Designer's NOTEBOOK

SUSTAINABILITY

Sustainability Concepts

Sustainability is often defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Worldwide, people are currently using 20% more resources than can be regenerated. In particular, the U.S. population consumes more resources on a per capita basis than any other nation.

The environmental impact of constructing and operating buildings in most countries is significant. Consider that buildings consume 65% of the electricity generated in the U.S. and more than 36% of the primary energy (such as natural gas); produce 30% of the national output of greenhouse gas emissions; use 12% of the potable water in the U.S.; and employ 40% of raw materials (3 billion tons annually) for construction and operation worldwide.[1]

Building materials can have a significant effect on the environmental impact of the construction and operation of a building. Some materials may have to be used in special configurations, or employ different combinations, to achieve sustainability; the inherent properties of precast concrete, however, make it a natural choice for achieving sustainability in buildings. Precast concrete contributes to sustainable practices by incorporating integrated design, using materials efficiently, and reducing construction waste, site disturbance, and noise.

Although most consumers are concerned with the present and future health of the natural environment, few are willing to pay more for a building, product, process, or innovation that minimizes environmental burdens. The concept of sustainability, however, balances sustainable design with cost-effectiveness. Using integrated design (also called holistic or whole building approach), a building's materials, systems, and design are examined from the perspective of all project team members and tenants. Energy efficiency, cost, durability (or service life), space flexibility, environmental impact, and quality of life are all considered when decisions are made regarding the selection of a building design.

Triple bottom line

The triple bottom line — environment, society, and economy — emphasizes that economic consequences are related to environmental and social consequences. Consequences to society include impacts on employees, communities, and developing countries, as well as ethics, population growth, and security. Reducing material, energy, and emissions used by buildings has impacts far beyond those of the buildings themselves, such as:

- Using less materials means fewer new quarries are needed.
- Using less energy means fewer new power plants need to be constructed, less pollution is emitted into the air, and dependence on foreign energy sources is reduced.
- Less emissions to air means a reduction in respiratory conditions, such as asthma.
- Using less water means a reduction in demands on the infrastructure to find and deliver new sources of water.

All of these examples indicate how building energy and utility use affect the local community. These are especially important since most communities do not want new power plants, quarries, or landfills built near them.

The community can also be considered globally. Carbon dioxide (CO_2) emissions in the U.S. were reduced in 2002 for the first time; this reduction, however, was due to a decrease in manufacturing and a stagnant economy. That same year, China's production of CO_2 increased by more than the reduction realized in the U.S., but this increase was primarily due to production of materials consumed by U. S. citizens. Energy and material consumption, waste, and emissions to air, land, and water need to be considered from a global as well as regional perspective in a global market.

Table 1 Integration Strategies.

INTEGRATION STRATEGY	SUSTAINABILITY ATTRIBUTE
Use precast concrete panel as interior surface.	Saves material; no need for additional framing and drywall.
Use hollow-core panels as ducts.	Saves material and energy; eliminates ductwork and charges thermal mass of panel.
Use thermal mass in combination with appropriate insulation levels in walls.	Thermal mass with insulation provides energy benefits that exceed the benefits of mass or insulation alone in most climates.
Design wall panels to be disassembled for when building function changes.	Saves material; extends service life of panels.
Use durable materials.	Materials with a long life cycle and low maintenance will require less replacement and maintenance during the life of the building.
Use natural resources such as daylight as a source for building lighting, trees for shading, and natural ventilation	Reduces lighting and cooling energy use. Increases indoor air quality and employee productivity.
Reduce and recycle construction waste.	Reduces transportation and disposal costs of wastes. Less virgin materials are used if construction waste is recycled for another project.
Use building commissioning quality control, and inspections to ensure that building standards are met.	Energy savings and indoor air quality are most likely attained during the building life if inspections are made to ensure construction was completed as designed.

Cost of building green

A sustainable design can result in reduced project costs and a building that is energy and resource efficient. Energy and water efficient buildings have lower operating costs (in the range of $0.60 to $1.50 versus $1.80 per sq ft) and a higher facility value than conventional buildings.[2] Lower energy costs translate into smaller capacity requirements for mechanical equipment (heating and cooling) and lower first costs for such equipment. Effective use of daylighting and passive solar techniques can further reduce lighting, heating and cooling costs. Reusing materials, such as demolished concrete for base or fill material, can reduce costs associated with hauling and disposing of materials.

When sustainability is an objective at the outset of the design process, the cost of a sustainable building is competitive. Often green buildings cost no more than conventional buildings because of the resource-efficient strategies used, such as downsizing of more costly mechanical, electrical, and structural systems. Reported increases in first costs for green buildings range from 0 to 2% or more, with costs expected to decrease as project

1 U.S. Green Building Council, "An Introduction to the U.S. Green Building Council and the LEED Green Building Rating System," PowerPoint presentation on the USGBC website, October 2005, www.usgbc.org.

2 U.S. Green Building Council, "An Introduction to the U.S. Green Building Council and the LEED Green Building Rating System," PowerPoint presentation on the USGBC website, October 2005, www.usgbc.org.

Glossary

Admixture: material, other than water, aggregate, and hydraulic cement, used as an ingredient of concrete, mortar, grout, or plaster and added to the batch immediately before or during mixing. Chemical admixtures are most commonly used for freeze-thaw protection, to retard or accelerate the concrete setting time, or to allow less water to be used in the concrete.

Albedo: solar reflectance; see reflectance.

Building envelope: the components of a building that perform as a system to separate conditioned space from unconditioned space.

Calcination: process of heating a source of calcium carbonate, such as limestone, to high temperatures, thereby causing a chemical reaction that releases CO_2. This CO_2 is not related to the fuel used to heat the calcium carbonate.

Cement: see portland cement.

Cementitious material (cementing material): any material having cementing properties or contributing to the formation of hydrated calcium silicate compounds. When proportioning concrete, the following are considered cementitious materials: portland cement, blended hydraulic cement, fly ash, ground granulated blast-furnace slag, silica fume, calcined clay, metakaolin, calcined shale, and rice husk ash.

Concrete: mixture of binding materials and coarse and fine aggregates. Portland cement and water are commonly used as the binding medium for normal concrete mixtures, but may also contain pozzolans, slag, and/or chemical admixtures.

Emittance: the ability of the material to emit, or "let go of" heat.

Green buildings: buildings designed considering the concepts of sustainable design and reduction of environmental impacts due to site selection, water use, enegy use, materials and resources, the building's impact on the environment, and indoor air quality.

Greenhouse gas emissions: emissions that have the potential to increase air temperatures at the earth's surface, including carbon dioxide, methane, nitrous oxide, CFCs, water vapor, and aerosols (particles of 0.001 to 10µm diameter).

Portland cement: Calcium silicate hydraulic cement produced by pulverizing portland-cement clinker, and usually containing calcium sulfate and other compounds.

Pozzolan: siliceous or siliceous and aluminous materials, like fly ash or silica fume, which in itself possess little or no cementitious value but which will, in finely divided form and in the presence of moisture, chemically react in the presence of portland cement to form compounds possessing cementitious properties.

Reflectance: the ratio of the amount of light or solar energy reflected from a material surface to the amount shining on the surface. Solar reflectance includes light in the visible and ultraviolet range. For artificial lighting, the reflectance refers to the particular type of lighting used in the visible spectrum.

Silica fume: very fine noncrystalline silica which is a byproduct from the production of silicon and ferrosilicon alloys in an electric arc furnace; used as a pozzolan in concrete.

Slag cement (Ground granulated blast-furnace slag): a nonmetallic hydraulic cement consisting essentially of silicates and aluminosilicates of calcium developed in a molten condition simultaneously with iron in a blast furnace. Slag cement can be used as a partial replacement or addition to portland cement in concrete.

Supplementary cementitious materials: materials that when used in conjunction with portland cement contribute to the properties of hardened concrete through hydraulic or pozzolanic activity or both.

Sustainability: development that meets the needs of the present without compromising the ability of future generations to meet their own needs.[1] In more tangible terms, sustainability refers to the following: not compromising future quality of life; remediating environmental damage done in the past; and recognizing that our economy, environment, and social well-being are interdependent.

Sustainability rating systems: a set of criteria used to certify that a construction, usually a building, is sustainable, green, or energy-conserving.

Thermal mass: the storage properties of concrete and masonry that result in a reduction and shift in peak energy load for many buildings in many climates, compared to wood or metal frame structures.

Urban heat island: microclimates near urban or suburban areas that are warmer than surrounding areas due to the replacement of vegetation with buildings and pavements.

1 World Commision on Environment and Development, "Report on Our Common Future," Oxford University Press, New York, NY, 1987.

teams become more experienced with green building strategies and design.[3] Generally, a 2% increase in construction costs will result in a savings of 10 times the initial investment in operating costs for utilities (energy, water, and waste) in the first 20 years of the building's life.

Buildings with good daylighting and indoor air quality — both common features of sustainable buildings — have increased labor productivity, worker retention, and days worked. These benefits contribute directly to a company's profits because salaries — which are about ten times higher than rent, utilities, and maintenance combined — are the largest expense for most companies occupying office space.[4] In schools with good daylighting and indoor air quality, students have higher test scores and lower absenteeism.

Holistic/integrated design

A key tenet of sustainable design is the holistic or integrated design approach. This approach requires coordinating the architectural, structural, and mechanical designs early in the schematic design phases to discern possible system interactions, and then deciding which beneficial interactions are essential for project success. For example, a well-insulated building with few windows that face east and west will require less heating and air-conditioning. This could impact the mechanical design by requiring fewer ducts and registers and perhaps allow for the elimination of registers along the building perimeter. Precast concrete walls act as thermal storage to delay and reduce peak loads, while also positively affecting the structural design of the building. Table 1 provides other integrated design strategies.

A holistic viewpoint will also take into account the surrounding site environment:

- Are shelters needed for people who take public transportation to work?
- Can bike paths be incorporated for those who bike to work?
- Can native landscaping be used to reduce the need for irrigation?

The eight elements of integrated design are:

1. Emphasize the integrated process.
2. Consider the building as a whole — often interactive, often multi-functional.
3. Focus on the life cycle.
4. Have disciplines work together as a team from the start.
5. Conduct relevant assessments to help determine requirements and set goals.
6. Develop tailored solutions that yield multiple benefits while meeting requirements and goals.
7. Evaluate solutions.
8. Ensure requirements and goals are met.

Contracts and requests for proposals (RFPs) should clearly describe sustainability requirements and project documentation required.[5]

3R's – reduce, reuse, recycle

The 3R's of reducing waste can be applied to the building industry.

Reduce the amount of material used and the toxicity of waste materials. Precast concrete can be designed to optimize (or lessen) the amount of concrete used. Industrial wastes such as fly ash, slag cement, and silica fume can be used as partial replacements for cement with certain aesthetic (color) and stripping

3 *Green Value, Green Buildings Growing Assets*, www.rics.org/greenvalue.
4 U.S. Green Building Council, "Making the Business Case for High Performance Green Buildings," www.usgbc.org.
5 Portland Cement Association, website for sustainable solutions using concrete, www.concretethinker.com

time restrictions. Thereby reducing the amount of cement used in concrete. Precast concrete generates a low amount of waste with a low toxicity. It is generally assumed that 2% of the concrete at the plant is waste, but because it is generated at the plant, 95% of the waste is used beneficially.

Reuse products and containers; repair what can be reused. Precast concrete panels can be reused when buildings are expanded. Concrete pieces from demolished structures can be reused to protect shorelines. Since the precast process is self-contained, formwork and finishing materials are reused. Wood forms can generally be used 25 to 30 times without major maintenance while fiberglass, concrete and steel forms have significantly longer service lives.

Recycle as much as possible, which includes buying products with recycled content. Concrete in most urban areas is recycled as fill or road base. Wood and steel forms are recycled when they become worn or obsolete. Virtually all reinforcing steel is made from recycled steel. Many cement plants burn waste-derived fuels such as spent solvents, used oils, and tires in the manufacture of cement.

Life Cycle

A life cycle analysis can be done in terms of the economic life cycle cost or environmental life cycle impact. Although the two approaches are different, they each consider the impacts of the building design over the life of the building — an essential part of sustainable design. When the energy and resource impacts of sustainable design are considered over the life of the building, a sustainable design often becomes more cost-effective. Conversely, when the energy consuming impacts of a low first cost design are considered over the life of the building, the building may not be an attractive investment.

Practitioners of sustainable design believe that the key to sustainable building lies in long-life, adaptable, low-energy buildings. The durability and longevity of precast concrete makes it an ideal choice.

Life cycle cost and service life

A life cycle cost analysis is a powerful tool used to make economic decisions for selection of building materials and systems. This analysis is the practice of accounting for all expenditures incurred over the lifetime of a particular structure. Costs at any given time are discounted back to a fixed date, based on assumed rates of inflation and the time-value of money. A life cycle cost is in terms of dollars and is equal to the construction cost plus the present value of future utility, maintenance, and replacement costs over the life of the building.

Using this widely accepted method, it is possible to compare the economics of different building alternatives that may have different cash flow factors but that provide a similar standard of service. The result is financial information for decision making, which can be used to balance capital costs and future operation, repair or maintenance costs. Quite often building designs with the lowest first costs for new construction will require higher costs during the building life. So, even with their low first cost, these buildings may have a higher life cycle cost. Conversely, durable materials, such as precast concrete, often have a lower life cycle cost. In the world of selecting the lowest bid, owners need to be made aware of the benefits of a lower life cycle cost so that specifications require durable building materials such as precast concrete.

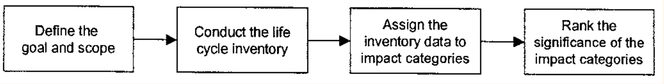
The Building Life-Cycle Cost software from the National Institute of Standards and Technology (NIST) provides economic analysis of capital investments, energy, and operating costs of buildings, systems, and components. The software includes the means to evaluate costs and benefits of energy conservation and complies with ASTM standards related to building economics and Federal Energy Management Program requirements.

Accepted methods of performing life cycle cost analyses of buildings assume a 20-year life with the building maintaining 80% of its residual value at the end of this time period. Buildings actually last hundreds of years if they are not torn down due to obsolescence. Sustainability practitioners advocate the foundation and shell of new buildings be designed for a service life of 200 to 300 years. Allowing extra capacity in the columns and floors for extra floors and floor loads and extra capacity in roofs for roof-top gardens adds to the building's long term flexibility.

On the other end of the spectrum, real estate speculators plan for a return on investment in 7 years and generally do not buy into the life cycle cost approach. Similarly minimum code requirements for energy conserving measures in the building shell are generally for 5 years, meaning initial insulation levels pay for themselves in 5 years. Since it is difficult and costly to add more insulation to the building shell after it has been constructed, the 5-year payback for insulation is not consistent with the life cycle cost associated with 100 year use of buildings.

Advanced building design guidelines from the New Buildings Institute (www.NewBuildings.org), American Society for Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) (www.ASHRAE.org), and others specify insulation levels for those who want to build cost effective buildings above minimum code levels. Alternatively, thermal mass and insulation can be included in the life cycle cost analysis to determine cost-effective levels. However, this requires whole building energy analyses to determine annual costs to heat and cool the building. Economic levels of insulation depend on the climate, location, and building type.

Figure 1

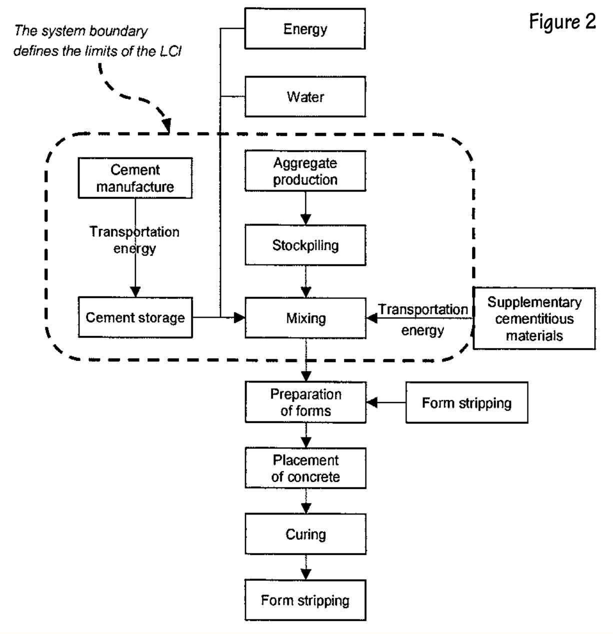


Environmental life cycle inventory and life cycle assessment

A *life cycle assessment* (LCA) is an environmental assessment of the life cycle of a product. An LCA looks at all aspects of a product life cycle — from the first stages of harvesting and extracting raw materials from nature, to transforming and processing these raw materials into a product to, using the product and ultimately recycling it or disposing of it back into nature. An LCA consists of the four phases shown in Fig. 1.

The LCA of a building is necessary to evaluate the full environmental impact of a building over its life. Green buildings rating systems, models such as BEES (www.bfrl.nist.gov/oae/software/bees.html), and programs that focus only on recycled content or renewable resources provide only a partial snapshot of the environmental impact a building can leave. An LCA of a building includes environmental effects due to:

- Extraction of materials and fuel used for energy.
- Manufacture of building components.
- Transportation of materials and components.
- Assembly and construction.
- Operation including energy consumption, maintenance, repair, and renovations.
- Demolition, disposal, recycling, and reuse of the building at the end of its functional or useful life.



A full set of effects includes land use, resource use, climate change, health effects, acidification, and toxicity.

An LCA involves a time consuming manipulation of large quantities of data. A model such as SimaPro (www.pre.nl/g) provides data for common building materials and options for selecting LCA impacts. The Portland Cement Association (PCA) (www.concrete.org) publishes reports with life cycle inventory (LCI) data on cement and concrete. All models require a separate analysis of annual heating, cooling and other occupant loads using a program such as DOE-2 (http://simulationresearchLBL.gov) or Energy Plus (www.EnergyPlus.gov).

An LCI is the first stage of an LCA. An LCI accounts for all the individual environmental flows to and from a product throughout its life cycle. It consists of the materials and energy needed to make and use a product and the emissions to air, land, and water associated with making and using that product.

Several organizations have proposed how an LCA should be conducted. Organizations such as the International Organization for Standardization (ISO) (www.ISO.org), the Society of Environmental Toxicology and Chemistry (SETAC), (www.SETAC.org), and the United States Environmental Protection Agency (US EPA), (www.EPA.gov), have documented standard procedures for conducting an LCA. These procedures are generally consistent with each other: they are all scientific, transparent, and repeatable.

LCI Boundary. The usefulness of an LCA or LCI depends on where the boundaries of a product are drawn. A common approach is to consider all the environmental flows from cradle-to-cradle. For example, the system boundary in Fig. 2 shows the most significant processes for precast concrete operations. It includes most of the inputs and outputs associated with producing concrete — from extracting raw material to producing mixed concrete ready for placement in forms. The system boundary also includes the upstream profile of manufacturing cement, as well as quarrying and processing aggregates, and transporting cement, fly ash, and aggregates to the concrete plant. Energy and emissions associated with transporting the primary materials from their source to the concrete plant are also included in the boundary. It does not include, however, upstream profiles of fuel, electricity, water, or supplementary cementitious materials. This LCI also does not include form preparation, placing the concrete in the formwork, curing, and stripping. A complete precast concrete LCI would include all these steps.

An upstream profile can be thought of as a separate LCI that is itself an ingredient to a product. For example, the upstream profile of cement is essentially an LCI of cement, which can be imported into an LCI of concrete. The LCI of concrete itself can then be imported into an LCI of a product, such as an office building.

To get the most useful information out of an LCI, precast concrete should be considered in context of its end-use. For example, in a building, the environmental impact of the building materials is usually dwarfed by the environmental effects associated with building operations such as heating, ventilating, cooling, and lighting.

The LCI of materials generally do not consider embodied energy and emissions associated with construction of manufacturing plant equipment and buildings, nor the heating and cooling of such buildings. This is generally acceptable if their materials, embodied energy and associated emissions account for less than 1% of those in the process being studied. For example, the SETAC guidelines indicate that inputs to a process do not need to be included in an LCI if (i) they are less than 1% of the total mass of the processed materials or product, (ii) they do not contribute significantly to a toxic emission, and (iii) they do not have a significant associated energy consumption.

Concrete and concrete products LCI

The data gathered in an LCI is voluminous by nature and does not lend itself well to concise summaries; that is the function of the LCA. The data in typical LCI reports are often grouped into three broad categories: materials, energy, and emissions. These LCI data do not include the upstream profiles of *supplementary cementitious materials* (such as fly ash, silica fume, etc.) or energy sources (such as fuel and electricity).

Raw Materials. Approximately 1.6 lb (0.73kg) of raw materials, excluding water, are required to make 1 lb (0.45kg) of cement.[6,7] This is primarily due to the *calcination* of limestone. In addition to the mixture water, the LCI assumes that precast concrete consumes 17.5 gallon/yd^3 (85 l/m^3) of water for washout of the mixer and equipment used to transfer concrete to molds.

Solid waste from precast concrete plants is insignificant. Waste is about 2.5% of the mass of concrete used in production. About 95% of this waste is further beneficially reused through crushing and recycling, resulting in about 0.2 pcf (3 kg/m^3) (about 0.1%) of actual waste.

Fuel and Energy. The amount of energy required to manufacture or produce a product can be shown in units of energy, such as joules or Btu's, or as amounts of fuel or electricity. Embodied energy per unit volume of concrete is primarily a function of the cement content of the mixture. For example, cement manufacturing accounts for about 80% of total energy in a 5,000 psi (35MPa) concrete mixture. Energy used in operations at the concrete plant contributes close to 10%, while aggregate processing and transportation each contribute about 5%.

The embodied energy of a concrete mixture increases in direct proportion to its cement content. Therefore, the embodied energy of concrete is sensitive to the cement content of the mixture and to the assumptions about LCI energy data in cement manufacturing.

Replacing cement with supplementary cementitious materials, such as slag cement or silica fume, has the effect of lowering the embodied energy of the concrete. Fly ash, slag cement, and silica fume do not contribute to the energy and emissions embodied in the concrete (except for the small energy

6 Marceau, M.L., Nisbet, M.A., and VanGeem, M.G., "Life Cycle Inventory of Portland Cement Manufacture," PCA R&D Serial No. 2095b, Portland Cement Association, Skokie, Illinois, 2005. www.cement.org

7 Nisbet, M.A., Marceau, M.L., and VanGeem, M.G., "Environmental Life Cycle Inventory of Portland Cement Concrete," PCA R&D Serial No. 2095a, Portland Cement Association, Skokie, Illinois, 2002.

contributions due to slag granulation/grinding, which is included).[8] These products are recovered materials from industrial processes (also called post-industrial recycled materials) and if not used in concrete would use up valuable landfill space. With a 50% slag cement replacement for portland cement in a 5,000 psi (35 MPa) mixture, embodied energy changes from 2.3 to 1.5 GJ/m^3 (1.7 to 1.1 MBtu/yd^3), a 34% reduction. Fly ash or slag cement replacement of portland cement can also significantly reduce embodied emissions. For instance, a 45% carbon dioxide emissions reduction is achievable with 50% substitution of slag for portland cement in a 7,500 psi (50 MPa) precast concrete mixture. Certain aesthetic (color) and stripping time restrictions apply when using supplementary cementitious materials.

Embodied energy of reinforcing steel used in concrete is relatively small because it represents only about a 1% of the weight in a unit of concrete and it is manufactured mostly from recycled scrap metal. Reinforcing steel has over 90% recycled content according to the Concrete Reinforcing Steel Institute (www.crsi.org) The process for manufacturing reinforcing bars from recycled steel uses significant energy and should be considered if the reinforcing bar content is more than 1% of the weight of the concrete.

It is assumed that at a typical site and in a precast concrete plant, concrete production formwork is reused a number of times through the repetitious nature of work, so its contribution to an LCI or LCA is negligible. Steel and wood formwork is generally recycled at the end of its useful life.

When looking at a complicated product, such as an office building, the categories of fuel and energy are considered. However, depending on the life span of the building, the magnitude of energy use due to operations can be quite large. Building energy-use, including heating, cooling, ventilating, and lighting, is generally 90 to 95% of life cycle energy-use. This means that the office building life cycle energy is not sensitive to variations in cement manufacturing, concrete production, or transportation. The embodied energy of the material comprising a building is relatively minor compared to the building life cycle energy usage. The building life cycle energy is primarily a function of climate and building type, not concrete content.

Emissions to Air. The greatest amount of particulate matter (dust) comes from cement manufacturing and aggregate production. The single largest contributor to particulate emissions in both cement manufacturing and aggregate production is quarry operations (quarry operations include blasting, haul roads, unloading, and stockpiling). In cement manufacture, quarry operations account for approximately 60% of total particulate emissions. In aggregate production, quarry operations are responsible for approximately 90% of particulate emissions. Approximately 30% of the particulate emissions associated with concrete production are from aggregate production and approximately 60% are embodied in the cement. However, particulate emissions from quarries are highly variable and sensitive to how dust is managed on haul roads and in other quarry operations.

The amounts of carbon dioxide (CO_2) and other combustion gases associated with concrete production are primarily a function of the cement content in the mixture designs. Emissions of CO_2 increase in approximately a one-to-one ratio with the cement content of concrete. That is, for every additional pound of cement per cu yd of concrete, there will be an increase in CO_2 emissions by approximately 1 lb (0.45kg). Because of the CO_2 emissions from calcination and from fuel combustion in cement manufacture, the cement content of the concrete mixture accounts for about 90% of the CO_2 emissions associated with concrete production. Thus, concrete LCI results are significantly influenced by the cement content of the concrete mixture and the basis of the CO_2 data in the cement LCI.

8 Marceau, M.L., Gajda, J., and VanGeem, M.G., "Use of Fly Ash in Concrete: Normal and High Volume Ranges," PCA R&D Serial No. 2604, Portland Cement Association, Skokie, Illinois, 2002.

Table 2 Some Impact Categories for Performing a Life Cycle Assessment.

Bulk waste	Global warming potential	Production capacity of drinking water
Carcinogens	Hazardous waste	Production capacity of irrigation water
Climate change	Human toxicity, air	Radiation
Crop growth capacity	Human toxicity, soil	Radioactive waste
Depletion of reserves	Human toxicity, water	Respiratory inorganics
Ecotoxicity soil, chronic	Land use	Respiratory organics
Ecotoxicity water, acute	Life expectancy	Severe morbidity and suffering
Ecotoxicity water, chronic	Morbidity	Severe nuisance
Eutrophication	Nuisance	Soil acidification
Fish and meat production	Ozone depletion	Species extinction
Fossil fuels	Photochemical smog	Wood growth capacity

The fact that cement manufacturing accounts for approximately 70% of fuel consumption per unit volume of concrete indicates that the amounts of combustion gases, sulfur dioxide (SO_2), and nitrous oxides (NO_x), are sensitive to cement content of the mixture.

Cement kiln dust is a waste product of the cement manufacturing process and can be used to help maintain soil fertility. An industry-weighted average of 94 lb of cement kiln dust is generated per ton (39 kg per metric tonne) of cement. Of this about 75 lb (31 kg) are land-filled and about 19 lb (8 kg) are recycled in other operations.

Most emissions to air from the life cycle of an office building come from the use of heating and cooling equipment, not from the cement or concrete.

Life cycle impact assessment

In the next phase of analysis, the LCI data is assigned to impact categories and the relative effect of the inventory data within each impact category is weighted. Among LCA practitioners, this phase is called life cycle impact assessment, and it consists of category definition, classification, and characterization. Category definition consists of identifying which impact categories are relevant to the product being studied. Classification consists of grouping related substances into impact categories. For example, the gases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) contribute to climate change; therefore, they can be grouped together in an impact category called climate change. There are many impact categories to choose from. The categories chosen depend on the goal and scope of the LCA. Table 2 lists some possible impact categories.

According to ISO 14041, the only mandatory step in life cycle impact assessment is characterization. In characterization, weighting factors are assigned according to a substance's relative contribution to the impact category. In terms of global warming potential, one pound of CH_4 is 20 times more potent than one pound of CO_2, and one pound of N_2O is 320 times more potent than one pound of CO_2. Therefore, in assessing the potential for global warming, CO_2 is assigned a weighting factor of 1, CH_4 a factor of 20, and N_2O a factor of 320. It is important to consider that there is no scientific basis for comparing across impact categories. For example, global warming potential cannot be compared with potential ozone depletion.

The methodology for life cycle impact assessment is still being developed, and there is no general and widespread practice at this time or an agreement on specific methodologies. As a result, it is common to use several of the available methods to perform the life cycle impact assessment.

Green Building Rating Systems

LCI and LCA are valid methods of assessing sustainability, but they are a complex accounting of all materials, energy, emissions, and waste; and their impacts. Conversely, green building rating systems have gained popularity because they are comparatively easy to use and straightforward. Focus groups have shown that consumers are interested in furthering sustainability but are unable to define it. Labeling a green building with LEED, Energy Star or Green Globes certification sends the message the building is green without having to perform a complex LCI or LCA.

LEED

The Leadership in Energy and Environmental Design (LEED) green building rating system is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. LEED is both a *standard* for certification and a *design guide* for sustainable construction and operation. As a standard, it is predominantly performance-based, and as a design guide, it takes a whole-building approach that encourages a collaborative, integrated design and construction process. LEED is administered by the U.S. Green Building Council (USGBC, www.usgbc.org). LEED-NC[9] is a document that applies to new construction and major renovation projects and is intended for commercial, institutional, and high-rise residential new construction and major renovation.

9 "LEED for New Construction," Version 2.2, United States Green Building Council, October 2005, www.USGBC.org.

Essentially, LEED is a point-based system that *provides a framework for assessing building performance meeting sustainability goals.* Points are awarded when a specific intent is met, and a building is LEED certified if it obtains at least 26 points out of a total availability of 69 points (LEED-NC). The points are grouped into five categories: (i) sustainable sites, (ii) water efficiency, (iii) energy and atmosphere, (iv) materials and resources, and (v) indoor environmental quality. The more points earned, the "greener" the building. Silver, gold, and platinum ratings are awarded for at least 33, 39, and 52 points, respectively.

Appropriate use of precast concrete can help a building earn up to 23 points; 26 are required for LEED certification. Using concrete can help meet minimum energy requirements, optimize energy performance, and increase the life of a building. The constituents of concrete can be recycled materials, and concrete itself can also be recycled. Concrete and its constituents are usually available locally. These attributes of concrete, recognized in the LEED rating system, can help lessen a building's negative impact on the natural environment. Points applicable to precast concrete are summarized in Table 3 and explained throughout this chapter. Points must be documented according to LEED procedures to be earned. The USGBC website contains a downloadable "letter template" that greatly simplifies the documentation requirements for LEED.

The buildings in the corporate campus for CH2M Hill in Englewood, CO are framed with a total precast concrete system, including precast

Table 3 – LEED* Project Checklist: Precast Concrete Potential Points.

LEED CATEGORY	CREDIT OR PREREQUISITE	POINTS AVAILABLE
Sustainable Sites	Credit 5.1: Site Development, Protect or Restore Habitat	1
Sustainable Sites	Credit 5.2: Site Development, Maximize Open Space	1
Sustainable Sites	Credit 7.1: Heat Island Effect, Non-Roof	1
Energy and Atmosphere	Prerequisite 2: Minimum Energy Performance	—
Energy and Atmosphere	Credit 1: Optimize Energy Performance	1-10
Materials and Resources	Credit 1.1: Building Reuse, Maintain 75% of Existing Shell	1
Materials and Resources	Credit 1.2: Building Reuse, Maintain 95% of Existing Shell	1
Materials and Resources	Credit 2.1: Construction Waste Management, divert 50% by weight or volume	1
Materials and Resources	Credit 2.2: Construction Waste Management, divert 75% by weight or volume	1
Materials and Resources	Credit 4.1: Recycled Content, the post-consumer recycled content plus one-half of the pre-consumer content constitutes at least 10% (based on cost) of the total value of the materials in the project	1
Materials and Resources	Credit 4.2: Recycled Content, the post-consumer recycled content plus one-half of the pre-consumer content constitutes at least 20% (based on cost) of the total value of the materials in the project	1
Materials and Resources	Credit 5.1: Local/Regional Materials, Use a minimum of 10% (based on cost) of the total materials value	1
Materials and Resources	Credit 5.2: Local/Regional Materials, Use a minimum of 20% (based on cost) of the total materials value	1
Indoor Environmental Quality	Credit 3.1: Construction Indoor Air Quality Management Plan, During Construction	1
Innovation and Design Process	Credit 1.1: Use of high volume supplementary cementitious materials. Apply for other credits demonstrating exceptional performance	1†
Innovation and Design Process	Credits 1.2: Apply for other credits demonstrating exceptional performance	1†
Innovation and Design Process	Credits 1.3: Apply for other credits demonstrating exceptional performance	1†
Innovation and Design Process	Credits 1.4: Apply for other credits demonstrating exceptional performance	1†
Innovation and Design Process	Credit 2.1: LEED Accredited Professional	1
	PROJECT TOTALS	**23**

*LEED: Leadership in Energy and Environmental Design.

† Up to 4 additional points can be earned, must be submitted and approved (not included in total).

Note: Scoring System: Certified, 26-32 points; Silver, 33-38 points; Gold, 39-51 points; and Platinum, 52-69 points.

Fig. 3. All three total precast concrete buildings are LEED certified. CH2M Hill World Headquarters, Englewood, CO Architect: Barber Architecture.

concrete shearwalls, double tees, inverted tee beams and loadbearing exterior walls, Fig. 3. The buildings are some of the first total precast concrete office buildings LEED-certified.

The Arizona Departments of Administration and Environmental Quality (ADOA & ADEQ) project is a 500,000 sq. ft (46,450m^2), single contract project consisting of two architectural precast concrete clad office buildings and two precast/prestressed concrete parking structures, Fig. 4(a and b). The Arizona Department of Administration (ADOA) is an 185,000 sq. ft (17,187m^2), 4-story office building with an 800 space parking structure. The Arizona Department of Environmental Quality (ADEQ) is a 6-story, 300,000 sq ft (27,870m^2) office building with a 1,000 space parking structure. Both buildings are registered with the United States Green Building Council's LEED program.

The 27-story LEED Platinum certified existing office building in downtown Sacramento, CA, has precast concrete panels with punched openings, Fig. 5. The windows were pre-mounted, glazed, and caulked at the plant after casting. The precast concrete panels on the south and west sides of the building have integral sun shades with a 1 ft

Fig. 4(a).
Arizona Department of Administration (ADOA), Phoenix, Arizona; Architect: Opus Architects and Engineers; Photos: Alex Stricker, Stricker LLC.

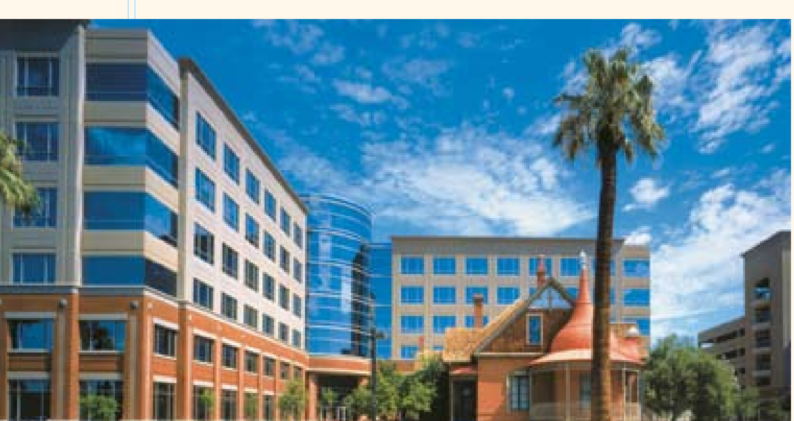


Fig. 4(b).
Arizona Department of Environmental Quality (ADEQ), Phoenix, Arizona;
Architect: Opus Architects and Engineers.

Fig. 5. First LEED Platinum certified existing high-rise. The Joe Serna Jr. California EPA Headquarters Sacramento, CA; Architect: A. C. Martin Partners.

Fig. 6. LEED registered mixed-use development. Bookends, Greenville, SC; Architect & Photo: Johnston Design Group, LLC.

(3m) overhang. The building's sustainable features can be grouped into three general categories; air quality; energy conservation and management; and recycling and recycled products.

The project in Fig. 6 is a USGBC LEED registered mixed-use development featuring street level retail and residential condominiums. The structure's framing consists of 7 in. (175mm) and 12 in. (300mm) loadbearing walls which support double tees and flat slabs. The precast concrete walls have a combination of sandblasted and cast-in thin brick finishes. The façade of this one building has four distinct architectural styles to appear as four separate and unique buildings. Mechanical, electrical and plumbing (MEP) accessories, such as conduit boxes, and mechanical and electrical embeds and openings were cast integrally into the panels.

Energy Star

Energy Star (www.energystar.gov) is a government/industry partnership designed to help businesses and consumers protect the environment and save money through energy efficiency. Energy Star labeling is available for office equipment such as computers and monitors, appliances such as refrigerators, and residential and commercial buildings. Buildings that meet certain criteria and achieve a rating of 75 or better in the Energy Star program are eligible to apply for the Energy Star (see www.energystar.gov).

The rating consists of a score on a scale of 1 to 100. The score represents a benchmark energy performance. For example, buildings that score 75 or greater are among the United States' top 25%. In addition, buildings must maintain a healthy and productive indoor environment.

At the present time, five commercial-building types are eligible for the Energy Star certification: offices, K–12 schools, supermarket/grocery stores, hotel/motels, and acute care/children's hospitals. These building types are broken down further into a number of specific occupancies. For example, office buildings include general office, bank branch, courthouse, and financial center.

Demonstrating conformance is accomplished through a web-based software tool called Portfolio Manager (www.energystar.gov). The program hinges on the unbiased opinions of a professional engineer who must visit the building and verify that data entered about the building are correct.

Through the Portfolio Manager, the engineer inputs the building location and energy consumption and describes its physical and operating characteristics. Operating characteristics include such things as average weekly occupancy hours, number of occupants, and number and types of equipment such as personal computers, refrigeration cases, cooking facilities, and laundry facilities. Energy consumption is based on all sources of energy used per month. In addition to energy performance, the engineer is responsible for demonstrating compliance with industry standards on thermal comfort, indoor air quality, and illumination.

The professional engineer assessing the building is expected to give an opinion about the capability of the building to provide acceptable thermal environmental conditions per ASHRAE Standard 55[10] and its capability to supply acceptable outdoor air per ASHRAE Standard 62[11] (see www.ashrae.org). The engineer is also expected to give an opinion about the capability of the building to provide minimum illumination levels per the Illuminance Selection Procedure in the *IESNA Lighting Handbook*[12] (see www.iesna.org).

In addition, Portfolio Manager has the capability to manage energy data, analyze trends in energy performance (to make budget and management decisions regarding investments in energy-related projects), verify building performance, and track the progress of building improvements.

10 American Society of Heating, Refrigerating, and Air-Conditioning Engineers, *ASHRAE Standard 55—Thermal Environmental Conditions for Human Occupancy*, Atlanta, GA, www.ASHRAE.org.

11 American Society of Heating, Refrigerating, and Air-Conditioning Engineers, *ASHRAE Standard 62.1-2004—Ventilation for Acceptable Indoor Air Quality*, Atlanta, GA.

12 Illuminating Engineering Society of North America, *Illuminating Engineering Society of North America Lighting Handbook*, 9th edition. December 2000, New York, NY, www.IESNA.org.

Green Globes

Green Globes is an online, point-based green building rating system administered by the Green Building Initiative (www.thegbi.org). Many of the points are similar to those in LEED, though the point structure differs; Green Globes has 1000 total points compared with the 69 for LEED-NC. Certification for Green Globes is available at 35% achievement of the total applicable points compared with LEED at 38% (26 points). It is easier to obtain certification in Green Globes, however, because points that are not applicable to the building are subtracted from the total number of applicable points, so a higher percentage is obtained for those criteria that are met.

Durability

A key factor in building reuse is the durability of the original structure. Precast concrete panels provide a long service life due to their durable and low-maintenance concrete surfaces. A precast concrete shell can be left in place when the building interior is renovated. Annual maintenance should include inspection and, if necessary, repair of sealant material.

Modular and sandwich panel construction with concrete exterior and interior walls provide long-term durability inside and out. Precast concrete construction provides the opportunity to refurbish the building should the building use or function change, rather than tear it down and start anew. These characteristics of precast concrete make it sustainable in two ways: it avoids contributing solid waste to landfills and it reduces the depletion of natural resources and production of air and water pollution caused by new construction.

LEED Materials Credit 1 in Building Reuse. *The purpose of this credit is to leave the main portion of the building structure and shell in place when renovating, thereby conserving resources and reducing wastes and environmental effects of new construction. The building shell includes the exterior skin and framing but excludes window assemblies, interior partition walls, floor coverings, and ceiling systems. This credit should be obtainable when renovating buildings with a precast concrete façade, because concrete generally has a long life. This is worth 1 point if 75% of the existing building structure/shell is left in place and 2 points if 100% is left in place*

Corrosion resistance

The inherent alkalinity of concrete results in a system of concrete and reinforcing steel that does not corrode in most environments. The most common reason for surface spalling of concrete in buildings is corrosion of reinforcing steel due to inadequate concrete cover. Precast concrete offers increased resistance to this type of spalling because reinforcement and concrete are placed in a plant, with more quality control than cast-in-place construction. This reduces variations in concrete cover over reinforcing steel and reduces the likelihood of inadequate cover.

Inedible

Vermin and insects cannot destroy concrete because it is inedible. Some softer construction materials are inedible but still provide pathways for insects. Due to its hardness, vermin and insects will not bore through concrete.

Resistant to Natural Disasters

Concrete is resistant to wind, hurricanes, floods, and fire. Properly designed precast concrete is resistant to earthquakes and provides blast protection for occupants.

Fire resistance

Precast concrete offers noncombustible construction that helps contain a fire within boundaries. As a separation wall, precast concrete helps to prevent a fire from spreading throughout a building or jumping from building to building. During wild fires, precast concrete walls help provide protection to human life and the occupant's possessions. As an exterior wall, concrete that endures a fire can often be reused when the building is rebuilt.

The fire endurance of concrete can be determined based on its thickness and type of aggregate. Procedures for determining fire endurance of building materials are prescribed by ASTM E119. Concrete element fire endurance is generally controlled by heat transmission long before structural failure, whereas other construction materials fail by heat transmission when collapse is imminent. So, a 2-hour fire endurance for a precast concrete wall will most likely mean the wall gets hot (experiences an average temperature rise of 250 °F [140 °C] or 325°F [180°C] at any one point) whereas a 2-hour fire endurance of a frame wall means the wall is likely near collapse. Concrete helps contain a fire even if no water supply is available, whereas sprinklers rely on a problematic water source.

Tornado, hurricane, and wind resistance

Precast concrete can be economically designed to resistant to tornadoes, hurricanes, and wind. Hurricanes are prevalent in coastal regions. Tornadoes are particularly prevalent in the path of hurricanes and in the central plains of the U.S.

Case Study: In 1967, a series of deadly tornadoes hit northern Illinois. Damages at the time were estimated at $50 million, with 57 people were killed and 484 homes were destroyed. Two precast/prestressed concrete structures, a grocery store and a high school, were in the direct path of two of the tornadoes, which struck almost simultaneously. Repairs to the structural system of the grocery store (limited to a single crack in the flanges and stem of a beam subjected to uplift) were less than $200. In the high school, structural damage was limited to the flange of one double-tee member (24 ft [7.5 m] of which was broken off by flying debris) and damaged concrete diaphragm end closures.

Flood resistance

Concrete is not damaged by water; concrete that does not dry out continues to gain strength in the presence of moisture. Concrete submerged in water absorbs very small amounts of water even over long periods of time, and this water does not damage the concrete. Conversely, building materials such as wood and gypsum wallboard can absorb large quantities of water and cause moisture related problems. In flood-damaged areas, the concrete buildings are often salvageable.

Concrete will only contribute to moisture problems in buildings if it is enclosed in a building system that does not let it dry out, trapping moisture between the concrete and other building materials. For instance, impermeable vinyl wall coverings in hot and humid climates will act as a vapor retarder and

Fig. 7 High-reflecting (usuallly light-colored) surfaces help mitigate urban heat islands.

Cape Coral City Hall
Cape Coral, Florida
Architect & Photo: Spillis Candela/DMJM.

moisture can get trapped between the concrete and wall covering. For this reason, impermeable wall coverings (such as vinyl wallpaper) should not be used in hot and humid climates.

Earthquake resistance

Precast concrete can be designed to be resistant to earthquakes. Earthquakes in Guam, United States (Richter Scale 8.1); Manila, Philippines (Richter Scale 7.2); and Kobe, Japan (Richter Scale 6.9), have subjected precast concrete buildings to some of nature's deadliest forces. Appropriately designed precast concrete framing systems have a proven capacity to withstand these major earthquakes.

Case study: The 1994 earthquake in Northridge, California (Richter Scale 6.8), was one of the costliest natural disasters in U.S. history. Total damage was estimated at $20 billion. Most engineered structures within the affected region performed well, including structures with precast concrete components. In particular, no damage was observed in precast concrete cladding due to either inadequacies of those components, or inadequacies of their connections to the building's structural systems, and no damage was observed in the precast concrete components used for the first floor or first-floor support of residential housing. It should be noted that parking structures with large plan areas—regardless of structural system—did not perform as well as other types of buildings.

Weather Resistance

High humidity and wind-driven rain

Precast concrete is resistant to wind-driven rain and moist, outdoor air in hot and humid climates. Concrete is impermeable to air infiltration and wind-driven rain. Moisture that enters a precast concrete building must come through joints between precast concrete elements. Annual inspection and repair of joints will minimize this potential. More importantly, if moisture does enter through joints, it will not damage the concrete.

Good practice for all types of wall construction is to have permeable materials that breathe (are allowed to dry) on at least one surface and not encapsulate concrete between two impermeable surfaces. Concrete breathes and will dry out. Therefore, as long as a precast concrete wall is allowed to breathe on at least one side and is not covered by an impermeable material on both wall surfaces, the potential for moisture problems within the wall system is minimal.

More information on condensation potential and moisture control in precast concrete walls is covered in Designers Notebook *Energy Conservation and Condensation Control*, DN-15.

Ultraviolet resistance

The ultraviolet (UV) range of solar radiation does not harm concrete. Using non-fading colored pigments in concrete retains the color in concrete long after paints have faded due to the sun's effects. Precast concrete is ideal for using pigments because the controlled production allows for replication of color for all panels for a project (Figs. 3 and 4).

Mitigating the Urban Heat Island Effect

Precast concrete provides reflective surfaces that minimize the urban heat island effect. Cities and urban areas are 3 to 8 °F (2 to 4 °C) warmer than surrounding areas due to the *urban heat island effect*. This difference is attributed to heat absorption of buildings and pavements that have taken the place of vegetation. Trees provide shade that reduces temperatures at the surface. Trees and plants provide transpiration and evaporation that cool the surfaces and air surrounding them. Research has shown the average temperature of Los Angeles has risen steadily over the past half century, and is now 6 to 7 °F (3 to 4 °C) warmer than 50 years ago.[13]

Warmer surface temperatures

Urban heat islands are primarily attributed to horizontal surfaces, such as roofs and pavements, that absorb solar radiation. In this context, pavements include roads, streets, parking lots, driveways, and walkways. Vertical surfaces, such as the sides of buildings, also contribute to this effect. Using materials with higher albedos, such as concrete, will reduce the heat island effect, save energy by reducing the demand for air conditioning, and improve air quality (Fig. 7).

Studies indicate people will avoid using air-conditioning at night if temperatures are less than 75 °F (24 °C). Mitigating the urban heat island effect to keep summer temperatures in cities less than that temperature at night has the potential to save large amounts of energy by avoiding air-conditioning use.

13 Heat Island Group Home Page, eetd.lbl.gov/HeatIsland/.

Smog

Smog levels have also been correlated to temperature rise. Thus, as the temperature of urban areas increases, so does the probability of smog and pollution. In Los Angeles, the probability of smog increases by 3% with every degree Fahrenheit of temperature rise. Studies for Los Angeles and 13 cities in Texas have found that there are almost never any smog episodes when the temperature is below 70 °F (21 °C). The probability of episodes begins at about 73 °F (23 °C) and, for Los Angeles, exceeds 50% by 90 °F (32 °C). Reducing the daily high in Los Angeles by 7 °F (4 °C) is estimated to eliminate two-thirds of the smog episodes.

Smog and air pollution are the main reasons EPA mandates expensive, clean fuels for vehicles and reduced particulate emissions from industrial facilities such as cement and asphalt production plants. The EPA now recognizes that air temperature is as much a contributor to smog as nitrogen oxide (NO_x) and volatile organic compounds (VOCs). The effort to reduce particulates in the industrial sector alone costs billions of dollars per year, whereas reduction in smog may be directly related to the reflectance and colors of the infrastructure that surround us. Installing low-albedo roofs, walls, and pavements is a cost-effective way to reduce smog.

Albedo (solar reflectance)

Albedo, which in this case is synonymous with solar reflectance, is the ratio of the amount of solar radiation reflected from a material surface to the amount shining on the surface. Solar radiation includes the ultraviolet as well as the visible spectrum. Albedo is measured on a scale not reflective (0.0) to 100% reflective (1.0). Generally, materials that appear to be light-colored in the visible spectrum have high albedo and those that appear dark-colored have low albedo. Because reflectivity in the solar radiation spectrum determines albedo, color in the visible spectrum is not always a true indicator of albedo.

Surfaces with lower albedos absorb more solar radiation. The ability to reflect infrared light is of great importance because infrared light is most responsible for heating. On a sunny day when the air temperature is 55 °F (13 °C), surfaces with dark acrylic paint will heat up to 90 °F (32 °C) more than air temperatures, to 145 °F (63 °C). Light surfaces, such as white acrylic, will heat up to 20 °F (11 °C) more, to a temperature of 75 °F (24 °C). The color and composition of the materials greatly affect the surface temperature and the amount of absorbed solar radiation. The effect of albedo and solar radiation on surface temperatures is referred to as the sol-air temperature and can be calculated.

Traditional portland cement concrete generally has an albedo or solar reflectance of approximately 0.4, although values can vary; measured values are reported in the range of 0.4 to 0.5. The solar reflectance of new concrete is greater when the surface reflectance of the sand and cementitious materials in the concrete are greater. Surface finishing techniques also have an effect, with smoother surfaces generally having a higher albedo. For concrete elements with "white" portland cement, values are reported in the range of 0.7 to 0.8. Albedo is most commonly measured using a solar-spectrum reflectometer (ASTM C 1549)[14] or a pyranometer (ASTM E 1918).[15]

14 American Society for Testing and Materials, ASTM C 1549, "Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer," Conshohocken, PA, www. ASTM.org.

15 American Society for Testing and Materials, ASTM E 1918, "Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field," West Conshohocken, PA.

Emittance

In addition to albedo, the material's surface emittance affects surface temperature. While albedo is a measure of the solar radiation reflected away from the surface, surface emittance is the ability of the material to emit, or "let go of" heat. A white surface exposed to the sun is relatively cool because it has a high reflectivity and a high emittance. A shiny metal surface is relatively warm because it has a low emittance, even though it has a high albedo. The emittance of most non-reflecting (non-metal) building surfaces such as concrete is in the range of 0.85 to 0.95. The emittance of aluminum foil, aluminum sheet, and galvanized steel, all dry and bright, are 0.05, 0.12, and 0.25, respectively.

Moisture

Moisture in concrete helps to cool the surface by evaporation. Concrete when placed has a moisture content of 100% relative humidity. The concrete surface gradually dries over a period of one to two years to reach equilibrium with its surroundings. Concrete surfaces exposed to rain and snow will continue to be wetted and dried. This moisture in the concrete surface will help to cool the concrete by evaporation whenever the vapor pressure of the moisture in the surface is greater than that of the air. In simpler terms, when the temperature and relative humidity of the air are greater than that just beneath the concrete surface, the concrete will dry and cool somewhat by evaporation.

The albedo of concrete decreases when the surface is wet. Consequently, albedo is lower when concrete is relatively new and the surface has not yet dried, and when the concrete becomes wet. The albedo of new concrete generally stabilizes within two to three months.

LEED Sustainable Sites Credit 7.1 on Heat Island Effect, Non-Roof. *The intent of this credit is to reduce heat islands. The requirements are met by placing a minimum of 50% of parking places underground or covered by a parking structure. Precast concrete parking structures, can be used to help obtain this point. Any roof used to shade or cover parking must meet specified criteria. This credit is worth 1 point.*

Mitigation approaches

One method to reduce the urban heat island effect is to change the albedo of the urban area. This is accomplished by replacing low albedo surfaces with materials of higher albedo. This change is most cost effective when done in the initial design or during renovation or replacement due to other needs. Planting trees for shade near buildings also helps mitigate the urban heat island effect. Shade also directly reduces the air-conditioning load on buildings. Using deciduous trees shades the buildings in the summer and allows the sun to reach the buildings in the winter.

Thermal mass and nocturnal effects

The thermal mass of concrete delays the time it takes for a surface to heat up but also delays the time to cool off. For example, a white non-concrete roof will get warm faster than concrete during the day, but will also cool off faster at night. Concrete surfaces are often warmer than air temperatures in the evening hours. Concrete's albedo and thermal mass will help mitigate heat island effects during the day but may contribute to the nocturnal heat island effect. The moisture absorbed by concrete during rain events helps reduce the daytime and nocturnal heat island effect when it evaporates. The challenge is to use concrete to mitigate heat islands while keeping evening temperatures as cool as possible.

Environmental Protection

Radiation and toxicity

One goal of sustainability is to reduce radiation and toxic materials; concrete provides an effective barrier against radiation and can be used to isolate toxic chemicals and waste materials. Concrete protects against the harmful effects of X-rays, gamma rays, and neutron radiation.

Concrete is resistant to most natural environments; it is sometimes exposed to substances that can attack and cause deterioration. Concrete in some chemical manufacturing and storage facilities must be specifically designed to avoid chemical attack. The resistance of concrete to chlorides is good, and using less permeable concrete can increase the resistance even more. This is achieved by using a low water-to-cementitious materials ratio (around 0.40), adequate curing, and supplementary cementitious materials such as slag cement or silica fume. The best defenses against sulfate attack where this is an issue, are the measures suggested previously, in addition to using cement specially formulated for sulfate environments.

Resistance to noise

Precast concrete walls provide a buffer between outdoor noise and the indoor environment. Because land is becoming scarcer, buildings are being constructed closer together and near noise sources such as highways, railways, and airports. The greater mass of concrete walls can reduce sound penetrating through a wall by over 80% compared to wood or steel frame construction. Although some sound will penetrate the windows, a concrete building is often two-thirds quieter than a wood or steel frame building.

Precast concrete panels also provide effective sound barriers separating buildings from highways or industrial areas from residential areas.

Security and impact resistance

Concrete is often used as a first line of defense against explosions or blasts. Rows of concrete planters or bollards are now positioned in front of most federal buildings such as court houses, office buildings. and other high-security areas. Decorative concrete walls are also used as a primary line of defense to prevent vehicles from coming close to buildings. From a holistic perspective, the barriers may also provide benches and a visual separation between the street and plaza.

Precast Concrete Production

The production of precast concrete has many environmental benefits, including:

1. Less materials are required because precise mixture proportions and tighter tolerances are achievable.
2. Optimal insulation levels can be incorporated into precast concrete sandwich panel walls.
3. Less concrete waste is created because of tight control of quantities of constituent materials.
4. Waste materials are more likely to be recycled because concrete production is in one location.
   a. Gray water often recycled into future mixtures.
   b. Hardened concrete recycled (presently about 5 to 20% of aggregate in precast concrete can be recycled concrete; in the future this could be higher.)
   c. Steel forms and other materials are reused.
5. Less dust and waste is created at the construction site because only needed precast concrete elements are delivered and there is no debris from formwork and associated fasteners—construction sites are cleaner and neater.
6. Fewer trucks and less time are required for construction because concrete is made offsite; this is particularly beneficial in urban areas where minimal traffic disruption is critical.
7. Precast concrete units are normally large components, so greater portions of the building are completed with each activity.
8. Less noise at construction site because concrete is made offsite.

LEED Sustainable Sites Credit 5.1 on Site Development, Protect, or Restore Habitat. *The intent of this credit is to encourage the conservation of natural areas on the site and restore damaged areas. The requirements are met by limiting site disturbance to prescribed distances. Tuck-under parking, such as precast concrete parking structures, can be used to help obtain this credit worth 1 point. Also precast concrete requires minimal site disturbance for erection of panels.*

LEED Sustainable Sites Credit 5.2 on Site Development, Maximize Open Space. *The intent of this credit is to provide a high ratio of open space to development footprint. The requirements are met by limiting the size of the development footprint; specifically, by exceeding the local zoning's open space requirement for the site by 25%. Tuck-under parking, such as precast concrete parking structures, can be used to help obtain this credit worth 1 point.*

Less concrete is generally used in precast concrete buildings than in other concrete buildings because of the optimization of materials. A properly designed precast concrete system will result in smaller structural members, longer spans, and less material used on-site; this translates directly into economic savings, which can also result in environmental savings. Using less materials means using fewer natural resources and less manufacturing and transportation energy—not to mention the avoided emissions from mining, processing, and transporting raw and finished material.

Concrete products can provide both the building structure, and the interior and exterior finishes. Structurally efficient columns, beams, and slabs can be left exposed with natural finishes. Interior and exterior concrete walls offer a wide range of profile, texture, and color options that require little or no additional treatment to achieve aesthetically pleasing results. Exposed ceiling slabs and architectural precast concrete panels are some examples of this environmentally efficient approach. This structure/finish combination reduces the need for the production, installation, maintenance, repair, and replacement of additional finish materials. It also eliminates products that could otherwise degrade indoor air quality. This approach provides durable finishes that are not prone to damage or fire. Exposing the mass of the structure moderates heating and cooling loads.

Constituent materials

Concrete. Concrete is basically a mixture of two components: aggregates and paste. The paste, comprised of portland cement and water, binds the aggregates (usually sand and gravel or crushed stone) into a rocklike mass. The paste hardens because of the chemical reaction of the cement and water.

Fig. 8 [a] Fly ash

Fig. 8 [b] Slag cement

Fig. 8 [c] Silica fume (top) and white silica fume (bottom)

Supplementary cementitious materials and chemical admixtures may also be included in the paste. The absolute volume of cement is usually between 7% and 15% and the water between 14% and 21%.

Portland Cement. Portland cement (hereafter called cement) is made by heating common minerals, primarily crushed limestone, clay, iron ore, and sand, to a white-hot mixture to form clinker. This intermediate product is ground, with a small amount of gypsum, to form a fine gray powder called cement. To trigger the necessary chemical reactions in the kiln, these raw materials must reach about 2700°F (1482°C)–the temperature of molten iron. Although the portland cement industry is energy intensive, the U.S. cement industry has reduced energy usage per ton of cement by 35% since 1972.[16,17]

Carbon dioxide emissions from a cement plant are divided into two source categories: combustion and calcination. Combustion accounts for approximately 35% and calcination 65% of the total CO_2 emissions from a cement manufacturing facility. The combustion-generated CO_2 emissions are related to fuel use. The calcination CO_2 emissions are formed when the raw material is heated and CO_2 is liberated from the calcium carbonate. As concrete is exposed to the air and carbonates, it reabsorbs some of the CO_2 released during calcination. Calcination is a necessary key to cement production. Therefore, the focus of reductions in CO_2 emissions during cement manufacturing is on reducing fuel and energy use.

White portland cement is a true portland cement that differs from gray cement chiefly in color. The manufacturing process is controlled so that the finished product will be white. White portland cement is made of selected raw materials containing negligible amounts of iron and magnesium oxides–the substances that give cement its gray color. White cement is used primarily for architectural purposes in structural walls, precast concrete, and glass fiber reinforced concrete (GFRC) facing panels. Its use is recommended wherever white or colored concrete, grout, or mortar is desired. White portland cement should be specified as white portland cement meeting the specifications of ASTM C 150, Type I, II, III, or V.

Abundant Materials. Concrete is used in almost every country of the world as a basic building material. Aggregates, about 85% of concrete, are generally low-energy, local, naturally occurring sand and stone. Limestone and clay needed to manufacture cement are prevalent in most countries. Concrete contributes to a sustainable environment because it does not use scarce resources. Limestone and aggregate quarries are easily reused. While quarrying is intense, it is closely contained and temporary. When closed, aggregate quarries are generally converted to their natural state or into recreational areas or agricultural uses. In contrast, other material mining operations can be extensive and involve deep pits that are rarely restored, and deforestation can have negative environmental effects.

Fly Ash, Slag Cement, and Silica Fume. Fly ash, slag cement, and silica fume are industrial by-products; their use as a replacement for portland cement does not contribute to the energy and CO_2 effects of cement in concrete. If not used in concrete, these supplementary cementitious materials (SCMs) would use valuable landfill space. Fly ash (Fig. 8 [a]) is a by-product of the combustion of pulverized coal in electric power generating plants. Slag cement (Fig. 8 [b]) is made from iron blast-furnace slag.[18] Silica fume (Fig. 8 [c]) is a by-product from the electric arc furnace used in the production of silicon or ferrosilicon alloy. These types of industrial by-products are considered post-industrial or pre-consumer recycled materials. Fly ash is commonly used at cement replacement levels up to 25%, slag cement up to 60%, and silica fume up to 5 to 7%. When slag cement replaces 50% of the portland cement in a 7500 psi (50 MPa) concrete mixture, greenhouse gas emissions per cu. yd. of concrete are reduced by 45%. Because the cementitious content of concrete is about 15%, these pozzolans typically account for only 2 to 5% of the overall concrete material in buildings.

SCMs may slightly alter the color of hardened concrete. Color effects are related to the color and amount of the material used in concrete. Many SCMs resemble the color of portland cement and therefore have little affect on color of the hardened concrete. Some silica fumes may give concrete a slightly bluish or dark gray tint and tan fly ash may impart a tan color to concrete when used in large quantities. Slag cement and metakaolin (a clay SCM without recycled content) can make concrete lighter. Slag cement can initially impart a bluish or greenish undertone that disappears over time as concrete is allowed to dry.

The optimum amounts of supplementary cementing materials used with portland or blended cement are determined by testing, the relative cost and availability of the materials, and the specified properties of the concrete. When supplementary cementitious materials are used, the proportioned concrete mixture (using the project materials) should be tested to demonstrate that it meets the required concrete properties for the project. Some pozzolans increase curing times, but this is not as great a concern for precast concrete manufacturing as it is in cast-in-place applications where construction schedule has a greater impact.

The durability of products with recycled content materials should be carefully researched during the design process to ensure comparable life cycle performance. There would obviously be a net negative impact if a product offering a 20 to 30% recycled content had only half the expected service life of a product with a lower or no recycled content.

Recycled Aggregates. The environmental attributes of concrete can be improved by using aggregates derived from industrial waste or using recycled concrete as aggregates. Blast furnace slag is a lightweight aggregate with a long history of use in the concrete industry.

Recycled concrete can be used as aggregate in new concrete, particularly the coarse portion. When using the recycled concrete as aggregate, the following should be taken into consideration:

1. Recycled concrete as aggregate will typically have higher absorption and lower specific gravity than natural aggregate and will produce concrete with slightly higher drying shrinkage and creep. These differences become greater with increasing amounts of recycled fine aggregates.

2. Too many recycled fines can also produce a harsh and unworkable mixture. Many transportation departments have found that using 100% coarse recycled aggregate, but only about 10 to 20% recycled fines, works well.[19] The remaining percentage of fines is natural sand.

3. When crushing the concrete (Fig. 9), it is difficult to control particle size distribution,

16 Portland Cement Association, *U.S. and Canadian Labor-Energy Input Survey*, Skokie, IL,www.cement.org.
17 Portland Cement Association, "Report on Sustainable Manufacturing", *2006*,www.cement.org.

18 Slag Cement Association, "Slag Cement and the Environment," Slag Cement in Concrete No. 22, 2003, www.slagcement.org.

19 Portland Cement Association, *Design and Control of Concrete Mixes*, Chapter 5, EB001, 2002, Skokie, IL.

Fig. 9 Crushed concrete from other sources can serve as recycled aggregate. Photo: Portland Cement Association.

meaning that the "aggregate" may fail to meet grading requirements of ASTM C33.[20]

4. The chloride content of recycled aggregates is of concern if the material will be used in reinforced concrete. This is particularly an issue if the recycled concrete is from pavements in northern climates where road salt is freely spread in the winter.
5. The alkali content and type of aggregate in the system is probably unknown, and therefore if mixed with unsuitable materials, a risk of alkali-silica reaction (ASR) is possible.

LEED Materials Credit 4 on Recycled Content. *The requirements of this credit state: "Use materials with recycled content such that post-consumer recycled content plus one-half of the pre-consumer content constitutes at least 10% (based on cost) of the total value of the materials in the project." The percentage is determined by multiplying the price of an item by the percent of recycled materials—on a mass basis—that make up that item. To earn this credit, the project must meet the threshold percentages based on the total of all permanently installed building materials used on the project. Supplementary cementitious materials, such as fly ash, silica fume, and slag cement, are considered pre-consumer. Since the cementitious content of concrete is about 15%, these pozzolans typically account for only 2 to 5% of the overall concrete material in buildings. For this reason, LEED-NC v2.2 allows the recycled content of concrete to be based on the recycled content of the cementitious materials. Using recycled concrete or slag as aggregate instead of extracted aggregates qualifies as post-consumer. Although most reinforcing bars are manufactured from recycled steel, in LEED, reinforcement is not considered part of concrete. Reinforcing material should be considered as a separate item. This credit is worth 1 point for the quantities quoted above and 2 points for double the amount.*

LEED Innovation Credit on Reducing Cement Content. *LEED has an innovation credit that allows 1 point for a 40% reduction of cement content compared to common practice. This can be met by using at least 40% less portland cement or replacing at least 40% of the cement in concrete with fly ash, slag cement, silica fume, or a combination of the three. Slag cement is commonly used at replacement levels up to 60%. However, fly ash replacement levels for portland cement greater than 25% are not common, as the fly ash and portland cement need to be chemically and physically compatible to ensure durable quality concrete that sets properly. For quality concrete, mixtures with fly ash at replacement levels greater than 25% should not be used without proven field experience or laboratory testing. Certain aesthetic (color) and stripping time restrictions will apply when using supplementary cementitious materials.*

Admixtures. The freshly mixed (plastic) and hardened properties of concrete may be changed by adding chemical admixtures to the concrete, usually in liquid form, during batching. Chemical admixtures are commonly used to (1) adjust setting time or hardening, (2) reduce water demand, (3) increase workability, (4) intentionally entrain air, and (5) adjust other fresh or hardened concrete properties. Admixtures provide enhancing qualities in concrete but are used in such small quantities that they do not adversely affect the environment. Their dosages are usually in the range of 0.005 to 0.2% of the concrete mass.

Color Pigments. Non-fading color pigments are used to provide the decorative colors in precast concrete. They are insoluble and generally non-toxic, although some may contain trace amounts of heavy metals. Many iron oxide pigments are primarily the byproduct of material recycling (manufactured by precipitating scrap steel).

Local Materials. Using local materials reduces the transportation required to ship heavy building materials, and the associated energy and emissions. Most precast concrete plants are within 200 miles (300 km) of a building site. The cement, aggregates, and reinforcing steel used to make the concrete and the raw materials to manufacture cement are usually obtained or extracted from sources within 200 miles of the precast concrete plant. The primary raw materials used to make cement and concrete are abundant in all areas of the world.

Precast concrete elements are usually shipped efficiently because of their large, often repetitive sizes and the ability to plan their shipment during the normal course of the project.

LEED Materials Credit 5 on Regional Materials. *The requirements of this credit state: "Use building materials or products that have been extracted, harvested, or recovered, as well as manufactured, within 500 miles (800 km) of the project site for a minimum of 10% (based on cost) of the total materials value." This means that a precast concrete plant within 500 miles of the building would qualify if the materials to make the concrete were extracted within 500 miles. Calculations can also include concrete either manufactured or extracted locally.*

Precast concrete will usually qualify because precast concrete plants are generally within 200 to 500 miles (300 to 800 km) of a project. Precast concrete plants generally use aggregates that are extracted within 50 miles (80 km) of the plant and within 200 to 500 miles of the project. Cement and supplementary cementitious materials used for buildings are also primarily manufactured within 500 miles of a project. Reinforcing steel is also usually manufactured within 500 miles of a project and is typically made from recycled materials from the same region.

Using materials that are extracted or manufactured locally supports the regional economy. In addition, reducing shipping distances for material and products to the project minimizes fuel requirements for transportation and handling. This credit is worth 1 point for the quantities quoted above and 2 points for double the amount, or 20% of the materials.

Energy Use in Buildings

Energy conservation is a key tenet of sustainability. About 90% of the energy used during a building's life is attributed to heating, cooling, and other utilities. The remaining 10% is attributed to manufacturing materials, construction, maintenance, replacement of components, and demolition.[21]

20 American Society for Testing and Materials, ASTM C 33, "Standard Specification for Concrete Aggregates," West Conshohocken, PA, www.ASTM.org.

21 Marceau, M.L. and VanGeem, M.G., "Modeling Energy Performance of Concrete Buildings for LEED-NCv2.1 EA Credit 1," PCA R&D Serial No. 2880a, Portland Cement Association, Skokie, Illinois, 2006, www.cement.org.

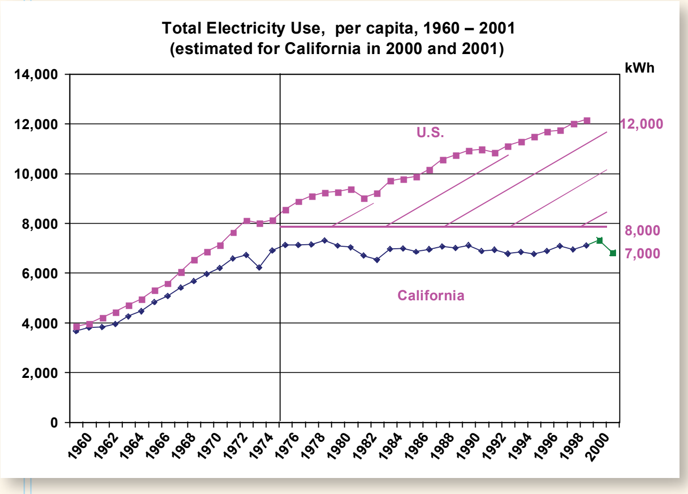


Fig. 10
Energy savings due to implementation of energy codes in 1976 in California (California Energy Commission).

Approximately 5% of the world's population resides in the U.S., yet 25% of the world's energy is consumed in the U.S. The U.S. dependence on foreign energy sources is greater than ever, which has an effect on U.S political and defense policies. Meanwhile, many developing nations like China have increased energy demands due to increased manufacturing and urbanization.

Energy codes

Energy codes provide cost effective, minimum building requirements that save energy. The energy saved is a cost savings through lower monthly utility bills, and smaller, and thus less expensive HVAC equipment. More than two-thirds of the electricity and one-third of the total energy in the U.S. are used to heat, cool, and operate buildings.[22] This means that implementing and enforcing energy codes will result in fewer power plants and natural resources being used to provide electricity and natural gas. It also means fewer emissions will be released into the atmosphere. Emissions have been linked to smog, acid rain, and climate change. In the U.S. most buildings are constructed to meet minimum energy code requirements; energy codes contribute to sustainability by saving energy and protecting the environment.

Energy codes are effective in reducing per capita energy usage (energy use per person). The per capita energy use in California has remained steady due to the state's active use and enforcement of energy codes for buildings, while in the rest of the U.S. that energy use has increased (Fig. 10).

The U.S. Energy Conservation and Production Act[23] requires that each state certify it has a commercial building code that meets or exceeds ANSI/ASHRAE/IESNA Standard 90.1. In this sense, "commercial" means all buildings that are not low-rise residential (three stories or less above grade). This includes office, industrial, warehouse, school, religious, dormitories, and high-rise residential buildings. The ASHRAE standard and most codes recognize the benefits of thermal mass and require less insulation for mass walls.

22 "An Introduction to the U.S. Green Building Council and the LEED Green Building Rating System," a PowerPoint presentation on the USGBC website, October 2005, www.usgbc.org.
23 1992 National Energy Policy Act, U.S. Department of Energy, www.DOE.gov.

Thermal mass in exterior walls have the following benefits and characteristics:

1. Delays and reduces peak loads.
2. Reduces total loads in many climates and locations.
3. Works best in commercial applications.
4. Works well in residential applications.
5. Works best when mass is exposed on the inside surface.
6. Works well regardless of the placement of mass.

Mass works well in commercial applications by delaying the peak summer load, which generally occurs around 3:00 p.m. to later when offices begin to close. As a case in point, the blackout in the northeastern U.S. in August 2003 occurred at 3:05 p.m.[24] A shift in peak load would have helped alleviate the demand and, possibly, this peak power problem.

Also, many commercial and industrial customers incur significant time-of-use utility rate charges for the highest use of electricity for any 1 hour in a month in the summer. Thermal mass may help shift the peak hour of electric demand for air conditioning to a later hour, and help reduce these time-of-use charges. Nighttime ventilation can be used to cool thermal mass that has been warmed during the day. Local outdoor humidity levels influence the effectiveness of nighttime ventilation strategies.

As occupant and equipment heat is generated, it is absorbed not only by the indoor ventilated air but also by the massive elements of the building. Mass works well on the inside surfaces by absorbing the heat gains generated by people and equipment indoors. Interior mass from interior walls, floors, and ceiling will help moderate room temperatures and reduce peak energy use.

LEED Energy and Atmosphere Prerequisite 2 on Minimum Energy Performance. *All buildings must comply with certain sections on building energy efficiency and performance as required by the ANSI/ASHRAE/IESNA 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential Buildings, or the local energy code, whichever is more stringent. The ASHRAE standard is usually more stringent and applies for most states. This prerequisite is a requirement and is not worth any points. The requirements of the ASHRAE standard are cost-effective and not particularly stringent for concrete. Insulating to meet or exceed the requirements of the standard is generally a wise business choice. Determining compliance for the envelope components is relatively straightforward using the tables in Chapter 5 of the ASHRAE standard. Minimum requirements are provided for mass and non-mass components such as walls and floors.*

Thermal mass is most effective in locations and seasons where the daily outdoor temperature rises above and falls below the balance point temperature of the building. The balance point temperature is the outdoor temperature below which heating will be required. It is less than room temperature, generally between 50 and 60°F (10 and 15°C), at the point where internal heat gains are about equal to the heat losses through the building envelope. In many climates, buildings with thermal mass have lower energy consumption than non-massive buildings with walls of similar thermal resistance. In addition, heating and cooling needs can be met with smaller equipment sizes.

More information on thermal properties and energy code compliance of precast concrete walls is available in Designers Notebook, Energy Conservation and Condensation Control (DN-15).

24 U.S. Department of Energy, *Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations*, 2004, Washington, DC.

Table 4 Measured Air Leakage for Selected Building Materials.

MATERIAL	AVERAGE LEAKAGE AT 0.3 IN. WATER, CFM/FT² SURFACE
6 mil (0.15 mm) polyethylene	No measurable leakage
1 in. (25 mm) expanded polystyrene	1.0
1/2 in. (12 mm) fiberboard sheathing	0.3
Breather type building membranes	0.002 – 0.7
Closed cell foam insulation	0.0002
Uncoated brick wall	0.3
Uncoated concrete block	0.4
Precast concrete wall	No measurable leakage

Table 5 LEED NC v2.2 Points Awarded for Energy Costs Saved Beyond Minimum Code.

NEW BUILDINGS, ENERGY SAVED	EXISTING BUILDINGS, ENERGY SAVED	POINTS
10.5%	3.5%	1
14%	7%	2
17.5%	10.5%	3
21%	14%	4
24.5%	17.5%	5
28%	21%	6
31.5%	24.5%	7
35%	28%	8
38.5%	31.5%	9
42%	35%	10

Lighting

Light-colored precast concrete and other surfaces will reduce energy costs associated with indoor and outdoor lighting. The more reflective surfaces will reduce the amount of fixtures and lighting required. Light-colored precast concrete exposed to the interior will help reduce interior lighting requirements, and light-colored exterior walls will reduce outdoor lighting requirements.

Air infiltration

Precast concrete panels have negligible air infiltration. Minimizing air infiltration between panels and at floors and ceilings will provide a building with low air infiltration. These effects will lower energy costs and help prevent moisture problems from infiltration of humid air. In hot and humid climates in the southeastern U.S., infiltration of moist air is a source of unsightly and unhealthy moisture problems in buildings. Some building codes[25] now limit air leakage of building materials to 0.004 cfm/ft^2 (0.0012 m^3/min/m^2) under a pressure differential of 0.3 in. (7.6 mm) water (1.57 psf [0.75 kPa]); precast concrete meets this requirement. Table 4 lists the measured air leakage values for selected building materials.

25 Massachusetts Energy Code, www.mass.gov/bbrs/780_CMR_Chapter_13.pdf.

Advanced energy guidelines

Sustainability or green building programs (such as LEED™ or EnergyStar) encourage energy savings beyond minimum code requirements. The energy saved is a cost-savings to the building owner through lower monthly utility bills and smaller, less expensive heating, ventilating, and air-conditioning (HVAC) equipment. Some government programs offer tax incentives for energy-saving features. Other programs offer reduced mortgage rates. The EnergyStar program offers simple computer programs to determine the utility savings and lease upgrades associated with energy saving upgrades.

Many energy-saving measures are cost-effective even though they exceed minimum codes. Insulation and other energy-saving measures in building codes generally have a payback of about 5 years, even though the building life may be anywhere from 30 to 100 years. The New Buildings Institute has developed the E-Benchmark guidelines to save energy beyond codes (see www.NewBuildings.org). ASHRAE *Advanced Energy Design Guide For Small Office Buildings* (see www.ASHRAE.org) has a similar purpose. Many utilities are interested in these advanced guidelines to delay the need for new power plants.

The panelized construction of precast concrete lends itself to good practice and optimization of insulation levels. To maximize the effectiveness of the insulation, thermal bridges should be minimized or avoided. Metal thermal bridges may occur as connectors that penetrate insulation to connect concrete layers. Concrete thermal bridges may occur at the bottom and top of concrete panels. Using fiberglass or carbon-fiber composite fasteners or thermal breaks may minimize thermal bridges.

LEED Energy Credit 1 on Optimizing Energy Performance. *This credit is allowed if energy cost savings can be shown compared to a base building that meets the requirements of ANSI/ASHRAE/IESNA 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential Buildings. The method of determining energy cost savings must meet the requirements of Appendix G "Performance Rating Method" of the standard.*

Many engineering consulting firms have the capability to model a building to determine energy savings as required using a computer-based program such as DOE2. When concrete is considered, it is important to use a program like DOE2[1] that calculates annual energy use on an hourly basis. Such programs are needed to capture the beneficial thermal mass effects of concrete. Insulated concrete systems, used in conjunction with other energy savings measures will most likely be eligible for LEED points. The number of points awarded will depend on the building, climate, fuel costs, and minimum requirements of the standard. From 1 to 10 LEED points are awarded for energy cost savings of 10.5% to 42% for new buildings and 3.5% to 35% for existing buildings (Table 5). A small office building less than 20,000 ft^2 (1900 m^2) complying with ASHRAE "Advanced Energy Design Guide For Small Office Buildings 2004" can achieve 4 points, and a building complying with "E-Benchmark" v1.1 (www.newbuildings.org) can achieve 1 point.

1 Visual DOE 4.0, Architectural Energy Corporation, Boulder, CO, www.archenergy.com.

Table 6 Concentrations and Emission Rates of VOCs for Common Materials.

BUILDING MATERIAL	VOC CONCENTRATION, mg/m³	VOC EMISSION RATE, m²h
Concrete with water-based form-release agent	0.018	0.003
Acryl 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

Indoor Environmental Quality

Concrete contains low to negligible VOCs. These compounds degrade indoor air quality when they off gas from new products, such as interior finishings, carpet, and furniture. Manufactured wood products such as laminate, particle board, hardboard siding, and treated wood can also lead to off gassing. In addition, VOCs combine with other chemicals in the air to form ground-level ozone. Table 6 presents the VOC concentration and emission rates for common materials. Complaints due to poor indoor air quality routinely include eye, nose, and throat irritation; dryness of the mucous membranes and skin; nose bleeds; skin rash; mental fatigue and headache; cough; hoarseness; wheezing; nausea; dizziness; and increased incidence of asthma.

Polished concrete floors do not require carpeting. Exposed concrete walls do not require finishing materials—this eliminates particulates from sanding drywall tape seams. VOCs in concrete construction can be further reduced by using low-VOC materials for form release agents, curing compounds, dampproofing materials, wall and floor coatings and primers, membranes, sealers, and water repellents.

***LEED Indoor Environmental Quality Credit 3.1** on Construction IAQ Management Plan, During Construction. This credit prevents indoor air quality problems resulting from the construction process. The intent is to reduce and contain dust and particulates during construction and to reduce moisture absorbed by materials that are damaged by moisture. During construction, the project must meet or exceed the recommended Design Approaches of the Sheet Metal and Air Conditioning National Contractors Association (SMACNA) IAQ Guidelines for Occupied Buildings under Construction, 1995, Chapter 3 on Control Measures (www.smacna.org). Using precast concrete can help meet the requirements because it is delivered to the site in pieces that do not require fabrication, processing, or cutting, thereby reducing dust and airborne contaminants on the construction site. Concrete is not damaged by moisture and does not provide nutrients for mold growth. This credit is worth one point.*

Demolition

Precast concrete panels can be reused when buildings are expanded and precast concrete can be recycled as road base or fill at the end of its useful life. Concrete pieces from demolished structures can be reused to protect shorelines. Most concrete from demolition in urban areas is recycled and not placed in landfills.

***LEED Materials Credit 2 on Construction Waste Management.** This credit is extended for diverting construction and demolition debris and land clearing waste from landfill disposal. It is awarded based on diverting at least 50% by weight or volume of the previously listed materials. Since precast concrete is a relatively heavy construction material and is frequently crushed and recycled into aggregate for road bases or construction fill, this credit should be obtainable when concrete buildings are demolished. This credit is worth 1 point if 50% of the construction and demolition debris and land clearing waste is recycled or salvaged and 2 points for 75%.*

Innovation

***LEED Innovation and Design Process Credit 1.** This credit is available for projects that demonstrate exceptional performance above the requirements in LEED or not specifically addressed in LEED. For example, close collaboration with engineers on a given project to develop innovative systems that are more resource efficient or use less energy may earn a project an additional point. To earn credits (up to 4), the user must submit the intent of the proposed credit, the proposed requirement for compliance, submittals to demonstrate that compliance, and the design approach used to meet the requirement.*

***LEED Innovation and Design Process Credit 2.** One point is also given if a principal participant of the project team is a LEED Accredited Professional. The concrete industry has LEED-experienced professionals available to assist teams with concrete applications and help maximize points for concrete.*

Conclusion

Sustainable practices contribute to saving materials and energy and reducing the negative effects of pollutants. The use of precast concrete contributes to these practices by incorporating integrated design, using materials efficiently, and reducing construction waste, site disturbance, and noise. Concrete is durable, resistant to corrosion and impact, and inedible.

Precast concrete structures are resistant to fires, wind, hurricanes, floods, earthquakes, wind-driven rain, blast forces, and moisture damage. Light- or natural-colored concrete reduces heat islands, thereby reducing outdoor temperatures, saving energy, and reducing smog. Recycled materials such as fly ash, slag cement, silica fume, and recycled aggregates can be incorporated into concrete, thereby reducing the amount of materials that are taken to landfills and reducing the use of virgin materials.

Concrete structures in urban areas are recycled into fill and road base material at the end of their useful life. Cement and concrete are generally made of abundant local materials. The thermal mass of concrete helps save heating and cooling energy in buildings. Concrete acts as an air barrier, reducing air infiltration and saving more energy. Concrete has low VOC emittance and does not degrade indoor air quality.

Sustainability attributes can be evaluated by performing a life cycle assessment. Because these procedures are time consuming, green building rating systems such as LEED have become popular. Precast concrete can help a project earn up to 23 points towards LEED certification for new buildings (a total of 26 are required.)

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