A DESIGN APPROACH TO ENVELOPE REMEDIATION OF HERITAGE BUILDINGS: FIELD MONITORING OF SALT BUILDING

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ABSTRACT:

The Salt Building is a significant landmark in the Southeast False Creek neighborhood of Vancouver, B.C. The heavy timber industrial structure was built circa 1930 to refine raw salt. Now considered a heritage building, the Salt Building recently underwent a major rehabilitation to be transformed into a commercial building, with restaurant, bakery and cafe.

With the rehabilitation, the interior operating conditions of the building changed from an unconditioned space to a conditioned space. The exterior wall assemblies, which consisted of dimensional lumber clad with horizontal cedar siding installed directly over diagonal shiplap sheathing, needed to be improved to provide adequate protection against rainwater and to incorporate an adequate level of thermal insulation, air barrier and vapour diffusion control. The absence of a moisture barrier in the existing wall assembly and the designation as a heritage building, where the cladding was considered a significant component that needed to be retained, made this a challenging project. Removal of the cladding and upgrading of the exterior portion of the wall was not a viable option.

This paper will discuss our innovative design approach to provide the exterior wall assemblies with the appropriate components to control heat, air and moisture flow with a focus on long-term durability. It will describe how the walls were upgraded from the inside using spray polyurethane foam and a drainage mat to create a vented air space inboard of the sheathing.

The hygrothermal performance of the remediated innovative wall assemblies was monitored by installing sensors to collect the temperature and moisture content of the wall sheathing and studs at specific locations on the four elevations of the building over a period of two years. This paper presents the monitoring results and discusses the performance implications of the applied strategy in dealing with similar envelope remediation of wood frame heritage buildings.

INTRODUCTION:

The Salt Building is a historic landmark centrally located in the Southeast False Creek neighborhood of Vancouver. Constructed in the 1930's, the Salt Building was originally a refinery for salt shipped from San Francisco. Decades later, following the decline of the local salt industry, the facility was converted into a paper recycling plant (Photo 1) [1].

The restoration and rehabilitation of the Salt Building began in 2007. The plan was to integrate heritage conservation in the context of sustainable practices as identified by the LEED Core and Shell system. The rehabilitation included raising the building with steel pile extensions and the restoration of the shell. The shell rehabilitation of the building was completed in 2009 for use by the Vancouver Organizing

Committee for the 2010 Olympic and Paralympic Winter Games (Photo 2) [2]. The building is intended to be converted into a public gathering space that will house a brewpub/restaurant, and coffee bar.

With the rehabilitation, the envelope assemblies became environmental separators between conditioned interior space and unconditioned outside space. The envelope assemblies had to be upgraded to deal with the new environmental loads all the while integrating heritage conservation and principles of sustainability to meet LEED Gold. Considering that the alteration to the outside of the building walls had to be kept to a minimum due to the heritage nature of this building, the building envelope design team was faced with some challenges to ensure that the proper critical barriers (to control air, vapour and water transport through the exterior walls) would be incorporated. The following sections describe these challenges as well as the innovative design strategies to deal with them.

Photo 1: Year 1943

Photo 2: Year 2010

ORIGINAL WALL ASSEMBLIES:

The original wall assembly was made of 2″ x 6″ wood studs, sheathed with diagonal lumber and covered with horizontal cedar siding (Photo 3). For the most part there was no thermal insulation, air, vapour and moisture barrier in the exterior walls. We did find some localized sections of walls where there was asphalt type building paper over the sheathing. We took this as an indication that some alterations were made through the years. Batt insulation and polyethylene vapour retarder sheets had also been added at some sections along the east elevation of the building.

During the investigation of the condition of the existing walls, it was found that the walls with no insulation, air, vapour and moisture barrier - as original construction wall assemblies - were still in good condition. Some horizontal cedar siding was removed to allow for close review of the diagonal sheathing condition. Except for some staining at the nail penetrations and some splitting, the sheathing and cedar siding were generally in good condition (Photo 4). The wood framing, which could be easily observed as it was exposed to the inside, was also in good condition. This was not the case for the modified walls. Where insulation and vapour retarder were installed at the conditioned section of the building, the walls were heavily deteriorated with the cladding, sheathing and stud framing completely rotten at the base of the wall.

Photo 3: Original wall assembly viewed from the inside

Photo 4: Existing sheathing viewed from the outside

DESIGN CHALLENGES:

The intent of the rehabilitation was to turn the interior of the building into conditioned space with temperature and relative humidity suitable for the occupants. To achieve the energy targets, it was necessary to add thermal insulation and to provide the envelope assemblies with an effective air barrier.

A key consideration was that the siding was identified as a significant component of the heritage fabric and therefore needed to remain in place. Since no alteration could be made to the exterior face of this heritage building, providing an exterior insulated rainscreen wall was not an option; insulation had to be added to the stud cavity. Furthermore, a moisture barrier could not be installed between the existing siding and sheathing.

With the original un-insulated wall, the sun-induced heat, water vapour and air were easily transferred through the walls. The cladding and the sheathing may have gotten wet from rain but they were open to dry to both inside and outside when weather conditions changed, and therefore managed to dry fast enough to avoid deterioration [3].

The evidence also showed that this balance was fragile. In the portion of building that had been heated and the wall modified with the addition of batt insulation and polyethylene vapour retarder, there was serious deterioration of wood, particularly at the base of the wall. Adding thermal insulation reduced heat transfer through the assembly, in turn reducing the temperature of the sheathing and decreasing evaporative drying potential [3 & 4]. In addition, the presence of a low permeance material (polyethylene sheet) further reduced the drying potential to the inside of the building. This resulted in the wood remaining wet too long and deteriorating.

Another consideration was the absence of moisture barrier in the walls. Without it, the sheathing and part of the wood framing would sustain higher levels of moisture.

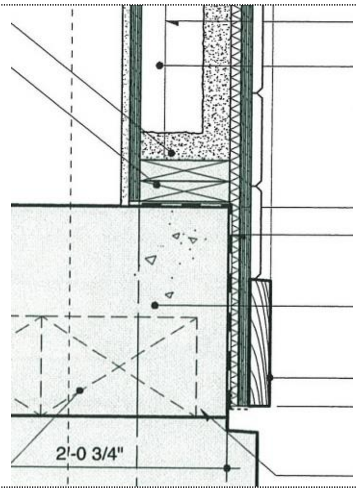
In summary, effective drying potential for the walls at the Salt Building – something that appears to be a prominent factor in keeping the walls in fairly good condition for so many years – needed to be maintained with the new building use and new rehabilitated wall design.

DESIGN APPROACH:

There were many parameters to take into account in the development of the new wall assembly. Without due consideration, the addition of the three new control layers (insulation, air and vapour retarders) would upset the balance that had been working to date. The main concern was that elements introduced to control heat, air and vapour flows would reduce the potential for the sheathing and siding to dry to the inside. In addition, the design had to take into account the requirement for structural upgrades and would have to minimize any disturbance to the exterior cladding. As such, a series of performance objectives to be incorporated in the design were developed:

- Any components that would be added would need to be durable; for instance, the additional wood structure or any replacement sheathing would be preservative treated.
- Any components that would remain in place and had the potential to get wet should be allowed to dry effectively by means of a vented cavity introduced behind the sheathing.
- To avoid any complications due to air leakage, a fairly sturdy air barrier was desirable.
- The cladding should not be disturbed unless absolutely necessary.

To achieve the ventilation inboard of the sheathing, it was proposed to install a drainage mat at the inside of the building to the back of the sheathing. That drainage mat would be installed in each stud cavity (from stud to stud), and be connected to the exterior at the bottom and at the top to allow for venting inboard of the sheathing. The latter would involve a small amount of disturbance to the cladding and sheathing but it was felt to be necessary. At both locations, a few feet of the existing cladding and sheathing would need to be removed. Before removal, the cladding would be marked in order to be reinstalled in the same location. The sheathing would simply be discarded and replaced with new pressure treated plywood at the base (Figure 1 and Photo 5) and an additional layer of drainage mat at the top (Figure 2 and Photo 6).



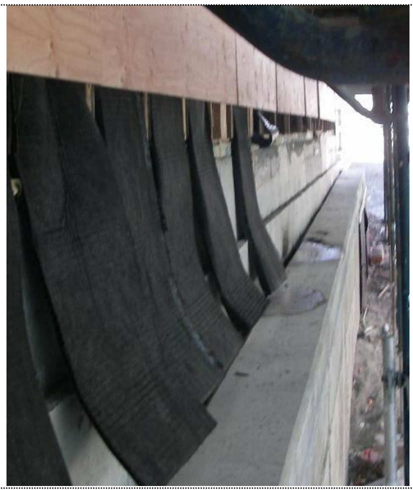


Figure 1 & Photo 5: Drainage mat detail at the base of wall

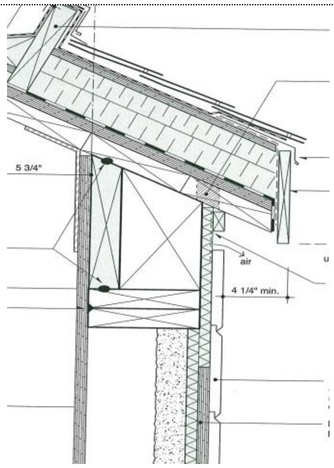
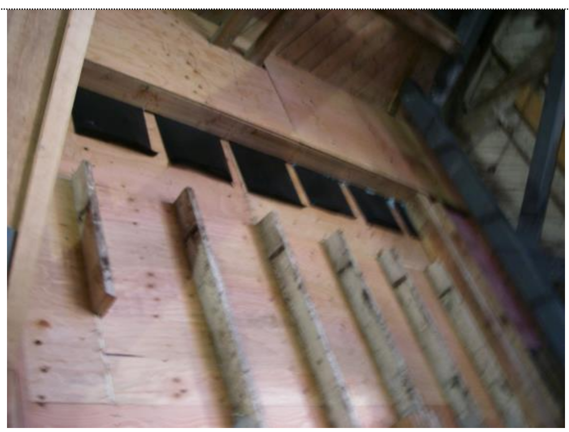


Figure 2 & Photo 6: Drainage mat detail at the top of wall

As a first step, the wall structure needed to be upgraded to meet the seismic requirements. This was, in part, accomplished by sistering the existing 2x6 wood studs with new 2x8 pressure treated wood studs and eventually adding a plywood sheet on the inside face of the wall as a finish (Photos 7 and 8). The structure also needed to be modified to accommodate the venting at the bottom of the wall. Principally, this consisted of notching the base plate to accommodate the drainage mat to go through.




Photos 7 & 8: Structural upgrades of the studs and new pressured treated plywood on the inside

Medium density, closed cell, spray applied polyurethane insulation was chosen to provide the thermal insulation, air barrier, and vapour diffusion control for the exterior walls (Photos 9 and 10). Considering the number and type of penetrations in the wall for structural and service purposes, the concept of using fibrous insulation and sealing the interior sheathing or vapour retarder to form an air barrier was judged to be a more problematic alternative.

Photo 9: Closed Cell Polyurethane foam against drainage mat   *Photo 10: Gaps between studs are sealed*

With the design team on board with the concept, the details were drawn for implementation on site. But similar to most construction projects, things do not always go as planned nor are they as simple as originally anticipated. There were additional details to be developed, such as where the walls met a sloped roof at the base, around windows and other penetrations, and where structural members interrupted the cavity. Some examples of these details are presented below (Figure 3 and Photo 11).

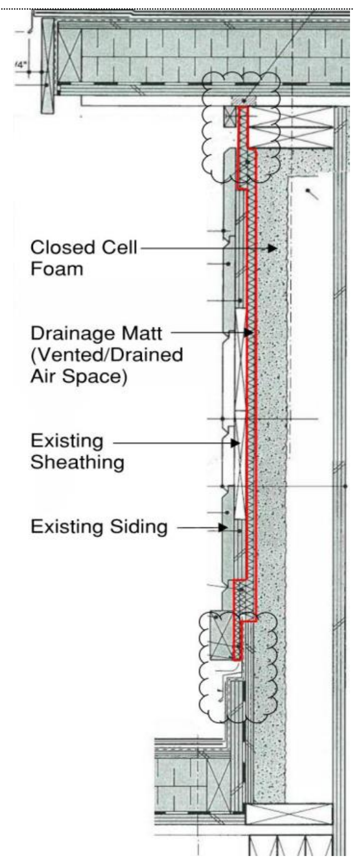


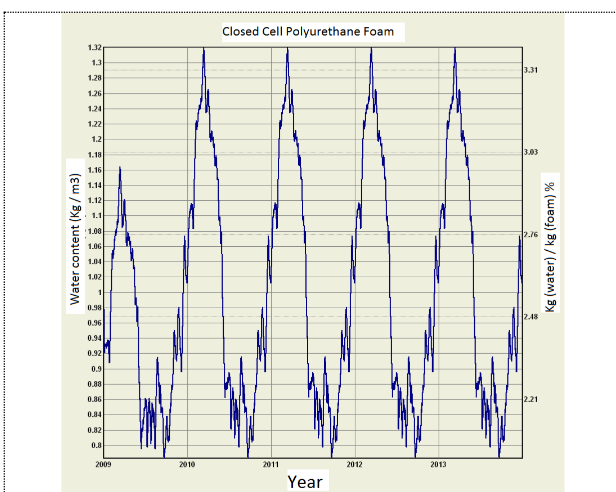
Figure 3 & Photo 11: Drainage mat detail at the top and base of wall and at the stud transitions

What generated the most discussion was what was the best type of drainage mat to create a venting space inboard of the exterior sheathing. Originally, it was anticipated that we would be using a drain mat made up of a core of three-dimensional looped filaments with a filter fabric face. It was considered desirable to use a material that had higher water vapour permeance than the materials inboard of the foam insulation.

Some pre-installation tests were done where the spray foam was applied to the filter fabric of the drainage mat. It was found that adhesion was good but foam expanded through the cloth and into the drainage core. Sourcing of a thicker drainage mat, one that would ensure a nice clear air space inboard of the sheathing, proved to be impossible within the constraints of the construction schedule. As such, it was decided that a drainage mat with a polystyrene dimple core would be used instead. The drainage mat was placed with the fabric facing out, and the foam was applied to the back of the mat. This assembly creates a vapour retarder on the “cold in winter” side of the foam insulation. While closed cell polyurethane has a high resistance to vapour diffusion, long exposure to a high outward water vapour pressure drive could result in sustained moisture accumulation in the foam. However, both practice and hygrothermal analyses using WUFI show that in buildings with modest vapour pressure difference between the indoor and outdoor, moisture accumulation over winter months is minor and disperses over the warmer months.

Hygrothermal analyses with WUFI were performed on the north-facing wall to assess whether or not there would be the risk of sustained moisture collection in the foam. Considering that the Salt Building, in its new use, will be highly ventilated and as such will have minimal moisture levels inside the building, 240 Pa was used as the water vapour pressure difference across the wall assembly. This number represents low interior moisture generation (classified as class 2 in the European Indoor Climate Class Model during winter -ISO Standard 13788-01-) [5]. Since the building is a low-rise with overhangs and surrounded by high-rise buildings, the inward drying due to sun was not included in the model.

Graph 1 shows the moisture content of the spray foam from 2009 until 2014. During this five-year period, the moisture content of the foam has increased during the cold seasons and then has decreased during the warm seasons. There has not been an escalating moisture accumulation rate in the foam and the moisture content (MC) of the foam at the end of each year stayed the same throughout the five-year period. It should be noted though that for buildings with high interior moisture generation rates, the use of low permeance drainage mat on the cold side of the foam insulation requires caution since the risk of sustained moisture accumulation in the spray foam could potentially be increased.



Graph 1: MC of foam

Ultimately, a good part – but not all – of the project was remediated with a polystyrene dimple core drainage mat. It was found that locations where the walls had previously been modified with batt insulation and polyethylene sheet were heavily deteriorated, including the cladding. As such, the wall in these locations was fully reconstructed, which allowed the installation of a moisture barrier. Unfortunately, even at these locations, strapping could not be added as it was important to keep the existing plane of the wall in relation to the other elements (roof eaves, windows, etc.). For consistency, in some locations where a moisture barrier was installed, the drainage mat on the inside was not always removed.

This resulted in three types of wall on the project:

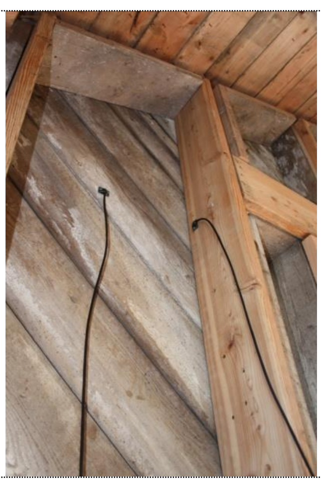
- North and south elevations (short sides): The siding was removed, new moisture barrier (Tyvek) was installed over the existing diagonal sheathing and then the siding was installed back. From the inside, the closed cell polyurethane foam insulation was sprayed against the existing diagonal sheathing.

- West elevation: The existing diagonal sheathing and siding were left in place. Drainage mat was installed against the sheathing between the stud spaces. From the inside, closed cell polyurethane foam insulation was sprayed against this drainage mat.

- East elevation: The existing siding and the diagonal sheathing were removed and then new plywood sheathing was installed, covered with new sheathing membrane (Tyvek) and new cedar siding. Similar to the west elevation, drainage mat was installed against the new plywood sheathing between the stud spaces and then closed cell polyurethane foam insulation was sprayed against it.

FIELD MONITORING:

In order to monitor the hygrothermal performance of the wall assemblies, moisture and temperature measurement sensors were installed to measure the moisture content and temperature of the sheathing and studs. These sensors were located at both the top and base of walls, and they were installed on the inside face of the existing diagonal sheathing and beside the 2″ x 8″ stud, 1″ away from the sheathing, as shown in photos 12 and 13. Following the installation, drainage mat was installed over the inside face of the sheathing with 3″ of 2 lb closed cell polyurethane insulation over it (Photos 14 and 15).




Photos 12 & 13: Moisture and temperature sensors at the existing sheathing and studs

Photos 14 & 15: Upon installation of the sensors, drainage mat and foam were installed

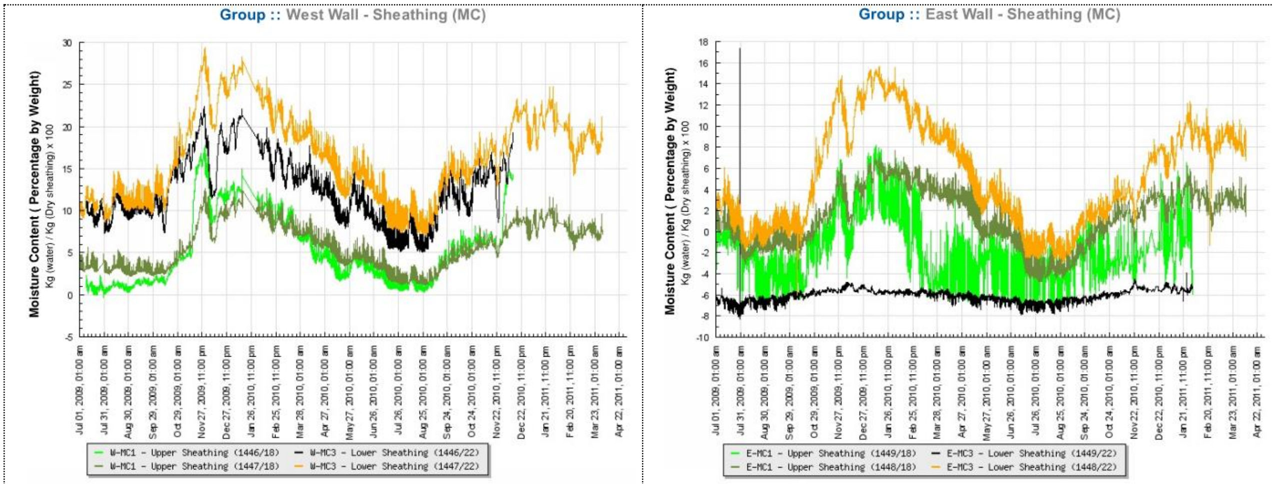
The monitoring of the walls started in June 2009 and was intended to record the readings for two years until June 2011. The data shown below is related to the period from June 2009 until April 2011. It should be noted that the occupancy of the building changed during this period. The construction of the building finished at the end of October 2009. From November 2009 until April 2010, the building was used by the Vancouver Organizing Committee for the 2010 Olympic and Paralympic Winter Games. Final tenant improvements have been ongoing since the end of the games, and eventually the building will turn into a public gathering space that will house a restaurant, brewpub and coffee bar.

MONITORING RESULTS:

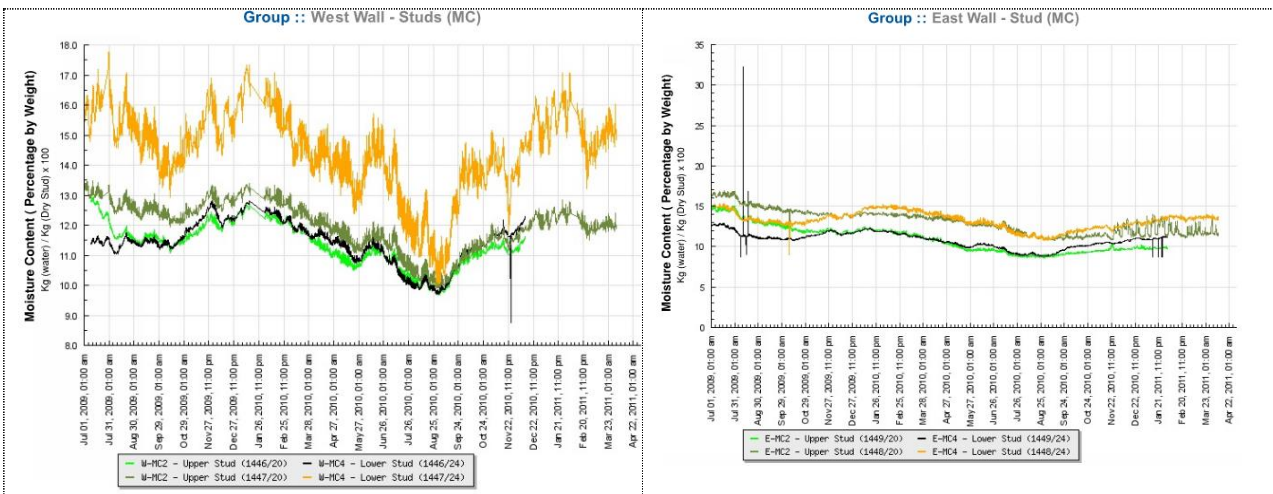
The moisture content (MC) readings of the sheathing at the west and east elevations are presented in Graphs 2 and 3. The MC of the sheathing has fluctuated throughout the year with increased MC during the winter months and decreased MC for the rest of the year. For example, the MC of the lower sheathing at the west elevation goes up to 28% in November 2009, and then it manages to go down to 10% in July 2010. The MC of the lower sheathing at the east elevation follows a similar trend: it goes up to 15% in January 2009 and then goes down as low as 10% in July 2010.

Interestingly, while most of the wind driven rain in Vancouver is from the east, it is the west elevation that experiences the higher moisture content at the sheathing level. The west elevation also happens to be an elevation that does not incorporate a moisture barrier (as opposed to the east elevation which does). One could speculate that the moisture barrier does in fact provide a certain level of protection for the sheathing. In any case, a fluctuation of the MC in the sheathing is expected since the moisture content is closely related to relative humidity of the air. During the winter, the relative humidity of the outside air is higher than that during the rest of the year. This will result in increased MC of the sheathing during winter [6]. The graphs indicate that although the sheathing gets wet during the winter, it managed to dry out during warmer weather. As long as the wetness is not sustained over a long period and drying can take place effectively, there would not be a concern with regard to moisture damage due to high MC.

The MC readings of the studs at the west and east elevations are presented in Graphs 4 and 5. As shown in these graphs, the MC of the studs has been below 19% for the majority of the year and has decreased since the start of monitoring. The MC of the studs is relatively stable without significant fluctuations.

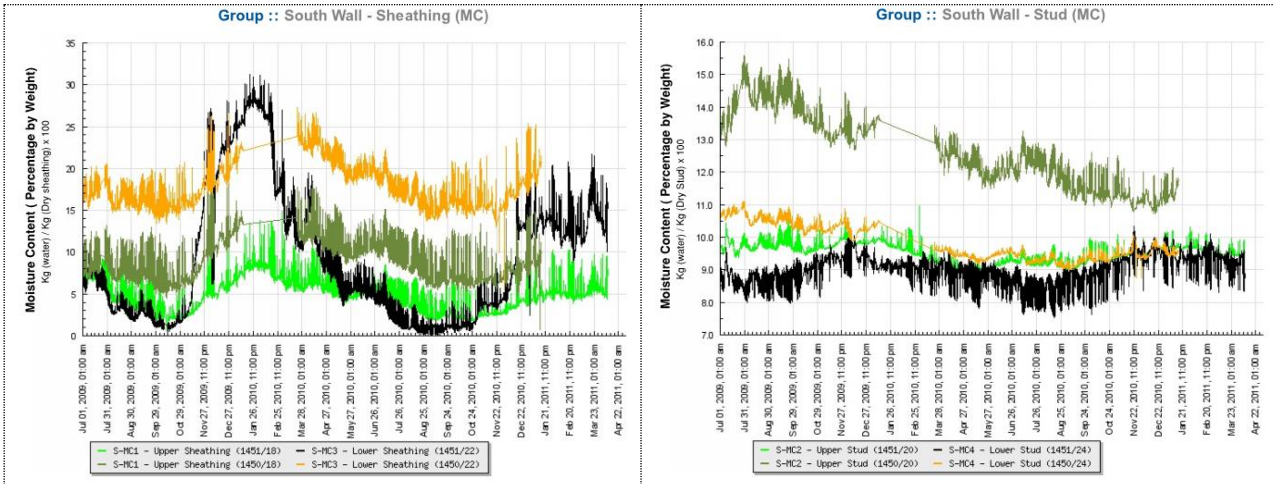


Graphs 2 & 3: MC of sheathing at west and east elevations



Graphs 4 & 5: MC of studs at west and east elevations

As discussed earlier, during construction, it was decided that the existing siding should be removed and replaced with new on the south elevation. As a result, the drainage mat strategy was not incorporated for the south elevation and instead, a spun bonded polyolefin fabric was installed over the existing diagonal sheathing, with new or reused horizontal siding installed over that. Graphs 6 and 7 show the MC readings of the sheathing and studs at this elevation. The results follow similar trends as observed at west and east elevations. The collected data on the north elevation was not conclusive and is not included here.



Graph 6 & 7: MC of sheathing and studs at south elevation

CONCLUSIONS:

This paper describes an innovative design approach to increase the drying potential of walls of an un-conditioned heritage wood frame building – The Salt Building – that has now been turned into a conditioned space. In the absence of moisture barrier over the existing diagonal sheathing, an assembly using closed cell spray polyurethane foam insulation and a drainage mat on the inside face of the exterior sheathing provided the wall with a high level of heat, air, and vapour transport control layers with the added benefit of a vented air space inboard of the sheathing.

Monitoring shows that the moisture content of the sheathing increased to 28% during the winter at the west elevation however, it decreased to around 10% during the summer. The drying potential of the wall during warm outdoor conditions has managed to eliminate the sustained wetness in the assembly which would otherwise provide the conditions for decay.

BIBLIOGRAPHY

[1] The Challenge Series, *False creek's ecological + industrial history*, www.thechallengeseries.ca/chapter-01/history

[2] Russell Acton, *Salt Building Revival*, Sustainable Architecture and Building Magazine, June 2010

[3] Joseph W. Lstiburek, *Insight: five things*, 2010, www.buildingscience.com

[4] Morton Mott-Smith, *The concept of heat and its working simply explained*, Chapter VII, 1962

[5] ISO Standard 13788-01, 2001, *Hygrothermal Performance of Building Components and Building Elements—Internal Surface Temperature to Avoid Critical Surface Humidity and Interstitial Condensation—Calculation Methods*, International Organization for Standardization, Geneva, Switzerland.

[6] Neil B. Hutchen & Gustav O.P. Handegord, *Building Science for cold climate*, Chapter 5