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SUPER-INSULATE THE BUILDING ENVELOPE
Step 4

Insulating, along with sealing, all six sides of the net zero building envelope are fundamental steps in the construction of zero energy homes. It is important to insulate the walls, floors and ceilings with types and thicknesses of insulating materials that fit the specific needs of each surface, and to design wall, floor and ceiling assemblies to accommodate those materials.

R-Value

Most building materials resist the flow of heat to some degree. This thermal resistance property is expressed as R-value. Each type of material (wood, drywall, fiberglass, etc.) has a different R-value per inch of thickness. While thermal resistance of a given material increases with thickness it is not a linear relationship. Each additional inch of thickness has slightly less impact than the one before it, so eventually, you reach a point of diminishing returns at which it's no longer cost-effective to add more insulation. Optimizing insulation thickness and R-value is a key design task for all high-performance homes.

R-Value and Climate

R-values for insulation should be appropriate for the local climate. Use energy modeling to optimize the insulation value for various climates. Case studies of zero energy projects around North America provide helpful examples. Wall insulation values range from R-19 in mild climates to R-40 in cold climates to as much as R-60 in very cold locations. For ceilings the insulation value can be R-60 for cold climates, R-80 for very cold climates, and R-30 for warmer climates. For floors, insulation levels can be R-38 in cold climates, R-60in very cold climates and R19 in mild climates. For an extreme example, in Alaska insulation in the walls has been used up to R-90 and in the ceiling up to R-140. Warmer climates have a different insulation R-Value strategy.

A cost-effective zero energy home strives to balance the cost of efficiency measures with the cost of on-site photovoltaic (PV) generation, and it often happens that smaller homes find this balance with lower insulation levels. This is because houses with less surface area also have less overall heat loss, while a square foot of PV panels always generates the same amount of electricity in a given climate.

Advanced Framing

Use advanced framing techniques to save wood, allow space for added insulation and reduce thermal bridging. In addition to saving energy, advanced framing allows you to build more efficiently.

High Performance Walls

There are two methods of wall construction that lend themselves to high R walls at the least cost:

Double Wall: Build two 2×4" walls, with off-set studs on 24" centers to save wood without compromising structural integrity. They can be spaced 5" apart to form a 12" thick wall cavity in colder climates. In more moderate cold climates, double walls with an 8" or 9" cavity may suffice.

Exterior Rigid Insulation: Install sufficient exterior rigid insulation on a single frame wall to achieve the necessary insulating value.

Both systems can easily be adapted to match a specific R-value design target. For double-stud walls, adjust the distance between the walls to achieve anywhere from R-30 to R-50 depending on the climate. In a similar way, the thickness of exterior rigid insulation can be increased to reach the desired insulation value.

Highly Insulated Ceiling or Roof

There are two methods for insulating the top side of the building envelope box:

Blow insulation onto a flat ceiling: Ample vertical space (about 22 inches is ideal) exists under most roof slopes to achieve R-60 insulation. However, there is one tight spot that needs special attention. Where the roof slope approaches exterior walls, there will be less space and seldom enough for R-60 plus the required attic ventilation. One good solution to this problem is a raised-heel truss. By adding additional height to the truss at the point where it sits on the wall, insulation can extend all the way to the outside of the wall.

Build and insulate a cathedral ceiling: Using properly sized roof framing, it's possible to build sloped ceilings with space for ample insulation. Scissor- and parallel-chord trusses can be ordered in virtually any configuration. Loose fill insulation can be blown onto a ceiling with a roof pitch of 2-in-12 or less, although you should check with your insulation installer for guidance. Another option – and a generally less expensive one – would be I-joist rafters. Sixteen-inch I-joists allow space for R-60 and ventilation. It's best to use dense-pack insulation for greater R-value and to prevent insulation settling in roof pitches of 3-in-12 or greater.

Blown-in Insulation

Dense-pack blown-in insulation has two advantages over the more common batt insulation. First, dense-pack naturally fills all gaps and cracks, while hand-cutting batts inevitably leaves voids and squeezing batts into odd spaces leads to compression. Voids and compression increase unnecessary heat loss. Fill walls and floors with dense-pack fiberglass or cellulose to get the necessary insulating value. Dense pack fiberglass insulation or cellulose insulation is considerably less expensive than closed cell spray foam and uses techniques all builders know. Loose fill fiberglass insulation has an R-value of about 3 per inch, while dense pack fiberglass has an R-value of about 4.2 per inch. For example, Owens Corning ProPink L77 has an R-value of R 4.25 per inch. Blown-in cellulose is a good natural, recycled and more sustainable alternative to fiberglass. However, it must be installed at the proper density (3.5 pounds per cubic foot) to avoid settling and it should be protected from moisture with an effective moisture barrier.

Closed-Cell Spray Foam

Closed-cell spray foam insulation has some important advantages. It can achieve the same insulating value in a 6" wall, as a 12" wall filled with fiberglass or cellulose and would therefore allow for about 6" more of additional living space on each side of the house. Closed cell foam, also called high-density foam, is impermeable to water vapor, making it a good choice for unvented attics or crawl spaces. Most importantly, it greatly improves airtightness. However, at current prices for equivalent R-values, it is about two to three times more expensive than dense-pack fiberglass blown in between double offset studs walls and it can have some negative global warming and environmental impact. Depending on local costs and climate, fiberglass or cellulose may be better choices for your overall insulation approach. However in other cases, the unique qualities of spray-foam make it ideal for solving thermal problems or reducing moisture risks at specific locations in the building shell, such as sealing and insulating rim joists in two-story construction.

Rigid Foam Board

Rigid foam board insulation can be used as a reasonable alternative to blown-in fiberglass or cellulose in limited spaces where more R-value is needed. To effectively use rigid foam board, wall, ceiling and floor assemblies should be designed so they can be used most cost effectively. Good applications for rigid insulation include:

- on the exterior of standard walls where added R-value is needed
- above roof sheathing as part of an unvented vaulted ceiling to gain adequate insulation value near the eaves of a low-slope roof instead of raised-heel trusses
- in locations where plumbing or ducts must be placed too close to outside wall sheathing

Floor Insulation

While there may be some truth to the idea that floors lose less heat than walls or ceilings it's still essential to the goal of net zero energy consumption to insulate them well. This means attaining roughly the same R-value in floors as in other building components. There are several options for insulating floors:

Crawl Space: In colder climates, the most cost-effective floor system is a ventilated crawl space. Installing 12" I-joists and blowing in dense pack insulation will bring floors to around R-45. It might be tempting to reduce cost by choosing batt insulation but the many wires and pipes present in most floors make it difficult to install well. In this case, the structural subfloor serves as the air barrier. Most builders choose to carefully seal the perimeter of each floor sheet with construction adhesive. Crawl spaces require foundation vents. It's common for these vents to be cut through the rim joist where they displace insulation and promote air intrusion into the insulated space. It's better to block out crawl space vents in the foundation wall where they will not interfere with insulation. If the foundation wall is mostly below grade, a well can be installed.

Insulated Slab: Slab-on-grade floors tend to have fewer air leaks than wood-frame floors, although plumbing penetrations must be sealed. In colder climates, achieving the necessary R-value below a slab floor requires between 8 and 10 inches of expensive extruded polystyrene or high-density expanded polystyrene insulation. Care should be taken to install the same thickness of insulation around the perimeter where heat loss is greatest. Warmer climates may need much less, or even zero, insulation depending on local conditions, making a slab more economical in such climates. Learn more about insulated slabs here.

Insulated Basement: With full basements, below grade walls would ideally be insulated on the exterior to bring the thermal mass of the concrete wall into the building's thermal boundary. The easiest way to do this would be to build the basement wall with insulating concrete forms. This is likely to be the most expensive option. Alternatively, place two-inch layers of expanded polystyrene against the concrete – staggering the joints) – and then build a 2×4" frame wall with R-21 batt insulation to get a total of about R-38 in the basement wall. Depending on design requirements, it may be possible to insulate the floor above the basement and declare the lower space unconditioned.

HRV/ERV Ducts and Insulation

It may be tempting to run ventilation ducts from HRVs/ERVs through attic spaces or wall cavities where they can interfere with the insulation. The simplest and least costly solution is to add more insulation over the ducts. But a better approach is to design the home so that the ducts are contained within the conditioned space. This can be done with soffits, false ceilings, or insulated airtight chases. Some projects bring the entire attic into the thermal boundary by insulating the roof. A similar approach can be used with an unvented crawl space, although this can be more challenging. Any of these solutions should be integrated at the design phase and analyzed for cost-effectiveness.

Minimize Thermal Bridging

In conventional construction, framing touches both the inside surface and outside surface of the wall. This allows for the direct conduction of heat and cold from the outside wall through the studs to the inside wall, resulting in an important and unnecessary source of heat flow. Preventing or minimizing thermal bridging is best done at both the design phase and during the construction phase. Pay special attention to door jams, second-story floor interfaces, walls, foundations, edges, corners, soffits, eaves, connections, decks and penetrations.

- Select a wall system that minimizes thermal bridging, such as a double-stud wall or one with exterior rigid insulation.
- Thermal bridging can best be minimized in the design phase by a designer who includes cost-effective thermal-bridge-free details. Some thermal bridging does occur where the ends of floor joists touch the rim joists and where the bottom chord of the roof trusses extends over the wall. Where thermal bridging cannot be avoided, closed cell spray foam or aerogels may help reduce it, but may not be cost-effective compared to eliminating thermal bridging in the design phase, or just accepting some minor heat losses.
- Design and construct decks, porches and porch roofs to be separate from the house, so no thermal bridging occurs between the house and the porch or deck. Porch beams should be attached to the exterior sheathing as opposed to being secured deep inside the wall.
- Eliminate thermal bridging in basement floors or slabs. To do so, use two sheets of hard foam polystyrene insulation under the slab to achieve R16. This insulation should connect to the foam insulation in the basement walls along the perimeter to form a continuous barrier.

See the fully illustrated Thermal Bridging Guide (section #4) in the Energy Star Thermal Enclosure Guide Book for more detailed information on how to minimize thermal bridging.