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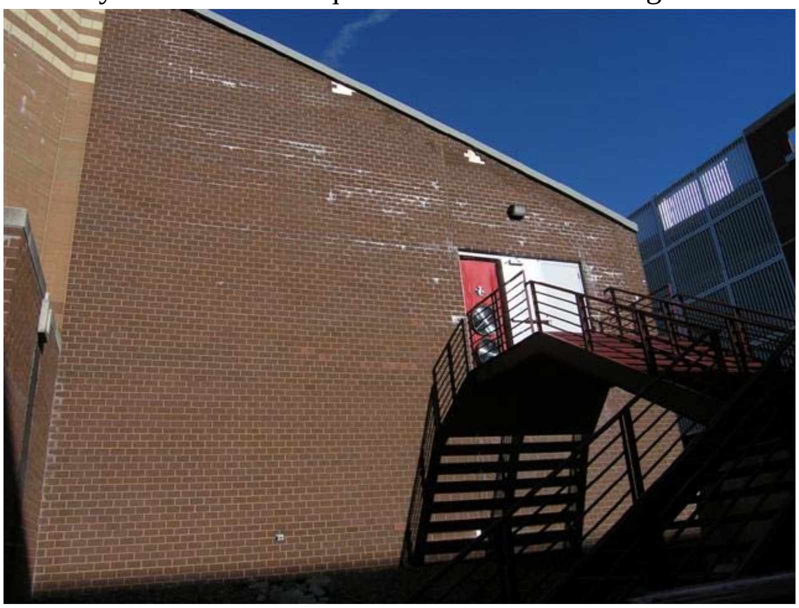
Re: Moisture Analysis of the University of Minnesota Aquatic Center

Background

As requested, the following is an analysis of the moisture-related damage to the east wall of the University of Minnesota Aquatic Center. The damage is visible as efflorescence on the brickwork and deterioration of mortar joints. The picture shows that the most efflorescence occurs near the top of the wall with complete mortar deterioration appearing just below the parapet flashing. The two white areas below the flashing are locations where bricks have been removed for inspection and temporarily replaced with rigid insulation. Note the red blower door assembly installed in the exit door.



The damage mechanism is believed to be primarily as follows: Warm, moist air from the pool area enters the cavity between the exterior brick and the structural masonry wall behind it through gaps between the masonry and the interior side of exterior door frames and at failed caulking along expansion joints and control joints. As the warm air rises to the top of the cavity, it cools and releases its excess moisture into the mortar and brick. Gradual deterioration of the mortar joints provides an ever more effective exit for the pool air, increasing air flow and accelerating the moisture process. The excess moisture carries soluble salts to the brick surface creating efflorescence. The mortar becomes saturated to the point that repeated freezing and thawing cycles blow it apart.

Braun Intertec has proposed a series of work items that will repair these cracks so that air infiltration into the east brick wall cavity will be greatly reduced. This analysis seeks to answer the question: Will sealing these cracks reduce the moisture flow into the cavity enough to stop the brick and mortar damage or are additional remedies required?

Analytical Method

The analysis will use the WUFI Pro computer program to model the heat and moisture flows in the wall. WUFI is one of the most advanced hygrothermal modeling programs available today. WUFI calculates hourly heat and moisture flows for as many years as desired and accounts for many variables including material properties, surface orientation, solar radiation, indoor and outdoor climates, infiltration and rain absorption and penetration. It was developed by the Fraunhofer Institute in Germany and the Oak Ridge National Laboratory in the U.S. It has had, and continues to have, extensive field testing against actual building assemblies here and abroad. Much of this validation work has involved masonry buildings. For more information, visit www.wufi-pro.com.

The analytical procedure will be in two steps:

1. Run WUFI using existing air leakage conditions to validate its results against the observed freeze thaw damage, i.e. significant damage to mortar, little or no damage to brick. Use the Braun Intertec blower door test results to estimate the air leakage value used as WUFI input.
2. Reduce the air leakage into the wall to a value consistent with a masonry wall with well-sealed joints and openings and containing an intact air barrier. The air barrier in this case is the existing peel and stick membrane on the outside of the structural masonry wall. Assess the estimated potential brick and mortar damage in the repaired wall.

WUFI Simulation Assumptions and Methodology

Minneapolis "cold year" weather data
Rain load and wind-driven rain penetration of cladding per ASHRAE 160P
Shading of east wall by surrounding buildings reduces available solar radiation by 50%
Interior conditions: temperature, 86 F. and relative humidity, 53%
Mechanical system building pressurization relative to exterior: -3 Pascals

Existing Wall Construction:
4" nominal red brick, type SW
Portland cement type lime mortar. type S
2" airspace
2" extruded polystyrene insulation board
Continuous asphaltic sheet air and water barrier adhered to concrete block (.08 perms)
12" nominal concrete block interrupted by steel columns
2" airspace
4" nominal Spectraglaze concrete block (1.64 perms including mortar joints)

To be conservative, the reported interior conditions of 83 F and 53% relative humidity are used in the WUFI simulation instead of the stated interior system design conditions of 82 F and 50% relative humidity. The stated interior system design fan pressurization relative to ambient is about -25 Pascals which is within the range of -12 to -37 Pa recommended by ASHRAE for natatoriums.[1] Depressurization protects the building components by reducing the moisture drive through the enclosure. However, a relative pressure of only -3 Pascals was observed during setup for the blower door test. This more conservative -3 Pa will be used in the WUFI simulation. It seems likely that because of the deterioration of the east wall sealant and mortar joints, the design depressurization can no longer be reached and since the proposed remedial work will treat about 2/3 of the observed crack area, pressure control may be restored to the building.

The efflorescence on the brick is seen as an indication of excessive moisture migration through the wall and a maintenance problem that can be cured by cleaning rather than serious damage itself. It is the mechanical damage to the mortar, which appears to be freeze/thaw related, that will be the focus of this investigation. The hypothesis is that if the moisture concentration in the mortar is reduced to a level that eliminates the freeze/thaw damage, the brick efflorescence will also stop.

Freeze/thaw damage to masonry materials occurs when freezing water in the pores of the material expands. The amount of stress put on the material is proportional to the quantity of air remaining in the pores; the compressibility the air relieves the stress of the water expansion. The "saturation coefficient" represents the ratio of water volume to total pore volume. This is a material property that can be estimated by testing; safe saturation coefficients are normally in the range of 75% to 90%. It is repeated freeze/thaw cycles that tear the material apart. The type of brick and mortar used in this building are unknown but it is surmised from the age of the building (1989) and from local practices that type SW brick and Portland cement lime mortar were used. Both have good resistance to freeze/thaw cycling. Type SW brick is rated for at least 20 freeze/thaw cycles annually.[2] Freeze/thaw damage does not usually occur until the temperature drops well below freezing. A damaging freeze/thaw cycle will be defined as a temperature excursion in the material from above 32 F to below 23 F.[3] when coincident with the saturation of the material exceeding the threshold saturation coefficient. In this report, the threshold saturation coefficient for the onset of freeze/thaw damage will be 85% for brick and mortar, which is believed to be reasonable for the assumed brick and mortar types.

WUFI Pro provides a one dimensional analysis of heat and moisture flows in the wall. The section chosen for the concrete blocks is through the cores (comprising about 75% of the cross-section) rather through the webs (comprising about 25% of the cross-section). The one dimensional WUFI model has been shown to give reasonable results when compared to field measurements for brick and mortar walls.[4]

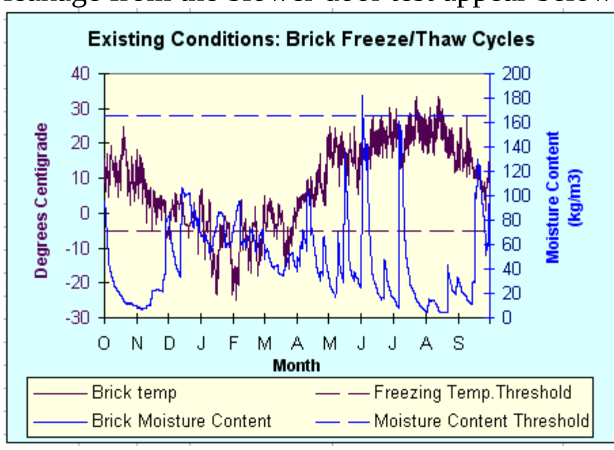
Step 1: Analysis of Existing Conditions

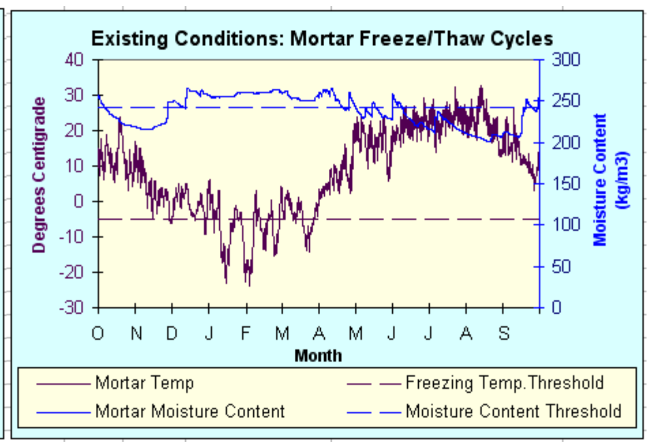
The blower door test for the Aquatic Center produced an EqLA (equivalent leakage area) of 14.83 square feet at a pressure difference of -30 Pascals. The EqLA is the total area of air leakage cracks through the building envelope at the given pressure difference. This translates to an EqLA under ambient pressure conditions of 18.35 square feet.[5]

The crack areas in the Table 1 were estimated by the architectural team during their building inspections. The percent joint openness in most cases represents an estimated observed amount of sealant failure. The building total is in good agreement with the blower door results of 18.35 square feet at 10 Pascals. There are undoubtedly other uncounted leaks such as infiltration through vestibule doors, mechanical penetrations, concrete masonry joints, etc. that could account for the difference. Additional leakage areas were added to the table for the east wall and for the remainder of the building in proportion to the observed areas so that the total matched the blower door test results. The important point for this analysis is that about 2/3 of the measured air leakage can be plausibly assigned to the east wall. This provides an air leakage rate that can be input to WUFI to represent the amount of pool air currently entering the brick cavity.

Table 1: Estimated Building Leakage Areas	Gross Crack Area sq. ft.	Openness of Joint	Net Crack Area sq. ft.
East Wall Leakage Area			
Two 8'-4" h. x 9'-8" w. door frames with 1/2" gaps at head and jambs	2.19	100%	2.19
Twelve control joints at 37' ea. x 3/8" thick	13.87	20%	2.77
Two expansion joints at 38' ea. x 2"	12.66	40%	5.06
Additional Leakage Area			1.31
Total East Wall			11.34
Other Leakage Areas			
Ridge skylight perimeter, 1300' x 1/16" wide	6.80	30%	2.04
Pyramid skylight perimeter, 12 at 120' x 1/16" wide	7.20	30%	2.16
Metal panel skylight wall at roof, 12 gaps at 2 sq. in. ea.	0.20	100%	0.20
Roof to wall transition at west end of building, 2 at 80' x 1/8"	1.70	75%	1.28
West wall metal panel to roof transition, 250' at 1/4"	5.20	10%	0.52
Additional Leakage Area			0.81
Total Other Areas			7.01
Building Total of Observed Leakage Areas			16.22
Total Leakage Area Adjusted by "*Additional Areas*" to match blower door results			18.35

The results of the WUFI simulations to assess potential freeze/thaw damage based on the air leakage from the blower door test appear below:





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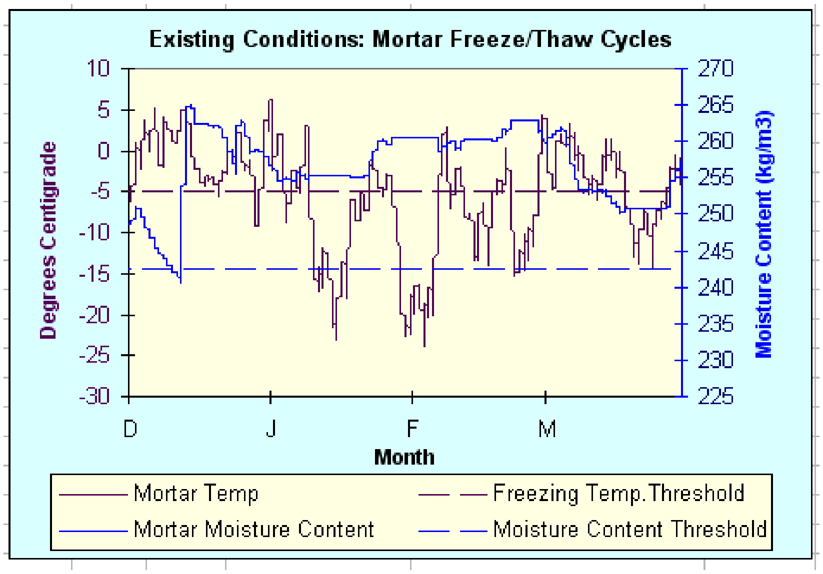
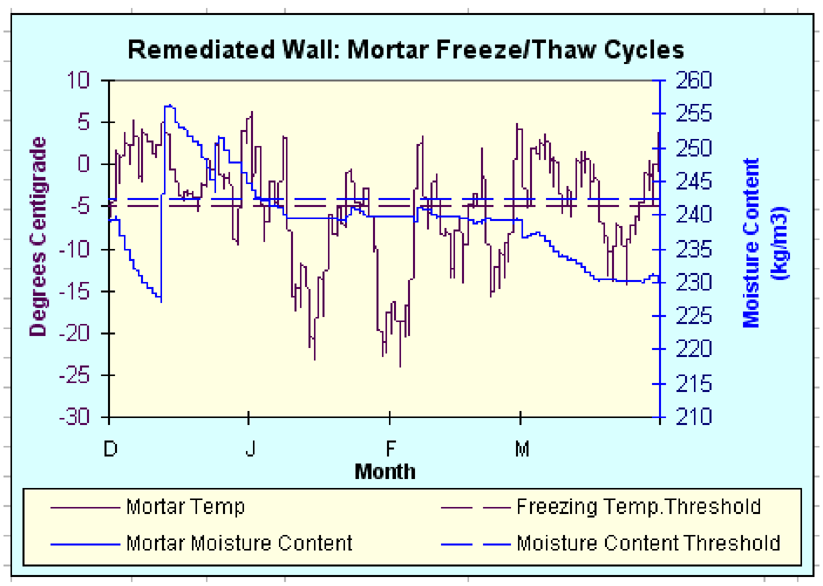
For the brick, the moisture content rarely exceeds the saturation threshold and when it does, it is in summer when the temperature is well above freezing. The blue spikes in summer indicate rain events rather than infiltration moisture coming from within the building. So consistent with observations, there is little potential for freeze/thaw damage to the brick.

For the mortar, the moisture content exceeds the threshold consistently throughout the winter, much of which time the temperature is well below freezing. Inspection of the WUFI film shows that the moisture fluxes that saturate the mortar are coming from within the building and not from rain. If we blow this graph up and look more closely at the winter months, freeze/thaw cycles can be observed. Inspection of this graph reveals 10 freeze/thaw cycles when the mortar is above its saturation threshold. Portland cement lime mortar should remain durable from 50 to over 300 cycles depending on the exact mix and water to cement ratio.[6] Since this building is about 20 years old, at 10 cycles a year the mortar would have experienced 200 cycles. The observed deterioration would put the durability of this mortar at the lower end of its expected lifetime. The are several variables which could explain this apparently short service life: the mortar may not be a Portland cement lime mix, it may have had a high water to cement ratio, or the moisture penetrating it may be carrying soluble salts from the pool environment. Mechanical freezing damage to masonry materials can accelerated by ionic solutes even in concentrations as low as 2%.[7]

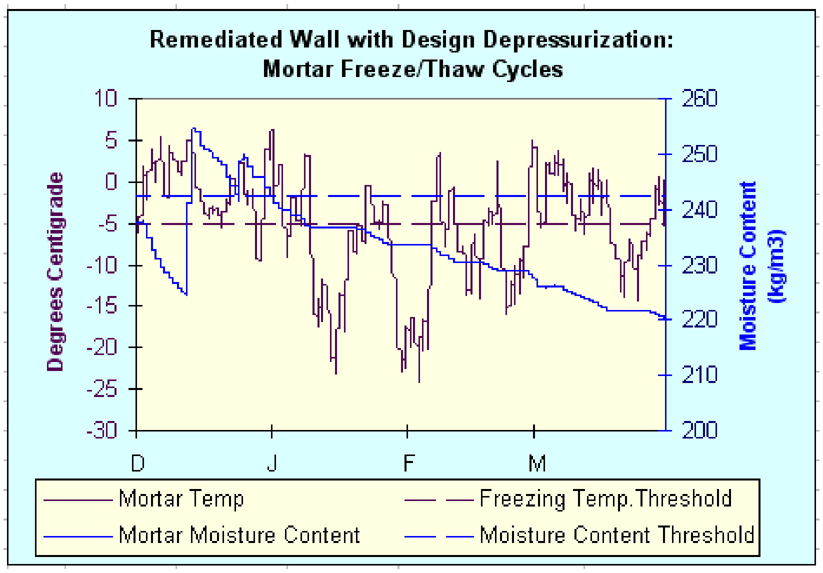


Step 2: Estimation of the Effects of the Proposed Remedial Work

If the repairs to the east wall remove 90% of the observed crack area listed for the east wall in Table 1, not including the additional leakage areas that were not observed, the equivalent leakage area for the entire building would be halved. This should provide a significant reduction in building energy consumption. The effect on east wall air leakage would be a reduction from 3.0 cubic feet per minute per square foot of surface at 50 Pascals to .4 cfm/sq.ft. @ 50 Pa. The air leakage rate of .4 cfm/sq.ft. seems reasonable and achievable for this project. It is the same as the maximum air league rate required to meet ASHRAE 189.1 Standard for energy efficient buildings yet less stringent than levels routinely achieved for high performance buildings with air barriers tested and sealed during blower door tests. Inspection of the WUFI results for the reduction in air leakage shows that the mortar in the remediated wall would be above the saturation threshold one month per year instead of three and would experience an estimated 3 annual freeze/thaw cycles instead of 10, which would extend the mortar lifetime by a factor of three in the absence of any other improvements to the performance of the mortar. If the east wall remedial work tightens the building enough so that the design depressurization of -25 Pa can be reached, less pool air reaches the brick cavity and further drying



of the mortar occurs, as the accompanying chart shows. Annual freeze/thaw cycles are further reduced from 3 to 2 which represents a fivefold increase in mortar lifetime compared to existing wall conditions with 10 annual freeze/thaw cycles.



Conclusions

The estimated building crack leakage area from field inspections was in good agreement with the equivalent leakage area at 10 Pascals calculate from the blower door test results. This agreement lends confidence to the ability to determine the initial average pool air infiltration rate into the east wall brick cavity which in turn provides a basis for estimating the effects of the remedial sealing work. Since the damage to the east wall masonry is believed to be primarily due to moist air leakage from the interior, the validity of the WUFI simulation rests on this infiltration benchmark.

For the existing east wall conditions, the freeze/thaw cycling results from WUFI confirm that the observation that the mortar is being stressed by about 10 freeze/thaw cycles per year but the brick is not. The simulation also indicates that the damaging moisture fluxes are coming from cold weather infiltration and not from rain during the swing seasons. However the amount of damage to the mortar is somewhat high compared to the expected durability of Portland cement mortar under the predicted freeze/thaw frequency.

If 90% of the observed air leaks in the east wall are sealed by the remediation work, the equivalent leakage area for the entire building would be halved; this should provide a significant reduction in energy consumption. According to WUFI, annual freeze/thaw cycles would be reduced from 10 to 3 which would triple the mortar lifetime in the absence of further improvements to the mortar performance.

The observed negative building pressure relative to the exterior during the blower door tests was about -3 Pascals; the stated design depressurization for the Aquatic Center is -25 Pascals. WUFI simulation indicates that if reducing the east wall air leakage allows the system to reach the design depressurization, annual freeze/thaw cycles would be incrementally reduced to a level representing a fivefold increase in mortar lifetime relative to existing building conditions.

[1] Air Barriers in High Interior RH Specialty Buildings: Considerations for Control of Moisture-Laden Air in Museums, Labs and Natatoriums, Totten and O'Brien, ASHRAE 2007
[2] Technical Note 9a on Brick Construction, Brick Institute of America
[3] A Limit States Design Approach to Assessing F/T Resistance, Building Science Corporation presentation, 2010
[4] Measuring the Impact of Interior Insulation on Solid Masonry Walls in a Cold Climate, Wilkinson, De Rose, Sullivan and Straube, Journal of Building Enclosure Design, summer 2009
[5] Refer to the Braun Intertec Blower Door Report for the air leakage coefficient and depressurization exponent. For flow, pressure and leakage area conversion formulas, see 2009 ASHRAE Handbook of Fundamentals. EqLA calculations are based on the Canadian standard of 10 Pascals with a .61 discharge coefficient per recommendations at www.energyconservatory.com
[6] Effect of Air Entrainment on Freeze-Thaw Durability of Type S Portland Cement-Lime Masonry Mortar, Tate and Thompson, 9th Canadian Masonry Symposium
[7] Freeze-Thaw Durability of Porous Building Materials, Litvan, ASTM, Bulletin 691, 1980