THERMAL INSULATION

PROPERTIES and APPLICATIONS in HOUSING

TECHNICAL MANUAL

Promoting community level job creation and income-generating activities through the development of cost-effective building materials production in Kyrgyzstan

UNIDO
UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

ISID Inclusive and Sustainable Industrial Development

THERMAL INSULATION

PROPERTIES and
APPLICATIONS in HOUSING

TECHNICAL MANUAL

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

INDUSTRIAL UPGRADING
& MODERNIZATION
PROGRAMME

INDUSTRIAL UPGRADING & MODERNIZATION PROGRAMME

TAKING YOU AND YOUR INDUSTRY
TO THE NEXT LEVEL

STI SCIENCE TECHNOLOGY INNOVATION

**United Nations
Industrial Development
Organization**
Vienna International Centre
P.O. Box 300
A-1400 Vienna, Austria
Telephone (+43-1) 26026 3570
Fax: (+43-1) 26026 6842
E-mail: IUMP@unido.org
www.unido.org/iump

FOREWORD

Every building material comes with some kind of environmental cost. For mitigating this cost, a number of principles can be used to provide help and guidance for selecting sustainable materials and construction systems. Careful analysis and reasoned selection of materials, including considering how the materials are being combined, can yield significant improvements in the comfort and cost effectiveness of homes, greatly reducing their life-cycle environmental impact.

In design and construction, it is also important to incorporate approaches that will make it easier to adapt, reuse, and eventually dismantle a building. By choosing durable, low-maintenance materials, the need for new materials and finishes can be minimized over the building's lifetime. In addition to the choice of construction materials and other aspects of design, in countries with high seismic activity and cold climates like Kyrgyzstan, special attention must be paid to earthquake-resistant design and insulation, if houses are to be durable and energy efficient.

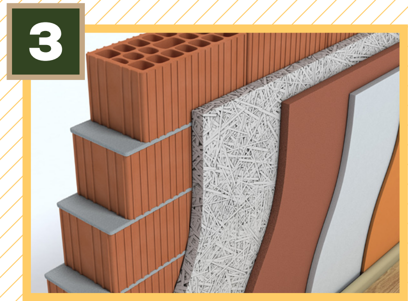
These days, a large number of synthetic and natural materials insulation options are available on the market. For the most part, the house-building industry chooses readily available and cost-effective insulation materials. However, there is a need to identify, distribute, and use environmentally-friendly and cost-effective insulation products that have been produced from locally-sourced materials. These materials, which are made from natural fibres, may appear more expensive initially, but their use can also benefit society through job creation. Natural, local products also offer significant long-term environmental benefits, compared with artificial insulation materials.

Sheepwoolbased insulation has been introduced under the UNIDO project in Kyrgyzstan. Sheep wool is a natural, sustainable, recyclable material, which is biodegradable and has low embodied energy. It does not endanger people's health or the environment, and, unlike glass wool, does not require an installer to wear personal protective equipment. Wool is a highly-effective insulating material, which can perform better because it is able to absorb and release moisture.

This technical manual covers various aspects of insulation materials, including their properties, applications, worldwide marketing and patenting. Reference and bibliography is compilation of large numbers of research papers, articles and web links to share basic information about insulation materials among students and researchers. We sincerely hope that this technical manual will help in the dissemination of basic knowledge about the different kinds of insulation materials available to stakeholders in the building materials and construction industries.

Dr. Amit Rai
UNIDO International Expert

TABLE OF CONTENTS



1

INTRODUCTION

Insulation is one of the most efficient ways to save energy at home: It is estimated that a typical three-bedroom semi-detached house can see energy bills reduced by up to US $400 a year, as a result of installing loft and cavity wall insulation. Insulation helps keep a house at a desired temperature all year round, protecting it against cold in winter and excess heat in summer.

Whether we are considering investing in solar panels, solar water heating, heat pumps, or any other source of green energy for our home, the first step we should take is to improve our home's insulation. This will ensure that the use of natural resources can be maximized without wasting energy. If we ignore this step, we may end up spending a lot of money on buying a very powerful system to meet the energy needs of a badly insulated house.

Insulation is one of the most efficient ways to save energy at home: It is estimated that a typical three-bedroom semi-detached house can see energy bills reduced by up to US $400 a year, as a result of installing loft and cavity wall insulation.

Insulation helps keep a house at a desired temperature all year round, protecting it against cold in winter and excess heat in summer. Insulation also has noise reduction benefits. A well-insulated house can be highly energy efficient, needing very little additional heating and cooling.

How much money can be saved by insulating a home depends on a number of different factors, like the type of insulation and the size of the house. Moreover, depending on the age of a building, planning permission may be required to fit insulation, yet most houses do not require such permission. In the long run, insulation will pay back any initial outlay, and is invariably considered a wise investment.

Modern houses are usually built to very good insulation standards, but older houses often require a lot of work in this respect. Fortunately, there are many options to improve the energy efficiency of older houses.

In cold weather, heat can be lost from the house in all directions, and owners should consider integral insulation to ensure that heat is properly retained.

A wise choice is to insulate roofs, floors, walls, windows and doors. The most important of these is walls, because in a typical house, they account for 30 to 40% of heat losses. Next come roofs, which account for approximately 25% of heat losses; then windows and doors, through which 10-20% is lost; and finally, floors.

Home insulation needs are met by a variety of natural or synthetic materials. The production process and applications differ depending on the specific design of houses and the particular structure involved. The energy requirements of the materials also vary in terms of the energy consumed in production, transportation and application. Building insulation is a broad term and refers to any object in a building that is used to insulate for any purpose. While the majority of insulation in buildings is for thermal purposes, the term also applies to acoustic insulation, fire insulation and impact insulation (for example, where vibrations have to be damped in industrial applications). Often an insulation material is chosen for its ability to perform several of these functions at once.

Insulation requires intelligent planning. Not only does it make homes warmer in winter, it also helps keep them cooler in summer. The principle here is the same as a flask, which can keep drinks hot or cold by providing an insulating layer between the liquid and the outside air.

Air is a poor conductor of heat and it is the tiny pockets of air trapped within the insulating material which minimize the amount of heat that can pass between the inside and outside of a house. This means that in winter, the heat stays inside a home, and in the summer it stays outside. Different types of insulation materials possess different properties, and as a result, are suited to different areas of buildings.

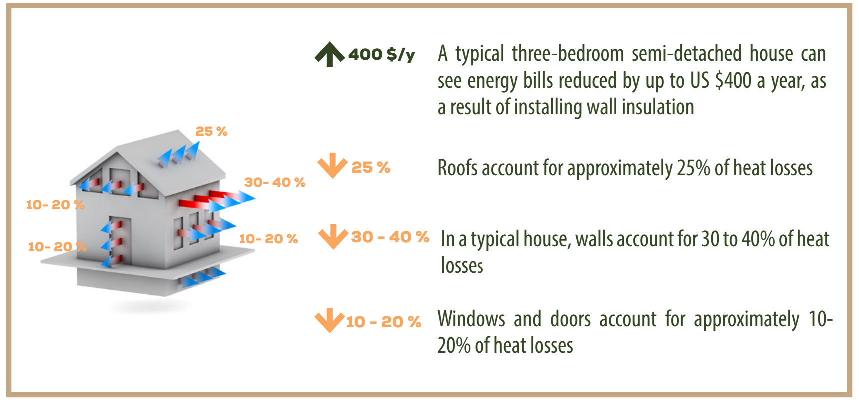


Figure 3: Heat loss and prevention areas for home insulation

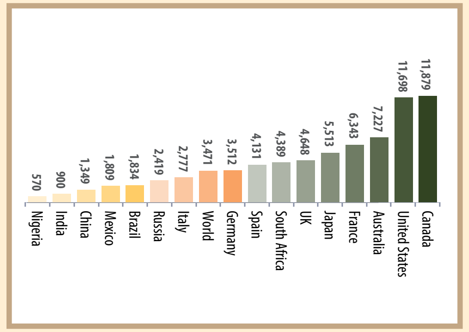


Figure 1: Worldwide scenario of household electricity use (kWh / year)

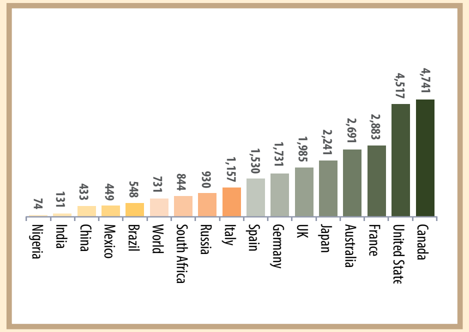


Figure 2: Residential electricity use per capita (kWh / year)

2

PROPERTIES OF INSULATION MATERIALS

Most common insulation materials work by slowing conductive heat flow and, to a lesser extent, convective heat flow. Radiant barriers, which are not classed as insulation products, and reflective insulation systems work by reducing radiant heat gain. To be effective, the reflective surface must face an air space.

How insulation works

To understand how insulation works, it helps to have some knowledge of heat flow which involves three basic mechanisms: conduction, convection and radiation. Conduction is the mechanism seen when heat passes through materials, such as when a spoon placed in a hot cup of coffee conducts heat, through its handle to our hand. Convection is in evidence when heat circulates through liquids and gases, and is why lighter, warmer air rises, and cooler, denser air sinks in our houses. Radiant heat travels in a straight line and heats anything solid in its path that absorbs its energy.

Most common insulation materials work by slowing conductive heat flow and, to a lesser extent, convective heat flow. Radiant barriers, which are not classed as insulation products, and reflective insulation systems work by reducing radiant heat gain. To be effective, the reflective surface must face an air space.

Regardless of the mechanism, heat flows from warmer to cooler areas until there is no longer a temperature difference. In our homes, this means that, in winter, heat flows directly from all heated living spaces to adjacent, unheated attics, garages and basements, and also to the outdoors. Heat flows can also occur indirectly through interior ceilings, walls and floors, wherever there is a difference in temperature. During the seasons when cooling is needed, heat flows from the outdoors to the interior of a house.

To maintain comfort, the heat lost in the winter must be replaced by the heating system, and the heat gained in the summer must be removed by the cooling system. Properly insulating a home will reduce these losses and gains by providing effective resistance to the heat flows.

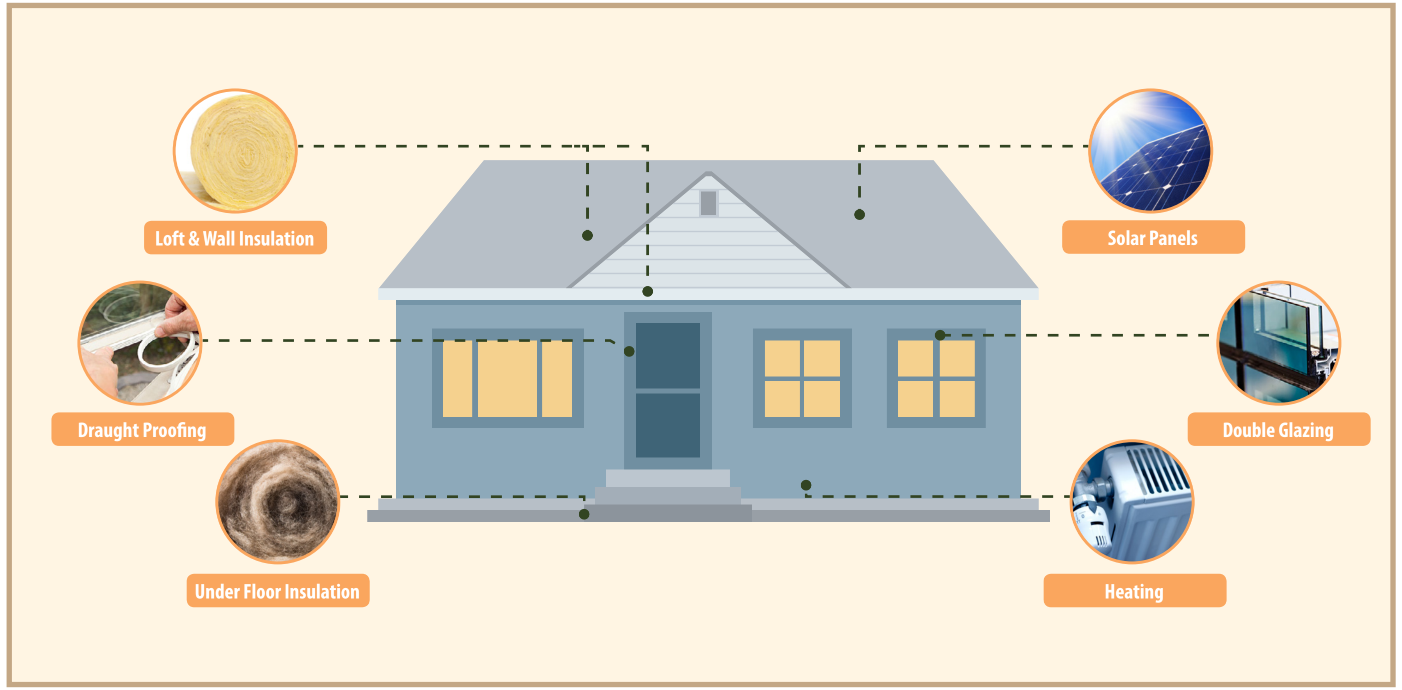
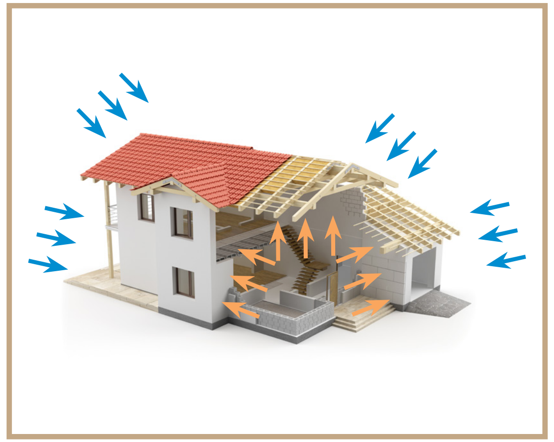


Figure 4: Important factors for energy efficient home insulation

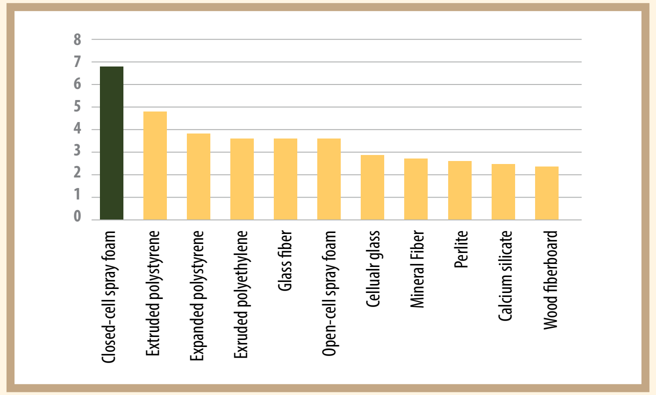


Important properties of insulation materials

Thermal insulation involves the reduction of heat transfer (the transfer of thermal energy between objects at different temperatures), between objects in thermal contact, or between objects within range of radiating influence. Thermal insulation can be achieved through specially engineered methods or processes, as well as by selecting suitable object shapes and materials.

Heat flow is an inevitable consequence when objects of different temperatures come into contact with each other. Thermal insulation provides an insulating area in which thermal conduction is reduced, or thermal radiation is reflected, rather than being absorbed by the lower-temperature body.

The insulating capacity of a material is determined by its thermal conductivity,low thermal conductivity is equivalent to a high insulating capacity (R-value). In thermal engineering, other important properties of insulating materials are: product density (ρ) and specific heat capacity (c).

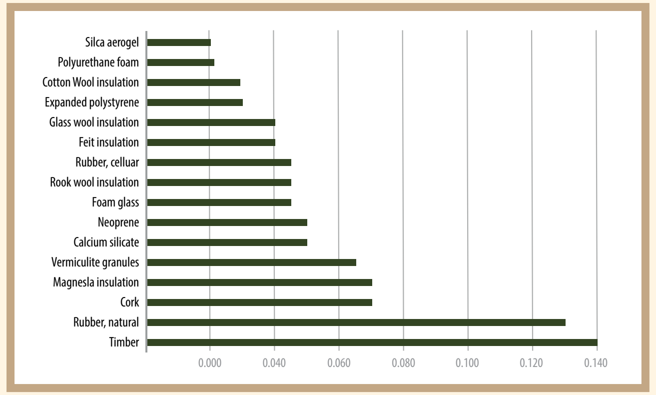


R-Value

An insulating material's resistance to conductive heat flow is measured, or rated, in terms of its thermal resistance or R-value; the higher the R-value, the greater its effectiveness as an insulator. The R-value depends on the type of insulation, its thickness and density. When calculating the R-value of a multi-layered installation, the R-values of the individual layers must be added together. Installing more insulation in a home increases the R-value, and, therefore, the resistance to heat flow. Insulation experts can determine the degree of insulation that is appropriate for any given climate.

The effectiveness of an insulation material's resistance to heat flow also depends on how, and where, the insulation is installed. For example, insulation that is compressed will not provide its full, rated R-value. The overall R-value of a wall or ceiling will be somewhat different from the R-value of the insulation itself because heat flows more readily through studs, joists and other building materials, in a phenomenon known as thermal bridging. In addition, insulation that fills building cavities densely enough to reduce airflow can also reduce convective heat loss.

The amount of insulation, or R-value, needed depends on the climate, the type of heating and cooling system, and the part of the house that is to be insulated. Air sealing and moisture control are important to a home's energy efficiency, health, and comfort.



Thermal conductivity

Thermal conductivity measures the ease with which heat can travel through a material by conduction, which is the main way that heat is transferred through insulation. Thermal conductivity is often termed the λ (lambda) value, or k value; and the lower the figure, the better the performance.

In simple terms, this value is a measure of the capacity of a material to conduct heat through its mass. Different insulators and other types of materials, have specific thermal conductivity values that can be used to measure their effectiveness as insulators. Thermal conductivity can be defined as the amount of heat/energy (expressed in kcal, Btu, or J) that can be conducted in unit time through a material of unit area and unit thickness, when there is a unit temperature difference. Thermal conductivity can be expressed in kcal m-1 °C-1, Btu ft-1 °F-1 and, in the SI system, in watt (W) m-1 °C-1.

Vapour permeability

Vapour permeability is the extent to which a material permits the passage of water through it. It is measured by the rate of vapour transmission through a unit area of flat material of unit thickness, induced by a unit of vapour pressure difference between two specific surfaces, under specified temperature and humidity conditions.

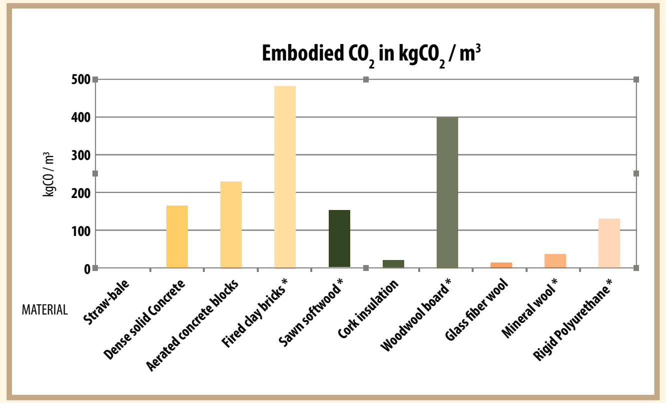
Thermal insulation is usually characterized as vapour permeable or non-vapour permeable. Often referred to, erroneously, as being of 'breathable construction', walls and roofs so termed are characterized by their capacity to transfer water vapour from the inside to the outside of the building – so reducing the risk of condensation.

Vapour Permeability (building materials)

Material	µ-value (=typical)	Typical thickness in construction (mm)	sd-Value in typical construction (m)
Air	1 (reference)	100	0.1
Dense Concrete	60-250 (200)	100	20
Bricks	5-30 (10)	100	1
Expanded polystrene	30-50 (40)	100	4
Mineral wool, flax, hemp, sheepwool insulations,Woodfire insulation	2-5 (5)	100	0.5
Spruce, Pine	45-400 (150)	100	15
OSB, plywood	100-700 (200)	10	0.2
Metals and metal cladding, some plastics and asphalts	250,000	1	1000

Embodied energy

Though not a factor in the thermal performance of an insulation material, embodied carbon is a key concept when it comes to balancing the greenhouse gas emissions generated when producing a material with the emissions saved by the insulation over its lifetime. Embodied carbon is usually considered as the amount of carbon released as gas from the fossil fuels used to produce the energy needed for the extraction of raw material and its manufacture into a finished product, to the point where it leaves the factory gate. In reality, of course, the extent of embodied carbon goes much further than this. It includes transportation to the site where the product will be used, and the energy used in installation, through to that required for demolition and disposal. The science related to embodied carbon is still evolving; consequently, firm and reliable data is difficult to obtain.



Specific heat capacity

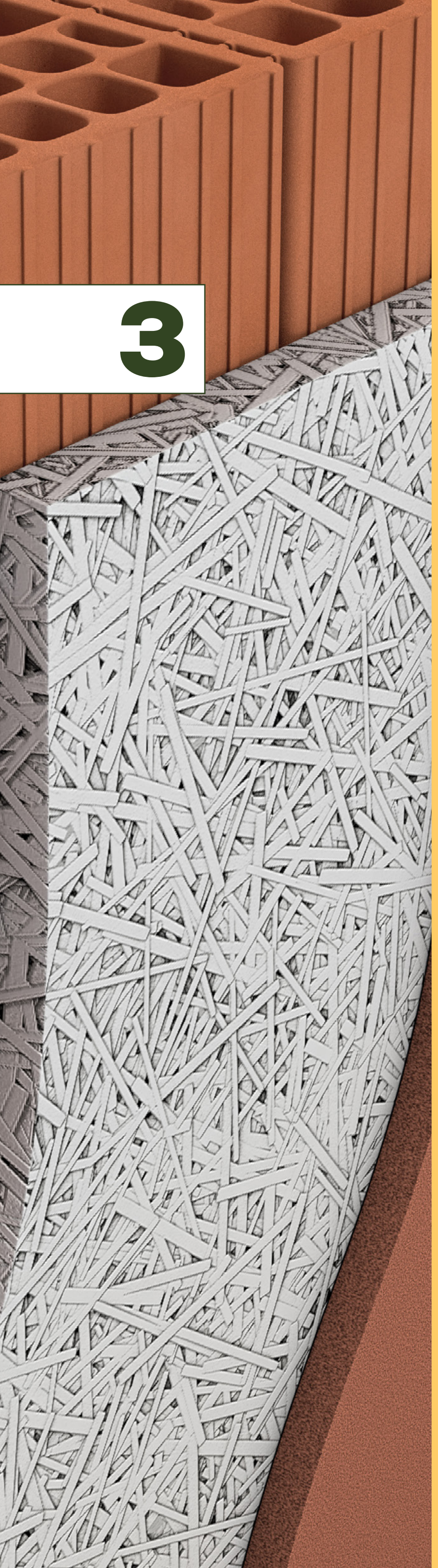
The specific heat capacity of a material is the amount of heat needed to raise the temperature of 1kg of the material by 1K (or by 1 °C). A good insulator has a higher specific heat capacity, meaning it takes time to absorb more heat before actually heating up (showing a temperature rise) and transferring the heat it has absorbed. High specific heat capacity is a feature of materials providing thermal mass or thermal buffering.

Density

The density refers to the mass per unit volume of a material and is measured in kg/m3. A high-density material maximizes the overall weight and is a feature of 'high' thermal diffusivity and 'high' thermal mass materials.

Thermal diffusivity

Thermal diffusivity measures the ability of a material to conduct thermal energy relative to its ability to store it. Insulators have low thermal diffusivity. For example, metals transmit thermal energy rapidly (which is why they are cold to the touch) whereas wood is a slow transmitter. Copper has a thermal diffusivity of 98.8 mm2/s, whereas that of wood is 0.082 mm2/s. The variables described above are linked by the following equation: thermal diffusivity (mm2/s)=thermal conductivity/density x specific heat capacity.



3

TYPES OF INSULATION MATERIALS

In terms of energy efficiency, investing in high levels of insulation materials for use in a home is more cost-effective than investing in expensive heating technologies. It is worth taking the time to choose the right materials in the context of the design of the entire building.

Insulation is a key component of sustainable building design. A well-insulated home reduces energy bills and this, in turn, reduces the associated carbon emissions which are linked to global climate change.

In terms of energy efficiency, investing in high levels of insulation materials for use in a home is more cost-effective than investing in expensive heating technologies. It is worth taking the time to choose the right materials in the context of the design of the entire building.

Insulation materials are used in roofs, walls and floors. Timber-framed homes require wall insulation in the form of batts (pre-cut sections that are designed to fit between stud walls), rolls or boards. Other types of construction, such as brick or concrete, are insulated using spray foam, loose fill or rolls. It is far easier and cheaper to install insulation in the walls and floors of a new-build home than to retrofit an existing home. However, the insulation of roofs is easily achieved in any home using rolls or bags of loose fill material.

A variety of available insulation materials, and their average R-values, are discussed below.

FIBREGLASS INSULATION MATERIALS

Fibreglass is the most commonly used insulation material of recent times. As a result of the way it is being produced, by weaving fine strands of glass into an insulating material, fibreglass is able to minimize heat transfer. It is commonly used to produce two different types of insulation: blankets (batts and rolls) and loose fill, and it can also be found in the form of rigid boards and duct insulation.

Manufacturers now produce medium and high-density fibreglass batt insulation products that have slightly higher R-values than the standard batts. The denser products are intended for insulating areas with limited cavity space, such as cathedral ceilings.

Fibreglass is an nonflammable insulation material, with R-values ranging from 2.9 to 3.8 per inch. Moreover, it is a cheap form of insulation and is therefore the recommended option. However, installing it requires safety precautions. It is important to use eye protection, masks and gloves when handling fibreglass.

MINERAL WOOL INSULATION MATERIALS

The term "mineral wool" refers to several different types of insulation. First, it may refer to glass wool, which is fibreglass that has been manufactured from recycled glass. Second, it may mean rock wool, which is a type of insulation made from basalt. Finally, it may also refer to slag wool which is produced from the slag generated by steel mills.

Mineral wool can be purchased in batts or as a loose material. Most forms of mineral wool do not have additives that make them fire resistant, which means they are a poor choice for use in applications where extremes of heat may be present. However, mineral wool is not combustible. Therefore, when used in conjunction with other, more fire-resistant forms of insulation, mineral wool can be an effective choice of material to insulate large areas. Mineral wool has R-values ranging from 2.8 to 3.5 per inch.

CELLULOSE INSULATION MATERIALS

Cellulose insulation is arguably one of the most eco-friendly forms of insulation. It is produced from recycled cardboard, paper and other similar materials, and is supplied in a loose form. Cellulose has an R-value between 3.1 and 3.7 per inch. Some recent studies on cellulose have shown that it may be an excellent product to prevent fire damage. As a result of its dense nature, cellulose contains virtually no oxygen. This lack of oxygen retards combustion, and, therefore, helps to minimize the amount of damage that a fire could cause.

Manufacturers tend to add the mineral borate, sometimes blended with less costly ammonium sulphate, to cellulose insulation to ensure fire and insect resistance. Cellulose insulation typically requires no moisture barrier and, when installed at the appropriate densities, does not settle in building cavities.

PLASTIC FIBRE INSULATION MATERIALS

Plastic fibre insulation is primarily made from recycled plastic bottles (polyethylene terephthalate or PET). The fibres are formed into insulation batts, similar to those manufactured in high-density fibreglass.

The insulation is treated with a fire retardant to ensure it is not readily combustible, but it does melt when exposed to flames. The R-values of plastic fibre insulation vary with the batts' densities, which range from 3.8 per inch at 1.0 lb/ft3 density, to 4.3 per inch at 3.0 lb/ft3 density. Plastic fibre insulation does not tend to act as an irritant when working with it, but that batts can be difficult to handle and cut when using standard tools.

NATURAL FIBRE INSULATION MATERIALS

Some natural fibres, including cotton, sheep wool, straw and hemp are used as insulation materials.

COTTON INSULATION MATERIALS

Cotton insulation consists of 85% recycled cotton, and 15% plastic fibre treated with borate: the same flame retardant and insect/rodent repellent used in cellulose insulation. One type of product, for example, are recycles waste trimmings from the manufacture of blue jeans. As a result of its recycled content, cotton insulation requires minimal energy to manufacture. It is available in batts with an R-value of 3.4 per inch. Cotton insulation is also nontoxic, and can be installed without the use of respiratory or skin-exposure protection. However, cotton insulation costs about 15% to 20% more than fibreglass batt insulation.

SHEEP WOOL INSULATION MATERIALS

When it is to be used as an insulating material, sheep wool is also treated with borate for pest, fire and mould resistance. It can hold large quantities of water, which may be an advantage in some walls, but repeated wetting and drying can result in borate being leached from the material. The R-value of sheep wool batts is about 3.5 per inch, which is similar to other fibrous types of insulation.

Sheep wool is a proven material when it comes to absorbing and neutralizing harmful substances. It is a natural protein made up of 18 different types of amino acid chain, 60% of which have a reactive side chain. These reactive areas allow the wool to absorb harmful and odorous substances including nitrogen dioxide, sulphur dioxide and formaldehydes, which are then neutralized through a process known as chemisorption. Therefore, using sheep wool as insulation can offer benefits in terms of wellbeing, and help create a healthy indoor climate.

STRAW-BASED INSULATION MATERIALS

Straw bale construction, which was popular some 150 years ago, has received renewed interest in recent times. When a recognized international laboratory tested straw bales, it determined them to have R-values of 2.4 to 3.0 per inch. However, many experts claim that an R-value of 2.4 per inch is more representative of the performance of a typical straw bale because bales, when stacked together, contain numerous gaps. A process for fusing straw into boards, without adhesives, was developed in the 1930s. Panels are usually 2 to 4 inches (5 to 102 mm) thick and faced with heavyweight kraft paper on each side. Although manufacturers' claims vary, a realistic range of R-values is about 1.4 to 2 per inch.

HEMP WOOL INSULATION MATERIALS

Hemp is one of the oldest cultivated plants on earth and is an excellent insulating material, as well as being widely used for clothing, paper, oil, fuel, food and other construction materials.

Hemp can grow to a height of nearly four metres in a period of 100-120 days. Because the plants naturally shade the soil, no chemicals, or potentially toxic compounds, are required in hemp cultivation. As well as having low embodied energy during manufacture, hemp insulation is carbon negative because the plant absorbs carbon from the atmosphere, "locking it in" as it grows.

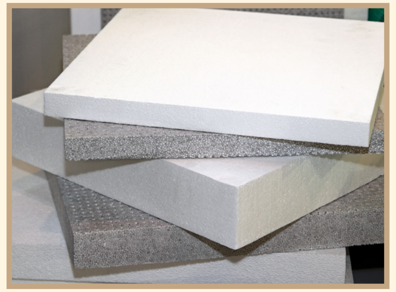
Hemp insulation is a little-known material that is not commonly used. Its R-value, of about 3.5 per inch, is similar to other fibrous types of insulation.

POLYSTYRENE INSULATION MATERIALS

Polystyrene, a colourless, transparent thermoplastic is commonly used to make foam or bead board insulation, concrete block insulation, and a type of loose fill insulation consisting of small beads of polystyrene.

Moulded expanded polystyrene (MEPS), commonly used in foam board insulation, is also available as small foam beads. These beads can be used as a pouring insulation for concrete blocks or other hollow wall cavities, but, because they are extremely lightweight and hold a static electric charge very easily, they are notoriously difficult to control.

Other polystyrene insulation materials similar to MEPS are expanded polystyrene (EPS) and extruded polystyrene (XPS). The R-value of polystyrene foam board depends on its density, and ranges from 3.8 to 5.0 per inch. Polystyrene loose fill or bead insulation typically has a lower R-value, of about 2.3 per inch, compared with the equivalent foam board.



POLYISOCYANURATE INSULATION MATERIALS

Polyisocyanurate, also known simply as polyiso, is a thermosetting type of plastic, closed-cell foam that contains a low-conductivity, hydrochlorofluorocarbon-free gas in its cells. The high thermal resistance of the gas gives polyisocyanurate insulation materials an R-value ranging from 5.6 to 8 per inch.

Polyisocyanurate insulation is available as a liquid, as a sprayed foam, and as a rigid foam board. It can also be produced as laminated insulation panels with a variety of facings. Over time, the R-value of polyisocyanurate insulation may fall as the low-conductivity gas in its voids escapes and is replaced by air, a phenomenon known as thermal drift. Foil and plastic facings on rigid polyisocyanurate foam panels can help stabilize the R-value. Panels with foil facings have stabilized R-values of 7.1 to 8.7 per inch. Some manufacturers use polyisocyanurate as the insulating material in structural insulated panels (SIPs), which can be manufactured from both foam board and liquid foam.

POLYURETHANE INSULATION MATERIALS

Polyurethane is a foam insulation material that contains a low-conductivity gas in its cells. The high thermal resistance of the gas gives polyurethane insulation materials R-values ranging from 5.5 to 6.5 per inch. Polyurethane foam insulation is available in closed-cell and open-cell forms. In closed-cell foam, the high-density cells are closed and filled with a gas that helps the foam expand to fill the spaces around it. Open-cell foam cells are not as dense and are filled with air, giving this form of insulation a spongy texture and a lower R-value.

Foil and plastic facings on rigid polyurethane foam panels can help stabilize the R-value, slowing down thermal drift. Reflective foil, if installed correctly and facing an open-air space, can also act as a barrier to radiated heat transfer. Depending on the size and orientation of the air space, this can add another 2 per inch to the overall R-value. Panels with foil facings have stabilized R-values of about 6.5 per inch. Polyurethane insulation is available in liquid sprayed foam and rigid foam board forms.

VERMICULITE AND PERLITE INSULATION MATERIALS

Vermiculite and perlite insulation materials are commonly found as attic insulation in homes built before 1950. Vermiculite insulation materials are not widely used today because of the risk of their containing asbestos. Having said that, only a few sources of vermiculite have been found to contain more than trace amounts of asbestos.

Vermiculite and perlite consist of very small, lightweight pellets, which are made by heating rock pellets such that they expand and pop. This creates a type of loose fill insulation with thermal resistance of up to 2.4 per inch. The pellets can be poured into place, or mixed with cement to create a lightweight form of concrete that has lower heat conductivity than conventional concrete.

UREA-FORMALDEHYDE FOAM INSULATION MATERIALS

Urea-formaldehyde (UF) foam was used in homes during the 1970s and early 1980s. However, as a result of numerous health-related court cases caused by improper installations, UF foam is no longer available for residential use and has been discredited due to its tendency to emit formaldehyde and shrink. It is now used primarily to insulate walls in commercial and industrial buildings.

UF foam insulation has an R-value of about 4.6 per inch and uses compressed air as the foaming agent. Nitrogen-based UF foam may take several weeks to cure completely, and, unlike polyurethane insulation, UF foam does not expand as it cures. Water vapour can easily pass through it and it breaks down when exposed to temperatures above 190°F (88°C) for prolonged periods of time. Moreover, UF foam contains no fire retardants.

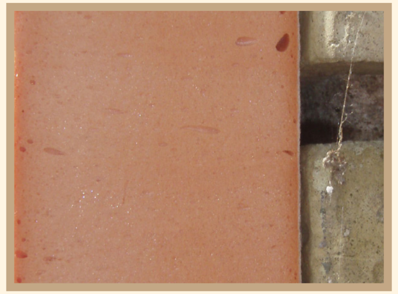
CEMENTITIOUS INSULATION MATERIALS

Cementitious insulation material is a cement-based foam used as sprayed-foam or foamed-in-place insulation. One type of cementitious spray-foam insulation contains magnesium silicate and has an R-value of about 3.9 per inch. With an initial consistency similar to cream, it is pumped into closed cavities. The cost of cementitious foam is similar to that of polyurethane foam, and it is nontoxic, non-flammable and made from minerals extracted from seawater, such as magnesium oxide.

PHENOLIC FOAM INSULATION MATERIALS

Phenolic (phenol-formaldehyde) foam was quite popular in the past, in the form of rigid foam board insulation, but in these days it is available only as a foamed-in-place insulation.

Phenolic foamed-in-place insulation has an R-value of 4.8 per inch and uses air as the foaming agent. One major disadvantage of phenolic foam is that it can shrink by up to 2% after curing, a property that contributes to its lack of popularity today.



4

INSULATION FOR RESIDENTIAL HOUSING

Insulation acts as a barrier to heat flow and is essential for keeping homes warm in winter and cool in summer. A well-insulated and well-designed home can provide year-round comfort, potentially cutting cooling and heating bills in half. This, in turn, reduces greenhouse gas emissions.

Insulation commonly works through a combination of two characteristics:

- The insulating material's natural capacity to inhibit the transmission of heat; and
- The use of pockets of trapped gas which act as natural insulators.

Gases possess poor thermal conduction properties, compared with liquids and solids; therefore, if they can be trapped, they make good insulation materials. Dispersing the gas into small cells, that cannot transfer heat effectively by natural convection, will further enhance a gas's insulating effectiveness. Convection involves larger, bulk flows of gas, driven by buoyancy and temperature differences: it does not take place effectively in small cells where there is little density difference to drive it. In foam materials, small gas cells or bubbles are present in the structure; in fabric insulation, such as wool, small variable pockets of air occur naturally.

General concepts for insulation of residential housing

Insulation acts as a barrier to heat flow and is essential for keeping homes warm in winter and cool in summer. A well-insulated and well-designed home can provide year-round comfort, potentially cutting cooling and heating bills in half. This, in turn, reduces greenhouse gas emissions. Climatic conditions influence the appropriate level and type of insulation. For example, there is a need to establish whether the insulation is predominantly needed to keep heat out, or in, or both. Insulation must be designed to cope with seasonal, as well as daily, variations in temperature. Using a combination of appropriate insulating materials, and solar passive architecture, is always good practice for insulation and energy saving.

The two general types of insulation

Insulation products come in two main categories – bulk and reflective – which are sometimes combined as a composite material. Bulk insulation is mainly provided in walls and roofing areas of houses, in order to resist the transfer of direct heat inside the house. The trapped air in the insulation materials restricts heat transfer by providing thermal resistance. For the most part, the thermal resistance remains the same, regardless of the direction of heat falling on the outside surface of the house.

Bulk insulation could be provided using a large number of natural, as well as artificial materials, such as glass wool, wool, cellulose fibre, polyester and polystyrene. Most bulk insulation products have a defined R-value for a given thickness.

Reflective insulation mainly resists radiant heat flows as a result of its high reflectivity and low emissivity (ability to re-radiate heat). As this insulation works by reflecting heat, air flow and the angle at which the sun rays fall on the surface of the house also play an important role in overall insulation where reflective insulators are used. The thermal resistance of reflective insulation varies according to the direction of heat flows through it.

Reflective insulation usually consists of shiny aluminium foil laminated onto paper or plastic, and is available as sheets (sarking), concertina-type batts, and multi-cell batts. Together these products are known as reflective foil laminates, or RFLs. To achieve the best results from this kind of reflective insulation the outer surface must be clean.

Composite bulk and reflective materials are available, which combine some of the features of both of the above types of insulation. Examples include reflective foil-faced blankets, foil-backed batts and foil-faced boards.

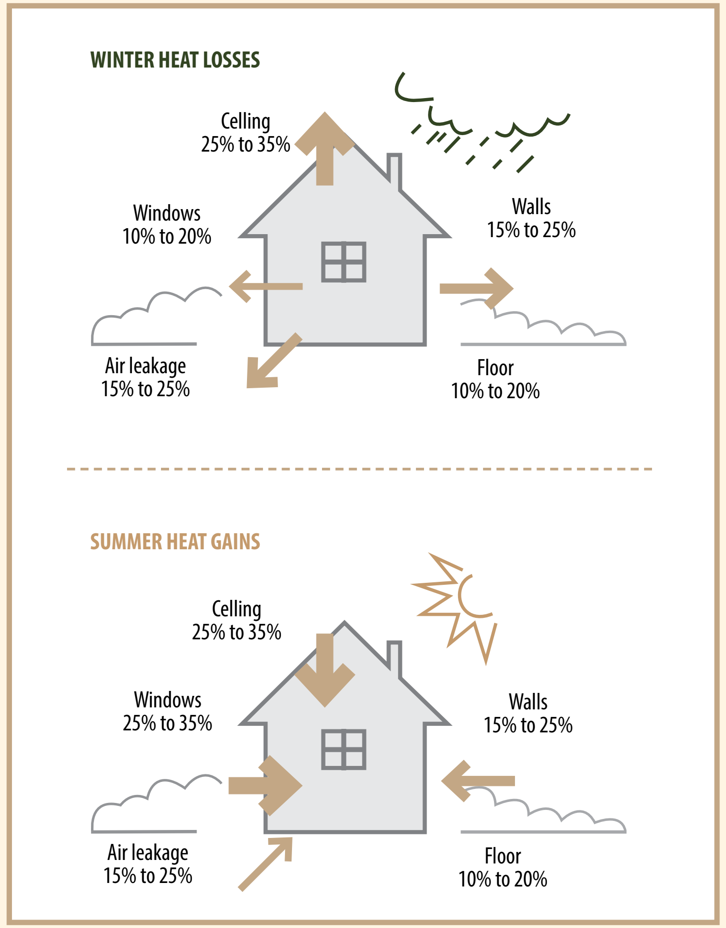


Figure 5: Thermal heat losses and gains without insulation in a temperate climate

The total R-values for reflective insulation are supplied as 'up' and 'down' values. Total values depend on where and how the reflective insulation is installed. You must ensure that any system values provided by the manufacturer relate to your particular installation.

Worldwide patterns in the use of housing insulation

Rural-to-urban migration in developing countries in the Asia/Pacific and Africa/Middle East regions will stimulate building activity in urban areas. As urban buildings are usually more insulation intensive than those in rural areas, this will, in turn, stimulate demand for insulation. Additionally, rising per capita incomes will encourage the use of modern building techniques and materials, including insulation. In some countries in the Africa/Middle East and Asia/Pacific regions, the adoption of minimum insulation requirements will also contribute to demand.

Foamed-plastic insulation to grow the most rapidly

Of the major insulation types, foamed-plastic segments will see the most rapid rise in demand. Foamed plastic insulation will be used more frequently in construction applications as a result of its high insulation value, which will allow it to capture market share from fibreglass and mineral wool insulation. Demand for fibreglass insulation will benefit from strong growth in residential construction activity in North America, as it is a product that is used extensively in the United States of America and Canada. Mineral wools are expected to show the slowest growth among major insulation materials, though gains will still be considerable, since requests from China, where fire safety is a major concern, will boost demand for this product.

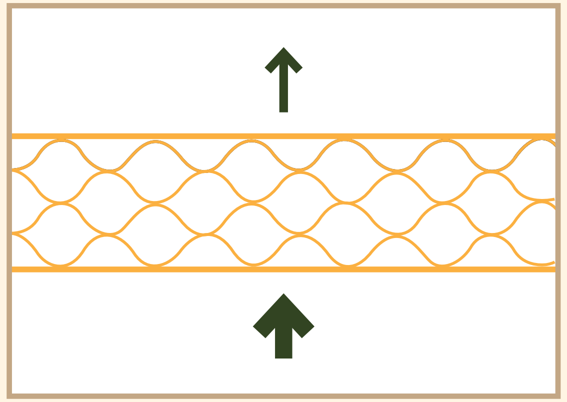


Figure 6: Bulk insulation traps air in still layers

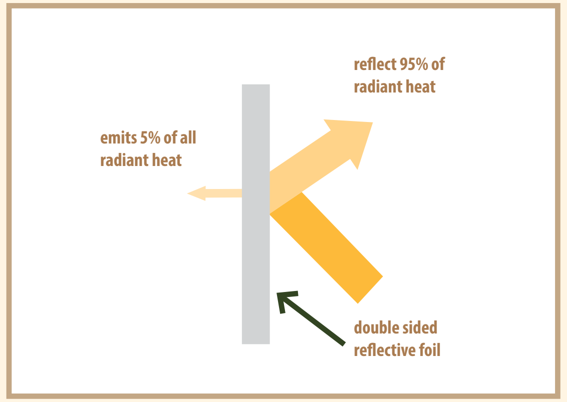


Figure 7: Reflective insulation and heat flow

Building insulation for cost-effective energy consumption

A well-insulated building, whether commercial or residential, is both an energy-efficient and cost-efficient choice because it reduces the cost incurred by a heating or cooling system. Insulation relates to the prevention of the passing of thermal energy between two objects from a region of higher heat concentration to one of lower heat concentration and thereby maintaining the heat in a given area. A properly insulated building saves unnecessary wastage or gain of heat energy. More specifically, building insulation means the use of specific materials in a building in order to lower the heat loss that occurs in it.

Important considerations in house insulation

The level of insulation required for a home or office depends on the design of the building, climate, personal preferences, available budget and energy costs. Selecting the strategy for the insulation of a building is based on considerations such as the modes of energy transfer that occur within it and the intensity and direction of energy flows. These may vary over the day and from one season to another.

Therefore, to maximize the benefits that can be derived from insulation, the right design, combination of materials and building techniques must also be selected. Where a requirement has been identified to add insulation, the levels of existing insulation in the building should be determined before taking additional measures.

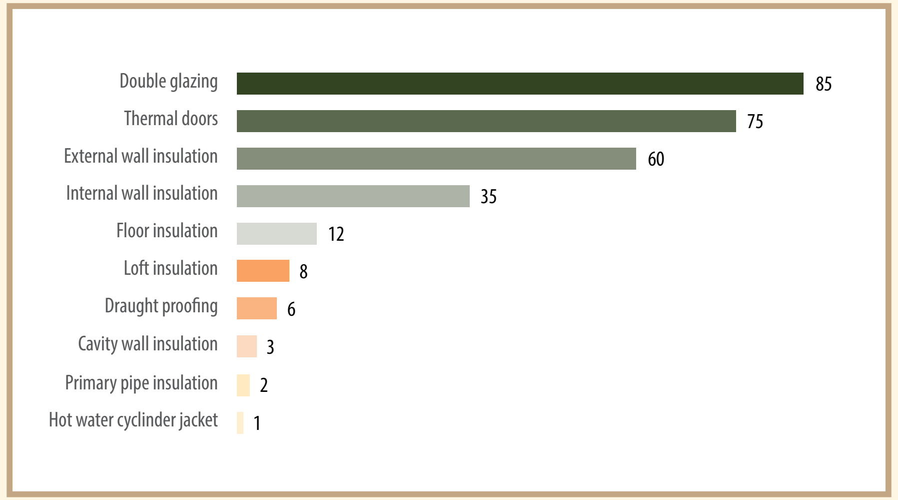


Figure 8: Payback time for insulation technologies - Years

5

AN OVERVIEW OF THE MARKET FOR GLOBAL INSULATION MATERIALS

The insulation market is dominated by the residential-buildings segment, which accounted for over 50% of the share of the total revenue generated in 2014. The growth of this segment can mainly be attributed to increasing urbanization coupled with high disposable income.

In 2016, an international market research company published a new report titled *Insulation (Plastic Foam, Mineral Wool, Fibreglass and Others) Market for Residential Buildings, Non-Residential Construction, Analysis, Size, Share, Growth, Segment, Trends and Forecast, 2014–2020*. According to this report, the global insulation market is expected to reach approximately US $65.0 billion by 2020, growing at a compound annual growth rate (CAGR) of about 8.0% between 2015 and 2020.

The insulation market is segmented on the basis of its key products, including plastic, foam, mineral wool, fibreglass and others. Fibreglass is the largest product segment and accounted for over 40% of overall market share in 2014. Fibreglass is commonly used in a range of applications, owing to its excellent properties and low cost. Plastic foam is another key product segment in insulation and is expected to see significant growth in the near future.

Insulating materials are widely applied in the residential-building, non-residential-construction, industrial, heating, ventilation and air conditioning (HVAC), Original Equipment Manufacturer (OEM) and other sectors. The insulation market is dominated by the residential-buildings segment, which accounted for over 50% of the share of the total revenue generated in 2014. The growth of this segment can mainly be attributed to increasing urbanization coupled with high disposable income.

The Asia/Pacific market is the largest regional market for insulation, accounting, in 2014, for over 40% of the total revenue generated in the sector. The market for insulation in the Asia/Pacific region is expected to exhibit strong growth as a result of rising government support and rapid infrastructure development. In revenue terms, North America was the second-largest market for insulation.

Market drivers and trends

Construction sector output, manufacturing industry output, construction industry spending and the trend towards urbanization, are some of the macro-economic drivers in the insulation market. Developed economies, such as North America and Europe, have introduced regulations concerning energy-efficient buildings, and, according to the Concerted Action Energy Performance of Buildings Programme (a joint initiative between the Member States of the European Union and the European Commission), all new buildings constructed in the Member States by 2020 should comply with zero-energy standards. Even governments in emerging countries are actively promoting the use of thermal-insulation materials. For example, in 2014, Andhra Pradesh (a state in South-East India) adopted the Energy Conservation Building Code (ECBC), under which commercial and public buildings in the state are expected to cut costs and dramatically reduce energy usage by 40% to 60%, through the use of green building materials. Such regulations and initiatives have been identified as the underlying driving factors in the market. However, there are challenges facing the thermal insulation sector, such as low awareness of its materials in emerging economies, and the high capital cost of installing thermal insulation in buildings.

The favourable regulatory environment that can be found in most parts of the world, for example, building codes in the European Union which require increased use of insulation to reduce energy consumption, is expected to have a positive influence on demand growth. In addition, increased spending on infrastructure in the emerging markets of the Asia/Pacific region, such as India, China, Indonesia and Thailand, is also expected to spur growth in the period to 2024.

Volatile prices of key raw materials are expected to remain a considerable challenge for players in the industry. Raw materials, such as styrene, which is used to manufacture plastic foams, are facing volatility on account of varying crude oil prices.

Such issues are expected to present challenges to industry players in terms of production costs and profitability. However, the current period of lower crude oil prices is expected to benefit demand for plastic foams.

High levels of integration exist in the foamed-plastic market as the raw material suppliers are forward integrated and also manufacture insulation products. The major players in the industry are likely to pursue a first-mover advantage in order to achieve a large market share and product portfolio.

Increasing expenditure on research by key players is also likely to positively impact the market. Moreover, leading players have been focusing on mergers and acquisitions to expand their presence in emerging regions.

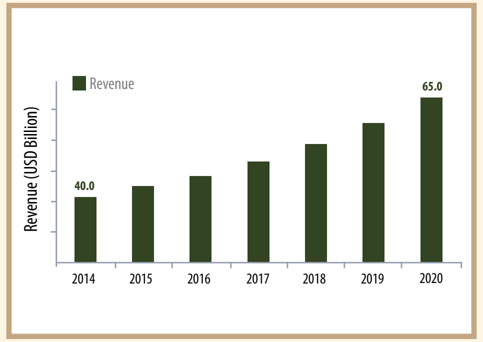


Figure 9: Global insulation market revenue (2014-2020, USD Billion)

Product insights

Foamed plastic was the largest product consumed in 2015, accounting for over 45% of the sector's total revenue. Foamed plastic is widely used for thermal as well as acoustic insulation, in residential as well as non-residential applications, on account of its high insulation value.

Fibreglass insulation material is likely to see a surge in demand from the rebounding construction sector in the United States of America and Canada. The product is widely used in North America, and is the country's preferred choice of insulating material, as a result of its properties, low cost and ease of installation. Rising demand, especially for thermal insulation in energy efficient applications, is expected to drive the overall growth of this product segment.

Application insights

The residential application segment is expected to dominate the insulation market, with sales reaching a value of over US $36.3 billion by 2024.

The US Department of Energy's Weatherization Assistance Program (WAP), which aims to improve the energy efficiency of low-income households through federal funding, is expected to have a positive impact on insulation demand in residential construction.

Urbanization in the emerging economies of the Asia/Pacific region has increased the need for better commercial and public infrastructure. This trend, coupled with favourable regulations regarding the energy efficiency of the buildings involved, is expected to drive demand for insulation in non-residential construction applications over the forecast period.

Regional insights

The Asia/Pacific insulation market led the global industry and accounted for over 40% of global revenue in 2015. The market in this region is characterized by high insulation demand for residential and commercial buildings. High industrialization rates and increased construction spending in the emerging economies of China, India, Indonesia, Thailand, Malaysia and the Philippines have driven the need for better infrastructure.

Growing demand for thermal insulation in residential and commercial buildings is expected to be a major driver of demand in North America. High awareness among consumers regarding energy conservation and regulatory policies to reduce greenhouse gas emissions are expected to have a positive impact on regional growth in this area.

Growth in the North American insulation market will be influenced by government initiatives such as the Weatherization Assistance Program, which promotes thermal insulation, especially in low-income households. Regional demand growth can also be attributed to the demand for insulation materials that is generated by building refurbishment.

Competitiveness insights

The global insulation market is characterized by the presence of multinational conglomerates. Production of insulation materials is capital-intensive and, as a result, entry barriers are high. Achieving economies of scale remains the major focus for players in the industry participants in terms of competitiveness.

The industry is dominated by a small number of major companies with very small differences in their product offerings. Key players include Saint-Gobain, Rockwool, Johns Manville, Knauf, and the Huntsman Corporation.

As a result of the rapid development of infrastructure in emerging regions, the major players are now focusing on achieving a first-mover advantage in the lucrative markets that this has generated. Competition in the industry is greatly affected by environmental regulations.

The winning market-share strategy

Leading players in the global insulation materials market have adopted various strategies to gain additional market share. The main strategies employed have been gathered from analysis of press releases, annual reports of players operating in the market and direct discussions with industry experts. The market players profiled in this manual are insulation materials producers and distributors serving industries such as construction, oil and gas, HVAC and OEM, automotive, wires and cables. The key strategies adopted by these players include new product launches, joint ventures, acquisitions, partnerships, expansion and investment.

Patent analysis

From January 2011 to January 2016, compared with other world regions the Asia/Pacific region registered the highest number of patents related to insulation materials, while North America was second and Europe third.

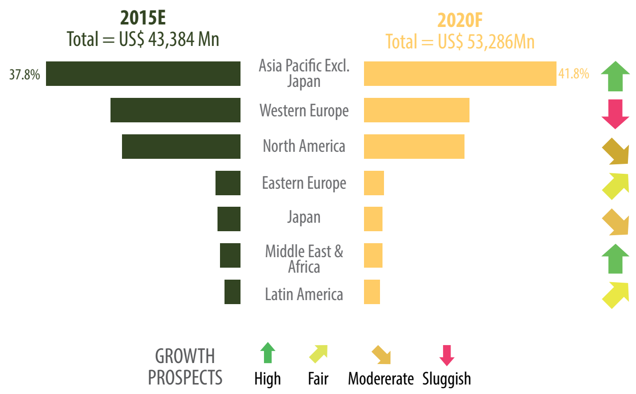


Figure 10: Global thermal insulation material market value split, by region (2016 and 2020)

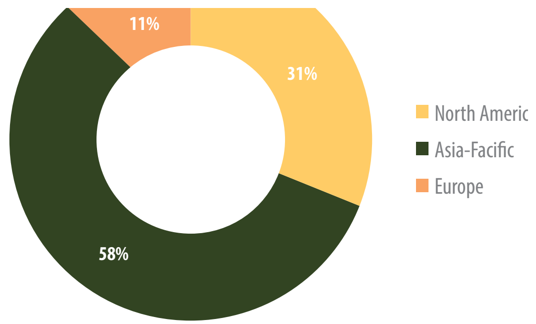


Figure 12: Patent analysis by geographic region (2011-2016, %)

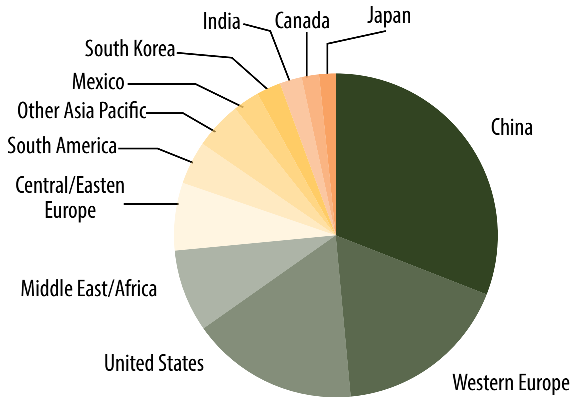


Figure 11: World consumption of polyurethane foam (2016, Source: IHS Chemical)

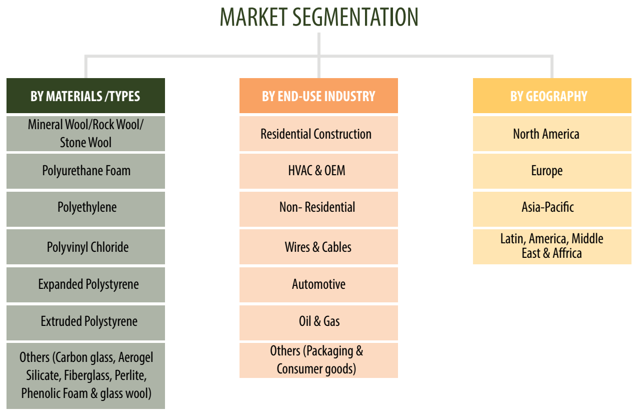


Figure 13: Important areas and segments for the insulation market

6

PROJECT PROGRESS AND INTRODUCTION OF SHEEP WOOL INSULATION

This technical manual provided an overview on various kinds of insulation materials, their properties, applications and marketing aspects, which will help to develop the technical know-how about these materials and their applications among aspiring engineers and architects. Interest in sheep wool insulation and its application will provide further opportunities for the expansion of this technology in Kyrgyzstan and other countries in the region.

The UNIDO low-cost housing project entitled "Promoting community level job creation and income-generating activities through the development of cost-effective building materials production in Kyrgyzstan" was conceived with the objectives of using locally available materials for the development of new and alternative building materials and employment generation. The project is funded by the Russian Federation and is fully consistent with the needs and the priorities set out by the country's government.

The technical and administrative implementation of the UNIDO project in Kyrgyzstan has generated a large number of new ideas, which have been shared and discussed among large numbers of stakeholders to help ensure their appropriate and effective adoption as part of the project.

A procurement process was initiated for the adoption of new materials and technologies covering roofing, walling, flooring, paving, insulation materials and thermal modifying of wood.

During the technical discussions among team members and the advisory board, various ideas for technology adoption using local materials were analysed. It was decided that a sheep wool insulation product/technology should be introduced working jointly with a private company. This technology is considered an excellent choice for Kyrgyzstan. The advantages of sheep wool insulation, listed below, also lent weight to the adoption of this environmentally friendly technology as one of the elements of this project.

ADVANTAGES

OF SHEEP WOOL INSULATION

MANAGES MOISTURE

Sheep wool can absorb 33% of its weight in moisture without compromising its insulating ability. The core of the sheep wool fibre is hygroscopic, meaning that it will absorb water vapour – making it perfect in the loft space where you tend to encounter more condensation.

NON-FLAMMABLE

A great thing about sheep wool is that it doesn't burn; it is just about the only fibre that naturally resists flaming and as soon as the flame is removed it will actually self-extinguish. As a result of the wool's high nitrogen content, it will simply smoulder and singe away instead of bursting into flame. In fact you will need to heat the wool to a temperature in excess of 560°C before it burns.

AIR QUALITY

Not only does it not give off formaldehyde, nitrogen dioxide and sulphur dioxide; sheep's wool absorbs and breaks them down.

SHEEP WOOL DOES NOT ITCH

Both the glass wool and rock wool cause major irritation if you handle them with bare skin and can cause damage to lungs and eyes. Therefore it is strongly recommended that you wear a mask and goggles when installing either of these. However, sheep wool insulation is a breeze to work with as it is safe and harmless.

RAPID ENVIRONMENTAL PAYBACK

Wool requires 85% less energy to manufacture than traditional fibreglass.

REFERENCES AND BIBLIOGRAPHY

7

Research publications

[1] **Shandong Polytenchni**, The research and development of heat insulation materials with low thermal-conductivity in high temperature, International Conference on Materials, Environmental and Biological Engineering, pp 868-871(2015).

[2] **Fei Wang Jian Min Zhang and Qing Guo Tang**, Research progress on thermal insulation materials, Advanced Materials Research, vol. 427, pp 157-162 (2012).

[3] **Zach J. Heal R. Sedlmajer M. and Hroudova J.**, Development of thermal insulation plasters for insulating and sanitation of building constructions, IACSIT International Journal of Engineering and Technology, vol. 5, pp 395 (2013).

[4] **Hroudova J. Zach J. and Vodova L.**, Development of thermal insulation materials based on silicate using non-traditional binders and fillers, International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering, vol. 8, issue 6, pp 713-716 (2014).

[5] **Sagar Kumar Shah and Vinay Bhatt**, Study of thermal insulating materials and costing of economic thickness of insulation, Indian Journal of Applied Research, vol. 3, issue 8, pp 77-80 (2013).

[6] **Long Tao, Zhou Baoshan and Xu Jian**, Technical and economical comparison between different kinds of materials and different geometries for electrostatic precipitator insulators, Paper 12A3, ICESP X – Australia (2006).

[7] **Robert Dylewski and Janusz Adamczyk**, Economic and environmental benefits of thermal insulation of building external walls, Fuel and Energy Abstracts, vol.4, issue 12 (2011).

[8] **Subhash Mishra Usmani J. A. and Sanjeev Varshney**, Energy saving analysis in building walls through thermal insulation system, International Journal of Engineering Research and Applications, vol. 2, issue 5, pp128-135 (2012).

[9] **Jiří Zacha Jitka Hroudováb Jiří Brožovskýc Zdeněk Krejzad and Albinas Gailiuse**, Development of thermal insulating materials on natural base for thermal insulation systems, Procedia Engineering, vol. 57, pp 1288 –1294 (2013).

[10] **Gesa F. Newton Atser A. Roy and Aondoakaa I. Solomon**, Investigation of the thermal insulation properties of selected ceiling materials used in Makurdi Metropolis, American Journal of Engineering Research , vol. 3, Issue 11, pp 245-250 (2014).

[11] **Ajibola K.**, Ventilation of spaces in a warm-humid climate-case study of some housing types, Renewable Energy, vol. 10, issue 1, pp 61–70 (1997).

[12] **Kisanga A. U.**, The challenge faced by the building materials industries in the developing countries in the 1990s: with special reference to Tanzania, Habitat International, vol. 14, issue 4, pp 119-132 (1990).

[13] **Moriarty P.**, The case for traditional housing in tropical Africa. Habitat International, vol. 4, issue 3, pp 285-290 (1979).

[14] **Zhai Z. and Previtali J.M.**, Ancient vernacular architecture: characteristics categorization and energy performance evaluation, Energy and Buildings, vol. 42, issue 3, pp 357-365 (2010).

[15] **Nahar N. M. Sharma P. and Purohit M. M.**, Performance of different passive techniques for cooling of buildings in arid regions. Building and Environment, vol. 38, issue 1, pp 109-116 (2003).

[16] **Nahar N. M. Sharma P. and Purohit M. M.**, Studies on solar passive cooling techniques for arid areas, Energy Conversion and Management, vol. 40, issue 1, pp 89-95 (1999).

[17] **Akbari H.**, Measured energy savings from the application of reflective roofs in two small non-residential buildings, Energy, vol. 28, issue 9, pp 953-967 (2003).

[18] **Bozonnet E. Doya M. and Allard F.**, Cool roofs impact on building thermal response: A French case study, Energy and Buildings, vol. 43, issue 11, pp 3006-3012 (2012).

[19] **Hernández-Pérez I.**, Thermal performance of reflective materials applied to exterior building components—A review, Energy and Buildings, vol. 80 issue 1, pp 81-105 (2014).

[20] **Synnefa A. Santamouris M. and Akbari H.**, Estimating the effect of using cool coatings on energy loads and thermal comfort in residential buildings in various climatic conditions, Energy and Buildings, vol.39, issue 11, pp 1167-1174 (2007).

[21] **Sanjai N. and Chand P.**, Passive cooling techniques in buildings: past and present a review. ARISER 4, pp 37–46 (2008).

[22] **Susanti L. Homma H. and Matsumoto H.**, A naturally ventilated cavity roof as potential benefits for improving thermal environment and cooling load of a factory building. Energy and Buildings, vol. 43, issue 1, pp 211-218 (2011).

[23] **Özdeniz M. B. and Hançer P.**, Suitable roof constructions for warm climates - Gazimagusa case, Energy and Buildings, vol.37, issue 6, pp 643-649 (2005).

[24] **Crawley D. B.**, Energy plus: creating a new-generation building energy simulation program, Energy and Buildings, vol.33, issue 4, pp 319-331(2001).

[25] **Perez R.**, Modeling daylight availability and irradiance components from direct and global irradiance, Solar Energy, vol. 44, issue 5, pp 271-289 (1990).

[26] **Awbi H. B.**, Design considerations for naturally ventilated buildings, Renewable Energy, vol. 5, issue 5-8, pp 1081-1090 (1994).

[27] **Nouidui T. Wetter M. and Zuo W.**, Functional mock-up unit for co-simulation import in energyplus, Journal of Building Performance Simulation, vol. 7, issue 4, pp 192-202 (2014).

[28] **Jiří Zach Jiří Brožovský and Jitka Hroudová**, Research and development of thermal -insulating materials based on natural fibers, Modern Building Materials Structure and Techniques, vol. 6, pp 330-334 (2010).

[29] **Tuomo Ojanen Pinto Seppä. and Esa Nykänen**, Thermal insulation products and applications - Future road maps, Science Direct, vol. 78, pp 309-314 (2015).

[30] **Jun Kono,Yutaka Goto and Holger Wallbaum**, Factors for eco-efficiency improvement of thermal insulation materials, Key Engineering Materials, vol. 678, pp 1-13 (2016).

[31] **Philippa Howden-Chapman**, Effect of insulating existing houses on health inequality: cluster randomised study in the community, Building Materials Journals, vol. 334, pp 7591(2007).

[32] **Francesco Asdrubali Francesco D'Alessandro and Samuele Schiavoni**, A review of unconventional sustainable building insulation materials, Sustainable Materials and Technologies, vol. 4, pp 1–17 (2015).

Online technical articles & information

[1] **Joseph Lstiburek**, BSI-001 The perfect wall, Building Science Cooperation, www.buildingscience.com (2010).

[2] **J.F. Straube, K. Ueno, and C.J. Schumacher**, Measure guideline: Internal insulation of masonry walls, , Building Science Corporation, www.nrel.gov (2012).

[3] **Alan Carson Dunlop & Associates**, Urea formaldehyde foam insulation, www.carsondunlop.com (2014).

[4] **National University of Singapore**, Researchers turn paper waste into ultra light super material that improves oil spill cleaning, heat insulation, Science Daily, www.sciencedaily.com (2016).

[5] **Linshuang Long and Hong Ye**, The roles of thermal insulation and heat storage in the energy performance of the wall materials: a simulation study, Science Reports, www.nature.com (2016).

[6] **Giama E. and Papadopoulos A. M.**, Environmental performance evaluation of thermal insulation materials and its impact on the building, www.fibran.gr (2000).

[7] **Mariana Palumbo , Antonia Navarro and Ana Maria Lacasta**, Characterization of thermal insulation materials developed with crop wastes and natural binders, World Barcelona, www.wsb14barcelona.org (2014).

[8] **Ted Kesik Eng P.**, Cost effective levels of thermal insulation for basements in Canadian housing, 11th Canadian Conference on Building Science and Technology Banff, Alberta, www.nbec.net (2007).

[9] **Delghust M. and A. Janssens A.**, Retrofit cavity-wall insulation: performance analysis from in-situ measurements, www.ikisoleermijnspouw.be.

[10] **Chris Woodford**, Heat insulation, www.explainthatstuff.com (2016).

[11] **Lucintel USA**, Growth opportunities in the global building thermal insulation market, www.lucintel.com (2016).

[12] **Building Envelop Forum**, Insulating solid masonry walls, www.cebq.org.

[13] **Heinrich Wigger, Kerstin Stölken and Britta Schreiber**, Cavity wall insulation in existing buildings, Sustainable Energy Planning, www.archive.northsearegion.eu (2011).

[14] **Joanne Hopper and John R. Littlewood**, Assessing retrofitted external wall insulation using infrared thermography, www.emeraldinsight.com (2012).

[15] **Mark Crawford**, A green alternative to insulation materials, www.asme.org (2013).

[16] **Paul E. Totten P E Sean M. O'Brien and P E Marcin Pazera**, The effects of thermal bridging at interface conditions, www.c.ymcdn.com.

[17] **Lucy Crowmak**, Australian insulation standards are not the most cost-effective, www.smh.com.au (2016).

[18] **Juan Rodriguez**, All about insulation - tips and materials, www.thebalance.com (2016).

[19] **Ministry of Business and Employment New Zealand**, Building code requirements for house insulation, www.building.govt.nz (2008).

[20] **URSA Insulation Belgium**, Insulation for a better tomorrow, www.ursa.com (2012).

[21] **Brian Bannon**, Five most common insulation materials, www.thermaxxjackets.com (2011).

[22] **Susan Lahey**, The best Insulation types for your home, www.motherearthliving.com (2006).

[23] **US Department of Energy**, Where to insulate home, www.energy.gov.

[24] **Home Advisor International France**, How much does it cost to insulate a house? www.homeadvisor.com.

[25] **House Logic USA**, Insulation types and tips, www.houselogic.com.

[26] **House Logic USA**, Smart Homes, Insulation types and tips, www.houselogic.com.

[27] **FAO Corporation Documents**, Thermal insulation materials, technical characteristics and selection criteria, www.fao.org.

[28] **Greenspec UK**, Insulation materials and its thermal properties, www.greenspec.co.uk.

[29] **USA Insulation**, Compare insulation types for homes, www.usainsulation.net.

[30] **Conrad Mackie**, Insulation options for metal or steel buildings, www.buildingsguide.com.

[31] **Department of Environmental Conservation**, University of Massachusetts, Cellulose insulation-A smart choice, www.bct.eco.umass.edu.

[32] **The GreenAge UK**, Cavity wall insulation, www.thegreenage.co.uk.

[33] **US Department of Energy**, Type of insulation, www.energy.gov.

[34] **General Steel Buildings**, Metal building insulations options and prices, www.gensteel.com.

[35] **Green Building Alliance**, Building insulation, www.go-gba.org.

[36] **Con Edison**, Well insulated houses, www.coned.com.

Online technical reports

[1] **Linshuang Long & Hong Ye**, The roles of thermal insulation and heat storage in the energy performance of the wall materials: A simulation study, www.nature.com (2016).

[2] **Jonathan Cline Emily Domingue Emily Fournier Marco Villar**, Sustainable paper insulation for kambashus in informal settlements of Namibia, Interactive Qualifying Project for the Degree of Bachelor of Science, www.web.wpi.edu (2012).

[3] **Norwegian Science and Technology University**, State-of-the-art highly insulating window frames–research and market review, www.windows.lbl.gov (2007).

[4] **Partnership and Advancing Housing Technology USA**, Cost and Benefits of Insulation concrete forms for residential construction, www.pathnet.org (2001).

[5] **Tomáš Vrána Licentiate**, Impact of moisture on long term performance of insulating products based on stone wool, www.diva-portal.org (2007).

[6] **DG Environment by AEA for European Commission**, Green public procurement thermal insulation technical background report, www.ec.europa.eu (2010).

[7] **Report Green Building Insulation: The Environmental Benefits**, A supplement of Building Design and Construction, www.greenguard.org (1998).

[8] **Government of Western Australia Department of Commerce**, Home insulation, www.commerce.wa.gov.au (2015).

[9] **Australian Government**, Your Home, Australian guide for environment friendly sustainable home, www.yourhome.gov.au.

[10] **Beacon Pathway Limited**, Thermal insulation in New Zealand homes: A status report , www.beaconpathway.co.nz (2008).

[11] **Thermal Energy Association of Southern Africa**, The guide to energy efficient thermal insulation in buildings, www.aaamsa.co.za (2010).

[12] **Irish Agreement Board**, Limiting thermal bridging and air infiltration acceptable construction details Introduction, www.housing.gov.ie (2011).

[13] **North American Insulation Manufacturer Association**, Air infiltration & insulation by Manufacturer's Instructions to Achieve Energy Efficiency of Any Building, www.c.ymcdn.com (2009).

[14] **Par Jahansson**, Vacuum insulation panels in buildings, www.publications.lib.chalmers.se (2012).

[15] **Elizabeth Milsom**, Solid wall heat losses and the potential for energy saving, www.bre.co.uk. (2016).

[16] **Bill Lippy**, Technical report, R- values for hybrid insulation values for ceiling above garage, www.fifoil.com (2014).

Inclusive and Sustainable Industrial Development

This project is funded by the Russian Federation

United Nations Industrial Development Organization
Vienna International Centre
P.O. Box 300, 1400 Vienna, Austria
Telephone (+43-1) 26026-3570
Fax: (+43-1) 26026-6842
Email: IUMP@unido.org
www.unido.org/iump

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION