EE13-3 Improving Building Enclosures Thermal Performance as a Goal of Energy Efficiency

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ABSTRACT

Energy efficiency of buildings will continue to be a critical factor as the design community strives to pave a path toward a sustainable future. All too often project economics lead to value engineered building enclosure designs that are thermally inefficient or lack features that can improve their overall energy performance. In addition, the extensive stock of existing older buildings in the United States is mostly untouched and remains mostly energy inefficient. Improving the thermal performance of these strcutures will become critical in reducing future energy use, achieve compliance with new energy standards and improve thermal comfort of the occupants. No matter what forces will drive energy efficient design, the authors are in agreement that improving the thermal efficiency of new and existing building enclosures will play a critical function in reduicng the energy consumption of our buidlings.

The authors present two case studies that highlight critical aspects of building enclosure thermal performance and improvements for new and existing buidlings. The authors discuss how optimizing thermal performance at details and critical transitions can contribute to the improved energy efficiency of the building enclosure.

INTRODUCTION

Development of alternative energy sources to power our buildings and strides toward energy conservation are at the forefront of the building design profession. The significance of designing energy efficient building enclosures is a critical component in achieving an energy sustainable future. New buildings can be designed to have superior energy performance provided that consideration are given to a continuous thermal plane, inclusion of air barrier system(s) in combination with careful detailing at critical building enclosure condition such as wall-to-window/door and wall-to-roof transitions. Existing buildings comparable in size and function comprise a significant portion of built infrastructure and are typically less energy efficient. In retrofit cases, design and the development of building enclosure details with thermal and air barrier consideration are even more important.

The recent versions of American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1 (2009) and new ASHRAE standard 189.1 (2010) for high performance green buildings include requirement for increased thermal resistance of walls assemblies (specifically better guidance for metal framed buildings) and are a step toward improved energy performance. Nevertheless, designers must still evaluate their designs to minimize localized thermal bridging at all components (i.e. sun shades, awnings, window transitions and optimize glazing (i.e. day lighting, passive solar). Computer modeling tools provide a feasible and reliable approach to optimize energy and thermal performance of building enclosures. Sensitivity type analyses can be employed to evaluate thermal aspects of the building enclosure such as the effect of material type and thickness on thermal response of building enclosure assembly, impact of material configuration on temperature distribution and heat flux across various building enclosure components as well as the effect of localized thermal bridge effects. The authors present selected portions of two case studies that address the above

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mentioned thermal performance aspects. Two dimensional, numerical analysis (THERM software 5.2.14) was used to evaluate the relative thermal improvement of various insulation options and configurations. The case studies highlight that computer models are important tools and can aid the designers in evaluating and developing thermally improved building enclosure solutions. Improving thermal response at detail conditions, such as wall-to-window as well as roof/slab-to-wall transitions is critical towards improving the overall thermal efficiency of building enclosures. Computer modeling tools provide a feasible and reliable approach to optimize energy and thermal performance of building enclosures. Sensitivity type analyses can be employed to evaluate critical thermal aspect of building enclosure such as; effect of material type and thickness on thermal response, impact of material configuration on temperature distribution and heat flux across various building enclosure components and impact of localized thermal bridge effects.

CASE STUDIES

Case Study I - Pool Addition

Swimming pools can have higher operating costs than a comparable commercial building. These costs are partly associated with higher electricity demand required to operate mechanical systems specific to the pool system. Building enclosures in swimming pools are at an increased risk for interstitial condensation and moisture related damage. Improving thermal efficiency and air tightness of the building enclosure can reduce costs and eliminate moisture related performance problems. Optimizing the location, type and thickness of insulation is one critical component of achieving better thermal performance of the building enclosure. Providing a continuous air barrier system reduces uncontrolled air flow through the building enclosure and can reduce costs due to more efficient HVAC control and reduced heat losses.

Building enclosure consulting services were provided on a pool addition located near Washington, DC. The project included the addition of a new indoor pool building, fitness facility, bowling alleys, children’s game rooms and support spaces to an existing country club. The consultant’s scope of work included review of the design drawings and specifications and development of recommendations for the proposed 2-story indoor pool building enclosure with specific focus on moisture management as well as thermal and air barrier system considerations. The design team selected a drained EIFS system for the wall system with a fluid applied weather barrier and air barrier system. The original design provided a limited moisture (liquid and vapor) management. The recommendations for improvements to the exterior walls resulted in the exterior wall assembly at the pool building listed from the exterior to the interior; a drainable exterior insulations and finish system (EIFS) with 4-inch expanded polystyrene (EPS) adhered to mechanically attached self-furring galvanized metal lath, self-adhered vapor impermeable vapor and air barrier membrane, 1/2 inch exterior grade glass-mat faced gypsum sheathing; 8-inch steel stud framing (without insulation between the stud), and 1/2 inch interior cement board sheathing with interior moisture tolerant coating. The interior partitions between the pool and the adjacent spaces at the north and the south end of the pool building consisted of the following components listed from the interior to the exterior pool side; tile near the pool deck and interior stucco finish elsewhere, 1/2 inch interior cement board sheathing, 6 inch steel stud framing without insulation between the studs, and 1/2 inch interior gypsum wall board sheathing with two coats of paint.

The pool building included two types of roof systems; a low-slope membrane roof and a steep slope clay tile roof. The selected low-slope roof system over the pool consisted of the following building components, listed from the exterior to the interior; single-ply, 4-6 inch polyisocyanurate insulation, self-adhered vapor and air barrier and metal deck supported on steel beams. The steep-slope roof tile consists of the following components, from the exterior to the interior; clay tile roof, self-adhered waterproofing underlayment, ventilated sheathing with polyisocyanurate insulation, ventilated air space at trusses that support the deck, fiberglass batt insulation with a self adhered air and vapor barrier, and interior gypsum wallboard secured to the underside of the truss bottom cord and mechanically fastened to the metal deck below.

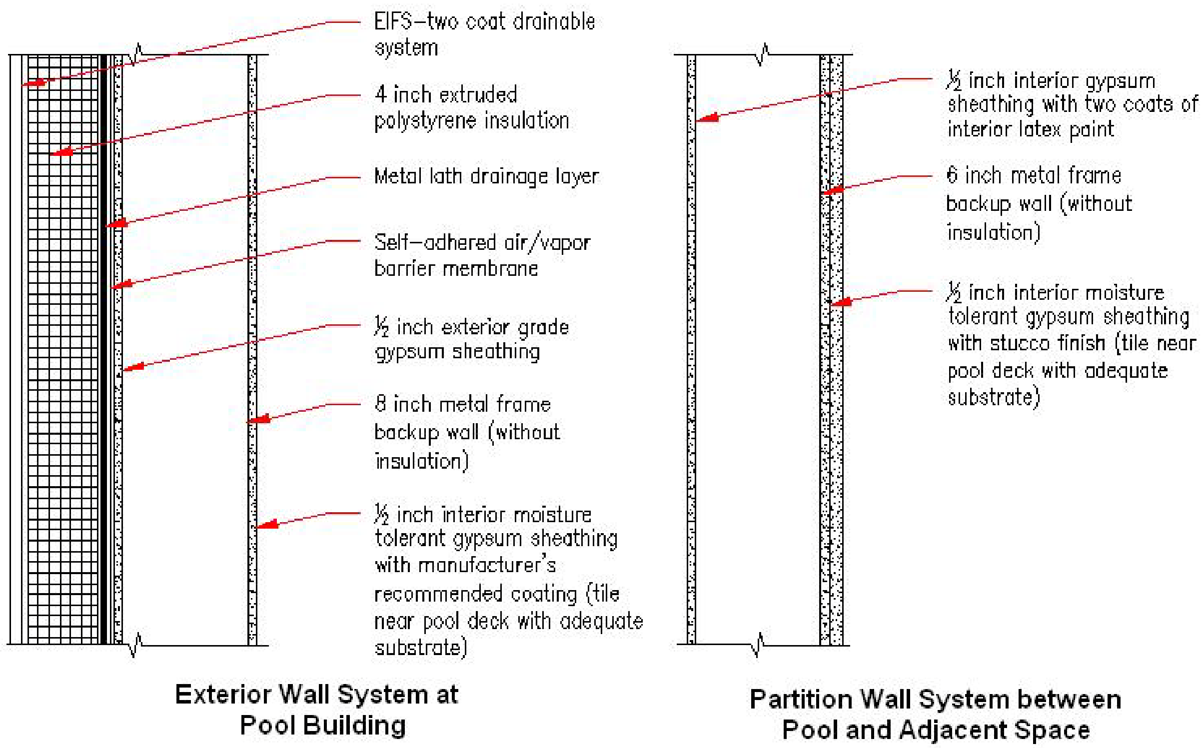

Figure 1. Proposed wall system for the new pool building addition.

Thermal analysis was conducted to determine temperature distribution through the opaque portion of the building enclosure (Figure 2) and at critical details such as wall-to-window transition at the window head (Figure 3) and sill (Figure 4) to identify locations with lower surface temperatures and condensation risk. The analysis showed that the proposed design was not thermally deficient and that condensation risk was minimal. The continuous 4 inch extruded polystyrene insulation outboard of the exterior sheathing provides resistance to heat transfer and maintains the metal frame of the backup wall above the dew-point temperature. Surface temperatures at the window head and sill frame are above the dew-point temperatures for the interior conditions and surface condensation was not a risk.

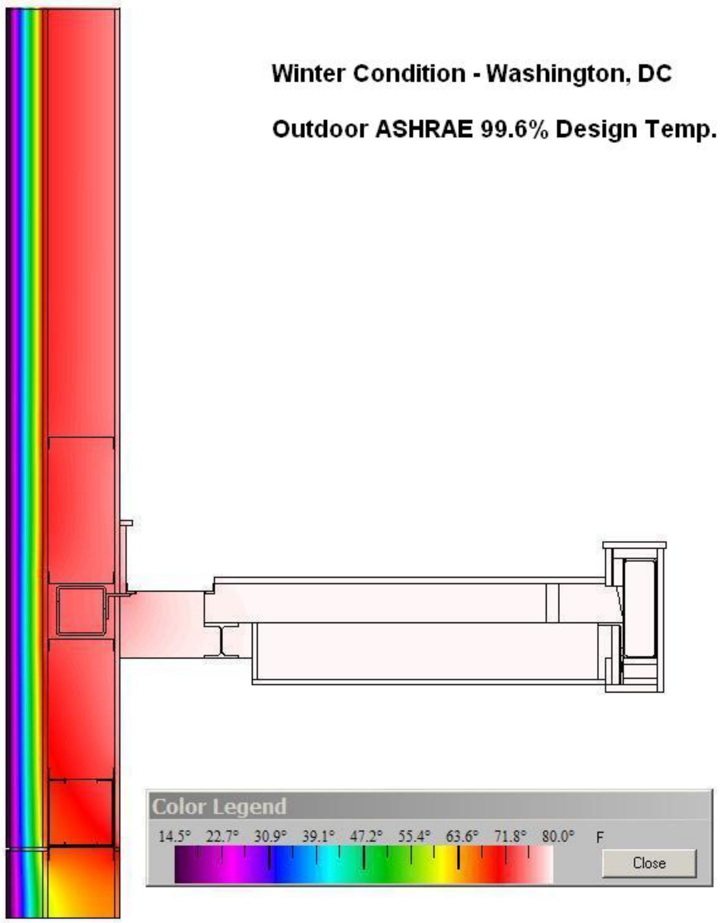

Figure 2.Temperature distribution through proposed and thermally improved wall-to-window transition at sill.

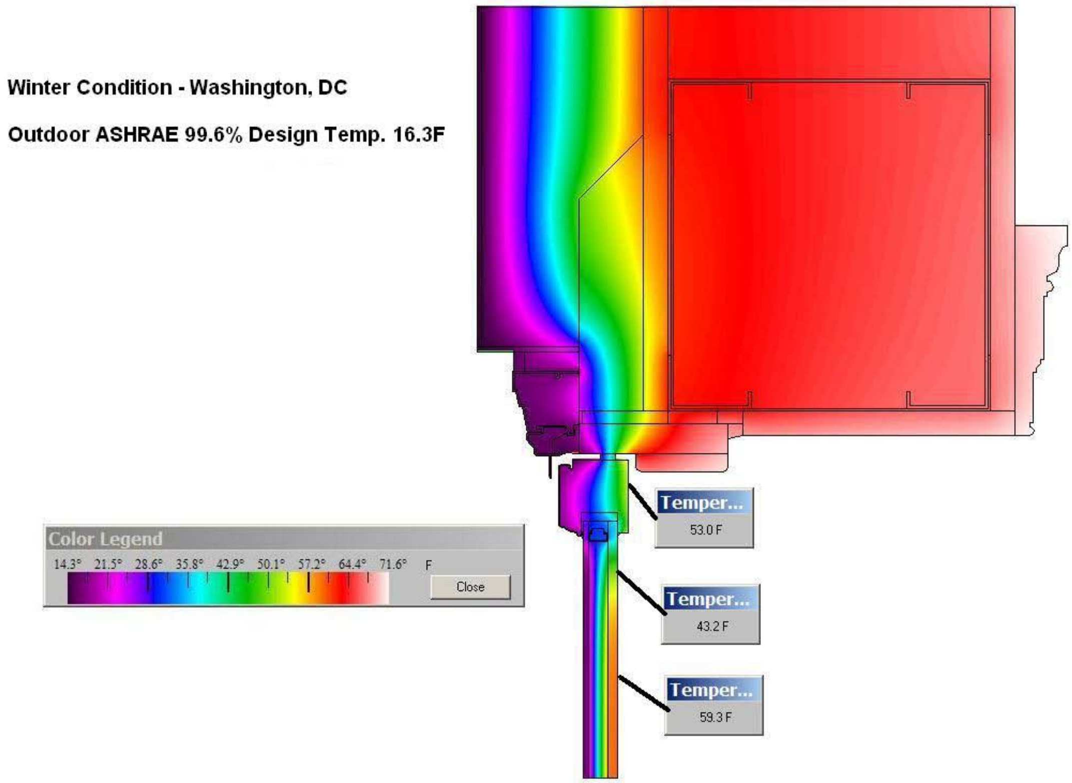

Figure 3.Temperature distribution at the window head condition.

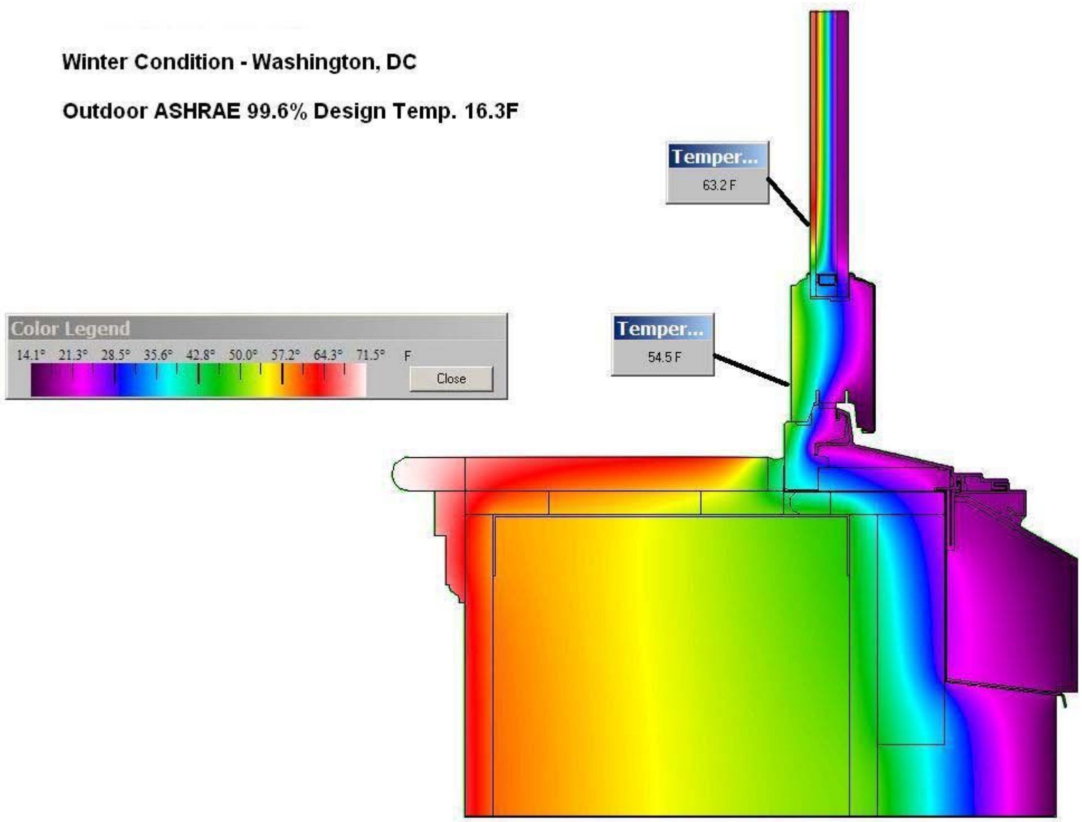

Figure 4. Temperature distribution at the window sill condition.

The review of the architect's proposed design showed that air barrier was discontinuous and was lacking many elements required to complete airtight transitions. Although, the hygrothermal analysis of the building enclosure (not the focus in this paper), specifically the EIFS clad walls and the roof systems showed that there was no risk for interstitial condensation due to diffusive vapor transport, leakage of moisture leaden indoor air into the building enclosure can lead to interstitial condensation. Uncontrolled air flow through the partition walls between the pool and the adjacent spaces can also lead to undesirable air quality conditions as well.

In extreme environments such as swimming pool the relative humidity typically exceed 80%. The air barrier systems are essential in eliminating uncontrolled air flows through building enclosures. For the air barrier to be effective it must form a continuous plane of air tightness across all transitions such as walls, roofs, and floors, fully enclosing the pool building and creating a separation between the adjacent interior spaces as well as the building exterior. In this context the air barrier is a system comprised of several materials that are; compatible, properly sequenced and detailed to achieve continuity. Details that must be considered include but are not limited to:

- Exterior pool wall-to-partition wall (Figure 5);
- Exterior pool wall-to-roof deck transition (Figure 6);
- Exterior pool wall-to-pool deck transition (Figure 7);
- Wall-to-window transition at sill, head and jamb (Figure 8).
- Air barrier transitions at all penetrations in building enclosure for the pool.

The air barrier transitions are clearly defined in Figures 5 through Figure 8. Typically, two or more options were developed for each detail for consideration by the design team to provide level of flexibility in sequencing materials while maintaining the constructability as straight forward as possible.

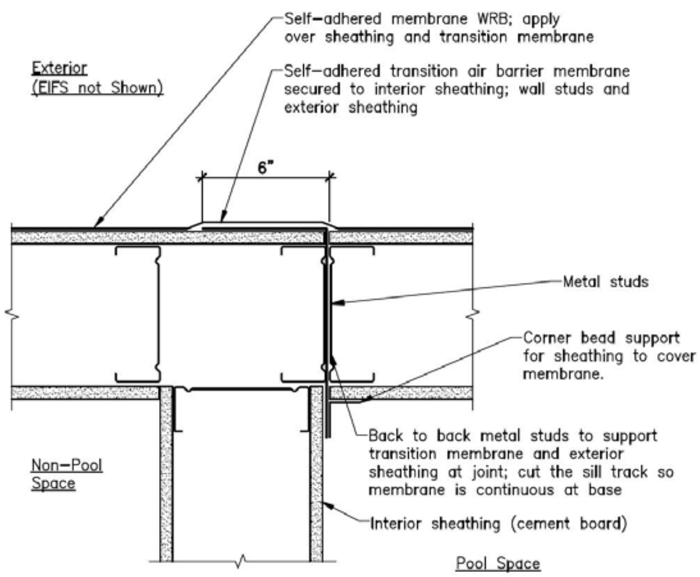

Figure 5. Air barrier transition at exterior pool wall-to-partition wall transition.

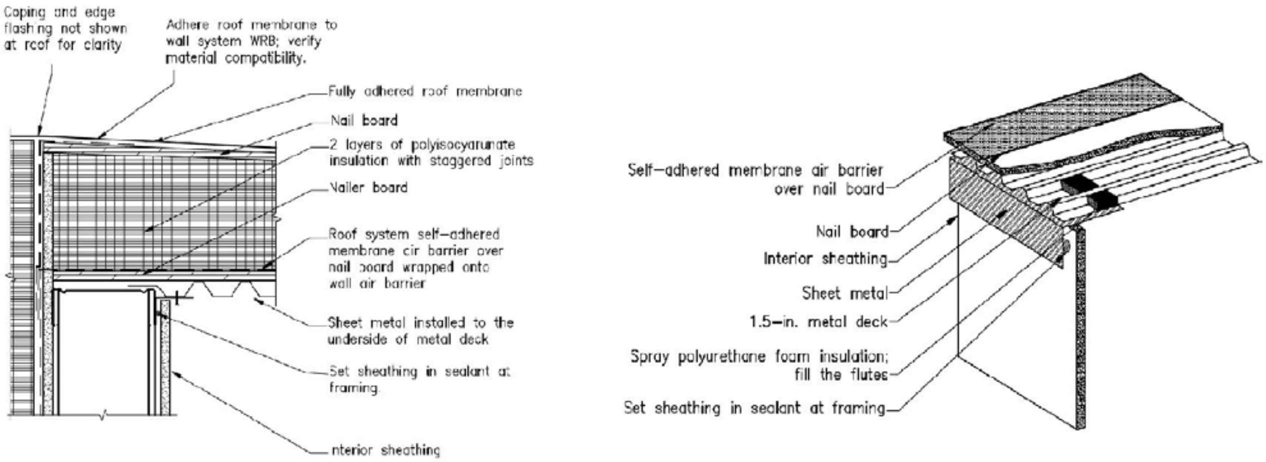

Figure 6. Air barrier transition at exterior pool wall-to-roof deck transition.

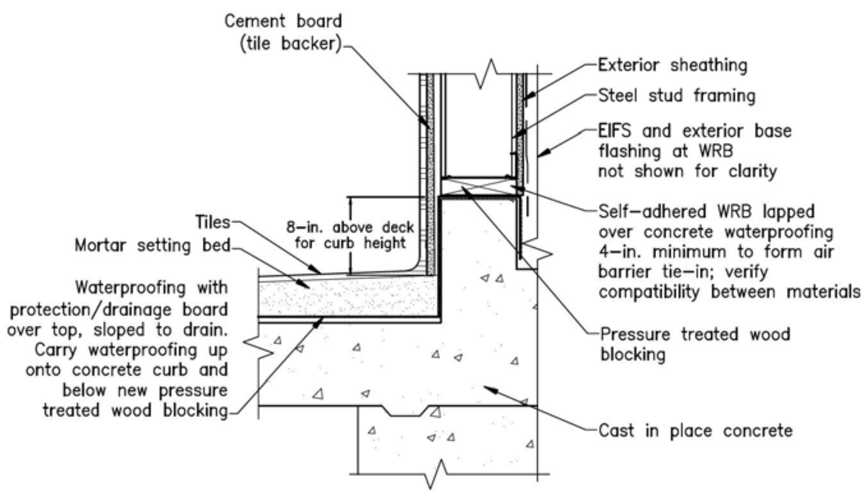

Figure 7. Air barrier transition at exterior pool wall-to-pool deck transition.

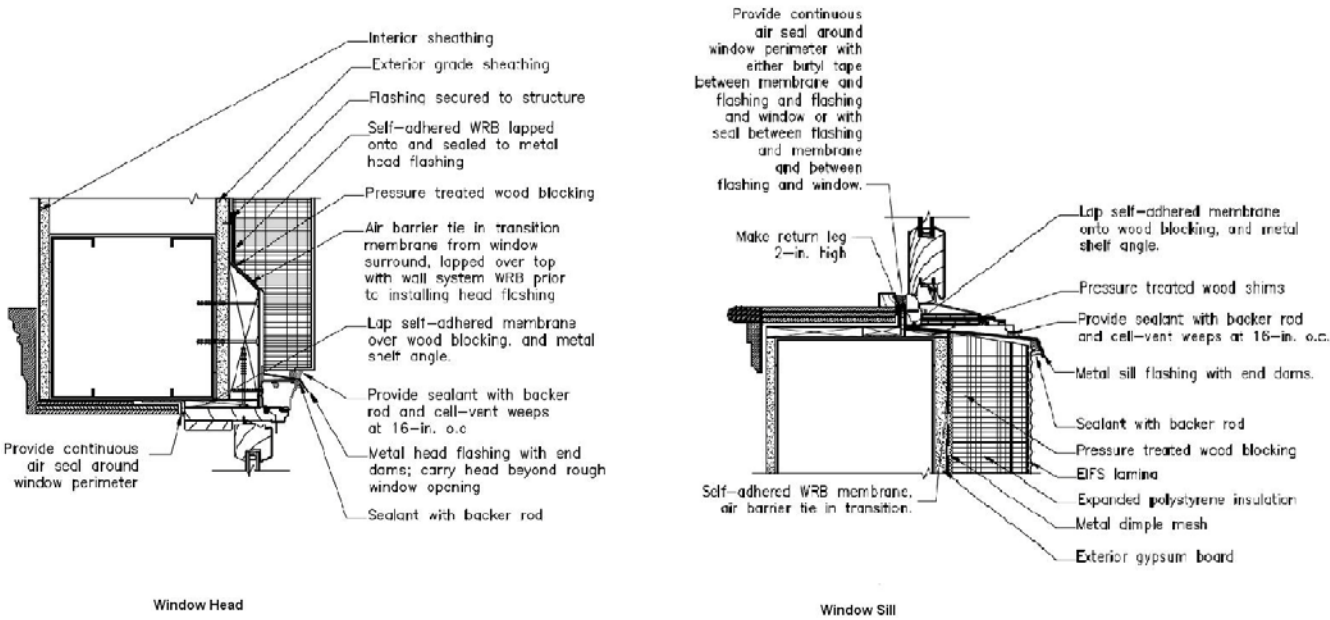

Figure 8. Air barrier transition at window sill and head.

For complex air barrier transitions such as those at window head and sill it is prudent to develop more comprehensive isometric drawings to show configuration of all material layers and step-by-step installation sequence. Field mock-ups for the selected options should be constructed to clarify material sequencing and resolve any unforeseen constructability issues.

Case Study II - School Building

An existing University student residence constructed in 1962 is undergoing a selective renovation. The renovation includes remedial thermal improvements to the wall system, specifically the addition of new insulation and interior finishes without the replacement of existing cladding. New thermally improved windows were already installed as part of the prior year's phase of enclosure upgrades. The existing wall system (Figure 9) consisted of the following elements; 3-5/8 inch clay brick masonry, 5/8 inch mortar parge coat, 1-1/2 inch air space, and 6-inch concrete masonry unit (CMU) with painted interior finishes. The parapet wall (approximately 2 feet in width) consisted of decorative precast concrete cornice attached to a CMU block backup, brick masonry and precast concrete copping was to remain intact (Figure 9).

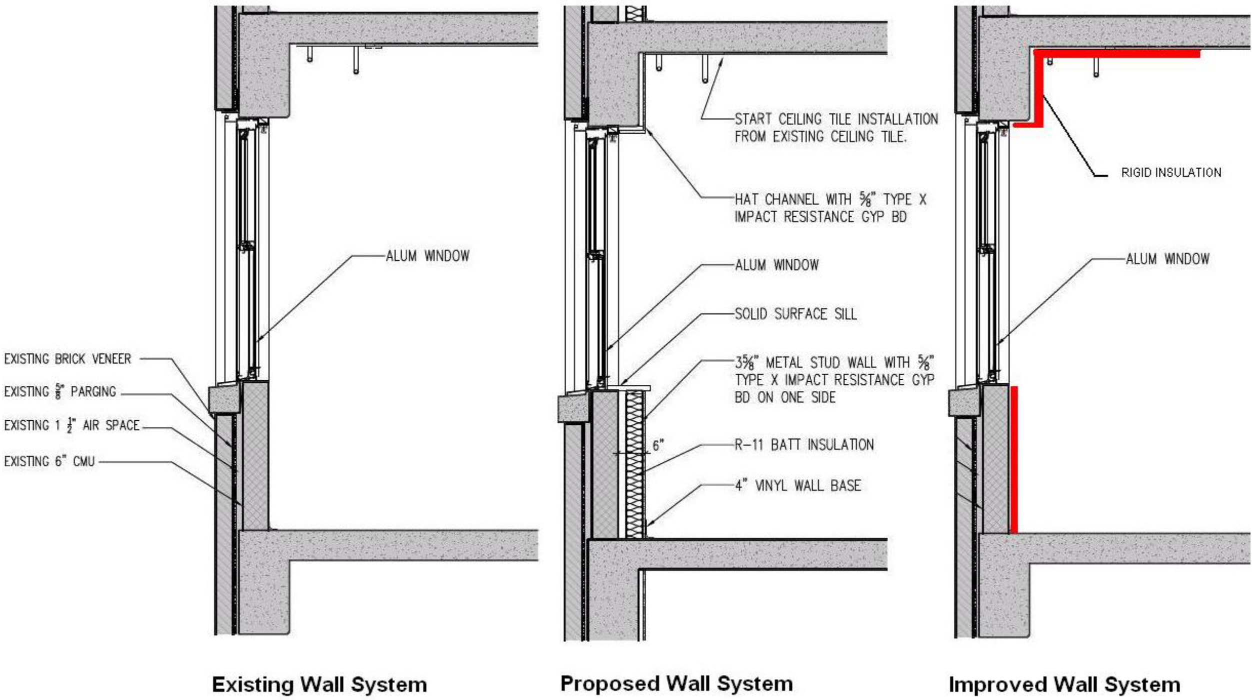

Figure 9. Configuration of the existing brick masonry clad wall system (left) and configuration of the existing wall-to-roof transition at decorative precast concrete cornice (right).

The existing roof system consisted of modified bitumen roof over; 2-inch of polyisocyanurate insulation, 4-inch of structural lightweight concrete and concrete roof deck and was not planned to be replaced during this repair program which, limited thermal improvement considered for the roof parapet. The existing and two remedial retrofit options were analyzed. The remedial wall system proposed by the designer-of-record included new 3-5/8 inch metal-framed walls with unfaced fiberglass insulation offset 1-3/4 inch from the interior surface of the CMU back-up wall and 5/8 inch gypsum wall board with painted finish (Option 1). Alternative option (Option 2) included 2-inch extruded polystyrene insulation installed on the inboard surface of the CMU back-up wall, 3-5/8 inch metal-framed wall without insulation and 5/8 inch gypsum wall board with painted finish. In the latter option, the insulation was extended along the vertical surface of the concrete beam extending 3 feet to the building interior on the underside of the concrete slab to reduce localized thermal bridge effects at the slab transition. Figures 10 through 12 show the temperature distribution, through the wall assembly at slab transition for the; existing conditions (Figure 10), remedial option with fiberglass insulation as proposed by the designer-of-record (Figure 11) and alternative option with rigid insulation on the inboard surface of the CMU (Figure 12).

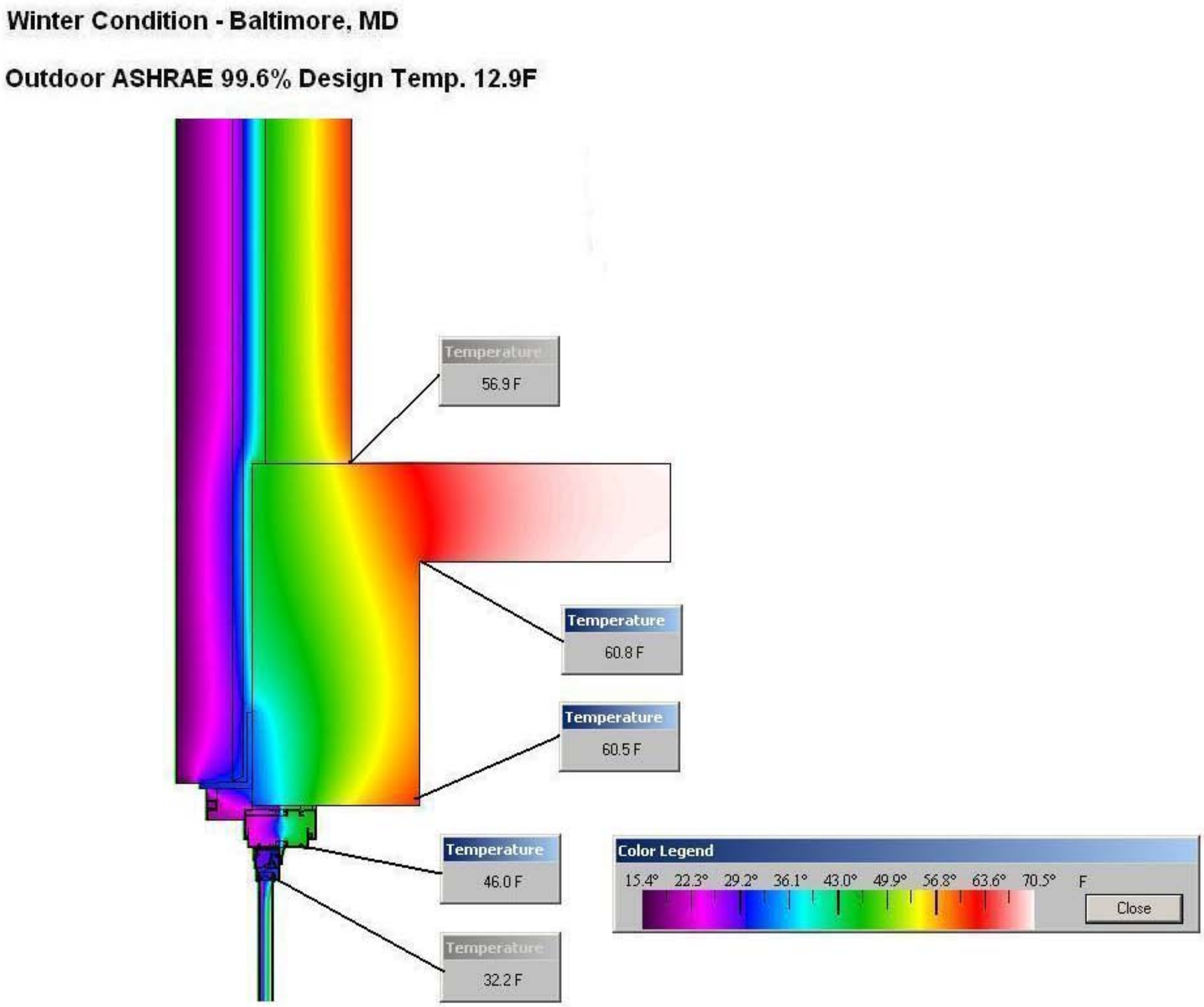

Figure 10. Temperature distribution through the wall assembly at the slab transition (existing condition).

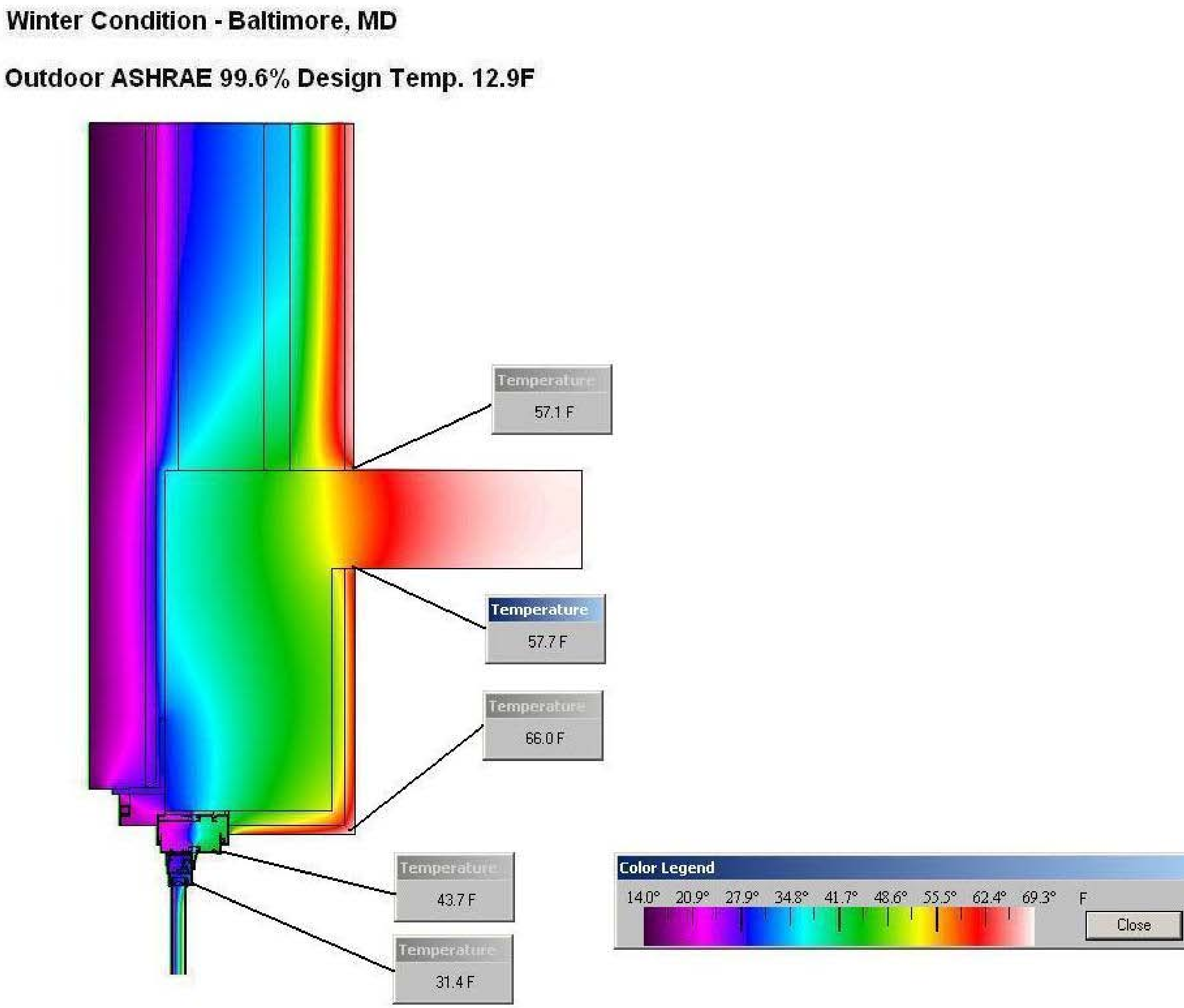

Figure 11. Temperature distribution through the wall assembly at the slab transition for remedial option with fiberglass insulation as proposed by the designer-of-record.

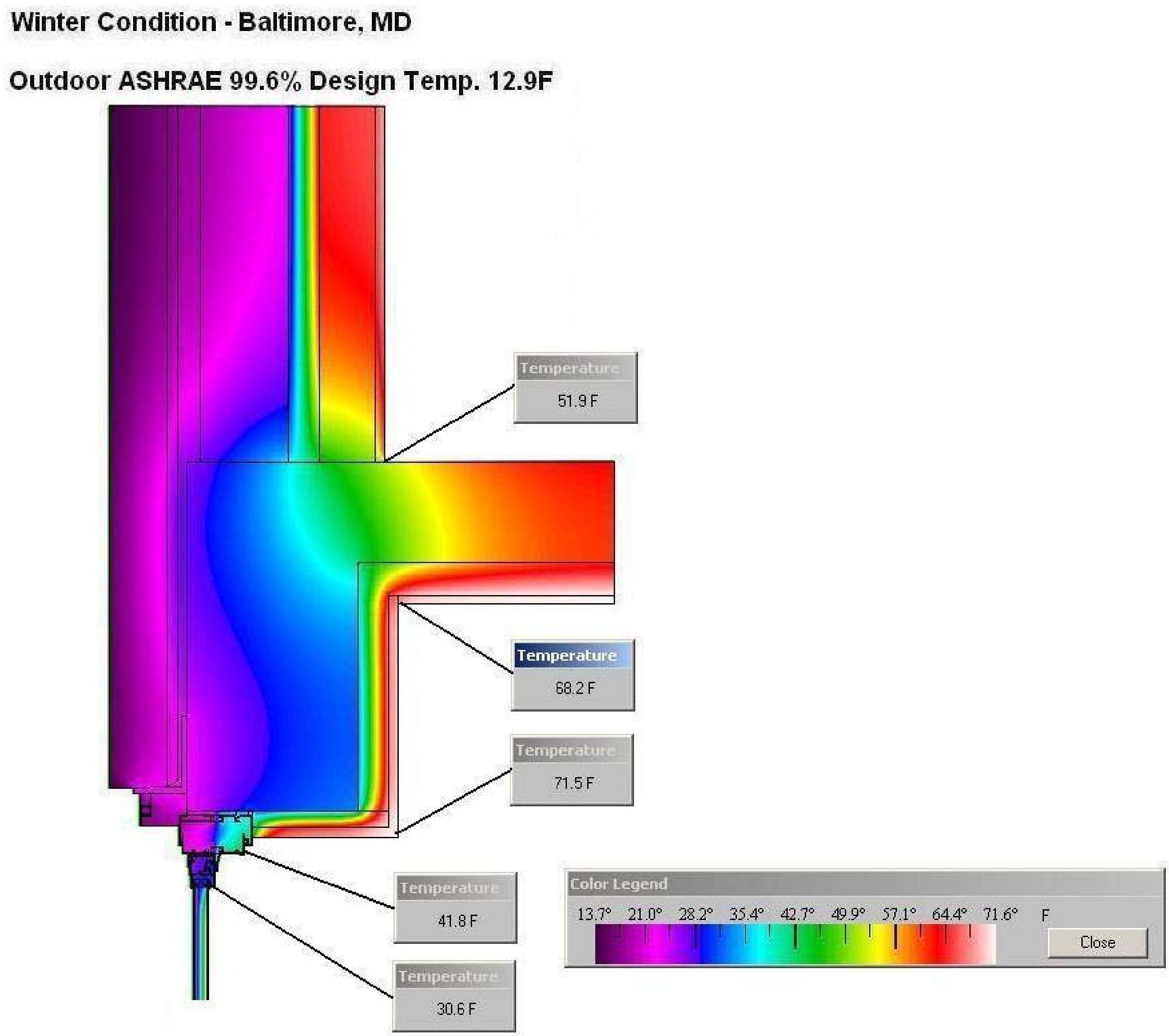

Figure 12. Temperature distribution through the wall assembly at the slab transition for alternative option with rigid insulation on the inboard surface of the CMU.

The temperature distributions in Figures 2 through 4 show important aspects of thermal performance for the proposed options. The existing condition (Figure 10) shows the lowest surface temperatures on the inboard side of the CMU. Providing fiberglass batt insulation (Figures 11) changes the temperature distribution of the portion of the wall extending above the concrete slab. Insulating the cavities in the metal-framed wall with fiberglass insulation offers limited benefit as effective R-value for the assembly is significantly reduced by the metal framing. With the concrete beam and the underside of the slab uninsulated, this portion of the assembly acts as an effective heat fin, dissipating the heat to the building exterior. The most thermally improved options included rigid insulation on the inboard surface of the CMU, concrete beam and a 3 foot wide strip on the underside of the slab.

The analysis was extended to roof parapet with window head condition and window-to-wall sill transitions. Temperature distribution for the existing parapet condition with window head and two thermally improved options; metal-framed wall insulated with 3-5/8 inch unfaced fiberglass batt (Option 1) and 2 inch extruded polystyrene insulation on the interior side of the concrete beam extending at the underside of the concrete roof deck (Option 2) are shown in Figure 13 and 14, respectively. Two options were evaluated with extruded polystyrene insulation extending 3 and 4 feet on the underside of the roof deck. The addition of extra foot of insulation does not change the temperature profile through the deck. In the existing configuration, lack of insulation at the roof parapet edge promotes heat loss through slab, beam and parapet wall. The parapet wall consisting of precast concrete cornice, CMU, brick masonry and precast concrete copping functions as an effective heat fin in transferring through conduction energy from the building interior to the exterior.

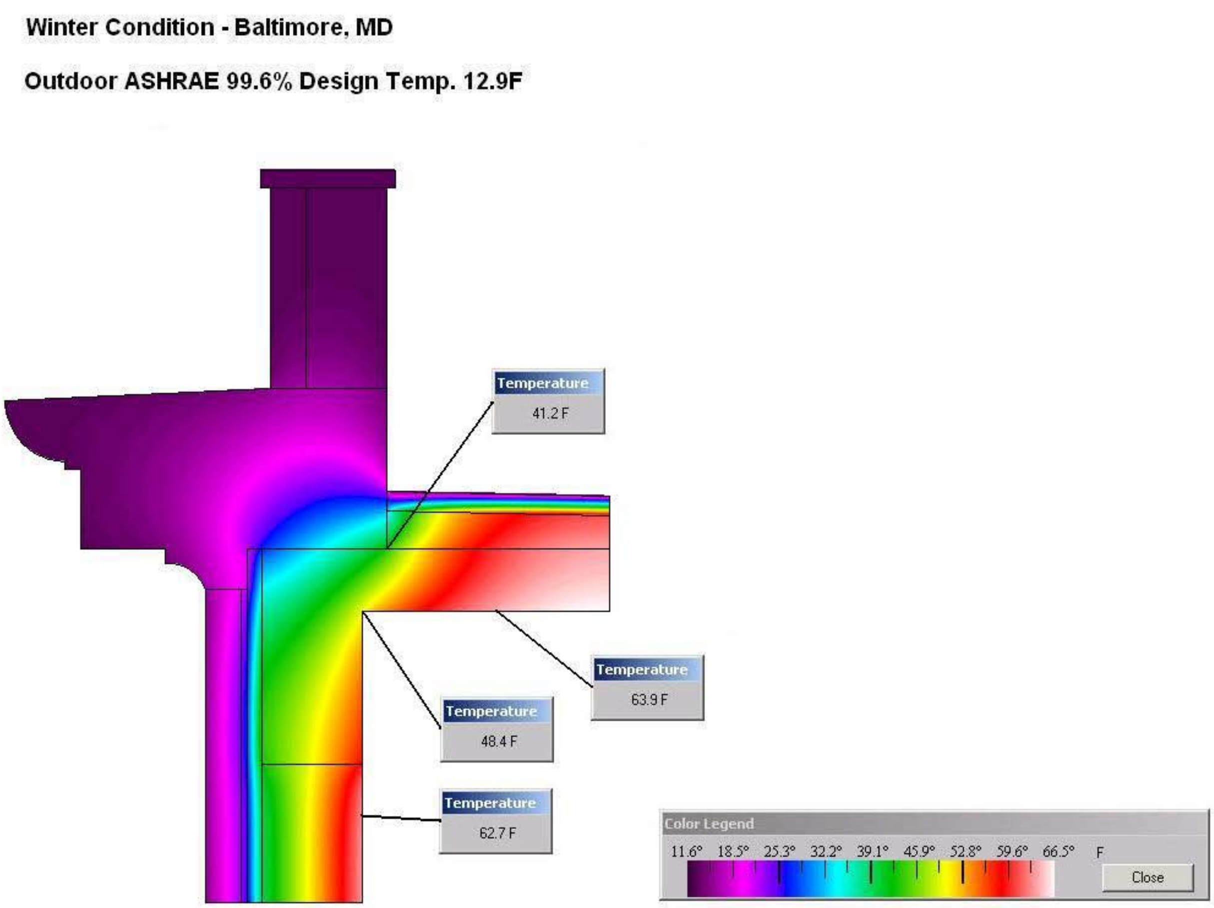

Figure 13. Temperature distribution at the roof parapet (existing condition).

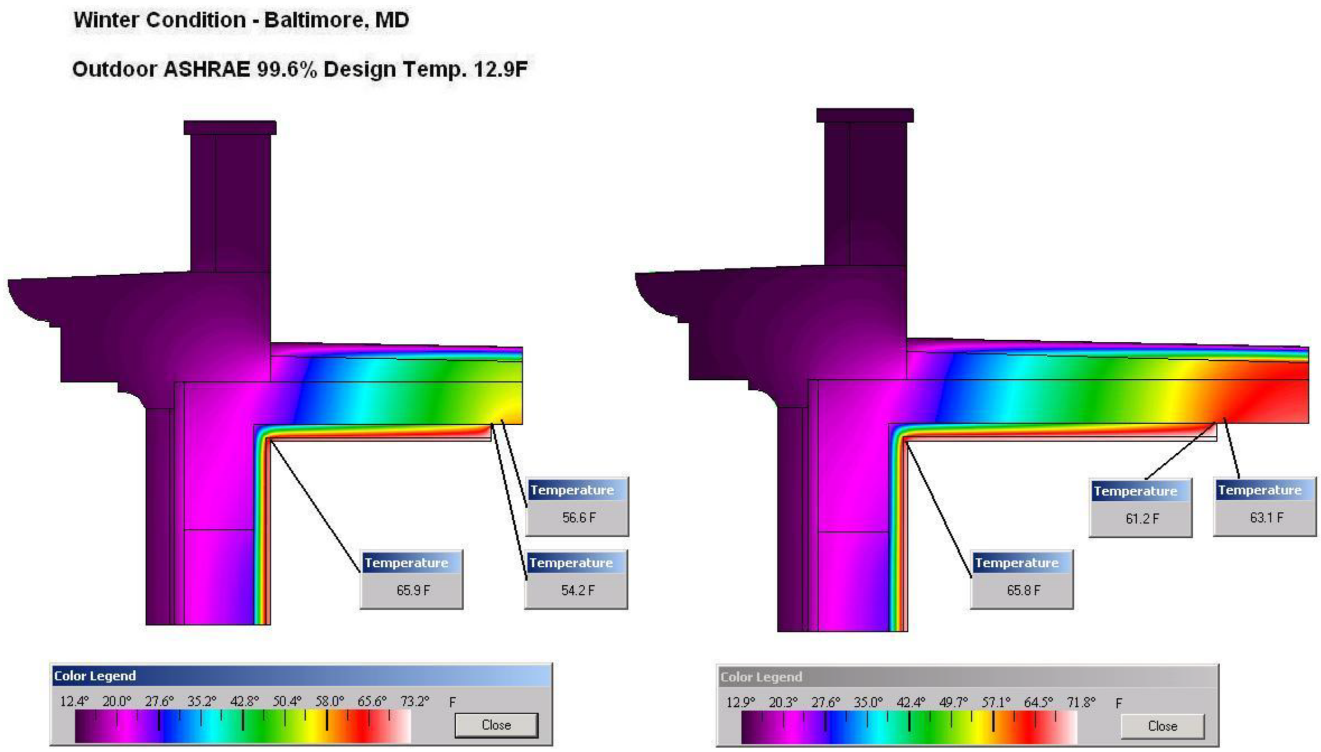

Figure 14. Temperature distribution at the roof parapet with for option with rigid insulation on the inboard surface of the CMU.

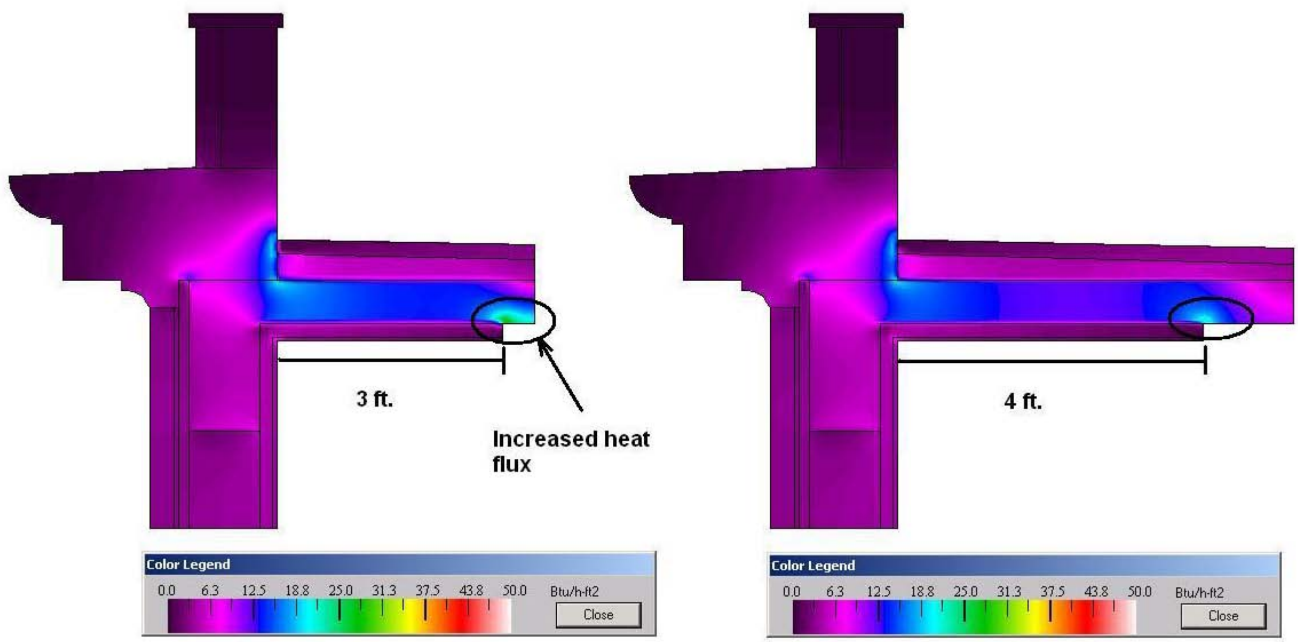

Figure 15. Temperature distribution at the roof parapet with for option with rigid insulation on the inboard surface of the CMU.

Providing 2 inch of extruded polystyrene insulation inboard of the concrete beam below the roof parapet and extending it 4 feet below the roof slab improves thermal resistance and increases surface temperatures on the uninsulated sections of the deck. Sensitivity analysis showed that carrying the insulation 4 feet on the underside of the roof slab was the optimum solution from thermal standpoint. The plots in Figure 15 show lower heat flux at the underside of the roof deck with 4 feet of insulation. Temperature distribution for the existing window sill condition and the two thermally improved options; with cavities in metal-framed wall filled with 3-5/8 inch unfaced fiberglass batt insulation (Option 1) and 2 inch extruded polystyrene insulation on the interior side of the concrete beam extending 4 ft from the exterior wall at the underside of the concrete roof deck (Option 2) are shown in Figure 16 through 18, respectively. Similarly, to the roof parapet condition the window sill transition with rigid insulation provides a thermally superior solution.

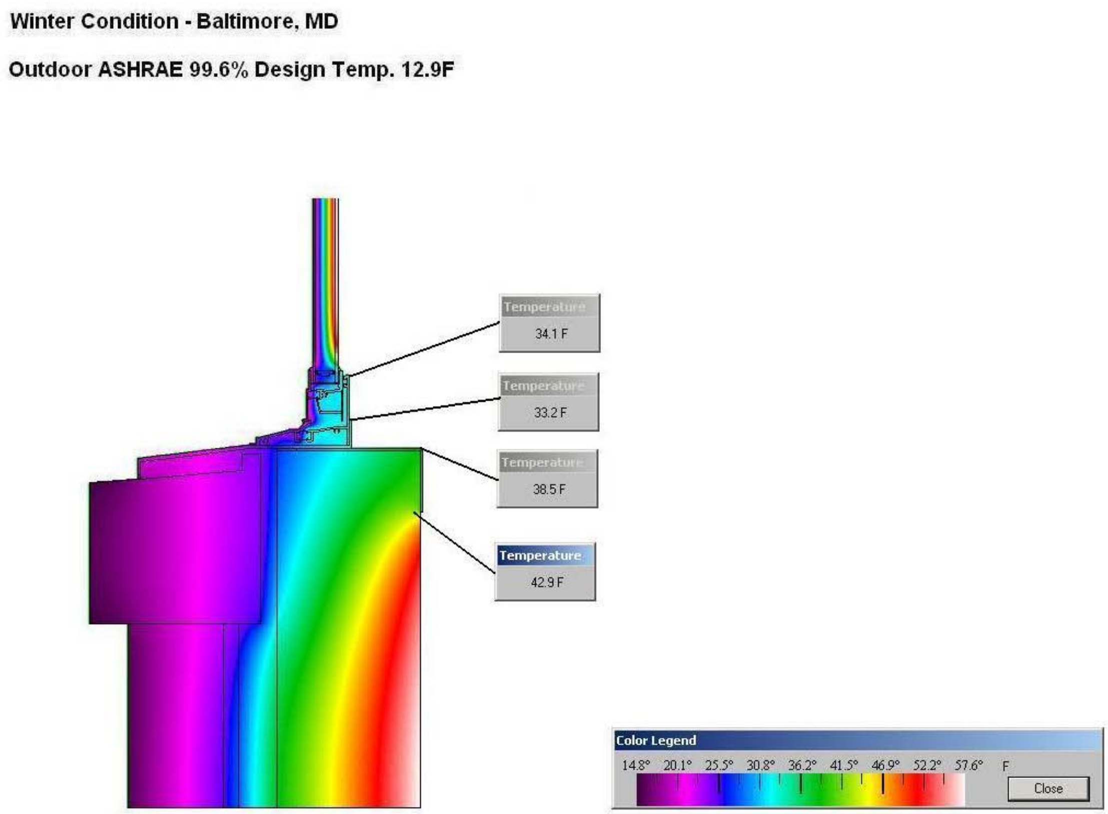

Figure 16. Temperature distribution at window-to-wall sill transition (existing condition).

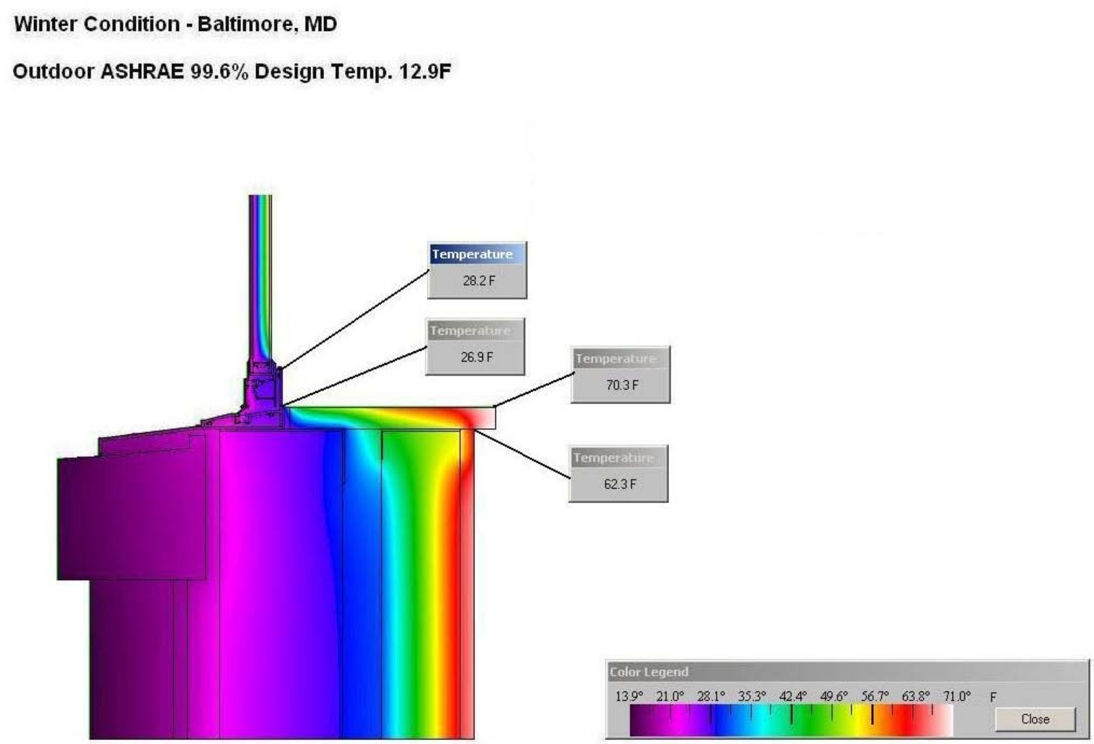

Figure 17. Temperature distribution at window-to-wall sill transition for option with fiberglass batt insulation.

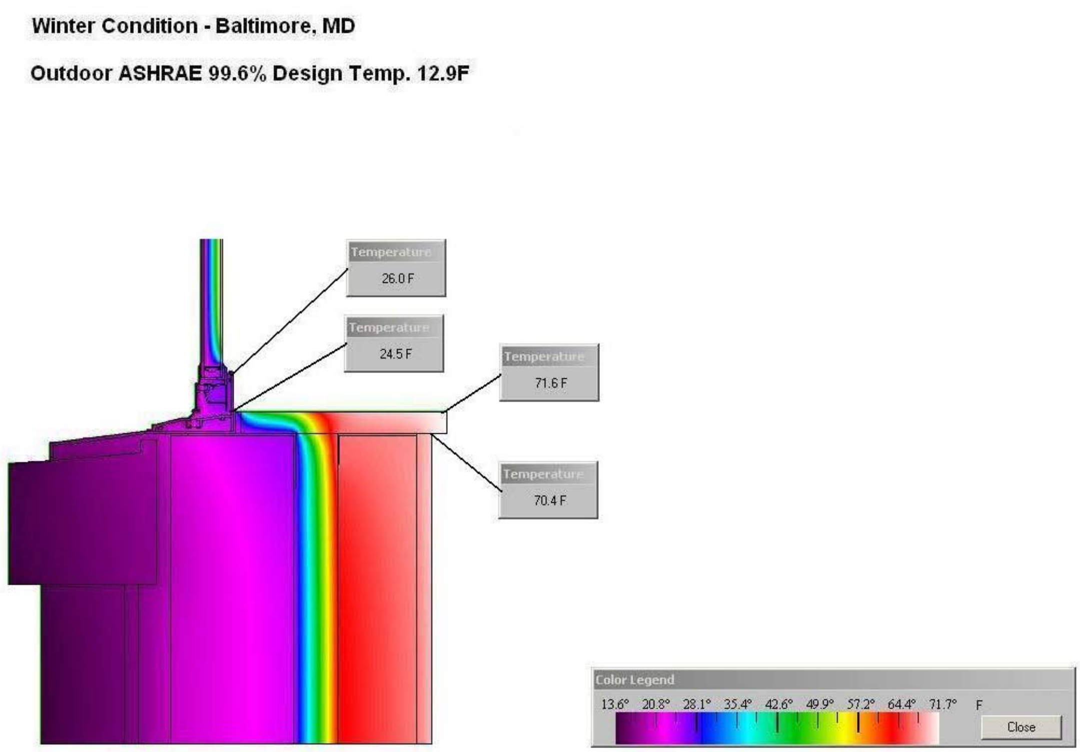

Figure 18. Temperature distribution at window-to-wall head transition for option with rigid insulation on the inboard surface of the CMU.

Provide new insulation on the inboard side of the masonry into previously uninsulated mass walls changes the temperature profile of the wall and no longer allows the wall to be tempered by interior environment conditions. During wintertime, the masonry remains at lower temperatures for longer duration of time which increases its susceptibility to freeze/thaw damage provided that critical moisture content of the brick masonry can be attained. Building enclosure engineers and architects therefore need to be aware of such risk and must take necessary precautions (i.e., freeze/thaw analysis) to quantify the risks and determine long-term effect. On this project, the design team analyzed and determined that the changes to the wall system introduced a minimal risk for freeze/thaw induced masonry damage.

CONCLUSIONS AND RECOMMENDATIONS

The case studies presented showed that new buildings can be designed with thermal performance improvements in mind during the early conceptual design and design development project phases. Existing buildings can be upgraded, but careful evaluation of the enclosure systems needs to be completed to determine how the proposed changes will affect the existing system. The use of thermal analysis software highlights that these tools are becoming more reliable and widely used by the design professionals. However, the results generated have to be interpreted with caution to degree of experience to separate meaningful and erroneous data.

Energy efficient designs are achievable; however much work is still necessary within the United States. Based on the case studies provided above, designers need to:

- Review thermal, air and waterproofing barrier systems in building enclosures for continuity at opaque portion of the below and above-grade walls and roofs but and at all details, transitions and penetrations.
- Reevaluate how we insulate and provide new and innovative methods to insulating, examining multiple material options and configurations.
- Air barrier systems are an essential component of building enclosure. Air barrier system function to provide air flow control and is an important factor in improving energy efficiency of buildings.
- Computer analysis such thermal and hygrothermal modeling should be used on as needed basis to verify and optimize aspect of building enclosure performance,
- Determine impact of specific remedial thermal improvement options (e.g., adding additional insulation on the interior side of the back-up wall system) on adjacent components in the system as well as the overall performance aspects of the system.

REFERENCES

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