XII DBMC
International Conference on Durability of Building Materials and Components
PORTO - PORTUGAL, April 12th-15th, 2011

Durability of Roof Insulation in Re-Roofing Applications

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ABSTRACT

Designers expect that the components of a facility last for the life of that facility. Buildings are increasingly being expected to perform longer due to a shrinking availability of land, sustainability practices, and economic trends that force re-purposing of space. The roof system of a building may be expected to perform for 25-30 years. Re-covering or re-roofing may be needed, which may be predicated on the leak history reported or the deterioration of the roof membrane. When decisions are made about the next roof system, the condition of the original roof insulation should be considered. We will explain how various technologies including thermographic imaging, nuclear-moisture gauge readings, laboratory moisture testing, and visual assessment can be used to determine if the existing insulation is suitable for re-use in the new roof system. Consideration is also given to the long-term thermal resistance (LTTR) and what R-Value can be expected from wet insulation that remains in place after re-covery. This paper examines options associated with various types of insulation considering relative first-cost, potential for re-use, durability, assessment of remaining material, likelihood of damage, LTTR, R-Value of wet insulation, migration of water through the insulation, and eventual recycling. Both low-slope roofs and protected membrane roofs will be considered. The right insulation, if selected at the time of design, is more cost-effective over the life of the facility.

KEYWORDS

Durability, Wet insulation, Long-term thermal resistance (LTTR), R-value, Sustainability.

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1 INTRODUCTION

Key tenets of sustainability include keeping building products in-use as long as possible and avoiding contributions to landfills and waste production. Most agencies recognize that increasing the average R-Value of the roof system will lead to decreased heating and cooling costs. Additionally, it is widely accepted that increasing the reflectively of the roof system will aid in decreasing conditioning costs in most climates as well as in lessening the urban heat island effect. With all these aspects of sustainability in mind, the benefits of a complete tear-off and replacement of a roof system must be carefully weighed against the impact of the waste created when disposing of the existing material. When performing a complete roof replacement, the existing insulation that is removed is many times the bulkiest component and eventually ends up in a landfill.

It is not the intent of this paper to assess roof membrane options for initial construction or re-reroofing, but rather to look at the insulation as an independent component and determine what insulation type presents the most viable option for re-use at the time when the membrane deteriorates to the point of no longer being a viable weatherproof layer. If various insulation characteristics are considered at of initial construction, with the end goal of re-use in mind, the roof system will be more sustainable. The paper is a starting point for further research into insulation design and selection. It is not the intent of this paper to develop a methodology for insulation selection or define limits on insulation moisture content; such activities would be undertaken during the development of standards related to the re-use of insulation.

2 INSULATION TYPES

Insulation types have varied widely over the past 30-40 years. Prior to the energy crisis of the 1970’s in the United States, insulation used in commercial roof systems was minimal to non-existent. Most roof systems were simple multi-layered built-up roofs on concrete or thin layers of rigid fibreglass which was installed more as a backing for the roof over a metal deck rather than as a thermal layer. As energy regulation became stricter and building energy consumption for heating and cooling came under the microscope, the need for more thermal insulation in the roof system increased. Over the past approximately 40-years, insulation types have varied as manufacturers have tried to create thinner materials with higher R-Values. Today, several insulation types may be combined in the roof system in order to achieve various design criteria. For example, an insulated roof system with sloped primary thermal insulation may incorporate polyisocyanurate (ISO), extruded polystyrene (XPS), or expanded polystyrene (EPS) as the thermal insulation with a coverboard of glass-faced gypsum board (GB), perlite board (PB), or wood fibreboard (WFB). These layers can be mechanically-fastened, ballasted, or adhered. Sloped lightweight concrete with insulating fill (LWIC) is also an option as the primary insulating material. The R-Values of the insulations just mentioned are shown in Table 1. LTTR is a method to calculate the 15-year, time-weighted average R-value of roof insulation. Over time, the R-value of polyisocyanurate insulation can drop as the low-conductivity gas escapes and air replaces it.

Table 1. Insulation R-Values. Values are for typical average based on dry insulation and Long-Term Thermal Resistance (LTTR) is used where designated by a double plus (++).

Insulation Type	*R-Value per inch* [ft^2*hr*°F/BTU]	*Abbreviation*
Polyisocyanurate	6++	ISO
Extruded Polystyrene	4.8++	XPS
Expanded Polystyrene	3.7	EPS
Glass-Faced Gypsum Board	1.0	GB
Perlite Board	2.6	PB
Wood Fibreboard	2.6	WFB
Lightweight Insulating Concrete	5.0+	LWIC

+ Value varies with concrete density. Value includes EPS in conjunction with LWIC.

For the purposes of this paper, we are limiting our discussions to insulations in membrane roofing systems. Consequently, we have not considered sprayed-polyurethane foam (SPF).

3 WET R-VALUE

For many of the various insulation types listed in Table 1, the detrimental effects of moisture on R-Value have been documented through various studies [Tobiasson & Ricard 1979] [Tobiasson, *et.al* 1991]. The various insulations lose R-Value when exposed to moisture as shown in Table 2.

Table 2. Insulation R-Values. Wet R-Value based on Tobiasson, Greatorex, & Van Pelt 1991.

Insulation Type	*Dry R-Value per inch* [ft^2*hr*°F/BTU]	*Wet R-Value per inch* [ft^2*hr*°F/BTU]	*Percent Decrease* [%]	*Time Wetting at end of test* [Days]	*Moisture Content* [% mass water]
ISO	6.0++	3	50	300	150
XPS	4.8++	3.8	20	1000	150
EPS	3.7	1.7	50	1000	150
GB	1.0	0.4	60	50	150
PB	2.6	0.91	65	300	150
WFB	2.6	1	62	100	150
LWIC	5.0	2.5	50	50	150

As seen from Table 2, less than half of the insulations retain even half of their R-Value when wet. Furthermore, it can be seen that XPS retains its R-Value best when exposed to moisture, hence the reason for the wide-spread use of XPS in Protected Membrane Assembly (PMA) roof systems. Based on field observations and experience, XPS, EPS, and LWIC retain their many of their physical properties when wet; however the other materials, ISO, GB, PB, and WFB begin to degrade when exposed to high moisture levels. In the case of GB, PB, or WFB the remaining insulation breaks down to the form of a powder in a liquid suspension. In the case of ISO the material becomes saturated similar to a sponge.

The effect of leaving wet insulation in-place and performing a recovery roof application has been documented [Desjarlais, A. 0. *et. al*. Oak Ridge National Labs (ORNL) 1995]. Current industry standard remains much the same as discussed in the ORNL paper of 1995. The amount of wet insulation must be determined prior to the recovery roof application and the designer must decide to either remove and replace the wet insulation or cover over it and attempt to vent the trapped moisture. The effects of trapped moisture on built-up roofing were well documented by Cash [1985]. Moreover, our experience has shown that similar effects occur on other types of membrane roof systems such as blistering of the membrane due to evaporation of trapped moisture and loss of attachment due to insulation and fastener degradation. In general, trapped moisture can lead to structural deck deterioration, compromised roof system attachment, internal pressures on the membrane (blistering), and a continued deterioration of insulation. All these factors must be considered when designing a recovery roof system. The insulation that remains will likely have a decreased R-Value which should be accounted for in the design.

4 INITIAL INSTALLATION CONSIDERATIONS

Relative to the cost of replacement, first cost of a new insulated membrane roof system meeting today's standards for attachment, R-Value, and fire-rating is low. The labor component of the roof replacement along with accessibility and material removal and disposal make re-roofing significantly more difficult and expensive than installation over an unoccupied, unfinished space at the time of initial construction. However, at the time of initial construction, often times the benefits of a longer lasting roof are over-looked in the interest of lesser-cost or faster installation. As indicated in Table 3 below there are various installation aspects of each insulation type that contribute to the first cost of the system.

Table 3. Insulation Initial Installation Considerations.

Insulation Type	*Installation Types* [Board or Fluid]	*Resistance to Construction Traffic*[Yes/No]	*Flexibility* [Yes/No]	*Attachment* [M, A, or B]	*PMA* [Yes/No]
ISO	Board	No	No	M or A	No
XPS	Board	No	No	M, A, or B	Yes
EPS	Board	No	Yes	M or B	Yes
GB	Board	No	No	M, A, or B	No
PB	Board	No	No	M, A, or B	No
WFB	Board	No	No	M, A, or B	No
LWIC	Fluid	Yes	Yes	None	Yes

For Flexibility, Yes=ease in accounting for in-field changes and variations, No=difficulty in accounting for field variations due to need for fabrication.
For Attachment, M=Mechanically-Attached, A=Fully-Adhered, B=Ballasted.

To meet code requirements for the R-Value of a roof system, different average thicknesses of the various insulations must be used. Therefore, for a given roof system, it can be seen that ISO would typically represent the least average thickness required because of the higher R-Value per inch. When costs are considered, ISO many times will prove to be the lesser first cost insulation, even though the cost per square foot may be more. ISO has variability in attachment methodologies and the ability to be fabricated in a given taper layout in advance. The lack of resistance to construction traffic and the decreases in R-Value over time due to moisture are not typically weighed against the first cost. However, if the cost of expensive re-fabrication of tapered sections and patchwork repairs due to damage from other trades during the construction process are considered, the ISO system starts to approach the cost of the LWIC system.

While LWIC seems to excel in many categories, the first cost of LWIC is usually the highest of the indicated insulations. The inherent constructability issue of dealing with the water from the placement process presents an added complication for the construction team. Once installed, the system is highly resistant to construction traffic and, can be left open during construction since typically an underlying waterproofing layer is used to contain the water from placement. This can delay the installation of the roof membrane, therefore not exposing it to construction traffic until the building is nearly complete.

5 POTENTIAL FOR RE-USE

In order to re-use insulation, the material must meet the hygrothermal, mechanical, and physical properties of the new roof assembly. In evaluating insulations, the properties shown in Table 4 are typically considered in initial design and in assessing the potential for re-use. These properties relate to the selection of the intended recovery roof system as well as the evaluation of the actual condition of the insulation. Aged-in-place insulation can have differing characteristics than new insulation and when planning to bury the insulation under a recovery roof the effects of further aging must be considered. Additionally, the aged-in-place material will respond differently to the construction process than would the new material, so consideration must be given to how much damage will be caused by the process of reroofing. Utilizing an insulation that exhibits the least change in properties over time will result in a more viable re-use situation. When selecting a suitable insulation type for either new construction of for re-use in a recovery roof, the compressive strength of the insulation is vital to the overall performance of the roofing system. Not only can the wetting and drying cycle of insulation reduce the R-value, but increased mechanical loads, such as heavy foot traffic, and impact damage, such as the effects of hailstorms, can also reduce the R-value of roofing insulation. Testing and research by various organizations has shown that mechanical and impact damage will reduce R-value within insulation. This research is still under development and the testing and limits for these reduced R-values have not yet been established. This is mentioned in this paper as an example of other ways R-value can decrease in a material over time and is not intended to serve as a references to such testing.

Table 4. Insulation Properties.

Property	*Description*
Hygrothermal	
Dry Density	The mass of one cubic meter of dry material.
Air Permeability	Rate of airflow across the material and the pressure differential.
Sorption & Desorption	The equilibrium moisture content as it relates to relative humidity.
Thermal Conductivity	Heat flow rate of the thermal gradient in the direction of flow.
Water Vapor Permeability	The ratio between density of the vapor flow rate and the vapor pressure in the direction of flow.
Water Absorption Coefficient	The amount of water diffusion from the surface of the material to the interior of the material.
Heat Capacity	The energy need to raise the temperature of the material
Mechanical & Physical	
Dimensional Stability	Material change in dimension from exposure over time.
Compressive Properties	The response of the material under axial loads.
Flexural Strength	Ability to resist deformation under loads that induce bending.

6 DURABILITY

As previously mentioned, LWIC has an inherent resistance to construction foot traffic which adds to what could be considered the initial or post-installation durability of the material. Durability of insulation is defined as resistance to compromised strength, R-Value, or attachment while subject to the loads imposed on the material during pre-construction, construction, service, and potential re-use.

If designers understand the loads, and specify insulation materials that adequately support the intended loads, then the insulation will have the greatest potential for re-use and extended service life. Conversely, if some of the loads are not considered it can affect the life of the roof system. Table 5 on the following page summarizes the typical loads that may be imposed on insulation during the service life of the material.

7 ASSESSMENT OF WET INSULATION

The assessment of wet insulation can be performed in the form of several non-destructive techniques, nuclear hydrogen testing, electrical capacitance survey, and infrared thermography. Destructive testing through core sampling can also be performed; however, for this paper we look to non-destructive methods as a means of determining insulation re-use. Destructive tests may decrease the amount of insulation that is available for re-use and should only be performed to obtain comparative samples for analysis. If during the assessment of the insulation more than 40% of the roof plan area can be seen to have wet insulation, especially in sporadic areas, the cost to salvage the remaining insulation may outweigh the cost for full replacement. The specifics of these testing methodologies are beyond the scope of this paper. The means to assess the amount of wet insulation that is present in a roof system are available to assessors and should be utilized any time insulation re-use is considered. What is important to note is that, regardless of the type of testing that is selected, confirmation of the detected anomalies should be verified by either core samples that are oven-dried to determine the moisture content or by probing the suspected areas with an electrical resistivity probe. The electrical resistivity probe is designed to test moisture levels in building materials through qualitative comparative readings. The moisture content of the roof material is read through two electrical probes that are inserted into the roof insulation. The concept being dry insulations are poor conductors of electricity and wet insulations are good conductors, thus sending the reading to the probe.

The type of existing membrane and surfacing may affect the ability to utilize different methods of assessment and; therefore, may be cause for concern when considering insulation re-use. Re-use of insulation should only be considered when quantitative data can be obtained and a strategy for dealing with entrapped moisture can be developed and implemented.

Table 5. Loads on Insulation.

Load Type	*Description or Components of Each Load Type* *Loads Specific to LWIC Shown in Italics*
Pre-Construction	
Manufacturing	Internal stresses in the material created from the manufacturing process, blowing agents, chemical reactions, heating and cooling, *and/or curing*.
Storage	Sustained loading while in stacked storage, damage due to warehouse or other traffic, warehouse temperature and humidity concerns, compromised protective coverings *or torn bags*.
Shipping	Stacking of pallets, transport within the warehouse, forklift damage, transport on trucks to the site, damage due to road hazards, *or time on the road or in the mix truck.*
Delivery	Lifting by crane or hoist to the roof level. Man-handling into elevators, stairwells, or through hatches. On-site storage and exposure to the elements. *Hydraulic forces when pumping to the roof.*
Construction	
Insulation Installation	Impact of dropping tools on the material. Storage of other roofing materials on top of the insulation. Cutting material to fit. Stresses induced by the installation process including heat from asphalt cooling, adhesive curing, primer flash-off, screw penetration, *or heat of hydration and drying shrinkage.*
Construction Traffic	Movement of people or products across completed roof sections.
Wind Uplift *(also a Service Load)*	Force exerted due to suction on the roof from wind moving across the roof. The insulation may need to accommodate the wind uplift prior to membrane installation.
Ultra-Violet Radiation *(also a Service Load)*	Exposure to sunlight before membrane installation. Exposure due to wind scour in PMA systems.
Membrane Installation	Impact of dropped rolls on the roof, fastened installation, adhesive or primer application, or screwing of fasteners.
Service Loads	
Heat Transfer	Resistance to heat flow across the material, typically addressed by R-Value and thickness of the material.
Vapor Transmitance	Resistance to the flow of water vapor across the material, typically addressed by permeance or adding a vapor retarder at the deck level.
Leak Migration	Resistance to the movement of liquid water through the insulation.
Live Load	Support of code required live loads such as snow and ice on the roof, rain, ponding, or personnel.
Dead Load	Support of material self-weight.
Roof Traffic	Activity on the roof due to service personnel and other trades. Façade access equipment on the roof.
Reroofing Loads	
Membrane Removal	Potential for damage to the insulation during removal of the existing membrane, storage of trash on the roof,
Reroofing	Installation of the new roof membrane over the old insulation.

8 LEAK MIGRATION

Insulation type and installation methodologies can play a role in the way water from leaks and condensation move through the roof system. Material properties as indicated in Table 4 can be specified to provide a level of moisture storage within the insulation, as well as the incorporation of vapor retarders. Each of the indicated insulations has an inherent resistance, or lack thereof, to the movement of moisture through the matrix. Furthermore, the method of installation can help prevent or become a detriment to the movement of water throughout the system.

Table 6. Attachment Effects on Resistance to Leaks.

Attachment	*Effects*
M	Fastener corrosion, potential compromised attachment, leaks and thermal breaks at fasteners, lateral movement beneath insulation and between layers highly likely.
A	Facer delamination, resistance to lateral movement of leaks, potential for adhesive to act as a vapor retarder, adhesive can dry out along with insulation.
B	No resistance to lateral movement of moisture, moisture storage within insulation only, but vapor retarder can be loose-laid and minimal installation loads result in less potential for damage to the insulation.

Attachment: M=Mechanically-Attached, A=Fully-Adhered, B=Ballasted as shown in Figure 1.

Water penetration through leaks into the roofing system can not only result in degradation of the insulation, but it can also shorten the life of an existing roofing system and a recovery system. Through solar loading the entrapped moisture turns to vapor and the vapor pressure exerts pressure on the roofing system that can delaminate the membrane from the insulation. The delaminations increase the vulnerability of the roofing system to physical and mechanical damage and decrease the ability of the system to shed water by creating non-uniform surface conditions.

9 RECYCLING AND SUSTAINABILITY

Re-use, reduce, and recycle are three key words when discussing sustainability. Recycling and re-use will ultimately reduce the consumption of goods needed as well reduce the amount of disposed materials sent the landfills. In the United States, there are several initiatives for recycling roofing products such as PVC, EPDM, and TPO membranes, asphaltic based material such as shingles, and insulations produced with plastics, such as EPS, XPS and ISO. The initiative so far is on a small scale and is slowly gaining momentum. For the most part, the recycling of roofing products is mainly on residential properties with selective commercial sites across the country adding to the mix. Recycling roofing insulation is in its infancy as an industry; re-using the existing insulation on a re-cover or roof replacement is a viable alternative to recycling when trying to achieve some degree of sustainability related to the roof system. Re-using the existing insulation can save the building owner the expense of disposal costs and also reduce the costs of purchasing and installing the new materials.

The U.S. Environmental Protection Agency (EPA) estimates that the construction industry generates approximately 320 billion pounds of solid waste each year. The total estimated solid waste generated from roofing waste accounts for 80 billion pounds each year. To put that into perspective; the average cost of disposal for 2,000 pounds of roofing debris is approximately fifty dollars that is equivalent to over two billion dollars a year in roofing generated waste, not to mention the environmental impact on the country's landfills. The U.S. Green Building Council's (USGBC) LEED program will issue one point under the heading of Solid Waste Management: Facility Alterations and Additions if the requirement of diverting 70% of the waste (by volume) generated by facility alterations and additions from disposal to landfills and incineration facilities is met. Regardless if the building owner is aspiring to gain a LEED certification, the practice of recycling construction debris is a good measure, and potentially re-using the existing insulation can play a large part in achieving this goal.

10 SUMMARY

Using the various aspects discussed in this paper, a basis for the selection of insulation with durability and eventual re-use in-mind can be developed. No one insulation will likely meet every need and roof system maintenance will always play a vital role in the preservation of insulation integrity for use in re-roofing. If roofs are well-maintained, the likelihood of having viable, re-useable insulation will certainly increase. If re-use is not possible, recycling options should also be considered in more detail for the disposed insulation. As “cradle-to-grave” analysis becomes increasingly more prevalent and building designers and owners are aiming for achieving the least impact, the choice of a roof insulation that may eventually be re-useable could be an untapped resource for sustainability.

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