Thermal Insulation Systems of the Future

by Mark Bomberg, Marcin Pazera and Robert Aird

During the BEST1 (2008) and BEST 2 (2010) conferences, a shift in the design paradigm that requires a systems approach to build ecologically correct, durable, energy-efficient enclosures that contribute to a good indoor environment became evident. A systems approach leads to airtight and highly insulated enclosures that allow drying to the outside. The emergence of new, moisture-breathable, no-crack renderings that we called eco-wrap, which fall between strong and rigid cement-based plasters on one end of the spectrum and flexible and thinner-than-3/16th-inch EIFS lamina on the other end was highlighted. The BEST 3 paper, previewed here, connects all these concepts into one thermal insulation system of the future that links building physics with current practice and recognizes the need for new exterior insulation systems that are suitable for both new buildings and existing building retrofits.

EFFICIENCY FACTOR FOR THERMAL INSULATION

This paper focuses on thermal performance of *assemblies*. It starts with a concept of thermal insulation efficiency that compares the nominal and the average U-values for an assembly. (The U-value is the inverse of R-value, which means a ratio of the average thermal resistance of the assembly to the nominal R-value is obtained as the sum of thermal resistance of all components, or measured in a cross-section with 1-D heat flow through the thermal insulation).

To illustrate the significance of this concept, without performing[1] calculations, we can use an article by Sandin (1990), where external and internal insulation is added to a 1½ brick-wide wall as illustrated in Table 1. The results illustrate the effect of a thermal bridge typical for masonry construction, with bounding temperatures of -4 °C and 20 °C and a height of 2.8 m. for the wall.

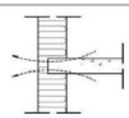
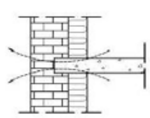
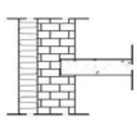
Drawing	Description	Additional flux	U-value $W/(m^2 \cdot K)$ Excl. thermal bridge	U-value $W/(m^2 \cdot K)$ Incl. thermal bridge	Temperature decrease due to thermal bridge
	a) Floor joining woof frame wall	0.16	0.28	0.38	17.6 → 15.4
	b) Interior thermal insulation of 11/2 brick wall	0.17	0.30	0.38	17.9 → 12.6
	c) Exterior thermal insulation of 11/2 brick wall	0.005	0.30	0.30	17.9 → 17.9

Table 1: Additional heat flux, U-values "without" and "with thermal bridge" and temperatures "without" and "with thermal bridge" (termed here as "temperature decrease due to thermal bridge") measured in the corner between wall and concrete floor in typical masonry construction quoted from Sandin (1990).

Examination of the temperature in the junction between wall and floor for Case a) shows a wood-frame wall where temperature without bridge was 17.6°C. Adding a thermal bridge reduced it to 15.4 °C. Case b), shows a masonry wall, and the corresponding temperature values are 17.9 (54.7°F) and 12.6 °C. One can observe that higher thermal conductivity of masonry introduced larger temperature drop in the corner of wall and floor.

Adding thermal insulation on the exterior is a better solution, because the temperature reduction caused by the thermal bridge (Case (c)) was eliminated and the same temperature is obtained in the corner of wall and floor as without the thermal bridge.

Let us now examine the changes in the heat flux caused by the thermal bridge. Case a) shows additional heat flux as 0.16 W/m^2, while Case b) with interior insulation shows almost the same value of 0.17 W/m^2. Case c) exterior insulation shows an increase in flux, though significantly less than the increase in Case b). The increase in heat flux for interior insulation was 0.17 $W/m^2 K$, and for the exterior insulation only 0.005 $W/m^2 K$. There is no doubt that exterior insulation is the way to go.

PROGRESS ON THERMAL UPGRADE SYSTEMS

Let us now continue to speculate what is the ideal thermal upgrade system for low- and mid-rise buildings. Airtightness is, obviously, a primary concern when considering an assembly for a thermal upgrade. For airtightness, *closed cell sprayed polyurethane foams* (SPF), is suggested, because of proven adhesion to most surfaces, durability of more than 50 years and thermal performance in the top of traditional insulations (Bomberg and Lstiburek, 1998). A generic assembly (sub-system) for thermal upgrade may use SPF.

Changing socio-economic conditions typically spur modification of construction materials to better fit the preferred manner of their application. For instance, traditional lime plaster was excellent, but its long curing time resulted in replacement by a cement-lime mixes and then finally by cement plasters. On the other hand, the exterior insulation finish systems (EIFS) went through polymer-modified to polymer-based thin lamina. Figure 1 shows thermal upgrade of a Vermont high school, which was completed in Fall 2009 where expanded polystyrene was replaced by SPF.

Figure 1: High school in Vermont, Application of SPF (top) shown before and after trimming (bottom).

Figure 2: Base coat application: Touch-up on the first layer of stucco (left) and trimmed foam (right). The

Protective barrier was removed for the photo.

Figure 3: The finished project; an insulation value of R-10 was added.

FIRE AND MOISTURE PROTECTION

While the building renovation shown in Figures 1 - 3 may be considered as a step forward in the design of better cladding systems, it is still far from the optimum because it needs to address both fire protection and the ability to remove moisture from building enclosures to avoid growth of mold, which remain as two chief concerns for existing buildings.

To this end, one may introduce another layer of fibrous thermal insulation separated by an air gap. The materials used in the second layer are either (1) stone wool (Rockwool) or another type of mineral fiber insulation boards manufactured with a significant fraction of vertically oriented fibers, or (2) wood-fiber insulation boards (see: Bomberg and Chrenka (2010). The first solution may be preferred for high-rise buildings that typically require a *non-combustible cladding system,* while the second solution may offer better durability of cladding system for low and midrise claddings.

From a building physics point of view, one material may satisfy both hygroscopic and fire performance requirements. To characterize such a material, the name *eco-fiber insulation* is introduced*,* to emphasize achieve both improved hygrothermal and fire performance by using a mixture of different fibers man-made as well as natural fibers. For the optimal cladding assembly, we need, however, light and durable 3-coat plaster instead of heavy cement board or brick veneer, which would have required thermal bridges for support. Expanded polystyrene insulation can be replaced with polyurethane foam if one has technology for removing the skin from the sprayed polyurethane foam

CORRECT HYGROTHERMAL DESIGN IS THE KEY

A correct hygrothermal design for stucco mixes is the first step to ensure durable performance of stucco-clad walls. As they have evolved, the drying ability of stucco claddings has been reduced by a factor of 10 - 100. Current stucco will become wetter and stay wet over prolonged periods of time. Add to that the fact that new polymer-based water-resistant board (WRB) products have much higher permeance than asphalt-impregnated Kraft paper and under certain environmental conditions increase the rate of moisture transport from wet stucco to oriented strand board (OSB). In exposures with prevailing solar radiation in the winter and only one layer of polymeric WRB (plastic wrap) with a permeance of 80-100 perms, the OSB sheathing may became wet and decay. Under these conditions, the use of a "water vapor tight" finishing layer in stucco may be detrimental to the durability of walls.

The proposed insulation system uses two continuous layers of thermal insulation (closed cell polyurethane foam and the eco-fiber layer).The latter also needs to be protected from the effects of weather, and *eco-wrap* fulfills this function. The correct design of stucco requires that each layer toward the outside has lower stiffness (to avoid warping) and increased water vapor permeance to accelerate drying. While previously this was achieved by changes in porosity, we have shown that adequate hygric properties can be independent of the density and stucco composition. Because we also are specifying moisture permeable (breathing) walls, we are calling for this layer to be ecologically designed wrap, *eco-wrap*, not stucco or plaster.

While wood-based rigid boards have acoustic and thermal properties similar to those of loose-fill cellulose, are moisture-breathable (typical WV permeance is about 15 perms), VOC-free and provide a sustainable alternative to glass-fiber technology, they can complement mineral fiber technology in roofing, flooring and other applications, where compressive strength is required.

Figure 4. Climatic[1] stucco (left) and EIFS lamina (right) placed on wood-fiber board.

PUTTING THE PROPOSED INSULATION SYSTEM TOGETHER

This system will be placed on the exterior and will include two continuous layers of thermal insulation separated by an air gap. The first layer is a poured or sprayed polyurethane foam that provides heat, air and moisture control. The second layer is either wood- or mineral-fiber insulation or a new multi-fiber eco-fiber material with climatic plaster ("eco-wrap"), which provides rain protection and accelerated drying.

The optimal system has a 3 to 9 mm wide air gap, functions as an accelerator for removal of incidental water, and provides a unique system of water removal after flood events. Our insulation system can also be integrated with the HVAC system to enhance energy efficiency in mixed climates. (It is important to point out that the popular name of "drainage cavity" can be misleading; in a well-designed wall, there is no water to drain. The cavity serves to accelerate drying by convection.)

A NOTE OF CAUTION

Evaluation of performance of such systems can be difficult, particularly North America, where testing favors laboratory rating of materials instead field performance of materials as assemblies. Some materials that have been used for centuries, such as plaster, do not have a test method to evaluate crack-resistance. Materials of the future, such as spray polyurethane foam, do not have a dimensional stability test for defining performance under field conditions. And while there is an ASTM test method of rating for selected environmental effects, such as high or low temperature or moisture condensation, it does not account for strains or effects of thermal gradients acting on the material.

Unfortunately, it may take several years to develop this kind of optimal insulation system, because there is little research and development support from Federal or state sources for small companies to evaluate the performance of novel systems. This is in stark contrast to 20 - 30 years ago, when North America was the undisputed leader in the new technology development for housing.

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Credits

Mark Bomberg is a Research Professor of Civil Engineering at the University of Toronto and in the

[1] The word "climatic" denotes a moisture-breathable plaster. It can also be made with acrylic polymers, but it must contain additives to ensure sufficient water vapor permeance. It means a water-repellent plaster developed for wind-driven rain protection with specific requirements for water vapor permeance.

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