



Precast/Prestressed Concrete Institute

High Performance Precast Insulated Sandwich Wall Panels



designer's notebook

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High performance buildings are designed to satisfy functional, human comfort, environmental and economic considerations. They incorporate the highest level of design, construction, operation and maintenance principles to provide maximum performance while meeting the owner's project requirements. All the components of the building should be addressed in a cohesive, whole building approach, taking into account cost effectiveness—particularly life-cycle costs, sustainability, security and safety, accessibility, productivity of occupants, functionality and serviceability, and aesthetics.

Whether derived from reduced energy and operating costs, lower maintenance costs, improved functionality or productivity, or continued operational capability after a catastrophic event, a high performance building offers its owners a greater return on investment than a conventional building. High performance precast insulated sandwich wall panels can provide significant contributions toward these goals. These panels are composed of two wythes of concrete separated by a continuous (edge-to-edge) wythe of insulation. Panels can be bearing walls, supporting gravity loads, as well as resisting wind, seismic, and blast loads, or they can be cladding panels transmitting wind, seismic, and blast loads to the structural frame and foundation. Sandwich wall panels provide a versatile and economical means to meet the structural, thermal, moisture, and architectural requirements of a structure.

Energy Efficiency. A high performance building must deliver better energy efficiency than a building meeting the minimum requirements of the governing energy code. A building's energy performance involves the interplay of the environmental (climate and weather), the building's systems (envelope, mechanical, plumbing, and lighting), and the building's occupancy (people, appliances, equipment, devices, and function). An energy efficient envelope is one that integrates and optimizes insulation levels, shading of glazing, solar reflectivity of exterior surfaces, air and vapor barriers, and thermal mass.

The interior and exterior concrete layers (wythes) protect the insulation layer against damage during construction. They limit the production of toxic gases during and after building fires and do not promote the spreading of flames to adjacent components. The concrete wythes are resistant to rodent, insect and impact damage, and they do not support mold growth. The insulation cannot shift or settle during or after construction, so there are no gaps in thermal protection. The concrete wythes provide excellent air barriers and limit air infiltration.

The thermal performance of edge-to-edge insulated precast concrete sandwich wall panels



Figure 1 Insulated sandwich wall panel with continuous edge to edge insulation.

with no or minimal thermal bridges maintains the R-values for continuous insulation as defined by ASHRAE 90.1-2010¹, thereby lowering energy costs (**Fig. 1**). In some climates, increasing wall and roof R-values by as little as 5 can reduce energy costs by 5 to 20%.² High performance precast concrete sandwich wall panels commonly have steady state R-values ranging from 12 to 20 hr ft² °F/Btu. The thickness of the insulation is determined by the thermal characteristics of the insulating material and the thermal loads on the structure.

Specific wall thermal characteristics can be designed for each face of the structure to suit its sun orientation. Precast concrete cladding can be detailed with integral shading devices or deep window recesses to manage solar heat gain. They can also be detailed with shallow recesses or light shelves to maximize daylighting, significantly reducing reliance on artificial illumination and its associated energy costs.

A key benefit of a concrete structure is its “thermal mass”, its ability to absorb and release heat. Concrete has a high specific heat, high density and low conductivity, therefore a large amount of heat energy can be absorbed with little change in temperature. The high thermal mass provides thermal storage, reducing daily and seasonal temperature swings, absorbing heat during the day in summer and cooling the building by storing heat from the sun over the surface of the building rather than allowing it to flow into the building. This cycle reverses at night, during the cooler time of the day, when heat is released back out into the atmosphere. By damping and shifting peak loads to a later time, thermal mass reduces peak energy requirements for building operations. As an added benefit, indoor temperature fluctuations are reduced and occupant comfort is enhanced. The required capacity of the heating/cooling equipment is also reduced, lowering initial costs as well as ongoing operating costs since smaller equipment running continuously uses less energy than large equipment running intermittently. (See Designer’s Notebook “Energy Conservation and Condensation Control”, www.pci.org/publications.)

ASHRAE 90.1-2010 acknowledges the thermal mass benefits of concrete walls in specifying lower minimum insulation R-values and higher maximum wall U-factors for mass (concrete) wall construction in specific geographic areas. Thermal mass is not a total substitute for insulation. Although much of the heat stored in mass exterior walls is reradiated to the exterior of the building, some is also radiated to the interior. High performance precast concrete sandwich wall construction is an excellent way to combine mass and insulation in walls. The function of insulation is to form a zone with low thermal conductivity (high R-value) that slows transmission of heat energy through the building envelope. When used in the right combination, insulation and thermal mass, along with a building design that captures solar light and heat energy, can improve the thermal performance of buildings and lower overall energy requirements. Also, smooth steel trowelled interior concrete walls or ceilings can be painted or left bare to provide a clean, durable and mold resistant surface. Not only is less material used, but the exposed thermal mass elements can more readily absorb heat from the interior spaces and later release the heat in the evenings when buildings are not occupied.

Due to the thermal mass effect of high performance insulated sandwich wall panels, the effective whole wall R-value of the high performance wall system can be up to two times greater than that of the material (steady state) R-value, resulting in energy cost savings. The degree of improvement in R-value in a given structure is greatly dependent upon the climate (location), the occupancy type, the building orientation and other features of the building design.

A continuous air barrier is also important for building performance. Low air infiltration leads to reduced sensible and latent heat loads in summer and reduced sensible and latent heat demand in winter. Unfortunately, air infiltration is not readily modeled in many energy analysis tools, so air infiltration is often overlooked. However, concrete 4 in. or more in thickness functions as an air barrier and reduces air infiltration.

Solar reflectance index. The solar reflectance index (SRI), is the ratio of the amount of solar radiation reflected from a material surface to the amount that shines on the surface. It is measured on a scale of 0.0 (not reflective) to 1.0 (100% reflective). Concrete has the following SRI values:

Material surface	Solar Reflectance Index
Aged concrete	0.2 to 0.3
New concrete (traditional)	0.4 to 0.5
New concrete with white portland cement	0.7 to 0.8

Solar reflectance requirements for walls are contained in Section 5.3.2, Mitigation of Heat Island Effect of ASHRAE 189.1-2009, "Standard for the Design of High Performance Green Buildings". On exterior surfaces, SRIs above 0.3 (generally light colors) result in low solar heat gain. For instance, a low solar reflectance north wall and high solar reflectance east and west walls and roof form the most energy-conserving arrangement in a northern hemisphere climate that uses both heating and cooling. Changing an insulated wall from a low solar reflectance to a high solar reflectance can reduce annual cooling energy flux (heat flow through the building envelope). High solar reflectance surfaces are especially important where cooling dominates the energy requirements. It should be noted, however, that the solar reflectances of exterior walls will have less effect on energy consumption when the walls have high R-values and thermal mass. The benefit of high solar reflectance surfaces in decreasing cooling loads is often greater than the benefit of low solar reflectance surfaces in decreasing heating loads even in cold climates. This occurs because of the decreased benefit of the sun in the winter due to its low angle of incidence, shorter days, and cloudier conditions.

Commissioning. Green building rating approaches include prerequisites for minimum energy performance and may include commissioning to verify performance of building components and systems. Commissioning or the verification of how a building performs once the certificate of occupancy is issued is the only way to ensure the design and performance of the building is being maintained, therefore reducing energy and emissions. The commissioning process is outlined in ASHRAE Guideline 0-2005³: “The Commissioning Process.” The National Institute of Building Sciences’ (NIBS) Guideline 3-2006: “Exterior Enclosure Technical Requirements for the Commissioning Process”⁴ describes the specific tasks necessary for implementation. The minimum energy performance prerequisite is a design submission item, meaning that the project can submit and earn approval of the prerequisite at the end of the design phase. Because the completed project may be slightly different than it was modeled, the measurement of energy consumption should be conducted over time. This will be a requirement of the International Green Construction Code.⁵ The first step of any energy audit or commissioning should be thermal imaging of the building envelope to verify actual building performance and compliance with owner’s project requirements. Thermal imaging includes an infrared survey of the exterior walls, windows (from both the outside and inside), and roof to locate thermal bridges or breaches in the air barrier. Once the high performance building is thermally efficient, the next step in the energy auditing process should be to evaluate HVAC, plumbing, electrical power, lighting, and building equipment and systems. This analysis should consider optimization, not just proper operations. ASHRAE Guideline 32P, “Sustainable High Performance Operation and Maintenance” provides guidance on optimizing operation and maintenance of buildings to achieve the lowest economic and environmental life cycle cost without sacrificing safety or functionality. In addition, the building should be properly pressurized and the HVAC dehumidifying properly.

Thermal imaging or infrared thermography of a building envelope provides a visual representation of temperature differences which allows for the analysis of heat losses. It makes it possible to immediately detect air or water leakage pathways, as well as identify thermal bridges caused by conductive materials or a lack of insulation (see Fig. 2). An infrared survey is a relatively inexpensive process to perform, but is infrequently done. Instead, the focus is on the mechanical and electrical systems within the buildings.

Reduced Life Cycle Costs. Making full life-cycle costs of a building project part of the cost benefit analysis will provide a major step towards a unified approach for the construction of high performance buildings. Life-cycle costing is a sound means of assessing the cost of all elements involved in constructing and operating a building throughout its life so that rational economical choices can be made. Energy and maintenance costs can be significant over a building’s life, so the owner and designer should consider the long-term impact of these costs throughout the design process.

Precast’s speed of erection helps bring the structure on-line quickly as high performance wall



Figure 2 Thermographs of a high performance precast building show that the exterior concrete surfaces have a nearly uniform temperature, verifying the lack of thermal bridges or air leaks. Only the windows and parapet areas show higher local temperatures.

panels can be preglazed at the plant or window installation can be immediately completed in the field resulting in quick enclosure of the shell in any weather condition. Faster completion reduces interim financing and construction management costs, results in earlier cash flows, and produces other economic benefits. Loadbearing architectural precast concrete walls support floor loads and simultaneously form the exterior finish of the building, eliminating the redundancy between exterior finish and structural components. This ultimately lowers the building's long-term overall cost and can make the use of precast concrete more economical. Cost savings are greatest for low to mid-rise structures with a large ratio of wall-to-floor area.

Precast concrete manufacturing cost efficiencies have made precast concrete walls and structural systems very competitive. The cost advantages shift strongly to precast's favor when the long-term benefits are factored in. Due to precast's high durability, a high performance precast concrete structure can be designed to match the intended life of a building with minimal maintenance, providing substantial long-term savings. Because precast concrete panels are normally large, the quantity of joints in the building is reduced. Fewer joints reduce the life-cycle cost of replacing joint sealants and add value to the client's project. Typically, the only maintenance precast concrete panels require is recaulking (service life of caulking depends on sealant material, installation, and exposure conditions). Joint sealants should annually be inspected and repaired if necessary. Precast concrete panels present a durable, aesthetically pleasing exterior surface that is virtually air and watertight and does not require painting. Within a building's interior, precast insulated sandwich wall panels provide a finished steel trowelled surface that doesn't require furring or drywalling after installation, eliminating some interior work. They can be left exposed or painted (**Fig. 3**). They also eliminate the need for



Figure 3 The insulated sandwich wall panels of the high school media center allowed the interior finish to be exposed painted precast concrete.

separate insulating and finish subcontractors. Integral finishes not only result in a savings of material and labor, but also reduce the overall thickness of the exterior wall, permitting maximum interior space utilization.

Design Flexibility or Functionality. In building practice, the most economical application of precast concrete wall units is as loadbearing structural-aesthetic components. The loadbearing units become an integral part of the structure, transferring loads to the foundation, including gravity loads from the floors and roof and lateral forces from the effects of wind or seismic events. Such an arrangement can be economical, not only from a structural design viewpoint, but also from the viewpoint of overall construction. The loadbearing elements also provide for the horizontal stability of the building.

From a design perspective, the greatest advantage of a loadbearing precast concrete system is the flexibility it provides for space planning as it allows interior space to be unencumbered by



Figure 4 Electrical conduit and outlet box being installed in insulated sandwich wall panel.

a multitude of perimeter columns. Large open floor plates can then be accommodated quite easily offering great flexibility in marketing the space.

Combining loadbearing wall panels with an economical precast structural floor system creates long, clear unobstructed spans with large, open bays with interior heights up to 55 feet. In most cases, the height is restricted only by what can be transported and delivered to the site. For offices, 45 to 50 foot spans are optimal because beyond that length, bays become so deep that daylighting is compromised.

With early coordination, panels can be designed with electrical conduits and outlet boxes cast right into the panel, eliminating additional interior furring and material (**Fig. 4**). This decreases trade overlap problems and eliminates unsightly surface mounted materials and the need for a separate wall cavity. Field labor costs are reduced, as installations can be completed simply by pulling the wires, installing fixtures and covering the boxes.

Description	STC (OITC)
4 in. flat panel, 54 psf	49 (43)
5 in. flat panel, 62 psf	52 ¹
6 in. flat panel, 75 psf	55 (46)
8 in. flat panel, 95 psf	58 (50)
10 in. flat panel, 125 psf	60 ¹

1. Estimated values

Table 1 Sound Transmission Class (STC) and Outdoor-Indoor Transmission Class (OITC) of Precast Concrete

The integration of architectural and structural precast concrete offers an aesthetically pleasing and structurally efficient marriage. It allows the precast insulated sandwich panels to serve structural functions, limiting the need to incorporate multiple materials and trades.

Precast concrete walls usually do not need additional treatments to provide adequate sound insulation, as mass is concrete's greatest asset when used as a sound insulator. **Table 1** presents the acoustical ratings of various solid flat precast concrete panels. The STC of a sandwich panels is about the same as the STC of a wall with a thickness equal to the sum of the two concrete wythes (ignoring the insulation). The opaque portion of a high performance wall should have an STC of 50⁵.

Life Safety/Environmental Conditions. A high performance building must assure the continued operational capacity and performance of a facility after natural disasters or manmade catastrophic events. For example, the Gulfport Federal Courthouse **Figure 5**, constructed of a concrete frame with architectural precast concrete cladding panels, sustained 130 mph winds and the storm surge from Hurricane Katrina with no damage to the precast. Water reached a level of 2 feet in the courthouse, which is about 28 feet above sea level. There was evidence of impact damage from floating debris to the granite cladding at the base of the building. However, the precast concrete panels behind the granite were unaffected by these forces, as the outer wythe of the integrally insulated walls provided excellent protection from any flying debris during high winds. Courthouse employees were able to return to work soon after the interior had dried.

In the interest of life safety and property protection, building codes require that resistance to fire be considered in the design of buildings. Precast concrete panels are inherently non-combustible and do not serve as fuel or contribute to the fire load. The panels can be designed to meet any degree of fire resistance that may be required by building codes or insurance companies. Precast concrete eliminates the need for and cost of additional fireproofing measures. The insulation is protected by the concrete and also does not contribute to the fire load. Also,



Figure 5 Insulated sandwich wall panels provided excellent protection from hurricane force winds and flying debris.

the danger of toxic fumes caused by burning of cellular plastics is practically eliminated when the plastics are completely encased within concrete sandwich panels.

Insulated precast concrete walls provide structural integrity and security, plus an added measure of fire safety. The fire resistance of insulated sandwich wall panels is conservatively equivalent to the fire resistance of a solid panel with a thickness equal to the sum of the thickness of the two wythes. Fire ratings of one, two, three or more hours can be achieved by varying the thickness of the wythes (**Table 2**).

Aggregate	Thickness in inches for various fire durances			
	1 hour	2 hour	3 hour	4 hour
All lightweight	2.5	3.6	4.4	5.1
Sand-lightweight	2.7	3.8	4.6	5.4
Carbonate	3.2	4.6	5.7	6.6
Siliceous	3.5	5.0	6.2	7.0

Table 2 Thicknesses of Concrete Wall Panels for Various Fire Endurances Based on Results of Fire Tests

In today's environment of enhanced risk, some facilities require protective design and management for risk of intentional and accidental explosions. Solid architectural precast concrete and precast, prestressed concrete insulated sandwich wall panels can provide a significant level of protection from blast loads. Insulated sandwich wall panels have been tested at Tyndall Air Force Research Laboratory in Panama City, Florida with a combination of standoff distance and amount of explosive. Results provided valuable information concerning precast insulated sandwich panels' ability to withstand explosive blasts. For more information on the insulated sandwich wall panel tests performed by the Air Force, visit www.pci.org/ascent, winter 2011.

Indoor Air Quality. Condensation control and mold prevention focuses on preventing infiltration (which can carry significant amounts of water vapor) through the building envelope, interrupting water-vapor diffusion, typically by using a vapor retarder, and maintaining temperatures above the dew point for surfaces exposed to moisture, typically by installing insulation or increasing circulation of warmer air. Guidance on design for mold avoidance is available in Designer's Notebook "Avoidance of Mold" at www.pci.org/publications.

A concrete panel with concrete on the indoor surface generally serves the dual function of primary air barrier and vapor retarder, eliminating the need for additional materials required with other façade systems. By using edge-to-edge, closed-cell foam insulation in high performance precast concrete sandwich wall panels, the primary vapor retarder is prevented from reaching the temperature at which condensation may occur, thereby reducing the potential for mold. The insulation also resists moisture and provides a barrier to liquid and vapor transfer through the wall. The dewpoint temperature will usually fall within the insulation. For cooler and freezer structures, it may be desirable to add a vapor retarder rolled and pushed in joint or add moisture resistant fire rated expandable polyurethane foam-in-place insulation in the joint. Insulation and a moisture and air-barrier system are critical parts of a high performance building envelope. Depending on its thickness, concrete is either a semi-impermeable or semi-permeable vapor retarder; thicker and drier concretes are more impermeable.

Because of its panelized construction, fewer points of potential moisture penetration exist with precast concrete. Fewer joints help control moisture and eliminate the possibility for mold growth from water that may penetrate walls. Precast concrete is not a food source for mold as it is not organic. As a result, it does not promote mold growth, even if wetted.

Concrete has low volatile organic compounds (VOC) emittance and no off-gassing that can cause deteriorated indoor air quality. ASHRAE Guideline 10-2011 “Interactions Affecting the Achievement of Acceptable Indoor Environments” summarizes available knowledge on the complexity of the indoor environment and its impact on building occupants.

Durability. Precast concrete wall panels provide proven long-term durability. They provide a façade that is exceptionally resistant to impact, break-ins, corrosion, weathering, abrasion, and other ravages of time, making it virtually maintenance-free and resulting in preservation of the building’s original look. High performance insulated precast concrete wall panels are strong enough to withstand high winds and wind driven projectiles, hurricanes and wildfires. The high strengths and low water-cement ratios used in the precasting process, combined with proper compaction and curing in a controlled factory environment ensure a dense, highly durable concrete. Low water-cement ratio concrete has been proven to resist weathering and corrosion of embedded steel. Air-entrainment is used to improve freezing and thawing resistance, particularly in severe environments.

Precast concrete also creates a durable interior wall that can be finished to provide a distinctive and aesthetically pleasing look. At the same time, the wall features a surface that will not be dented, punctured, corroded, rusted or otherwise damaged by heavy-duty use or equipment. Damage-resistant interior steel-trowelled concrete walls can accept direct-applied coverings, coatings or paint to minimize interior obstructions and fit-out costs. Precast concrete resists abrasion and high-moisture atmospheres that can corrode metal. Panels can be cleaned easily, even with harsh chemicals and steam pressure, ensuring a clean, crisp, hygienic environment. Vermin and insects cannot destroy concrete because it is inedible.


High performance precast concrete insulated sandwich wall panels can provide an aesthetically pleasing durable exterior finish, a paint-ready, durable interior surface, and effective thermal and moisture protection for a building⁶. These durability advantages can reduce costs over the building’s life—a great advantage to owners who understand the need to consider long-term costs during the design phase. High performance insulated precast concrete panels can provide a building with a long design service life (a minimum of 50 to 60 years) that far outpaces other façade designs due to their durable and low maintenance concrete surfaces.

Precast concrete has functional resilience due to its robustness, longevity, and durability combined with disaster resistance. This creates safe, secure, comfortable, and productive environments to live and work.

Aesthetics. Architectural precast insulated sandwich concrete panels provide the designer an unlimited vocabulary of design expression with visually interesting shapes that are functional in application and project an image of strength. Concrete offers limitless potential for the development and manipulation of massing, color, form, texture and detail.

The plasticity of concrete allows the designer to achieve a high level of detail in the profile, scale, and character of a building. Design flexibility is possible in both color and texture by varying aggregate and matrix colors, size of aggregates, finishing processes and depth of exposure. Combining different finishes using the same or different concrete mixes within a single precast concrete unit can provide additional flexibility.

Finishing techniques include sandblasting, acid etching, and retarding (exposed aggregate). Each technique renders a distinctly different appearance, and varying the aggregate exposure depth of any one of these finishing techniques changes the precast's surface appearance. In addition, color and/or texture can be altered even within a single panel. Employing standard or custom molded formliners is another effective and economical way to heighten aesthetic interest.

Thin brick, tile, terra cotta, or natural stone can be cast into the panel either as a feature or as an entire facing, increasing color options. Thin brick faced precast concrete gives the traditional appearance of brick while leveraging the strength, speed of enclosure and economy of precast concrete. Due to low absorption of thin brick, efflorescence is reduced or eliminated. In addition, inlaid thin brick precast concrete walls do not require periodic tuckpointing. Using cast-in thin brick precast concrete panels reduces the cost of coordinating numerous exterior wall subcontracting trades. 

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