THE COMPLETE GUIDE TO INSULATION OPTIONS FOR TINY HOUSES

Andrew and Gabriella Morrison

www.TinyHouseBuild.com

Note from the authors

This report is offered completely free. You are welcome and encouraged to share it with anyone that you think will benefit from it.

..INTRODUCTION..

Are you unsure about what type of insulation is best for your tiny house? Are you confused by the contradictions in manufacturer's claims? Do you want an eco-friendly focused option or one that's easy on the wallet? The list of insulation options for tiny houses is long and it can hard to decode it all.

Having been in the general construction industry for over 20 years and specializing in straw bale construction for 15 of them, insulation is a topic that interests us greatly. Though insulation options for tiny houses have oft been covered, it can be tricky to navigate through all the information and to determine which makes the most sense for ***your*** specific project. With that in mind, we created this report to help guide you through the various options so that you can make the best choice for your climate, budget, environmental/health concerns, and weight constraints.

This report is presented in two sections. The first describes each type of insulation by definition, pros/cons, cost and R Value. The second ranks each insulation option (from best to worst) within four tiny house categories/priorities: WEIGHT, RVALUE, COST, ENVIRONMENT/EMBODIED ENERGY.

We have made every attempt to write this report from an unbiased standpoint. We haven't covered every single insulation option out there because we want to keep this report relevant to tiny house construction and some are just not appropriate for this type of building.

..INSULATION 101..

The Department of Energy states that space heating and cooling consumes 44% of all energy in a typical home. Insulating a house pays off and every $1 invested into insulation yields a $12 savings in energy costs says the North American Insulation Manufacturer's Association (NAIMA).

Insulations are most commonly compared by R-values (Resistance-value) and the higher the R-value, the better the insulating potential. For example, a brick maintains an R-value of 0.20 per inch while fiberglass batting has an R-value of 3.17 per inch. Fiberglass thus does a better job of insulating a house than a brick does. Though R-values don't tell the whole story of how a specific insulation protects a home in various temperature ranges, it is a standardized measure and for this report, will be how we compare each material to the other.

There are five primary styles of insulation available for tiny house construction: Batts (rolled insulation), Loose Fill (blown in), Spray Foam (expanding foam), Rigid Foam, Reflective Foil, and Natural Block (straw bale and cob). Each has its pros and cons. In selecting which insulation to use, it's important to consider how much energy is used to manufacture it (Embodied Energy), how energy efficient it is (R-value), how much it costs, how available it is locally, how toxic it is (effects of toxicity are heightened in a tiny space), how much it weighs (if you are building on a trailer), and how flammable it is.

As in any building project, be sure to check with your local building code department before you begin construction (or even the design process). Different building areas and climates require different construction and insulation techniques. Be sure to build your tiny house to your local insulation code as code requirements are a ***minimum*** building standard. Follow all safety measures when installing insulation and make sure you understand the risks and challenges of working with whichever insulation material you use.

PART 1

..BATT INSULATION..

SHEEP WOOL INSULATION

Ingredients (vary by manufacturer): wool, borax salt, polyester binder
R=3.5 per inch

Wool insulation is made from sheep wool fibers. The wool used to manufacture insulation is the material discarded as waste by other industries due to color or grade. Some companies bind wool with 5%-15% recycled polyester adhesive which helps batts hold their shape. One can find wool insulation in the form of batts or rope (used primarily in log homes).

PROS: Sheep wool is natural, sustainable, biodegradable, and made from a renewable material. It is easy to install and is applied with the same techniques used with fiberglass batt insulation. No specialty tools are required during installation and it's well within the ability of the do it yourselfer. Some claim that sheep wool can absorb formaldehyde, nitrogen dioxide, and sulfur dioxide from the air and break it down, essentially acting as a healthy filter for a home. It is naturally resistant to insects and mold (unlike cellulose and cotton) and is excellent at absorbing sound. Wool is a hygroscopic material and can absorb up to 30%-40% of its own weight in moisture without a compromise in insulation potential and without becoming wet to the touch. This quality makes this a very desirable insulation option in areas with high humidity. Sheep wool has very low embodied energy (half of that of cellulose and 1/6 of mineral wool). It resists settlement, meaning that the thickness, and consequently thermal performance is maintained.

CONS: It can be challenging to find locally. Because sheep are often treated with fungicides and insecticides, the residue left after washing wool can contaminate ground water (the insecticide and fungicide are washed off the wool in this wash so there is no residue left on the wool itself). The cost of

sheep wool is significantly higher than more conventionally available insulations.

HEMP BATT INSULATION

Ingredients (varies by manufacturer): hemp, recycled fiber, polyester fiber, borate, phosphate
R=3.5/inch

Hemp insulation batts are a natural product produced from the straw portion of the hemp plant. Hemp grows extremely rapidly and also absorbs CO2 at a much faster rate than trees do, helping reduce atmospheric CO2. It is completely renewable. Growing hemp in the US remains against the law from a Federal standpoint but is legal at the state level in a few US states. Over 30 countries grow industrial hemp.

PROS: Hemp insulation is able to absorb and release moisture, helping regulate interior moisture levels and reducing risk of condensation issues. Hemp is naturally a pest and moth repellent. It requires no specialty tools and is well suited to the do it yourselfer. It resists settlement, meaning that the installed thickness, and consequently thermal performance is maintained. It is biodegradable. Very little energy is needed in the production of hemp insulation. No toxic additives or chemical protection is needed for hemp cultivation.

CONS: The cost of importing hemp insulation to the US is high as is the environmental impact of shipping the product from abroad. Some manufacturers use polyester fiber (about 15%) in hemp insulation. The fibers are treated with a fire retardant (borate or phosphate based compounds). Both of these compounds raise difficult environmental issues. Be sure to ask individual manufacturer what additives they use.

ROCK WOOL INSULATION

Ingredients (vary by manufacturer): mineral wool fiber, urea extended phenolic cured resin, petroleum hydrocarbon
R=3.3/inch (Batt)

Rock wool is produced by heating natural basalt rocks or industrial steel-mill slag in a furnace to about 2,910F. As the material melts, it is drawn out into fibers and formed into felts, blankets, or batts. The finished product is a mass of very fine intertwined fibers, bound together with starch. It is also known as stone wool, mineral wool insulation, or slag wool insulation. The EPA requires that rock wool insulation be comprised of at least 70% recycled content. Today, rock wool has been generally replaced in residential construction with fiberglass insulation.

PROS: Readily available material. High flame retardation. Rodents are not attracted to rock wool insulation. One of least expensive insulations available. Easy to install for the do it yourselfer and no specialty tools required. Good sound insulation. Made from abundant rock or recycled slag from iron-ore blast furnaces. Rock wool insulation does not absorb moisture.

CONS: Use of rock wool insulation has decreased over the years. Its ability to retain a large volume of water can create condensation issues (though less than with fiberglass insulation). There are some health concerns and potential risks associated with using this material. These include concerns that the fibers can lodge in the lungs in the same way that asbestos can as well as a risk of irritating skin, lungs, nose and eyes during installation. A face mask, goggles, gloves and long sleeved shirt/pants should be used during installation. Some companies add 5% phenolformaldehyde** (more than in fiberglass insulation). Rock wool is often contaminated with lignite (a type of coal) and mineral oil to control dust. It is typically bound into batt form by the use of a phenolic resin. These materials can be bothersome to sensitive people who are directly exposed. Make sure to read the package label and research additives before selecting rock wool insulation.

***There are two types of formaldehyde compounds used in building: Urea-formaldehyde (UF): urea is a toxic chemical contained in urine. Phenol-formaldehyde (PF) is another form. Both are resinous and are elements in combustion, according to the EPA. They are toxic, although PF is somewhat less so.*

FIBERGLASS INSULATION

Ingredients (vary by manufacturer): fibrous glass, formaldehyde (some don't use it), phenol, ammonia, dedusting oil. Adhesives to adhere facing: mineral oil, polyethylene wax, paraffin wax
R=3.1/inch (Batt)

Fiberglass insulation is created when natural sand and recycled glass are fused together at a temperature of 2,640F. Individual fibers are created by forcing molten hot glass through a minuscule opening which creates a thin, small fiber, much in the same way that cotton candy is made. Resins and other chemicals are then added to make it heat resistant and to cement the fibers together.

PROS: Readily available and least expensive insulation option. It is very lightweight. Fiberglass insulation is fabricated in part with recycled glass and uses sand as its main ingredient (a readily available resource). Relatively easy to install in that no specialty tools are needed and the do it yourselfer can undertake this task. Some companies are now offering fiberglass insulation with an acrylic resin, rather than a formaldehyde-based one.

CONS: Lowest R value per inch. If a water leak presents itself in your tiny house, the fiberglass insulation will grow mold more quickly than other insulation types. Rodents like to make nests in the fiberglass insulation. The paper backing on fiberglass insulation batts is very flammable. Producing fiberglass insulation creates more air pollution than many other insulation options. Vapor barriers are required when insulating with it. Fiberglass irritates eyes, skin and respiratory system. Some believe that airborne glass fibers can become deeply lodged in the lungs leading to cancer (this is a hotly contested issue as the National Toxicology Program declassified fiberglass insulation from being "Reasonably Anticipated" of causing cancer to *not* "Reasonably Anticipated" in 2011). There is also concern about off gassing with fiberglass

insulation containing phenolformaldehyde. Studies by Oak Ridge National Laboratory show that fiberglass insulation degrades dramatically when there is more than a 30 degree differential between internal and external temperatures.

COTTON INSULATION

Ingredients (vary by manufacturer): recycled cotton fiber, binder fiber, boric acid, ammonium sulfate
R=3.5/inch

Cotton insulation is created from recycled cotton material and mill waste. It can be packaged as batts or loose fill. Remnants of cotton clothing are shredded, treated with boric acid, and rolled into batts.

PROS: Cotton insulation uses a renewable resource and some manufacturers use 100% post consumer recycled natural fiber. It has the highest ASTM testing rating for fire, fungi and corrosiveness. The manufacturing process is not very energy intensive. Non toxic and can be handled without protective gear (though a dust mask is recommended). No specialty tools are required for installation and it is well suited for the do it yourselfer. High sound insulation. Does a decent job of repelling rodents.

CONS: Cotton farming is high in pesticide and water use and even though many companies use mostly post consumer denim waste, raw cotton is sometimes used as well (check with manufacturer for percentage of post consumer cotton used). It weighs twice what fiberglass insulation does. May take a long time to dry if a leak creates excess moisture in the insulated cavity. Cotton batts can be bound (depending on manufacturer) with melted synthetic, non-cellulosic polyolefin fibers (about 5% of the finished product). Can be difficult to install in horizontal applications (floors and ceilings) due to weight.

CELLULOSE INSULATION

Ingredients (vary by manufacturer): newsprint (not less than 85% recycled content), borax, boric acid, ammonium sulfate, zinc sulfate, mineral oil, aluminum sulfate, mono- and diammonium phosphate, zinc chloride, lime, aluminum hydrate
R=3.7/inch

Cellulose insulation is created from a combination of wood and recycled paper. It works well when blown into existing wall cavities. In the application of new tiny house construction, only a wet, blown-in application makes sense.

PROS: Uses on average of 75% post consumer paper content. Has less risk to installer than fiberglass. Wet spray applications do an excellent job of filling all voids in wall cavities. Very good fire safety rating (Class 1). No formaldehyde binders or petrochemicals are used in cellulose insulation. Relatively low embodied energy to manufacture (750 BTUs (British Thermal Units) per 1 pound compared to 12,000 BTUs per pound of fiberglass and 30,000 BTUs for spray foam insulation). Provides high sound insulation.

CONS: Compounds sometimes used in cellulose insulation include boric acid, borax, ammonium phosphate, ammonium sulfate, aluminum sulfate, and zinc chloride, totaling about 20% of the final product. Requires a professional to install the insulation as a wet spray. Heavy when applied as a wet spray (weighs three times more than fiberglass insulation). Complete drying of the insulation can take a few months depending on ambient climate.

When creating spray foam insulation, a two component mixture made of Isocyanate (Side A) and resin (Side B) combines at the tip of a gun, forming an expanding foam. Spray foam insulation can be categorized into Open Cell and Closed Cell. Both types have a side A and side B and both Open and Closed Cell insulations use Isocyanate in side A.

OPEN CELL INSULATION

Ingredients: Side A: methylene bis(phenylisocyanate), polymethylene polyphenylene isocyanate, benzene, 1-isocyanate-2-[(4-isocyanatophenyl)methyl], Side B: 2-propanol, 1-chloro-, phosphate, surfactant (trade secret ingredient not disclosed), tertiary amines (trade secret ingredient not disclosed), dimethylaminoethoxyethanol, alkanolamine, polyether polyol, water
R=3.7/inch

In open-cell foam systems, gas pockets connect to each other kind of like in a bath sponge. They're often used in interior walls as sound protection but are typically not recommended in exterior applications. The term "Open Cell Foam" is often incorrectly intertwined with Isynene. Isynene is the name of a leading manufacturer of spray foam insulation but Isynene is not the name for ALL open cell foam insulation (in the same way that Kleenex is a common name for tissue but not all tissues are Kleenex).

PROS: Some open cell foam insulations are water based and have no ozone depleting compounds in them (check with manufacturers) and some contain a percentage of renewable ingredients like soy and castor oil. Lowest cost among spray foams. Very good sound insulation. Doesn't shrink, settle or sag over time. Fills all voids and gaps in wall cavities. The foam, when dry, is softer than closed cell and can withstand motion (as in a tiny house on wheels) much better than closed cell foam installations. Open cell foam is relatively lightweight at 0.5lb per cubic foot. Spray foam is better than any other type of insulation at reducing air leakage. Less expensive.

CONS: The health risks of using any spray foam material are potentially high. ALL spray foams contain the toxic ingredient Isocyanate, even those that use a percentage of soy ingredients and advertise as being 'green'. You must do your own research if you are considering using any type of spray foam and really consider the health risks. The EPA is gathering mounting evidence on the toxic effects of Isocyanate. Tiny houses are, well, tiny by definition and any off gassing will affect inhabitants to a much greater degree than those in a larger home. There is contradictory information out there on the topic of using open cell foam on exterior walls. I have read several claims that it is OK in exterior wall applications while others are saying that it should not be used in those locations (only closed cell should). Since tiny houses typically are comprised of pretty much only exterior walls, this is an important point and one that you will want to speak with an installer about. The embodied energy of spray foam is extremely high (14,000 Embodied Energy/ft2 at R-20 in BTU, compared to 600 in cellulose, for example) while the R Value is relatively low and equivalent to other less expensive and more eco friendly insulations out there. The soy and castor oil content in open cell foam is only about 10% at most in volume of Side B. Future remodeling (rewiring for example) will pose a significant challenge as the spray foam will need to be carved out to create room for new configuration. Installation must be done by a professional. Expensive. Fires inside a structure insulated with spray foam burn hotter and quicker, requiring a fire barrier to be installed over the spray foam (ex. 1/2" sheetrock). The off gassing during a fire is extremely toxic and can cause fatality.

CLOSED CELL INSULATION

Ingredients: Side A: isocyanicacid, polymethylenepolyphenyl isocyanate, polymethylene, diphenylmathane. Side B: propane, propanediamine, hexadecanamine, propanol, phosphoric acid, hexanoic acide, polyester polyol
R=6.0/inch

Closed cell spray foam insulation is much denser than its open cell foam equivalent. The cell structure in the material is smaller. It provides a good water vapor and air barrierr. It's often used in exterior wall applications.

PROS: Has one of highest RValue ratings of any insulating material out there. Closed cell foam insulation traps and

prevents air from flowing through it, therefore reducing wind-washing. Adds structural rigidity to a wall system. It is classified as a water resistive barrier. Resistant to pests. Doesn't sag over time. Spray foam is better than any other type of insulation at reducing air leakage. One can purchase a kit for installing closed cell foam insulation (eliminating need for hiring a professional).

CONS: The health risks of using any spray foam material are potentially extremely high. All spray foams contain the toxic ingredient of Isocyanate, even those that contain a percentage of soy ingredients and advertise as being 'green'. You must do your own research if you are considering using any type of spray foam and really consider the health risks. The EPA is gathering mounting evidence on the toxic effects of Isocyanate. Tiny houses are, well, tiny by definition and any off gassing will be felt to a much greater degree than in a large home. Because closed cell systems are so rigid, they tend to develop cracks in the material, compromising the air-seal and resulting in air leakage. There is an overwhelming sentiment on RV blog posts that closed cell foam should not be used in RVs because of vehicle movement (which has been known to pulverize closed cell foam insulation over time). If you plan on moving your tiny house around, this will be an important consideration. If the material is not mixed in the right proportions, it can emit toxic gas perpetually. Even professionals get the mixing ratio wrong. Do it yourselfers have blown out their walls and ceilings by improperly applying the material. Fires inside a structure insulated with spray foam burn hotter and quicker, requiring a fire barrier to be installed over the spray foam (ex. 1/2" sheetrock). The off gassing during a fire is extremely toxic and can cause fatality. Not as effective at insulating sound compared to others.

AIR-KRETE INSULATION

Ingredients: Unable to find comprehensive ingredient list or comprehensive MSDS for Airkrete.
R=3.9

Air-Krete is a foamed-in-place insulation product considered to be non-toxic (in fact, we watched footage of an installer ingesting some to prove its lack of toxicity!). Air-Krete is primarily made up of magnesium oxychloride and sodium silicate, both of which are inert. Compressed air activates the liquid material and turns it to a foam.

PROS: Very good sound insulation. No petro based chemicals used. Least toxic spray-in foam. Does not off gas. Fireproof. Doesn't shrink or settle. Mold resistant. No risk of blowing out walls during application. Not made of Portland cement but rather of magnesium oxide and magnesium chloride which requires 20%-40% less energy than producing Portland Cement. Non-toxic. It contains no asbestos or formaldehyde. Air-Crete has more insulating potential than cellulose or fiberglass.

CONS: Does not do well with movement and would not be recommended for a tiny house on a trailer as the foam will disintegrate in time with enough movement. Hard to find installers. Expensive. Must be installed by trained technicians. Holds moisture.

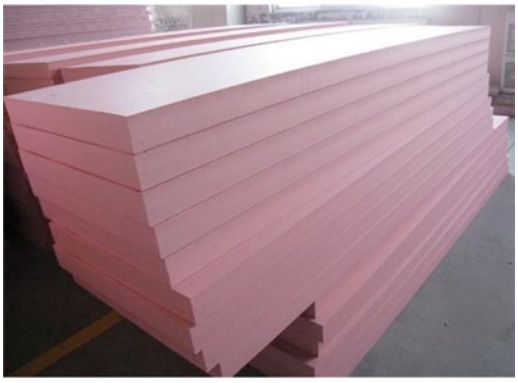
..RIGID BOARD INSULATION..

Various insulating boards exist on the market. Ones commonly used in residential applications include Extruded and Expanded Polystyrene, Polyisocyanurate, Rock Wool, Glass Fiber, and Cork. Most board insulations come in a variety of thicknesses and sizes. You can get them in 4'x8' sheets as well as 2'x8' ones. They're often used as sheathing, underneath siding, or as insulation on a foundation. However, a growing number of builders interested in energy-efficient construction are using rigid foam insulation between the wall sheathing and the exterior siding, creating a continuous insulating layer.

EXTRUDED POLYSTYRENE INSULATION (XPS)

Ingredients (vary by manufacturer): polystyrene, talc, 1-Chloro-1, 1-difluoroethane, hexabromocyclododecane
R=5/inch

Extruded polystyrene (XPS) rigid foam is typically blue or pink and has a smooth plastic surface. Extruded polystyrene is made when a chemical mixture is pushed



through a rectangular die, and then cut into sheets once cooled. XPS is midrange in cost and R-value when compared to the other rigid foams out there. It comes un-faced or with the option of different plastic facings. You can get XPS in low-density and high density options. The high density options are used in foundations, roofs, and other applications.

PROS: Least expensive and most commonly used of the rigid foam insulations. Easily found in local building supply stores. Lightweight and doesn't need specialty tools for installation, making it well suited for the do it yourselfer. Resists moisture and air infiltration (from wind, etc…). Strongest of rigid boards so you can use it without fear of breakage. Doesn't absorb water like polysio. It's also more durable and stronger than expanded polystyrene.

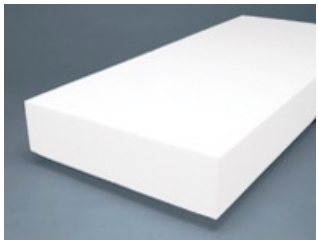
CONS: Has high global warming potential and moderate ozone depletion potential. XPS produces toxic fumes when burned. It should be covered with drywall when installed to the interior of a house. It's manufactured from crude oil byproducts, resulting in some toxic pollution during manufacturing. Individuals that are particularly sensitive to chemicals and impurities may want to avoid this material in their homes. All brands of XPS sold in the US include a brominated fire retardant-hexabromocycldodecane (HBCD) that many, including the EPA, find worrisome. Very high embodied energy in the manufacturing process. Gloves, protective eye wear and dust mask/respirator are recommended by manufacturers for protection during installation.

EXPANDED POLYSTYRENE (EPS)

Ingredients (vary by manufacturer): polystyrene foam (ethenylbenzene homopolymer), pentanes (n-pentane, isopentane, cyclopentane, styrene (vinyl benzene), continuous filament glass fibers

R=3.8/inch

Expanded polystyrene is created in low-density and high density versions. The high density option is used for roofs, foundation slabs, and other applications.



PROS: Expanded polystyrene is the least-expensive rigid foam insulation option. EPS typically uses pentane rather that high global warming potential CFCs as a blowing agent. Lightweight, resists moisture, doesn't need specialty tools for installation, can be installed by do it yourselfer and is highly resistant to air infiltration (from wind, etc…). EPS uses 1/7 of petroleum based products when compared to XPS.

CONS: Pentane doesn't damage the ozone layer, but it does create smog. All brands of EPS sold in the US include a brominated fire retardant-hexabromocycldodecane (HBCD) that many, including the EPA, find worrisome. It lets vapor through so not best choice in high humidity areas. It is flammable and produces toxic fumes when it burns. It should be protected by fire-rated sheetrock on interior walls. It's made from crude oil byproducts and produces some pollution during the manufacturing process. Individuals that are particularly sensitive to chemicals and impurities may want to avoid this material in their homes. It's also more susceptible to damage than the other types of rigid foam. Gloves, protective eye wear and dust mask/respirator are recommended by manufacturers for protection during installation.

POLYISOCYANURATE FOAM BOARDS (ISO)

Ingredients (vary by manufacturer): ethyldimethylmethane (isopentane), n-Pentane
R=6.7/inch

Polyisocyanurate (polyiso for short) foam is high density and made from a closed cell structure rigid insulation board. All ISO panels are faced. Foil-faced ISO panels are impermeable and create an exterior vapor barrier. Therefore, they shouldn't be used with interior vapor barriers.

PROS: has the highest R-value per inch of any rigid insulation. Lightweight, resists moisture, doesn't need specialty tools for installation, can be installed by do it yourselfer and is highly resistant to air infiltration (from wind, etc…). Usually

contains some recycled plastic content. The most eco-friendly of the rigid foam board options.

CONS: ISO panels are expensive. R-values start around R-8 and degrade slightly over time due to off gassing. It produces toxic fumes in a fire so should be covered with fire-rated sheetrock when installed to the interior wall. It's manufactured from oil byproducts, and produces some toxic pollution. Individuals that are particularly sensitive to chemicals and impurities may want to avoid this material in their homes. Gloves, protective eye wear and dust mask/respirator are recommended by manufacturers for protection during installation.

ROCK WOOL & GLASS FIBER INSULATION

These insulation board products offer the same basic health advantages and disadvantages as their batt counterparts. They are denser and more-rigid, but are created by the same materials used in rock wool and fiberglass batts. See Pros and Cons above for Rock Wool and Fiberglass insulation.

CORK BOARD INSULATION

R=3.6/inch
7.3 pounds per cubic foot
Cost: $1.05 per board foot

Cork insulation is made from the outer bark of evergreen oak trees grown grown in the Mediterranean. The bark is ground up into granules, which are then exposed to superheated steam. The granules are shaped into sheets and bound together by suberbin, a natural binder. .

PROS: It is one of the few all-natural, manufactured insulations still readily available. Typically comes from managed healthy forests. Lightweight, rot resistant, naturally fire resistant. 100% sustainable and renewable resource. Available in North America as well as Europe and other regions in the world. Cork harvesting is done by hand. Biodegradable. No fire retardants are needed as it naturally meets fire

safety ratings. Has been used for decades in Europe. All waste is returned to the production process.

CONS: Because the number of cork trees in the world is limited, there is a limited supply of cork insulation. Cork can cost ten times as much as fiberglass. Sometimes resins are used to hold the particles together to form sheets (look for manufacturer that steam-bake their cork into boards instead). Shipment costs and environmental impact to bring cork insulation panels to US must be considered.

..REFLECTIVE FOIL INSULATION..

R=0/inch

Reflective-foil insulation ("builder's foil") is of minimal value in cold climates, but it can be advantageous in hot climates as it reflects radiant solar energy out of attics. Reflective foils are made of a variety of metals including stainless steel, aluminum foil, and foil-coated paper. Reflective aluminum foil placed inside a wall with 3/4" air space can yield an R-value of 3.28 in the summer when compared to 0.91 for 3/4" air space without aluminum foil. Some claims for higher insulating values can be difficult to achieve.

Here are some important points to bear in mind if you are considering using reflective foil insulation. Use it only in hot or mixed climates where one has significant cooling loads. In order for reflective foil insulation to work, it requires an air gap. If you install a radiant insulation somewhere and then spray foam over it, you've wasted all the money on the reflective foil and all the heat will conduct right through it.

Reflective-foil products are prone to moisture-condensation issues when installed incorrectly. To mitigate this potential risk, some foils are lightly perforated, allowing moisture to pass through.

PROS: Ease of installation. Very lightweight. Doesn't degrade in time so performance remains constant.

CONS: More expensive than fiberglass insulation. If enough dust accumulates on its surface, the insulating properties can be greatly reduced. Reflective insulations are often not very sturdy, and they can get torn in some applications.

..STRAW BALE INSULATION..

R=1.5/inch

Straw bale construction is a building technique that uses bales of straw (wheat, rice, rye, and oats straw) either as the structural building element of a home (load bearing construction) or as insulation in a framed house (post and beam straw bale construction). Bales are stacked in courses, much in the way that Legos are laid out, from foundation level to ceiling. Once the bales are installed, the loose chaff is smoothed out with a weed whacker. The building receives three coats of plaster (natural hydraulic lime, for example). Straw bale construction should not be confused with using hay bales for building. Hay has live components, is highly subject to rot because of moisture content, and would wreak havoc inside a plastered wall system over time.

PROS: Made from a waste product that is often either just burned, flooded in the field, or disposed of. Walls are 18" thick which adds depth for creating deep window seats, storage in the walls and nice visual aesthetic. The concept of straw bale construction is simple and geared towards the do it yourselfer. Very low embodied energy (just energy for baling process and transportation to job site). Readily available in many locations around the world. 100% biodegradable. Three times more fire resistant than conventional wall systems. Three times less energy use for heating and cooling than conventional houses. Straw bales are generally inexpensive. Bales provide fewer spaces for pests

than do conventional wood framed houses and straw is not a food source for pests. Significantly outperform typical stick frame construction in hurricane and earthquakes. Acoustically very insulating. Good air quality and often a great solution for people with allergy, pulmonary sensitivities.

CONS: Can be hard to find a contractor locally that has experience with straw bale construction. If bales become wet for a sustained period of time, mold issues can develop (good construction practices are vital to keep bales dry). It is recommended that plumbing be run through isolation walls that have no straw in them in case of leakage over time. Areas of high humidity may not be suitable for straw bale construction. Because the walls are thick, the outside footprint of the house will increase. If straw needs to be trucked in from a distance that can increase costs and environmental impacts substantially. Bales are heavy and installation is slow. It can be challenging to find insurance and conventional financing on a straw bale house. Very heavy compared to other insulation materials. Not an option on trailer tiny homes.

..COB..

R= 0.5/inch

Cob construction combines sand, clay and straw which is then applied to a foundation in continuing layers. Each layer supports the next, and the wall tapers in as you build it up. When dry, the walls are very hard and become the support system for the entire roof structure. An earth or lime plaster is applied over the top to protect the cob beneath from weather. Cob is a terrible insulator, but has extreme thermal mass potential.

PROS: Requires almost no money or previous building experience. Totally fireproof. Can be shaped and molded into very organic shapes. Can create alcoves, shelves, and seats into the wall. Has high thermal mass due to the thickness (1-2 feet). Built of materials found readily in nature. 100% biodegradable. Good air quality and often a great solution for people with allergy, pulmonary sensitivities. Very good at sound absorption. Not attractive to termites or pests.

CONS: Very slow building process. Can run into challenges at the building permit level. Extremely heavy wall system and not an option for trailer tiny house construction. Can be hard to find local experienced builders who are familiar with the technique. Because the walls are thick, the outside footprint of the house will increase. It can be challenging to find insurance and conventional financing for a cob house.

PART II

In this next section we compare the various insulation options presented above and rank them in order from best to worst within 5 separate categories: RValue, Weight, Cost, Health and Environmental Impact. Some ratings were easier to create than others. For example, it was easy to obtain data on RValues, cost and embodied energy for each insulation type; however, in the health category, there was no real standard or measure that compared data between each of the various insulation options.

In the Cost category, we priced out each material at national building material chain stores. All of the costs were based on materials alone except for the materials that require professional installation (spray foams as well as wet cellulose insulation products). We noted the materials whose price includes installation labor. We made the assumption that you will be building using 2x4 construction. All of the prices assumed a wall assembly unit yielding an R Value of 13. If your R value is much higher, your costs will increase. Same principle applies to a wall system with lower R Value.

In the weight column, values are expressed in pounds per cubic foot. All of the insulation options were standardized to represent approximately R15 per inch. It was challenging to find accurate weight information on some of the less common options and there were errors on some of the popular ones (different websites had different weights for the same product). Further, weights were represented in various values so we did our best to standardize them so that we were comparing apples with apples. All that said, please don't put too much "weight" on this ranking. Think of it as a very rough guideline. Weight data was not available for all materials and if it's not listed, it's because we weren't able to find it.

For the environmental cost, we used a standardized measure of Embodied Energy (the amount of energy required to manufacture the product). These figures are expressed in units of MJ/kg or Mega Joules per Kilogram.

Every attempt has been made to validate this information from at least two sources. Though we have done our very best to make sure that all of the information presented is accurate, we can't guarantee it. We encourage you to do your own research so that you can make an insulation choice that you are confident with.

	R Value per inch *(Highest - Lowest)*	**WEIGHT ESTIMATE** *(Lowest - Highest)*	**COST PER 100 SqFt** *(Lowest - Highest)*	**HEALTH TO INHABITANT** *(Least Toxic - Most)*	**EMBODIED ENERGY** *(Lowest - Highest)*
1	ISO Rigid Foam R6.7	Reflective Insulation	Cob (if sourced on site and locally) R=0.5	Cork	Cob (if sourced on site or locally)
2	Closed Cell Spray Foam R6.0	EPS .94#/cf	Fiberglass Batt $25 R13 ($9.98/40sqf	Cob	Straw Bale (if sourced on site or locally) 0.91 MJ/kg
3	XPS Rigid Foam R5.0	Fiberglass Batt 1.03#/cf	Rock Wool Batt $66 R15 (47”x3’11” $45.99)	Straw Bale	Cork 1.4 MJ/kg
4	Air Krete Spray Foam R3.9	ISO 1.3#/cf	Wet Spray Cellulose (installed)$50 R13	Wool Insulation	Cellulose 17 MJ/kg
5	EPS Rigid Foam R3.8	Denim Batt 1.3#/cf	Denim Batt $65.71 R13 ($669/1020sqfts qft)	Hemp Insulation	Rock Wool 17 MJ/kg
6	Cellulose Wet Spray R3.7	Sheep’s Wool 1.4#/cf	Cork $77.16 R10.8 ($185/8sheets of 12”x36”)	Cotton/Denim	Hemp 20 MJ/kg
7	Open Cell Spray Foam R3.7	Open Cell Spray Foam 1.5#/cf	ISO (Polyiso) Rigid Foam $82.75 R13 ($28.85/4x8 sheet)(.60/ sqftx1”)	Cellulose Wet Spray	Sheeps wool 20.9 MJ/kg
8	Cork Rigid Panel R3.6	XPS Rigid 1.8#/cf	Straw Bale $88 R27 ($6 per bale)	Reflective Foil	Denim Insulation

	R Value per inch *(Highest - Lowest)*	**WEIGHT ESTIMATE** *(Lowest - Highest)*	**COST PER 100 SqFt** *(Lowest - Highest)*	**HEALTH TO INHABITANT** *(Least Toxic - Most)*	**EMBODIED ENERGY** *(Lowest - Highest)*
9	Cotton/ Denim R3.5	Rock Wool 2.8#/cf	EPS Rigid Foam $91 R13 ($30 4x8) (.31/ sqftx1”)	Air Krete	Fiberglass 30 MJ/kg
10	Sheep’s Wool Batt R3.5	Closed Cell Foam 3.5#/cf	XPS Rigid Foam $130 R13 ($40 4x8)(.47/ sqft/1”)	Rock Wool	AirKrete
11	Hemp Batt R3.5	Air Krete/ Straw bale/ Cob Very heavy Not appropriate for THOWs	Hemp Batt Insulation $155 R13 (not including shipping from Quebec to your site) ($1.55/sqft)	ISO Poyliso	Reflective Insulation 56 MJ/ kg
12	Rock Wool Batt R3.3		Sheep Wool Insulation $180 R13 ($57.60 per 22.5”x16’ roll)	EPS	(ISO) Polyiso 70 MJ/kg
13	Fiberglass Batt R 3.1		Open Cell Spray Foam R13 (installed) $110	XPS	Open Cell Spray Foam 70 MJ/kg
14	Straw Bale R 1.5		AirKrete $175 (installed)	Fiberglass Batt (non-formaldehyde free)	Closed Cell Spray Foam 72 MJ/kg
15	Reflective Insulation R1 in winter; R5 in summer		Closed Cell Spray Foam $175 R=12 (installed)	Open Cell Spray Foam	Rigid Board EPS 101.5 MJ/kg
16	Cob R0.5			Closed Cell Spray Foam	XPS 110 MJ/kg