmosphere. This process is called the greenhouse effect. Other greenhouse gases include water vapor, methane, ozone, and others. Since the beginning of the Industrial Revolution in the late 1700s, the concentration of CO_2 in our atmosphere has increased by about 100 ppm. Half of this increase occurred in 200 years, from the late 1700's to 1973. The second half occurred in a mere 33 years, from 1973 to 2006. In this time period, there has been an exponential increase in CO_2 and an increase in global average air

FIGURE 3. Damping and lag effect of thermal mass.

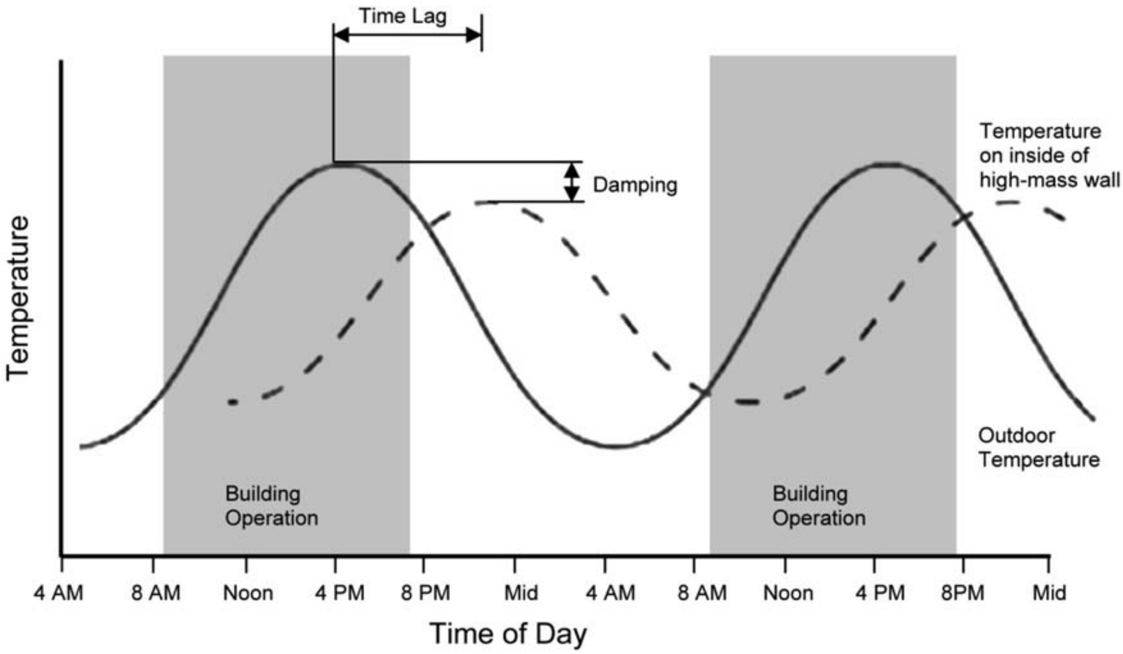
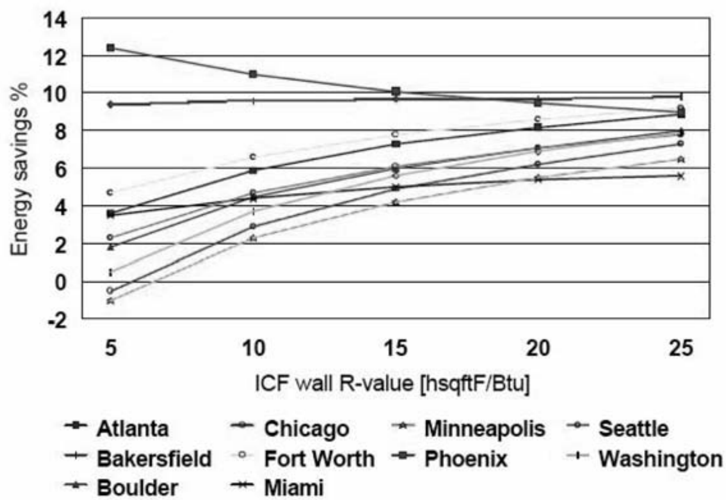


FIGURE 4. A potential whole building energy that can be saved in 10 U.S. locations by the replacement of conventional wood frame walls by ICF walls.



temperatures, leading many to believe a direct correlation between the greenhouse gases in our environment and global warming (EPA, 2008).

Water, sand, stone, gravel, and other ingredients make up about 90% of the concrete mixture by weight. The process of mining sand and gravel, crushing stone, combining the materials in a concrete plant, and transporting concrete to the construction site requires very little energy and therefore only emits a relatively small amount of CO_2 into the atmosphere. The amount of CO_2 embodied in concrete is primarily a function of the cement content in the mix. It is important to note that structures are built with concrete and not cement.

The terms cement and concrete are often used interchangeably. Cement is an ingredient of concrete. It's the fine, gray poweder that, when mixed with water, sand, and gravel, forms the rock-like mass known as concrete. Cement acts as the binding agent or glue. Cement is produced by cement manufacturers around the world in cement plants. Concrete is used to build our homes, buildings, roads, bridges, airports, and subways, among other critical structures. Concrete is used in almost every form of construction. When concrete producers combine materials, including cement, water, sand, and gravel, along with other chemicals and minerals to create concrete, the result is approximately 100 to 300 kg of CO_2 is embodied for every cubic meter of concrete (170 to 500 lb per yd^3) produced or approximately 5% to 13% of the weight of concrete produced, depending on the mix design.

When comparing carbon footprint of concrete versus other building materials, concrete performs well. In one study that compared the embodied CO_2 in concrete and steel-framed buildings on a per-square-meter basis, concrete accounted for 550 kg of CO_2 per square meter of floor area (112 lb/ft^2) and steel accounted for 620 kg of CO_2 per square meter of floor area (127 lb/ft^2) (Guggemos, 2005).

Studies conducted by the National Resources Council of Canada compared fuel consumption and emissions for a 100 km (62.14 mi) section of a major urban arterial highway, one paved with asphalt and the other paved with concrete. These studies concluded that heavy trucks traveling on concrete pavement accumulate statistically significant fuel savings, ranging from 0.8% to 6.9%. These fuel savings lead to reductions in greenhouse gas emissions and air pollutants (Taylor, 2006).

Athena Institute conducted a life cycle analysis on concrete and asphalt roadways to compare embodied energy and global warming potential for construction and maintenance over a 50-year life cycle. The study concluded that for high volume highways asphalt generated global warming potential of 738 t/km (1309 tons/mi) of CO_2 equivalents compared to 674 t/km (1196 tons/mi) of CO_2 equivalents for concrete (Athena, 2006).

The concrete industry is making further progress with regard to reducing its carbon footprint. The U.S. concrete industry uses a significant amount of industrial byproducts such as fly ash, blast furnace slag, and silica fume to supplement a portion of the cement used in concrete. These Supplementary Cementitious Materials (SCMs) work in combination with Portland cement to improve strength and durability in addition to reducing the CO_2 embodied in concrete by as much as 70%, with typical values ranging between 15 and 40%. These industrial products would otherwise end up in landfills (NRMCA, 2008).

The cement industry was among the first to tackle the issue of climate change. Since 1975, it has reduced emissions by 33%. Portland Cement Association members adopted a voluntary Code of Conduct (principles, performance measures, and a reporting protocol) to support the Cement Manufacturing Sustainability Program. By the year 2020, the industry plans to voluntarily reduce CO_2 emissions by 10%, energy use by 20%, and cement kiln dust by 60% below a 1990 baseline. The primary options for reducing the quantity of CO_2 generated during the cement manufacturing process are to use alternatives to fossil fuels, change the raw ingredients used in manufacture, and intergrind additional materials with the Portland cement. The most recent progress involves newly introduced guidelines that will allow for greater use of limestone as interground material in finished cement. This will have no impact

TABLE 1. Annual savings and reductions for major urban arterial highway (Taylor, 2006).

	Results based on driving on concrete vs. asphalt pavement		
	Minimum 0.8%	**Average 3.85%**	**Maximum 6.9%**
Fuel Savings (liters)	377,000	1,813,000	3,249,000
Dollar Savings ($)	338,000	1,625,000	2,912,000
CO_2 Equivalent Reductions (t)	1,039	5,000	8,950

on product performance but will ultimately reduce CO_2 by more than 2.5 Mt (2.8 million tons) per year in the U.S. Using interground limestone in cement is already common practice in Europe and Canada (PCA, 2007).

STORMWATER MANAGEMENT

Improperly managed stormwater runoff can flow over impervious surfaces, picking up pollutants along the way and washing them into lakes, rivers, and streams. Pollutants, such as heavy metals and sediment, can alter the basic natural habitats of several species and can result in the death of animals and organisms. Stormwater runoff has been traditionally controlled through the use of detention or retention basins that store the stormwater runoff and allow it to percolate through the soil below. Retention and detention basins take up a significant amount of land that could otherwise be left in its natural state.

FIGURE 5. Typical pervious concrete.

Pervious concrete is a unique and innovative means to manage stormwater as shown in Figure 5. A pervious concrete mixture contains little or no sand, creating a substantial void content. Using sufficient paste to coat and bind the aggregate particles creates a system of highly permeable, interconnected voids that drains quickly. Typically, between 15% and 25% voids are achieved in the hardened concrete; flow rates for water through pervious concrete are typically around 480 in./hr (0.34 cm/s), although they can be much higher. Pervious concrete has been used successfully in many types of applications such as parking lots, streets, plazas, nature trails, and walkways. While pervious concrete can be used for a surprising number of applications, its primary use is in pavement.

Pervious concrete pavements are typically supported on a base layer of uniformly sized stone to form a basin where rainwater can be stored before percolating into the soil below. The system basically forms a dry detention pond that can reduce the need for expensive stormwater drainage and wet pond detention/retention systems, thereby allowing for more effective land use. In effect, the pervious concrete pavement system serves two functions: 1) as a paved surface for driving, parking, or walking, and 2) as a retention basin for storing rainwater during a storm event.

Pervious pavement systems can treat common pollutants found in the urban environment. Pollutants are those typically found on parking areas, including but not limited to cadmium, oils, lead, and gasoline. The pollutants are captured in the voids of the pervious concrete and the treated water is filtered into the groundwater below. The oil-based pollutants that are stored in the voids of the pervious pavement are digested by naturally occurring microorganisms that inhabit the large surface void surface area (Ferguson, 1996).

A study performed at the University of Central Florida assessed the infiltration rates and the water quality of the stormwater in a pervious concrete reservoir (Wanielista, 2007). The pervious concrete was constructed on the shoulder adjacent to the parking lot of a rest area in Florida. The shoulder width was 10 feet and the length 90 feet, with a 10-inch pervious concrete thickness over a 12-inch deep reservoir.

The site was monitored for infiltration rate, water quality, and truck loads over a 12-month period. Infiltration rates were measured using embedded and surface infiltrometers. The infiltration rates ranged from 2.5 inches per hour to 6.3 inches per hour, depending on the size of the infiltrometer head. An acceptable rate of infiltration for an 80% yearly volume control is 1.5 inches per hour.

Water quality was measured and documented at the bottom of the pervious concrete reservoir. Two measures of water quality were assessed, dissolved phosphorous and nitrates. The results indicated that the quality of the water in the pervious concrete reservoir was equal to the quality of the rainwater. Therefore, it can be assumed that pollutants from the impervious surfaces were not transferred through the pervious concrete and into the groundwater below. The water quality at the bottom of the reservoir was compared to the runoff water quality from the adjacent impervious surface areas. It was determined that the reservoir water quality was better than the runoff water quality.

URBAN HEAT ISLAND REDUCTION

The use of light colored pavements, cladding, and roofing such as concrete in our urban areas can contribute to overall energy savings and safety. Concrete absorbs less heat and reflects more light than dark-colored materials, therefore maintaining a low surface temperature. Concrete has been demonstrated to have a positive impact on the localized ambient temperatures and can reduce energy needed to air condition buildings. Light colored pavements also require less site lighting to provide safe nighttime illumination levels, whether on parking lots, driveways, or sidewalks. Less sight lighting requires less energy.

A material's ability to reflect solar radiation is measured by the material's albedo or measure of solar reflectivity. A material's albedo is the extent to which the material diffusely reflects light from the sun. Although not always an indicator, materials with a light color have a high albedo where materials that appear darker typically have a lower albedo. A material's ability to reflect infrared light is directly proportional to a material's ability to reflect heat from the surface. During the hot summer months, the ambient air surrounding dark colored paving or cladding materials can be up to XX °C (10 °F) warmer than material with a light color, or high albedo (USGBC, 2007).

Several studies illustrate this point. One study analyzed temperature differentials in California at an ambient temperature of 13°C (55°F) for various colored materials (Berdahl, 1994). The study found that the maximum temperature differential between a material covered with a black acrylic paint and a material covered with a white acrylic paint was 20°C (68°F.). A second study measured the temperature of various pavement types during a hot 32°C (90°F) summer day and found that weathered concrete had

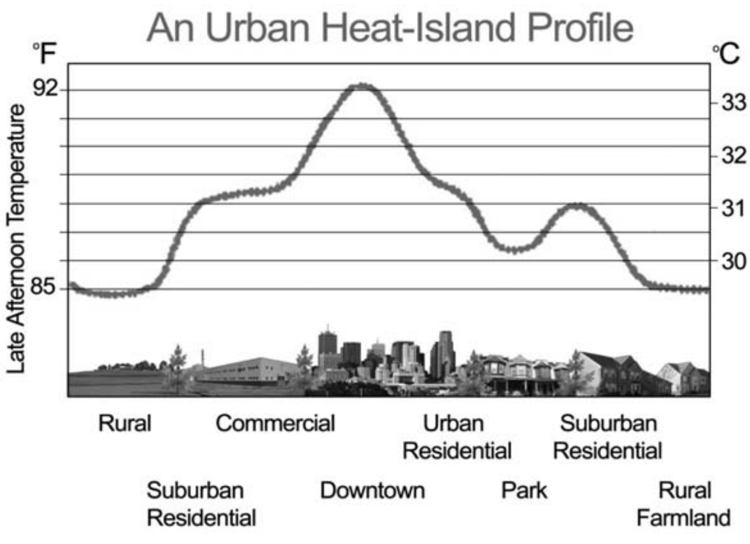


FIGURE 6. Urban Heat Island Effect for various localities.

a temperature of 68°C (155°F) at the material surface where dark asphalt had a temperature of 90°C (195°F). The asphalt pavement was 32°C (40°F) hotter than the lighter colored concrete pavement (Rosenfeld, 1993).

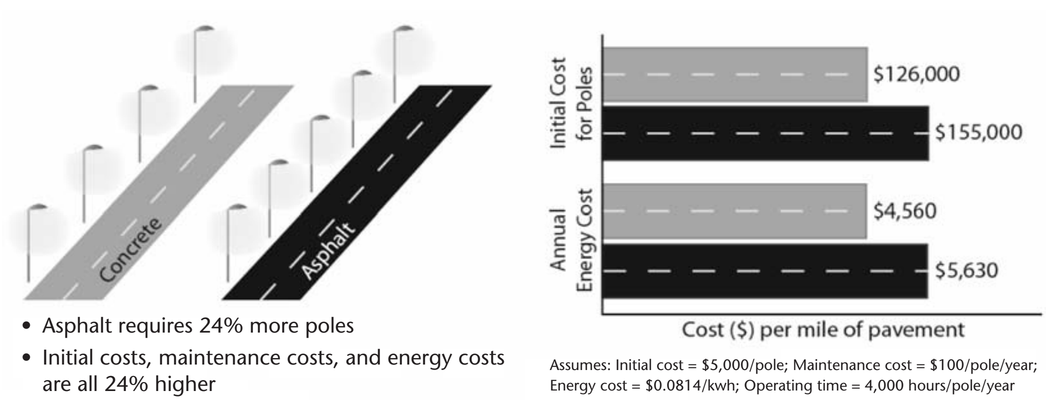
The effect of higher ambient temperatures in metropolitan areas is apparent when you compare the health of those who reside in the city versus those who reside in more rural areas. Compared to rural areas, cities experience higher rates of heat related illness and death. Heat islands can exacerbate hot weather events or periods that may cause heat stroke and lead to physical discomfort, organ damage, and even death—especially in vulnerable populations such as the elderly (Cleveland, 2007). The Centers for Disease Control and Prevention (CDC) says that excessive heat claims more lives in the United States each year than hurricanes, lightning, tornadoes, floods, and earthquakes combined. Between 1979–1998, the CDC estimates that 7,421 deaths resulted from exposure to excessive heat in the U.S.

Urban heat island reduction is further demonstrated by the Cool Communities program sponsored by the Department of Energy (Department of Energy, 2008). The program suggests that by replacing dark colored pavements with light and heat-reflective concrete-based materials, along with careful planting of trees, the average summer afternoon temperature in urban areas can be reduced by as much as 5 degrees, cutting the need for air conditioning by 18% and even reducing air pollution.

In addition, concrete's ability to reflect light improves safety on roadways by providing superior illumination during the nighttime hours. Concrete pavements can also decrease energy demand by reducing lighting requirements. One study indicates that the cost savings in initial energy consumption and ongoing maintenance of light poles is reduced by 31% where concrete pavements are used. Operational energy costs to illuminate a concrete roadway compared to a dark-colored roadway were 33% less. To maintain the specified illumination of a roadway, an asphalt roadway will require 24% more light poles, an increase in project costs of $30,000. The annual energy consumption of these extra light poles equates to a cost of $1,100 per mile of roadway as shown in Figure 7 (Gadja, 1997).

Another study analyzed the light required to meet specified luminance for an asphalt and a concrete parking lot. Results indicate that a 250 Watt lamp used in a concrete parking lot would produce background luminance equal (or greater) to a 400 Watt lamp used in an asphalt parking lot with the same geometric configurations. Therefore, by using a concrete parking surface, energy savings of up to 41% could be obtained. With the assumption that an average parking lot lighting system operates up to five hours per day, in one year the asphalt parking lot would consume 60% more energy than the concrete parking lot. In addition, with the increased luminance of a concrete parking lot, the number of light poles can be reduced (Jobanputra, 2005).

FIGURE 7. Cost and light pole differential between concrete and asphalt roadways. *(Reprinted from "Enlightened" [QD-010P], a publication of the American Concrete Pavement Association. ©2007, American Concrete Pavement Association. All rights reserved.)*



RECYCLED MATERIALS

The U.S. concrete industry uses a significant amount of industrial byproducts such as fly ash, blast furnace slag, and silica fume to supplement a portion of the cement used in concrete. These industrial products, which would otherwise end up in landfills, are called supplementary cementitious materials or SCMs for short. The use of SCMs in concrete work in combination with Portland cement to improve strength and durability, in addition reduces the CO_2 embodied in concrete by as much as 70%, with typical values ranging between 15 and 40%.

Fly ash is the waste byproduct of burning coal in electrical power plants. Generally, 15% to 20% of burned coal takes the form of fly ash. At one time, most fly ash was landfilled, but today a significant portion is used in concrete. Based on NRMCA research, the amount of fly ash used in concrete was about 80 kg (135 lb/yd^3) in 2002, extending cement supply and enhancing concrete performance.

Blast furnace slag is the waste byproduct of iron manufacture. After quenching and grinding, the blast furnace slag takes on much higher value as a supplementary cementitious material for concrete. Blast furnace slag is used as a partial replacement for cement to impart added strength and durability to concrete. In 2002, when blast furnace slag was used in concrete, the average quantity was about 150 kg/m^3 (250 lb/yd^3), extending cement supply and enhancing performance.

Silica fume is a waste byproduct of processing quartz into silicon or ferrosilicon metals in an electric arc furnace. It consists of superfine, spherical particles that when combined with cement significantly increases strength and durability of concrete. It is used for some high-rise buildings to produce concretes that exceed 140 MPa (20,000 psi) compressive strength and in bridge and parking garage construction to help keep chlorides from de-icing salts from corroding steel reinforcement.

The concrete industry also incorporates a variety of environmental best management practices in the production of its product. These include the reuse and recycling of waste from concrete manufacture such as water and unused returned concrete. It also incorporates waste byproducts from other industries such as recycled industrial waste water, foundry sands, glass, and other materials that would typically end up in landfills.

In addition to the use of SCMs in the concrete mix, concrete from demolition can be crushed and recycled as aggregate. Recycled aggregate is often used as paving, backfill, or a road base and is sometimes used for making new concrete. Even the reinforcing steel in concrete (which often is made from recycled materials) can be recycled and reused. Concrete also provides the distinct benefit of being a locally produced material. The use of locally manufactured materials reduces the environmental impact of transportation. In addition, using concrete that is produced and manufactured in the same community as the construction site supports the local economy.

INDOOR AIR QUALITY

Indoor air quality can directly impact the quality of one's health. Poor indoor air quality can impact asthma or cause irritation to eyes, nose, and throat. Incidences of nose dryness often leading to nose bleeds, skin rash, headaches, upper respiratory distress, and dizziness. Outdoor air quality has been regulated and has become cleaner; however, indoor air has deteriorated. The indoor air quality in our homes and offices may be two to five times more polluted than the outside air. Indoor air quality can be impacted by cigarette or tobacco smoke, high Volatile Organic Compound (VOC) levels due to materials used in laminate, particleboard, hardboard, treated wood, etc., carpeting and cleaning materials, among others.

Concrete has one of the lowest levels of VOCs and off-gassing when compared to other commonly used building materials as shown in Table 2. Concrete, when used on the exterior envelope of the building, reduces the amount of air infiltration into the building, therefore reducing the amount of airborne moisture entering the building. This provides for better air quality, less chance of molds, and more efficient use of HVAC systems (Concretethinker.com, 2008).

DURABILITY

Concrete structures have withstood the test of time. For a building to last for generations, durability must be an inherent quality of the construction material. Concrete does not rust, rot, or burn. Concrete

TABLE 2. Concentrations and Emission Rates of VOCs for Common Materials.

Building Material	VOC Concentration, mg/m^3	VOC Emission Rate, mg/m^{2}h
Concrete with water-based form-release agent	0.018	0.003
Acrylic latex paint	2.00	0.43
Epoxy, clear floor varnish	5.45	1.3
Felt carpet	1.95	0.080
Gypsum board	N/A	0.026
Linoleum	5.19	0.22
Particle board	N/A	2.0
Plastic silicone sealer	77.9	26.0
Plywood paneling	N/A	1.0
Putty strips	1.38	0.34
PVA glue cement	57.8	10.2
Sheet vinyl flooring	54.8	2.3
Silicone caulk	N/A	<2.0
Water-based EVA wall and floor glue	1,410.0	271.0

used for buildings and pavements are durable, long-lasting structures. Because of its longevity, concrete is a viable solution for environmentally responsible design and requires less maintenance over the lifetime of the building.

LEADERSHIP IN ENVIRONMENTAL AND ENERGY DESIGN (LEED)

One cannot discuss sustainability without addressing green building rating systems. Leadership in Environmental and Energy Design (LEED) is the most widely used green building rating system in the U.S. Concrete's many environmentally friendly benefits can contribute to LEED credits. LEED is a rating system developed by the U.S. Green Building Council (USGBC) to evaluate the environmental performance of buildings and is a consensus-based national standard for developing high-performance, sustainable buildings.

LEED provides a framework for evaluating a building's environmental performance and provides guidance for meeting sustainability goals through five credit categories: sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality. It should be noted that LEED points are not gained directly by the use of a product or material but by meeting a specific sustainability goal of the rating program. Concrete can contribute to all LEED categories: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, and Innovation in Design.

LEED does not require that every project meet identical requirements or have identical design to achieve certification. Instead, the LEED rating system provides credit for achieving a level of sustainability, in most cases regardless of the material or method. Four levels of certification are available: Certified, Silver, Gold, and Platinum. A minimum of 26 points are required to achieve the Certified level, 33 points for the Silver level, 39 points for the Gold level, and 52 points for the coveted Platinum level.

Specific credits where concrete can contribute to achieving LEED certification include:

LEED Credit SS-C6.1 Stormwater Management—Rate and Quantity
LEED Credit SS-C6.2 Stormwater Management—Quantity Control

The intent of these credits is to limit disruption and pollution of natural water flows by managing stormwater runoff, increasing on-site infiltration, and eliminating contaminants. Pervious concrete can contribute to this credit by reducing stormwater flow by allowing water to soak through and infiltrate to the ground below. Pervious concrete can also reduce the pollutant loads by filtering contaminants as the water is transferred through the pavement.

On building sites where the existing imperviousness is greater than 50%, credit SS-C6.1 requires reducing the rate and quantity of stormwater runoff by 25%. On building sites where the existing imperviousness is less than 50%, the requirement specifies that the post-development discharge rate and quantity from the site shall not exceed the predevelopment rate and quantity. Generally, by incorporating a pervious concrete pavement system on site, the project can meet these criteria and thus obtain the LEED points for these credits.

LEED Credit SS-C7.1 Landscape and Exterior Design to Reduce Heat Island Effect

The intent of this credit is to reduce heat islands to minimize impact on microclimate and human and wildlife habitat. This credit requires high albedo materials (reflectance of at least 0.3) and/or open-grid pavement for at least 50% of the site's non-roof impervious surfaces such as sidewalks, parking lots, drives, and access roads. A second method to achieve this credit includes providing a minimum of 50% of parking spaces under cover (defined as under ground, under deck, under roof, or under a building). Any roof used to shade or cover parking must have an SRI of at least 29. Concrete acts to reduce the heat island effect of concrete by absorbing less heat from solar radiation than darker pavements.

The heat island effect can be further minimized by the addition of trees planted in parking lots. The trees offer shade and produce a cooling effect for the paving. Pervious concrete pavement is ideal for protecting trees in a paved environment (many plants have difficulty growing in areas covered by impervious pavements, sidewalks, and landscaping because air and water have difficulty getting to the roots). Pervious concrete pavements or sidewalks allow adjacent trees to receive more air and water and still permit full use of the pavement.

LEED Credit WE Credit 2.0 Water Efficient Landscaping

The intent of this credit is to limit or eliminate the use of potable water, or other natural surface or subsurface water resources available on or near the project site, for landscape irrigation. To earn this credit, potable water for irrigation must be reduced by 50% when compared to a mid-summer baseline case. The gravel sub-base under pervious concrete can be used to store stormwater for irrigation, helping to satisfy this credit. If no irrigation is required for a project, two points may be earned.

LEED Prerequisite EA2 Minimum Energy Performance
LEED Credit EA Credit 1 Energy and Atmosphere—Optimize Energy Performance

The intent of prerequisite EA2 is to establish the minimum level of energy efficiency for the base building and systems. To achieve this credit, the building should comply with ASHRAE/IESNA Standard 90.1-1999 (without amendments) or the local energy code, whichever is more stringent. The intent of Credit EA-C1 is to achieve increasing levels of energy performance above the baseline in the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use. To achieve this credit the design must demonstrate improvement in the proposed building performance rating when compared to the baseline building performance rating per ASHRAE/IESNA Standard 90.1-2004. Up to 10 points are available for new buildings that show a 42% energy cost savings.

The primary role of ready mixed concrete in improving energy performance is in reducing heat loss and gain through foundation and building walls using insulated wall technologies and high thermal mass systems. Concrete is one of the primary building materials that provide advantages of thermal mass in building systems. The thermal mass of concrete delays peak temperatures, reduces and spaces out peak energy loads, and therefore may shift and reduce energy demand. When buildings are properly designed and optimized, incorporating thermal mass can lead to a reduction in heating, ventilating, and air conditioning equipment capacity. Reduced equipment capacity can represent energy and construction cost savings.

LEED Credits MR Credit 4.1 and MR Credit 4.2 Recycled Content

The intent of this credit is to increase the demand for building products that have incorporated recycled content material by reducing the impacts resulting from the extraction of new material. The requirements for these credits are the use of materials with recycled content such that the sum of post-consumer recycled content plus one-half of the pre-consumer recycled content constitutes at least 10% or 20% (based on the dollar value of the material), respectively, of the total value of materials in the project. Almost all ready mixed concrete contains recycled materials in the form of supplementary cementitious materials (SCM) such as fly ash, slag, or silica fume. The use of SCMs or recycled aggregate in concrete or base material contributes to recycled content needed for this credit. SCMs are considered pre-consumer recycled material and recycled aggregate from a demolished project are considered post-consumer recycled material.

LEED Credit MR Credit 5.1 and MR Credit 5.2 Regional Materials

The intent of this credit is to increase demand for building products that are extracted and manufactured locally. This reduces the environmental impacts resulting from their transportation and supports the local economy. To meet the intent of this requirement, 10% (based on cost) of the total materials must be harvested, extracted, or recovered within 500 miles of the project site. An additional point is awarded for 20% regional materials. The majority of materials in ready mixed concrete are considered regional materials.

Other LEED Credits

Concrete parking garages, especially when placed underground or within buildings, can be used to limit site disturbance. This strategy is worth one point (Sustainable Sites Credit 5.1: Site Development, Protect or Restore Habitat). Parking garages can also be used to help reduce the footprint of the development. This is worth one additional point (Sustainable Sites Credit 5.2: Site Development: Maximize Open Space).

Concrete structures are resistant to natural disasters such as fires, hurricanes, tornadoes, floods, and earthquakes. Since concrete buildings are durable and have a long service life, they can be reused when undertaking a major renovation. This strategy is worth 1 to 2 points: 1 point if 75% of the existing building structure/shell is left in place and 2 points if 95% is left in place (Materials and Resources Credit 1: Building Reuse).

At the end of its useful life, a concrete structure can be demolished, crushed, and recycled into aggregate for road bases, construction fill, or aggregate for new concrete. This diverts material from landfill disposal. This strategy is worth 1 point if 50% of construction, demolition, and land clearing waste on a construction project is recycled or salvaged and 2 points for 75% (Materials and Resources Credit 2: Construction Waste Management).

There is a credit category in LEED called Innovation and Design Process. The intent is to provide design teams the opportunity to be awarded points for exceptional performance above the requirements set by LEED. The project can gain 1 to 4 points for innovations in design. One strategy used to obtain a LEED point is to reduce CO_2 in concrete by 40%. One way to accomplish this is by using high volumes of fly ash, slag, or silica fume in concrete.

Another potential credit in the Innovation and Design Process could be obtained by improving indoor air quality. Concrete has low emissions of volatile organic compounds and does not degrade indoor air quality. If properly coated, the concrete structure itself, such as floors, walls, and ceilings, can be the finished surface, eliminating the need for additional sheathing materials.

Ready mixed concrete is a perfect material for environmentally conscious business owners for use in LEED green building rating designs. With its environmental and energy saving benefits, concrete can provide a low-maintenance and durable construction material that will assist in gaining the highly regarded LEED certification.

CONCLUSION

The use of concrete for new construction is an environmentally responsible choice that provides building owners with energy efficient buildings and provides occupants with optimal comfort and health. Concrete maintains a low embodied energy, utilizes recycled materials, and provides a cleaner indoor environment. Utilizing concrete in the exterior environment helps to reduce the urban heat island effect and provides for a beautiful exterior landscape.

Concrete can also provide solutions for achieving LEED certification. Concrete pavements are a durable, long lasting choice that can provide for long-term sustainable solutions for infrastructure.

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