

The formulae  $\frac{\partial \rho U}{\partial x} + \frac{\partial (\rho U V)}{\partial y} = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial x} \left( \mu \frac{\partial U}{\partial x} \right) + g_x(\rho - \rho_0)$  for building  $\frac{\partial}{\partial x} (\rho U V) = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial x} \left( \mu \frac{\partial U}{\partial x} - \rho u'v' \right) + g_x(\rho - \rho_0)$  state of the art  $\frac{\partial}{\partial x} (\rho U V) = \frac{\partial}{\partial x} \left( \mu \frac{\partial U}{\partial x} - \rho u'v' \right)$  biomedical research facilities.

# High-Performance Precast Concrete in Federal Biomedical Building Exterior Envelopes: Integration, Safety, and Security

Federal biomedical facilities demand exceptional performance from their building envelopes. Precast high-performance concrete (HPC), particularly ultra-high-performance concrete (UHPC), offers superior durability, strength, and resilience for these critical structures. Precast components can feature exposed concrete or integrate thin brick for an architectural finish typical of the NIH Bethesda campus. HPC/UHPC precast components use similar materials to conventional concrete yet offer compressive strengths up to 29,000 psi<sup>1,2</sup> and flexural strengths reaching 2,900 psi.<sup>3</sup> UHPC surpasses conventional concrete, with low porosity and permeability and steel fiber (typically) reinforcement enhancing ductility and durability, making it ideal for federal biomedical building exteriors.

To be effective, building envelopes must manage four control layers: bulk water, water vapor, air, and thermal. Precast HPC components and panels excel at integrating these layers, even at complex junctions, such as mechanical penetrations, windows, and doors, including:

**Bulk Water (Weather-Resistive Barrier):** Provide outstanding control as a barrier to exterior water penetration, aligning with the requirements of NIH *Design Requirements Manual (DRM)* Section 4.1.2, Exterior Walls.<sup>4</sup> Best practice detailing should include two-stage drained joints for superior rain control and pressure-equalized rain screen systems for enhanced wind-driven rain protection. At penetrations and fenestrations, robust flashing systems, backer rods, and high quality, compatible sealants complete the bulk water control layer.

**Water Vapor:** Concrete permeability is well-established as the leading indicator of its longevity in exterior envelope applications, and HPC has exceptionally low permeability compared to conventional concrete and most stone materials. Dewpoint analysis is performed on the wall assembly during design to prevent condensation within the wall assembly, with consideration for the impact of negative pressurization of the interior via the HVAC system in many biomedical facilities on the vapor drive. Vapor barrier continuity must be maintained at penetrations and fenestrations using high quality, compatible materials. Generally, HPC panels over 2 inches thick act as effective vapor barriers, but perms vary based on mix design.<sup>2</sup>

**Air:** HPC panels can be components of an effective, continuous air barrier system; however, it is common to utilize the bulk water control layer to prevent water and air penetration, reducing the amount of water vapor in the panels. Continuity across panel joints, penetrations, and fenestrations is ensured via high-quality sealants, airtight collars for mechanical penetrations, and compression gaskets with properly tooled topping sealant joints at window and door interfaces.

**Thermal:** Concrete, including HPC, has limited insulating properties, but this is offset by high thermal mass, which contributes to energy efficiency. Continuous exterior insulation, insulated precast sandwich panels, and high-performance glazing systems help meet energy performance goals.

Thermal bridging at penetrations and fenestrations must be mitigated by thermal breaks, such as insulated sleeves.

Beyond the control layers, in federal facilities, exterior envelopes must also address safety and security attributes. :

**Seismic Resilience:** HPC connections are designed to allow movement while maintaining envelope integrity, while mechanical penetrations and fenestrations are designed with sufficient clearance to accommodate anticipated displacements, making these components a preferred building material to withstand earthquakes. Ductile fiber-reinforced concrete enhances energy absorption during seismic events, minimizing cracking, spalling, and potential falling materials.<sup>2</sup>

**Lateral Load, Uplift, and Overturning Resistance (Wind):** Achieved through high component and panel strength, while connections and anchors effectively transfer lateral loads to the building structure.

**Flood Resilience:** HPC construction is inherently water-resistant and can be detailed to be an important component in a flood resilient building by ensuring wall bases and penetrations are designed to resist hydrostatic pressure during flood events or are located above the anticipated flood elevation.

**Fire Resistance:** Resistance to combustion or smoke development is inherent in HPC, meeting or exceeding code requirements. Penetrations must utilize firestopping materials and listed details that maintain the wall assembly's fire-resistance rating.

**Security Attributes:** Federal biomedical facilities require enhanced security measures to resist man-made hazards.

**Blast Resistant Wall Systems:** HPC's strength, ductility, and energy absorption make it ideal for blast-resistant design, with connections allowing load redistribution during overpressure events. Mechanical penetrations should be designed to withstand impacts and blast pressures with tamper-resistant sealing systems.<sup>2,3</sup>

**Fenestration Systems (Windows and Doors):** HPC-integrated windows and doors provide overpressure, ballistic, impact, and intrusion resistance. Security-rated fenestration systems integrate seamlessly with HPC panels, offering consistent protection across the facade.

**Biosafety Considerations:** HPC components meet security, blast, and forced entry requirements for high-containment laboratories while maintaining visual appeal and maintainability.

HPC and UPC components have some disadvantages which need to be considered, including high initial cost, specialized handling, transportation

challenges, and limited onsite modification. However, by integrating precast HPC components with the four control layers and implementing robust safety and security measures, designers can create building envelopes that meet the stringent requirements of the NIH *DRM* and *BMBL-6* guidelines, ensuring critical facilities maintain their integrity, safety, security, and biosafety performance throughout their lifecycle.

## References

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4. *Design Requirements Manual (DRM)*, Revision 2.1, Division of Technical Resources, National Institutes of Health, August 2, 2024, <https://orf.od.nih.gov/TechnicalResources/Pages/DesignRequirementsManual2016.aspx>