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Principles of Low Carbon Design and Refurbishment
Executive Summary

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About this Document:

This document summarises a guide to *Principles of Low Carbon Design and Refurbishment* developed by the RIBA as part of a suite of Climate Change Tools to encourage architects to engage with the issue of climate change and to deliver low carbon new buildings and low carbon refurbishment of existing buildings.

To download the full guide to *Principles of Low Carbon Design and Refurbishment,* or to explore all of the RIBA Climate Change Tools, visit: www.architecture.com/climatechange

Cover image Oxley Woods. Rogers Stirk Harbour + Partners design for the Oxley Woods houses utilises a unique 'EcoHat'. Essentially a chimney, the EcoHat is situated on top of the services spine and reuses hot air circulating through the stack – complemented by solar energy – to optimise energy consumption and provide passive solar water heating.

Photo Katsuhisa Kida/Rogers Stirk Harbour + Partners

Introduction

Climate change brought about by man-made emissions of greenhouse gases has been identified as the greatest challenge facing human society at the beginning of the twenty-first century.

Carbon dioxide is one of the major greenhouse gases. In 2003, carbon dioxide emissions associated with energy use in the UK were approximately 560 million tonnes. Almost half of this came from energy use in buildings.

Architects face a new challenge at the beginning of the twenty-first century: how to ensure that the new buildings they design and the existing buildings they refurbish emit dramatically less carbon dioxide than has been common practice in recent decades. Low carbon buildings are designed to produce significantly lower carbon dioxide emissions than others, helping to mitigate climate change.

Principles of Low Carbon Design

There are some well-established, over-arching principles of low carbon design:

1 Understand energy use in the building type

It's vital that architects understand the breakdown of energy use for the building type, at least by fuel type and ideally by end-use, i.e. heating, cooling, lighting etc. This enables the designer to focus on the most important issues and identify how to minimise carbon dioxide emissions. The pattern of energy use is important, not just annual totals, particularly when renewable energy technologies are being considered.

2 Use the form and fabric of the building to do the work

Architects should use the form and fabric of the building to do as much of the work of environmental modification as possible, thus minimising the demand on services such as heating and lighting. Low carbon buildings should exploit useful solar and internal heat gains (from people, equipment, etc.) to satisfy as much of the heat demand as possible, but exclude unwanted solar gains when they may lead to overheating[1].

3 Focus on insulation and air tightness

Low carbon designs seek to reduce unwanted heat losses and gains by adopting appropriate standards of insulation and air tightness. To identify appropriate standards it is necessary to understand the heating and/or cooling balance of the building. Generally the design of a dwelling will focus on keeping heat in and making use of heat gains, while the design of an office will focus on keeping the building cool, especially in summer.

4 Use high efficiency building services with low carbon fuels

The architect should satisfy the remaining energy demand with building services that are as efficient as possible, and that use fuels with low carbon dioxide emissions factors. Emissions factors are explained in more detail in the Carbon Literacy Briefing that forms part of the RIBA Climate Change Tools. Architects should also ensure that heating controls are as responsive as possible, making use of solar and internal heat gains without over-heating the building.

1 Note that the more a building is insulated, the shorter its heating season. Consequently there are less useful solar gains (because there is less sun in winter). Note also that as insulation standards and summer temperatures increase, avoiding overheating has become a significant problem in buildings of all types, including dwellings.

5 Use renewable energy systems

Low carbon buildings use renewable energy systems to reduce the carbon dioxide emissions associated with the provision of heat and power within the building.

6 Manage energy within the building

Low carbon design is not enough; low carbon operation is also needed. Architects can enable efficient operation of the building by ensuring that appropriate metering and energy management systems are in place, and that the occupants are well-informed about how the building and its services are intended to be used.

Domestic Buildings

Total space heating load

The total space heating load is made up from:

- **Fabric losses** – through walls, floors, roofs, windows, rooflights and doors. Fabric losses typically account for over 50% of the total space heating load.
- **Thermal bridging losses** – at junctions and around openings
- **Ventilation losses** – via infiltration and ventilation

Factors used in calculating heat losses

Several numerical factors are used in calculating the heat losses from buildings.

Thermal conductivity (λ value)

The thermal conductivity of a building material (in W/mK) is a measure of its ability to conduct heat. It represents the amount of heat (in W) that will be conducted through the material per unit of thickness (in m) per unit of temperature difference across it (in degrees K). Thermal conductivities vary from 0.023 W/mK for high-performance insulation to 50 W/mK (2,000 times greater) for steel.

Thermal transmittance (U value)

The thermal transmittance of a construction element (in W/m2K) is a measure of its ability to transmit heat. It represents the amount of heat (in W) that will be transmitted through the construction per unit of area (in m^2) and per unit of temperature difference across it (in degrees K). The U values of building elements are multiplied by their areas to calculate the heat losses through them.

Linear thermal transmittances (Ψ value)

The linear thermal transmittance (in W/mK) of a construction detail is a measure of its transmission of heat by thermal bridging. It represents the amount of heat (in W) that will be transmitted through the detail, per unit of its length (in m) and per unit of temperature difference across it (in degrees K). The Ψ values of construction details are multiplied by their lengths to calculate the thermal bridging losses through them.

Thermal bridging transmittance (y value)

The thermal bridging transmittance of a building envelope is a measure of the overall transmission of heat through the construction details by thermal bridging. It represents the amount of heat (in W) that is transmitted through all the construction details per unit area of the entire building envelope (in m^2) per unit temperature difference between inside and outside (in degrees K).

When Ψ values are unknown, a whole-building y value may be used instead to represent the overall heat loss due to thermal bridging. U values and y values have the same units, and the overall thermal transmittance of the building envelope is the sum of the average U value and the y value.

Infiltration is the uncontrolled, unintentional wind- or stack-driven leakage of cold external air into the building through cracks and imperfections in the fabric.

Infiltration is of course accompanied by exfiltration – the loss of warm air, usually from the opposite (downwind) side of the building.

Ventilation is the deliberate introduction of fresh air to combat odours and contaminants – particularly water vapour.

Infiltration and Ventilation Heat Losses

If infiltration is not controlled it can be a significant source of heat loss accounting for as much as 30% of the total space heating load in a well insulated dwelling. As importantly, if the exfiltration of moisture laden warm air passes through the fabric, interstitial condensation will take place on any cold surfaces. This can be a problem particularly in timber constructions.

Dwellings in the UK are notoriously leaky. While much has been done to improve insulation levels, little has been done to reduce heat losses due to infiltration. Unless air leakage is controlled, it can form a large proportion of the heat loss in a well insulated house. The mantra must be: 'build tight, ventilate right'. Ventilation should be provided where and when it is needed – not as a huge continuous background infiltration rate.

In air-tight homes, infiltration cannot be relied on to supply ventilation air. Ventilation is required to maintain good air quality and remove moisture and other contaminants, so an appropriate ventilation system must be specified.

There are several options for ventilation systems[2]:

- Passive stack ventilation
- Whole-house mechanical extract ventilation
- Whole-house mechanical ventilation with heat recovery

Construction details – points for architects to watch

Achieving low carbon homes requires a fundamental rethink of many traditional construction details. They need to be re-examined in terms of their levels of insulation, thermal bridging and air-tightness. Many common details are poorly insulated, contain repeating, non-repeating and random thermal bridges and are poor at reducing infiltration. Many of these problems can be overcome if certain 'dos' and 'don'ts' are observed.

Do

- Allow for much thicker insulation than has been common in the past
- Remember that wide fully filled cavities can be used in areas of severe exposure

2 The use of positive input ventilation (PIV) should not be considered. It relies on air escaping from the house via gaps and cracks in the construction. Such cracks and gaps should not be present in a low carbon home, but if they were then passing warm moist air through the construction where it will condense would not be wise!

- Make sure that the insulation layer in one element connects with the insulation layer in the adjacent one
- Make sure there is a clearly defined air barrier in each element that connects to the air barrier in the adjacent element
- Make sure that the air barrier can be installed on site
- Ensure that there is an air barrier on each side of a layer of insulation to prevent air circulation from the cold side to the warm side
- Remember that wood is not a good insulator; therefore reduce the effect of repeating thermal bridges in timber constructions by the use of counter battens, additional insulation layers, spaced studs, or I studs and I beams
- Consider insulation at rafter level to avoid problems with cold roof spaces
- Keep all the services within the insulated envelope, create services zones on the warm side of the insulation and air barrier and detail any penetrations to eliminate air leakage

Don't

- Use quilt insulation in lofts with trussed rafters – it is impossible to lay the insulation properly across the ceiling joists; use a blown insulation
- Specify partial cavity insulation unless the insulation is fixed to the inner leaf with adhesive and all joints between boards are taped on the cavity side
- Build timber joists into masonry walls; use joist hangers instead
- Use plasterboard on dabs without sealing the wall behind; consider the use of gypsum parging and air barriers or tapes around openings

Heat gains

Heat gains come from:

- Solar gains through south facing windows
- Cooking and the use of lights and appliances
- Hot water storage and use in the house
- The occupants themselves.

To be effective a heating system should be:

- **Efficient – e.g. a seasonal (SEDBUK) efficiency of over 90%**
- **Responsive – responding rapidly to heat loads and temperatures**
- **Well controlled – user-friendly time and temperature control.**

Careful design can optimise the benefit of solar gains without causing summer overheating.

Heating systems

Even very well insulated, air-tight dwellings require some form of heating system. It will be needed on exceptionally cold days, and to bring the dwelling up to temperature after and during periods with low occupation.

Whilst fossil fuels are presently dominant, there are already some technologies available that have the potential to significantly reduce carbon dioxide emissions. These include biofuels, heat pumps and combined heat and power, and are explored further in the full guide to *Principles of Low Carbon Design and Refurbishment*.

In well insulated, air-tight, low carbon homes, the main use of the heating system is often to provide hot water, with space-heating as a by-product. This means that CO_2 emissions associated with energy use for hot water supply will usually be more than those associated with energy use for space heating. This is the opposite of what we are used to.

Much can be done to reduce hot water fuel use by:

- Specifying an efficient heating appliance
- Strategic positioning of any hot water cylinder
- Specifying an efficient, well insulated cylinder
- Sizing and insulating distribution pipework properly.

Summer overheating

Now that new and existing dwellings are very much better insulated, small heat gains can cause summer overheating.

Complaints of overheating in new homes have led to the inclusion of a requirement in the Building Regulations for an overheating check to be carried out via SAP 2005. Three key strategies for tackling summer overheating are:

- Reducing heat gains – by selecting energy efficient appliances and reducing summer solar gains through glazing
- Increasing heat losses – by secure night time ventilation

- Increasing thermal mass – allowing heat gains to be stored in the fabric before being removed by night time ventilation.

Lights and appliances

In modern homes, carbon dioxide emissions associated with energy use for lights and appliances will account for around half of all emissions.

It may be thought that the provision of low energy appliances is the occupants' responsibility, but there is a lot the designer can do to reduce emissions from this source. By careful selection of efficient lights and appliances, the carbon dioxide emissions associated with this energy end-use can be halved.

The trend towards providing new homes with built-in appliances offers an excellent, simple opportunity to reduce carbon dioxide emissions.

Non-Domestic Buildings

There are two key differences between dwellings and non-domestic buildings that significantly affect their energy use and carbon dioxide emissions, and thus demand a different approach to low carbon design. These differences are:

- The activities accommodated – which are much more varied than in dwellings
- The built form – non-domestic buildings are often much larger than dwellings.

Activities

Non-domestic buildings accommodate a huge range of activities, many of which involve relatively high densities of occupation, high lighting levels and high equipment densities, all of which give rise to internal heat gains.

Built form

Since the middle of the twentieth century, the designers of large, modern buildings have preferred to provide simpler building envelopes whose form is unrestrained by the need to contribute to the tempering of the internal environment.

Importance of a strategic approach

Irrespective of the type of non-domestic building that is being designed, it is important that a strategy for achieving a low carbon building is a high priority from the initial stages of design development.

As the design develops, choices are made about the building form and fabric, and about its servicing systems, and consequently the number of energy savings options is progressively reduced. It is much more difficult and expensive to 'bolt on' energy efficiency and low carbon features to a well developed design than to integrate them into the design strategy from the start.

Such buildings often have many floors, deep plans (typically 15–18 m) and relatively low storey heights. They rely on artificial lighting, mechanical ventilation and air conditioning to provide acceptable internal environments.

However, as they begin to address the challenge of climate change, some architects are realising that this shifting of responsibility for the internal environment is inappropriate.

The form and fabric of the building should be used to provide an acceptable internal environment, as far as possible, which can then be 'fine-tuned' by the minimum use of appropriate, efficient building services.

This means using built forms that incorporate relatively narrow plans (e.g. building tall and thin, or around courtyards) and increased storey heights to improve daylighting, and that promote natural stack-effect or cross-ventilation.

Daylighting

Good daylighting not only reduces the artificial lighting load of a building, it also reduces the heat gains from artificial lighting, and therefore the ventilation or cooling load. It is therefore important to understand the effect of glazing on the energy performance of buildings.

Daylighting can be enhanced using the following principles:

- Optimise the internal layout to facilitate daylight penetration, with work-stations at the perimeter and intermittently occupied spaces located centrally
- Use light surfaces to reflect light into deeper parts of the building. Light shelves can be used to reflect diffuse daylight on to the ceiling, where it will be reflected down to the working area
- Local lighting control will help to reduce energy use and increase occupants' satisfaction. Daylight and occupancy sensors can be used to increase, reduce or switch off electric lighting automatically when it is not required

Internal heat gains

In non-domestic buildings, the level of internal heat gains is usually higher than in domestic buildings and requires careful control. Heat gains from people, lighting and equipment such as computers and printers can be reduced by:

- Designing the building with adequate space for the intended number of occupants
- Removing equipment such as printers and copying machines from occupied spaces into separate spaces with local ventilation, and then specifying high efficiency equipment throughout
- Specifying efficient lighting with local control by daylight- and occupancy-sensors and manual switches, so that lights may be dimmed or switched off when the natural light level is adequate
- Ensuring that installed lighting loads are less than 3 W/m^2 per 100 lux.

Ventilation

Once solar and internal heat gains have been reduced, adequate indoor air quality and thermal comfort can be ensured by providing natural, mechanical or mixed mode ventilation.

The choice of ventilation method is often a critical component of the energy strategy for a low carbon building because it has implications for the building form, the building fabric, the building services and the way that the building should be used. The main ventilation options – natural, mechanical and mixed mode – are explored in more detail in the full guide to *Principles of Low Carbon Design and Refurbishment.*

Cooling

As a general principle, it is best to avoid the use of mechanical cooling and air conditioning altogether. Such systems use large amounts of electricity and significantly increase the carbon dioxide emissions associated with the operation of the building.

However, some types of non-domestic buildings do require cooling, at least in part. Some innovative and relatively efficient cooling techniques have been developed for application in these circumstances, including night ventilation and labyrinths.

Operation and management

A lot of attention is often given to the design and construction of low carbon buildings, but once the buildings are complete and occupied it is important that they are operated efficiently.

To ensure energy efficient operation of low carbon buildings, you will need to:

- Provide the occupants and managers with a sound understanding of how the building is intended to work
- Make the occupants and managers aware of the design team's performance targets for the building and how the targets relate to appropriate best practice benchmarks
- Provide the occupants and managers with the means to monitor performance, assess it against the established targets and benchmarks, and identify problems.

Remember to ensure that an efficient building design and building services strategy has been developed first, and then look at meeting the remaining demand using renewable energy.

New and Renewable Energy Systems

Many low carbon buildings meet some or all of their energy demand using renewable energy systems.

Renewable energy technologies can be divided into thermal and electrical systems. The full guide offers an insight into the major renewable energy systems, covering:

- Passive solar design
- Biomass heating and hot water
- Solar water heating
- Ground source heat pumps
- Wind power
- Solar photovoltaic electricity generation.

Sources of Further Information

Accredited Construction Details and Enhanced Construction Details are available at www.planningportal.gov.uk

Two core CIBSE Guides are invaluable in low carbon building design:

- Energy Efficiency, Guide F
- Sustainability, Guide L

These are available from www.cibse.org

The Energy Saving Trust Housing programme provides free technical guidance and solutions to help UK housing professionals design, build and refurbish to high levels of energy efficiency. See www.energysavingtrust.org.uk/housing

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