

Global warming is the most immediate threat to global sustainability, driven primarily by **CO₂ emissions**. Achieving optimum **thermal design of buildings** can achieve large cuts in CO₂, with numerous other benefits. But at least half of Europe's existing buildings are uninsulated, while current construction standards in most of Europe are also still not high enough.

This guide shows in depth **Why** and **How** we should design well-insulated and energy-efficient buildings, and it discusses the criteria for choosing **Which** insulation material and design of insulating systems. The guide is extensively illustrated with diagrams and illustrative energy modelling.

Insulation for Sustainability

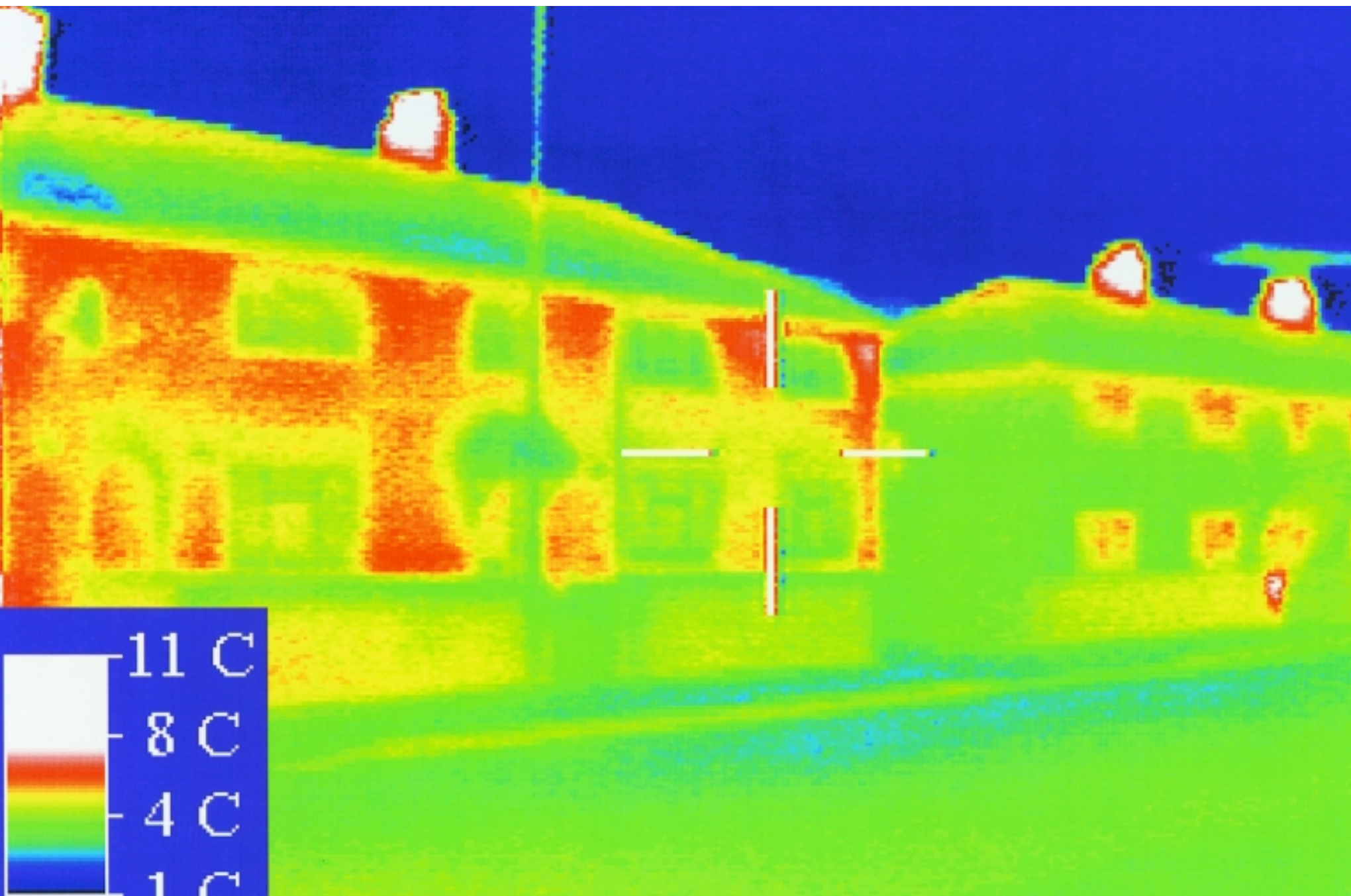
A Guide

A study by
XCO₂ for BING

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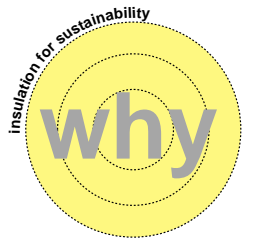


This research study is a result of research and analysis carried out by XCO2 conisbee and sponsored by:

BING

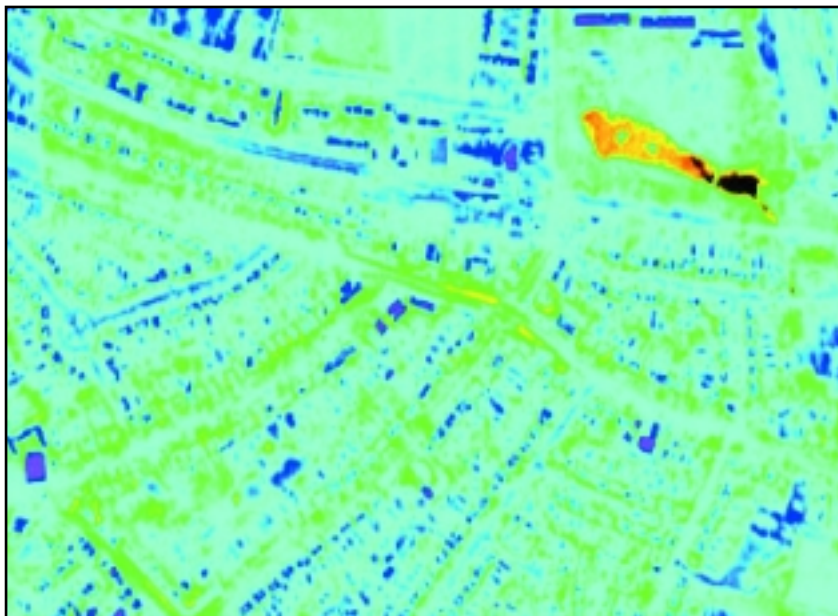
Federation of European Rigid Polyurethane Foam Associations
Fédération des associations européennes de mousse de polyuréthane rigide
Vereinigung der europäischen Polyurethan-Hartschaum-Verbände

Executive Summary - 1



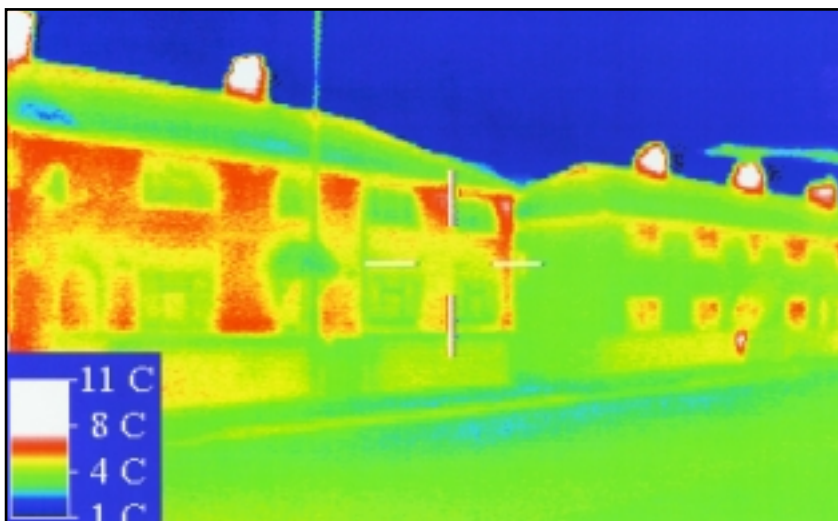
Energy technology is vital to a dynamic society but global warming, driven primarily by CO₂ emissions, now demands change in current patterns of generation and use.

Satellite imaging shows the concentrations of energy use in Europe



Half of our energy is used in buildings, which form an excellent focus for actions to reduce CO₂ emissions, starting with energy efficiency.

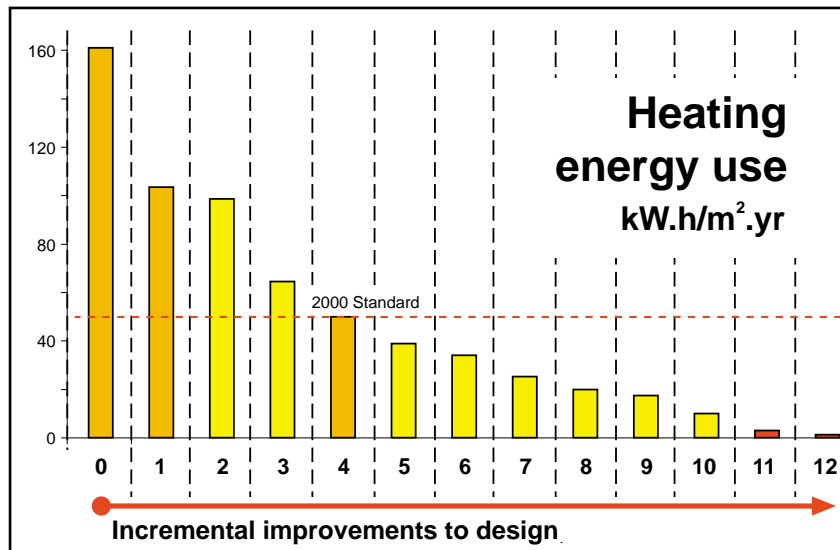
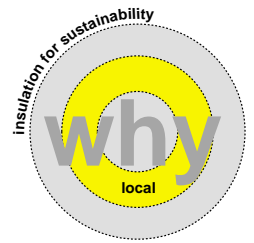
Aerial thermographic image showing heat loss from a city



In Europe, the largest share of energy in buildings is heating. Insulation and thermal design can dramatically reduce heat loss and help stop global warming.

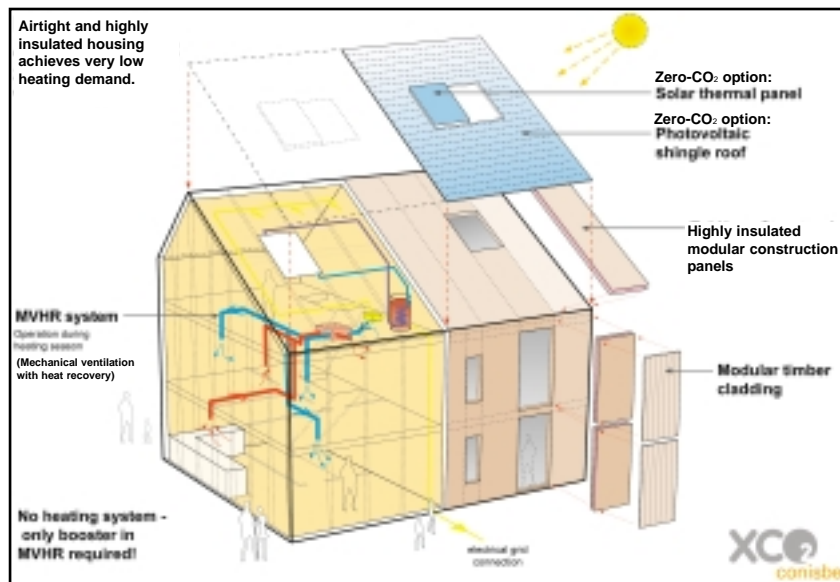
Thermographic image showing heat loss from typical houses

Executive Summary - 2



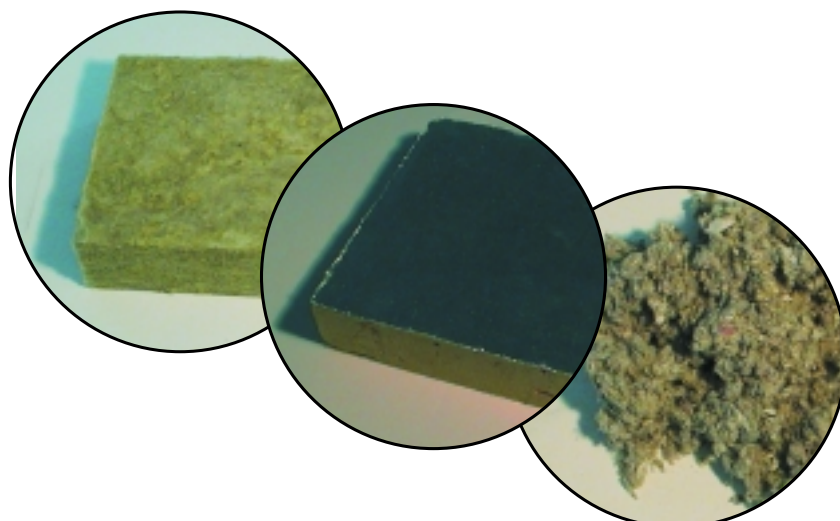
Heating energy demand in existing buildings can be reduced by 30-50% through retrofit, compared to the current average. In new buildings it can be reduced by 90-95%, using widely available technology and design knowledge and at competitive costs.

Graph based on analysis showing incremental reductions in heating demand possible



Incremental improvement to building codes is not fast enough, and the savings through retrofit are limited. Large savings can be achieved through programmes of replacement new-build to the best available standard.

Diagram showing principles of LowHeat housing to reduce heating energy use by 90-95%



The choice of insulating material is relatively insignificant compared to achieving optimum thermal resistance. The most important design issue is to ensure longevity of performance over the lifetime of the material.

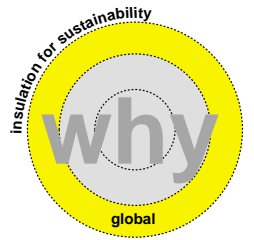
Image shows typical insulation materials

insulation for sustainability

why

The global context

Foreword



You see, we should make use of the forces of nature and should obtain all our power in this way. Sunshine is a form of energy, wind and sea currents are manifestations of this energy. Do we make use of them? Oh no! We burn forests and coal, like tenants burning down our front door for heating. We live like wild settlers and not as though these resources belong to us.

Thomas A. Edison, inventor of the tungsten lightbulb, 1916

Greenhouse gases are accumulating in the Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise. Temperatures are, in fact, rising... Human-induced warming and associated sea-level rises are expected to continue throughout the 21st century.

National Academy of Sciences report on global warming to the Bush Administration, June 2001
<http://www.nationalacademies.org>

Humanity currently faces its greatest challenge ever - to support continued growth in living standards worldwide within diminishing natural resources and saturated pollution sinks. This challenge is now driving change at all levels through government, business and civil society.

More and more business and government leaders are grasping the great opportunity - if we invest in innovative design and new technology, and if we only "cease to be stupid", we can cherish the natural environment alongside social and economic progress.

As we will show later, the biggest environmental problem of all is the atmosphere, where accumulating greenhouse gases are causing climate change and sea level rise. The most recent report of the International Panel on Climate Change (IPCC) confirms there is now very little doubt that anthropogenic (man-made) carbon dioxide is the main cause of climate change.

In response to this challenge, we are now entering an age of great innovation, another Industrial Revolution, which will see a tremendous pace of change. This is much bigger than just technology, requiring a new Renaissance in design, economics and society.

This revolution is driven by a quest to find solutions with overlapping benefits and positively reinforcing outcomes in many different sectors - where $1+1+1 = 5$ - we call them **XCO2** solutions.

One of these solutions is insulation, a key element of the energy efficiency strategies and technologies that we need to rely on to achieve this revolution. I hope that this guide helps to take this message to a wide audience within the construction industry, and to promote understanding and good design. We need to cut fossil fuel energy use by 60-90%, while supporting social and economic development. The means are there, all that we require is the will.

Robert Webb, **XCO2**
London, February 2002

Introduction to this study

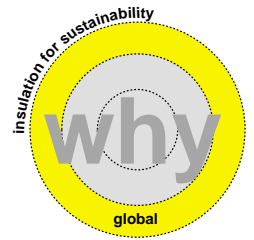
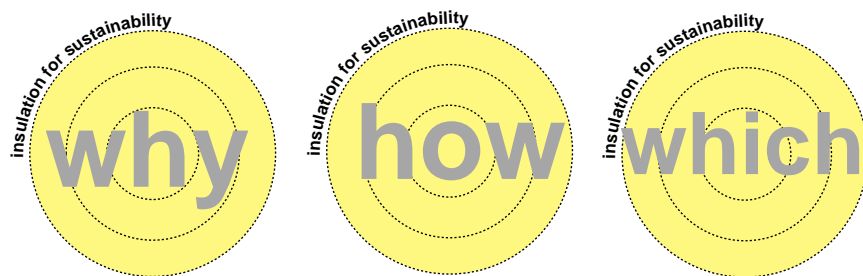


Diagram of the overall structure of the document;
We ask Why?, How? and Which? questions on three scales - Global, Local, and Detailed.

	Global	Local	Detailed
Why? use insulation	To stop global warming and minimise fossil fuel depletion	To reduce energy use and contribute to economy	To maintain good comfort conditions
How? to use insulation	To minimise heat loss in buildings	To achieve high performance in conjunction with energy systems	As required by construction method
Which? insulation to use	To achieve maximum performance and longevity	As appropriate for local exposure conditions	In response to individual choice & project conditions

Guidance for designers and specifiers - the aim is to provide clear guidance and specific examples on each of the points listed above.

Symbols used to indicate the report structure



Some definitions of standards

In this study we refer to a number of standards and types of housing for energy consumption comparisons in the European context. **Existing** refers to the average of a typical house built before 1970. **Refurbished** refers to an Existing property which has been upgraded with a range of energy-efficiency measures. **2000 Standard** is an average standard for new buildings in 2000 (which happens to be the same as the 2002 UK regulations). **LowHeat Standard** and **NoHeat Standard** are XCO2's proposed specifications for low-energy housing, which are defined on pages 39, and 50-51.

Insulation is a product or service which stands up very well on its own - offering clear and straightforward energy efficiency and economic advantages. So why focus on it?

Simply, because it can go much further! Insulation materials and systems offer many overlapping benefits to sustainability in society, the economy and the environment. Yet many existing buildings in Europe remain uninsulated, and most new buildings are still insulated far below optimum levels.

Those are failures to grasp simple opportunities for sustainable development. And they are massive failures. 40-50% of all energy in Europe is used in buildings, and 40-60% of this is heating energy. Every new building with suboptimal insulation may remain that way for 100 years or more.

The purpose of this document is to explore and champion the opportunities for sustainability which are presented by insulation technologies, especially environmental sustainability, and start to explore how the overlapping benefits can be capitalised on by business and society.

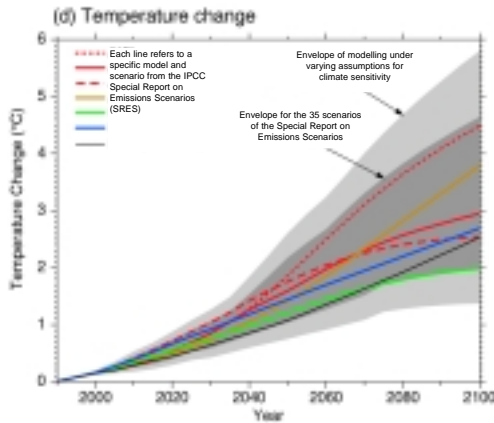
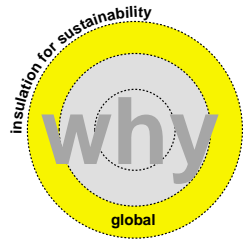
There are a number of factors to be overcome:

- Inertia and inefficiency in financial and management structures leading to drastic undervaluing of energy efficiency and whole-life costs.
- Resistance to change in the construction industry, leading for example to lobbying from some quarters for slower improvement in thermal standards.
- A misleading emphasis in many 'green building' publications, leading to a failure to properly weight whole-life issues.

We cannot tackle all of these problems in one study. We aim however to put the issues in context by providing a simple Why?, How? and Which? of insulation, a primer and reference guide for all those involved in the built environment.

Summary

1 - Global



Predicted temperature change as a result of global warming

Source: Intergovernmental Panel on Climate Change

Isn't sustainable development too difficult to achieve?

As a starting point we need to reduce our environmental impact by very large margins (between 60 and 90%), but we know we can do this through a combination of efficiency and technology. And with no sacrifices to quality of life.

But it's so complicated, how do we know where to start?

Energy use is the most important issue. This is because fossil fuel energy use is leading to global warming and sea level rise, raising the very real possibility of catastrophic climate change which might destroy life as we know it. It's also because our current reserves of fossil fuel will not meet growing world demand in the long-term.

So we should invest in renewable energy, right?

Yes, but at the same time we have to invest in energy efficiency. A unit of energy saved is as good as a unit of renewable energy generated – in fact better, because it's probably cheaper and easier.

So where do we start?

The single largest energy-consuming sector in developed countries is buildings (50% of the total), so let's start here. In European buildings, heating energy accounts for 40-60% of their energy use, so let's reduce this first. In new buildings you can do this through good design, and by specifying high levels of insulation. Existing buildings require retrofit of insulation and better glazing.

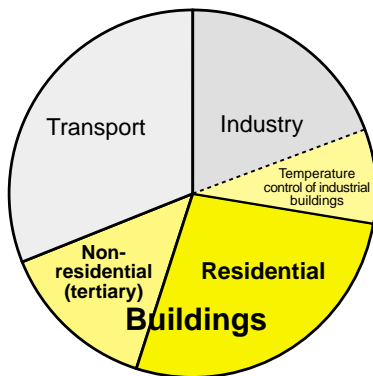
Note: reducing cooling energy use is also very important in Europe, particularly in office buildings and industrial uses - and insulation also plays an important part in this.

So we should prioritize insulation as an important part of reducing energy use in buildings?

Yes – it is a very important part of good thermal design.

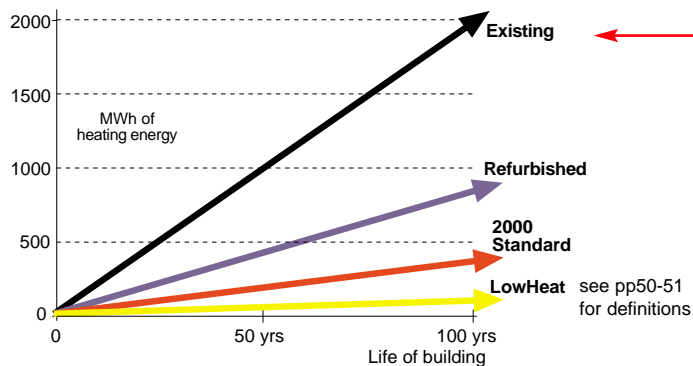
But aren't national heat loss regulations becoming more strict anyway?

Yes, but only on an incremental basis. Every house insulated below the optimum level may stay that way for its entire life – possibly 60-150 years or more of unnecessary carbon dioxide emissions and unnecessary fossil fuel depletion. We need more insulation in all new buildings.



50% of energy use in the EU is in buildings

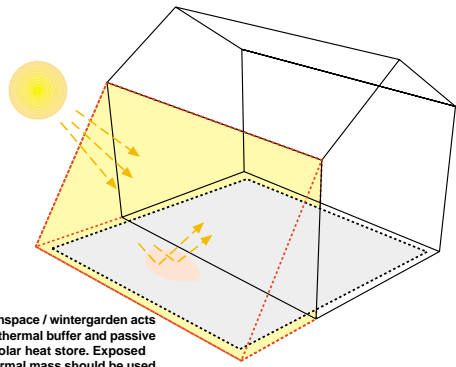
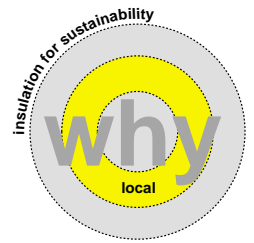
Source: DG TREN



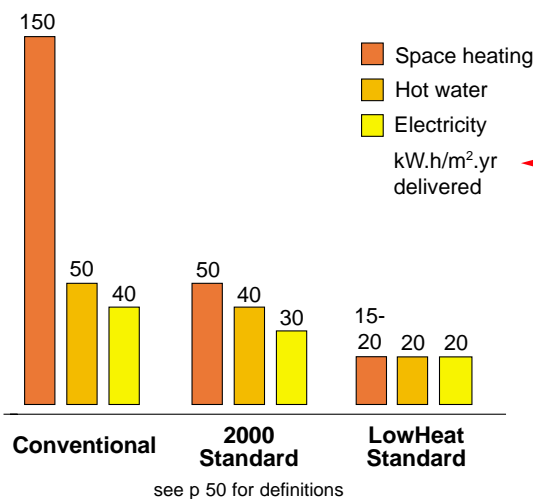
It is possible to reduce housing heating energy use to 7.5% of the average level through good design and high levels of insulation

Summary

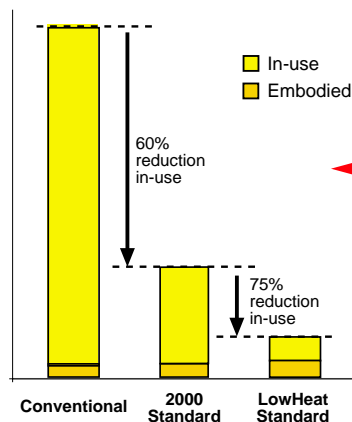
2 - Local/Detailed



Sunspace / wintergarden acts as thermal buffer and passive solar heat store. Exposed thermal mass should be used to store heat.



Energy-in-use must be optimised first. Embodied impact can then be reduced if it does not compromise in-use performance



Energy in-use compared to embodied energy in a typical dwelling
Note: 100-year life assumed
see p 50 for definitions

Is it difficult to reduce heating energy use in new and existing houses?

No - the knowledge and the tools are available. Simple guidelines are presented here to provide some guidance.

How much heating energy do existing houses use?

There is huge variation of course, but most existing properties built before 1990 will use 150-400 kWh/m².yr (we have taken the figure of 200 kWh/m².yr for comparisons).

How far can we reduce heating energy use?

Modelling shows that new buildings to the '2000 Standard' achieve 70% reduction compared to 'existing', while new buildings to our proposed LowHeat Standard can reduce energy use by 92% or more. In refurbishment of existing buildings assessment of the situation is more difficult but the savings possible are in the order of 30-50%.

Should we focus on refurbishment before new-build?

We need both. Modern new buildings can easily be built with extremely low heat demand, whereas retrofitting is complicated and achieves lower savings. It can be shown that a radically accelerated building replacement programme to LowHeat Standard can achieve much larger savings in a 10-50 year timescale than refurbishment.

How do we choose the best insulation materials?

Different materials will achieve the same performance with different thicknesses. What matters most is that the material will last a long time at a high level of performance.

What about the embodied energy of the materials?

Achieving low energy demand in-use is the most important factor. Embodied energy is especially misleading for materials and equipment which are critical to energy efficiency. Ensuring performance over life is much more important.

So how do we assess length of life and performance standards for an insulation material?

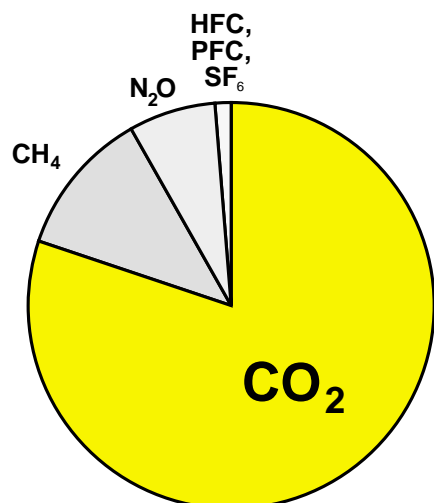
There is a shortage of concrete knowledge although different materials have different types of 'failure risks' associated with them. More research is urgently needed in this area.

The triple bottom line (TBL) focuses corporations not just on the economic value they add, but also on the environmental and social value they add – and destroy.... the term is used to capture the whole set of values, issues and processes that companies must address in order to minimize any harm resulting from their activities and to create economic, social and environmental value.

John Elkington, SustainAbility www.sustainability.com

Buildings Use...
 40% of total energy use, adding to: local air pollution, acid rain, damming of rivers, nuclear waste, risk of global warming.
 40% of raw stone, gravel and sand; comparable share of other processed materials such as steel, adding to: landscape destruction, toxic runoff from mines and tailings, deforestation, air and water pollution from processing.
 25% of virgin wood is used for construction adding to: deforestation, flooding, siltation, biological and cultural diversity losses.
 16% of total water withdrawals, adding to water pollution; competes with agriculture and ecosystems for water.
 Waste amounts produced are comparable in industrial countries to municipal solid waste generation, adding to landfill problems, such as leaching of heavy metals and water pollution.
 Poor air quality in 30% of new and renovated buildings, adding to higher incidence of sickness—lost productivity in tens of billions annually.
 Source: World Watch Institute

Emissions of CO₂ due to fossil fuel burning are virtually certain to be the dominant influence on the trends in atmospheric CO₂ concentrations during the 21st Century IPCC, Third Assessment Report



Greenhouse gas data: From the IPCC Second Report. Note SF₆ is also an anthropogenic greenhouse gas

Sustainability - where do we start?



Our species is enjoying unprecedented success on the planet we call Earth. Though huge inequalities remain in society, the last 150 years have seen unprecedented growth in population, life expectancy and education.

The largest single challenge of global sustainability is probably the reduction of poverty and inequality. This document contains no solutions to that problem, though as a context it should never be forgotten. Our focus here is however an essential requirement for any continuation of human development and civilisation, as we will show: the preservation of stability in the global environment.

To achieve sustainability we must balance human society with environment. The construction industry is a very good place to start - not only occupied with the creation of our physical environment, it is one of the largest sectors of the economy.

There are arguably three main threats to environmental sustainability: global warming (climate change driven by man-made emissions of gases); resource depletion (including depletion of non-renewable resources, and damage to renewable resources and ecosystems); and pollution including ozone depletion (the last is now largely dealt with under the Montreal Protocol).

The most immediate of these threats is global warming, which threatens catastrophic climate change and sea level rises whose impact is likely to be greater than all of humanity's wars combined (see following section).

Global warming is driven primarily by carbon dioxide emissions from fossil fuel energy use. Climate scientists agree that we need to cut carbon dioxide emissions by 60-90% to stabilise the climate, and we need to start now.

The extraction and use of fossil fuels is the primary source of man-made carbon dioxide, also causes the majority of eco-toxic pollution [Ref: 1], and is the prime resource depletion issue as our economies are currently dependent on fossil fuels. Action to reduce fossil fuel use not only helps prevent climate change, but also reduces resource depletion and pollution. Reducing CO₂ emissions is therefore by far the most significant issue in buildings.

Global warming - a summary



What is the greenhouse effect?

The International Panel on Climate Change (IPCC) has been charged with overseeing the development of climate science and it's latest report, the Third Assessment report published in July 2001 [Ref: 2], states that there is very little doubt that man's influence on global warming is real.

The introduction to the Summary for Policy-Makers explains the basic concept and the reasons for any controversy:

The Greenhouse concept... is simply that the composition of the gases that make up the atmosphere enveloping the earth is crucial to the existence of life, by acting as an insulator. This is because a precise gaseous composition allows heat which is radiated from the sun to be trapped in by the earth. Furthermore it allows the specific temperature range for life to flourish, as it allows the right amount of heat loss as well as heat retention to keep the balance of life stable.

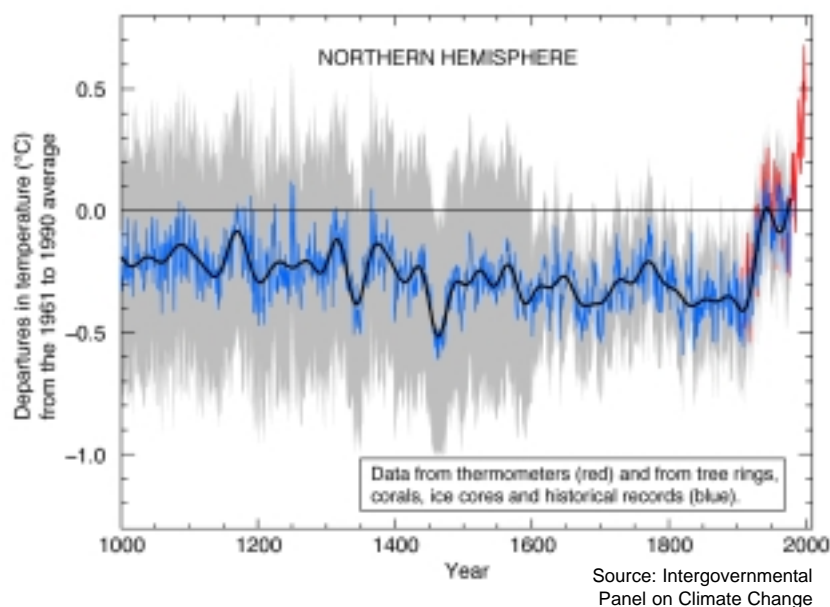
Changes in climate occur as a result of both internal variability in the climate system, natural change, and also external influence - unnatural or anthropogenic [man-made] change. The contentiousness behind 'Climate Change' has revolved mostly on the whether this 'external' anthropogenic influence can be attributed to the absolute changes observed.

Summary of the historical evidence

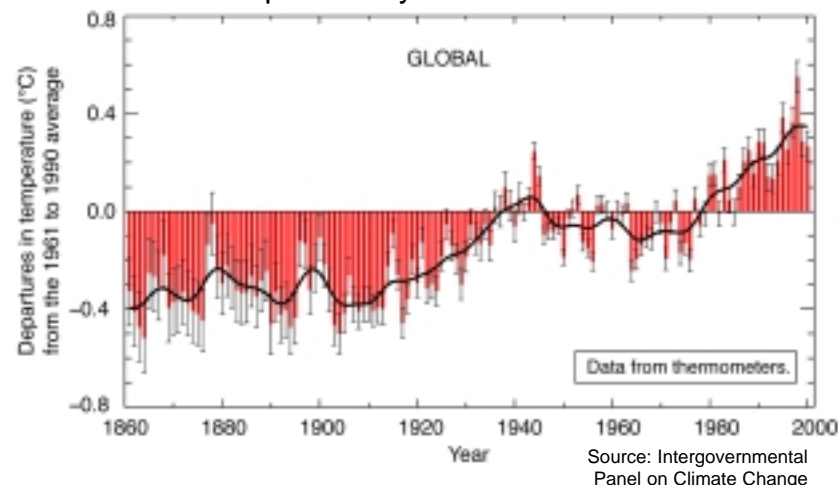
Here we quote some of the key points arising from the IPCC Third Assessment Report:

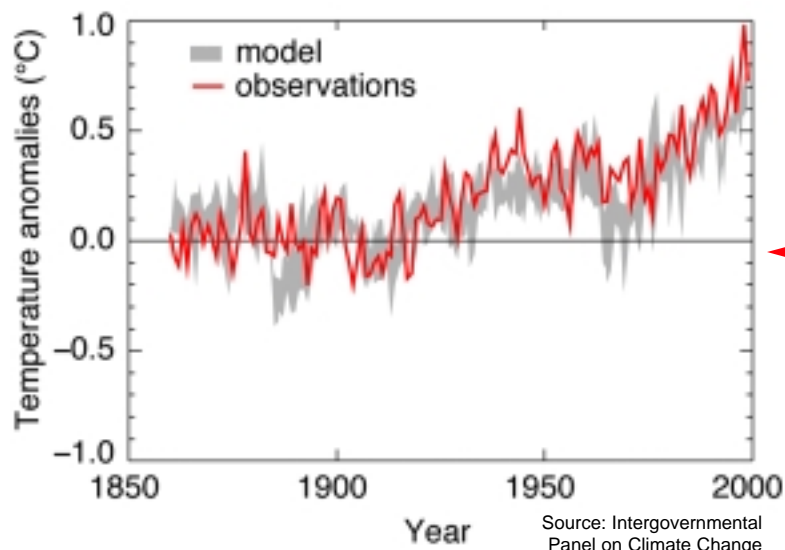
- Over the 20th Century global average surface temperature has increased by $0.6^{\circ}\text{C} \pm 0.2^{\circ}\text{C}$ with the period 1972-2000 being one of the times that most warming occurred.
- Globally, it is very likely that the 1990s was the warmest decade and 1998 the warmest year in the instrumental (meteorological) record, since 1861.
- The atmospheric concentration of carbon dioxide (CO_2) has increased by 31% since 1750. The present CO_2 concentration has not been exceeded during the past 420,000 years and likely not during the past 20,000,000 years. The current rate of increase is unprecedented during at least the past 20,000 years.
- About 3/4 of CO_2 emissions to the atmosphere in the past 20 years has been due to fossil fuel burning – with the rest being predominantly due to deforestation.

Variation of the Earth's Surface temperature Over the past 1000 years:



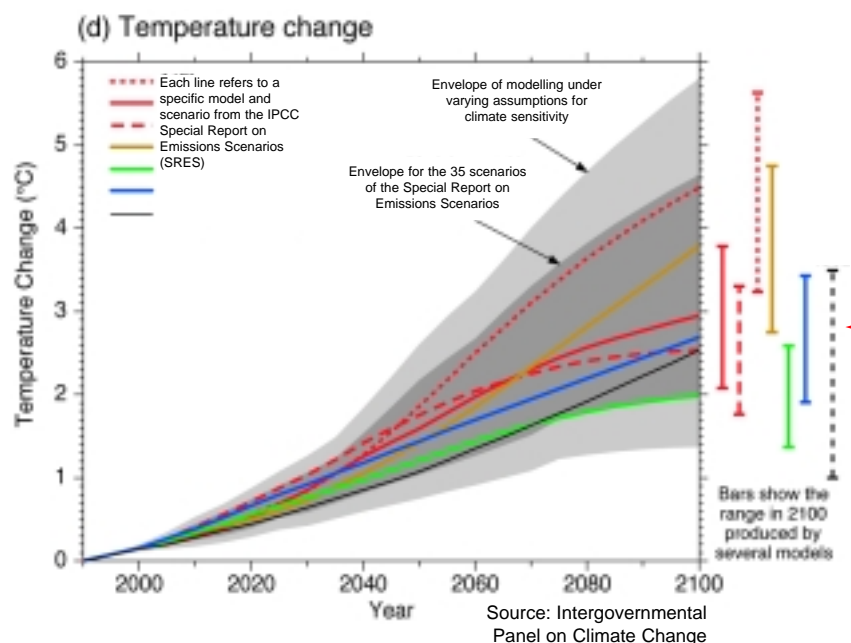
Over the past 140 years:





Status and future implications of the climate change models - from the IPCC 3rd Report

- Recent models are producing increasingly accurate simulations taking into account both natural changes and anthropogenic [man-made] influences. Simulations of both external and internal influences produce results which are sufficient and convincing in explaining the observed changes.

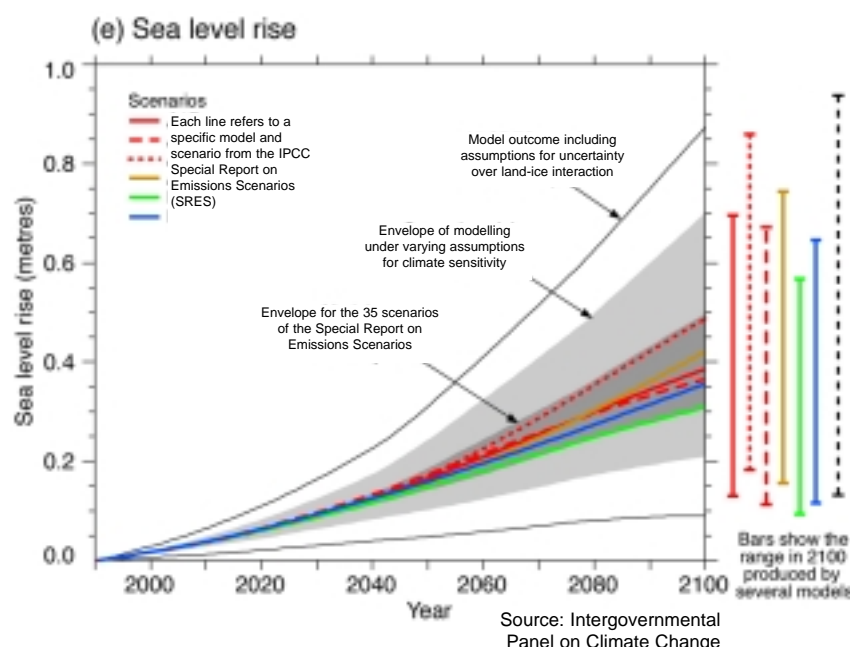


- Most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations.

- Emissions of CO₂ due to fossil fuel burning are virtually certain to be the dominant influence on the trends in atmospheric CO₂ concentration during the 21st Century.

- The globally averaged surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990 to 2100. These results are for the full range of 35 climate modelling scenarios, based on a number of climate models.

- The projected rate of warming is much larger than the observed changes during the 20th Century and is very likely to be without precedent during at least the last 10,000 years.



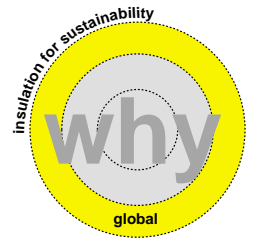
- Global warming is likely to lead to greater extremes of drying and heavy rainfall and increase risk of droughts and floods.

- Northern hemisphere snow cover and sea-ice extent are projected to decrease further... Glaciers and ice caps are projected to continue their retreat.

- Global mean sea level is projected to rise by 0.09 to 0.88 metres between 1990 and 2100.

- Surface temperatures will increase, ice caps will retreat and sea levels rise for hundreds of years, even if greenhouse gases are stabilised permanently to current levels.

The international response to global warming



Carbon Trading Markets

An international carbon trading scheme will be set up now that the Kyoto Protocol has been signed, probably based in London. In addition national schemes are being created in a number of countries. For example, the UK Emissions Trading Scheme is expected to be fully operational by April 2002.

Companies will be eligible to join the scheme if they agree to a target on greenhouse gas emissions reductions. If they do better than the target, they will create allowances that can be sold, whereas if they fail to meet their target they will have to buy allowances. For companies joining voluntarily with the financial incentive, targets will be framed in terms of absolute emission reductions (caps). from The Carbon Trust and the Emissions Trading Scheme, a leaflet produced by the UK Government

Draft Directive on the Energy Performance of Buildings

Published by the European Commission in May 2001, this calls for:

- Establishment of a common European methodology for calculating the integrated energy performance of buildings.
- Application of minimum standards across Europe, based on the methodology.
- Certification schemes requiring new and existing buildings to carry certificates with details of energy performance.
- Inspection of medium-sized and older boiler and heating/cooling installations.

The Certification Scheme is already coming into use in some countries. For example in the UK's trial Seller's Pack scheme, energy data about properties must be included. This means that potential purchasers of property are given the opportunity to judge value on the basis of energy running costs as well as other issues.

There are now many factors driving change to fight global warming, from public opinion and consumer pressure to changing global and local legislation. This combination of pressures is increasing the speed of change - and the most successful innovations provide benefits by motivating and educating people at the same time as realising the economic benefits of energy efficiency and carbon trading.

Global Scale - Kyoto

The Kyoto Treaty, signed at Bonn in July 2001 by 186 nations, is an unprecedented global agreement setting legally binding targets for carbon dioxide emissions for the 38 industrialised countries which are signatories (the only significant country which did not sign is the United States). The agreed target is a 5.2% reduction on 1990 emissions levels by 2010. This alone will have little impact on global warming; the treaty's significance is that it sets the framework for further reductions in future.

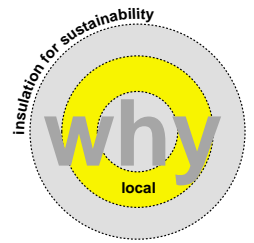
The agreement also includes the Clean Development Mechanism, a fund for green technology in developing countries; carbon credits gained through offset activities such as planting forests; and an international market in carbon credits will be established for companies which invest in clean technologies in other states.

Local Scale - European changes in building regulation

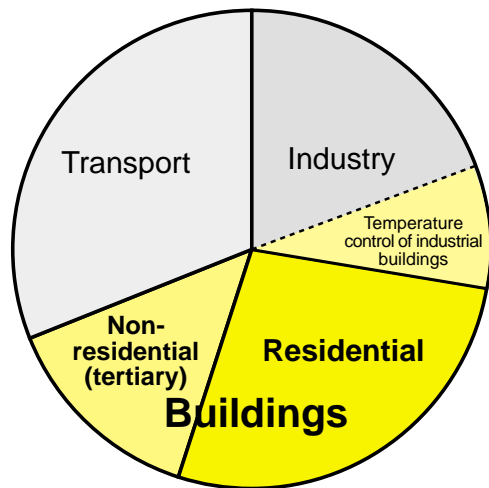
There is a general move in the EU towards upgrading thermal insulation and energy regulations for buildings in all European states, though as we argue later, this is not fast enough.

In addition, a number of countries are developing approaches to the assessment of building materials, and there are currently strong moves towards a harmonised European approach for environmental labelling of construction products - otherwise known as the Environmental Product Declaration, based on an audited Life Cycle Assessment of the product. This will act as a positive incentive for companies to compete on environmental issues as they currently do on quality, cost and other issues. However to be truly useful and meaningful these assessments should be carried out for the whole building over its life, rather than for an individual material.

Start with efficient buildings



Buildings are responsible for 50% of EU energy use (including industrial buildings)



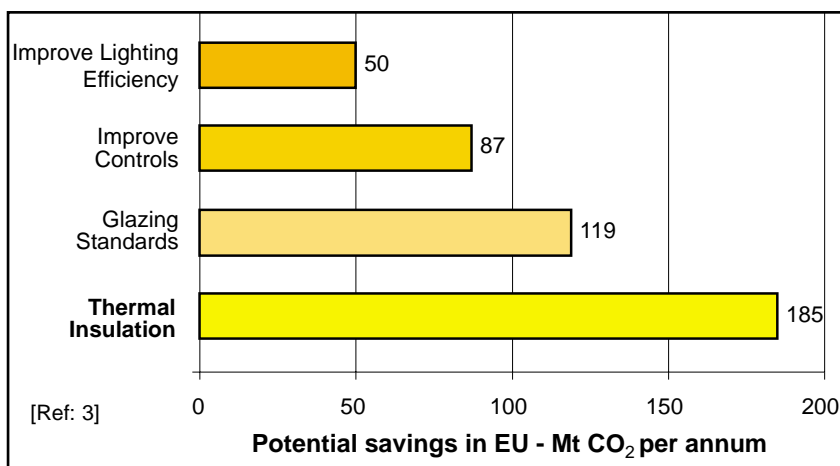
Source: DG TREN

Energy efficiency and renewable energy measures in buildings - what we refer to as XCO2 strategies - have huge potential to improve quality of life and increase productivity through better working conditions, as well as reducing running costs, and maximising lifetime return on investment.

Massive growth in renewable energy is now occurring which will reduce our dependence on fossil fuels. But the first step in reducing carbon emissions is through energy efficiency. Efficiency measures tend to be cheaper and easier to realise than renewables, and offer financial savings and other benefits.

Meanwhile extensive literature and examples have shown that efficiency improvements of at least factor four (75% reduction) are available in all the principle sectors which emit CO₂: buildings, transport and industry [Ref: 4] But buildings are the largest sector, responsible for 40-50% of the EU's CO₂ emissions, and therefore presents a massive potential for savings.

Insulation shows the greatest potential savings of CO₂ compared to other building efficiency measures



The majority of building energy use in Europe is in heating.

Up to 60% of total delivered energy use in Europe's buildings is in space heating.

Insulation is a central plank of building energy efficiency strategies.

Insulation measures to new and existing buildings offer potentially the single most effective building efficiency strategy in Europe. In existing buildings alone, a study published by EuroACE [Ref: 3] found that a European programme of building energy efficiency could bring reductions of between 430 and 452 million tonnes of CO₂ per year by 2010, a reduction of 12.5% of current EU emissions - based on conservative assumptions. The largest share of this figure is in improvements to insulation, giving savings of 185 Mt CO₂ per annum (20% reduction in heating energy use; amounting to 5% of total EU emissions).

Note: Reduce cooling energy also

For overall building energy efficiency and especially in office buildings, reducing cooling energy can also achieve massive impact. In most of northern Europe, passive design can eliminate or reduce the need for cooling; where this is not possible cooling and air conditioning systems should be designed to optimise efficiency.

And this is not including the improvements possible in new buildings, which have the potential of even greater impact, as we shall show.

What about climate differences?



The European climate varies quite widely from the north to the south, though there is also much common ground between countries in central Europe. Variations in thermal insulation standards are to be expected - however the actual variation is much greater than climatic differences, as a result of cultural (and to some extent economic) forces.

For example in Germany, with an average degree-day heating requirement of 3845, the annual insulation consumption is 0.35 m³ per capita [Ref: 3]. However in the UK, with a similar degree-day requirement of 3210, the annual insulation consumption is only 0.15 m³ of insulation per year. This difference is not accounted for by rates of construction, though insulation density may be a factor.

Present

The comparison of standards (see graph) confirms that even when climatic differences are taken into account, thermal insulation standards vary considerably and there is much room for improvement. Standards are in fact lowest in southern countries, where typical heat loss for a house may exceed that in the north of Europe, despite a warmer climate.

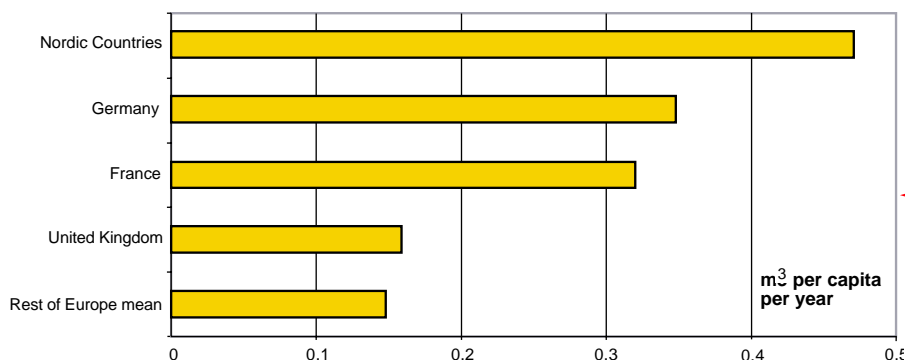
Future

At present many member states are improving their regulations separately; in 1999 Germany planned to reduce heat loss by 30% and Finland by a further 10%. An integrated calculation approach has already been applied in Germany, France, UK, Ireland and Netherlands.

It seems likely that in due course this will lead to a standardised European calculation with variation for climatic conditions.

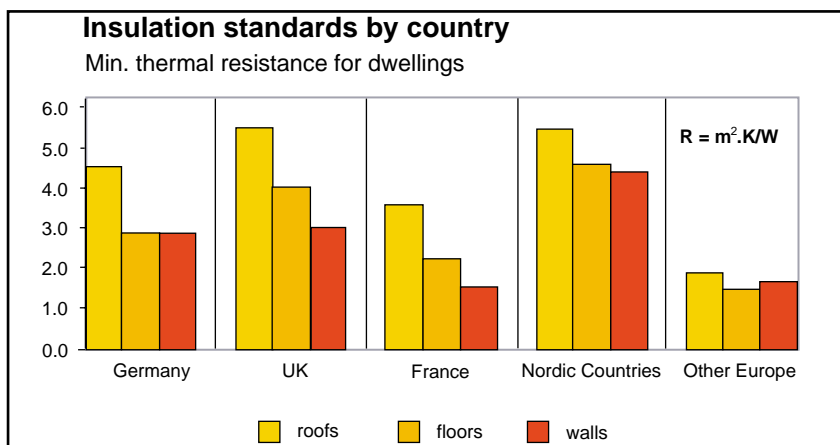
A European initiative intended to improve the energy performance of buildings by promoting improved Member State thermal insulation regulations to a level already attained by some Member States could result in substantial energy savings for the EU as a whole.

Draft Directive of the Commission on the Energy Performance of Buildings, May 2001

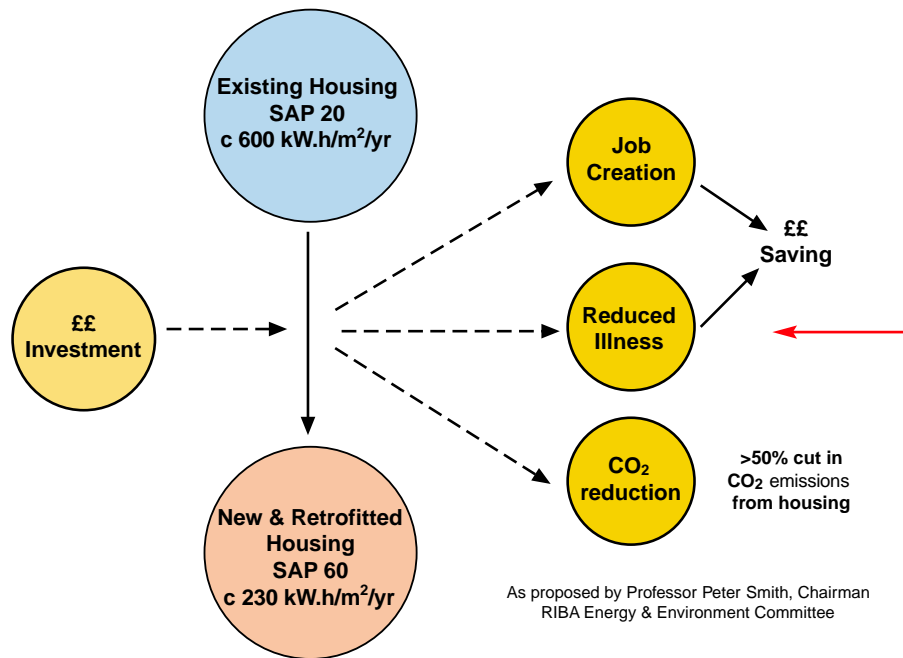


Annual insulation consumption per capita, m³ - selected European countries. [Ref: 3]

Varying thermal insulation standards across Europe. [Ref: 3]



A National Programme to improve the standard of housing and reduce carbon dioxide emissions



Professor Peter Smith of UK's Sheffield Hallam University has shown how the UK target of 20% cut in CO₂ emissions on 1990 levels by 2010 is achievable entirely by raising the energy standards required of new homes and by instigating a programme of energy efficiency measures in existing housing stock. This would create a major new industry in energy efficiency and reduce energy use in housing by up to 50%.

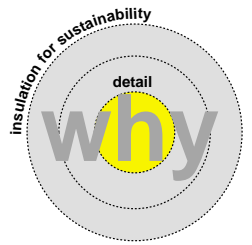
8 million households cannot afford basic standards of warmth, even though energy prices in the UK are relatively low... Raising thermal efficiency of their homes would meet an acute social need whilst generating jobs and cutting down on the £1bn annual health bill attributable to poor housing.

We need to refurbish poor-quality homes to an energy efficiency standard of SAP60 (UK government Standard Assessment Procedure). To put this in perspective, new homes have to achieve around SAP75 whilst most of the sub-standard homes will be SAP10-20. Professor Peter Smith

In 1996, one out of every twelve EU citizens (about 28 million people) lived in a household that was behind schedule with (re)payments of utility bills and/or housing costs.

From: European social statistics [Ref: 5]

Comfort and Fuel poverty



Comfort

Clearly, insulation is one of the key strategies for achieving thermal comfort efficiently in buildings.

Modern lifestyles require high levels of thermal comfort in buildings - typically 21°C for the main living spaces and 18°C for other spaces.

Demand for thermal comfort levels also become higher as more people work from home and spend irregular hours at home. The travel savings achieved by communications advances are then likely to be partially offset by increases in domestic heating energy... unless thermal insulation standards are improved.

Fuel Poverty

A prime driver for better insulation practice is the eradication of fuel poverty. Though not often recognised as a distinct issue outside the UK, fuel poverty certainly exists in many European countries.

Fuel poverty is found in poor areas and in substandard social housing, much of which built since 1945 was system-built with air-leaky construction and very little if any insulation. This is particularly applicable in eastern Europe.

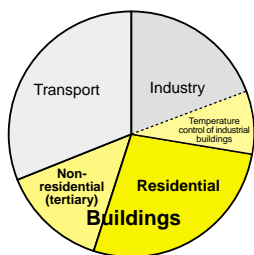
Retrofit of existing buildings in fuel-poor areas offers great advantages to both society and the environment.

"Fuel poverty arises when people have insufficient income to heat their homes to the standard required for health & comfort. Affordable warmth is defined by the World Health Organisation as having a temperature of 21°C in the living room & 18°C throughout the rest of the home." (Briefing from Age Concern, UK charity)

The common definition of a fuel poor household is one that needs to spend in excess of 10% of household income in order to maintain a satisfactory heating regime. "Evidence shows that it is the poorer households that have the least insulated homes." [Ref: 6]. The number of fuel poor in the UK in 1999 was around 4.5 million households.

insulation for sustainability

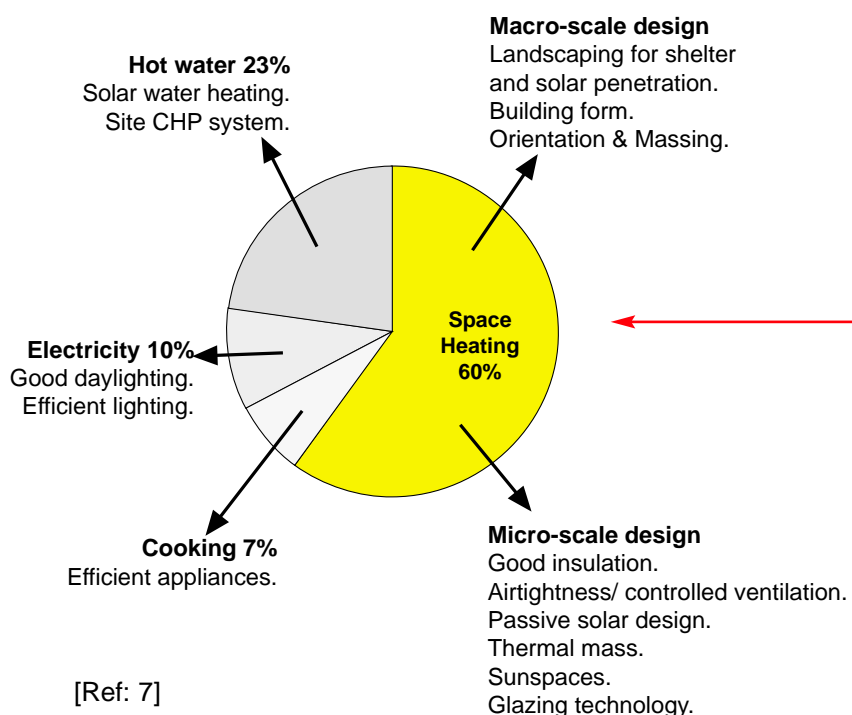
how



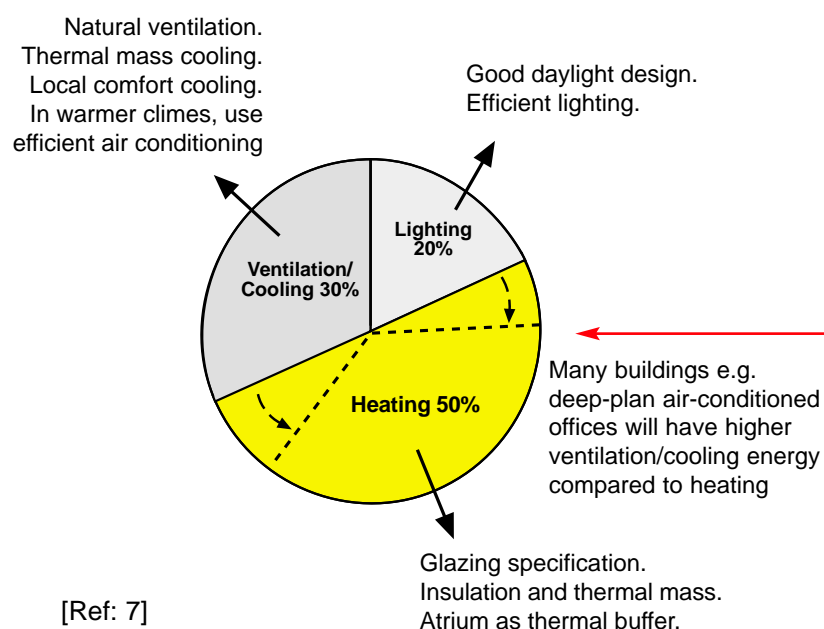
Domestic buildings are responsible for 60% of EU building energy use, about 40-60% of which is heating energy

Source: DG TREN

Key efficiency design strategies for housing



Key design strategies for commercial buildings



How do we reduce heating energy?

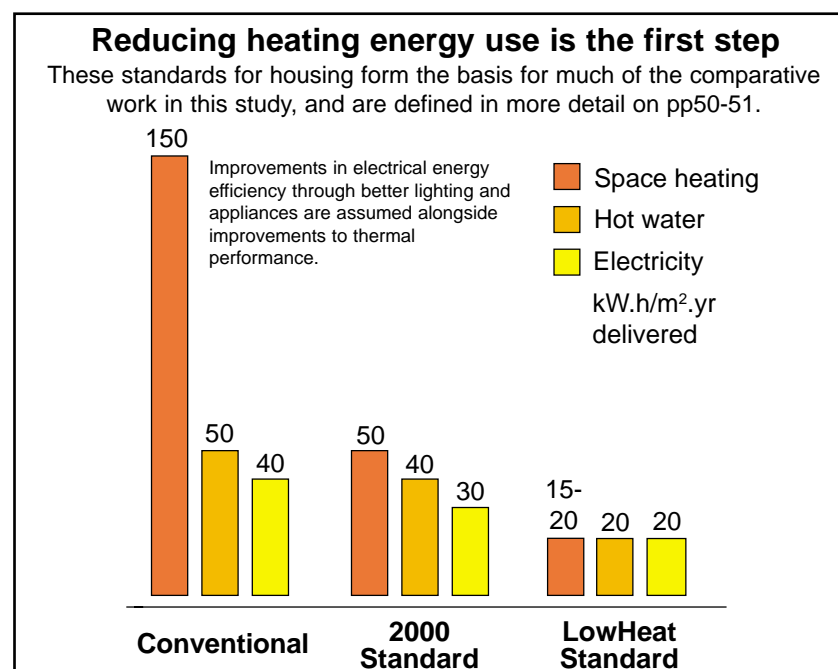
In this section we provide a simple guide explaining some of the principles of low-energy design, and showing how good thermal design and use of insulation can cut heating energy use to very low levels - in many cases to zero.

The charts on this page show that domestic buildings - housing - takes the largest share of building energy use, and offers the greatest opportunities for heating energy savings, hence our focus on it in this section.

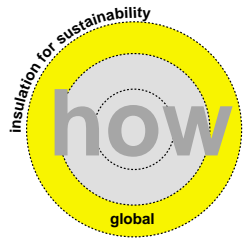
While thermal design standards are increasing gradually, we believe that a faster improvement could make major contributions to greenhouse gas reduction targets. Our proposed **LowHeat** standard offers a benchmark for such 'optimum' design.

It is commonly assumed that very low-energy and zero-heating houses are very difficult to achieve. This is not the case, especially in new-build; a simple combination of clear design steps can reduce energy use without large increases in capital cost, as we show in this section both analytically and graphically as Guidelines for the designer.

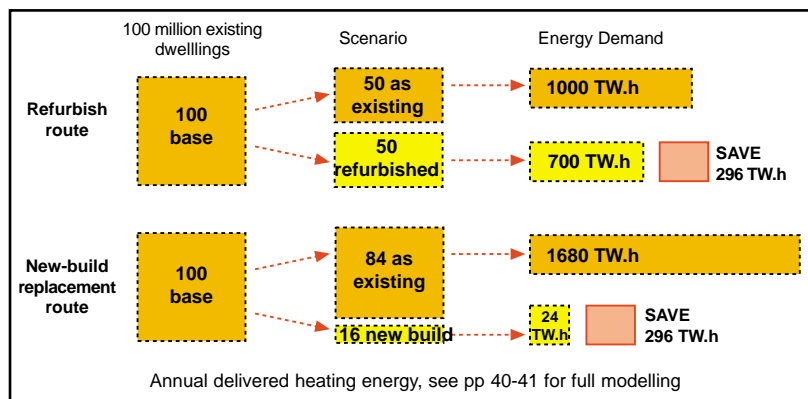
There is a complex dynamic between refurbishment and new-build strategies, where analysis shows that new-build replacement programmes perhaps have the best potential to reduce carbon dioxide emissions from domestic energy use.



Which building types?



A small programme of new-build LowHeat houses will achieve similar annual savings to a much larger programme of retrofit.



Over 50% of total building stock and 85% of that pre-1965 is without any wall insulation.. approximately 31% of walls are solid masonry walls of brick, block, or stone...

In total 58% of the domestic building stock is uninsulated... Where appropriate, 28% saving is expected through cavity wall insulation retrofit, and 41% saving is expected through solid wall insulation.

From the English House Condition Survey 1991 – Energy Report [Ref: 8], and interpretation in [Ref: 3]

Note: industrial process applications

This is a very important area, though only c.25% of EU energy use is in industrial uses. Large energy savings are achievable by increasing pipe insulation standards in industrial process applications to optimise them for insulation and life-time cost criteria.

Domestic buildings

Domestic buildings make up 60% of total building energy use, and about 60% of domestic energy use is in heating.

New buildings can easily reduce this heating energy use to very low levels through good design and sufficient insulation. This means that new-build replacement to LowHeat standards can potentially achieve greater CO₂ emissions abatement than refurbishment (see pp 40-41 for full discussion).

Existing buildings

It is very difficult to assess the total scope for retrofit in Europe, but it is thought that up to 50% of buildings in Europe are uninsulated. For example Germany, Ireland, Italy, Netherlands, Spain and UK together hold 100 million dwellings of which about 50 million are uninsulated.

Retrofitting insulation and glazing can reduce heating energy use by 30-40% in these buildings. This is most cost-effective when it takes place at the same time as major refurbishment.

Higher savings can be achieved where supply-side improvements like district heating and combined heat and power (CHP) are options. For example in Denmark, average space heating reductions of 53% were achieved in the period 1972-2000, through both demand and supply-side measures on both new and old buildings including better insulation standards and retrofit insulation. [Ref: 10]

However, many existing buildings do present restrictions to retrofit insulation due to practical and aesthetic constraints, and supply-side options are more applicable to new-build. A more realistic estimate of the potential reduction is perhaps 30%, achievable in half the stock.

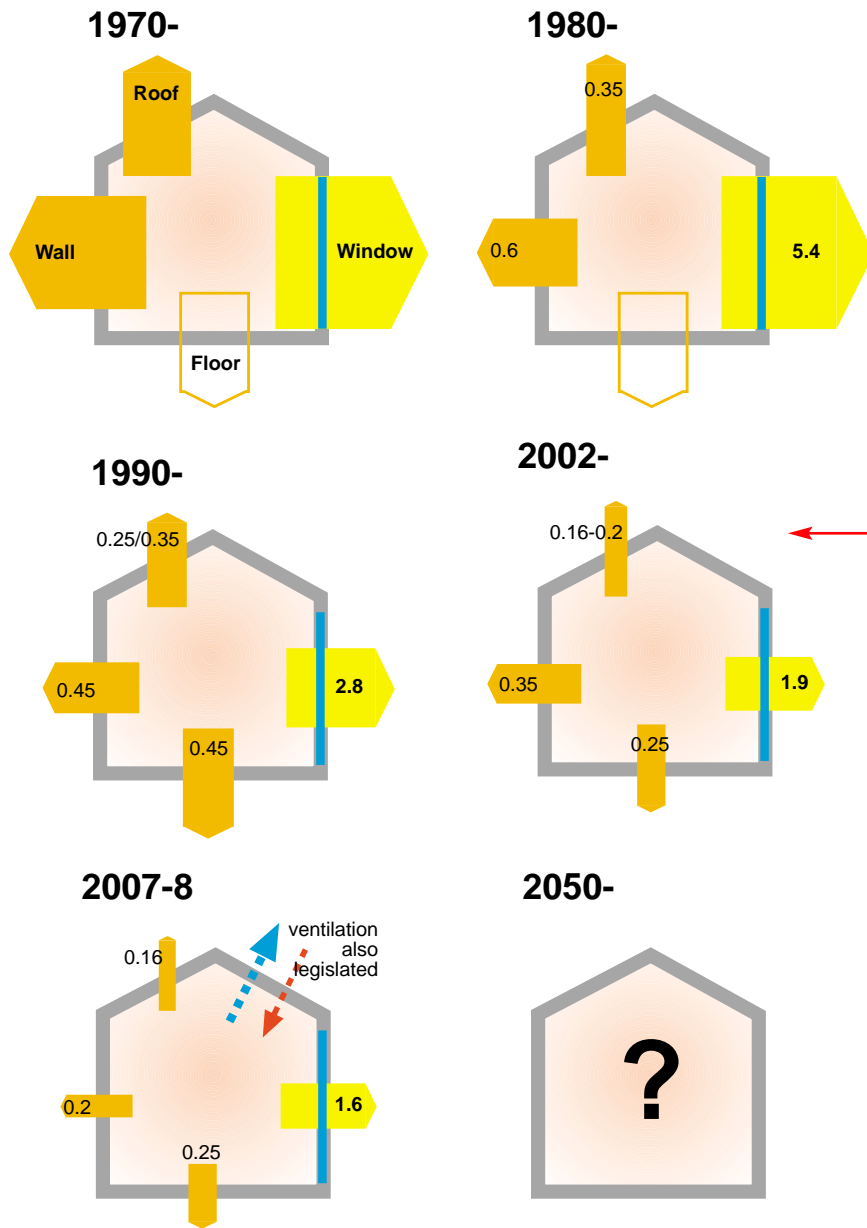
Commercial buildings

Heating savings arising from insulation are less significant in commercial and office buildings due to greater ventilation and glazing heat loss and other design constraints. However design for efficiency overall offers great scope for energy reductions in commercial buildings, and many of the principles are similar to those in housing discussed here.

What energy standards should we adopt?



Building insulation standards are improving over time, but not fast enough!



Example based on England and Wales Building Regulations

Window heat loss per square metre shown at 1/5 scale of opaque elements

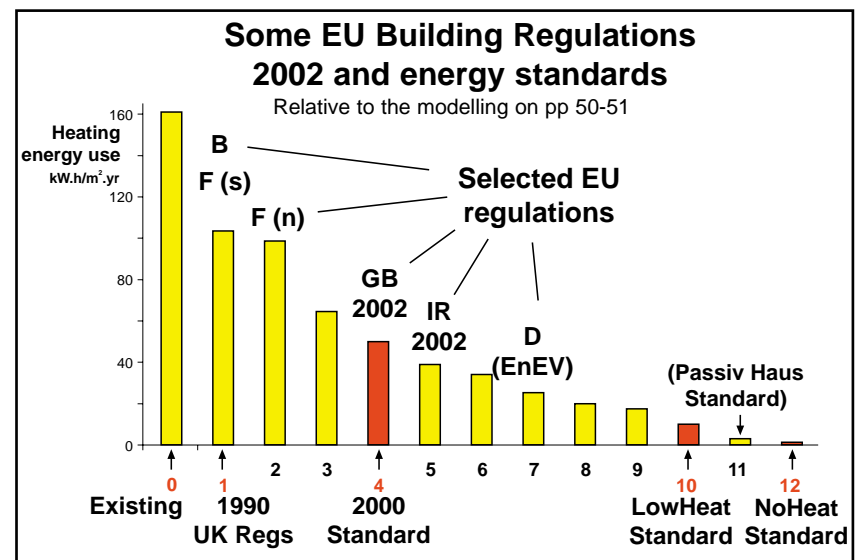
Elemental U-values are only one part of low-energy design.

Assessment of designs should be made using calculation and modelling software on the basis of the whole building, and European regulations will increasingly operate in this way. This enables designers to achieve the desired energy use standards through a range of design and technical strategies.

Building insulation standards have increased generally over the 20th Century as consciousness of energy conservation has increased, and will continue improving over time - as shown in the diagram.

Since this incremental improvement is so far below the potential energy and carbon savings possible, we argue for an immediate jump to better standards in new construction wherever possible - in particular our proposed LowHeat standard.

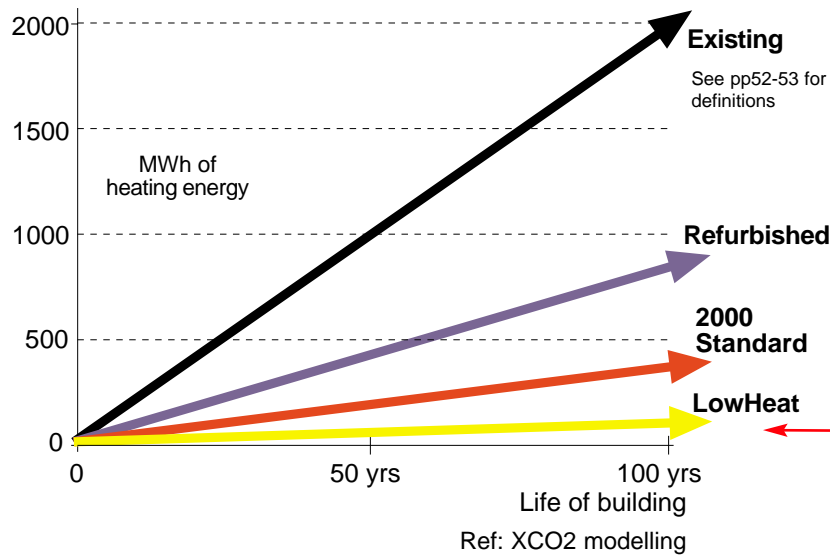
What is the cost impact of this proposal? On a Lifetime Cost basis, it is well documented that even more onerous standards than **LowHeat** will achieve the same cost over 30 years compared to standard housing (see pp40-41). Moreover experience suggests that the LowHeat Standard can be constructed at or very close to standard capital budgets for housing, and with good design and careful specification can even be achieved within social housing budgets (implying a lifetime cost far lower than conventional)



How to assess investment in thermal standards

'Economic' levels of insulation are usually judged on simple payback, which gives a poor indication of the advantages. If considered instead as Return on Investment, it can be seen that a relatively small capital investment in better insulation levels can produce a large return on investment by reducing running costs. As important is that the decision must consider the whole building system: for example main heating systems can be omitted as design improves, a saving which will pay for improvements to insulation and ventilation systems.

A LowHeat house uses 7.5% of the heating energy of an existing house, saving large amounts of energy over its life

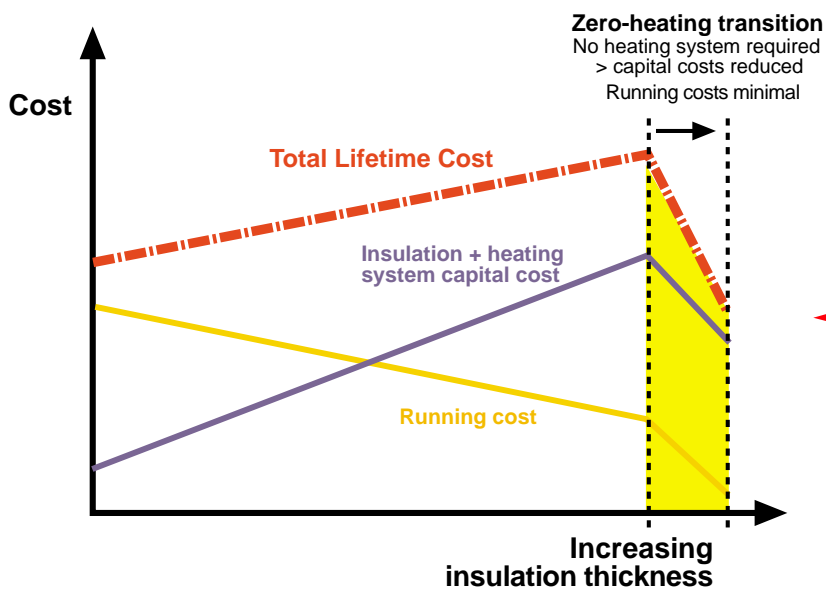


Why focus on LowHeat Standards?

While many European nations are approaching or have reached the 2000 Standard, on average across Europe new buildings are performing much worse. Building regulations are improving incrementally but buildings last from 60 to 150 years or longer, and insulation is not usually replaced or upgraded in that time. Every building built to suboptimal standards may continue to emit carbon for 100 years or more.

However it is possible to build very low-energy houses with very low or zero heating demand. There are exemplary schemes around the world, most notably the German, Austrian and Swiss scheme known as Passiv Haus. Many thousands of houses have been built as part of this scheme, showing that low heating levels can be achieved with no limit to living space or design creativity, and at very little or no additional lifetime cost thanks to the omission of a main heating system (and our proposed **LowHeat** standard is even less onerous than the Passiv Haus in order to be achievable within lower budgets).

Increasing insulation gradually reduces running costs but increases capital costs; but once the LowHeat standard is achieved, lifetime costs jump down as the radiator system is no longer required



The capitalized total costs (investments in the building including planning and building services plus running costs over a period of 30 years) are not higher than for an average new building.

from CEPHEUS, EU-funded Passiv Haus demonstration project.
www.cephesus.de

The main limit to the implementation of LowHeat housing on a wider scale is a lack of political will - though knowledge and understanding barriers also need to be overcome. The savings achievable relative to the average demand level are very large (92.5%). If the construction industry works together to encourage and speed the adoption of these standards, we can cut carbon dioxide emissions, minimise running costs and provide high levels of thermal comfort.

The LowHeat specification includes:

Envelope

Well insulated: $U = 0.2 \text{ W/m}^2\text{K}$
Airtight ($<0.6 \text{ ac/h @ } 50 \text{ Pa}$)
Low thermal bridging

Glazing

Orientation and area optimized; c 25-30% of floor area.
Double glazing with low-e coating and insulated shutters or blinds, average $U = 1.3 \text{ W/m}^2\text{K}$

Ventilation

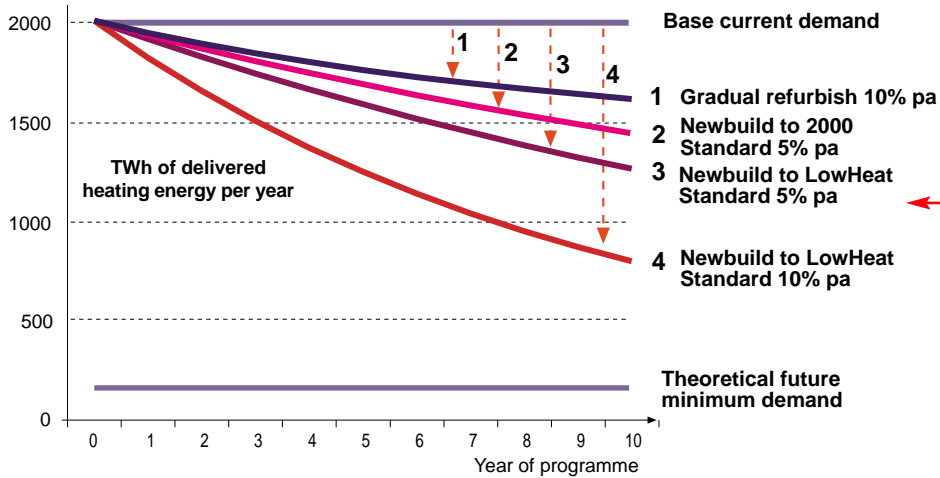
Mechanical winter ventilation with heat recovery 70% efficient. Supplementary heating via booster coil within air supply.

How to reduce heating energy use in Europe's housing stock

New buildings vs refurbishment?



1 annual heating energy use for different scenarios



On previous pages we raised the common question: to reduce domestic energy use, is it better to focus on new-build, or on refurbishment?

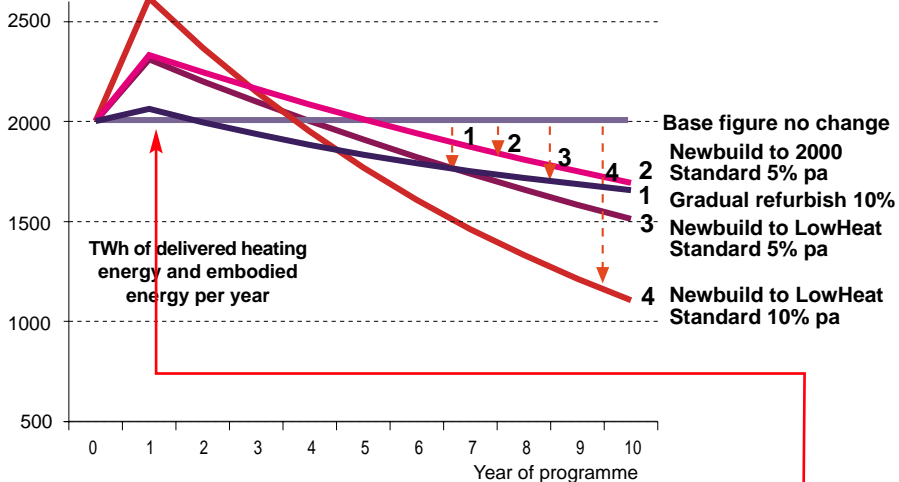
Refurbishment appears to require lower embodied energy, but can be complex, can't be carried out on all dwellings and will achieve modest savings (our research suggests that fabric improvement measure will probably cut heating energy use by 30% on average). New-build meanwhile can achieve cuts of up to 92% of heating energy compared to the current average, if houses are designed and built to the best of current knowledge - though a higher embodied energy burden is also implied.

The modelling illustrated on this page has been set up to compare different scenarios for refurbishing or replacing with newbuild a percentage of the housing stock, on the basis of annual energy demand, and then including consideration of embodied energy. It shows that a programme of radically accelerated new-build replacement to **LowHeat** standards can achieve more than refurbishing even double the number of buildings, even when embodied energy is taken into account.

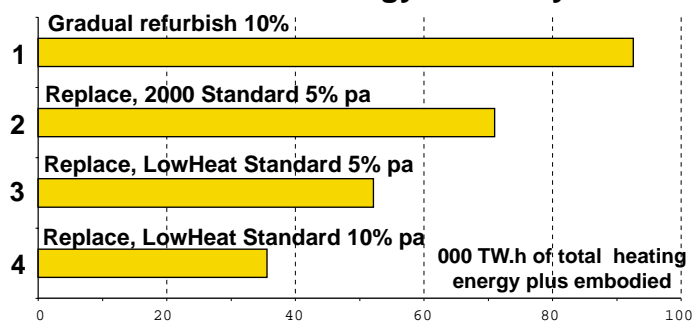
The peak at the beginning of the lower graph is due to the embodied energy in newbuild: but the annual demand still falls sharply, and the cumulative demand after 60 years shows a massive advantage to the new-build replacement strategies.

In reality it is not an either/or situation. A programme of accelerated replacement with newbuild to **LowHeat** standards where feasible and refurbishment elsewhere is a strategy which could achieve massive energy and carbon savings in the housing sector.

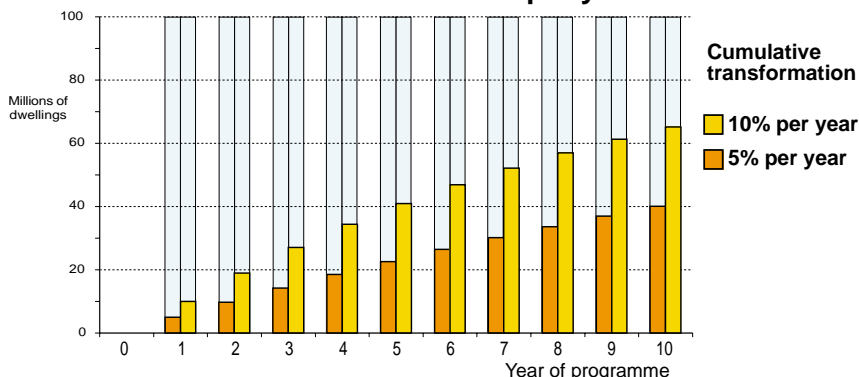
2 annual heating energy use + embodied energy for the same scenarios



Cumulative total energy after 60 years



Assumptions: no of dwellings refurbished and newbuild per year



Assumptions
Base: 100 million dwellings each with assumed average heating demand 20 MW.h/year. Total number of dwellings constant over time. Note: total number of dwellings in DE, IR, IT, NL, ES + UK is approx 100 million.
1 Refurbishment of 10% of stock per year with thermal efficiency measures achieving reduction to average demand 14 MW.h/yr per house
2 Replacement of 5% of stock per year with Newbuild to 2000 Standard, to 6 MW.h/yr per house
3 Replacement of 5% of stock per year with Newbuild to LowHeat Standard, to 1.5 MW.h/yr per house
4 Replacement of 10% of stock per year with Newbuild to LowHeat Standard, to 1.5 MW.h/yr per house
 Embodied energy: total new-build embodied assumed to be 80 MW.h per house, and refurbishment embodied assumed to be 12 MW.h per house). [Ref: 10]

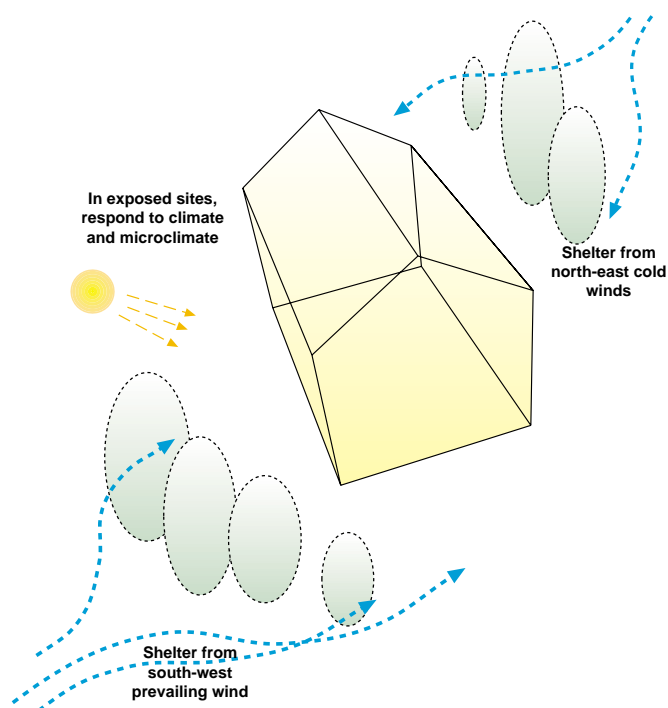
Design Guidelines 1

Basic principles for low-energy design, newbuild

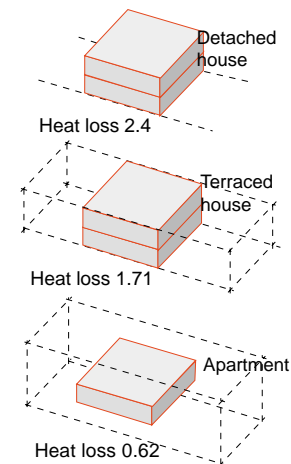
1 Site, orientation and built form

Design for solar access & wind protection, compact building form.

Compact form has a large impact on heat loss. Daylighting should not be compromised however - light pipes are one way to bring daylight into the centre of the building. In exposed sites, wind protection can reduce heating demand by up to 10%.



Relative heat loss for different house forms

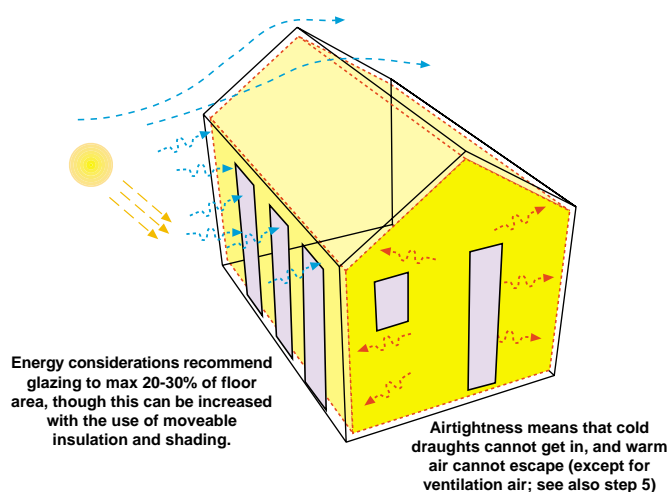
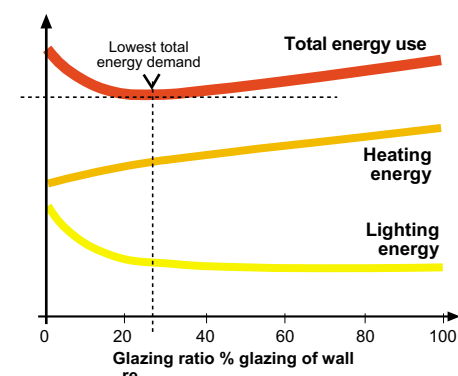


2 Optimise insulation (U-value) and airtightness

Minimise heat loss and maximise airtightness

Heat loss tends to be equally distributed between opaque fabric, glazing and ventilation - all three elements must be considered. Once insulation of opaque and glazed elements is improved beyond the 2000 Standard then airtightness is also critical. Area of glazing must achieve a balance between heat loss and daylighting (typically 25-30% of floor area if no external shading).

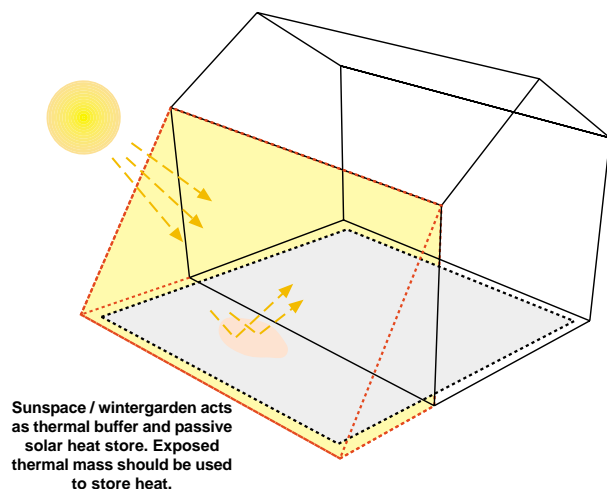
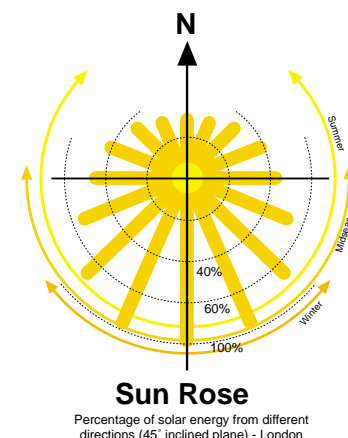
Typical variation in energy use with glazing area



3 Passive Solar design

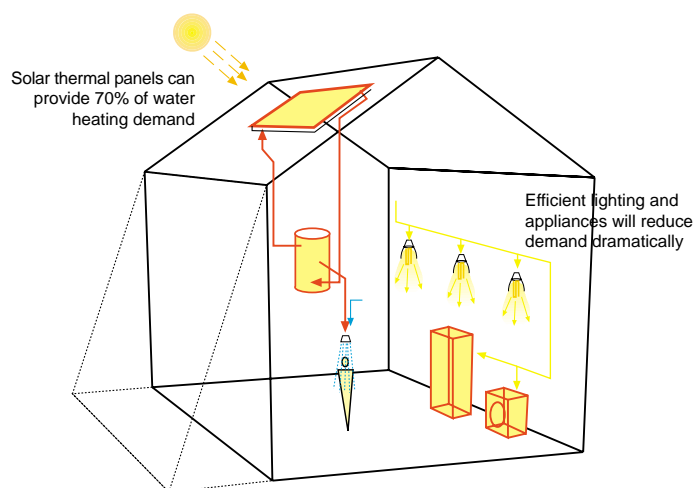
Optimise glazing, orientation and thermal mass strategy

Passive Solar design aims to use solar gains to maximum extent in winter, and most glazing needs to be oriented towards south - though external shading or overhangs should be provided to minimise summer overheating. In a passive solar design thermal mass located correctly is essential to store solar and occupant gains for use when needed. However as envelope insulation and airtightness increases, passive solar is less important.



Design Guidelines 2

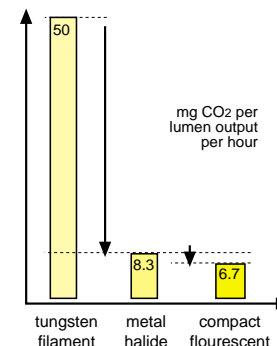
Basic principles for low-energy design, newbuild, continued



4 Energy system & appliances

Choose efficient, low carbon heating system, lighting and appliances

Though a small percentage of domestic energy use is in lighting and appliances, it relies on electricity which is valuable and of relatively high-carbon intensity. Modern lighting systems and appliances offer huge efficiency gains over traditional, and further improvements are possible. When specifying, energy ratings and eco-labels should be referred to.

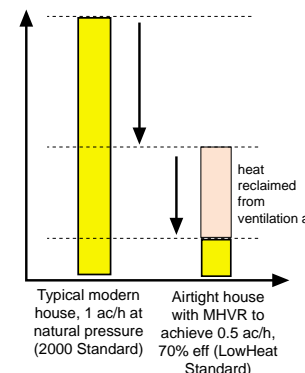
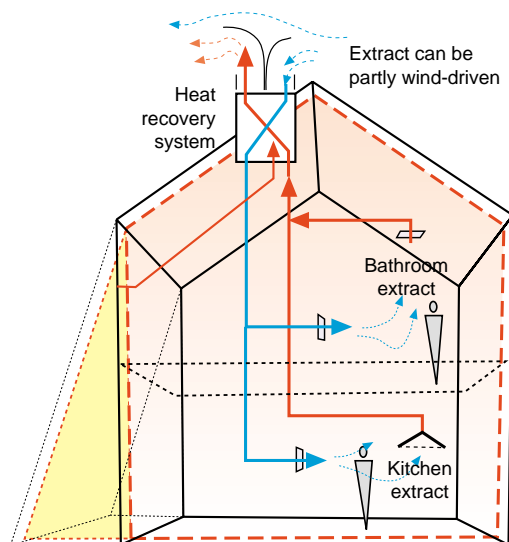


Lighting: Carbon Intensity

5 Ventilation strategy

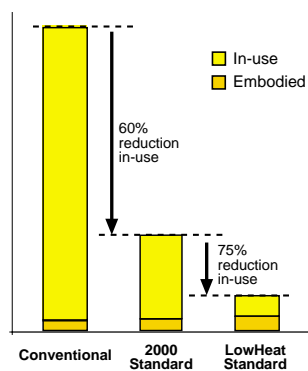
Design controllable system, consider mechanical ventilation & heat recovery

Once a highly-insulated and air-tight fabric has been created, control of ventilation heat losses becomes essential. In the winter, ventilation should be kept to a minimum (though sufficient to provide fresh air) and heat recovery should be considered. In colder climates whole-house mechanical ventilation with heat recovery (70-80% of outgoing heat recovered) should be considered. In slightly warmer climates humidity-controlled passive stack vents can be used.



Ventilation heat loss

Energy-in-use must be optimised first. Embodied impact can then be reduced if it does not compromise in-use performance



Energy in-use compared to embodied energy in a typical dwelling
Note: 100-year life assumed

The principles of LCA analysis of building materials

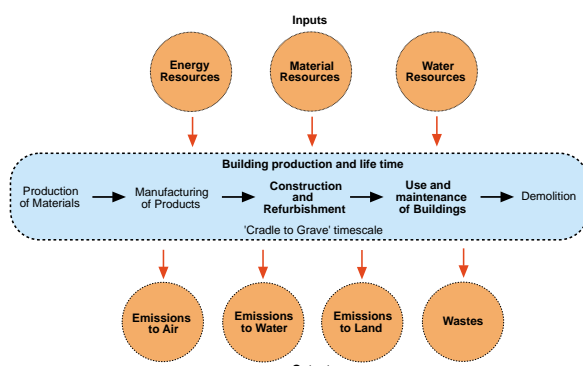


diagram after BRE

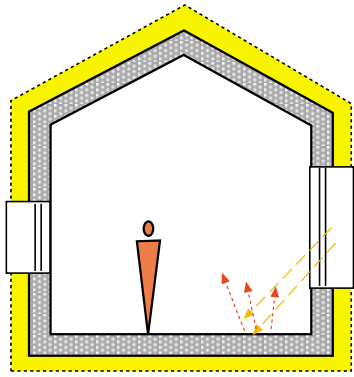
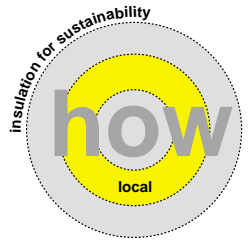
6 Materials issues

Final stage. Without compromising energy in-use performance, aim to reduce embodied impact where possible.

Materials' embodied impact makes up to 10-15% of the building's total impact, and it is more important to minimise energy-in-use. This means that the first materials to focus on are those which have least impact on the energy-efficiency strategy. Most buildings last much longer than a 'design life' of 70 years, and the longer they last, the less important is embodied energy.

Rating of materials on embodied impact alone is not common sense; using a life cycle assessment approach, the whole building system should be considered, in particular the energy use of the building over its life.

New-build housing: lightweight or heavyweight?



Heavyweight low-energy houses at Hockerton, UK

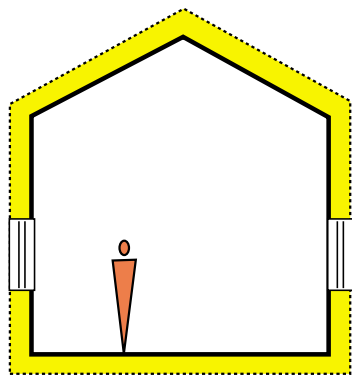
Heavyweight

- E.g. Masonry + overcladding.
 - Solar-oriented design can use thermal mass.
 - Design for constant temperature.
- More appropriate for orientations where 'passive solar' can be optimised, and for continuous occupancy.

Two of the key issues affecting choice of energy-efficiency strategy are wall thickness, which may be an issue in order to maximise living space in medium- to high-density developments; and thermal mass, which may conflict with mass-production system-build approaches. The two issues are related in the debate about thermally massive against lightweight construction. The dichotomy is in fact slightly false - as we explore here.

The heavyweight approach

The traditional wisdom in many parts of Europe would argue that heavyweight construction is required to give thermal mass which offsets temperature fluctuations: specifically to prevent summer overheating, and in winter to capture and store heat arising from occupants and solar gain. There are a number of case studies for this approach, particularly in the UK (Hockerton; BedZED), but it is not the only approach to zero-energy buildings. Indeed some energy design experts believe that airtightness is a more important factor than thermal mass.



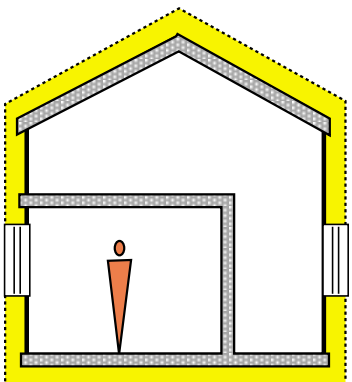
Lightweight low-energy houses at Altötting, Germany

Lightweight

- E.g. Timber or steel frame or SIPs (structural insulated panels)
 - Fast response heating.
 - MHVR works well with airtight construction.
- Ideal for sites requiring rapid construction, where space/density is at a premium, or ephemeral occupancy
- Appropriate where solar gains cannot be optimised.

The lightweight approach

Lightweight building construction (e.g. modular timber frame) is being increasingly explored in many circles because it offers opportunities for rapid, defect-free and low-cost construction with maximum opportunity for prefabrication. In the UK, particularly it is seen as part of the solution to a shortage of low-cost housing provision. From the macro scale, this approach can be seen to be more socially sustainable, assisting the construction of affordable housing.



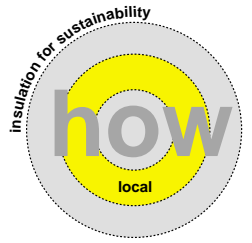
Hybrid

- Combination of precast or insitu mass components with airtight modular lightweight highly insulated 'skin' construction.
- Allows rapid construction and thin walls with some storage of solar and incidental gains.

The Hybrid approach

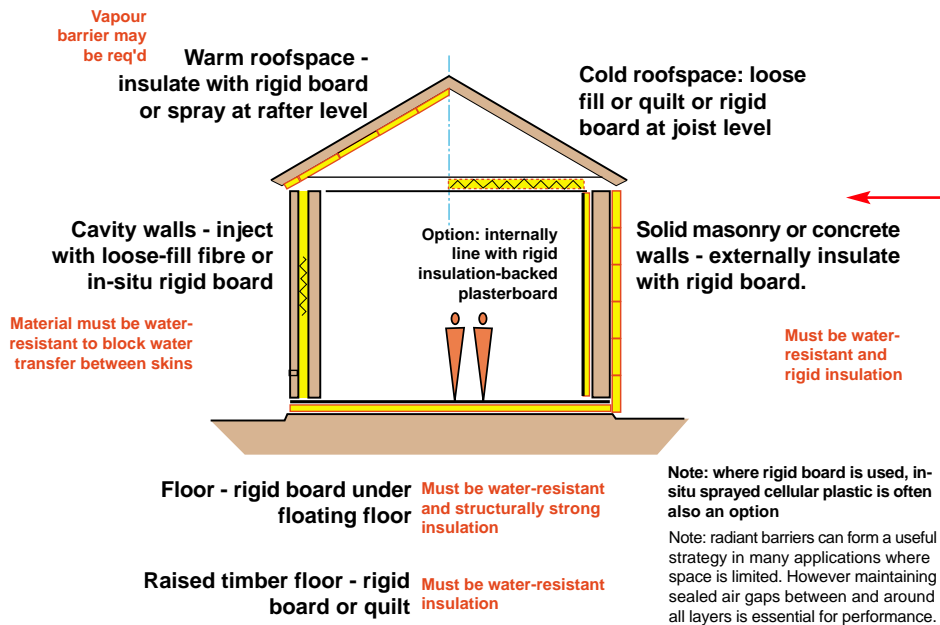
A realistic approach for the LowHeat standard is a hybrid approach combining the best of both. In circumstances where the lightweight approach proves insufficient to store incidental or solar gains then there are opportunities for localised exposed thermal mass. The key variable here is exposed mass - concrete floors may be rendered useless by carpet, or walls covered by hanging pictures. The key to a successful design is to get enough thermal mass in places where it does not conflict with useability.

Design Guidelines - retrofit



Where to insulate - retrofit

In general, external insulation of the fabric is preferable to internal as it makes it easier to avoid cold bridges, which as well as heat loss can sometimes cause damp in a poorly ventilated building.



The single best means of encouraging investment is to offer specific financial inducements to consumers. These can be by way of cash-back schemes, grants, tax breaks and accelerated capital allowances. These tax breaks are directly required in order to compensate for the substantial numbers of barriers which exist in the marketplace currently, which distort optimum levels of investment.

Report of the Working Group on Sustainable Construction, DG Enterprise

It is widely perceived [in Germany, Netherlands, and Switzerland] that work is needed on existing buildings as a matter of urgency.. The costs of such improvements are reasonable, if they are combined with major renovation work..

David Olivier, low-energy design specialist [Ref: 9]

While potential savings are not as large as in new-build, considerable improvements can be made in existing building stock (30% reductions on average in heating demand, 50% possible) and a refurbishment programme will form an important part of reducing heating energy in Europe while also reducing fuel poverty and increasing comfort.

Design considerations in retrofit place more limits on possibilities, and technical issues like condensation need to be carefully considered. The most common debate is about the best location for insulation, and we summarise some of the issues here.

There are pros and cons to each material and application which are not discussed here. There are also longevity criteria for the insulant, touched on in the appendix on pp 70-71.

The principle locations and types of insulation retrofit are:

Cavity wall

Injection of loose-fill or insitu-expanding material. Internal lining with rigid insulation-backed plasterboard.

Solid masonry wall

External insulation with rigid board material, which can then be overlaid with a rainscreen or rendered. Internal lining with rigid insulation-backed plasterboard.

Roofspace - cold

Between- and over-joist insulation with loose-fill or quilt material.

Roofspace - warm

Between or between and under-rafter insulation with rigid board material.

Solid concrete floor

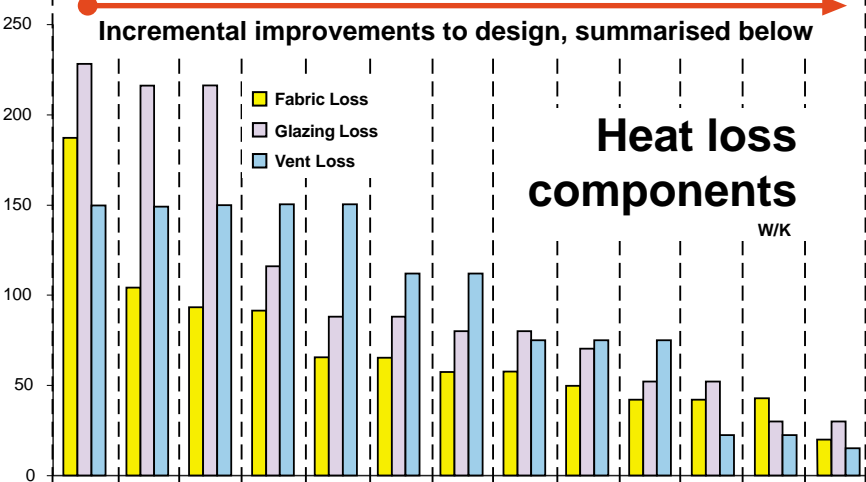
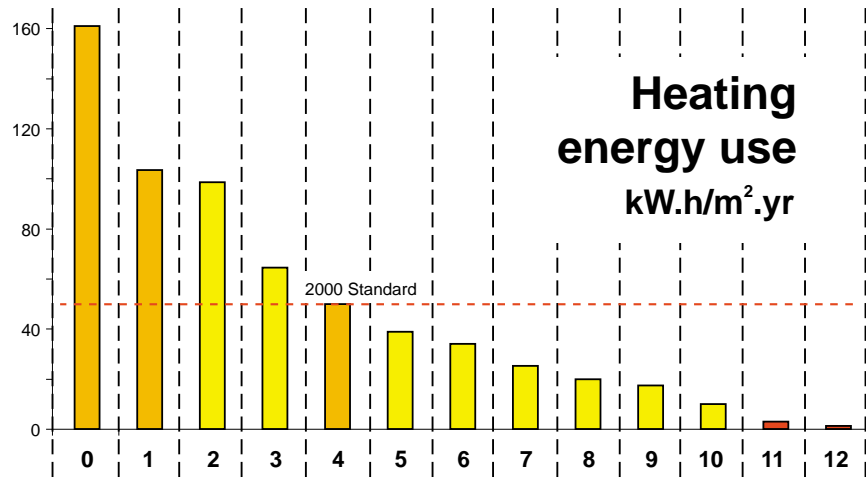
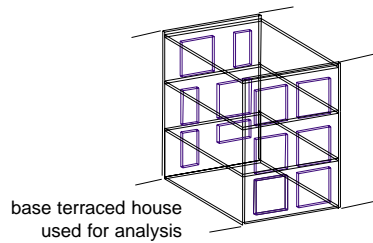
Rigid board under new screed or floor finish

Raised timber floor

Rigid board or quilt between and under floor joists.

Retrofit is more cost-effective when combined with other refurbishment works. In general, insulation levels should be specified to the maximum possible level as it is likely that further upgrades to the building will prove expensive and difficult.

Detailed modelling results



Conventional building as 1970 UK regs
As 1990 UK Regs. Fabric U = 0.5, 1 ac/hr, single glazed

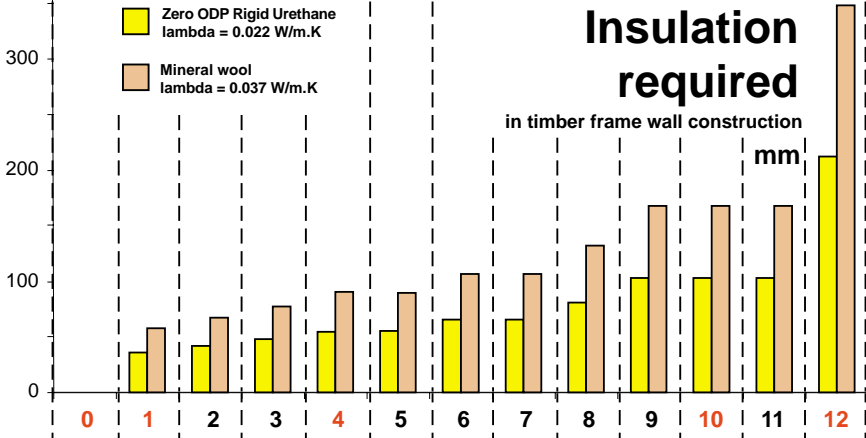
fabric U = 0.45
glazing double U = 2.9
fabric U = 0.4

2000 Standard: wall U = 0.35, glazing U = 2.2, roof U = 0.2
airtightness improved to 0.75 ac/hr
Wall U = 0.3, roof U = 0.2, glazing U = 2

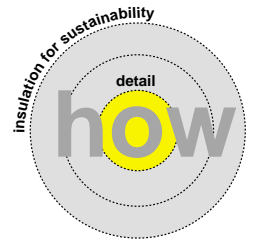
airtightness improved to 0.5 ac/h
wall U = 0.25, roof U = 0.2, glazing double low-e + curtains gives U = 1.71
fabric U = 0.2 glazing double low-e + insulated shutters U = 1.3

LowHeat Standard MVHR 70% eff
Glazing is superwindows, U = 0.75

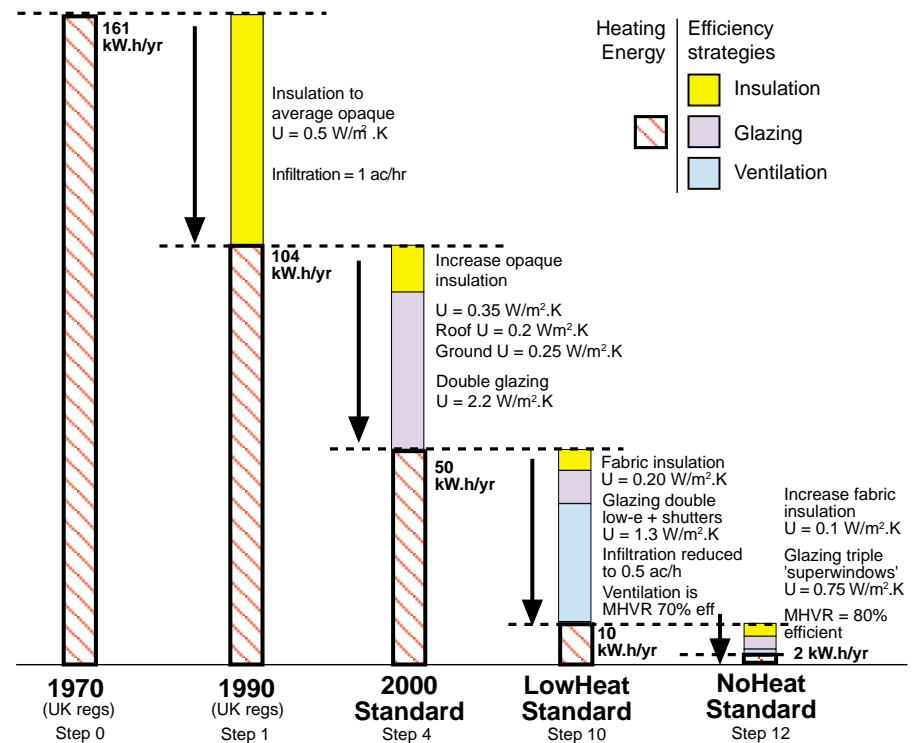
NoHeat Standard
Fabric U = 0.1 MHVR 80% eff



Twelve steps to a zero-heating house



Standards and specifications to reduce heating energy use



Fabric thermal specification and resultant heating energy use

Note: modelling is dependent on assumptions and these numbers should be taken as typical not absolute predictions, within correct orders of magnitude and based on this house type on the London climate. Infiltration rates are indicative of standard new construction ventilation + leakage at normal pressure.

Design for low heating energy involves optimising the thermal properties of the fabric in three ways: insulation of opaque fabric; heat transfer properties of glazing; and airtightness and ventilation strategy.

In order to demonstrate the relative contributions of these three elements we have used the INDEX computer model of domestic thermal design [Ref: 11]. Starting with a house built to 1970 UK standards, we have gradually upgraded the specification of three elements. It's clear from this modelling that thermal insulation, glazing and ventilation are all critical aspects of the overall thermal strategy.

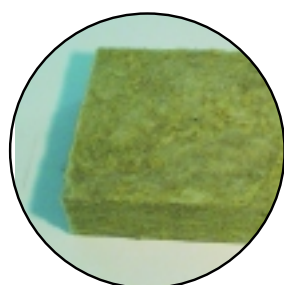
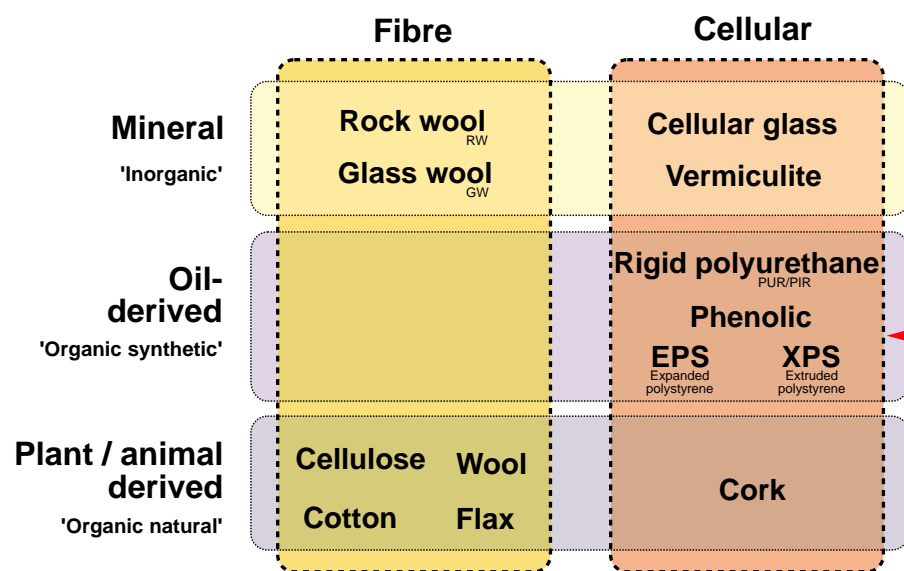
This and other modelling has shown that the **LowHeat** and **NoHeat Standards** can cut heating energy use by 80-96% compared to the **2000 Standard**, and by 90-98% compared to the typical existing dwelling.

insulation for sustainability

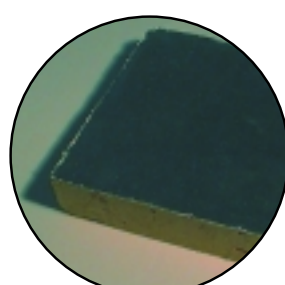
which

Introduction to insulation materials

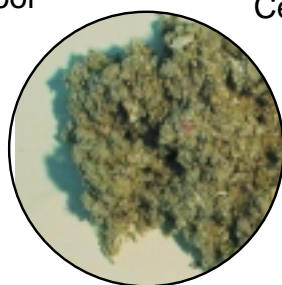
Classification of Insulation Materials



Mineral wool



Cellular plastic



Cellulose fibre

Note on assumptions

1 Thermal conductivity. Assessment methods for lambda values (thermal conductivity) currently vary slightly across Europe (a harmonised approach has been developed and will be in force in March 2003). For the sake of comparisons between materials, this report uses lambdas based on 'best available' values. Lambdas do vary for different manufacturers, and specifiers should always check the specific lambda rather than relying on a 'generic'.

2 Ozone depletion. In this document cellular plastics are assumed to be those versions available using non ozone-depleting blowing agents (as all materials will be after Jan 1 2004, see pp64-65), which have slightly higher lambdas than some of the materials available today.

Array of materials

There is a large array of different insulation materials, from many different sources and with different properties. This is as it should be - construction is complicated, different construction methods have very different performance requirements for insulation, and there is much scope for individual choice in response to specific project conditions. This diversity puts considerable responsibility on the specifier, and it is important to understand the process by which different materials are chosen.

Materials selection

In fact the choice of material per se has very little impact on the total environmental impact of the building, as we will show. What is most significant is the thermal design and specification: the overall design strategy and the particular U-value of components, which can be achieved with a variety of different materials at different thicknesses.

On the level of the material choice, there are three key points for selecting insulation materials:

- Choose a material with long life, sufficient durability and minimum failure risk (to maximise energy and carbon benefits).
- Choose a material with zero ozone depletion potential (ZODP) (a global pollution issue).
- Where thickness is constrained, choose the best thermal insulator appropriate to the construction type (to optimise U-value and energy savings).

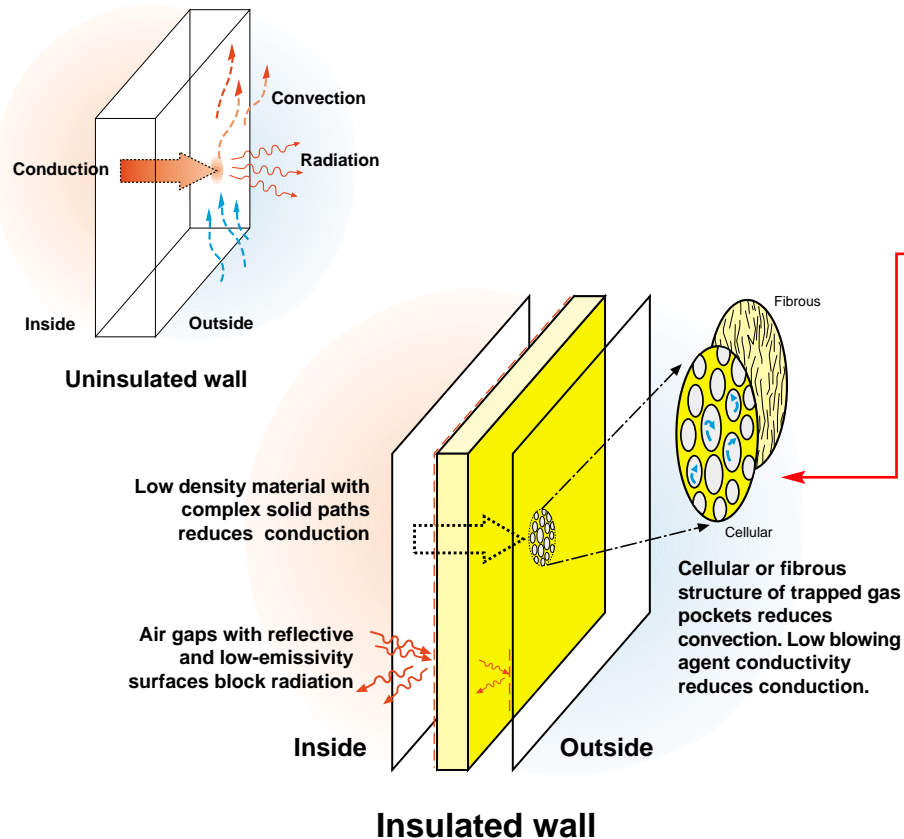
In this section

In this section we discuss the selection of insulation materials, and describe the key environmental issues in the choice of material. We also show how thermal resistance is much more significant than embodied energy, and we summarise the issues with respect to blowing agents. We discuss longevity as an essential environmental issue, and we review the ageing and failure risks in insulants which challenge longevity.

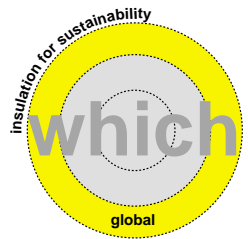
Finally for reference we summarise the key aspects of the most common material types including raw materials, manufacturing and general properties.

Don't substitute a 'green' insulation for a non-green material if the change will hurt energy performance. With lower R-value [higher lambda] materials, increase thickness.... Durability of building materials, including insulation, is a very important environmental consideration.

Environmental Building News, US publication
www.buildinggreen.com



Choosing insulation for sustainability



Overall performance targets

The most important factor overall in designing insulation systems is achieving very low U-values to minimise energy use and carbon dioxide emissions. This on its own does not provide limitation or guidance on one material over another, except where thickness is constrained. Those issues that are important are summarised below and expanded on in this section.

Ageing Issues

Most importantly, insulation materials must be durable and must not 'age' from stated thermal conductivity - they should provide consistent performance over the life of the building. Thermal performance over time is critically important to the total energy saving properties of the material. Most insulation is installed on the assumption that it will last as long as the building itself, but buildings can last anywhere between 50 and 500 years. An informed choice of materials needs to be made on the basis of an assessment of ageing or failure risk in any particular application.

The myth of embodied energy

Embodied energy has often been used by designers as a basis for environmental comparisons between materials. But in the case of energy-efficiency materials like insulation, this is extremely misleading, as we will show: the energy saved over the building lifetime is far more significant.

Ozone depletion

Perhaps the most well-known of environmental issues in relation to insulation is ozone depletion potential (ODP), though chemicals with ODP are being phased out. All insulation materials are now available in zero-ODP versions which should be specified in preference. We provide some background to the issues and blowing agents used.

Materials reference information

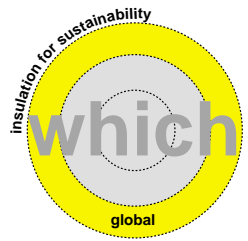
And finally, in order to help design teams make informed decisions and to start the longevity debate, we include in an appendix some guidance and opinion on the different properties of the many common insulation materials available, including their manufacturing process and associated detailed design issues and longevity issues.

Human health issues - summary

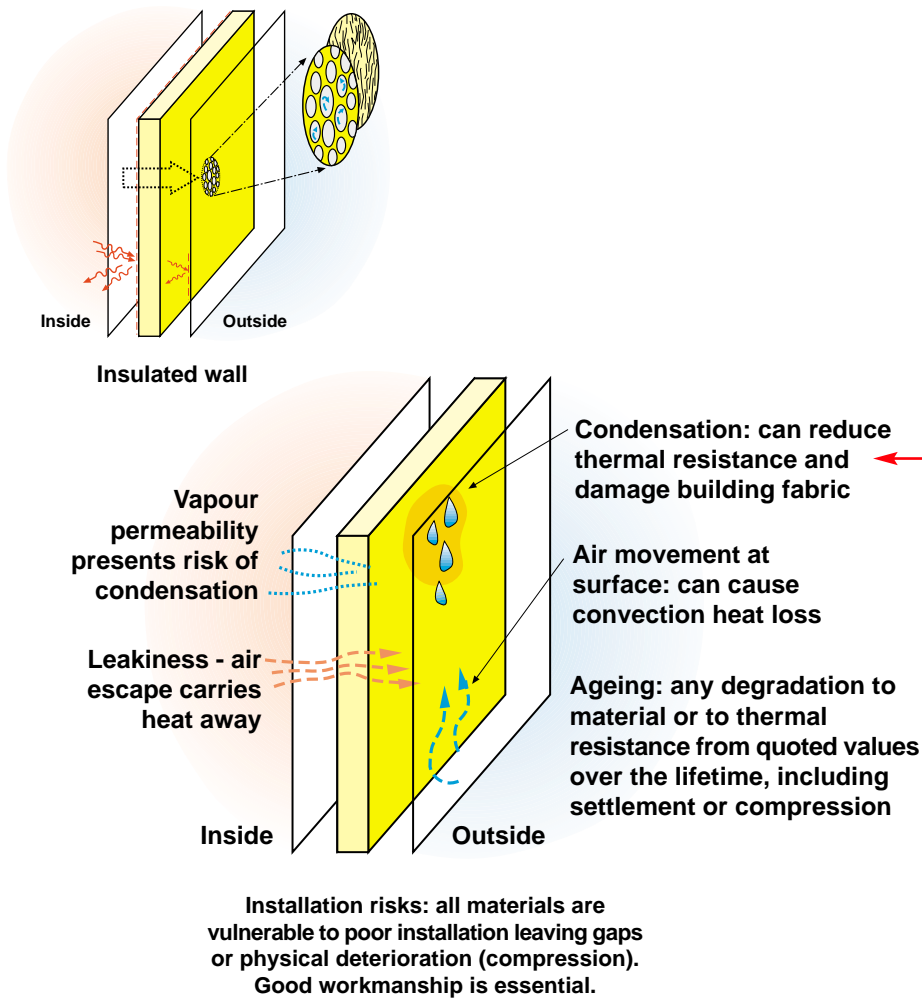
Fibrous materials: Some materials cause skin irritation and protective gear is advised for installation. Loose-fill fibre installations should not be ventilated to occupied internal building spaces. Whilst in the past some fibrous materials have been listed by research bodies like the International Agency for Research on Cancer as potential carcinogens, they are currently listed as not; classifiable as to carcinogenicity in humans;.

Cellular materials: In the past some materials had offgassing problems which could cause internal build-up of pollutants (notably Urea-Formaldehyde foam). These materials are no longer used and in general health terms there are no detectable problems with any of the products available today. There are also no special installation requirements or issues.

Durability and failure risks in insulants - 1



Challenges to insulation performance



Once low U-values have been achieved, the most important issue in choosing insulants is longevity of thermal performance. Buildings can last between 50 and 500 years, and the insulation will most likely not be replaced for the life of the building - unless it is specifically designed to enable replacement. It's clear however that more research in this area is required to determine long-term performance of insulants, as large-scale use of insulation is a relatively recent development compared to building lifespans. In future it may be useful to define 'failure risk factors' for insulation materials, to be used in assessing their long-term performance.

The biggest risk factor is perhaps moisture build-up (whatever the cause), which will increase thermal conductivity - especially in fibrous materials - and may in some cases damage the fabric of the insulant (see p 61).

Other risk factors include settlement - which some fibres may be susceptible to; air movement at surface, air leakiness, and attack by vermin and/or rot.

Design considerations

We believe that these issues should be considered alongside more conventional design issues. But there is in addition a potential 'macro' approach: one aspect of making buildings future-proof might be to design the building to allow for the future upgrade of insulation (the most practical way to do this might be by making the insulation external to the structure).

Fire

Behaviour of materials in fire is not an environmental performance issue or a longevity criteria as it constitutes a catastrophic failure to the entire building system, and it's not covered in any detail here. It has little meaning on the level of the insulant itself as it has to be defined for building components as a whole, relative to the particular function (legislative approaches do currently vary across Europe, though harmonisation is in preparation).

Workmanship

Poor workmanship is a common denominator of failure for all insulation materials. For example, fibre batts in cavity walls may suffer from mortar droppings, while cellular plastic boards may be left with gaps between boards. Whatever the material, good construction management is essential.

Durability and failure risks in insulants - 2

Idiosyncratic Norwegian commentator Bjorn Berge, in his book 'The Ecology of Building Materials' points out some insulation failure risks in general terms:

Lambda values... give no indication of a material's structure, moisture properties or reaction to draughts.... The thermal insulation value of a material is reduced when damp... this is important in hygroscopic materials... Age can also affect insulation value. Certain products have shown a tendency to compress through the absorption of moisture and/or under their own weight, while others have shrunk.

Solid boards.. need to be mounted as an unbroken surface on the structure and not within it.. Loose fill .. can settle over time. The disadvantages of hygroscopic materials become apparent here because they take up more moisture and become heavier..

[Ref: 12]

Many aspects of insulation materials' performance over long periods are not understood and more research is required. Some general points can be made on the sources of failure:

Fibrous materials

In fibrous materials the greatest ageing risks are probably temporary or permanent increase of conductivity due to wetting. Settlement due to compression or wetting of the material will also have 'catastrophic' impact on the performance.

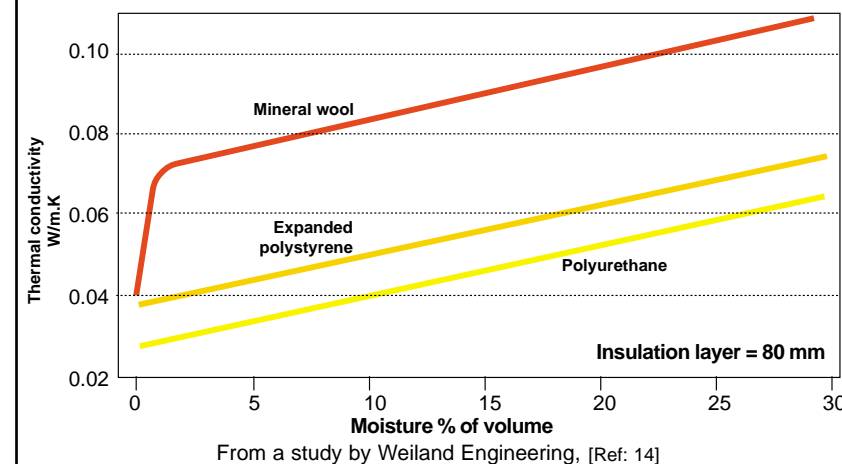
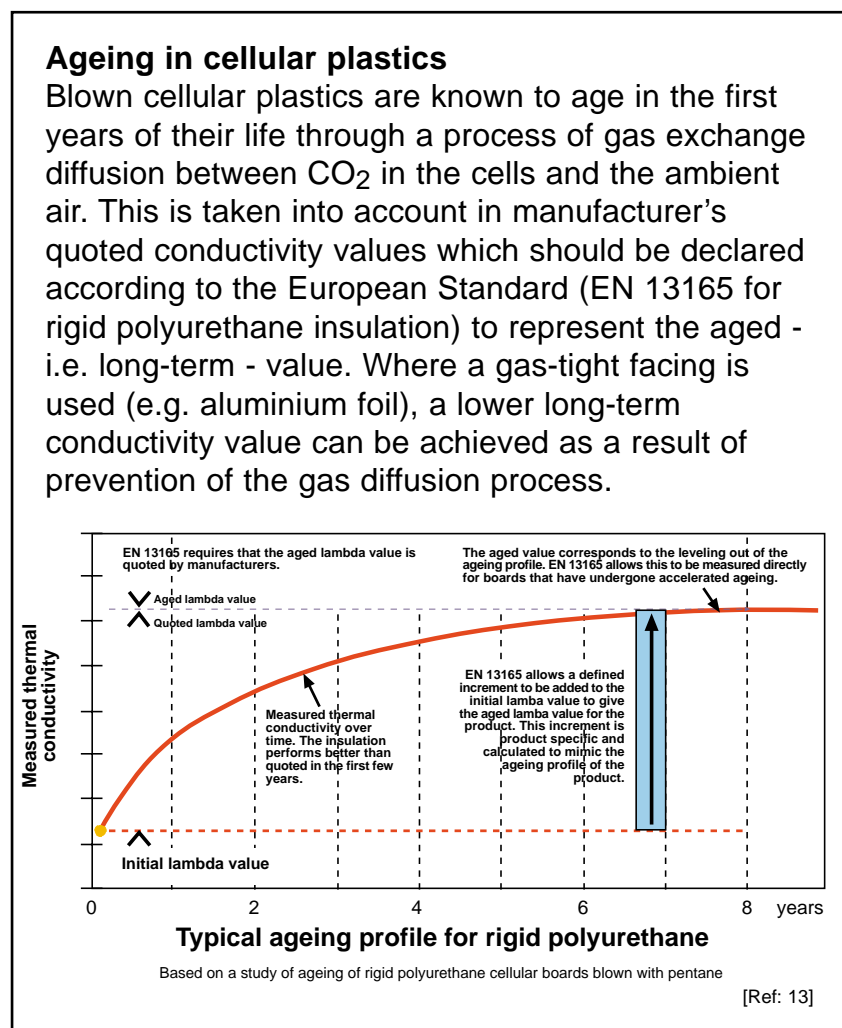
Animal- and plant-based fibres may be more vulnerable to vermin or insect attack, if the pest-resistant chemicals do not work or if they leach out.

Cellular materials

In some cellular materials ageing will occur through the loss of cell-gas resistance, usually through inward diffusion of air into the cells. This process is successfully limited through the use of gas-tight facings (aluminium foil). It is well-understood, and manufacturers state that it is taken into account in the stated insulation value of the material.

Moisture causes thermal conductivity increase

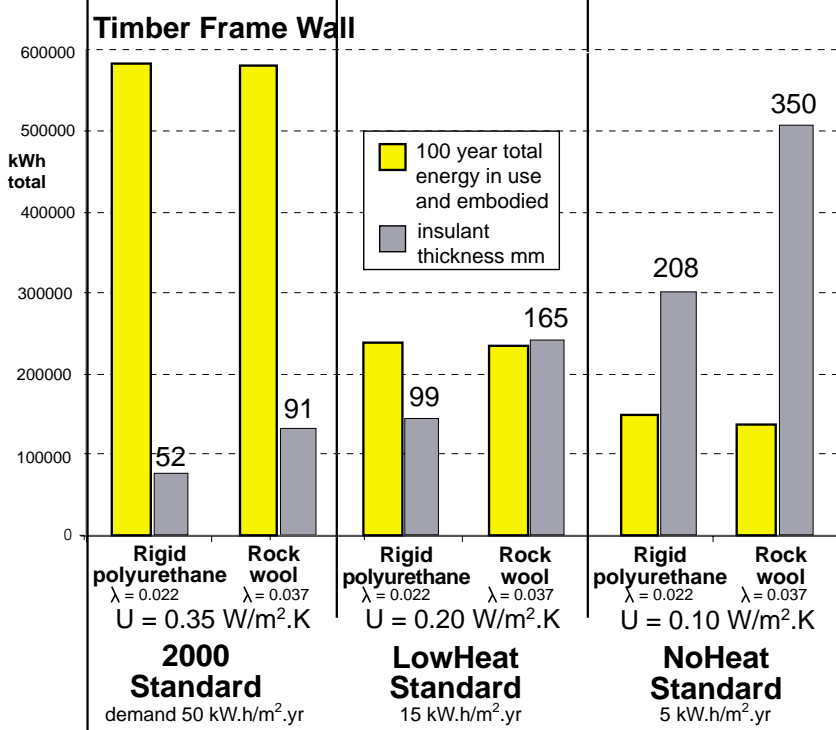
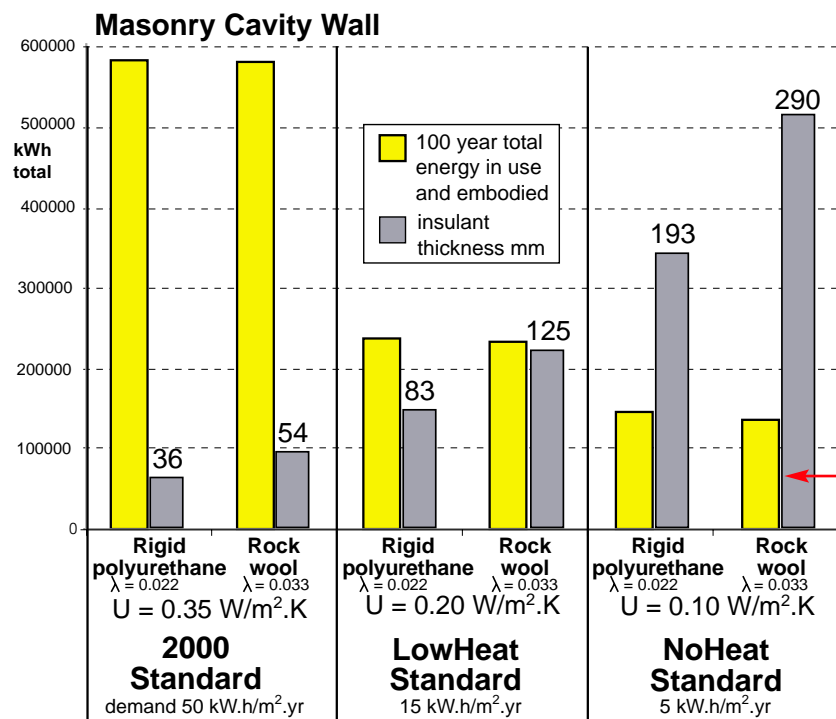
The presence of moisture in the insulant (which could occur as a result of condensation, rain penetration or plumbing leak) will increase the thermal conductivity by a large factor, especially in fibrous materials. A ventilated or vapour-permeable construction will potentially allow the insulant to dry out, but building heat loss will be much greater in the meantime.



How important is embodied energy?

For insulation, material type doesn't matter; but performance does:

Total energy consumption to achieve specified U-values with different materials



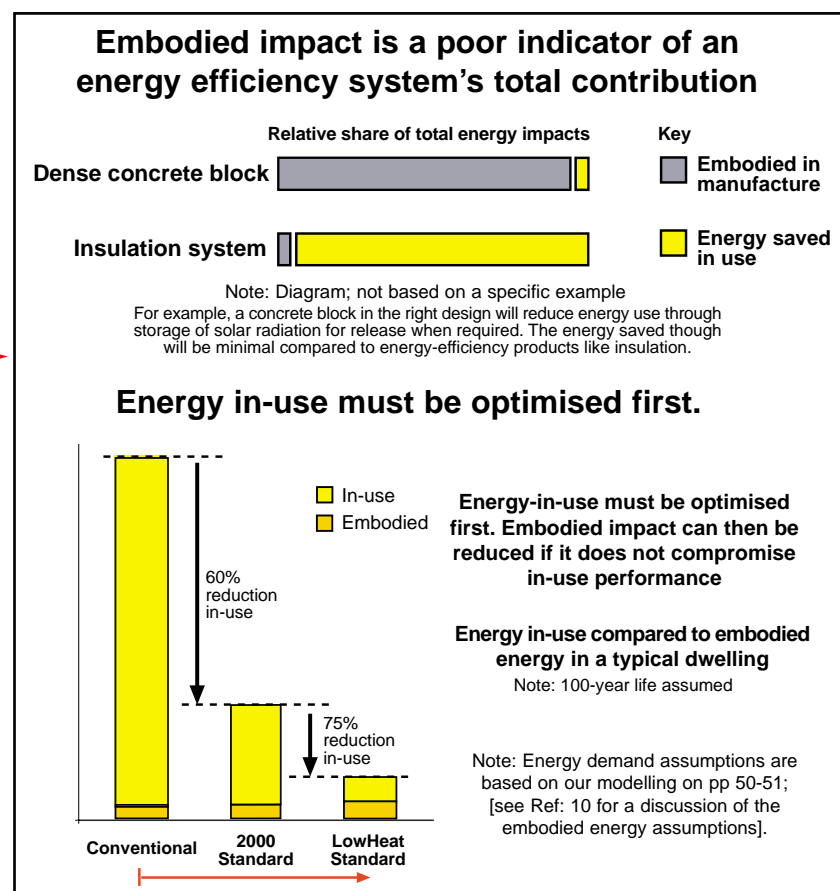
Based on the insulation to meet the required U-value in 100 m² of timber frame wall with timber cladding/and brick-block cavity wall (terraced house London). Whole building heat energy from INDEX model, assumed baseline embodied of 80 MW.h for each house construction plus calculated embodied energy for insulation, all other assumptions kept constant.

There is a common misconception that the most important factor in a material specification is the embodied energy of the material. For base construction materials, the replacement of one material with an equivalent with lower embodied energy will of course reduce the overall energy impact. But energy in-use is potentially much more significant, and must be optimised first.

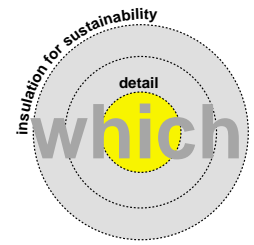
Embodied energy can be particularly misleading for energy efficiency materials and systems - where the embodied energy will typically be in the order of 1% - 3% of the energy saved over 100 years (based on calculations for 100 m² of wall insulated to U = 0.2 W/m².K).

Analysis shows that over a realistic timescale of 100 years, the lifetime energy is not sensitive to the choice of insulating material - though it is, of course, extremely sensitive to the thermal standards or U-values achieved.

This reiterates very clearly: thermal standards first, and longevity of performance second, are the two key environmental issues for choosing insulation materials.



Ozone depletion and blowing agents



	Agent	Ozone Depletion Potential	Global Warming Potential	Thermal Conductivity (gas)
Phased-out under Montreal (Class 1)	CFC-11	1	3800	0.0074
	CFC-12	1	8100	0.0105
Transitional (Class II)	HCFC-141b	0.11	600	0.0088
	HCFC-142b	0.07	1800	0.0084
	HCFC-22	0.055	1500	0.0099
Long-term Alternatives	HFC-134a	0	1300	0.0124
	HFC-245fa	0	820	0.0140
	HFC-365-mfc	0	810	0.0100
	n Pentane	0	11	0.0140
	CO ₂	0	1	0.0145

Properties of foam blowing agents

Note: GWPs are from the IPCC Second Assessment Report and the Montreal Protocol and are 100 year integrated time horizon values. Thermal conductivity is in W/mK measured at 10°C. Pentane value is from [Ref: 15]

The most commonly-known environmental issue with relation to cellular plastic insulating materials is the issue of ozone depletion, perhaps the best-known environmental issue after global warming since it was recognised by the British Antarctic Survey in the early 1980s and generated one of the first examples of rapid transnational action in response. The Montreal Protocol of 1987 (with amendments in 1990 and 1992) has set a timetable for the phasing-out of CFCs, and their less polluting cousins HCFCs.

Blowing agents for cellular plastics are chosen on the basis of two characteristics: thermal conductivity (as the gas will remain in the cells); and processability. CFCs were initially favoured because they give rise to very low conductivity materials (they were also used widely as refrigerants). Their Ozone Depletion Potential (ODP) is defined relative to the effect of CFC-11 which is given a value of 1.

The use of CFCs in cellular plastics was phased out in the developed world in 1995 (though they are still used in some parts of the world). In Europe the transitional HCFCs, which have a much lower ODP, are being phased out in insulation boards in 2002 - 2004, and in other parts of the world to a 65% reduction by 2010 and total elimination by 2030.

The preferred gases in view of thermal conductivity are HFCs, which have no effect on stratospheric ozone, but are quite potent greenhouse gases (defined relative to CO₂ which is given a value of 1). The impact of the material must here be considered in terms of Total Equivalent Warming Impact over lifetime, as the increased thermal resistance of the HFC-blown cellular plastics might offset the global warming impact of their blowing agents? There has been much debate on this issue. Some studies [Ref: 16] suggest that HFC-blowing agents have the advantage over others when 80% of the gas is reclaimed at the end of life (though this is not currently widely done). This is particularly relevant to high-demand refrigeration applications.

However, many manufacturers are now switching to hydrocarbons like pentane, and to CO₂, whose global warming effect is easily outweighed by their added insulating value.

Note on assumptions

All cellular plastic materials are now available with zero Ozone Depletion Potential (ODP), and total phase-out of ozone depleting substances in thermal insulation is occurring. We would argue that all materials should be specified in their zero-ODP form. Specifiers should be aware that 'CFC-free' or 'HCFC-free' does not mean zero-ODP. In this document, all comparisons are based on materials with zero-ODP blowing agents and the thermal conductivity values quoted are those for zero-ODP materials.

Typical indicators for building material Life Cycle Assessment (LCA)

Category	Description
Depletion of resources	Non-renewable raw material use - e.g. oil extraction
Global Warming Potential (GWP)	Greenhouse gas emissions - e.g. CO ₂ , CH ₄ , etc
Ozone Depletion Potential (ODP)	Ozone depleting emissions e.g. CFC, HCFC
Acidification Potential (AP)	Emissions to air causing acid rain - e.g. NO _x , SO ₂ , HCl
Nutrication Potential (NP)	Pollution of surface water and soil with nutrients - e.g. Nitrogen
Photochemical Ozone Creation Potential (POCP)	Emissions leading to ozone pollution at ground level (HCs)
Human Toxicity Potential (HTP)	Human-toxic emissions - e.g. heavy metals and dioxins
Ecotoxicity Potentials	Flora- and fauna- toxic emissions e.g. heavy metals, acids
Use of land and space	Type and duration of man-made change of land use -e.g. mining.

Construction products cannot be assessed on a standalone basis since construction works with the highest "green credentials" may use products which might have relatively high loads but which significantly contribute to reducing a building's impact throughout its lifetime.

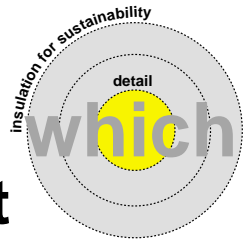
An Agenda for Sustainable Construction, DG Enterprise Construction Unit, Working Group Sustainable Construction, May 2001

Scope of LCA in buildings

The SETAC Working Group LCA in Building concluded that the final building or construction, defined by performance requirements, is the central subject of an LCA and provides the most accurate subject for any comparison. In practice, the products or components of a building or construction can provide a valid subject for the application of LCA. However, the context of the complete building or construction should be reflected or at least mentioned in comparative LCAs of building or construction components and incorporated whenever appropriate.

Alternatively, integrated building assessment tools like the British ENVEST and the Dutch EcoQuantum [Ref: 17] can enable the comparison of impacts for different construction and materials options, for the complete system over the life of the building. These systems are very much under development, and should be used with care by qualified experts.

Sustainability in building materials - detailed assessment



Background to LCA

Life Cycle Assessment or LCA is the process of evaluating the potential effects that a product has on the environment throughout its entire life cycle, from cradle-to-grave. In an LCA, the energy and materials used and released back into the environment during the life cycle of the product are identified and quantified. This allows an assessment of environmental impact from raw material extraction and processing, manufacture, transport and distribution, use, maintenance, re-use and recovery, to final disposal.

The International Standard Organization has developed a series of international standards (ISO 14040 series) based on the guidelines of The Society of Environmental Chemistry and Toxicology (SETAC) which was a pioneer in LCA methodology development. Regulators and industry increasingly use LCA because it provides objective data that help strengthen the communication between all stakeholders. If used properly, LCA can lead to genuine environmental benefits and support the development of more sustainable production and consumption patterns.

Limitations

LCA comparisons must be based on elements with functional equivalence - i.e. two wall constructions with the same U-value. However it is the whole-life performance of the whole system which is most significant and an elemental comparison only gives part of the picture (for example it won't consider airtightness, a key factor in heating energy use). To be meaningful enough to compare design options, LCA should be carried out for the whole building for its total life.

It should also be noted that during the building's life span it may undergo changes in its function and fabric which will have potentially large effects on its environmental impact, which will be outside the scope of an LCA.

In this document

There are currently only a few public LCA schemes and these tend to include information on a limited range of materials. While these are excellent initiatives, current data availability is partial and assumptions vary. As a result we have chosen not to include current LCA data in this document.

insulation for sustainability

appendix

**Some key properties of
insulation materials**

Design issues for longevity

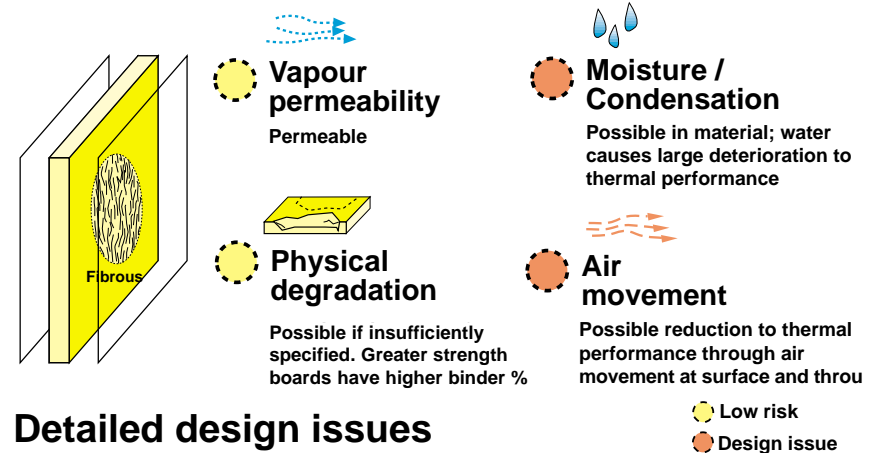
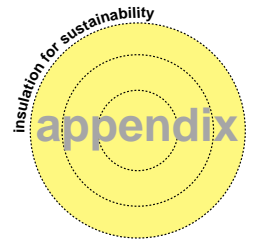
Mineral fibre

Mineral fibre materials have design issues relating to their open structure - they are vapour permeable and air permeable.

- **Moisture build-up in insulant**
Caused by condensation, leaking cladding or leaking pipework. Will cause large increases in conductivity.
- **Compression**
Lower-strength products with lower binder content offer compression risk - e.g. in flat roof applications. Good specification should avoid this problem.
- **Air movement**
The open structure means that surface air movement and air moving through may reduce the insulation value, though some products have facings used to prevent this.

Guidelines on key issues to achieve longevity in detailing insulation materials: the most significant environmental issue.

Note: as discussed poor workmanship is a common issue to all materials and is not discussed here.

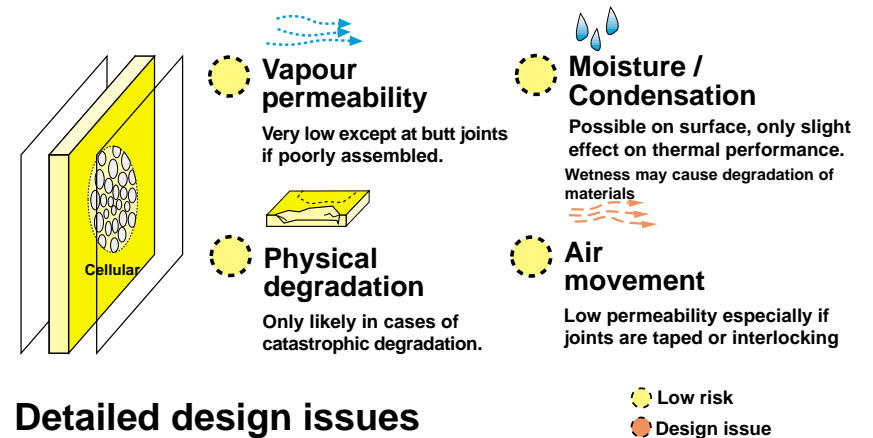


Detailed design issues

Cellular plastic

There are very few detailed design issues related to cellular plastics.

- **Gas exchange (in materials with blowing agent)**
The main known failure risk in cellular plastics relates to increased thermal conductivity due to gas exchange (esp in materials without gas-tight facings). As discussed on pp 60-61, according to the European Standard this is taken into account in the quoted lambda value.
- **Longevity**
Cellular plastics are not susceptible to rot, are not attractive to vermin as food, and are known to be very long-lasting materials.

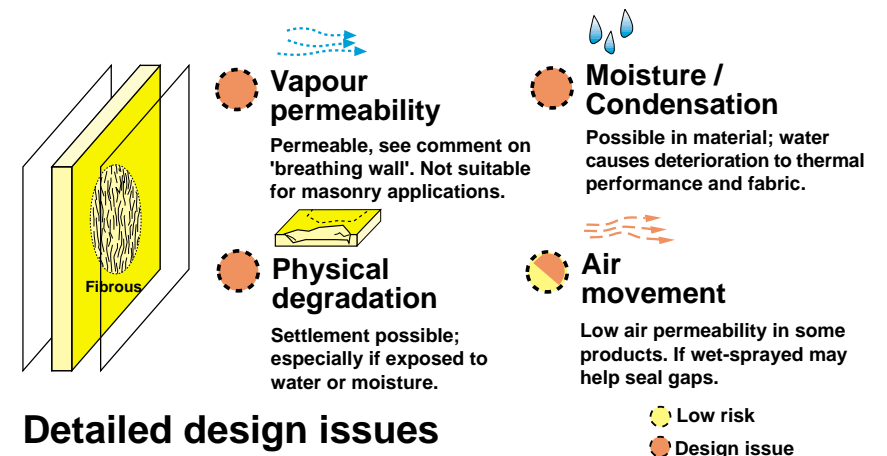


Detailed design issues

Plant / animal fibre

There appears to be greater need for risk awareness when detailing these materials, though more research is required to confirm longevity issues.

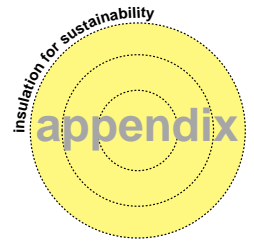
- **Rot / Vermin**
These fibres are naturally susceptible to rot and vermin and need to be protected with chemical treatment. If the material becomes wet there is a risk that this treatment may leach out.
- **Settlement**
Settlement may be an issue for loose-fill blown fibres as acknowledged for example in the British Standard on loft insulation.
- **Compression**
Physical strength and resistance to compression is very low, creating greater risk during installation and in trafficked areas.



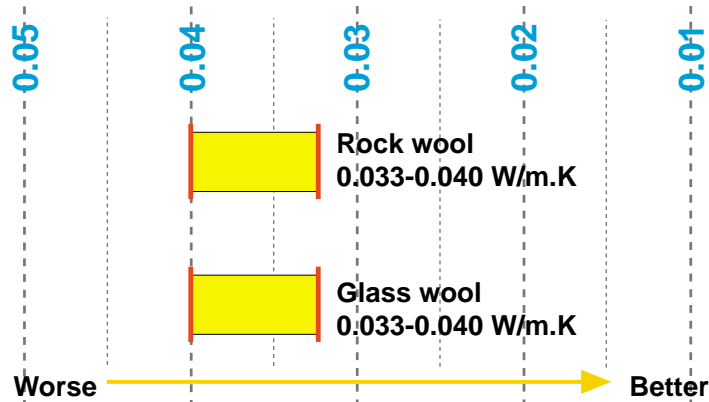
Detailed design issues

Lambda values / conductivity

Look-up charts on typical lambda values and typical construction thicknesses required for different U-values



Mineral fibre



The key equation relating U-value (heat loss rate) to lambda (thermal conductivity) and thickness (d)

$$U = \frac{\lambda}{d}$$

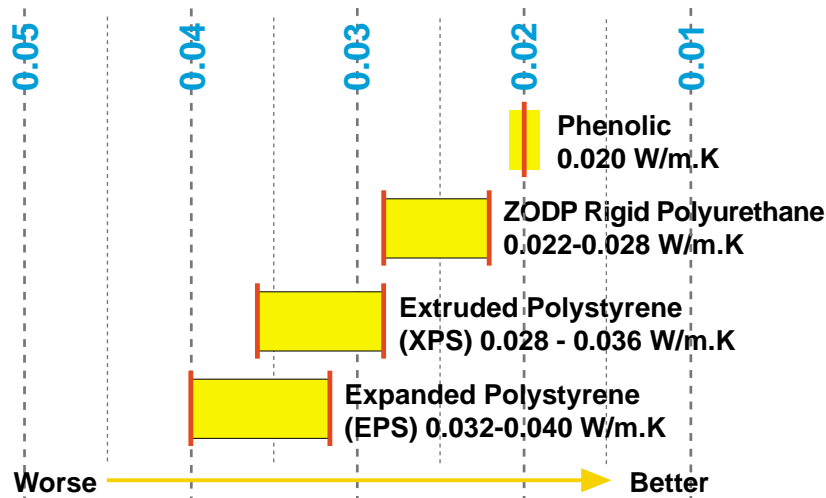
Heat loss rate: $W/m^2.K$

Lambda, thermal conductivity: $W/m.K$

thickness of material: m

Note: highly approximate, issues like thermal bridging must be considered

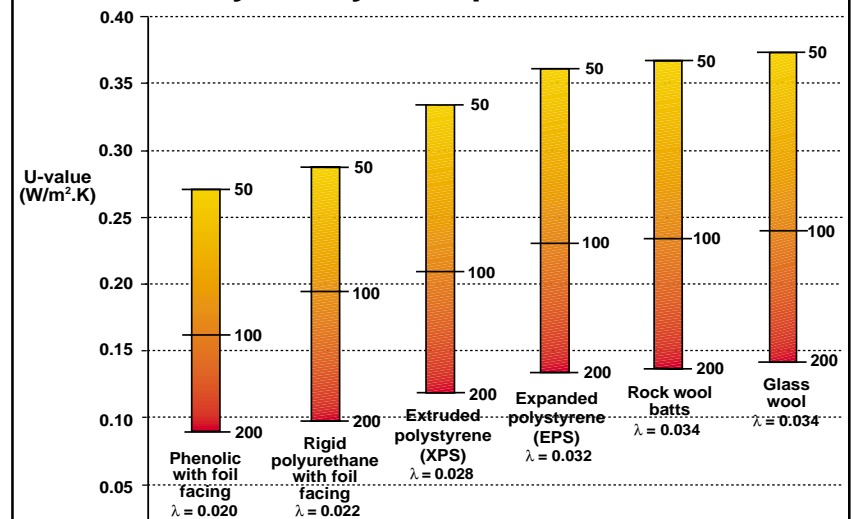
Cellular plastic



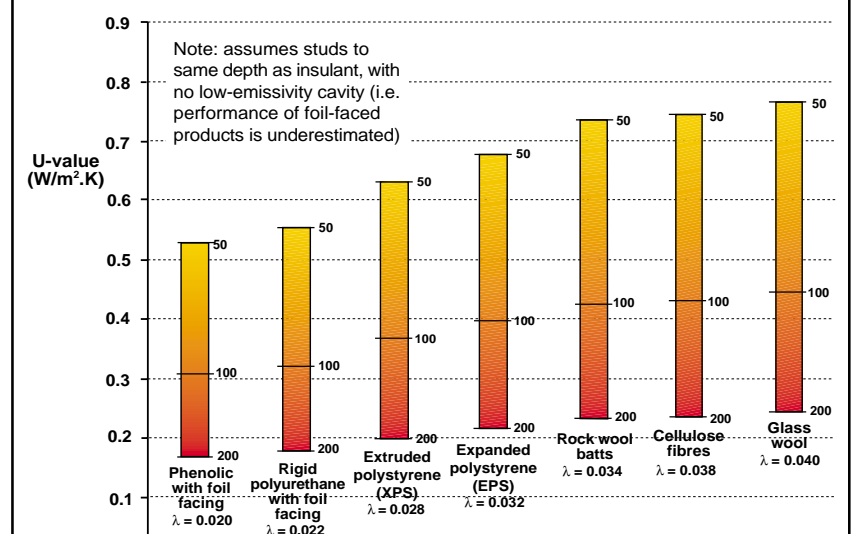
Thickness required to achieve specified U-values in walls

Note: based on 'typical' lambdas; actual values will vary with manufacturer

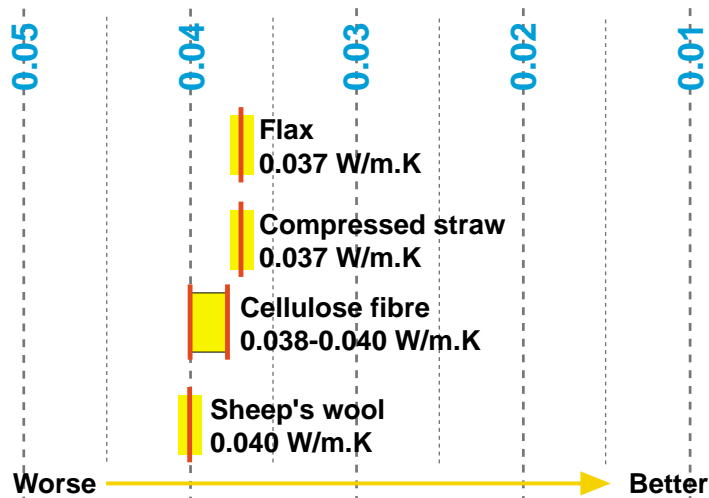
Masonry Cavity wall, partial fill



Timber-frame wall

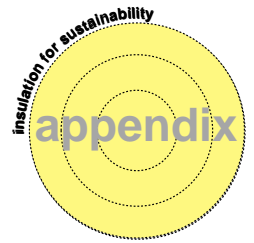


Plant / animal fibre

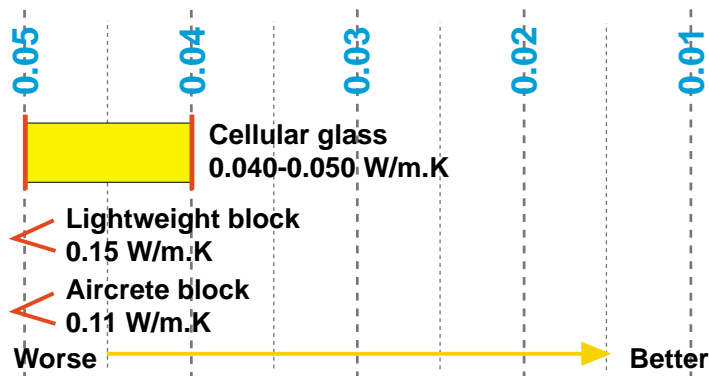


Lambda values / conductivity

Look-up charts on typical lambda values and typical construction thicknesses required for different U-values



Cellular mineral



The key equation relating U-value (heat loss rate) to lambda (thermal conductivity) and thickness (d)

$$U = \frac{\lambda}{d}$$

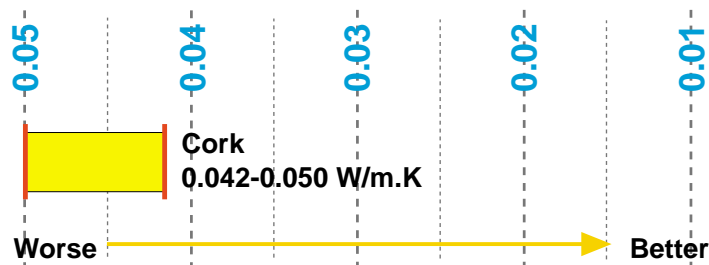
Heat loss rate U $W/m^2.K$

Lambda, thermal conductivity λ $W/m.K$

thickness of material d m

Note: highly approximate, issues like thermal bridging must be considered

Cellular plant derived



Future possibilities: Evacuated panels

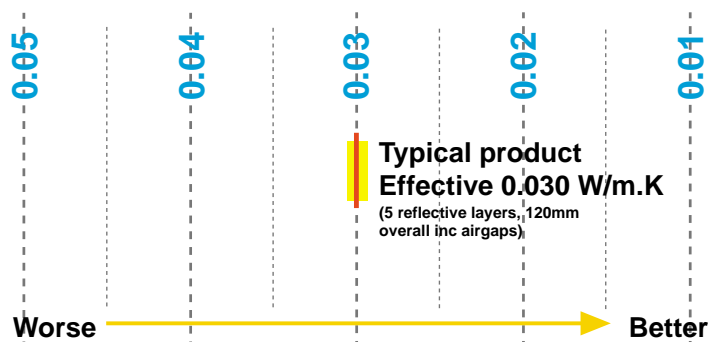
Evacuated panels can achieve extremely low lambda values in theory but are difficult in practice to manufacture (a few companies now claim to be developing them). The problem is keeping the skins (usually metal) apart with a low-conductivity material which doesn't become too much of a cold bridge. Once these technical barriers are overcome, the next problem is manufacturing at low enough cost. The first products available are likely to be for high-performance applications like refrigeration.

Note on breathing walls

Cellulose and natural fibres is commonly used in a 'breathing wall' construction, with no vapour barrier. It's not entirely clear what the benefits of this approach are, even amongst its proponents. In some respects it is a 'fail-safe' system - as there is no vapour barrier to puncture. There is concern though that moisture in the insulant may leach out fire retardants and/or cause settlement.

Radiant barriers

120 space mm 'including'



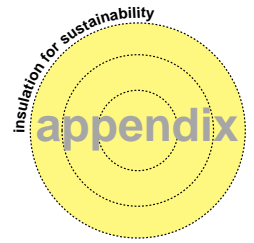
Note on Radiant Barriers

Assessing the overall effective lambda or U-value of radiant barrier insulation is slightly controversial because some manufacturers make claims not justified by the theory! (probably due to additional airtightness benefits when retrofitting historic buildings).

The lambda equivalent depends on the cumulative benefit of reflective layers of foil and air, and depends on the size of the air gaps, the fixing between layers and the conductivity of the fixings or interleavings.

Manufacturing process

Summary of key production steps and issues associated with each class of material - 1

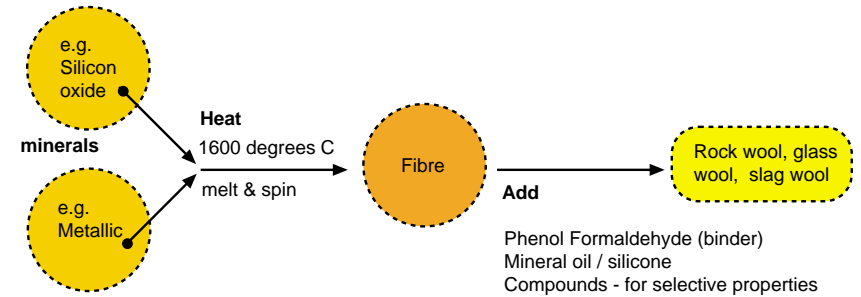


Mineral fibre

Products include - rock wool, slag wool and glass wool.

- Produced by melting at high temperatures and spinning into fibre.
- Binder added to give rigidity (quantity depending on application).
- Mineral oil or silicone often added for moisture resistance.
- End of life - recycling possible if not contaminated, currently landfilled in most countries.

Mineral fibre products

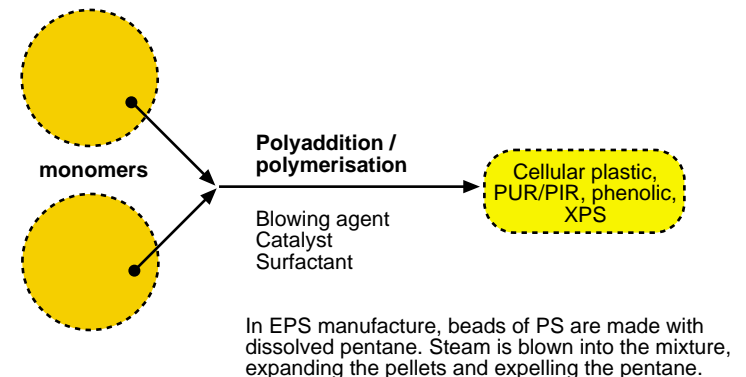


Cellular plastic

Products include - rigid polyurethane (PUR/PIR), phenolic, XPS and EPS.

- Produced by polymerisation using a blowing agent, catalyst and surfactant. EPS is slightly different >>.
- Some HCFCs currently still used in rigid polyurethane and phenolic as blowing agents (small ODP) - due to be phased out by 2004.
- Renewably-sourced monomers can be used in production (e.g. plant- or animal-based).
- End of life - incineration for energy recovery preferable, recycling is possible but dependant on stream quality and quantities.

Cellular plastic products

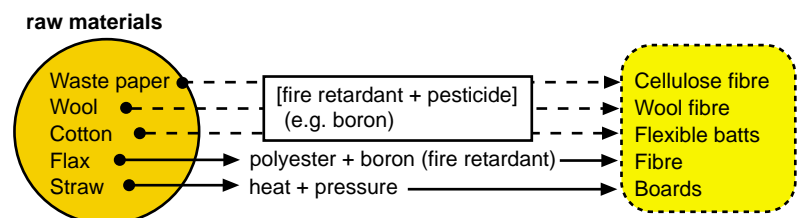


Plant / animal Fibre

Products include - cellulose fibre, sheep wool, cotton, flax and compressed straw.

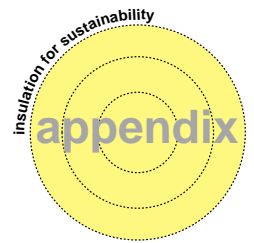
- Produced by treating plant or animal products, or waste newspaper, to form fibres, batts or boards.
- Fire retardants and pesticides are added to the raw material.
- End of life - energy recovery or landfill, although products treated with boron may require disposal to specified landfill sites. Incineration/energy recovery may prove difficult due to the addition of fire retardants.

Plant/animal fibre products



Manufacturing process

Summary of key production steps and issues associated with each class of material - 2

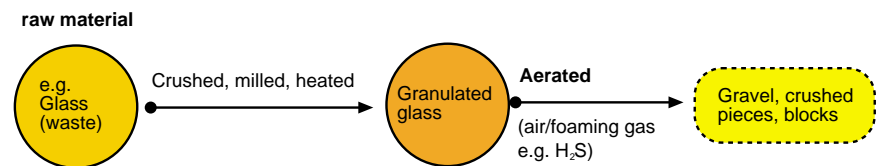


Cellular mineral

Products include - foamed glass, 'aerated' concrete, vermiculite and expanded clay pellets.

- Foamed material is produced by aerating (using air and/or foaming gas) granulated raw product in a furnace, or aerating a concrete slurry.
- Waste glass can be used in foamed glass production.
- Pre-1990 vermiculite (sourced from a particular mine) has been associated with asbestos contamination.
- End of life - glass and concrete products are theoretically recyclable, especially for aggregate.

Cellular mineral products (e.g. foamed glass)

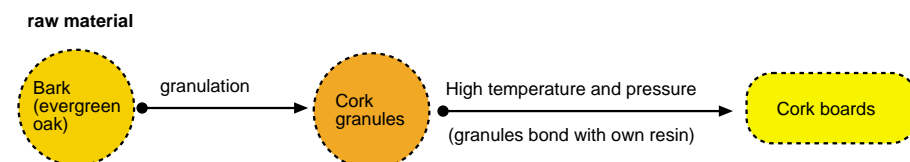


Cellular plant derived

Products include - cork.

- Produced by cooking cork granules at high temperature and pressure to form boards. Rubber/cork composites are also made with additives and binders.
- Renewable source with virtually no pollution associated.
- Large-scale availability not guaranteed and relatively expensive.
- End of life - incineration energy recovery or landfill.

Cellular plant derived (cork)

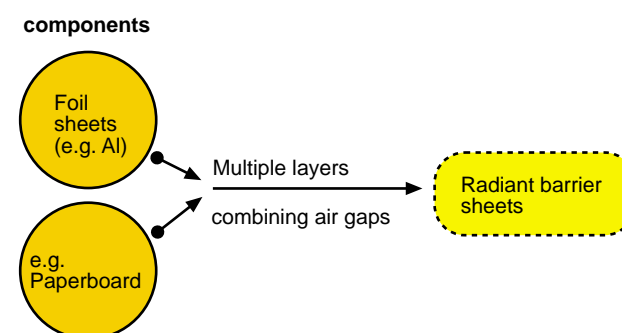


Radiant barriers

Products manufactured from multiple layers of (e.g.) foil-faced polyethylene sheet, foil-faced paperboard and bubble pack, or open-cell flexible foam.

- Produced by creating multiple layers of foil (usually aluminium) with air-gaps that are reflective to short-wave thermal radiation.
- Susceptible to loss of performance over time through build-up of dust and dirt and corrosion of foil.
- End of life - theoretically foil layers are recyclable, landfilling.

Radiant barriers



- 1
The World Environment 1972-1992 - Two Decades of Challenge. Tolba, El-Kholy, Holdgate, McMichael (eds), Kluwer Academic Publishers for United Nations Environment Programme, 1992
- 2
Intergovernmental Panel on Climate Change, Third Assessment Report: Climate Change 2001. July 2001 www.ipcc.ch
- 3
Based on Assessment of Potential for the Saving of Carbon Dioxide Emissions in European Building Stock. Report to EuroACE by Caleb Management Services, May 1998
Report is available on www.euroace.org, referred to as CALEB 1.
- 4
Factor Four: Doubling Wealth, Halving Resource Use, by von Weizsäcker, Lovins, and Lovins, 1997. ISBN 1853834068
- 5
European Social Statistics: Income, poverty and social exclusion. Eurostat, ISBN 92-828-9034-1
- 6
Best available technologies in housing, Case Study UK. A study as part of MURE II project, an EU SAVE project (Mesures d'Utilisation Rationnelle de l'Energie) www.mure2.com
- 7
These are based on UK figures, but the EU figures are very similar.

UK Data:
Domestic Energy Fact File 1998; BRECSU, LD Shorrocks and G A Walters

Energy Use in Offices, ref EGC 019. Published by Energy Efficiency Best Practice Programme, UK Government. www.energy-efficiency.gov.uk

EU Data: available from DG TREN, or for example in the presentation Improving the Energy Efficiency of Buildings, downloadable from the EuroAce website. www.EuroAce.org
- 8
English House Condition Survey 1991- Energy Report - UK Department of the Environment, 1996; and [Ref: 3]
- 9
David Olivier, Energy Efficiency and Renewables: Recent Experience on Mainland Europe, 1992 • ISBN 0-9518791-0-3
- 10
Authors note: There are a wide variety of embodied energy figures quoted in different studies. The Buchanan and Honey study (see below) quotes figures ranging from 64 – 154 MW.h depending on

construction materials (an average of 109 MW.h). The Newton/Westaway report quotes figures indicating an embodied energy of 21 MW.h/house on average. A BRE study of 1991 quotes figures of 28-70 MW.h for UK houses (an average of 49 MW.h). We have assumed what we consider a 'safe' (i.e. high) average of these and other figures for embodied energy for new-build of 80 MW.h per house, with a complete energy refurbishment at 15% of this, 12 MW.h per house.

Importantly the overall trends in the model on pages 40-41 remain the same within a wide range of values for newbuild embodied energy – the figure has to increase fourfold before any change is reached in the hierarchy of best overall energy saving.

Buchanan, A.H. and B.G. Honey. 1994. Energy and Carbon Dioxide Implications of Building Construction, Energy and Building 20: 205-217.

Embodied energy in residential property development - A Guide for Registered Social Landlords by John Newton and Nigel Westaway. Published by Sustainable Homes, a UK site www.sustainablehomes.co.uk

11
The INDEX model developed by Simos Yannas and colleagues at the Architectural Association School of Architecture, London. Calculation sheets are contained in Solar Energy and Housing Design, Simos Yannas, 1994, published by Architectural Association publications, 2 volumes, ISBN 1 870890 45 0

12
The Ecology of Building Materials by Bjorn Berge, Architectural Press, ISBN 0 7506 3394 8

13
After a study by Albrecht. Cell-gas composition - an important factor in the evaluation of long-term thermal conductivity in closed-cell foamed plastics, Cellular Polymers, Vol 19, no 5, 2000

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Building Physics in a Roof with two trapezoidal sheets, H Weiland, Weiland Engineering AG

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Montreal Protocol on substances that deplete the ozone layer. 1998 report of the flexible and rigid foams technical options. UNEP, December 1998

16
Thermal insulation and its role in carbon dioxide reduction, a research report by Paul Ashworth of CALEB Management Services, Arran Cottage, 6 the Row, Aust, Bristol, BS12 3MAY

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ENVEST - www.bre.co.uk/sustainable/envest.html

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The Green Guide to Specification Third Edition, by Anderson, Shiers, and Sinclair, January 2002. Blackwell Publishing, ISBN 0632059613

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Forum for the Future, think tank and research group on sustainable development. www.forumforthefuture.org.uk

Association for Environment Conscious Building, UK, publishers of Building for a Future magazine. www.aecb.net

Green Building News - US publication and website. www.buildinggreen.com

EuroACE, European Alliance of Companies for Energy Efficiency in Buildings

Some useful studies on the importance of building energy and the savings possible through efficiency. www.EuroAce.org

Climate Care, charity offering personal and corporate carbon offset through renewable energy and forestry. www.co2.org