The Use of ccSPF in HIGH-PERFORMANCE WALL ASSEMBLIES

By Mason Knowles

INTRODUCTION

How a wall is constructed can greatly diminish or enhance a building's ability to be labeled "high performance." This article will highlight the use of closed-cell spray polyurethane foam (ccSPF) utilizing HFC 245fa blowing agent packages in commercial wall assemblies, taking into consideration how the use of ccSPF accomplishes key high-performance building goals.

High-Performance Buildings

There are dozens of definitions of "high-performance buildings," but perhaps Michael Crosby, PhD, RA, said it best ten years ago in *Architecture Week* magazine: "In a nutshell, a high-performance commercial building is energy-efficient, has low short-term and long-term life-cycle costs, is healthy for its occupants, and has a relatively low impact on the environment."

The United States federal government has taken a strong stance in promoting high-performance buildings. The National Institute of Standards and Technology (NIST), in its *Whole Building Design Guide*, established five guiding principles for high-performance buildings: employing integrated design, optimizing energy performance, protecting and conserving water, enhancing indoor environmental quality, and reducing environmental impact of materials.

For the purpose of this article, we will focus on four of the five guiding principles in discussing ccSPF wall assemblies.

- **Employing integrated design** describes a process in which a design team establishes the performance goals of a building for siting, energy, water, materials, and indoor environmental quality. The team ensures the goals are incorporated throughout the design and lifecycle of the buildings. It considers all stages of the lifecycle of the building, including deconstruction.
- **Optimizing energy performance** is more complicated than it appears. The design team has to establish a whole-building energy performance target that takes into account the intended use, occupancy, operations, plug loads, and other energy demands. The executive order establishes a goal in new construction to reduce energy use by 30% compared to the baseline building performance rating per the American and National Standards Institute (ANSI) American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) Standard 90.1-2007 (Energy Standard for Buildings Except Low-Rise Residential). Major renovations would require 20% below the 2003 baseline.
- **Enhancing indoor environmental quality** takes into account providing thermal environmental conditions according to ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy, and ASHRAE Standard 62-1-2007, Ventilation for Acceptable Indoor Air Quality. The order also recommends a moisture-control strategy to prevent building damage, minimize mold contamination, and reduce health risks related to moisture. This is no small matter. At a moisture-control symposium, the Department of Energy's Oak Ridge National Laboratory (ORNL) reported that most damage and deterioration in buildings comes from moisture problems. According to ORNL, "Moisture transfer through building envelopes affects more than the energy efficiency of the building. It also influences the building's durability and indoor air quality and the health and safety of the occupants. Moisture damage to the exterior envelopes of numerous buildings has been widely publicized in the past few years. Moisture control is a key to the development of both energy-efficient and durable buildings."
- **Reducing the environmental impact of materials** specifically recommends the use of products that have a lesser or reduced effect on human health and the environment over their lifecycle when compared with competing products or services that serve the same purpose. It takes into account recycled content, bio-based content, construction waste, ozone-depleting compounds, and the release of global warming gases.

Presidents Bush and Obama reinforced high-performance building goals by issuing executive orders 13423 and 13514, respectively, in January 2007 and October 2009. President Bush's Executive Order 13423 established high-performance buildings as a key objective and adopted the five guiding principles.

Photos 1 and 2 – ccSPF can be installed between the studs to the thickness desired to provide energy efficiency, thermal comfort, condensation control, and to meet code requirements.

President Obama's Executive Order 13514 made the five guiding principles mandatory for all new construction and during repair or alteration of federal buildings.

HIGH-PERFORMANCE WALL ASSEMBLIES USING ccSPF

The use of ccSPF wall assemblies can help specifiers obtain many of these high-performance objectives, specifically optimizing energy performance, enhancing indoor environmental quality, improving durability of key building components, and reducing the environmental impact of materials. As we discuss the various wall assemblies, we will focus on how the use of ccSPF impacts the attainment of these high-performance goals. Features will be pointed out that address specific design challenges. Design details of representative assemblies will be presented that can assist the specifier in using ccSPF correctly to accomplish these goals.

Closed-Cell Spray Polyurethane Foam

Installed using specialized equipment by trained applicators, ccSPF is spray-applied to a prepared substrate as a liquid and expands 30 to 40 times its original volume within seconds to form a rigid, lightweight foam plastic. The foam is dry to the touch within a minute and achieves 90% of its physical properties within a few minutes. It bonds tenaciously to a wide variety of common building substrates such as masonry walls, concrete block, metal, polyiso boards, wood, and more. The combination of its strength-to-weight ratio and exceptional adhesion enable manufacturers to use ccSPF as the insulation, adhesive, and main structural core in insulated panel systems.

ccSPF can be used in interior spaces to provide insulation, air barriers, moisture control, and structural strength enhancement. It can either be installed between stud wall cavities or to a nonstudded surface such as masonry or a metal wall. It also reduces sound transmitted through the wall assemblies by reducing air infiltration.

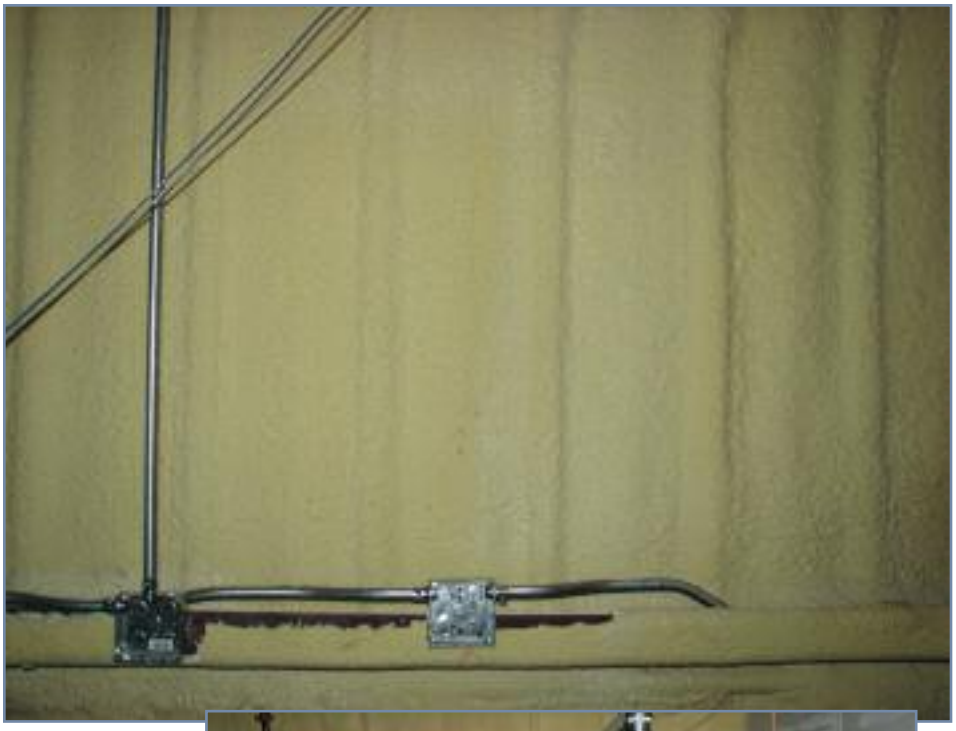
For exterior applications, it can be used to insulate, create an air barrier, reduce thermal bridging, provide better moisture control, and as a secondary weather barrier and rain screen.

Each application has its benefits. This article will describe a few commercial wall assemblies and how ccSPF can be installed to best enhance the high-performance characteristics of the buildings. Design considerations and performance testing will also be discussed.

Types of Wall Assemblies

While there are dozens of different wall types, this article focuses on using ccSPF with common wall assemblies used in commercial construction, including stud wall construction with exterior structural sheathing, metal buildings and metal skin panels, and masonry or CMU construction.

- **Exterior structural sheathing: plywood, OSB, gypsum drywall assemblies with stud wall configuration (metal, wood) construction.** Structural sheathing products are manufactured with different materials and methods, but the common ways they are constructed in the field and insulated with ccSPF place them in this category. Plywood and OSB are used primarily in residential and light commercial construction. Gypsum drywall products–due to their significant fire resistance–are used frequently in commercial construction, particularly as a substrate behind brick, siding, stucco, and exterior insulation finish systems. This makes it an attractive product for multistory construction.
- **CMU (concrete masonry unit) block construction.** CMU is frequently used for manufacturing, warehouse, shopping center, and office buildings. This type of construction is very popular in the commercial sector for its structural integrity and fire resistance.



Photos 3 and 4 – Here, ccSPF is installed to the interior of a metal building without studs. This type of application has an added benefit of reducing thermal bridging through the metal beams and columns.

- **Metal sheathing or panels.** This category includes fabricated metal buildings with metal columns, purlins, and beams, as well as post frame-constructed buildings with wood posts, trusses, and metal skins. The buildings vary significantly in size, use, and strength. Metal buildings are popular for manufacturing facilities, strip shopping centers, agricultural buildings, and warehouses.

Interior Applications of ccSPF

First we will discuss the interior application of ccSPF to wall assemblies. *Photos 1* and *2* show ccSPF installed between the studs to the thickness desired to provide desired energy efficiency, thermal comfort, condensation control, and code requirements.

Photos 3 and *4* show ccSPF installed to the interior of a metal building without studs. This type of application has an added benefit of reducing thermal bridging through the metal beams and columns.

High-performance benefits of an interior application of ccSPF include the following:

- **Enhanced energy performance.** In stud wall construction, ccSPF provides an air barrier and effective insulation that maintains a high energy efficiency in various (and extreme) climates and conditions. Comparative energy performance testing conducted at Architectural Testing Inc. (ATI) demonstrated that ccSPF-insulated wall assemblies were 30% to 40% more energy-efficient than fiberglass-insulated

ATI Thermal Performance of ccSPF-Insulated Wall Assemblies									
	Exterior	Interior	Pressure	U	Ru	C	R	Air Flow	Specimen Heat Flow
	Deg F	Deg F	In WC	BTUH / Ft²-F	Ft²-F / BTUH	BTUH / Ft²-F	Ft²-F / BTUH	SCFM	BTUH
Gypsum Board	24.98	70.00	0.000	0.078	12.823	0.090	11.169	0.00	231.771
Spray Foam	25.01	70.00	0.101	0.084	11.866	0.092	10.907	0.21	250.302
O.S.B.	-14.99	70.00	0.109	0.087	11.431	0.095	10.547	0.27	490.820
	70.00	115.00	0.082	0.092	10.891	0.100	9.983	0.18	272.760

U and Ru include the insulative effects of boundary air film coefficients. C and R do not include these effects.

Table 1 – Thermal performance of ccSPF installed to OSB sheathing.

ATI Thermal Performance of ccSPF-Insulated Wall Assemblies									
	Exterior	Interior	Pressure	U	Ru	C	R	Air Flow	Specimen Heat Flow
	Deg F	Deg F	In WC	BTUH / Ft²-F	Ft²-F / BTUH	BTUH / Ft²-F	Ft²-F / BTUH	SCFM	BTUH
Gypsum Board	25.03	70.00	0.026	0.064	15.695	0.071	14.085	0.00	188.210
Spray Foam	25.01	70.01	0.114	0.073	13.643	0.079	12.701	0.36	216.623
Polyisocyanurate	-14.99	70.00	0.125	0.081	12.384	0.087	11.539	0.53	450.753
	70.01	115.00	0.096	0.087	11.521	0.094	10.636	0.62	256.522

U and Ru include the insulative effects of boundary air film coefficients. C and R do not include these effects.

Table 2 – Thermal performance of ccSPF installed to polyiso sheathing.

walls when tested in high and low temperatures with air pressure differentials. Additionally, the study showed that ccSPF-insulated wall assemblies significantly reduced air infiltration into the wall. See *Table 1*.

Another energy-efficient use of ccSPF is to spray the foam to polyiso sheathing installed to the outside of a framed wall. This is a very good way stop thermal bridging. Adding ccSPF to the interior facing of the sheathing completes an air seal while adding structural strength.

As demonstrated in *Table 2*, the foam sheathing creates a great thermal break, while the ccSPF provides an air barrier and effective insulation that keeps its energy efficiency in various climates and conditions. Both products have high R-values that combine to form a highly efficient barrier against thermal bridges, air infiltration, and heat transfer from conduction and convection.

- **Better climate and indoor air quality control capability.** Walls insulated with ccSPF help seal and separate the inside and outside environment (air, humidity, and temperature) so that the interactions of heat, air, and moisture can be more effectively controlled by ventilation and HVAC equipment. This reduces the potential for condensation and subsequent mold growth and enables the ventilation system to more precisely control the temperature, humidity, and quality

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1992 NAHB Research Center Racking Study				
Average Maximum Racking Load (pounds)				
	Non SPF Panels		SPF Panels	
Stud Spacing	Vinyl sheathed	Plywood sheathed	Vinyl w/ccSPF	Plywood w/ccSPF
16 in	913	2,890	2,800	5,300
24 in	Not tested	2,420	Not tested	6,387
32 in	Not tested	Not tested	2,588	
48 in	Not tested	Not tested	2,298	

Table 3

1996 NAHB Research Center Racking Study	
Average Maximum Racking Load (pounds)	
Assembly	Maximum Racking Load
OSB w/R-19 fiberglass	4,800
OSB w/ccSPF	6,000
Drywall w/R-19 fiberglass	2,400
Drywall w/ccSPF	5,380

Table 4

ATI Racking Study	
Average Maximum Racking Load (pounds)	
Assembly	Maximum Racking Load
1½-in, 2-lb density SPF w/polyiso sheathing	2,259
3½-in, 2-lb density SPF w/polyiso sheathing	2,152
Polyiso sheathing	1,109
OSB sheathing	2,908

Table 5

of indoor air. Thermal comfort of the occupants is also enhanced in this way.

- **Increased durability.** ORNL reported that the majority of building deterioration is caused by unwanted water intrusion or condensation from bulk water entering the building through leaks and cracks in the building envelope or uncontrolled transfer of water vapor into the building. ccSPF helps control unwanted condensation by stopping airborne moisture from entering the assembly and reduces the amount of bulk water that can enter the building from outside leaks. Recognizing this fact, FEMA approved ccSPF for use in both interior and exterior applications as an insulation and air barrier in severe flood zone areas.

Research demonstrates that ccSPF can help increase the racking strength of wall assemblies. Three research studies have been conducted by the Spray Polyurethane Foam Alliance (SPFA) and its predecessor (Polyurethane Contractors Division of the Society of Plastics Industry (PFCD) on the racking strength of ccSPF. In 1992, and again in 1996, PFCD contracted with the NAHB Research Center to conduct racking load tests on ccSPF-insulated wall panels. NAHB Research Center concluded, "During a design racking event such as a hurricane, there would be less permanent deformation of wall elements and possibly less damage to a structure that was braced with SPF-filled walls."

In 2007, SPFA tested ccSPF-insulated walls constructed with 2-in x 4-in wood studs, 16-in OC to both polyiso- and OSB-sheathed wall assemblies at ATI. As indicated in *Table 4*, the ccSPF doubled the racking load of the polyiso-sheathed wall assemblies. See *Tables 3, 4* and *5*.

- **Reduced use of construction materials.** With its high R-value of six or more per inch, ccSPF can achieve an R-21 within a wall constructed with 2-in x 4-in studs. Most competitive insulation, such as fiberglass or cellulose, would require 2-in x 6-in construction to achieve the same R-value. ccSPF can perform multiple building material functions that include air barrier, insulation, secondary barrier against water intrusion, and vapor retarder. Using one material to take the place of other materials that would typically perform these functions (such as house wrap, interior film vapor retarders, and sealants) eliminates the life cycle environmental impact of these other materials.

Design Considerations

The design team should consider a few factors when specifying ccSPF.

- **Electric wiring and communication cables.** When installed to the interior of a wall cavity, ccSPF will encase wiring and cables that are close to the substrate. It will be difficult at a later date to remove or replace wiring or cables. To provide easier access in the future, the design team should provide a pathway, in the way of metal or plastic conduit, for these features.
- **HVAC sizing.** A more air-tight construction is provided with ccSPF

Photos 5 and 6 – Closed-cell foam should be installed in a "picture frame" technique to ensure uniform installation and to enhance adhesion to the studs.

than is possible with other types of insulation systems, such as fiberglass batts. The HVAC and ventilation system should be designed to accommodate the extra air-sealing qualities of the sprayfoam. Most often, smaller-sized HVAC equipment with provisions for make-up air, such as a heat-recovery unit (HRV) or an energy-recovery unit (ERV) would be used.

- **Insulate the beams and columns.** Metal buildings can lose a lot of insulation efficiency through thermal bridges created by metal beams and columns. When insulating metal skin panels or metal buildings, a layer of ccSPF foam over the beams, columns, and purlins can stop these thermal bridges, creating a more energy-efficient building with less chance for condensation.
- **Box-in recess lights.** Due to its insulating efficiency, ccSPF holds in the heat if sprayed directly to recessed lighting. The foam could char when sprayed against recessed lighting fixtures. Consequently, recessed lights need to be boxed-in before applying ccSPF.
- **Fire-blocking assemblies.** SPF may be used to seal cracks and crevices in fire-blocking assemblies if it has been tested and approved based on diversified fire tests specific to the application. An example of this would be foam sealants such as Dow Chemical's "Great Stuff."

Application Tips

Teh greatest benefit provided by ccSPF is obtained when it is installed using methods and techniques that enhance its physical properties. Listed below are a couple of tips to follow when installing ccSPF between stud wall cavities:

- **Picture-frame sprayfoam technique.** How the foam is applied can affect its adhesion and physical properties. To obtain the maximum adhesion and physical strength, the foam should be installed in a "picture-frame" pattern at the substrate/stud interface to form a cant approximately 2-4 inches in width as shown in *Photo 5*. After the foam sets and cools, then apply the foam in 0.5- to 1.5-in lifts, allowing sufficient time for the exothermic heat to dissipate before installing the next lift as shown in *Photo 6* (or in accordance with ccSPF manufacturers' written instructions).

Photo 7 – Measure moisture content of the substrate before installing the foam. Wood substrates such as plywood and OSB should contain no more than 18% moisture as measured by a Delmhorst Moisture Probe (or equivalent measuring tool).

- **Substrate preparation.** Surfaces should have moisture content no more than 19% and be sufficiently clean and dry. (Note: Substrate can be measured for moisture content with a moisture meter such as a Delmhorst Moisture Probe (as shown in *Photo 7*), or the substrate moisture can be detected with moisture-sensitive paper such as manufactured by NCFI.) For interior applications, primers are not typically required, but structural sheathing products frequently are treated with chemicals to resist insects and provide greater moisture resistance. Before applying ccSPF, the substrate should be inspected for contaminants that may affect adhesion.

Exterior Applications of ccSPF

The use of ccSPF on the exterior of wall assemblies of buildings is not as common as applications to the interior. Nevertheless, there is a growing use of the material–particularly in the more extreme climates. See *Photos 8* and *9*.

High-performance assembly attributes of exterior applications include the following:

- **Enhanced energy performance.** Used on the exterior walls of buildings, ccSPF provides similar energy-saving benefits as interior use, while adding other benefits. Applied to the outside of the sheathing, the ccSPF significantly reduces thermal bridging and provides even better air-sealing capabilities.
- **Better climate and indoor air-quality control capability.** Installed to the exterior of walls, ccSPF effectively eliminates thermal bridging through the wall assembly and air infiltration, thus providing even more climate- and indoor air-quality-control capability. By reducing the potential for bulk water entering the building assembly, ccSPF further reduces the potential for mold growth.
- **Increased durability.** The lightweight strength of the foam provides greater protection against structural damage from flying debris and racking forces created during wind events such as hurricanes. The monolithic seal of the ccSPF, combined with its water-resistant characteristics, protect the wall assembly better against water intrusion from rain, flood, and wind events.
- **Reduced use of construction materials.** Installed to the outside, ccSPF is more efficient, and less insulation can be used in the stud wall cavity. Additionally, since the ccSPF acts as a vapor retarder, rain screen, and weather barrier, those additional products can be mini-

Photos 8 and 9 – ccSPF provides a water-resistant air barrier to the exterior of buildings, reduces thermal bridging, and can enhance the resistance of the structure to high winds and wind-driven debris.

mized in the design of the building, along with their lifecycle environmental impact. (Note: Flashing is still required at roof/wall and floor/wall junctions to provide a watertight enclosure when using ccSPF as part of a drainage screen or rain/weather barrier.)

Design Considerations

- **Scheduling and sequencing.** As with other liquid-applied systems such as paint and coatings, ccSPF cannot be installed during climate conditions that exceed the manufacturer's recommendations. The general contractor should be aware of the temperature and humidity range of ccSPF applications in order to realistically schedule ccSPF applications and to sequence work with other trades.
- **Overspray protection.** ccSPF is lightweight and can travel several hundred yards during application (depending on the wind conditions). It will adhere well to most surfaces–even those that are not supposed to be foamed. Provisions should be made to protect property and equipment from overspray during application of the ccSPF by either moving it or masking it.
- **HVAC sizing.** ccSPF provides a tighter construction than is possible with other types of insulation systems such as fiberglass batts. The HVAC and ventilation system should be designed to accommodate the extra air-sealing qualities of the sprayfoam. In many cases, this entails using smaller-sized HVAC equipment with provisions for make-up air, such as adding a heat-recovery unit (HRV) or an energy-recovery unit (ERV)

Application Tips

The greatest benefit of ccSPF is provided when installed using methods and techniques that enhance its physical properties. Listed below are a couple of tips to follow when installing ccSPF between stud wall cavities:

- **Uniform application** is important when installing ccSPF to the exterior of a wall assembly. The degree of uniformity may vary depending on the type of exterior finish and the tolerances necessary to provide a surface with which other trades can work. Typically, edges and corners should be trimmed square and the foam installed to within at least 0.5-in tolerance. If the foam is being covered with plaster or stucco, stricter tolerances may be required. The foam should be installed in 0.5- to 1.5-in lifts, allowing sufficient time for the exothermic heat to dissipate before installing the next lift (unless authorized in writing by the manufacturer for thicker lifts of foam).
- **Substrate preparation.** Surfaces should have moisture content no more than 19% and be sufficiently clean and dry. (Note: Substrate can be measured for moisture content with a moisture meter such as a Demhorst Moisture Probe, or the substrate moisture can be detected with moisture-sensitive paper such as manufactured by NCFI.) Primers are recommended with plywood, OSB, and exterior-grade gypsum sheathing to minimize moisture pickup in the substrate and to help dry out the surfaces more quickly

and effectively. Some types of exterior-grade gypsum sheathing contain fiberglass resins that are more effective against moisture pickup and do not require primers. Check with the sheathing manufacturer for its recommendations. As in interior applications, before applying ccSPF, the substrate should be inspected for contaminants that may affect adhesion.

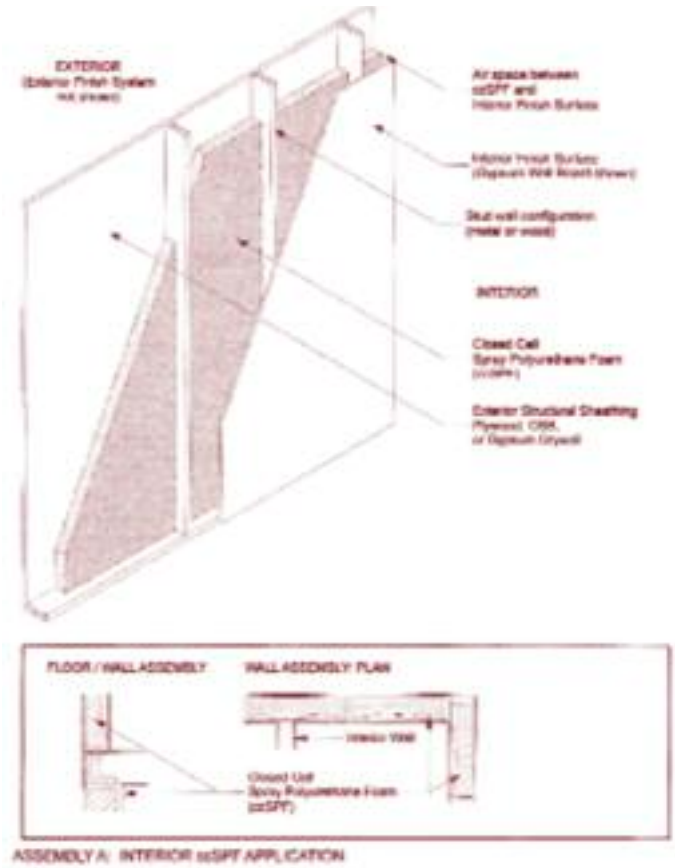
Safety, Health, and Fire Precautions

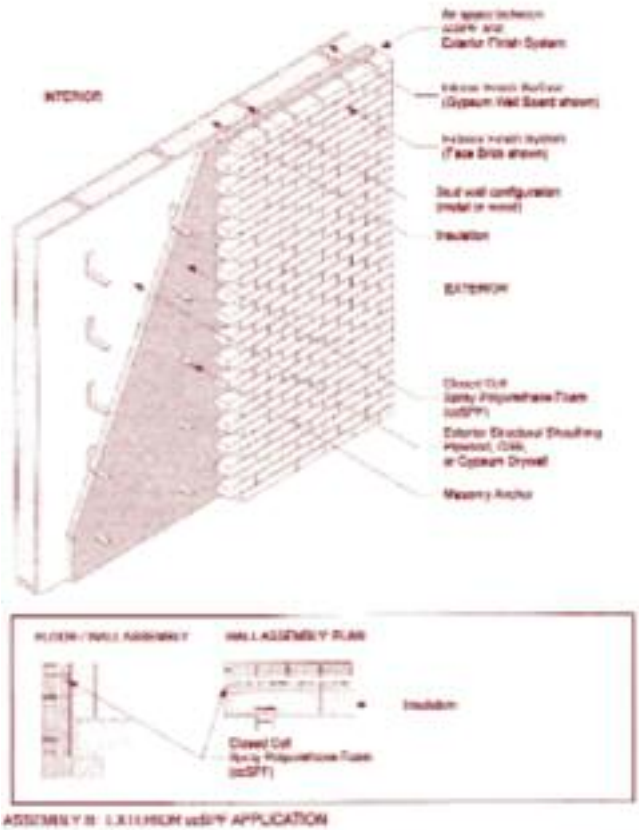
The properties in ccSPF can be hazardous during the application. The following are protective measures that should be followed during application of the foam. (Note: this is not a complete list of safety and health measures; each job should be evaluated specifically for its specific hazards and a written safety plan developed for that particular project.)

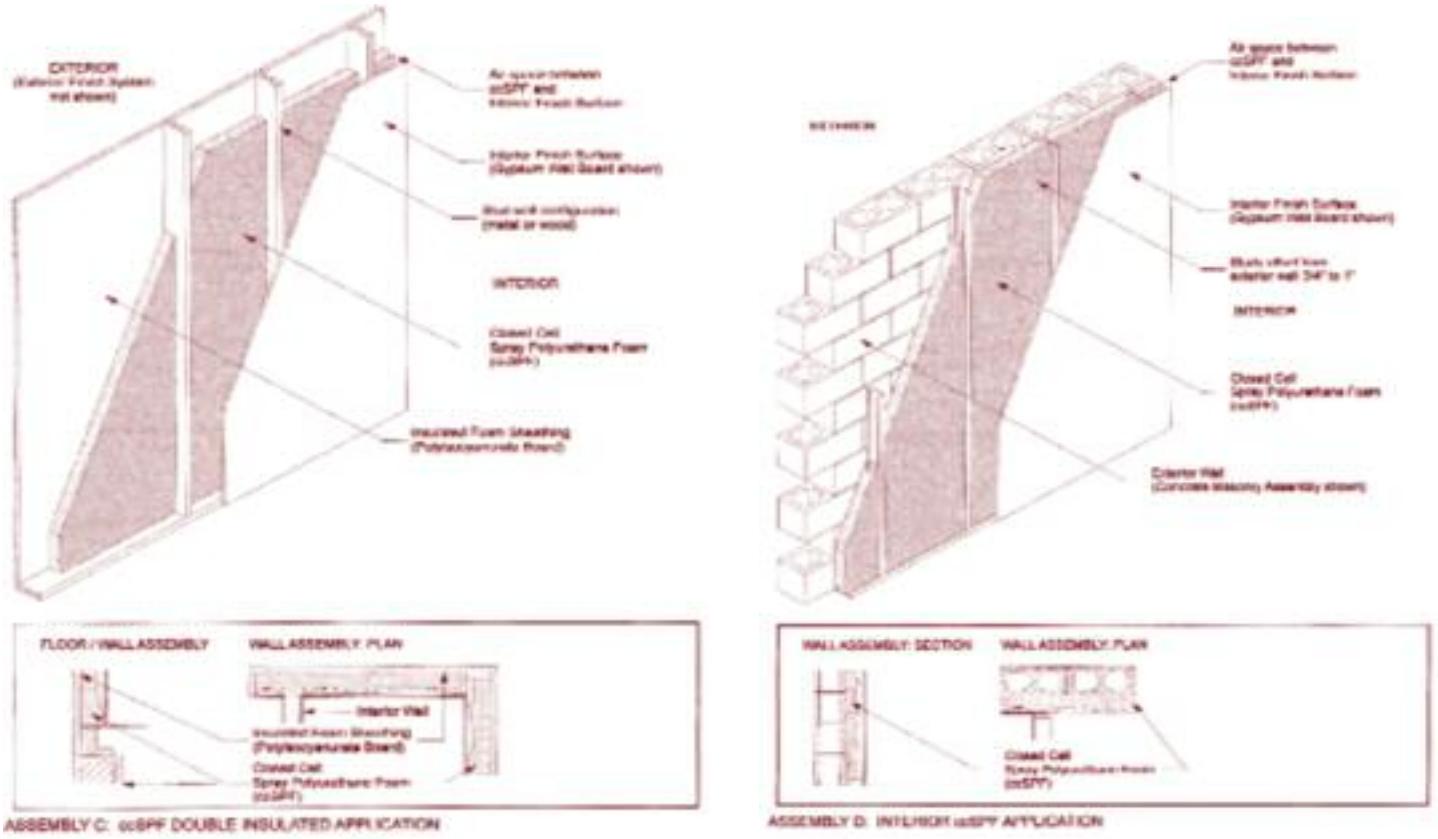
- **Fumes and mists.** Fumes and mists that can be hazardous to folks working in the immediate vicinity develop during application of ccSPF. Other workers should not be scheduled at the same time as SPF application. Other trades should be notified of the specific hazards–particularly of breathing in fumes. A work area should be designated where only persons with the appropriate personal protection equipment are allowed. When possible, ventilation should be provided to minimize the amount of fumes and mists accumulated in the application area.
- **Overspray.** ccSPF adheres very well to most substances and is very lightweight, so it can travel to areas beyond the immediate vicinity of application. Precautions should be made to identify areas of potential overspray and protect or move items, equipment, and surfaces that are likely to be affected such as cars, doors, windows, HVAC equipment, control panels, lighting fixtures, etc.
- **Protect against accidental ignition from "hot work."** ccSPF is combustible and can be ignited with cutting or welding torches or other types of hot work. All hot work should be completed before SPF is installed. If hot work is required after the ccSPF application, provide safeguards against accidental ignition. (Refer to the Center for the Polyurethanes Industry [CPI] document on six steps to fire safety during construction using SPF and polyisocyanurate foam.)
- **Fire rating.** Installing ccSPF to the interior of commercial building wall assemblies of CMU construction requires that the assembly be tested in accordance with NFPA 285 for nonload-bearing walls. Additionally, if the assembly requires a fire-resistive rating, it must be tested and rated in accordance with ASTM E119. Check with the ccSPF manufacturer for its fire ratings and approvals.
- **ASTM E84.** All foam plastics used in commercial insulation in exterior walls must be rated Class 1 for flame spread or smoke developed in accordance with ASTM E84. (Note: most E84 test apparatus are not capable of testing thickness greater than 4 in. If the design calls for greater thickness, NFPA 286 can be used to achieve code approvals of foam plastics.)

CONCLUSIONS

As demonstrated in this article, ccSPF can be used effectively in the design of high-performance wall assemblies. However, it is important for the design team to be fully aware of the specific properties and limits of the material, the testing that is required, and the application challenges before incorporating ccSPF into a specification.

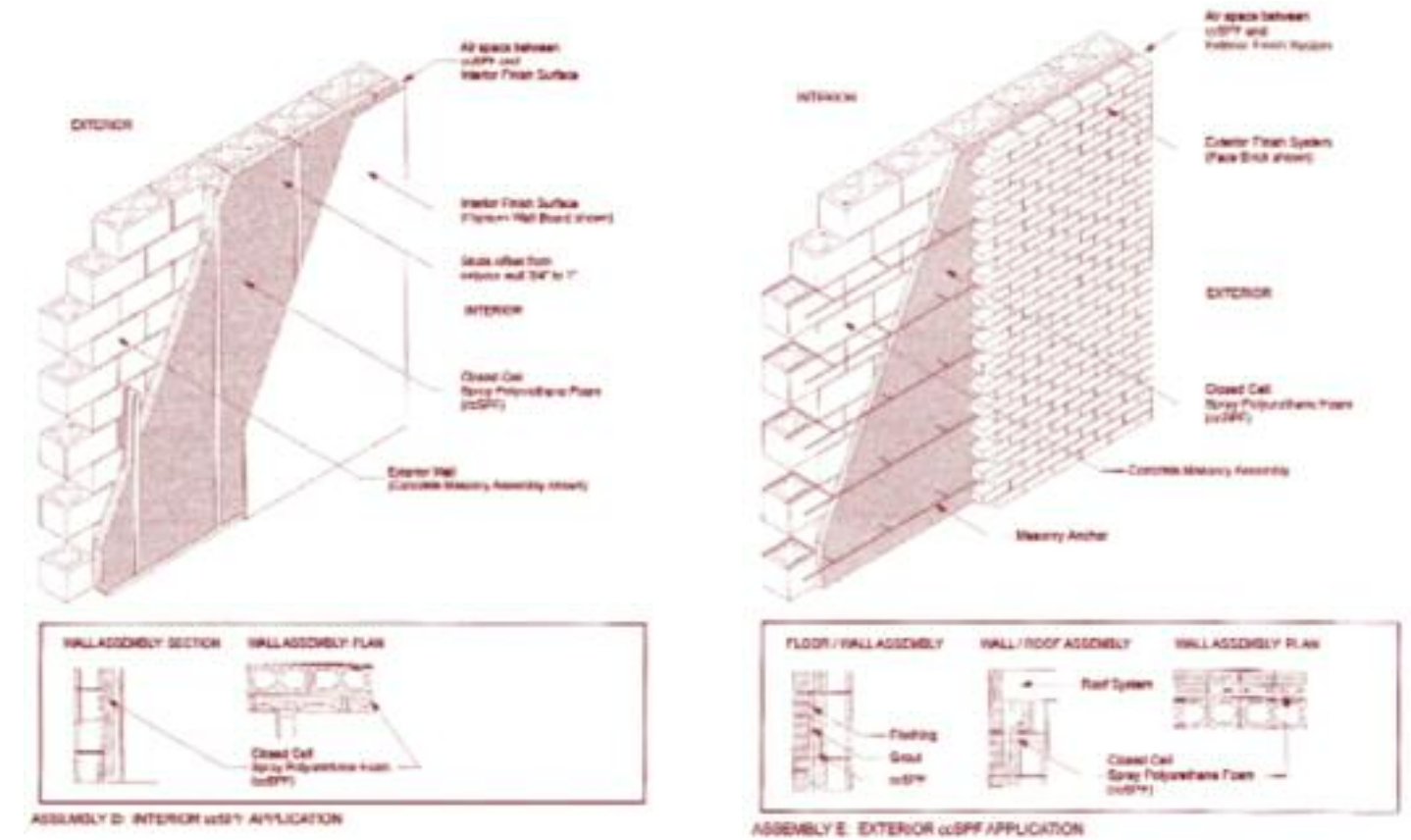






ASSEMBLY C: ccSPF DOUBLE INSULATED APPLICATION

ASSEMBLY D: INTERIOR ccSPF APPLICATION



ASSEMBLY D: INTERIOR ccSPF APPLICATION

ASSEMBLY E: EXTERIOR ccSPF APPLICATION

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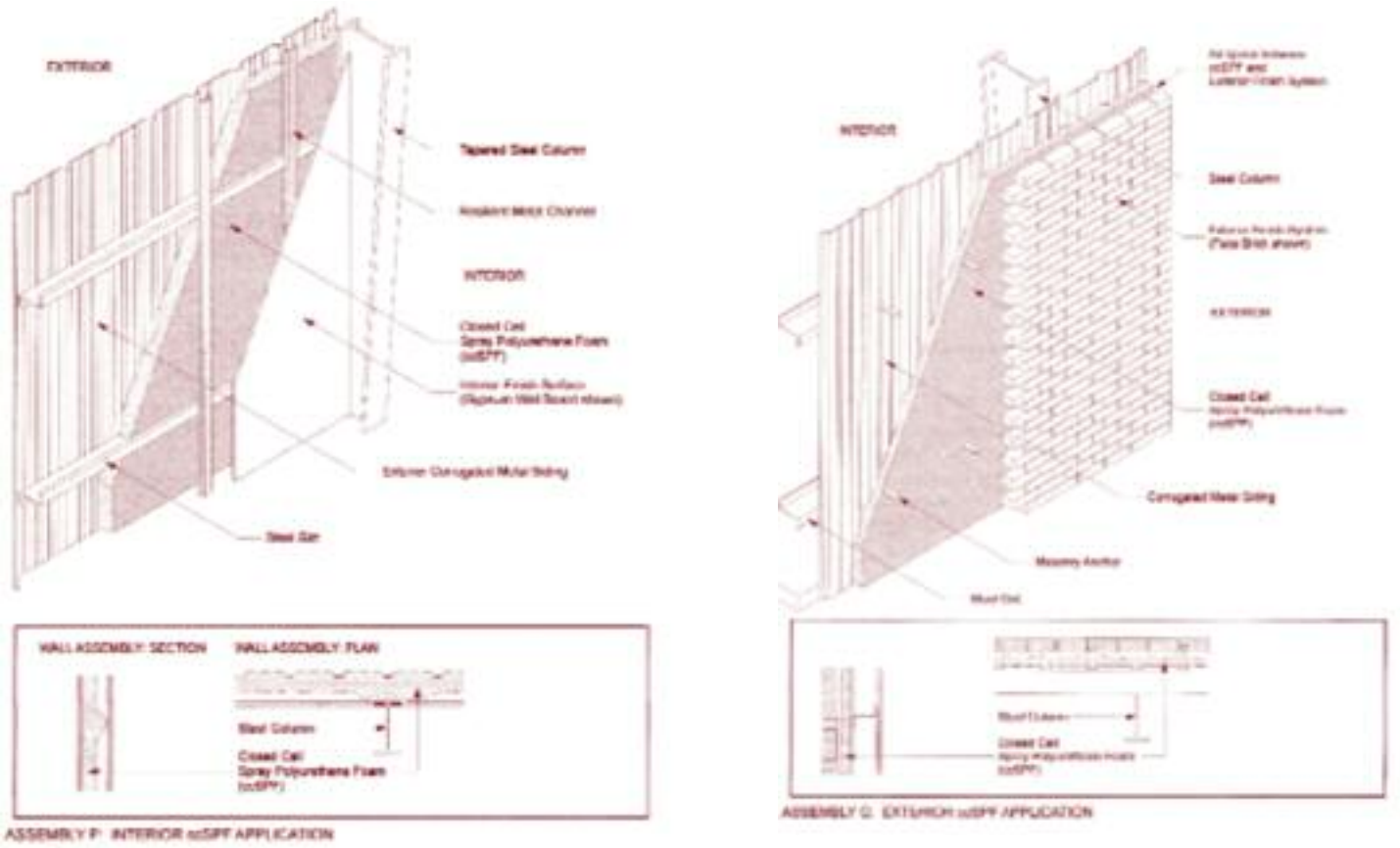

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