Designing Thermally Efficient Roof Systems

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Abstract. The past decade has seen the world building committee strive to ensure the energy efficiency of our built environment. A building’s roof is often the most effective envelope in conserving energy. The roof system, if designed properly, can mitigate energy loss or gain and allow the building’s mechanical systems to function properly for occupant comfort. Energy conservation is increasingly being viewed as an important performance objective for governmental, educational, commercial and industrial construction. Interest in the conserving of energy is high and is being actively discussed at all levels of the building industry: Governmental, Codes and Standards and Trade Organizations. As with many systems it is the details that are the difference between success and failure. This presentation will be based on the author’s 35 years of roof system design and infield empirical experience and will review key design elements in the detailing of energy conserving roof systems. Best design and detail practices for roofing to achieve conservation will be delineated, in field examples reviewed and details provided.

1. Advocacy for Improvement
In the past decade the American codes and standard associations have increased the required thermal values every updating cycle. They have realized the importance of energy conservation and the value of an effective thermal layer at the roof plane. They have done this by prescribing thermal R-values by various climatic zones defined by the American Society of Heating and Air Conditioning Engineers known more by its acronym ASHARE, [1]. The American Institute of Architects (AIA) has also realized the importance of conserving energy and defined an energy conservation goal called the 2030 Challenge in which they challenge architects, owners and builders to achieve ‘zero energy’ consuming buildings by 2030. These codes, standards and laudable goals have gone a long way to improving energy conservation, but are short on the details that are needed to achieve the vision.

2. Energy Conservation is More Than Insulation
Roofs are systems and act as a whole. Thus a holistic view of the system needs to be undertaken to achieve a greater good.
Roof systems parameters such as the following need to be considered [2-7]:
- Air and/or vapor barriers.
- Multiple layers of insulation with offset joints.
- Open voids in the thermal layer at perimeters and penetrations.
- Protection of the thermal layer from physical damage above and warm moist air from below.
Air intrusion into the roof system from the interior can have extremely detrimental consequences. Interior air is most often conditioned and when it moves into a roof system where the potential to condensate exists; wetting insulation, deteriorating insulation facers and creating conditions for mold growth and rendering the roof system vulnerable to wind uplift. Preventing air intrusion into the roof system needs to be considered in the design when energy efficiency is a goal.

One layer of insulation results in joints that are often open or open over time, allowing heat to move from the interior to the exterior – a thermal short. Energy high to energy low is a law of physics that can be severe. Thus at the recommendation of the author and others, the International Code Council now prescribes two layers of insulation with offset joints (see photo 1).

![Photo 1: Designing and installing thermal insulation in two layers with offset and staggered joints, prevent vertical heat loss through the insulation butt joints.](image)

When rigid insulation is cut to conform around penetrations, roof edges and rooftop items, the cutting of the insulation is often rough and not tight to the item which was cut to allow installation. This results in voids, often from the top surface of the roof down to the roof deck. With the penetration at the roof deck also being rough, heat loss can be substantial. Thus we specify and require that these gaps be filled with spray foam insulation (see photos 2 and 3).

3. Insulation Material Characteristics Influence on Energy Conservation

In addition to system components influence on energy loss, the insulation material characteristics should also be considered, [2, 6].

The main insulation type in the USA is polyisocyanurate (PIR). Specifiers need to know the various material characteristics in order to specify the correct material. Characteristics to consider are:

- **Density**: 18, 20, 22 or 25 psi; nominal or minimum.
- **Facer type**: Fiber reinforced paper or coated fiberglass.
- **Dimensional stability**: Will the material change with influences from moisture, heat or foot traffic.
- **Thermal R Value**.
Photo 2: Rigid insulation is often cut short of penetrations, in this case the roof curb. To prevent heat loss around the perimeter of the curb, the void has been sprayed with spray polyurethane foam insulation. Open joints in the insulation have also been filled with spray foam insulation.

Photo 3: Rigid insulation is often not tight to perimeter walls or roof edges. The roofing crew is spraying polyurethane foam insulation into the void to seal it from air and heat transfer. Once the foam rises it will be trimmed flush with the surface of the insulation.

In Europe a popular insulation is mineral wool, high in fire resistance, but as with polyisocyanurate, physical characteristic knowledge is required:

- Density
- Protection required: Cover Board or integral cover board.
- Thermal R-value.
4. **Protecting the Thermal Layer**

It is not uncommon for unknowledgeable roof systems designers or builders looking to reduce costs to omit or remove the cover board. The cover board, in addition to providing an enhanced surface for the roof cover adhesion, provides a protective layer on the top of the insulation, preventing physical damage to the insulation from construction activities, owner foot traffic and acts of God.

The underside of the thermal layers should be protected as well from the effects of interior building air infiltration. An effective air barrier or vapor retarder, in which all the penetrations and material laps are detailed and sealed, performs this feat. If a fire rating is required, the use of gypsum and gypsum based boards on roof decks such as steel, wood, cementitious wood fiber can help achieve the rating required.

5. **Insulation Attachment: Energy Saving Contributor or Energy Penalty**

The method in which the insulation is attached to the roof deck can influence the energy saving potential of the roof system in a major way. Attaching the insulation with asphalt and/or full cover spray polyurethane adhesive, can when properly installed, provide a nearly monolithic thermal layer from roof deck to roof membrane as intended by the codes.

Another very popular method of attaching insulation to the roof deck and each other is the use of bead polyurethane foam adhesive. The beads are typically applied at 6” (15.24 cm), 8” (20.32 cm), 9” (22.86 cm) or 12” (30.48 cm).

The insulation needs to be compressed into the beads and weighted to assure the board does not rise up off the foam. Even when well compressed and installed there will be a ±3/16” void between the compressed beads as full compression of the adhesive is not possible. This void allows air transport which can be very detrimental if the air is laden with moisture in cold regions. The linear void below the insulation also interrupts the vertical thermal insulation section.

The most detrimental method of insulation attachment in regard to heat loss is when the insulation is mechanically fastened with the fasteners below the roof cover. Thermal bridging takes place from the conditioned interior to the exterior along the steel fastener. This can readily be observed on heavy frost and light snowfall as the metal stress plates below roof cover heat the membrane, which in turn melts the frost or snow above.

The roofs thermal values are compromised even more when a mechanically attached roof cover is installed. The volume of mechanical fasteners increases, as does the heat loss, which is not insignificant. Singh, Gulati, Srinivasan, and Bhandari in their study “Three dimensional Heat Transfer Analysis of Metal Fasteners in Roofing Assemblies” found an effective drop in thermal value of up to 48%, when mechanical fasteners are used to attach roof covers. Which would suggest that for these types of roof systems, in order to meet code required, effective thermal R-Value code, needs to increase the required thermal R-value by 50% (see photo 4).
Photo 4: Heat loss through single layer insulation and mechanical fasteners was so great that it melted the snow, and when temperatures dropped to well below freezing, the melted snow froze. This is a great visual to understand the great loss of heat through mechanical fasteners.

6. Conclusion
Code and standard bodies as well as governments around the world all agree that energy conservation is a laudable goal. Energy loss through the roof is substantial and an obvious location to prevent energy loss and thus create energy savings. The thermal layer works 24 hours a day, 7 days a week, 52 weeks a year. Compromises in the thermal layer will affect the performance of the insulation and decrease energy savings for years to come. Attention to installation methods and detailing transitions at roof edges, penetrations, walls and drains needs to be given in order to optimize the energy conservation potential of the roof system.

7. Recommendations
Based on empirical field observation of roof installations and forensic investigations, the following recommendations are made to increase the energy saving potential of roof systems.

1. The thermal layer needs to be continuous without breaks or voids. Seal all voids at penetrations and perimeters with closed cell polyurethane sealant.
2. Design insulation layers to be a minimum of two with offset joints.
3. Select quality insulation materials.
   a. For polyisocyanurate that would mean coated fiberglass facers.
   b. For mineral wool that would mean high density.
4. Attach insulation layers to the roof deck in a manner to eliminate thermal breaks.
5. If mechanically fastening the insulation, the fasteners should be covered with another layer of insulation, cover board or both.
6. Design roof covers that do not require mechanical fasteners below the membrane as an attachment method.
7. Protect the thermal layer on top with cover boards and below with appropriate air and vapor barriers.
Saving limited fossil fuels and reducing carbon emissions is a worldwide goal. Designing and installing roof systems with a well thought out, detailed and executed thermal layer will move the building industry to a higher plan.

References
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