USING CONCRETE AS A SUSTAINABLE SOLUTION FOR BUILDINGS

Presented by:

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LEARNING OBJECTIVES

By the end of this educational unit you will be able to:

1. List the five main components in concrete mix design and understand their relative impacts on performance and the environment.
2. Calculate the mix design options to achieve optimal carbon footprint reductions and performance criteria.
3. Discuss concrete's inherent attributes of strength and durability in the face of natural disaster.
4. Learn how concrete contributes to thermal and acoustic comfort for building occupants.

CONTINUING EDUCATION

CREDIT: 1 LU

COURSE NUMBER: ARnov2015.2

Use the learning objectives above to focus your study as you read this article.

Visit http://go.hw.net/AR1115Course2 to read more and complete the quiz for credit.

By David Shepherd, AIA, LEED AP

The sustainable-design movement is evolving from checking boxes in credit templates to holistic design. And in the search for holistic sustainable solutions, designers are seeking new insight through life cycle analysis and building modeling to evaluate a project's impacts over its entire life. Certain attributes of sustainable buildings become increasingly important, such as:

- Energy
- Durability and resilience
- Reduced material manufacturing impacts
- Operational impact improvements
- Comfort—HVAC, noise, emissions

This article will update readers on steps the cement and concrete industries are taking to evaluate and reduce their environmental impact. It will also offer designers insight on how to increase sustainable performance on their projects through optimization of concrete applications in sustainable building. And to support this, the cement and concrete industry is developing detailed information to inform designers about the environmental impacts of their product choices.

EMBRACING TRANSPARENCY

The cement and concrete industry has embraced environmental transparency for some time, publishing its first industry-average LCA in 2000. Since then, the concrete industry has advanced its self-evaluation of environmental hot spots in its processes, and graduated to developing product category rules (PCR) and environmental product declarations (EPDs).

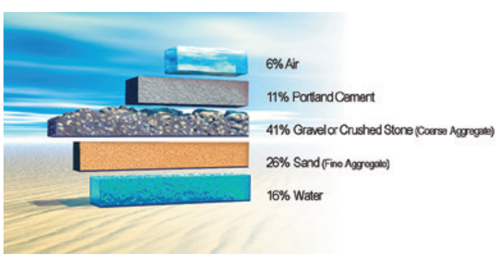
The Carbon Leadership Forum (CLF) at the University of Washington released a U.S.-specific PCR for ready mixed concrete in November 2012, which was revised in December 2013.[1] In February 2013, the World Business Council for Sustainable Development (WBCSD) also announced the development of a PCR for unreinforced concrete.[2]

Other concrete-related industry PCRs that have been published recently include:

- Slag Cement, published in August 2014[3],
- Portland, blended hydraulic, masonry, mortar, and plastic (stucco) cements, published in September 2014[4], and
- Manufactured Concrete and Concrete Masonry Products, published by ASTM in December 2014[5].

An industry-average environmental product declaration for ready mixed concrete was published by the National Ready-Mixed Concrete Association (NRMCA) in October 2014. NRMCA's *Industry-Wide Environmental Product Declaration (EPD) and Benchmark Report*[6] discloses average environmental impacts for concrete. These data are for concretes of varying strengths, uses, and mixture proportions. Several companies have also published EPDs for individual concrete-related products. Similarly, the U.S. cement industry expects to publish an industry average EPD for the most commonly used kinds of cement at the start of 2016.

FUNDAMENTAL CONCRETE COMPONENTS



To understand how the cement and concrete industries can reduce their collective environmental footprint, it is important to understand the components of concrete-related products. A unique attribute of concrete as a construction material is the ability to modify the proportion of ingredients in the mix design through specifications to achieve specific goals for the intended application. Concrete is primarily a mixture of two main components: aggregates and a binding paste. The paste is comprised of portland cement and water, which can be modified with supplementary cementitious materials and admixtures for achieving specific construction, structural and environmental characteristics. (See Sidebar—Mix Design Optimization) The paste can also contain entrapped or purposely entrained air. The aggregates are typically locally sourced sand, gravel and/or crushed stone.

PORTLAND CEMENT

Cement, which is typically 7 to 15% of the volume of concrete, provides the primary engineering and durability properties of concrete.

Portland cement is produced in a rotary kiln from a precise blend of constituents. The most common combination of ingredients is limestone (for calcium) along with much smaller quantities of clay, iron ore and sand (as sources of alumina, iron and silica, respectively). Increasingly, alternative sources from industry by-products (steel mill slag and scale, foundry sands, or bottom ash from coal fired power plants) can provide the essential elements for cement production.

The materials are heated to temperatures around 2700 degrees Fahrenheit (1500 degrees Celsius) to chemically transform the raw materials into clinker as it passes through the rotary kiln. After the clinker has cooled, it is very finely ground with gypsum, limestone, and minute amounts of other constituents to form portland cement.

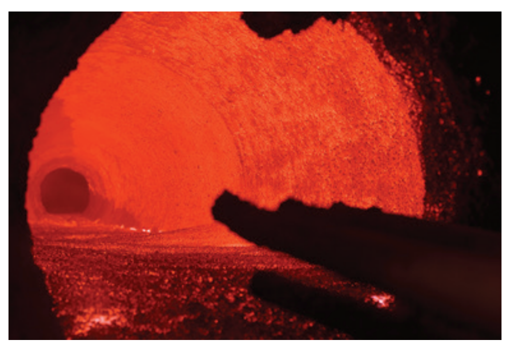


Figure 1–Limestone, silica, alumina and iron chemically combine to form clinker in the rotary kiln of a cement plant.

Cement-plant carbon-dioxide emissions come from two sources: combustion and calcination. Combustion accounts for approximately 40% of the total CO_2 emissions from a cement manufacturing facility. The remaining 60% CO_2 emissions from calcining are formed when the raw material (limestone) is heated and CO_2 is stripped from the calcium carbonate molecules. This reaction enables the chemical formation with the other ingredients to achieve the hydraulic properties of portland cement. According to the U.S. EPA, 2013 U.S. greenhouse gas emissions totaled 6,673 million metric tons of carbon dioxide equivalents (CO_2e). Production of cement accounted for approximately 75.44 million metric tons of CO_2e or 1.1% of the U.S. national total.

The kiln's combustion-generated CO_2 emissions are directly related to fuel use. Some of this energy comes from traditional sources, but over 73% of U.S. plants reporting in the 2013 PCA Labor-Energy Survey reported utilizing alternative fuels. Many plants use between 20 to 70% of alternative fuels for their energy requirement. Alternative fuels include waste oil, solvents, resins, scrap tires, refinery wastes, and other wastes that have high energy content. Cement kilns are one of the few options where these wastes can be safely and efficiently disposed, because of the high temperature in the kiln and the length of time exposed to this level of heat. The EPA has designated thermal destruction by energy recovery in cement kilns as the Best Demonstrated Available Technology (BDAT) for treatment of these wastes.

ENERGY RECOVERY FROM WASTE

Figure 2–Whole steel belted tires feed into a cement kiln for energy recovery and solid waste reduction.

The EPA recognizes tire derived fuel as a Best Management Practice and encourages industries to recover the energy from this waste stream while offering the added benefit of reducing the landfill for scrap tires. Tire derived fuel (TDF) has approximately 20% more BTUs than a comparable weight of coal, and since tires are manufactured in part with natural latex which literally grows in trees, TDF has a lower greenhouse gas impact than coal. The steel reinforcing belts in a tire are a recycled material source for some of the iron needed in cement production. The use of tires as fuel can actually reduce certain emissions in cement production.[7] The Rubber Manufacturers Association reports in 2013 an estimated 44,300,000 scrap tires were diverted from landfills for energy recovery in cement kilns.[8]

SUPPLEMENTARY CEMENTITIOUS MATERIALS

Figure 3–Fly-ash, slag and silica fume offer environmental and performance benefits when optimally combined with portland cement in concrete mix designs.

Supplementary cementitious materials (SCMs) such as fly ash, slag, and silica fume are industrial by-products which offer both environmental and performance benefits for concrete production. Fly ash is a residual from the combustion of pulverized coal in electric power generating plants. Slag cement is created from iron blast-furnace slag, a by-product of the steel-making industry. Silica fume is a waste created from the electric arc furnace used in the production of silicon or ferrosilicon alloy. In their 2014 Industry Wide EPD for Concrete, the ready mixed concrete industry reported that 95% of their plants use SCMs in their concrete products.

The intelligent use of SCMs can reduce the environmental footprint and contribute beneficially to the fresh and hardened properties of concrete. It is important to consider the impact on the properties of the concrete when determining the optimum amount of SCMs in a concrete mixture, which can affect water demand, curing times, durability, aesthetics, and other factors. Typical SCM proportions range from 15 to 40% of a mix design (by mass) and their use is also influenced by the local availability of these materials.

Aggregate

Aggregates, constituting 60 to 75% of concrete by volume, are customarily sand, gravel, or crushed stone which are typically locally sourced, naturally occurring, with low embodied energy. A typical sand or aggregate quarry is considered relatively shallow and small in scale, closely contained and monitored compared to most mining operations. When closed, aggregate quarries are often converted to their natural state, or into recreational areas, or agricultural uses.

Figure 4–Part of the 6 million tons of recycled concrete generated from runways, taxiways and structures at Denver's Stapleton Airport—image courtesy of RMCI

Recycled concrete from demolished buildings and pavements and reclaimed aggregate from concrete production and can be used to replace a portion of new aggregate in concrete, particularly the coarse portion. In a 2008 report, Federal Highway Administration noted that eleven states currently use recycled concrete aggregate in new concrete.[9] These states report that concrete containing recycled aggregate can perform equal to concrete containing natural aggregates. Applications such as foundation slabs and insulated concrete form walls are also well suited for recycled aggregate incorporation.

To conserve natural resources, the use of marginal aggregates in concrete is becoming more common. Some natural aggregates may react to the alkalinity of the cement paste, contain organic impurities or other chemicals which can be detrimental to durable concrete. Judicious mix design can accommodate some reactive aggregates with careful selection of cementitious materials (cements and SCMs) and appropriate testing.

Alternative aggregates are also available from industrial by-products, such as blast furnace slag aggregate, simultaneously reducing use of virgin resources and land-filled waste materials. Blast furnace slag is a lightweight aggregate derived from industrial waste with a century long history of beneficial use in the concrete industry.

Water

Water is essential to the hydration of cement in concrete. Almost any water suitable for drinking is acceptable for use in concrete. To improve water conservation, recently approved practices in concrete production include replacing of some of the potable water with water reclaimed from previous concrete production, industrial processes and other water sources typically not used for human consumption.

Admixtures

Chemical admixtures enhance the plastic and hardened properties of the concrete. Admixtures typically do not significantly affect the environment impact because they are used in such small quantities. Dosage rates are typically in the range of 0.005 to 0.2% of the concrete mass. They are primarily used to provide air entrainment, control set times, and improve workability in fresh concrete. When used in concrete for improved hardened properties, they can increase compressive strength, reduce shrinkage, and lower permeability. This can result in greater durability and longevity with a corresponding conservation of material resources and related environmental impacts.

MIX DESIGN OPTIMIZATION

With cement contributing a significant portion of concrete's environmental impact, a common specification strategy is to reduce the cement content of a mix design to the lowest possible level. This is often done in conjunction with increased percentages of supplemental cementitious materials, with the caveat that this can result in positive or negative performance consequences with the recognition that cement provides the primary engineering and durability properties of concrete.

Contrary to the strategy above, high percentage cement mix designs can be a solution for a lower carbon footprint in some applications. The use of high strength concrete for certain design elements can result in a significant reduction of cross section, may eliminate the need for multiple elements or may provide significantly longer service life.

Consider this simplified example of a forty story building with a floor plate supported by with sixteen columns (15' floor to floor height) per floor. Utilizing a 4,000 psi mix design (with 440 lbs of cement /cu. yard) requires columns with a cross sectional dimension of 36" x 36". Raising the cement content to 856 lbs /cu. yard yields a compressive strength of 9,000 psi. The column cross sectional area is reduced to 24" x 24".

	4,000 psi Concrete	9,000 psi Concrete
Total Cementitious Materials in lbs per cu. yd.	550	865
Supplementary Cementitious in lbs. per cu. yd.	110 (flyash)	40 (silica fume)
Portland cement in lb per cu. yd.	440	825
Column cross section in inches.	36 by 36.	24 by 24
Concrete per column (15 ft) in yd.	5.00	2.22
Portland cement per column in lbs.	2200 lbs	1833 lbs
Volume of cement reduction		**16%**
Volume aggregate reduction		**55%**

This results in a 16% net reduction for cement and a 55% reduction for aggregates, lowering the greenhouse gas footprint for these elements as well as providing an increase in net rentable floor area of 3120 s.f.

CHARACTERISTICS OF SUSTAINABLE BUILDINGS

As we've become more knowledgeable and experienced in sustainability, we've come to expect more from our buildings and the products from which they are constructed. Concrete has certain inherent properties that aid in creating more-sustainable buildings such as:

- Durability and resiliency
- Heat island mitigation

- Stormwater management
- Thermal mass
- Low or no volatile organic compounds
- Recyclable
- Local availability
- Sound attenuation

Durability

In determining the real value of a building, one must consider both the impacts over the entire life cycle of the project. Extracting optimal value from any material invested in a building demands durable products, design details and construction practices. Determining the impacts of material production is becoming more common as manufacturers publish data through EPDs. A key factor in building reuse and adaptability is the durability of the original structure and components. Structures require different types of durability depending on the intended use, environmental exposure and desired engineering properties.

Concrete components provide a long service life due to their durable and low-maintenance surfaces. Concrete can resist weathering action, chemical attack, moisture and abrasion while maintaining desired engineering properties. These characteristics of concrete make it sustainable in multiple ways: it avoids contributing solid waste to landfills, it reduces the depletion of natural resources, and the generation of air, water and solid waste from replacement materials. When properly designed, concrete structures can be reused or repurposed several times in the future.

Figure 5–Built in 1933, the Rainbow Bridge spanning the Payette River in Idaho remains in service today and is listed in the national historic register. Photo from Idaho Dept. of Transportation

Visit http://go.hw.net/AR1115Course2 to read more and complete the quiz for credit.

QUIZ

1. Where does the CO_2 originate in the cement manufacturing process?
   a. Fuel combustion in the kiln
   b. Calcination
   c. Both a and b
   d. None of the above

2. What volume of concrete is cement?
   a. 7 to 15%
   b. 15 to 30%
   c. 30 to 60%
   d. 60 to 80%

3. According to the EPA, 2013 cement plant greenhouse gas emissions were what percentage of the nation's total emissions?
   a. .36%
   b. 1.1%
   c. 5%
   d. 10%

4. What percentage of alternative fuels do cement plants use for their energy?
   a. 5 to 10%
   b. 10 to 20%
   c. 20 to 70%
   d. 70 to 100%

5. True or false: Fly ash is a by-product of steel manufacturing.
   a. True
   b. False

6. What federal agency recognizes the durability of concrete by promoting concrete safe rooms for providing occupant protection from natural disasters?
   a. Public Health Service
   b. Federal Emergency Management Agency (FEMA)
   c. U.S. Fire Administration
   d. Transportation Security Administration

7. What is the solar reflectance value (SRI) of new concrete without added pigments?
   a. >19
   b. >29
   c. >32
   d. >78

8. How does one take into account the thermal mass benefits when modeling energy performance of a building?
   a. Account for hourly heat transfer on an annual basis
   b. Account for hourly heat transfer on an hourly basis
   c. Account for annual heat transfer on an annual basis
   d. Account for annual heat transfer on an hourly basis

9. What component of concrete is the greatest by mass?
   a. Aggregate
   b. Cement
   c. Water
   d. Admixtures

10. Increased outdoor temperatures due to the urban heat island effect, have been linked to what?
    a. Greater air-conditioning loads
    b. Reduced outdoor air quality
    c. Increased cases of asthma
    d. All of the above

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America's Cement Manufacturers™

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The longevity of concrete structures is readily apparent. As the most widely used building material in the world, concrete structures have withstood the test of time for many years. Depending on the application, the design service life of building interiors is often 30 years. However, the actual average life span for a building in the U.S. is 75 years; more than double the service life. The concrete portion of structures often lasts 100 years and longer.

It's for these reasons you often see concrete in essential infrastructure (bridges, dams, tunnels, runways and foundations) where long life is important. The Hoover Dam remains as one of the most recognizable structures of the 20th century. It was opened in 1936 and remains in service providing power, flood control and recreational areas in the largest man-made lake in the U.S. Built around the same time, the Rainbow Bridge is the largest single span concrete arch bridge in the State of Idaho and a landmark structure on the Payette River National Scenic Byway. Designed by Charles A. Kyle, the first chief bridge engineer in Idaho, the structure was to blend in gracefully with its stunning surroundings. The structure is a reinforced concrete arch bridge approximately 410 feet (125 m) in length with a main span approximately 210-feet (64 m) in length over the North Fork of the Payette River.

RESILIENCY

Properly designed reinforced concrete is resistant to fire, wind, hurricanes, floods, and earthquakes, and can also provide blast protection for occupants. The Federal Emergency Management Agency (FEMA) recognizes these attributes by promoting concrete safe rooms for providing occupant protection from natural disasters.[10]

However, resilience is much more than natural disaster resistance. The increased robustness, longevity, and durability, combined with improved disaster resistance result in less energy and resources required for repair, removal, disposal, and replacement of building materials and contents due to routine maintenance and operations. Resilient buildings create safe, secure, comfortable, and productive communities in which to live and work. Concrete provide greater resilience helping essential service providers operating out of more robust fire and police stations, hospitals, and community shelters to continue operation after a disaster strikes.

Fire resistance

Noncombustible concrete buildings offer effective fire protection. As an exterior wall or roof, concrete helps to prevent a fire from involving other buildings. As an interior separation wall, concrete helps to prevent a fire from spreading within a structure. Concrete that endures a fire can often be reused when the building is rebuilt. During wild fires, concrete walls help provide protection to human life and the occupants' possessions.

Concrete helps contain a fire even if no water supply is available, instead relying on a passive fire suppression technique. The fire endurance of concrete can be determined by its thickness and type of aggregate used.

Tornado, hurricane, and wind resistance

Figure 6–A 2 x 4 projectile shot from a "tornado cannon" explodes on impact during a demonstration of an insulated precast concrete wall assembly's ability to resist windblown debris. Photo courtesy of Dukane Precast, Naperville, IL

Concrete can be economically designed to resist forces from 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.

The amount of fatalities and property damage in these extreme wind events is far greater from the windblown debris than wind loads against the structure. Impact resistance of wall systems to tornado and hurricane debris missiles is tested using a 50 mm x 100 mm (2 in. x 4 in.) piece of wood travelling at 45 m/s (100 mph) and weighing 6.8 kg (15 lb).[9] When tested against 3000 psi concrete walls as thin as 50 mm (2 in.), debris missiles shattered on impact without damaging the concrete.[11]

A proven strategy to reduce life safety risk in extreme wind events is installation of a safe room. Federal Emergency Management Agency defines these as a hardened structure

Figure 7–The Harrison family, next to their concrete safe room that provided safe haven during a tornado that decimated their neighborhood in 2011. Image courtesy of FLASH.org

specifically designed to meet the FEMA criteria and provide near-absolute protection in extreme weather events, including tornadoes and hurricanes. Near-absolute protection means that, based on our current knowledge of tornadoes and hurricanes, the occupants of a safe room will have a very high probability of being protected from injury or death.

They offer design recommendations in a free publication titled FEMA P320 "Taking Shelter from the Storm" at this link: https://www.fema.gov/media-library/assets/documents/2009. It includes safe room designs and shows how to construct a safe room for homes or small business.

Flood resistance

Concrete is not damaged by water; in fact, concrete continues to gain strength in the presence of moisture. Submerged concrete absorbs very small amounts of water, even over long periods of time, and this water does not damage the concrete. Because of its inorganic mineral makeup, concrete does not rot, rust or offer a food source for mold. In flood-damaged areas, the concrete elements of flooded buildings are often salvageable by pressure washing.

Earthquake resistance

In reinforced concrete construction, the combination of concrete and reinforcing steel provides the three most important properties for earthquake resistance: stiffness, strength, and ductility. Reinforced concrete walls work well because of the composite capabilities of materials within the structural system: concrete resists compression forces, and reinforcing steel resists tensile forces produced by an earthquake. The stiffness of concrete walls also limit in-plane lateral movement (racking) which reduces damage to interior finishes and cladding.

HEAT ISLAND MITIGATION

Studies have shown that urban environments are 2°C to 4°C (3°F to 8°F) warmer than adjacent areas, and this phenomenon is called the urban heat-island effect. This temperature difference is attributed to the replacement of natural vegetation with buildings and pavements. Replacing dark roofing and paving materials with more reflective choices reduces heat island impacts. Concrete is an obvious material choice for reducing the urban heat island effect.

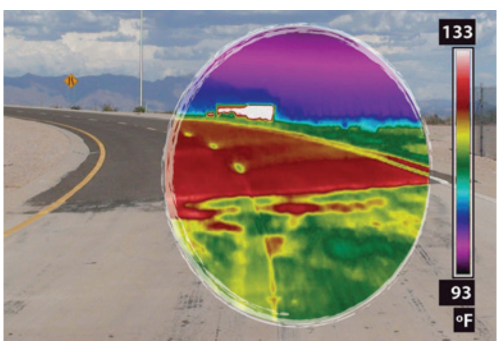

Figure 8–Infrared imaging reveals a 29 degree surface temperature differential between concrete (foreground) and asphalt paving. Photo courtesy of Larry Schofield, ACPA

Albedo is the ratio of the amount of solar radiation reflected from a material to the amount that shines on the material. Surfaces with lower albedos absorb more solar radiation. The absorbed radiation is converted into heat and the surface gets hotter. Where paved surfaces are required, using materials with higher albedos will reduce the heat island effect—consequently saving energy by reducing the demand for air conditioning. Research by NASA in the late 1990s revealed that the metropolitan area of Atlanta was up to 8 degrees F warmer in the summer than the surrounding rural area, increasing cooling energy consumption for residents by up to 18%, increasing air pollution and changing local weather patterns.[12]

Concrete constructed using ordinary portland cement generally has a reflectance of approximately 0.35, although it can vary. Measured values are reported in the range of 0.30 to 0.5. For concrete made with white portland cement, values are reported in the range of 0.7 to 0.8. The Solar Reflectance Index (SRI) is used to determine the effect of the reflectance and emittance on the surface temperature. SRI values vary from 100 for a standard white surface to zero for a standard black surface.

New concrete without added pigments has an SRI value greater than 29, the threshold value required for hardscape in most green building standards and rating systems.[11]

Reflectance values can decrease over time as the pavement collects dirt and the cement paste at the surface is abraded. Pressure washing of the surface can restore much of the original reflectance.

STORMWATER MANAGEMENT

Concrete plays a significant role in conventional surface water management by providing conveyance and treatment infrastructure that is durable and impermeable. With the advent of sustainable design, there is considerable interest in replicating pre-development hydrologic site characteristics and concrete continues to offer solutions for design professionals and building owners. Since the primary cause of stormwater runoff is an increased impervious surface, sustainable site design seeks to minimize impervious surfaces as a first step. The second step is to manage the stormwater and minimize off-site discharge. This generally requires creating conveyance and storage features that initially store and allow for infiltration and absorption of stormwater. This has resulted in strategies that emphasize conservation and integration of on-site natural features with small-scale hydrologic controls.

Collectively, these strategies are known as Low Impact Development (LID). In addition to providing a more natural solution to stormwater management, low impact development strategies can reduce flooding and the need for large (and frequently expensive) conventional stormwater facilities such as expansive detention basins. Reducing the size of stormwater facilities can often result in more buildable land area particularly important on tighter, more densely developed sites.

The inter-connected voids of pervious concrete paving have flow rates that exceed 400 inches of rain per hour.

Pervious concrete is a porous or no-fines concrete that has interconnected voids. Water percolates through these voids into the soil beneath the concrete system. If the absorptive capability of the soil is inadequate to effectively handle the anticipated runoff during a given period, the pervious concrete is placed over engineered granular base material, sized to provide temporary storage until the soil can absorb the runoff. For impervious soils, the storage layer of a pervious paving system can function as a detention basin, slowing the rate of discharge into a storm sewer system while enabling parking. Pervious concrete technology enables more efficient land use by eliminating the need for retention ponds, swales, and other stormwater management devices. After several decades of in-place pervious pavements, well developed maintenance practices are available to address potential clogging and snow removal issues.

In pervious concrete applications, carefully controlled amounts of water and cementitious materials are used to create a paste that forms a thick coating around similarly sized aggregate particles. A pervious concrete mixture contains little or no sand, creating a substantial void content (typically between 15 and 25%). Using sufficient paste to coat and bind the aggregate particles together creates a system of highly permeable, interconnected voids that drains quickly. Water flow rates through pervious concrete are commonly measured at 0.34 cm/s (480 in./ft^2/hr.), which is 200 L/m^2/min (5 gal/ ft^2/min), although they can be much higher.

Permeable interlocking concrete pavers and grid paver systems are constructed with special interlocking pavers that provide spaces between adjacent units. These spaces are typically filled with crushed granular material to allow water to infiltrate into the base of the pavement. The base course is designed to accept water so that it can be quickly diverted from the surface and provide a storage area that allows water to slowly percolate into the ground or to be controlled by other storm water management techniques.

Concrete pavers are made with dense concrete mixtures, come in a variety of shapes and can be colored or textured. As a result of their physical characteristics, pavers are durable in a most climates and appropriate for a range of loading and traffic. If utility or other subsurface access is necessary, the pavers can be easily removed and then replaced without damaging the surface of the pavement.

LOW OR NO VOCS

Reducing uncontrolled air infiltration is an integral part of building energy efficiency, but has lead to a decrease of indoor air quality. Concrete contains low to negligible volatile organic compounds (VOCs). These compounds degrade indoor air

Figure 9–Polished concrete provides subtle sophistication in a classroom setting. Image courtesy of Dancerconcrete.com, Fort Wayne, IN

quality when they off-gas from new products. In addition, VOCs combine with other chemicals in the air to form ground-level ozone. Complaints due to poor indoor air quality routinely include eye, nose, and throat irritation, dizziness and increased incidence of asthma.

Decorative concrete finishes can be integral to the interior or exterior surface of concrete walls and the walking surface of concrete slabs. Exterior decorative finishes eliminate the need for additional maintenance and replacement of short lived coatings. Interior decorative finishes eliminate the need for gypsum wallboard and also provide a durable inside surface.

THERMAL MASS

Centuries before the introduction of air conditioning, the integration of thermal mass and convection strategies enabled builders to create structures that worked with nature to keep occupants more comfortable. Fundamental for passive solar design but effective in most all

Figure 10–Thermal. mass walls enabled civilizations to thrive in extreme climates centuries before mechanical climate control.

environments and energy efficient strategies, buildings constructed of cast-in-place, tilt-up or precast concrete, insulating concrete forms (ICF) and masonry possess thermal mass that helps moderate indoor temperature extremes and reduces peak heating and cooling loads. This means concrete components have enough heat-storage capacity to moderate daily temperature swings.

The thermal-mass advantages of concrete should be utilized when designing for passive thermal strategies or minimizing energy use in a building. In many climates, these buildings have lower energy consumption than non-massive buildings with walls of similar thermal resistance. When buildings are properly designed and optimized, incorporating thermal mass can lead to a reduction in heating, ventilating, and air-conditioning equipment capacity. Reduced equipment capacity can represent both energy and capital equipment cost savings.

The ASHRAE Standard 90.1—Energy Standard for Buildings Except Low-Rise Residential Buildings, the International Energy Conservation Code and most other energy codes recognize the benefits for thermal mass and require less insulation for mass walls. It is important when modeling energy performance of a building to take into account the thermal mass benefits. Computer programs such as *DOE-2* and *EnergyPlus* can take into account hourly heat transfer on an annual basis, which allows for more accurate determination of energy loss in buildings with mass walls and roofs.

RECYCLABLE

Concrete is a relatively heavy construction material, yet is frequently crushed and recycled into aggregate for road bases or construction fill. The Construction Materials Recycling Association estimates that approximately 140 million tons of concrete is recycled annually. This reduces the amount of material that is landfilled and the need for virgin materials in new construction. Concrete pieces from demolished structures can also be reused in stacked landscaping walls, gabion walls or as riprap for shoreline protection. Recycled concrete can also be used as aggregate in new concrete, particularly as the coarse aggregate.

LOCAL AVAILABILITY

Concrete, and its constituent materials, are typically sourced locally. For example, ready-mix and precast concrete plants generally use aggregates that are extracted within 50 miles of the plant. Cement and supplementary cementitious materials used for buildings are also often manufactured within 500 miles of a job site. Reinforcing steel is usually manufactured within 500 miles of a job site, and is typically made from recycled materials from the same region.

According to the National Ready Mixed Concrete Association, the average distance between the batch plant and the project site is 14.2 miles. Most precast concrete plants are within 200 miles of the project site. Reduced shipping distances associated with local building materials minimize fuel requirements and the associated energy and emissions from transportation and handling. Locally produced materials contribute to the local economy and reduce imports of materials that may have been produced in countries with much less stringent environmental regulations than in the U.S.

SOUND ATTENUATION

Recent research has revealed that densely populated urban environments have the lowest carbon footprint per capita, with a significant influence from reducing automobile usage. However, high density also puts habitants close to noisy infrastructure and neighbors. Concrete provide the necessary mass to dampen sound from one space to the other. Assemblies with higher Sound Transmission Class values offer greater the sound attenuation. Concrete block or cast concrete partitions can be used to separate

STC	What can be heard
25	Normal speech can be understood quite easily and distinctly through wall
30	Loud speech can be understood fairly well, normal speech heard but not understood
35	Loud speech audible but not intelligible
40	Onset of "privacy"
42	Loud speech audible as a murmur
45	Loud speech not audible; 90% of statistical population not annoyed
50	Very loud sounds such as musical instruments or a stereo can be faintly heard; 99% of population not annoyed.
60+	Superior soundproofing; most sounds inaudible

Table 1–Dept. of Housing and Urban Development, "Sound Transmission Class Guidance", Chapter 4 Supplement.

Description	STC Rating
2" x 4" studs and 16" o.c. w/ ½" gypsum drywall (both sides)	37
2" x 4" studs spaced 16"o.c. and staggered 8"o.c. on 2" x 6" plates w/ ½" gypsum drywall (both sides)	39
Two separate 2" x 4" stud walls 16"o.c. on separate plates spaced 1" apart w/ ½" gypsum drywall (both exterior faces)	47
Two separate 2" x 4" stud walls (16"o.c). on separate plates spaced 1" apart w/. ½" gypsum board on exterior faces. Both stud cavities filled with 2 ¼" thick sound attenuation blankets.	56
6" x 8" x 16" 3-cell lightweight concrete masonry units (21 lbs./block). Paint both sides with primer-sealer coat and finish with latex paint>	46
8" x 8" x 18" 3-cell lightweight concrete masonry units (38 lbs./block). Fill cells with expanded mineral loose-fill insulation.	51
6" cast concrete wall (71 psf)	57
6" cast concrete wall (71 psf) with ½" gypsum drywall on one side over 2" x 2" furring and 1½" (4 pcf) rockwool	63

mechanical rooms and HVAC equipment, work areas and noisy areas such as lobbies and public corridors from adjacent living space.

CONCLUSION

Sustainable design and construction is motivating designers and building owners to re-evaluate the materials, methodologies and metrics for optimal building performance over decades of service. For the type of essential applications that concrete is selected to perform, it consumes minimal materials, energy, and other resources for construction, maintenance, and rehabilitation over its lifetime, while providing safe and essential infrastructure to society. Concrete's proven performance is enhanced by the designer's ability to specify a mix design tailored to the application's goals.

For the latest in cement and concrete research for sustainable applications, please visit the Massachusetts Institute of Technology Concrete Sustainability Hub at https://cshub.mit.edu.

Join us on Twitter or Facebook for breaking news, Fast Facts, and new product and project developments at http://twitter.com/PCA_Daily and https://www.facebook.com/ThinkHarder.Concrete ■

REFERENCES

1 Carbon Leadership Forum (CLF). *2013. Product Category Rules (PCR) for ISO 14025 Type III Environmental Product Declarations (EPDs) of Concrete*, Revised Version 1.1, December 4, 2013: CLF.

2 World Business Council on Sustainable Development (WBCSD). 2013. *UN CPC 375 Concrete Product Category Rules*, version 1.0: WBCSD.

3 ASTM International. 2014. *Product Category Rules for Slag Cement*, August 2014, West Conshohocken, PA: ASTM International.

4 ASTM International. 2014. *Product Category Rules for Portland, Blended Hydraulic, Masonry, Mortar, and Plastic (Stucco) Cements*, September 2014, West Conshohocken, PA: ASTM International.

5 ASTM International. 2014. *Product Category Rules for Manufactured Concrete and Concrete Masonry Products*, December 2014, West Conshohocken, PA: ASTM International.

6 Bushi, L. and G. Finlayson. 2014. NRMCA Member National and Regional Life Cycle Assessment Benchmark (Industry Average) Report. Prepared for the National Ready-Mix Concrete Association (NRMCA): Athena Sustainable Materials Institute.

7 Blumenthal, M., "The Use of Scrap Tires in Rotary Cement Kilns, Scrap Tire management Council, Washington DC, 1996

8 Rubber Manufacturers Association, 2013 Scrap Tire Management Summary, Nov 2014, http://www.rma.org/download/scrap-tires/market-reports/US_STMarket2013.pdf

9 FHWA, *Recycled Concrete Aggregate*, Federal Highway Administration National Review, Federal Highway Administration, Washington, D.C., USA, 2008.

10 FEMA, *Design and Construction Guidance for Community Safe Rooms*, 2nd edition, FEMA 361, Federal Emergency Management Agency, Washington, D.C., USA, 2008, 374 pages.

11 Kiesling, Ernst W., and Carter, Russell (1997), Investigation of Wind Projectile Resistance of Insulating Concrete Form Homes, 2nd ed., RP122.02, Portland Cement Association, Skokie, Illinois, 2005, 17 pages.

12 NASA website–http://science.nasa.gov/science-news/science-at-nasa/1999/essd26apr99_1

13 Fast Facts–www.sustainableconcrete.org, 2013