Designing Precast Concrete Enclosures for Thermal and Moisture Efficiency

By Brad Nesset and Emily Lorenz, PE

The design of the building enclosure and the performance of the exterior wall system are critical to a structure's performance and longevity, as well as the quality of the interior environment for those living and working inside.

It is paramount that designers and contractors understand the fundamentals of thermal and moisture management. As Joe Lstiburek, PEng, from Building Science Corporation said, "Good materials and good workmanship no longer constitute a high-quality structure…we must now understand how buildings work."

How well buildings perform depends on how well, and in what manner, their exterior wall systems perform. In addition to serving as an architectural façade or a structural element, precast concrete wall systems can also serve as both thermal and moisture protection. These can be great benefits to a project if they are properly accounted for in the design.

Thermal performance and moisture management are two of the most important and complex roles of the building enclosure. Thermal efficiency and moisture control are interdependent, and both need careful consideration to make a building enclosure perform efficiently. With approximately 70% of generated electricity being consumed by buildings, thermal performance has become a focal point for many building owners as they want to control heating, ventilation, and air-conditioning (HVAC) costs and contribute to a sustainable environment. However, it is equally important to understand and control moisture migration, a topic that is gaining importance as more people begin to understand the long-term damage possible if moisture transfer is not considered during design.

These topics can best be summarized by the acronym WAVE: water, air, vapor, and energy. All four areas must be addressed in order to properly design a building enclosure.

WATER

There are a number of different enclosure types used in building design, including rain screens, drain screens, and double-skin facades. This article will explore the differences between the two most common types of enclosures: cavity walls and barrier systems. When assessing the available means of controlling water ingress through the building enclosure, the initial question is whether the exterior walls act as a cavity or a barrier system.

A cavity system is essentially two wall elements separated by a hollow space or cavity. The outer wall element provides the finish and an initial defense against bulk rain water, either by shedding or absorption. The cavity or air space between the two wall elements is designed to collect any bulk water that penetrates the outer wall element and redirect it to the building exterior. This drainage plane is the primary moisture defense system. Given its concealed nature, it is often difficult to determine if there is a construction defect until damages are severe and expensive to fix. Connections and components are also hidden inside the cavity, where issues may go undetected for years.

Alternatively, a barrier system, or face-sealed system, relies on the integrity of the outermost wall system to resist bulk water and moisture ingress. This is typically more cost effective, and if problems occur, they are easier to detect. The key to a barrier system's performance is correct detailing. Besides precast concrete wall systems, other barrier systems include glass curtainwalls, and metal systems.

Editor's note
ASHRAE Standard 169-13, Climatic Data for Building Design Standards, includes climate zone maps and data for locations worldwide. Data are available for free download at: Ashrae.org/169_2013data

Material	Average air leakage, cfm/ft^2 of surface at 0.3 in. water
Solid precast concrete wall	No measurable leakage
Aluminum foil vapor barrier	No measurable leakage
Extruded polystyrene insulation	No measurable leakage
Closed cell spray foam insulation	0.0002
½ in. fiberboard sheathing	0.31
Breather-type building membranes	0.0022 to 0.71
Uncoated brick wall	0.31
Uncoated concrete block	0.41
1 in. expanded polystyrene	0.93

Table 1. Air Leakage of Various Materials

Material	Perms	Perm-in.
Concrete	—	3.2
Wood	—	0.4 to 5.4
Extruded polystyrene	—	1.1
Expanded polystyrene	—	2.0 to 5.8
Polyisocyanurate	—	0.02 to 6.6
Glass fiber batt	—	120
Kraft batt	1	—
Gypsum wallboard (⅜ in.)	50	—
Polyethylene (6 mil)	0.06	—

Table 2. Perm Ratings of Various Materials

AIR

Building enclosures are often constructed of many materials, some of which allow a certain amount of air to pass through them. Unsealed joints, window openings, flashings, and other similar openings can allow air movement through the building enclosure system. Together, the amount of air that can pass through a building's enclosure can be significant.

Air movement from the inside of the building to the outside through gaps, openings, and joints in the building materials is known as exfiltration and is usually caused by a difference in air pressure as a result of stack and wind effects. Similarly, infiltration is the movement of air into a building from the outside. In addition to stack and wind effects, infiltration can also be caused by depressurization from ventilation (negative pressure).

When not properly dealt with, the physical movement of air through the building enclosure can carry with it significant amounts of moisture which can severely impact the overall performance of the building.

Table 1 lists several building materials and their average air-leakage ratings. Sheathing products show a measurable amount of air leakage, whereas concrete shows no measurable leakage. This is important because a precast concrete wall can serve as a continuous air barrier, as required by the 2018 International Energy Conservation Code.

In panelized construction like precast concrete wall systems, the panels' connectivity, joint treatment, and continuity of insulation materials are critical not only to designing for water and air, but also for vapor and energy. *Figures 1-4* are examples of a few key details of various interfaces and treatments.

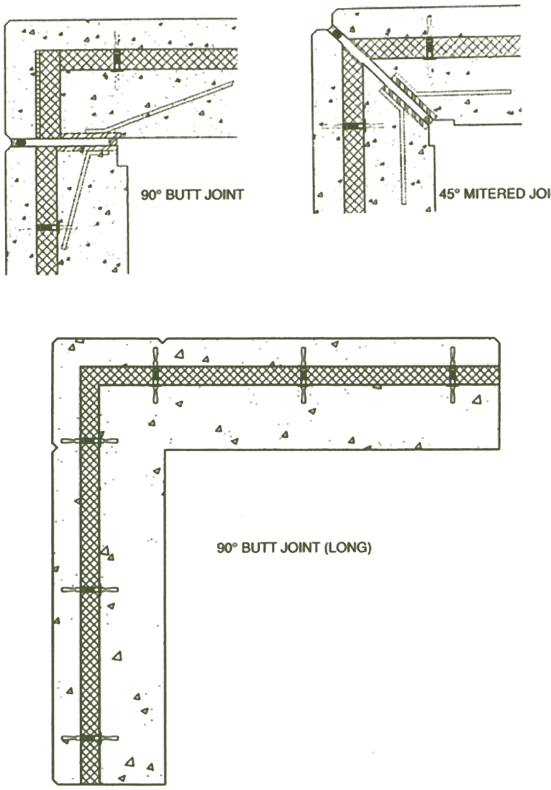

Figure 1. Example of precast concrete corner butt joints.

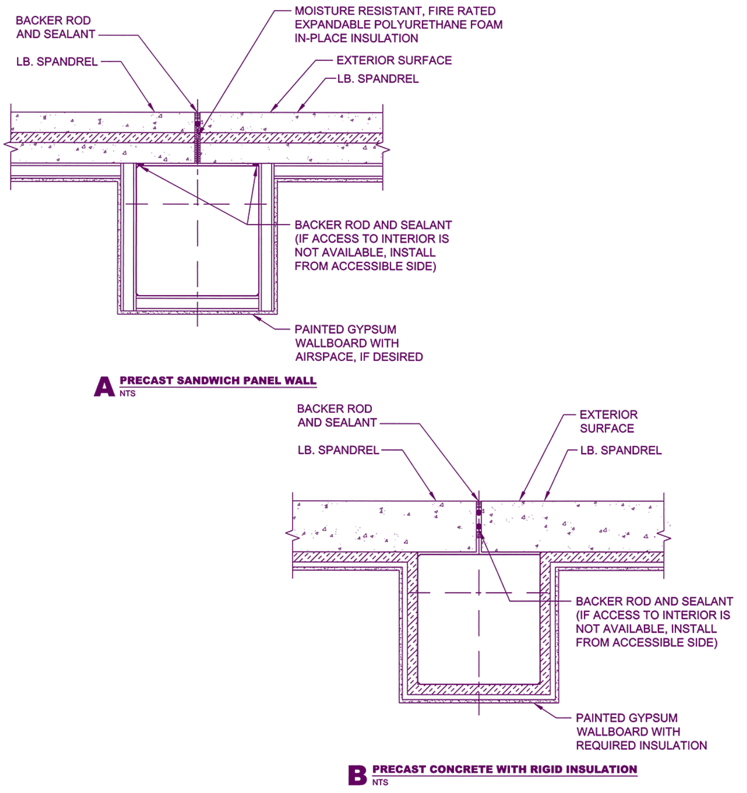

Figure 2. Example of precast concrete panel-to-panel joints.

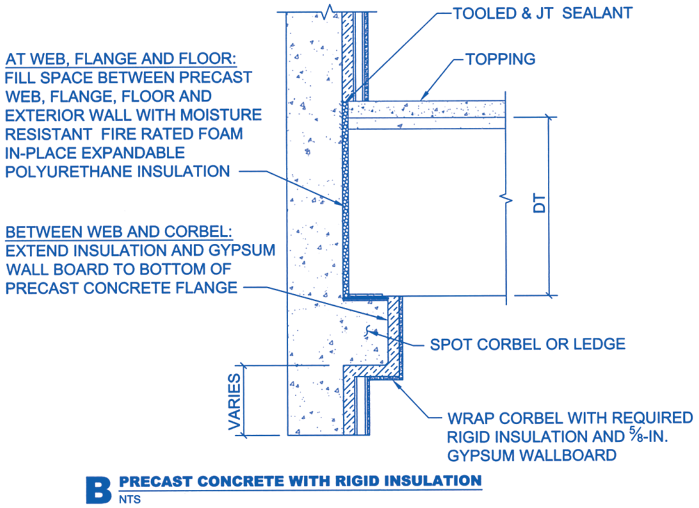

Figure 3. Example of precast concrete floor connection.

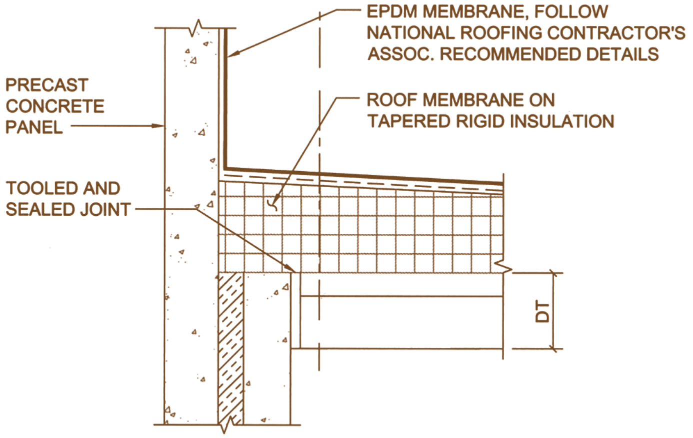

Figure 4. Example of precast concrete parapet connection.

The key item here is the continuity of the insulation and the treatment of the joint, both inside and out. Goals to be achieved in detailing this type of construction are:

- a panel that is free of thermal bridges,
- joints that are secure and free of gaps or cracks that would allow for moisture to enter the building, and
- materials that will not allow vapor to transfer.

VAPOR

With its direct path into a wall assembly, air movement transfers more moisture than vapor, but vapor transfer shouldn't be overlooked. Water vapor spreads through a wall assembly through a process known as diffusion. In vapor diffusion, moisture migrates from areas of high vapor pressure to areas of lower vapor pressure. This means that the moisture on the wet, exterior face of a wall assembly will attempt to spread into the dryer, interior materials in an attempt to equalize the vapor pressure. Achieving equilibrium is a fundamental force of nature and must be considered in building design and construction.

During cold winter months, warm indoor air migrates towards the colder exterior of a building. During the warmer months, warm exterior air is driven toward the air-conditioned interior of a building. Warmer air is able to hold more moisture than cooler air, so vapor diffusion dictates that the excess moisture spreads to the drier spaces in the wall assembly.

The key to stopping this migration lies in careful selection of the materials that comprise a particular wall system. Each component has a perm rating. Generally speaking, the lower the perm number, the better the ability to stop the migration of moisture.

According to the *International Building Code*, a material with a perm rating of 1.0 or less is considered a vapor retarder. A material with a lower perm rating, such as poly sheeting with a perm rating of 0.04, is typically considered a vapor barrier. One of the most common materials used to control moisture in wall assemblies is rigid insulation. The type of material and its detailing is important for vapor control. Below are several common building materials and their respective perm ratings. As *Table 2* illustrates, certain materials qualify as a vapor retarder, some act like a barrier, and others will need some additional detailing to stop the migration of moisture. The critical issue then is which materials should be used and in what manner.

The question of whether a vapor retarder or a vapor barrier will be needed in the assembly greatly depends on the building's intended use and the part of the country in which it is being constructed. To help guide the design process, the U.S. Department of Energy has developed a regional hygrothermal chart that divides the United States into eight zones and five climate types. The five climate types are:

- Severe Cold (Alaska and Northern Minnesota)
- Cold (Chicago and the majority of the country above the Mason/Dixon line)
- Mixed/Humid (Which is the Southeast and Pacific Northwest)
- Hot/Dry/Mixed (Desert South West)
- Hot/Humid (Florida and Gulf Coast)

Depending on the building's intended use and the materials selected for the wall assembly, the inclusion of a vapor barrier will be guided by which of the climate zones the building is located within. As an example, consider a cold climate like Chicago, where walls are typically designed for the heating season. If there are any inconsistencies or thermal bridges in the wall insulation, or if the wall makeup doesn't have a low perm rating, there is a chance that vapor diffusion will occur. In that situation, the warm, moisture laden, interior air may eventually meet with a colder surface near the exterior of the wall. If that happens, condensation is likely and water will build up inside the wall.

Figure 5 illustrates this phenomenon. This is a brick/block cavity wall school in the Cincinnati area. In the bottom photo, where the control joints and brick ledge are shown, moisture has migrated into these areas and impacted the thermal efficiency of the insulation. This creates an unequal thermal array and ultimately impacts the interior temperature of the concrete masonry units.

The thermal image on the top is the interior of that wall. Looking past the desks in this classroom, it is clear that the base of the wall is very cold, while the top remains quite warm. This is the unfortunate result of the insulation value being significantly reduced by the presence of water.

Warmer climates also require proper consideration to avoid similar moisture issues. In a hot/mixed climate, diffusion commonly occurs when wind-driven rain is absorbed by the wall's exterior material and stored. When the sun later comes out, this hot, wet air is pulled through the assembly to the cool, dry, interior air. Just as in the colder climate example above, it is critical that a defense mechanism be in

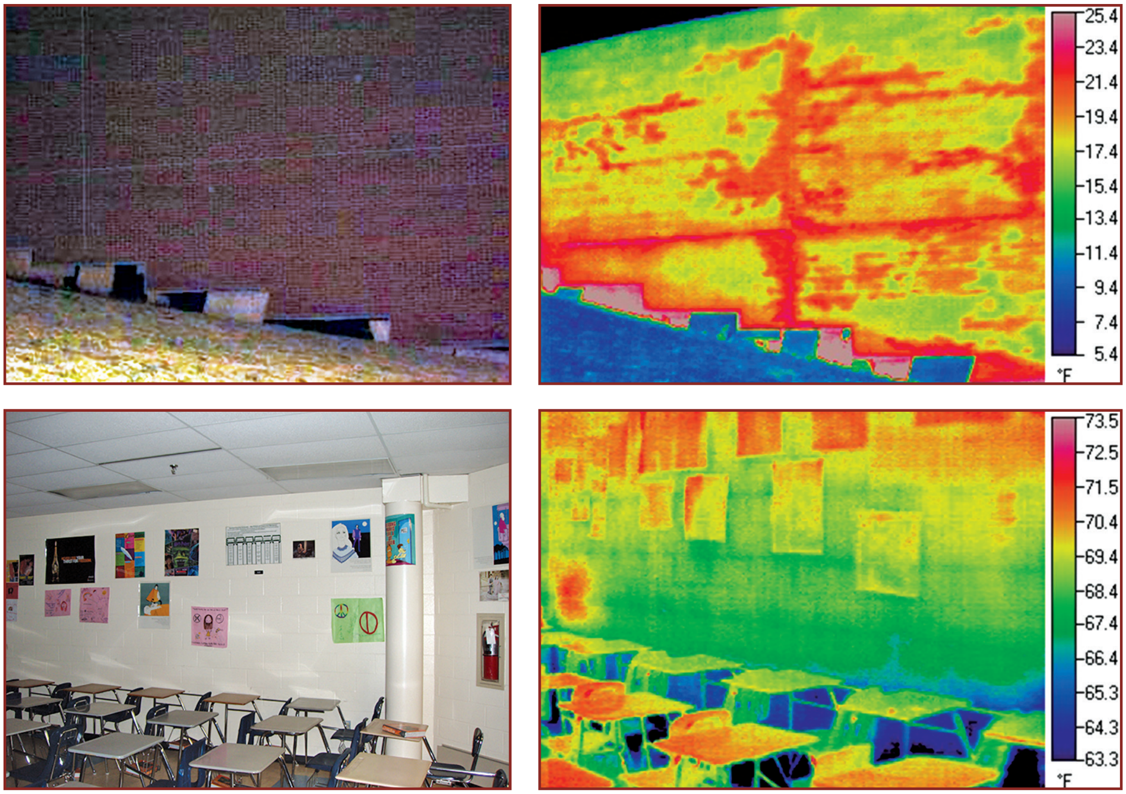

Figure 5. Thermal imaging of block and brick walls.

place within the wall assembly to stop this migration.

The actual selection, detailing, and placement (interior or exterior) of the vapor-retarding material is a process that involves a number of decisions, but ultimately, the key is how it is being integrated into the assembly. Simply put, the ideal material must have a low perm rating to slow vapor diffusion and be continuous, with no penetrations, so as to not allow air exfiltration and infiltration.

ENERGY

There are several variables that affect thermal performance and energy efficiency of building enclosure systems. Some of these include the exterior surface color (solar absorptivity), the heat capacity of the enclosure system components (including thermal mass, if applicable), and the type, amount, and position of the insulation. But before further explanation of those elements, we must understand heat flow.

Heat flows in three ways: conduction, convection, and radiation. Conduction is the flow of heat by direct contact. Convection is the flow of heat by air movement. Radiation is the transfer of heat energy only through the molecules between two objects some distance apart. For transfer of heat energy to occur, a temperature differential must exist. In those cases, the heat energy travels from the direction of high energy (warmer) to an area of lower energy (cooler).

Of course, it is often desirable to limit the flow of heat energy. During summer, people try to keep the heat from coming into their homes, and in the winter, they strive to keep it from leaving. This is accomplished through insulation.

The fundamental metric of insulation is its steady-state resistance to heat flow. This metric is typically referred to as R-value. In general, a higher R-value means more resistance to heat flow and a better insulating power for the material in question. As a point of comparison, *Figure 6* shows relative values of some typical construction materials and their respective R-values per inch.

It is interesting to note that concrete has a very low R-value, around 0.1 per inch, and would seem to be a poor material choice when discussing energy-efficiency in construction. However, that is only part of the equation. Concrete also possesses tremendous heat capacity, or the ability to store heat. Heat capacity is used by energy codes to determine if a material has enough thermal mass to use the mass criteria.

When properly integrated into a structure, thermal mass moderates the interior temperatures producing a comfortable space while significantly reducing energy demand needed to heat and cool a structure.

How is this accomplished? When heat energy strikes a wall, it warms its surface. Depending on the heat capacity of the material, a portion of this heat flows into the material, where it is temporarily stored, and some continues through the insulation and into the building. The rest either re-radiates back out of the material or warms the adjacent air. The greater the heat capacity (more thermal mass) of a material, the more heat energy it can temporarily store.

By slowing or temporarily storing this heat energy (in the case of precast concrete and integrally insulated wall systems), some of these heat gains can be released into the conditioned space during off-peak times of cooling, or discharged to the cooler, exterior air at night. In simple terms, the natural tendency for materials to achieve thermal equilibrium can be used to lower the energy consumption of a building.

The thermal mass effect is recognized in ASHRAE 90.1, which allows for a reduction

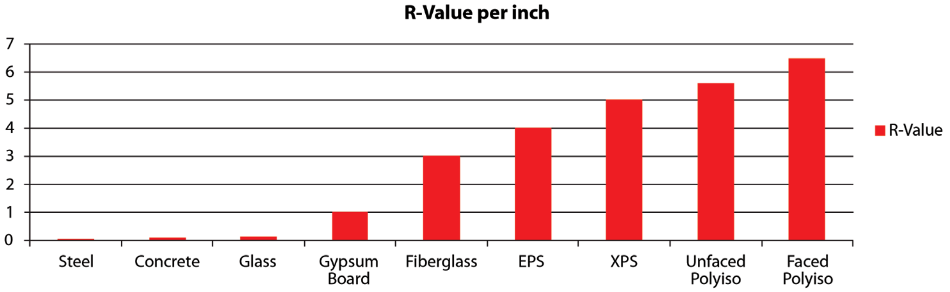

Figure 6. Typical R-value of materials.

in the effective R-value (and thus the amount of insulation) in mass wall systems. The benefits of thermal mass, coupled with minimal thermal bridging and continuous insulation, result in a very energy-efficient wall system. Often, precast concrete wall systems provide performance, or effective R-values, which are greater than the material R-value. In other words, a precast concrete wall system may have a material R-value of R-11, but an effective R-value of R-20. The effective R-value can be used in calculating heating and cooling loads, which can reduce the size of the HVAC equipment, and the associated initial costs. This is the opposite of what occurs with most stud and cavity wall systems. For example, a steel stud and batt insulation wall may have material R-value of R-19, but an effective R-value of only R-8.

SUMMARY

As energy codes increase in stringency, understanding building science is increasingly important to properly design a high-performance building.

Those with a deeper understanding of sustainable construction know that it is not just about high-tech components and quality materials, but the interactions among those components that ensures whether a building performs well or not. In the long run, the constant influence of water and heat play perhaps an even more critical role in the success or failure of any construction project. Understanding how to use and control their effects may also prove the deciding factor in the long term success of the designers and contractors building them.

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Brad Nesset

Brad Nesset is Commercial Vice President at Meadow Burke & Thermomass, a manufacturer of insulation systems for the concrete industry. He has a bachelor of science degree in construction management from the University of Northern Iowa and is an expert in wall panel applications, rigid foam insulations, and insulated concrete wall panels.

Emily Lorenz, PE

Emily Lorenz, PE, serves as the senior director of technical services at IIBEC. She has experience as an independent consultant in the areas of green structures and practices, energy efficiency, thermal properties, and moisture mitigation. Lorenz also specializes in green building code and standards work and advocacy.