Comparison of Two Structural Wall Assemblies Using ETMMS (Exterior Thermal and Moisture Management System) in Low-Income Applications

Marilou Cheple **Patrick H. Huelman**

Stephen R. Klossner **Thomas Schirber**

ABSTRACT

During 2004, two different wall assemblies using an exterior thermal and moisture management system (ETMMS) were used in the construction of two low-income projects in St. Paul, Minnesota. This paper discusses and compares the two types of wall assemblies, emphasizing the differences in construction methods and procedures. Comparisons include energy, moisture resistance, indoor air quality, constructability, and acceptance.

INTRODUCTION

Located in St. Paul, Minnesota, Project One is a 25-unit multifamily complex designed and built for formerly homeless and formerly chemically dependent adults with families. It is identified in this paper as the Jackson Street Project. Project Two is also located in St. Paul, Minnesota. It is a single-family house, the first built under a project with the goal of producing 20 single-family, owner-occupied units and 10 multi- or single-family rental units. This project will be identified in this paper as Project 20/20.

As technical partners in both projects, the authors were on-site periodically during the construction of both projects and were able to observe some similarities and some differences in the construction of each assembly. It is those comparisons that will be discussed in this paper.

Exterior Thermal and Moisture Management Systems

Both wall assemblies have employed a new approach that the authors refer to as the exterior thermal and moisture management system (ETMMS). This approach is based on a system known as PERSIST or pressure equalized rain screen insulated structure technique (Makepeace and Dennis 1998). ETMMS differs from PERSIST in that the ETMMS wall assemblies do not attempt to create a pressure equalized rain screen. Both projects use an exterior rigid insulation placed over a moisture/air/vapor layer applied to the sheathing. It is hoped that ETMMS will provide a lower cost and more durable alternative when compared to traditional cavity-insulated construction.

Building Envelope Descriptions

A brief description of the two projects follows. Although the description includes roof assemblies and foundations, the comparisons discussed in this paper are limited to the wall assemblies and specifically to the two different structural wall systems.

Jackson Street Village. The foundation walls of the Jackson Street Village project are poured concrete. All of the units have basements with daylight windows. The poured walls are covered with a 60-mil peel and stick waterproof membrane under a rigid foam insulation applied to the exterior. The peel and stick is applied so that it wraps over the footing. Any water that runs down the membrane is directed to an exterior drain tile system that allows the water to drain to an exterior location.

Exterior walls in the Jackson Street Village project were pre-manufactured off-site in sections. Sections were delivered to the site and assembled upward from the foundation. The wall sections were constructed with 2 in. × 4 in. framing

Marilou Cheple is an extension educator and instructor and **Patrick Huelman** is an associate professor at the University of Minnesota. **Stephen R. Klossner** is the owner of Advanced Certified Thermography. **Thomas Schirber** is community housing liaison at the Amherst H. Wilder Foundation.

Figure 1 *A photo of the moisture/air/vapor membrane at the Jackson Street Village Project.*

members and aligned so that the framing was vertically stacked from the foundation to the roof assembly. This design facilitated the installation of the exterior insulation, as the stud locations were continuous for any given wall assembly. This allowed for ease of marking of the studs for subcontractors. The sheathing is paper-faced gypsum, which is required to meet fire codes in this application. This sheathing was then primed as required by the membrane manufacturer and the 60-mil membrane was applied in rolls from the top-plate down. This was accomplished by mounting the rolls on a power lift and lowering the lift while setting and flattening the membrane. The membrane was wrapped into the window rough openings and applied shingle style over the foundation waterproofing. This membrane serves as the air barrier, vapor retarder, and drainage plane for the wall assembly. Two inches of rigid insulation (R10) was then applied using 3 in. screws with washers. The screws were fastened directly into the framing members of the wall assembly. If screws missed the framing member, crews were required to remove the insulation, remove all screws, patch all holes with new membrane, and begin again. This process was followed whenever project members were on site.

Three-inch vertical furring strips were applied to the face of the rigid insulation at 16 in. on center. Four-inch screws secured the furring strips into the framing. The location of the framing was easy to identify at this stage because the furring strips were placed over insulation that had already been secured and the washers used in this process were visible. The space between the furring strips on the second floor was filled in with ¾ in. rigid insulation (R-5 per inch). This additional insulation was a requirement of the vinyl siding manufacturer. The space between the furring strips on the first floor and basement levels was left open, providing a true drainage space. The finish siding on these sections is a cementitious product and does not require a solid backing. The exterior vapor/moisture/air layer precludes the need for interior air sealing and vapor retarder. The interior wall is one layer of ½ in. gypsum board finished in the traditional fashion.

Due to a scheduling and delivery conflict, nailing fins were removed from the windows before installation. Windows were instead installed with clips. The rough openings were first panned to ensure that any water leakage from the window opening or from the unit itself would drain to the outside of the wall membrane.

When moisture, water management, and infiltration characteristics of this wall assembly are evaluated, it is clear that the membrane provides a superior barrier for water, vapor, and air movement through the wall assembly from the outside. The window installation and panned rough openings protect the wall assemblies from moisture entry. Spaces between the installed windows and the rough opening were filled with low-expanding foam to ensure an airtight assembly. The foam insulation minimizes the thermal bypasses normally associated with framing in cold climates and should keep the interior wall assembly above the dew point. Any moisture from building products or summer relative humidity levels will dry to the interior.

The roof assembly for the Jackson Street Village project is a traditional truss system. Care was taken to isolate the attic from the conditioned space with use of a polyethylene air barrier and vapor retarder.

Project 20/20. In contrast to the wall assembly at Jackson Street Village, the wall assembly on Project 20/20 is nontraditional. This wall assembly is known as a structural engineered panel (SEP). The structural component of the wall assembly consists of moisture-resistant oriented strand board (OSB) panels. The walls were cut to the correct size and assembled on site from 8 ft × 24 ft OSB panels. Due to difficulty in obtaining the desired thickness (1-1/8 in.) of solid sheets, some walls were cut from two ¾ in. sheets of OSB that had been glued and mechanically fastened together, while others were cut from 1- 1/8 in. thick sheets. The panels were horizontally fastened to the rim of the structure. Corners were joined with a box-type joint that is mechanically fastened.

The walls were mechanically fastened to the rim joist and were placed directly on the foundation. Dormer end walls were reinforced with OSB pilasters keyed into the panels. A 60-mil peel and stick membrane was then installed over the OSB wall assemblies. In this project, the sheathing was not primed before the membrane was placed. Window openings were panned with a peel and stick product prior to window installation. Windows had traditional nailing fins that were incorporated into a flashing system, shingle style. Doors were installed in a similar fashion. Two inches of rigid insulation (R10) was installed over the membrane. With no framing members, attachment of the insulation was simplified. Because the entire wall assembly is structural, missing the framing during the attachment process was not an issue in this project. Horizontal furring was applied over the insulation. The space between the furring strips was filled with ¾ in. rigid insulation (R-5 per inch) as a backing for the siding. In this project the OSB wall assemblies acted as a primary air barrier for the wall assemblies. The moisture, infiltration, and thermal

Figure 2 *Erection of SEP at Project 20/20.*

qualities of this assembly should perform in a similar manner as the Jackson Village Project.

The foundation of the Project 20/20 house is poured concrete. The roof assembly is constructed in the same method as the wall assembly with the exception of a thicker insulation layer. An additional layer of OSB is applied over the insulation followed with roofing paper and asphalt shingles.

ENERGY COMPARISON

The ETMMS serves as the primary insulation for both wall systems. Therefore the energy performance of the two structural systems should be quite similar because both systems benefit from the airtight membrane and continuous insulation coverage used in the ETMMS. However, the frame wall system does have a few small advantages from an energy perspective. First, it shows an approximate 10% increase in R-value due to the enclosed air cavity and drywall finish. The overall calculated R-value (IP) for the ETMMS SEP is 15.8°F·ft^2·h/Btu. The frame wall, assuming a 20% framing factor, is R-17.3.

The frame wall does have another potentially larger energy benefit. The frame cavity could be insulated after the utilities are completed and before the drywall is installed. While this would dramatically change the overall insulating value of the frame system, it would also significantly change the moisture management objectives of this system. This would require additional study to make certain the additional insulation does not compromise the moisture impacts and long-term durability of the system. In the SEP system interior electrical and plumbing can be difficult and must be built into chaseways and raceways. For Project 20/20, the electrical outlets and switches on the exterior walls were built into baseboards and interior door trim. In the kitchen, a framed interior wall with an extended backsplash behind the cabinets serves as the utility chaise.

INDOOR AIR QUALITY AND MOISTURE MANAGEMENT

Indoor air quality and moisture management are intricately connected. Both projects focused on managing exterior bulk water, below-grade bulk water and water vapor, and interior water vapor and controlling occupant-generated moisture.

Although the understanding of moisture problems in today's residential buildings is incomplete, a significant number of moisture problems in wall assemblies have been noted and documented. Water damage to wall assemblies has generated significant concern about indoor air quality as it relates to biological contaminants such as mold. In addition, these problems have created significant damage to both sheathing and structural wall assemblies. These moisture problems have been attributed to many things, including permeability of the wall assembly, leaking wall fenestrations and flashings, interior generated moisture leaking through air barriers and vapor retarders, and positive pressures caused by HVAC systems. These are complicated, multifaceted problems for the building industry.

Building scientists have in recent times debated the optimal permeability of the exterior wall assembly. Many years ago the rule of thumb was that the exterior materials be 30 times more permeable than the interior wall assembly in heating climates. More recent discussions seem to suggest that in heating-dominated climates walls should be designed to dry to the exterior. Conversely, in cooling-dominated climates drying to the interior should be facilitated with highly permeable interior materials. Achieving this is complicated by reservoir claddings, solar driven diffusion, and management of condensation planes through temperature control.

Although it has long been recognized that our wall assemblies need to dry to the inside, the outside, or both, there have been few changes in the building codes to address these changing permeability needs. One of the significant advantages of the ETMMS system is that it not only facilitates this drying potential to the exterior in our wall assemblies, it can easily accommodate summer cooling conditions as well. While inward-moving moisture can pass through the thermal insulation, any condensation will occur on non-moisture-susceptible materials and ultimately the air/vapor/moisture barrier. This condensate can readily drain to the exterior and, when conditions are favorable, drying can occur back to the exterior. Interior air and vapor barriers are difficult to achieve and are dependent on multiple subcontractors understanding the process and working together to achieve them. Again, the ETMMS system simplifies this process.

The design process for both projects concluded that the risk of combustion byproduct release inside the buildings should be limited or eliminated. The Jackson Street Village complex is both heated and cooled with ground-source heat pumps (GSHP). The domestic hot water is provided with electric resistance water heaters and with a desuperheater connection to the GSHP. The desuperheaters provide domestic hot water on demand in the winter and by utilizing waste heat from air conditioning in the summer. The heating system installed in Project 20/20 home is a highly efficient (94%) sealed combustion furnace. Domestic hot water is provided by a power-vented gas hot water heater. A traditional, but energy-efficient (high SEER) air conditioner is installed in Project 20/20.

Soil moisture in the form of both bulk water and water vapor is considered to be a significant source of moisture in residential buildings today. The team expended significant effort in planning details that reduce the risk of water and vapor intrusion in both the design and construction phases. Below-grade moisture management at Jackson Street Village began with a spray-applied capillary break on the footings. The basement slab is placed over 6 in. of ¾ in. of washed river gravel and 2 in. of rigid foam board insulation. The basement slab was poured directly over the rigid foam insulation. The exterior of the poured foundation received a 60-mil bituminous peel and stick waterproofing membrane. The bottom of the peel and stick drapes over the footings; the top wraps under the bottom plate of the wood construction of the above-grade levels. By placing the peel and stick over the top of the poured foundation, the membrane acts as both a capillary break between the cement foundation and the wood portion of construction and as a gasket to minimize air movement into and out of the buildings. The waterproofing was then covered with 2 in. of rigid foam board. Both interior and exterior drain tile was installed and drained to an exterior location.

The below-grade moisture management of the Project 20/20 home was the same as that installed in the Jackson Street project. Both interior and exterior drain tile was installed; both empty into a sealed sump basket in the basement.

Ventilation for Jackson Street Village was provided with a 5 in. tube fan ducted to all bathrooms and the basement. A separate duct runs from the fan, which is located in the basement rim joist, into the gravel beneath the basement slab. This duct run is designed to mitigate both radon and soil water vapor. The inlet for ventilation is a 6 in. insulated flexible duct ducted from an outside hood at the rim and connected directly into the return plenum of the air-handling system. Supplemental ventilation is provided by an exhaust hood over the kitchen range that is vented directly to the outdoors.

Ventilation for the Project 20/20 house is a 6 in. tube fan that is ducted to all bathrooms, the kitchen, and the basement. This fan is located in the upper level future bathroom. The actual exhaust airflow was recently measured at 65 CFM. Although a rough-in ventilation system was installed, it was not attached to the mechanical ventilation system. Instead it runs from the gravel below the slab through the roof assembly and is expected to ventilate passively. The inlet air for the ventilation system is a 6 in. insulated flexible duct ducted from an outside hood at the rim directly into the return plenum of the air-handling system. Supplemental ventilation is provided by an exhaust hood over the kitchen range and is vented directly to the outdoors.

Filtration of the interior air for the Jackson Street Village is provided with an electronic air cleaner. The air cleaner is mounted on the return drop of the main air-handling unit and also downstream of the inlet for the outdoor air. This ensures high-efficiency filtration of the incoming air prior to delivery to habitable spaces. The main fan on the air handler consists of a DC or ECM motor designed to run continuously at low volume with very little electrical cost. Filtration of interior air for the Project 20/20 home consists of a traditional off-the-shelf filter. The main supply fan on the air handler is a 500-watt fan that is not designed to run continuously.

CONSTRUCTIBILITY

The Project 20/20 house envelope was constructed using structural engineered panels made from large OSB panels. The panels, which were 8 ft. by 24 ft. by ¾ in. in size, were assembled to completely replace stud framing. The goal was to develop a building envelope that was stronger, more airtight, quicker to erect, but less costly than stud framing. In this prototype house there were two main barriers to achieving the cost reduction goal. First, the skilled carpenters were not given appropriate construction technique instructions and had to develop the construction process as they proceeded. Secondly, the panels were laminated using two ¾ in. panels glued and screwed on site to form the wall shape. The cost was nearly three times the anticipated amount.

Future envelopes in this project will use single-ply panels with a thickness of 1-1/8 in. The erection process is now in place and a boom crane will be employed instead of a forklift. The panels will be tilted up and connected rapidly. Doors and windows can be cut virtually anywhere without any additional framing.

A cost and labor reduction may be possible with the membrane by using an experienced installer and a lower-priced membrane. Other trade-offs compared to conventional envelope may well result in a cost reduction for the SEP envelope. They include the elimination of drywall, exterior house wrap, and other required air and moisture barriers. It is estimated that the SEP construction method should result in a wall assembly cost reduction of up to 50% that of conventional framing.

ADOPTABILITY

Because the Jackson Street Project uses traditional wood framing and a traditional interior finish (gypsum), it could be adopted by a builder without risk of code violation or the need for engineering approvals. In contrast, the wall assembly in Project 20/20 employs materials and assembly practices that are untraditional and untested. Code officials may question the assembly and may require assurances in the way of sign-offs from a licensed structural engineer. This uneasiness is understandable and is, in part, due to the lack of standardized structural evaluation of panels, panel joints, and roof and floor connections.

The interior finish of Project 20/20 is exposed OSB. The cost benefit of not providing a gypsum-type wall finish may be offset by the lack of consumer acceptance. Consumer acceptance is likely to be higher for the Jackson Street Project as it is aesthetically more traditional. However, no research has been completed on this topic to date.

FUTURE RESEARCH ISSUES

There are several issues that require research before the wall assemblies used in either project have the ability to become mainstream practice in the United States. However, as noted above, the wall assembly as built in the Jackson Street Project is much closer to traditional practice and could be implemented immediately if a builder would choose to do so.

It is the opinion of the authors, however, that additional research on some issues is necessary before the wall assembly employed in Project 20/20 can reasonably be introduced into everyday construction practice. The following topics represent some, but not all, of those issues.

- Special issues as related to OSB
    - Structural
        - Issues of strength, creep, fasteners, connections
    - Nonstructural
        - Fire rating
        - VOCs emissions
        - Finishes (compatibility)
- Application of ETMMS as applied to each wall assembly
- Window installation methods to reduce or eliminate air and water entry

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