

# Retrofitting Masonry Buildings in Cold Climates: When and What to Test

By Randy Van Straaten, PEng

Older load-bearing masonry buildings are often good candidates for renovation and adaptive reuse. They typically have solid structures with flexible floor plans, useful urban locations, attractive aesthetic qualities, and sometimes cultural or historical significance. Given modern demands for low energy usage, thermal comfort, and carbon emission reductions, it makes sense to add thermal insulation to older masonry buildings as part of the renovation process.

Insulation retrofits affect the temperature profiles through masonry walls as illustrated in Figure 1. The impact of these thermal changes, as well as moisture and air movement within the system, are complex and can result in decay of embedded materials. Exterior thermal insulation retrofits have a beneficial impact, as the existing wall system will be maintained at warmer and generally drier conditions. Interior thermal insulation will subject a greater depth of the wall to freeze/thaw conditions and will typically raise

wintertime moisture levels in the wall, presenting a risk of freeze/thaw decay (Straube and Schumacher 2006). Assessments of freeze/thaw decay risk for various insulation options may involve testing the existing masonry, which is the subject of this article.

Guidance on thermal insulation of such walls is provided in ASTM E3069, *Standard Guide for Evaluation and Rehabilitation of Mass Masonry Walls for Changes to Thermal and Moisture Properties of the Wall*. The guide calls for evaluation of the increased potential for freeze/thaw damage by evaluating the “critical moisture content,” tem-

peratures, and freeze/thaw cycles of the retrofit relative to the existing wall. Neither the guide nor the reference, ASHRAE 160, “Criteria for Moisture-Control Design Analysis in Buildings,” provides specific thresholds for these conditions regarding freeze/thaw degradation.

Frost dilatometry can be used to measure the critical freeze/thaw moisture saturation of masonry (see Fagerlund 1977). This approach involves measuring the dilation (growth) of slices from samples at a range of moisture saturation levels after freeze/thaw cycling as shown in Figure 2.

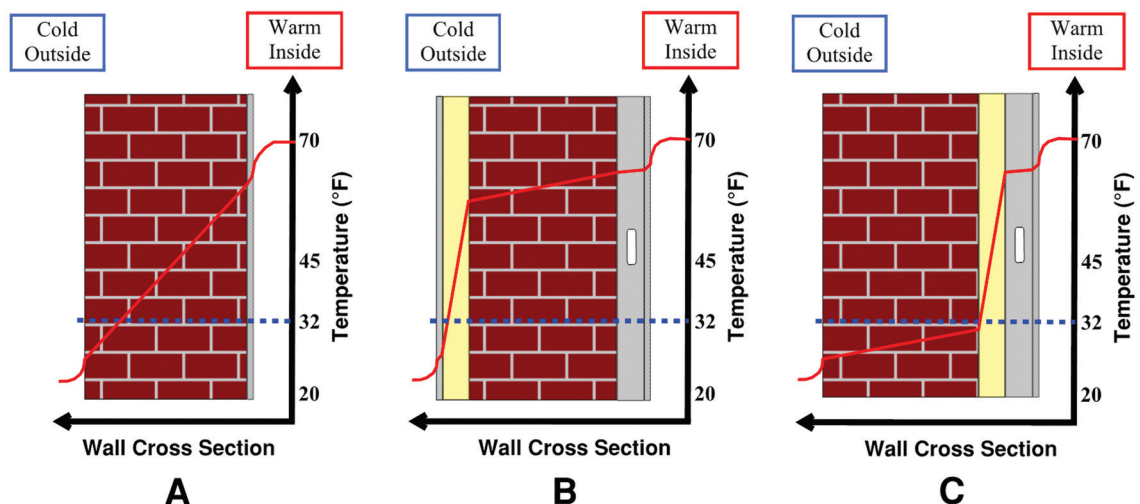


Figure 1 – Temperature profiles for masonry wall assemblies with A) no insulation, B) exterior insulation, and C) interior insulation.

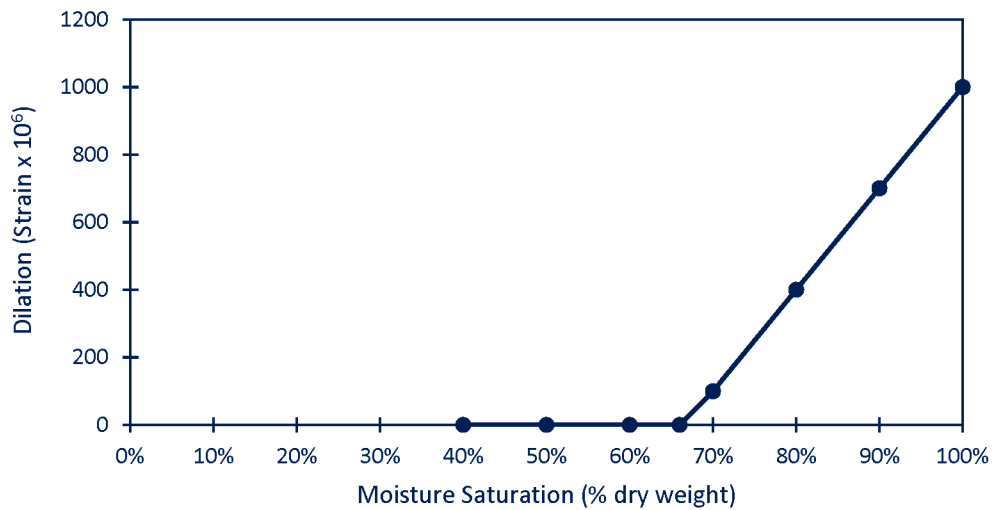


Figure 2 – Illustration of dilation measurements and estimation of the critical saturation for a brick sample (66% is the critical saturation in this case).

Below the critical saturation, dilation will not occur with freeze/thaw cycling. Freeze/thaw dilation will occur at moisture levels above the critical saturation and has been found for many materials to dilate at a linearly increasing rate, with higher moisture levels, during freeze/thaw events.

The critical saturation can be used in a limit-states approach as a material resistance indicator, which is then compared to in-service moisture content (or the load) of the building or exposed wall. In such analysis, the moisture content within the masonry wall is predicted using hygrothermal

modeling. Numerous case studies for projects using this assessment approach have been published (Ueno et al. 2013a; Ikenouye and Simon 2014), and the test methodology has been described in detail in previous publications (Ueno et al. 2013b; Van Straaten 2014). Within the last few years, research has led to test method refinements that have improved repeatability of frost dilatometry measurements (Van Straaten 2014 and 2016).

The limit-states approach allows project-specific risk assessment of proposed thermal insulation retrofit options. However, other assessment approaches are currently being used within the industry as well. Regardless of the

approach chosen for a particular project, some general recommendations can be made on the need for determining project-specific masonry material properties through laboratory testing.

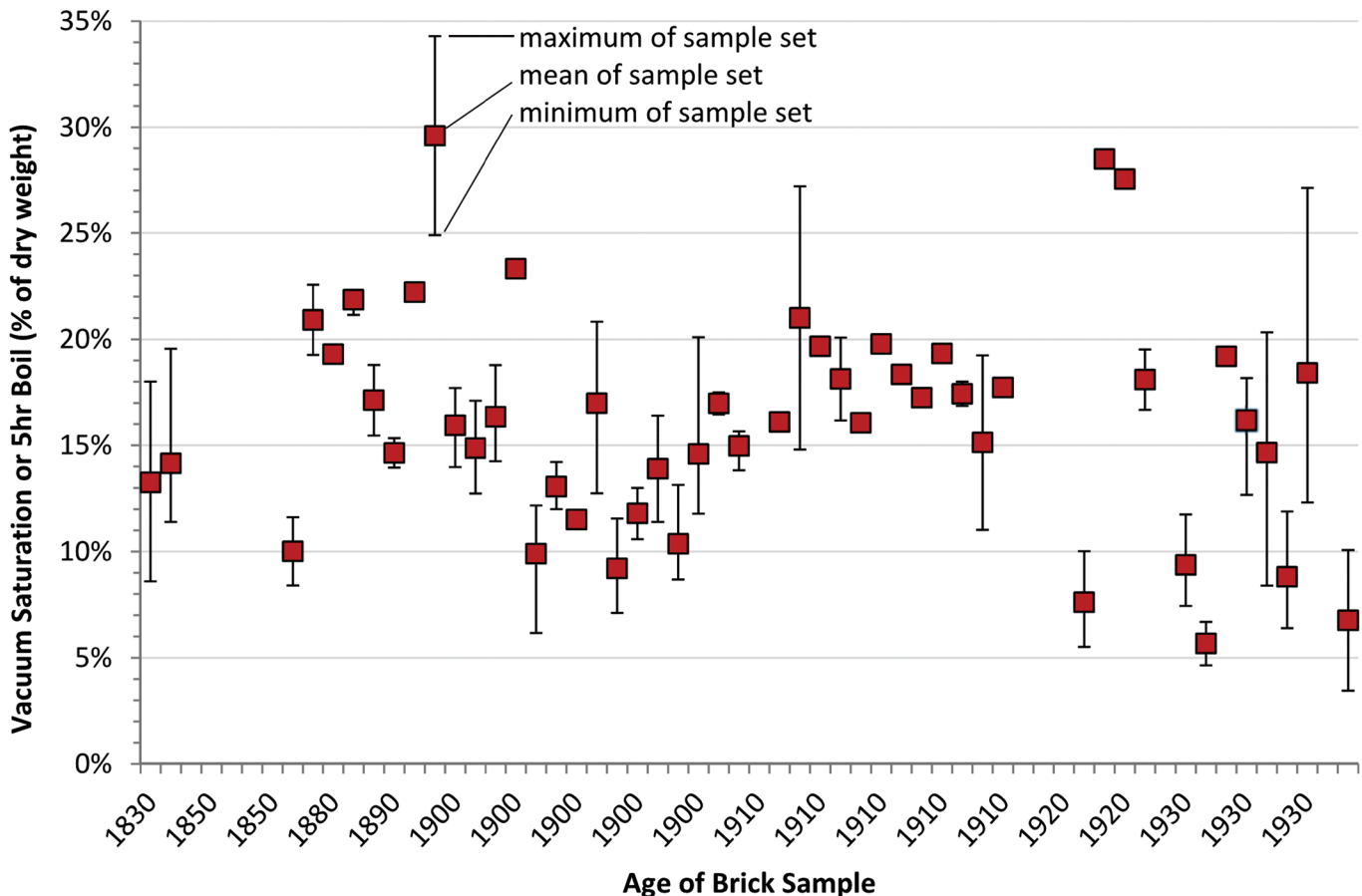


Figure 3 – Sample data set of vacuum saturation or five-hour boil results versus building age for clay bricks tested for projects within our archive (based on an image from Van Straaten 2014).

## WHEN TO USE LABORATORY TESTING IN RETROFIT PLANNING

Not all masonry retrofit projects will benefit significantly from testing masonry taken from the project walls. The choice of insulation strategy is one determining factor. Adding insulation to the exterior of the wall assembly will maintain a higher temperature in the masonry and hence does not typically increase freeze/thaw decay risks (see *Figure 1B*). There are some situations where a proposed exterior insulation wall retrofit will still merit lab tests to assess potential risk (for example, use of an exotic insulated cladding material).

For interior insulation retrofit projects, field inspection and design review can often provide adequate insight to assess retrofit risks. For example, if the retrofit will involve improving rain control measures (e.g., eaves, troughs, gutters will be fixed or added), and the building shows few signs of freeze/thaw decay—even though the masonry sees a high level of exposure—one may conclude that 1) the masonry is highly tolerant to freeze/thaw, and 2) the moisture content in the exposed masonry

is going to be significantly reduced. In this case, there is little risk in implementing an interior insulation retrofit, given new sources of moisture are not introduced. Similarly, if a wall is well sheltered (such as a bungalow with wide overhangs in a well-treed neighborhood), then the risks of adding interior insulation are inherently low because the walls will likely not have high moisture exposure. Finally, if the masonry façade is already severely deteriorated, a broader preservation discussion may be warranted before or as part of the insulation assessment.

There is also cost consideration for assessing insulation approaches. If the cost of a wall deterioration associated with interior insulation is low (e.g., minor mortar flaking), then it may not be practical to conduct detailed assessments. For other projects, the justified scope of testing and assessment can vary greatly and may range from a field inspection to sophisticated analysis and monitoring. This article will provide insights on where masonry lab testing fits within such scopes.

## RISK ASSESSMENT AND HYGTHERMAL MODELING

Hygrothermal modeling is used frequently to predict moisture durability problems. Given a specific assembly, material properties, and boundary conditions, the most common simulation software, WUFI® Pro, is a powerful and useful tool for hygrothermal modeling. But all simulations depend on the quality of their inputs. We have found that WUFI simulation for old masonry walls requires project-specific material properties derived from laboratory testing. Van Straaten (2014) summarized measured data from over 200 individual burnt clay bricks. As shown in *Figure 3*, significant variation from brick to brick was found in one building, and we also found significant variation from building to building. This plot shows the range (one bar with maximum and minimum measured values) for vacuum saturation of each collected set of masonry samples. These values are plotted relative to building age.

We have not found a correlation to age for face and common bricks, or project location for the vacuum saturation of brick



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- Criticality research, testing & analysis for selection of critical components.
- Equipment commissioned through the National Research Council of Canada (NRC).



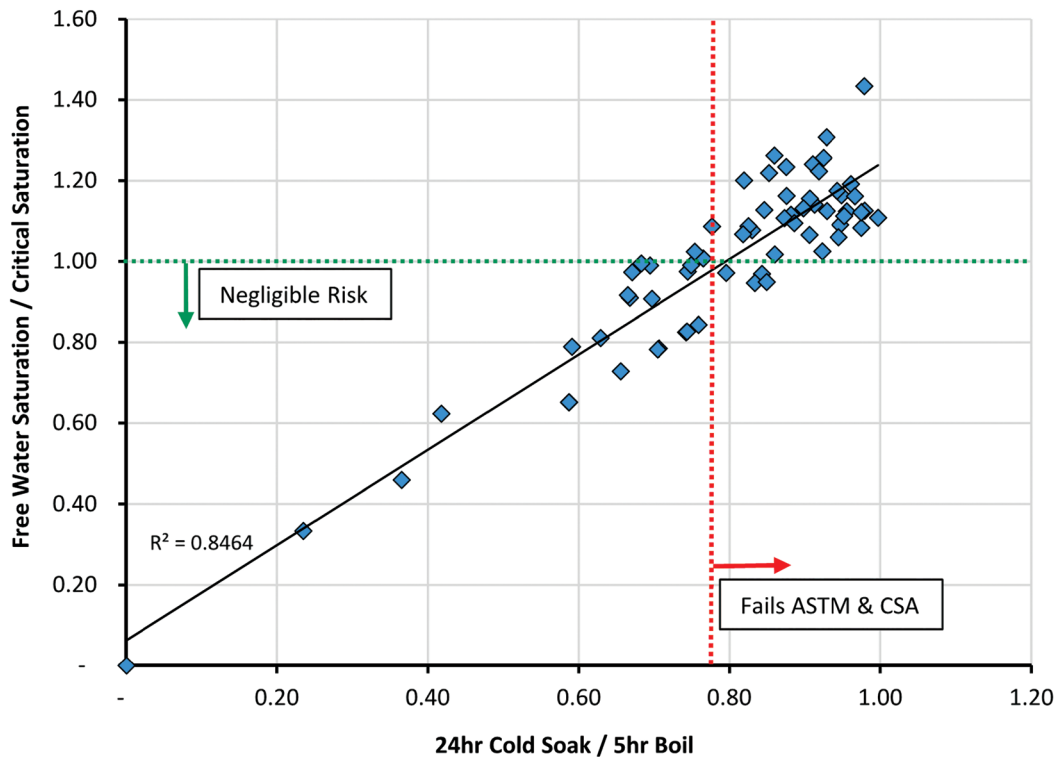


Figure 4 – Sample free-water/critical saturation ratio vs. cold soak/boil ratio results (based on an image from Van Straaten 2014).

masonry samples. Therefore, the value of hygrothermal analysis conducted by using information material inputs taken from other projects of similar age would not likely provide useful project guidance, since there is such a high uncertainty of material properties.

#### LABORATORY TEST METHODS

Hygrothermal model accuracy will be improved by using measured project-specific inputs for dry density, water uptake coefficient, vapor permeance, vacuum saturation (used for porosity), and sorption isotherm (or reference and free-water content). Some practitioners also use project-specific thermal conductivity and heat capacity values for masonry. The recommended types of material testing are based on project requirements and knowledge and experience with the WUFI software.

Figure 5 – The author demonstrating use of a moisture content meter as part of nondestructive masonry testing in the field.



Instead of frost dilatometry, some projects use pass/fail criteria to assess masonry durability, such as ASTM C216, *Standard Specification for Facing Brick (Solid Masonry Units Made from Clay or Shale)*, and CSA A82, *Fired Masonry Brick Made from Clay or Shale*. With these test methods, samples pass or fail a given criterion under specific test conditions. Masonry that passes is more likely to tolerate freeze/thaw cycling without deteriorating. However, pass/fail criteria (as opposed to a limit-states approach) do not allow for risk assessment based on the specific conditions that a real-world building is exposed to. For example, different bricks may be suitable for use in a wall under a large overhang, but not for use in a driveway, or vice versa.

Figure 4 shows an example of measured cold soak/boil ratio (C/B, also known as saturation coefficient) results from ASTM C216 testing, compared to the ratio of free water to critical saturation for the same bricks. If the critical saturation of a brick is greater than its free water saturation (the maximum amount of water a material will absorb), then its freeze/thaw tolerance is high (Fagurlund 1977). There is a visible correlation between results from the two test methods. However, some samples have C/B ratios above 0.78 ("fail" ASTM C216) but have negligible risk suggested by their free-water saturation being less than their critical saturation.

The reverse can also happen: Brick that passes C/B testing may perform poorly, depending on the in-situ building conditions encountered. This occurs because the C/B ratio criteria do not capture all freeze/thaw deterioration mechanisms. Further, the ASTM C666 (*Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing*) test (and similar exposure test standards for other masonry materials) use conditions that are much more severe than typical wall exposures; where samples fail ASTM C666, the test can lead to an overly conservative assessment.

#### BULK SAMPLING APPROACH

Regardless of the laboratory tests being used to assess masonry material properties, improper or inadequate sampling will affect the results. As seen in Figure 3, masonry material properties sometimes vary little, and other times, vary widely for the visibly same material on a building. The challenge, then, is to ensure that units selected for lab testing capture the range of material proper-

ties of brick units on the building.

Bulk sampling usually involves removal of large numbers of samples from the building with the goal of randomly capturing a range of units. This is a challenge for projects with large stone masonry units (difficult to remove and repair), masonry units that are difficult to ship and replace, and/or units that are historically important to the site and are not permitted to be removed. The cost and timing required for full testing of a large sample set is also prohibitive.

To minimize this issue, samples can be pre-tested on site without removing them from the wall to record the water uptake coefficient and approximate free-water saturation. Based on the results, a limited number of the samples can be selected and extracted from the building for more detailed, costly, and time-consuming full testing in a laboratory. For projects where bulk sample extraction is not feasible, nondestructive field tests are recommended.

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**SAMPLING BASED ON  
NONDESTRUCTIVE FIELD TESTING**

A common nondestructive field test for masonry is the RILEM tube test (1980), which correlates with laboratory water uptake coefficient measurements (Wilson et al. 1999). However, the testing is somewhat time-intensive, and it is difficult to utilize RILEM tube testing to prescreen a large number of masonry samples. Furthermore, it is also difficult, if not impossible, to use the RILEM tube on masonry with rough surfaces and/or significant cracks due to water

leakage out of the tubes.

An alternative novel nondestructive test was developed by Van Straaten et al. (2016) using a TrameX Moisture Plus electrical impedance-based moisture content meter and a simple water spray bottle (used to wet the brick in a relatively repeatable way). This technique involves the following steps:

1. Label masonry samples for testing on wall (using chalk or other non-permanent means).
2. Measure the “in-situ” moisture content of the sample with the TrameX

- meter and record.
3. Wet the samples with water from the spray bottle.
4. Wait two minutes.
5. Measure the “wet” sample brick moisture content with the TrameX meter and record.
6. Wait eight minutes.
7. Measure the “dried” sample brick moisture content with the TrameX meter and record.

The “drying” rate is then calculated as:  
drying rate =  
(wet reading – dried reading)/8 minutes

A significant portion of water applied to the masonry will be drawn via capillary action into the material. *Figure 6* shows a comparison of drying rate measured in the field for several bricks of two different types (“beige” and “red”) and water uptake coefficient values measured for these same brick samples in our laboratory. A clear linear correlation was found for the beige bricks. A nonlinear correlation is apparent for the red bricks, but is less clear, suggesting the methodology may need to be altered for less absorptive materials (which would have low water uptake coefficient values)

The in-situ readings with the TrameX moisture meter have been found to vary with exposure, wall assembly, and masonry material properties. We select samples to extract from the wall by capturing the range of measured “in-situ” and drying rates. For the pilot project, 80 bricks were tested on site in approximately four hours. The operator only needed access (a step ladder or lift), a spray bottle, the TrameX meter, and an audio recorder for recording results. Further development of this technique for less absorptive materials and more sophisticated assessment of in-service moisture content could completely replace the need for bulk sampling or material extraction from site.

**CONCLUSIONS**

Existing masonry buildings often present opportunities for installing increased insulation levels for greater energy efficiency. When installing exterior insulation is not an option, concerns about freeze/thaw damage related to interior insulation may cause retrofit opportunities to be missed or misunderstood. Improved risk assessment methodologies in the lab and field will allow designers and owners to have a



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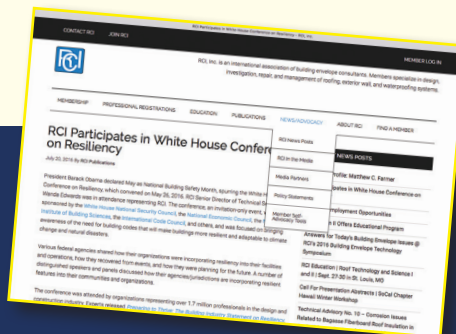
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clearer picture of benefits and risks of adding insulation to older buildings, leading to better-informed retrofit decisions. Material properties testing and better sampling procedures are recommended as part of these assessments where hygrothermal simulation is involved. 

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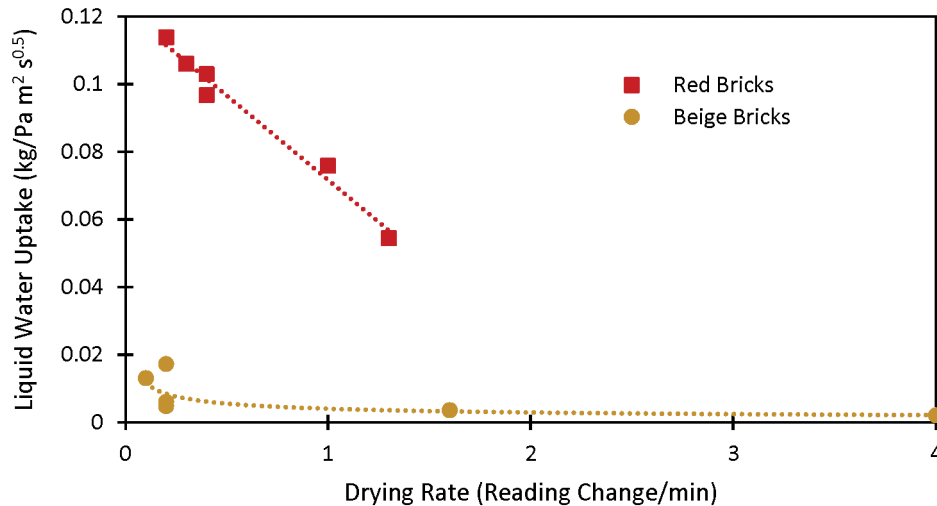


Figure 6 – Lab water uptake measurements and field-drying rates for sample bricks selected based on novel field-testing technique.

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## MRCA Issues Advisement on Vapor Retarders and New Concrete Roof Decks

The Midwest Roofing Contractors Association (MRCA) Technical and Research Committee has recommended that, based on the issue of rewetting and the current lack of an industry-accepted testing method for assessing the moisture content of concrete roof decks:

- Unless the designer of record approves in writing otherwise, a vapor retarder of less than 0.01 perm is necessary over new concrete roof decks.

## First 3-D Printed Equipment Debuts at CONEXPO



“Drawing” a lot of attention at the CONEXPO show in Las Vegas in March was a small mini excavator off in one corner. The amazing thing about it was that significant parts of the machine were produced using 3-D printing technologies, which were then integrated with conventional parts to create a functional 5.5-ton mini excavator.

Project leader Lonnie J. Love, a corporate research fellow from Oak Ridge National Laboratory, says printed components included the cab, which was printed in five hours with carbon-fiber-reinforced ABS plastic; the 7-ft.-long, 400-lb. “stick” at the end of the boom; and a 13-lb. aluminum heat exchanger. They were then attached to other traditionally built components to create a machine based on a Case New Holland 5.5-ton excavator.

The team of Project Additive Manufactured Excavator (AME) was a collaboration between ORNL and industry, academic, and government partners. Check it out at <https://www.youtube.com/watch?v=SMMYneravmQ>.

— ENR and other sources