Section 2: Sustainable Design and Construction

2.1: Sustainable Design Strategies

The chief goal of any sustainable design strategy is to provide healthy and comfortable interior spaces, in structures that are both energy and resource efficient. To this end, a number of different, but sometimes overlapping, strategies have been developed, such as 'passive solar', 'bioclimatic', 'low energy', and more recently 'Autonomous', 'Zero CO_2', 'Passive House' and 'Low-Heat'. These will be explored in detail later, following an examination of some common themes.

In practice, decisions have to be made fairly early on in the design process that influence the construction method, materials used, recyclability, durability and the energy efficiency of the whole project. Put simply, the choice at this stage is between a heavyweight or lightweight building, which in turn presupposes a choice between a monolithic or framed structure.

A heavyweight building will tend to be of monolithic construction. That is, all the walls are fully loadbearing and cannot be moved or pierced without supporting the structure above. In this case, the structure also provides thermal mass, sound insulation and impact resistance.

In lightweight buildings, made from timber, steel or concrete posts and beams, the frame itself provides all the necessary structural support. The walls are non-loadbearing and complete the envelope by 'infilling' between the posts. These framed buildings can incorporate high levels of insulation and energy efficiency, and moreover offer a greater degree of 'planning freedom' (internal organisation) and flexibility for future use. The specific benefits of timber frame housing are discussed in Section 2.2.1.

2.1.1 Structural Type

High thermal mass materials are dense, heavy, solid and compacted. Good examples are mass concrete, dense concrete blocks, bricks, stone and rammed earth (see Table 1). They can be used for any building element - walls, roofs or floors. They are relatively good conductors of heat, and therefore poor insulators. Their large capacity for storing heat (thermal capacity), makes them an essential element of Passive Solar Design.

Table 1. The density, thermal conductivity and thermal capacity of a range of materials [1]

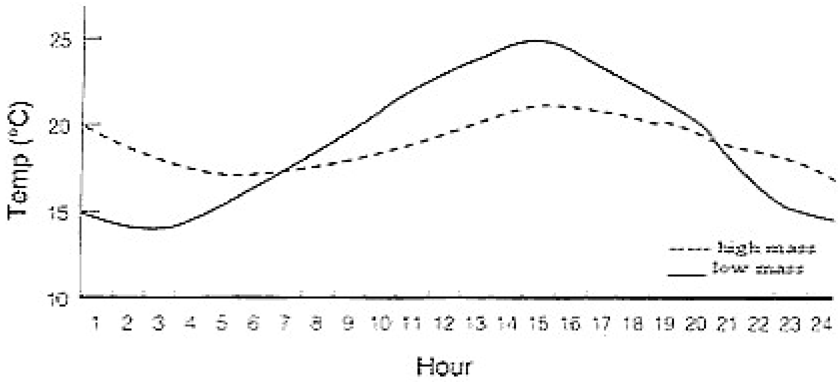
Material	Density kg/m^3	Conductivity W/mK	Thermal Capacity kJ/m^{3}K
Mineral fibre insulation	25	0.04	20
Timber	630	0.06	260
Brick	1700	0.62	1360
Stone	2180	1.50	1570
Dense concrete block	2300	1.63	2300

Water	1000	1.90	4200

Low thermal mass materials are lightweight, insulative, and have a low thermal capacity. Examples that can be used structurally include timber and straw. Unlike the more common high thermal mass materials mentioned above, they tend to be plant-based and renewable.

The advantage of high thermal mass in low energy design is that it will absorb excess heat (eg from solar or incidental gains) and release it when the surrounding temperature drops. A heavyweight building will also heat up and cool down over a longer period (known as 'slow response'), than a lightweight building ('quick response'). In this way, thermal mass stabilises internal temperatures, eliminates thermal peaks and troughs, and thereby reduces the demand on the heating and cooling systems (see Figure 1).

Figure 1: Internal temperatures on a hot day in buildings of high and low thermal mass [2]



Brenda and Robert Vale quote a study of 28 lightweight timber houses in New Zealand, which showed that with the addition of a concrete ground floor slab, the heating costs were reduced by 40 percent. [3]

On the other hand, many energy design experts believe that super-insulation and air-tightness are more important than thermal mass in reducing heating demand. For example, in the Pennylands housing scheme in Milton Keynes (an early example of passive solar design) 180 houses were extensively monitored for energy consumption. In these houses, it was found that the 100mm of Rockwool insulation in the wall cavity had a far greater effect than the thermal mass on fuel consumption. [4]

A study by Smithdale in 1997 looked at five sites around the UK from Plymouth to Aberdeen, and found that the difference in energy use between heavy and lightweight buildings was never greater than 5 percent. [5]

It has been found, from both experimental observation and mathematical modelling, that during a normal diurnal cycle, 90 percent of recoverable heat is contained in the first 50mm of dense concrete and 50 percent in the first 25mm. [Ibid] Thus, for thermal storage over a 24 hour time span, there seems little to be gained from high thermal mass, and a double thickness of 12.5mm plasterboard in a lightweight building could provide reasonable heat storage (the thermal capacity of plasterboard is 1050kJ/m^{3}K, which is roughly the same as lightweight concrete block).

Heavyweight buildings will perform best when there is a fairly constant occupancy, with relatively few heat-up and cool-down periods. The prevailing climate also needs to have a significant diurnal temperature range to take advantage of evening heat release, or nighttime cooling of the structure.

There is certainly an appropriate depth and exposure for thermal mass to work effectively (see Figure 2), and 'the more, the better' rule does not necessarily apply. Indeed, noting the high energy cost of transporting heavy bulky materials, the Vales suggest that "one of the potential disadvantages of thermal mass… is its mass". [6]

Figure 2a: Concentrated distribution of mass

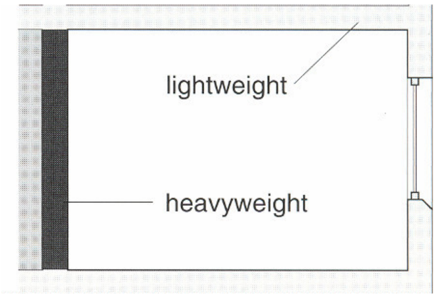


Figure 2b: Same amount of mass, evenly distributed

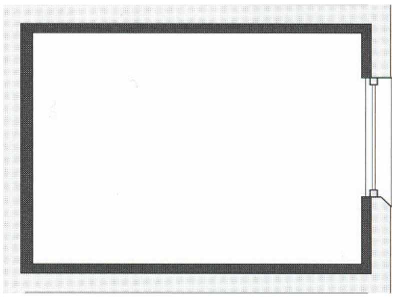
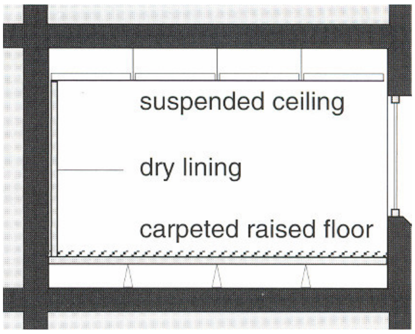


Figure 2c: Thermal mass isolated by lightweight finishes



It is important that there is a high degree of ‘coupling’ between the mass and the heated space. The same amount of mass is shown in Figures 2a and 2b, but it is far more effective in 2b because more of it is exposed to the room. In Figure 2c, where lightweight finishes isolate the mass, it will have little effect on the thermal performance of the building.

Carpets, net curtains or wall hangings can all interfere with the effective transfer of heat and negate the theoretical advantages of thermal mass. For the system to work, all present and future users of the building therefore need to understand how the mass works, and possibly modify their tastes and habits.

The Vales refer to a ‘mid-mass’ version as a “typical UK house, with a carpeted concrete ground-floor slab, aerated-concrete-block inner leaf to cavity walls and timber/plasterboard first floor” [7]. Unfortunately, it seems likely that this configuration actually combines the worst aspects of both types.

In effect, this is not so much a choice between two ideal types, as a question of degree. All buildings contain some level of thermal mass and increasingly eco-designers are looking at hybrid models to combine the advantages of lightweight and heavyweight construction. Thus, a lightweight, airtight, superinsulated building may have localised exposed thermal mass in a position where it can absorb maximum direct solar gain.

2.1.2 Passive Solar Design (PSD)

An essential part of any sustainable design strategy is a consideration of how to maximise the use of renewable sources of energy. PSD uses the design and fabric of the building to admit and store solar heat automatically, using the building itself as a solar collector, and relying on natural rather than artificial controls. It assumes an energy efficient design overall, without which the whole strategy would be much less effective. Essential elements of energy efficient design are examined later in this Section.

There are a number of design considerations that must be incorporated into a successful passive solar design:

Orientation

Ideally, in the northern hemisphere the building would 'face' due south to receive maximum solar gain. In practice, it is generally agreed that up to 30º either side of south is acceptable, with a preference towards south east, to maximise early morning heat gain after the house has cooled down overnight, and to minimise afternoon overheating.

Layout

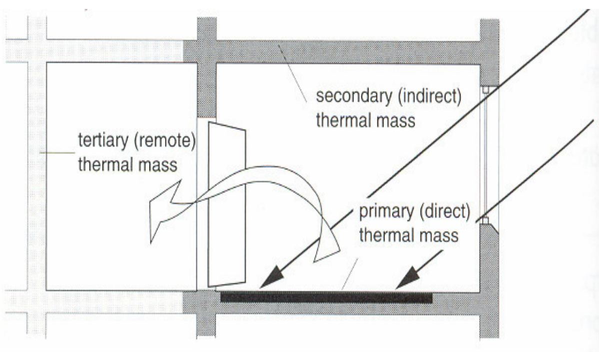
This refers to the internal organisation of rooms and spaces. Main living spaces, play or leisure rooms, kitchen/dining areas and possibly the main bedroom should be located to the south (or south east, or south west) of the building. Bathrooms, utility and storage areas, and possibly a study or guest bedrooms, should be located towards the north.

Building form

The actual shape of the building is an important factor in determining heat loss and solar penetration. To minimise heat loss, it is necessary to minimise the 'surface area : volume' ratio. The most efficient shape to build from this point of view is therefore a sphere or (failing that!) a cube. To maximise the areas receiving direct solar radiation however, for heating and daylighting purposes, it is better to have a long shallow plan.

The houses at Hockerton (see Figure 3), which rely totally on solar heating (and incidental gains), are only six metres deep, which allows all areas to benefit from primary or secondary solar gain.

Figure 3: Hockerton Housing Project, where the narrow floor plan allows the whole house to benefit from solar gain



Glazing

"One of the largest single factors affecting building energy consumption is the location and size of windows." [8] Typically, passive solar buildings will have large glazed areas to the south, moderate amounts of glazing to east and west, and minimal glazing to the north (see Figure 4).

Figure 4: The south facade of St George's County Secondary School in Wallasey, built in 1962 and the first major public building in the UK to be designed according to PSD principles.

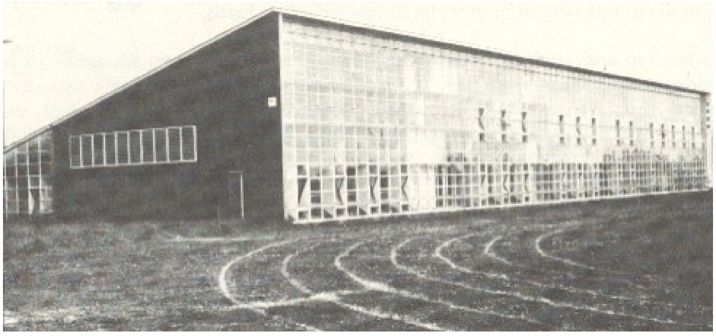
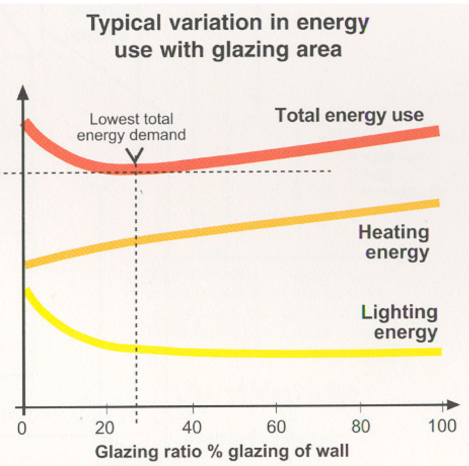


Table 2: Principal Heat Sources for the Wallasey School [8]

Source	Percentage of heating supplied
Solar energy	50
Incandescent lights: 1300 in classrooms, 2400 in art rooms	34
Students: 15-35 per class	16

Glass will always be an area of relative heat loss compared to opaque elements; however, its unique ability to admit solar radiation, while trapping long-wave (heat) radiation, is what makes solar heating possible. A good energy efficient design will use glazing to optimise heat gain, daylighting and views, and to minimise heat loss. Figure 5 shows that glazing of 25-30 percent of wall area is most effective in reducing overall energy use.

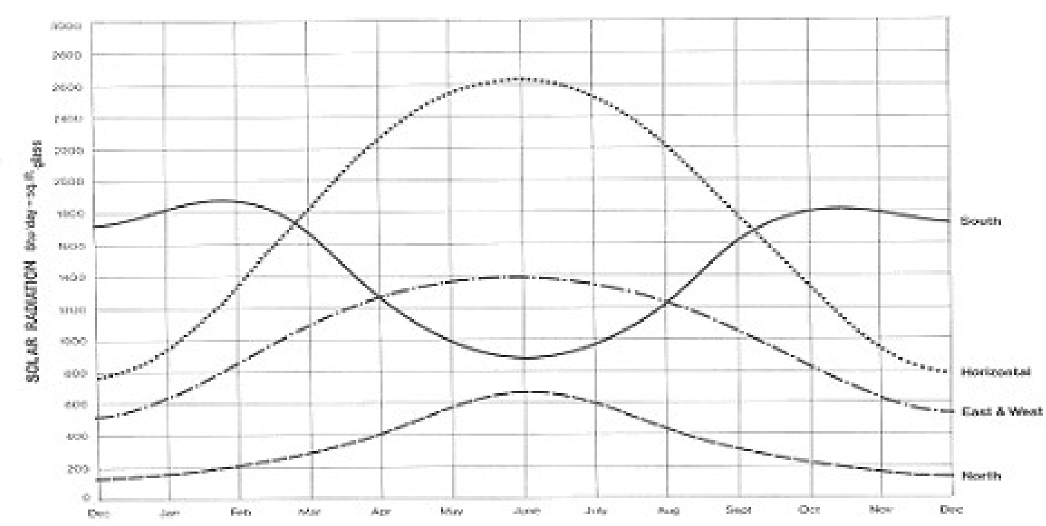
Figure 5: Typical variation in energy use with glazing area [9]



Shading

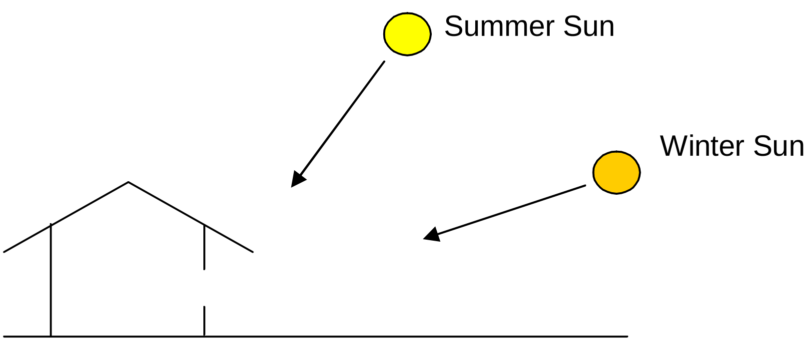
In winter, the south side of a building will receive nearly three times more solar radiation than the other facades, while in summer, south facing windows will admit a third less radiation than east and west facing glass (see Figure 6). This is because the midday sun is virtually overhead in mid-summer, whereas the lower position of the sun in winter allows deeper penetration into the building. Thus, southerly orientations have an element of natural protection against overheating in the summer.

Figure 6: Shows clear day solar radiation values for 40º Northern Latitude on windows of different orientations, with a horizontal reading for reference [8]



Shading devices such as roof overhangs, reflective blinds, louvres or shutters can be used to further screen out summer sun while admitting winter sun, as shown in Figure 7.

Figure 7: Simple Passive Solar Principle



Thermal mass

Once solar heat is admitted into the building, it should be stored until temperatures drop in the evening. High thermal mass materials, such as concrete walls or floors, are ideal for this purpose, but they must be left exposed and ideally finished with a dark colour. Lightweight buildings will still contain some degree of mass, and this can be increased in locations that ‘see’ maximum solar gain.

Protected entrances

Often, south facing (or SE / SW facing) conservatories will be added onto conventionally built older houses, or incorporated into new houses, thereby delivering some of the benefits of PSD. Conservatories, lobbies or porches around external doors will all provide a 'buffer space' between inside and outside the building. With some solar gain, this space will always be warmer than the outside air, thereby reducing heat loss through the wall. It also acts as a kind of 'air lock' to prevent outside air from entering the house directly. Instead, on a typical day when external temperatures are lower than internal temperatures, incoming air will have been slightly warmed, which is known as 'solar pre-heat'.

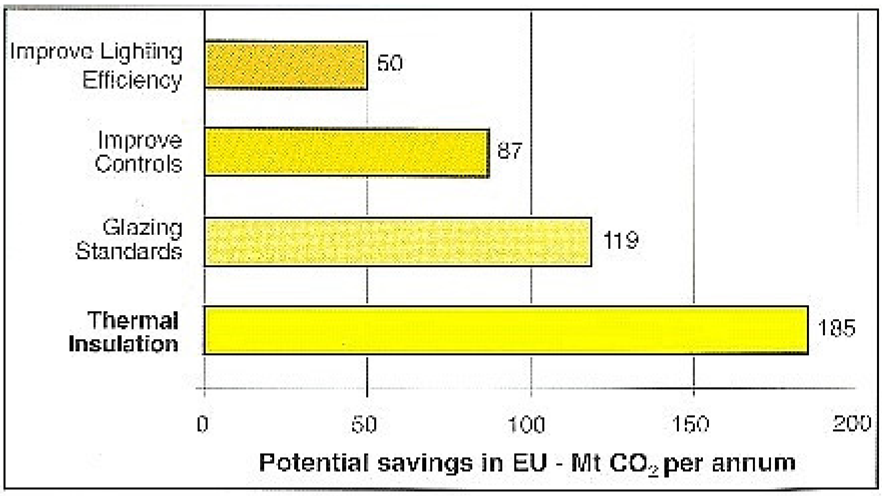
Conservatories are popular mainly because they provide external conditions of daylight in relative comfort - a sort of outside room. As a result, people will try to extend the period of the year during which they can be used comfortably, which invariably means heating them. In such highly glazed spaces, this is extremely inefficient and wasteful, and so conservatories should ideally be left unheated. If they are heated, then the glazing should be as efficient as possible.

In some situations it is just not possible to use a southerly orientation for PSD, because of surrounding buildings or roads, or the location of views or open spaces. It is still possible to build an ultra low-energy house in these cases however, by incorporating the design strategies set out in the following sections.

2.1.2a Super-insulation

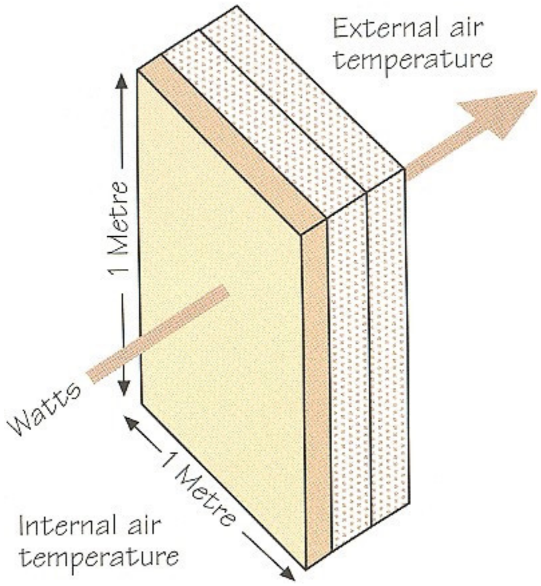
Insulation materials act to reduce heat flow through a material or building element, and installing high levels of insulation is the single most important measure that can be taken to reduce heat loss (and CO_2 emissions) in any new or existing building, as shown in Figure 8.

Figure 8: Evidence that insulation gives the greatest CO_2 savings of all energy efficiency measures [9]



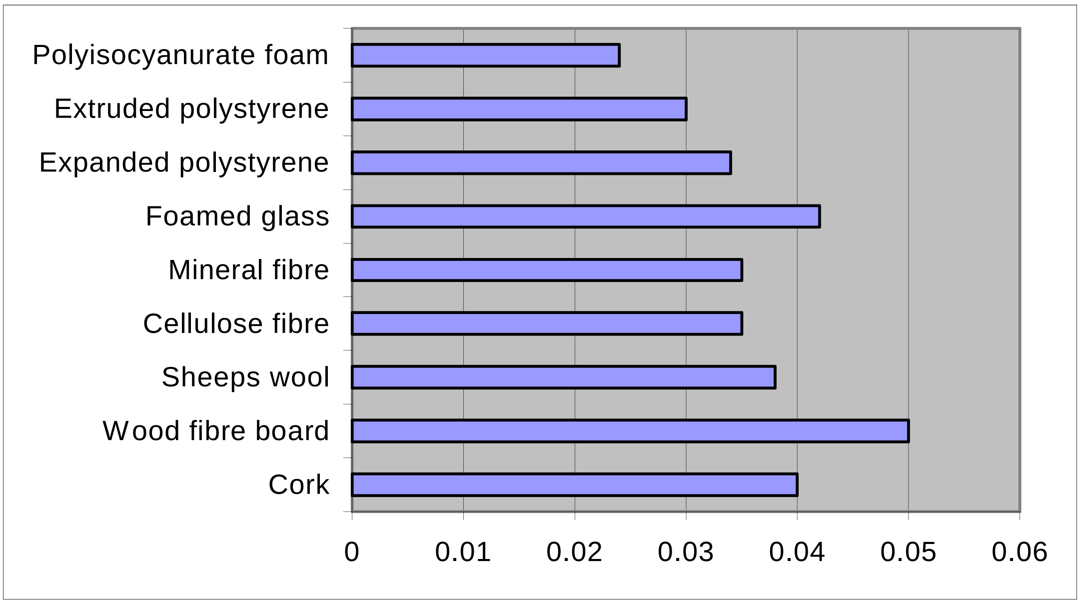
The rate of heat loss through a unit of construction is known in the UK as its U-value. This measurement is dependent on the thickness and conductivity (λ) of all the materials used in the construction, and refers to the amount of heat lost (W), per square metre, for every degree of temperature difference (K) between inside and outside (see Figure 9). The unit of measurement is W/m^2K, where W = Watts and K= Kelvin or ºC, and the lower the U-value the greater the level of insulation.

Figure 9: How U-values are measured [10]



Different materials have different inherent conductivities and therefore different insulating values. Basically, the best insulation materials are light and fluffy, with maximum air entrapment, as air is an extremely good insulator when convection losses are restricted.

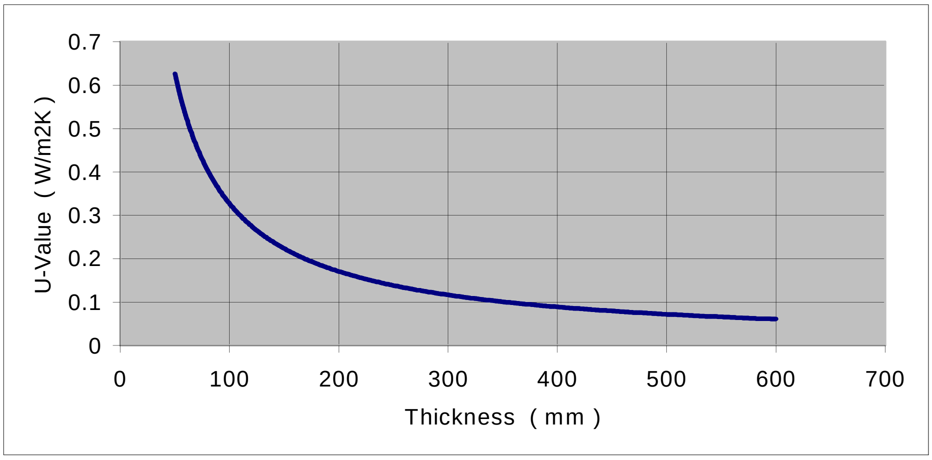
Figure 10: Conductivity values (λ) of common insulating materials in W/mK (the lower, the better) [10]



From a Life Cycle Analysis (LCA) based approach, renewable materials such as cork and sheep's wool, or recycled materials such as cellulose fibre, are the preferred insulation type. Any lack of performance due to an inferior conductivity can be more than compensated for by an increase in thickness.

The next question is how thick does the insulation have to be? Most energy saving is achieved in the first 100mm of insulation, then half as much with the next 100mm etc. (see Figure 11). Real benefits in lowering U-values continue to be shown for insulation levels of 500-600mm.

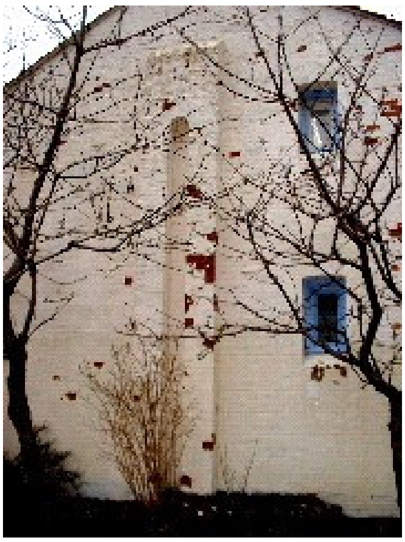
Figure 11: Achieved U-values against thickness of insulation [10]



Generally, super-insulation levels are taken to be in the range of 300-450mm, depending on the element in question. For example, a roof space can easily take increased depths of insulation without affecting the construction, and is particularly effective in preventing rising heat from escaping. With a solid ground floor or masonry wall, there may be structural reasons for not exceeding the statutory limits.

It is easier to insulate the walls of a framed building to a higher standard than monolithic masonry walls. Non-loadbearing infill walls can be made to virtually any thickness, for example with a spaced-stud construction. Double skin brick-and-block walls, however, are normally tied together across a cavity of restricted depth. An exception to this general rule is the Wates building at the Centre for Alternative Technology (C.A.T.), built in 1976, which is still the best insulated house in the UK. The brick-and-block walls of this house have a 450mm cavity filled with glass-fibre insulation, and the two skins are too far apart to be tied together. A number of extra piers and buttresses had to be added instead, to maintain the structural independence of the two skins (see Figure 12).

Figure 12: Brickwork buttress on gable wall of Wates building at C.A.T.



2.1.2b Daylighting

For Europe as a whole, 10 percent of all energy use goes on artificially lighting buildings. The lighting energy demand of non-domestic buildings, in particular, will often exceed the heating demand. The importance of using energy efficient luminaires and effective lighting controls is therefore clear.

The overall demand for artificial lighting within a building can be reduced by good daylighting design. For example, interiors with windows on more than one side usually provide a good quality distribution of light. Judiciously placed windows can offer pleasing views as well as admitting daylight. Roof windows admit more daylight per unit area than vertical windows. Lightpipes can bring daylight into the centre of deep plan buildings, or to rooms located on the north of a passive solar house. In addition to the energy-saving benefits, well daylit rooms have a 'feel good' factor and lift the spirits of the occupants, compared with dark or artificially lit rooms.

Studies conducted in the USA show that retail sales are boosted by an average of 40 percent in stores that have daylighting via rooflights, compared to those which did not. "Statistical analysis found a 99.9% certainty that this is a true effect associated with daylighting" [11]. A second study, which looked at student performance in daylit and non-daylit schools, found that students in classrooms with daylight had a 20 - 26 percent faster learning rate, with the best results seen in classrooms with light-diffusing skylights.

As windows are always an area of relative heat loss, the efficiency of the glazing system merits close attention and investment, particularly in a passive solar design, which by definition will have large glazed areas. A minimum standard should be double glazed units with a low-E (low emissivity) coating, and an inert gas such as argon or krypton in the cavity. This system will give a U-value of 1.8-2 W/m^{2}K; roughly equivalent to ordinary triple glazing.

Care should be taken to avoid 'glare' or excessive contrast caused by a single, overly bright light source.

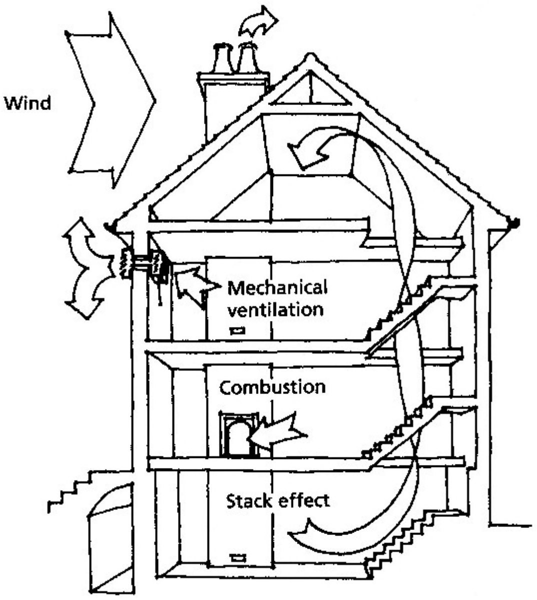
2.1.2c Ventilation and Air-tightness

The importance of these two components for the ultimate success of an energy efficient design has only recently been fully recognised. In a 'leaky' house, the uncontrolled air movement can reduce the effectiveness of the insulation by up to two thirds [12]. The incoming set of UK Building Regulations (2005) is, for the first time, to include a requirement for minimum air-tightness standards in new houses.

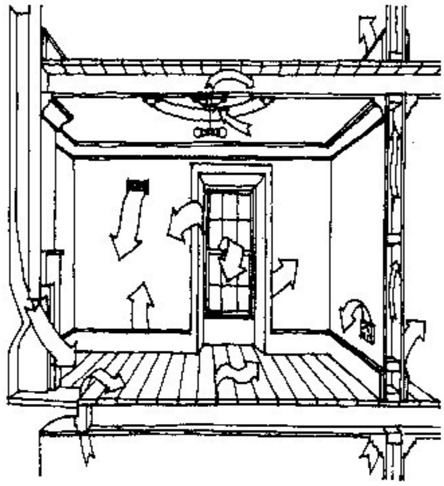
Air leakage is not the same thing as ventilation. The former is uncontrollable, inefficient and reduces thermal comfort; the latter should be well controlled, operate effectively with minimal energy input, and improve indoor air quality. Air-tightness and ventilation are both necessary and should act complementarily in a low-energy design.

Air leakage, or infiltration, occurs since air will always flow to neutralise pressure differences, some of the causes of which are shown in Figure 13. There are a number of typical entry points, as shown in Figure 14, such as joints in the building fabric around windows and doors, loft hatches, floorboards and skirtings; where pipes or cables pass through building elements; or a combination of the two.

Figures 13 & 14: Causes and paths of passive air leakage [13]



Causes of pressure differences.



Paths of least resistance.

Air-tightness / leakage is measured typically in air changes per hour at 50 Pascals (Pa) pressure difference between inside and outside (ac/h@50Pa). This involves testing a building by slightly depressurising it, and then measuring the air ingress. It is an instructive exercise for both designers and builders to note the sites of major leakage, although sadly it is usually done at too late a stage to make any basic alterations, if at all. A reasonably good standard for current low-energy buildings to achieve would be 3 ac/h@50Pa, although the German Passivhaus standard calls for 0.8 ac/h@50Pa (see Section 2.1.6b).

Once the building has been made as airtight as possible, it is then necessary to ensure adequate ventilation. Background ventilation can be provided (and controlled) by trickle vents in window frames, for example. Particularly humid areas such as kitchens and bathrooms can be vented at source, using ‘passive stack’ ventilation or mechanically driven fans. Ideally, humidity-sensitive valves and switches would control both.

Whole-house ventilation systems are also available, whereby stale, humid air is extracted and passed over a heat exchanger before being vented to the outside. Around 70-80 percent of outgoing heat is thereby recovered, and used to preheat the incoming fresh air that is ducted to living areas. This arrangement is known as mechanical ventilation with heat recovery, or MVHR systems. In airtight houses, MVHR can provide a high standard of draught-free comfort, and in very low-energy houses, they can serve as the heating system as well. If they are to be genuinely energy-saving, it is important to choose a system with low wattage fans and large diameter ducts to minimise resistance to air movement.

Well-designed and functioning ventilation systems, together with high levels of insulation and airtightness, contribute significantly to healthy buildings and good indoor air quality (IAQ). Thermal comfort is provided by constant temperatures and the absence of draughts; visual comfort by adequate daylighting and the absence of ‘glare’. Indoor pollutants should be vented away without loss of comfort, and levels of relative humidity (RH) should be maintained within the desired zone of 40-65 percent.

RH levels are particularly important for the health and comfort of occupants. If they are too low, it can result in a drying out of mucous membranes, causing dry throats and itchy eyes. If they are too high, it can lead to the growth and spread of mould spores, which can cause allergic reactions in some people.

2.1.2d Designing in Renewables

Passive Solar Design is based on a renewable source of energy which is both financially and environmentally cost free. The size of our solar resource is enormous and almost incomprehensible. The sun provides a constant 173,000 terawatts, whereas world fossil fuel use is only 12 terawatts. The solar energy falling on the earth in one hour is equal to the annual world demand for fossil fuels. We only need to harness a tiny proportion of solar energy to make a huge difference to our impact on non-renewable resources.

Solar space heating

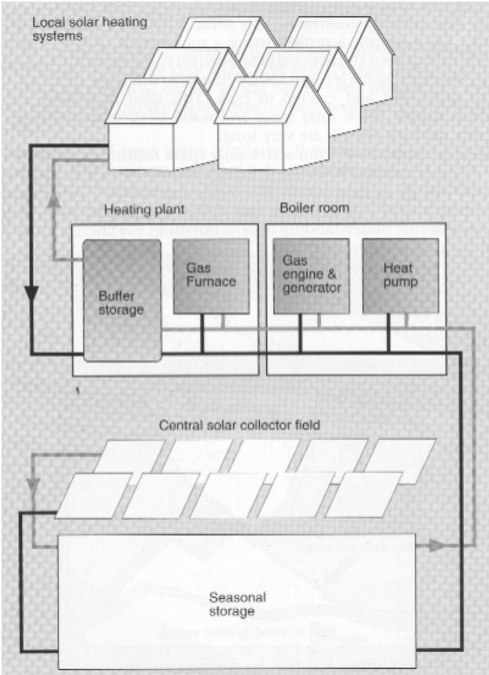
We have seen how, given a good, holistic, energy-efficient design, solar energy can make a significant contribution to meeting the demand for space heating. Occasionally, we see exemplary schemes where solar heat and incidental gains are the only heat sources in a building. The kind of solar heating described in Section 2.1.2, where building elements themselves act as the heat store and emitter, is known as a 'Direct Gain' system.

Indirect systems incorporate a separate heat store that acts as a moderator between the solar collector and the living space. One example of this is a Trombe wall, where a masonry wall is placed just behind a glazed facade and the air in between is heated and ducted to the inside (see Figure 15). The wall can also conduct heat through to the inside, but usually it is too thick to be useful over a 24-hour period. Alternatively, water can be used in transparent tanks behind glazing, as its high specific heat makes it an ideal heat storage medium.

Figure 15: Staff cottages at C.A.T. that feature a Trombe wall at the left-hand end of the terrace

Because of the fickle nature of the solar resource in Northern European climates (i.e. the sun doesn't shine every day) a heat store that lasts longer than 24 hours was designed to give an inter-seasonal heat store. In this system, solar heated water is stored in super-insulated underground tanks throughout the summer, and used for space heating six months later. This is often used in district heating schemes because of the large scale necessary to make it efficient. The system illustrated in Figure 16 is situated near Copenhagen, and uses a gas powered heat pump when the temperature in the tank falls to 45°C. A gas boiler is available as back-up.

Figure 16: Schematic of a solar powered district heating system in Denmark [14]



Solar Water Heating (SWH)

Once the space heating demand has been reduced to a minimum, domestic hot water represents the largest energy savings possible in the average home. Solar energy can be used to meet at least part of the hot water demand, via solar thermal panels mounted on a south (-ish) facing roof. There are many different types of panel available in the UK, the differences being in the cost and efficiencies. The basic components of a 'flat plate' collector (the most common generic type) are:

- a metal plate with water running through it. The simplest of DIY panels often use old radiators. Being highly conductive, the metal transmits solar heat to the water.
- an absorbent surface. Often this is simply a coat of black paint, but special 'selective surfaces' can be used to increase the absorption of solar energy even further.
- insulation behind the metal plate, to prevent heat loss through the back of the panel
- glazing over the front of the plate, to admit full spectrum sunlight and prevent heat energy from escaping

Solar thermal panels are usually sized to meet the total hot water requirement in mid-summer, and they still make a useful contribution at other times of the year by preheating the water, so that less fossil fuel based energy is needed to reach the set temperature. A 4m^2 panel will typically produce 50-60 percent of the hot water demand in an average house.

Solar electricity

Photovoltaic (PV) cells generate electricity directly from sunlight. To generate the electricity used by the average house in one year requires about 40m^2 of PV. The main barrier to using this technology at the moment is cost - the 40m^2 would cost about £28,000. It is anticipated however that costs will fall with increasing levels of subsidy and economies of scale. The USA and Japan have launched programmes to build one million PV roofs with government subsidy, and the UK government has made £20m available through the DTI, to part-fund appropriate PV installations.

This technology could be mounted on virtually any roof of any building in the country. The potential is enormous for the fabric of a building to be used to generate the electricity consumed within it. Rather than using panels stuck on top of a roof however, the industry and designers are now more interested in 'building-integrated PV'; where the PV panel itself forms the waterproof cladding, replacing slates or tiles.

Other renewables

Wind and hydropower are less directly applicable to individual buildings, and work more efficiently at a much larger scale of installation. It is now possible however, for every householder to purchase electricity from a 'green' supplier, which guarantees that at least part of the supply will come from renewable sources and/or that money will be invested in new renewable generation.

2.1.2e Efficient Heating and Appliances

Although this final issue completes the checklist for energy efficient design, its consideration should not be relegated to the latter stages of a project. The choice of heating system and type of fuel is integral to the energy performance of the whole building, and can impact upon the choice of structure, materials and internal finishes made at the design stage. The following considerations should inform an energy efficient space and water heating strategy:

Choice of fuel

Assuming that the potential for renewables has been explored, there may well still be a need for a backup source of heat derived from fossil fuels. In this case, it is important that the 'cleanest' (in terms of CO_2 emissions) of the fossil fuels be specified. Currently, this is mains gas, followed by LPG (Liquid Petroleum Gas: pentane and butane), oil and then the solid fuels such as coal and coke. Fortunately, mains gas is also the cheapest fuel. All of these energy sources are of course non-renewable, some have very limited reserves left, and all of them, especially oil, are subject to price fluctuations, especially as the supply becomes more precarious.

Sizing and zoning

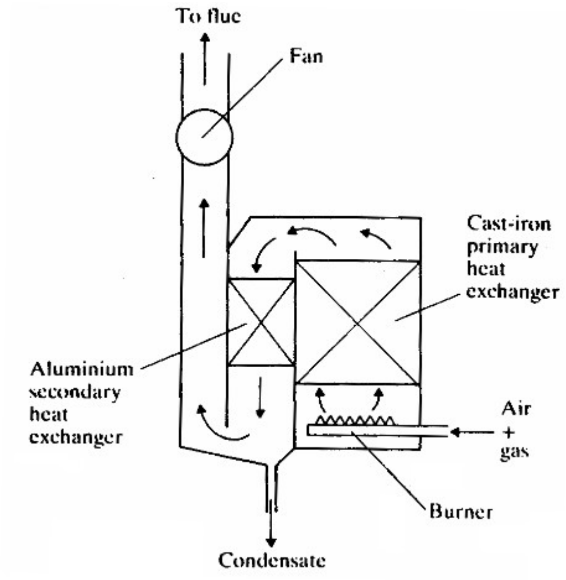
It is important that the heating system and the boiler are not oversized, especially in a super-insulated, airtight house, which should have a very low heating demand. Oversized boilers never reach their intended efficiency performance, as they are always running at part-load.

Different areas of a house may have different heating programmes applied to them. This 'zoning' could mean, for example, that the heating in a bedroom comes on and off at different times, for a different duration and to a different temperature, compared with the heating regime in a living room. The objective is to deliver only as much heat as is required for a particular pattern of use, and only for as long as necessary.

Boiler efficiency

The 2002 Building Regulations specify a minimum efficiency (SEDBUK rating) for all new and replacement central heating boilers, depending on the carbon intensity of the fuel used (see Section 3, Table 3). Condensing boilers currently perform best, with a seasonal efficiency of 85 percent. They differ from conventional boilers, which lose at least 10 percent of their energy input as flue gases, by condensing the hot gases in the flue, reclaiming the heat and returning it to the boiler.

Figure 17: Schematic of a condensing boiler [15]



'Combi' or combination boilers provide heat for space heating or domestic hot water instantaneously and on demand. They dispense with the need for storage cylinders and long pipe runs, which incur energy losses however well insulated. They may be less efficient overall however, because the boiler fires every time the hot tap is turned, even if no hot water is drawn, and the water is being heated from cold every time.

Efficient heat delivery

This is the means by which heat from the boiler is transmitted into the living areas. Conventionally this is done through the medium of water, via steel radiators, which should be sized according to the room area, prevailing climate and heating demand. There are also warm air systems, delivered through ducts and grilles at, or near, floor level.

The system known as 'underfloor heating' has become increasingly popular in recent years, for the improved comfort and liberation of wall space that it offers. It is inherently efficient because it runs at much lower temperatures (30-40ºC), compared to radiator based systems, and is therefore particularly compatible with solar thermal systems and condensing boilers. There are no 'cold spots' because the whole floor is heated, and the increased Mean Radiant Temperature (MRT) means that occupants will feel just as comfortable at slightly lower temperatures.

Effective controls

These ensure that heat is only emitted when and where required, with different zones having separate settings. They should be able to compensate for a sudden increase in solar gain, for example, and reduce the heating demand accordingly. Thermostatic radiator valves (TRVs) and whole room thermostats can save 10 percent of energy use, compared with manual controls. Timers and programmers tell the boiler when to switch on and off, in order to reach and maintain a certain temperature. More sophisticated devices, known as optimisers, take into account the outdoor temperature and the heat-up time for a particular building, to minimise the amount of boiler 'on time'.

Efficient appliances

Huge gains in the efficiency of 'white goods' have been made over recent years. Energy ratings are now displayed on all new kitchen appliances, which traditionally carry the heaviest domestic load, in the form of 'A' (excellent) to 'E' (poor) categories. Needless to say, ‘A’ rated appliances should be chosen if possible. A complementary strategy, exemplified by the Vales, is to refrain from expanding the numbers of appliances “deemed to be unnecessary (a dishwasher, a tumble dryer, a freezer)” [16]

Of course, all these energy efficiency technologies give the best results, in terms of reduced energy usage, if they are coupled with straightforward energy conservation measures. These are often reflected in ‘lifestyle’ choices, such as putting on a jumper rather than turning up the thermostat, or cooking more than one dish in the oven, etc.

2.1.3 Bioclimatic Design

This is based on an understanding of the physical, geographical and climatic conditions of a particular site, and the surrounding region. Climatic factors are:

Sun

The amount of solar radiation received on the site at different times of year. This is measured in kWh/m^2/day, assumes a horizontal surface, and is not simply a function of latitude. Factors such as prevailing winds, cloud cover and local pollution can affect solar radiation levels. This data will obviously inform the designers on the extent to which PSD principles are appropriate.

Wind

Measured in metres/second at a height of 10m above ground. Knowledge of both the speed and direction of prevailing winds are important, to allow the designer to use the building form and the topography of the site to protect the house from cold winter winds, and to design for a passive ventilation strategy.

Figure 18: The predominant wind speeds and direction for different parts of the U.K. in the spring. The figures in the centre indicate the percentage of time when it is calm. [17]

Temperature

Also known as Dry Bulb Temperature (DBT), and measured in degrees Centigrade (ºC). It is useful to know the average, maximum and minimum temperatures, as well as the diurnal range. This will impact on the number of Degree Days, which are part of the calculation necessary to assess the heating demand. It may also have a bearing on PSD, and consequently material choice and construction type.

Rain

Precipitation is measured in mm/day, and both the average and maximum readings are useful. The amount of rainfall can affect the drainage type and capacity, the roof cladding, external materials, construction methods and landscaping.

'Special weather events'

In other words, floods, hurricanes, and earthquakes. Knowing the extremity and frequency of such events is useful in assessing risk and detecting possible trends. The implications for design could be a need for extra foundations or special anchoring systems, a preference for flexible, shock-absorbing construction types, and/or framed construction lifted clear of the ground.

Having collected regional data for all the above, a bioclimatic designer will use individual features of the site, such as its orientation and topography, to maximise the use of solar radiation, minimise wind exposure, and to optimise daylighting, views and privacy.

2.1.4 Resource Efficient Design

Probably the biggest human impact on the ecology of the planet at the moment is our profligate use of non-renewable resources. As well as the raw materials for industry, manufacturing and construction, these resources include land, fossil fuel based energy and water. The construction industry accounts for 50 percent of all raw materials use in this country, which equates to 6 tonnes of material per person per year. [18]

2.1.4a Waste Minimisation

Waste is a problem because it can lead to environmental degradation and hazards to health. The environmental costs include the loss of primary resources and the impacts of disposal. Human health hazards can be caused by airborne pollutants such as combustion products, or by toxic materials such as heavy metals leaching into ground and water supplies.

Waste is produced in large quantities by many mining and manufacturing processes; a typical waste to finished product ratio would be 10:1. Construction, Excavation and Demolition waste accounts for 72 million tonnes a year, or four times the rate of household waste production which is the focus of so much attention. [19]

A DETR sponsored study looked at three new-build commercial projects in Central London, and measured all of the generated waste, in type and quantity. The researchers worked closely with designers, trades and suppliers, to analyse why waste arose, the cost to the project, and the cost to the overall supply chain. It was found that waste-related costs of £65/m^2 of building area were attributable to individual projects. Most of this came from wasted materials and the cost of re-ordering and re-instating. Waste disposal costs were only 2 percent of total waste costs. [20]

The problem of waste disposal can be minimised by designers, contractors, clients and government taking a dual approach. Firstly, the pressure on existing waste disposal facilities can be lessened by reducing the amount of waste created in the first place, through careful specifying/ordering and avoiding over-packaging. As much of the waste generated on a construction site is the result of careless handling or inadequate storage, a programme of waste management and good supervision is essential, and can bring real savings.

Secondly, by specifying reused or recycled materials where possible, designers and builders can actually remove items from the waste stream that would otherwise end up in landfill or incinerated. Similarly, it is important to ensure that materials used in today's buildings can themselves be reused in the future, and this is largely determined at the specification stage.

A 'hierarchical' approach to waste management was developed by the DETR, based on the environmental benefits of the various options. [21]

Reuse is generally preferable to recycling, as it does not involve any extra processing. The whole component is removed and reinstalled, usually with the same function, although much depends on the durability of the materials being reused. Recycling does involve additional energy input, and the energy payback varies widely (see Table 3). It is however always worthwhile in reducing primary resource use and promoting a 'culture' of recycling. Successful recycling depends on the purity of the material and the accurate labelling of composite materials.

Waste Management Hierarchy: the steps to be taken in order of preference

- Minimisation of waste creation at source
- Reuse
- Recycling
- Downcycling
- Incineration (heat recovery)
- Landfill (methane recovery)

Table 3: Energy saved by recycling rather than processing virgin materials [22]

Material	Percentage of energy saved by recycling
Aluminium	96
Steel (40% recycled stock)	10
Steel (100% recycled stock)	47
Copper	88 - 95
Glass	8
Plastics	97
Newsprint	23

When waste is incinerated, ideally in high-temperature incinerators conforming to all the latest EU regulations, some of the waste energy of incineration can be recovered, and this minimises the impact of disposal. Similarly, methane gas, which is generated by landfill sites and usually left to disperse to the atmosphere and contribute to global warming, can be reclaimed and incinerated to generate electricity.

There are unfortunately a number of obstacles preventing a wider take-up of reuse and recycled materials:

Availability

This concerns ensuring a predictable, regular and homogeneous supply, ideally from a local source. The energy saving benefits of reuse/recycling can easily be cancelled by excessive transportation.

Quality assurance

British Standard BS6543 relates to reclaimed materials and looks at, for example, uniformity, potential for swelling or degradation, frost susceptibility and content of deleterious substances. The standard is rarely used however, in what is predominantly a very 'ad hoc' and informal market. This may trouble architects, as they cannot guarantee the performance of a product. It is possible that the European CE mark could be extended to cover reclaimed materials.

Practical and programme constraints

Advance ordering or reservation may be necessary to ensure supply at the construction stage. This could incur extra cost and/or provision of extra storage space. As dismantling a building is a slower process than demolition, there may be a delay in supply, which could affect the building programme as a whole. Last minute changes in supply or type of materials may force alterations in the design. Any testing necessary to ensure 'fitness for purpose' will add to the project costs.

The culture of the 'new'

The idea that 'new' is always 'best', and that second-hand goods are inherently inferior and shoddy, needs to be challenged. This is already happening at the top end of the market, in the area of 'architectural salvage', where Victorian fireplaces, or handmade tiles and bricks, are valued much higher than their modern counterparts.

2.1.4b Design for Deconstruction

Deconstruction or dismantling of a building is a careful and discriminating process, very different from the haphazard and sometimes brutal business of demolition, and taking between two and ten times longer [23]. If it is to be effective as a source for reclaimed materials, then the following points should be incorporated into the design at an early stage:

Information

This refers to accurate 'as built' drawings handed over on the completion of all new buildings. This is now a requirement of construction (design and management) (CDM) legislation, but could be expanded to include labelling of individual components and materials, including identification of points of disassembly.

Access

Easy and safe access to building elements, services and fixings should be designed in. Dedicated service ducts with removable covers are essential for maintenance and replacement, as well as deconstruction.

Dismantling process

This should be simplified as far as possible, with mechanical fixing systems that can be removed by ordinary hand tools, rather than specialist machinery. Chemical fixings, such as adhesives, effectively prohibit easy dismantling. Fixing technologies should be sufficiently sturdy to withstand dismantling and reuse, with realistic tolerances.

Hazards

Obviously, any toxic materials found in the process of deconstruction would not be candidates for reuse or recycling. Where there is a small toxic component in a product, it could render the whole product unusable. Materials should also be made of a suitable size and weight, to allow for safe manual handling.

Time

The number of different parts and the number and types of fixings should be minimised, and parallel disassembly facilitated.

Composite materials

These should be specified with caution. Sometimes they are suitable for reuse, but almost always they are difficult or impossible to recycle.

Finishing materials

These should ideally be in the form of mechanically fixed panels, rather than applied in-situ plastered surfaces, which can make access to fixings difficult, and may contaminate the substrate.

Cement mortars

Again, these should be specified with care and only as a 'weak' mix. If the mortar is stronger than the bricks or blocks it is holding together, then it becomes impossible at a later date to separate them for reuse. There are other, good (structural) reasons for not using a strong cement mortar.

2.1.4c Prefabrication

The advantages claimed for prefabrication are:

- Waste minimisation
- Energy efficiency
- Low environmental impact
- Lower onsite construction impact
- Increased speed of construction

Specifically, the carefully controlled condition of factory production allows:

- Higher standards and greater reliability
- A reduction in the amount of onsite labour required and therefore a lower risk of poor workmanship and accidents
- The provision of safe and secure, factory based jobs, in clean, warm and dry conditions, rather than relatively dangerous and insecure site based jobs.

Prefabrication of whole buildings and building elements fits in well with the post-Egan emphasis on greater predictability and efficiency, with fewer defects. Various prefabrication systems have been developed by 'eco-designers' using low-impact, renewable materials and high standards of insulation and airtightness, resulting in very low energy use over the lifetime of the building (see Section 2.1.6). Some architects and urban planners are looking at combining swift and simple to install prefabricated units, or 'pods', in congested city sites, to provide affordable housing for essential workers.

2.1.5 Socially Responsive Design

Issues of energy and resource efficiency are important, but do not tell the whole story. Sustainable housing for the future must be durable, so that the energy invested in construction and maintenance represents a prudent use of resources. The houses that we build and renovate today should last far longer than the current industry standard of 60 years, and they should anticipate, in their design and specification, a time when environmental crises will be even more acute.

First and foremost, buildings should meet the daily functional needs of their present occupants, or the likelihood is that they will not survive for very long. When le Corbusier talked about a 'machine for living in', he was surely referring to an entity which worked in terms of shelter and protection from hazards, as well as comfort and aesthetic pleasure. The idea of buildings that actually threaten the health of people who live and work in them is a relatively new phenomenon, but it is being taken increasingly seriously by most Western governments and societies. Designers of sustainable buildings need to be aware of any possibility of low-level but long-lasting toxicity resulting from the siting, choice of materials, and services design and commissioning.

With an eye to the future, the design and construction of flexible, adaptable, buildings will allow future generations to maintain, upgrade and thereby preserve existing structures, achieving maximum return on the resources invested. Stewart Brand musters a wealth of evidence to show us that it is just those buildings which can adapt to future conditions, that are loved and cared for, modernised and converted, and thereby escape premature demolition [24].

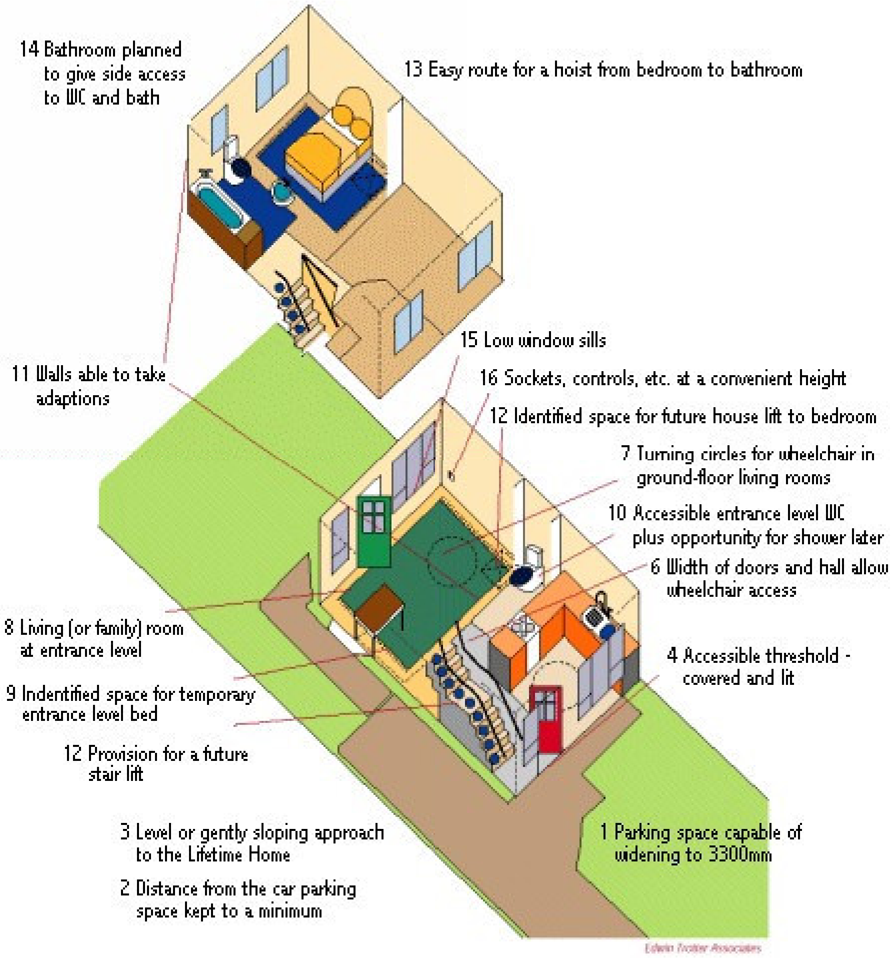
Adaptability of housing can also be useful within one generation, as children are born, leave home, and grandparents need family care, combined with independence. The 'Lifetime Homes' standard, developed by the Joseph Rowntree Trust, complements the Scheme Development Standards of the Housing Corporation, and both go a little further than Part M of the Building Regulations in their requirements for adaptability and flexibility to be designed into the home. The needs of different generations can be accommodated, with particular reference to mobility and access, as shown in Figure 19. According to the Joseph Rowntree Foundation website, "as these additions are minor, it seems sensible to design homes which achieve all of these requirements, and are thus 'universal' in their appeal and application".

A primary objective of socially responsive design is the creation of neighbourhoods and communities with a high level of social interaction among residents. Personal security and the ease with which people move around and between their homes can be affected by urban planning and estate layout. Stemming from an American initiative in the 1970s and '80s known as Crime Prevention Through Environmental Design (CPTED), the design approach known as 'Secure By Design' (SBD) began to develop in the UK in the 1990s. Its aim is to design out those factors conducive to crime and disorder, and the principles have since been incorporated into the building codes of some European countries, such as the Netherlands.

One example of the successful application of SBD principles was reported in 1999 during an evaluation of refurbishment schemes on social housing throughout West Yorkshire. The work incorporated changes based on CPTED concepts, and a before-and-after analysis showed that crime rates per dwelling had reduced by 66 percent on one scheme and by 50 percent on another [25].

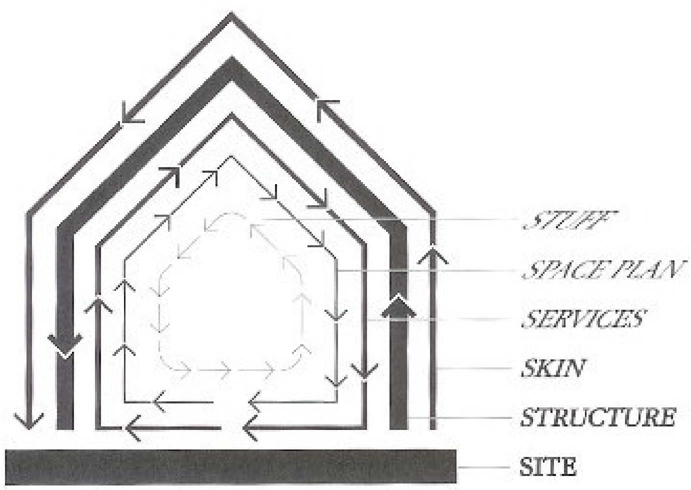
Building and landscape designers and planners are increasingly being asked to provide 'Secure by Design' schemes, with well-lit, visible open areas and accessways. As important as their design, is the sustained and appropriate management of the environment and buildings throughout their life.

Figure 19: Design features which illustrate the concept of Lifetime Homes [26]



Ease of maintenance is a subject that is easily neglected in the first flush of creating a building. It overlaps to a certain extent with 'Design for Deconstruction', in terms of access, labelling and avoidance of hazardous materials. This approach can be implemented by treating the building as a series of 'layers', each with different functions, and structurally independent of the others, as shown in Figure 20.

Figure 20: Building in layers, a design approach also known as 'Long Life, Loose Fit' [27]



Building in layers, and making the high-value and most frequently changed internal layers easy to dismantle and replace, ensures that the building can adapt and survive. Given different lifetimes and rates of replacement (see Table 4), internal finishes, layout and services can be changed or upgraded independently of the structure. Similarly, external cladding on a frame structure can be seen as another layer, whose upgrading or replacement can completely change the appearance of the building. It also helps to use simple structural grids, avoiding long spans and hidden support structures.

Table 4: Operational lifetime of different building 'layers' [28]

Layer	Typical Lifespan
Site	Permanent
Structure	30-100 years
Skin	15-25 years
Services	10-15 years
Finishes and fixtures	8-12 years
Mobile equipment	5-10 years

One of the most challenging areas when designing to meet social needs is that of urban design and the creation of sustainable cities. Around 75 percent of the European population live in urban or suburban areas. Demographic and economic factors mean that residential populations are declining, especially within our larger conurbations, and there is a particular lack of accommodation for single people and young families on moderate incomes. This needs to be addressed if we are to avoid city centres populated exclusively by the very poor and the very rich. In one attempt at solving the problem, the Joseph Rowntree Foundation has commissioned and invested in two CASPAR developments. CASPAR stands for City Centre Apartments for Single People at Affordable Rents, and development costs compare favourably with social housing in the same area, as shown in Table 5. Figures from the Joseph Rowntree Foundation indicate annual returns, after all costs have been deducted, of 6.4 percent for the Birmingham scheme, and 6.2 percent in Leeds.

Table 5: Building costs per apartment, excluding land and fees [28]

BIRMINGHAM	LEEDS
CASPAR cost: £65,100	CASPAR cost: £68,600
Social Housing: £60,600	Social Housing: £57,300

In many respects, developments such as this are outside the remit of individual designers, and depend upon support and subsidy from groups such as the major house providers, in particular the RSLs and Local Authorities, the policies of the Unitary Development Plans, and government sponsorship and initiatives. Here we are concerned with the social impact of buildings, and the degree to which they match the needs of the occupants, and enhance their ability to live as responsible citizens. The development of sustainable communities is measured not only in energy use and recycling levels, but also in crime rates, public health statistics and housing turnover.

2.1.6 Specific Strategies for Sustainable Housing

Beyond the general guidelines that have so far been outlined, some more radical and far-reaching approaches to sustainable housing have been developed. Some have demonstrated their success with built examples. Some are still at an experimental stage. They have all succeeded however, in pushing forward the boundaries of what is possible in low-energy design.

2.1.6a 'The Autonomous House'

Some confusion (and some dubious claims) has resulted from the lack of a clear understanding of what is meant in this context by 'autonomy'. One rather idealistic and all-embracing definition of an autonomous house, made in the 1970s, states that it must "be shaped by climate and living patterns; create rich visual variety; create shade and coolness in summer, warmth and shelter in winter; store its water; consume its waste; draw energy from the environment; enrich the soil; support its inhabitants; maintain itself; and be in tune with natural rhythms" [15].

Other definitions are based mainly on energy provision and the creation of cyclical rather than linear processes. In their first book on the autonomous house, Brenda and Robert Vale describe it as "a house operating independently of any inputs, except those of its immediate environment. (It) is not linked to the main services of gas, water, electricity or drainage, but instead uses the income-energy sources of sun, wind and rain to service itself and process its own wastes" [29].

By the time they had built their own 'autonomous house' in the 1990s, and made its design and construction the subject of their second book, the Vales became even more specific in their aims: "to demonstrate that the servicing needs of a small building can be met without the use of fossil fuels, and with minimal impact on the environment" [30]. The precise goals of zero CO_2 emissions and no heating system served to flesh out this objective, which was then expanded to include water storage, and sewage and grey water treatment within the building.

The autonomous house built at Southwell has high levels of insulation, efficient glazing (U = 0.95 W/m^{2}K), heat-recovery ventilation, and very good air-tightness (1.5 ac/h@50Pa). The only space heating is a small wood burning stove. Measured energy consumption is 22 kWh/m^2/year, and in 1994, 52 percent of this demand was generated by solar energy using a 2.2kW grid-linked photovoltaic array.

In the end, compromises were made, mainly due to cost, architectural considerations, and the fact that the house was a home to be lived in, rather than a theoretical prototype. The omission of solar water heating in particular has been noted in environmental critiques. The house and the renewable energy generation are grid-linked, in a departure from earlier ideals of complete self-sufficiency, but this decision was based on a more realistic and holistic assessment of the high environmental impact of a battery storage system.

The Southwell house was not an expensive one, and part of the idea behind the design was that in essence it should be easily replicable. Indeed, the Vales had previously worked to develop low-cost, energy-efficient housing for North Sheffield Housing Association (Cresswell Rd, 1992). The building costs for Cresswell Rd were £515/m2, slightly under the Housing Corporation's budget at the time, while the Southwell house cost £824/m2, which included a two storey high, double glazed conservatory and a cellar. [31]

In an interesting link between the environmental, technical and social possibilities for future housing of this type, Brenda and Robert Vale note an increased choice and autonomy for occupants (themselves and later their tenants), in the management of resource use and maintenance of services. There is no doubt that the architects have shown a conscientious adherence to a very exacting brief, and demonstrated above all that low-energy, sustainable housing can be designed to meet conventional tastes and expectations.

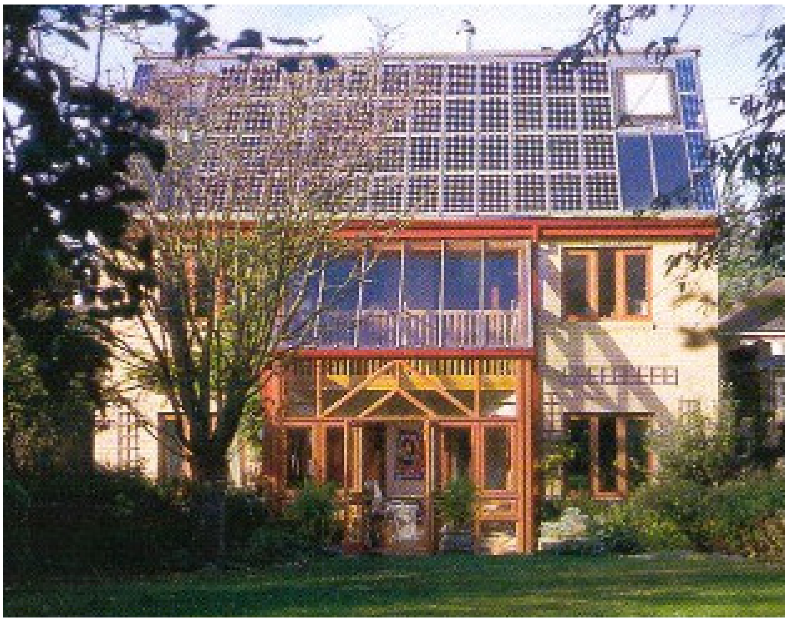
It must be said that, since the Southwell house was built in 1993, very few projects have emerged claiming to be 'autonomous'. In fact, the whole idea of autonomy has been somewhat undermined, for example by connection to the National Grid, and has given way to more appropriate and accurate descriptions such as 'Zero-CO_2' where a building exports at least as much energy as it imports.

One example of this is David Olivier's 'Energy Showcase' project, billed as "the first U.K. house planned to reach zero net CO_2" [32] and incorporating tree planting on site to offset the CO_2 impact of using LPG for cooking and back-up water heating.

Another example is Sue Roaf's 'Ecohouse' in Oxford (see Figure 20), completed in 1996, which features a 4 kWp photovoltaic roof and has a measured energy consumption very similar to the Southwell house, at 26 kWh/m^2/year [33].

It is worth noting that all of these examples feature heavyweight construction, using conventional brick and block, monolithic walls.

Figure 20: The Oxford Ecohouse, by Sue Roaf and David Woods



2.1.6b The 'Passivhaus' Standard

According to Dr Wolfgang Feist, from the Passivhaus Institute in Darmstadt, Germany, the basic idea behind this approach to low-energy design is that the heat losses from a building can be reduced to such a small amount that a separate heating system is not needed. Thus the house becomes 'passively' heated, without the need for an active system to generate and distribute heat. The whole heating demand is met by solar and incidental gains from people, appliances etc.

The first Passivhaus homes were a terrace of four houses built in 1991 in Darmstadt. There are now more than 1000 dwellings built to this standard in Germany and four other European countries, many under the auspices of the European funded 'Thermie' project.

The Passivhaus standard specifies a heating load less than 15 kWh/m^2/yr, and a total energy requirement no more than 42 kWh/m^2/yr, which is less than one quarter of the energy consumption of the average new house in the participating countries. The Darmstadt homes have been extensively monitored, and show measured energy use of 10 kWh/m^2/yr for heating, and 32 kWh/m^2/yr for total energy demand, stable over six years. The 22 terraced homes built in 1997 at Wiesbaden, shown in Figure 21, have an average energy consumption for space heating of 13.4 kWh/m^2'yr [34].

Conventional heating systems become unnecessary at this point, and the heating requirement can be met by the occasional heating of ventilation air. This heat could come from the domestic hot water system, or from a small heat pump. "If it is sufficient to use just supply air, not recirculated air, to meet the maximum heat load, then the building is called a 'Passivhaus'" [35]. In order to achieve such a low heating demand, the standard includes:

- Super-insulation, with U-values of not more than 0.15 W/m^{2}K for walls, ceilings and floor slabs, and insulation depths of 250-400mm
- Thermal bridging reduced to zero (confirmed by thermal imaging)
- Highly efficient glazing using triple pane units with two low-E coatings, giving a U-value of 0.7-0.8 W/m^{2}K
- A whole-house mechanical ventilation system with heat recovery and an efficiency of at least 80 percent
- Very low air leakage rates, with pressurised test results of 0.8 ac/h@50Pa
- Energy efficient appliances are obligatory, not only to save energy, but also to avoid overheating caused by incidental gains in the summer

Figure 21: Terraced houses at Wiesbaden, Germany, built to 'Passivhaus' standards in 1997

It is claimed that building costs are compatible with social housing, and they are demonstrably cost-effective if operating costs over 30 years are entered into the equation. A European funded project called CEPHEUS (Cost Effective Passive House European Standard) has shown that the average building costs of 12 Passivhaus projects across Europe were around 1143 Euro/m^2 [34].

Figure 22: Cartoon from Passivhaus website, www.passiv.de

The Passivhaus standard is not a particular building system, but a voluntary energy standard and a design tool. Certain building components and details have been approved for use in Passivhaus buildings, and these include:

- Efficient, well sealed and insulated door and window frames
- External insulation systems - 250mm thick
- Aerated monolithic concrete, 'lost form' concrete and expanded polystyrene
- Insulated timber panels and I-beam details
- Pre-fabricated insulated concrete panels
- Calcium silicate blocks
- Vacuumised insulating panels (especially for eco-renovation)
- High efficiency MVHR units

The monitoring of these standards is carried out by accredited bodies supported by the German Government. Although these are not the official Building Regulation standards, the Passivhaus initiative is supported in the form of tax rebates and special interest rates. These were at first taken up mainly by self-builders, thereby creating a consumer demand that the mainstream housing providers then had to meet.

2.1.6c Building to the 'LowHeat' Standard

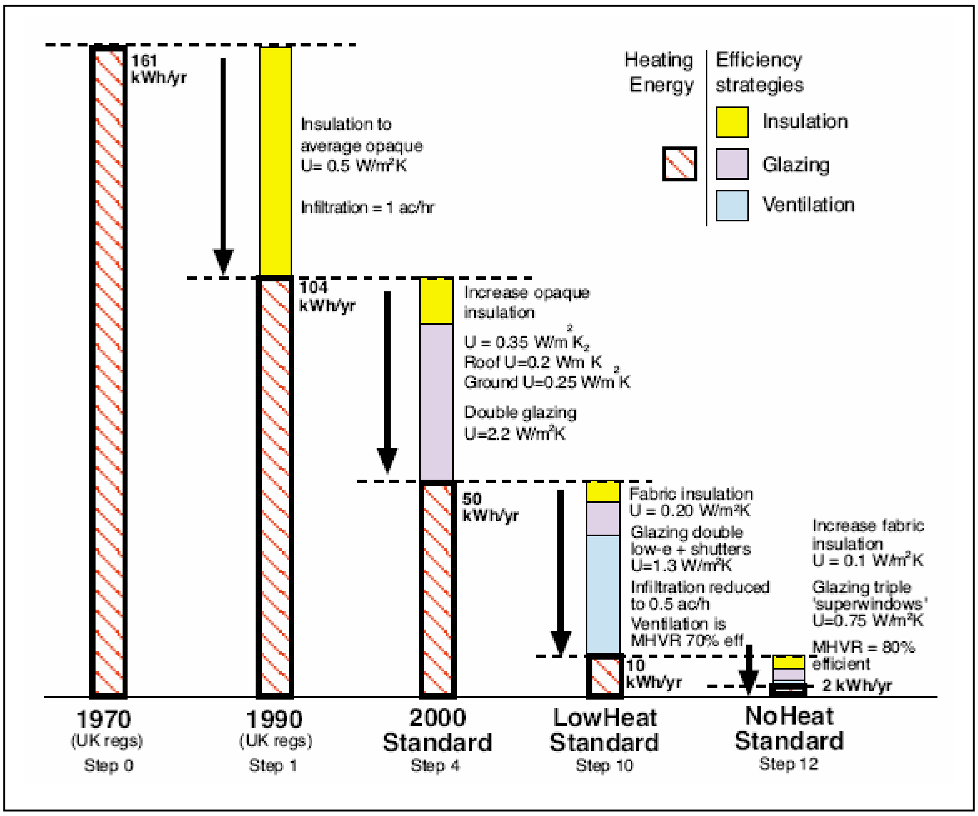
This standard has been developed by XCO2 Conisbee Ltd, a consulting engineering firm based in London. Like the Passivhaus Institut, they claim that a simple combination of design steps can reduce energy use without large increases in capital cost. They argue for a 'quantum leap' in UK energy-saving standards, rather than the slow, incremental improvement that has been the trend over the previous decades.

The LowHeat specification strongly echoes the Passivhaus standard, but is "less onerous in order to be achievable within lower budgets" [9]

- Insulation of the external envelope to a U-value of 0.2 W/m^2K
- Low thermal bridging
- Double glazed window units with low-E coating and insulated blinds or shutters, leading to a maximum U-value of 1.3 W/m^2K
- MVHR system with 70 percent efficiency
- Very low air leakage rates - 0.6 ac/h@50Pa

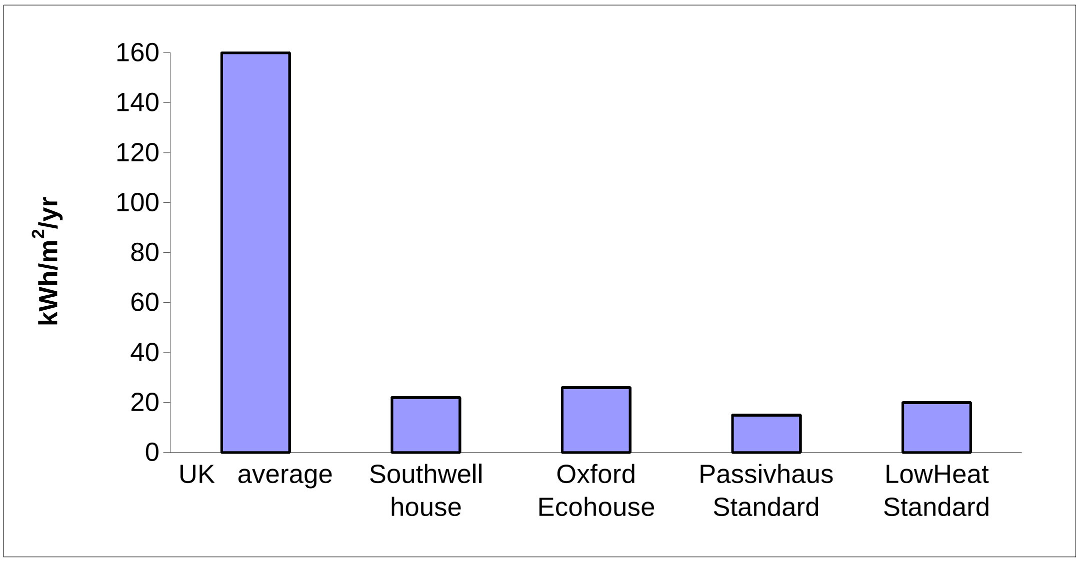
XCO2 have showed, using computer modelling of domestic thermal design, that the three main components of an energy-saving strategy are insulation, glazing and ventilation. The relative contributions of these three elements are shown in Figure 23.

Figure 23: Standards and specifications to reduce heating energy use [9]



From this data and other modelling, XCO2 show that, "the LowHeat and NoHeat standards can cut heating energy use by 80-96 percent compared to the 2000 standard (roughly equivalent to current UK Building Regulations) and by 90-98 percent compared to the typical existing dwelling" [Ibid]

Figure 24: The heat energy consumption of different low-energy design strategies



References

[1] CIBSE, *Guide A: Environmental Design*, London, CIBSE, 1999

[2] Energy Research Group University College Dublin, A Green Vitruvius, Principles and Practice of Sustainable Architectural Design, Dublin, James & James, 1999.

[3] Vale, Brenda and Robert, *The New Autonomous House*, London, Thames & Hudson, 2000. p69

[4] quoted in 'Building for a Future' magazine, vol 11, no 3

[5] Smithdale.P, *Should it be Wood?* MSc thesis, University of East London, 1997

[6] as [3], p79

[7] as [3], p76

[8] Mazria. E, *The Passive Solar Energy Book*, Pennsylvania, Rodale Press, 1979

[9] XCO2 Conisbee, *Insulation for Sustainability,* A Guide for BING, XCO2, 2000. Available from www.xco2.com

[10] Borer and Harris, *The Whole House Book,* Machyllenth, Centre for Alternative Technology, 1998

[11] Environmental Building News, vol 8, no 9

[12] Jennings Paul, Building for a Future magazine, vol 10, no 3

[13] Harland, E. *Eco-Renovation,* Vermont, Chelsea Green Publishing Company, 1999

[14] Boyle, G. Ed, *Renewable Energy,* Oxford *,* Oxford University Press, 1996

[15] Eastop, T.D. and Croft, D.R, *Energy Efficiency,* London, Longman Group, 1990.

[16] as [3], p236

[17] Page, J. and Lebens, R. *Climate in the United Kingdom,* London, ETSU, 1986

[18] UK Government Sustainable Development website, accessed 29/10/04 http://www.sustainable-development.gov.uk/consult/construction/con003.htm

[19] Howard N. *Sustainable Construction – the Data*, Centre for Sustainable Construction, BRE Watford, 2000

[20] Sustain Magazine Vol 2 No. 2

[21] DETR, *Waste Strategy 2000 for England and Wales, London, DETR*, 2000

[22] Mclaren, D., Bullock, S., Yousuf, N. *Tomorrows World,* London, Earthscan 1998

[23] Paola Sassi, School of the Built Environment, University of Nottingham, in 'Sustainable Building' magazine, issue 04

[24] How Buildings Learn' Stewart Brand, Orion Books, 1994

[25] Quoted in 'The Boiled Frog Syndrome' Thomas Saunders, Wiley-Academy, 2002

[26] *Lifetime Homes,* Joseph Rowntree Foundation website, accessed 29/10/04 http://www.jrf.org.uk/housingandcare/lifetimehomes/

[27] How Buildings Learn' Stewart Brand, Orion Books, 1994

[28] *Caspar projects,* Joseph Rowntree Foundation *w*ebsite, accessed 29/10/04 www.jrf.org.uk/housingandcare/caspar/howmuch.asp

[29] Vale, Brenda and Robert, *The Autonomous House,* London, Thames & Hudson, 1975

[30] as [3], p17

[31] as [3], p229

[32] David Olivier and John Willoughby, *Review of ultra-low-energy homes – A series of UK and Overseas Profiles*, London, HMSO, 1996

[33] Sue Roaf with Manuel Fuentes and Stephanie Thomas, *Ecohouse'*, London, Architectural Press, 2001

[34] CEPHEUS-Project information No. 38, Final Publical Report, July 2001
Available from www.passiv.de

[35] Rushbridge, B. and S, 5th Passivhaus Conference, *Building for a Future* 2001, Vol. 11 (No. 1), p 9-11