AECB CarbonLite Programme

Delivering buildings with excellent energy and CO_2 performance

VOLUME TWO: PRINCIPLES AND METHODOLOGIES
Calculating and minimising heat loss and CO_2 emissions from buildings

Version 1.0.0

AECB CarbonLite

CARBON LITERATE DESIGN AND CONSTRUCTION

Contents

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Glossary

SECTION 1

Air changes per hour (ac/h) – (volumetric), the number of times per hour that the air inside a building is changed. Units m^3 hr/ m^3.

Air permeability – defined in BS EN 13829. Units m^3/m^2hr at 50 Pascals or m/h @ 50 Pa.

Air leakage index – per unit thermal envelope area (the CLP preferred definition). Units m^3/m^2hr at 50 Pascals or m/h @ 50 Pa.

CLP – The AECB 's Carbon Literate Design and Construction Programme.

Delivered energy – the amount of energy which is supplied to final users, e.g., households, office buildings, schools, factories and cars.

Global Warming Potential (GWP) – a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is a relative scale which compares the gas in question to that of the same mass of carbon dioxide (whose GWP is by definition 1). For example, methane, nitrous oxide and sulfur hexafluoride have GWPs many times that of CO_2, although CO_2 is being emitted into the atmosphere in much larger quantities.

Heat Loss Parameter (HLP) – a building 's specific heat loss (in units of W/K) divided by the building 's floor area (measured internally – i.e. within the thermal envelope). Units $W/K.m^2$

Low-grade heat – normally used to mean heat at a temperature of ≤ 100°C

Mechanical Ventilation with Heat Recovery (MVHR) – a system of ventilating buildings, in which heat is recovered from the exhaust air stream to preheat the fresh air intake. Normally there are two sets of ductwork, both connected to an air-to-air heat exchanger, with the air flows in the supply and exhaust branches carefully balanced.

Passivhaus – a low energy building standard.

Passivhaus Institut (PHI) – originator of the Passivhaus movement and of the Passivhaus Standard.

Passivhaus Planning Package (PHPP) – a modelling and accreditation software tool developed and updated by the Passivhaus Institut.

Primary energy – the amount of energy mined or extracted at source; e.g., from coal, oil, natural gas, uranium or wood. Includes losses within processes such as electricity generation and transmission.

Stack effect – in winter, the warm air inside a building is less dense than the cold external air. Consequently, cold air tends to be drawn in through cracks and gaps at the base of the building, with warm air exfiltrating through openings in and near the top of the building.

Thermal capacity – the ability of the constituent materials in a building to store heat, for a given rise in temperature, measured in units of kWh/K for a whole building or in $Wh/K.m^2$ to indicate the building 's thermal capacity per unit floor area.

Thermal envelope – the insulated external fabric of the building.

Useful space heating energy – the amount of heat actually put into the heated space.

ψ-(psi) value – the heat loss per unit length of thermal bridge. Units W/mK.

λ-(lambda) value – thermal conductivity of a material. Units W/mK.

X-(chi) value – point thermal bridge heat loss coefficient. Units W/K.

R-value – thermal resistance. Units m^2W/K.

U-value – thermal transmittance. Units W/m^2K.

y-value – a notional additional U-value, spread uniformly over the whole thermal envelope.

Introduction

SECTION 1

The damaging contribution of buildings to climate change means that we must make significant and real reductions in their CO_2 emissions. This requires us not only to take the obvious measures like optimising orientation to utilise solar energy for heating and daylighting, adding extra insulation, designing out thermal bridges or improving airtightness, but also to get to grips with aspects of procurement, design and construction processes that can undermine those efforts.

If we systematically monitor the energy use of buildings post-occupancy, we can understand how effective such extra measures actually are. As energy use is, more often than not, higher than predicted we need to explore why. Additionally, feedback from monitoring helps us refine building design skills and building simulation tools and improve the accuracy of predicted environmental performance.

Organizations and households manage their buildings and the equipment and appliances in them differently. The results from monitoring post-occupancy energy use in buildings, built to the Passivhaus standard in Germany, Austria and Switzerland have shown large variations due to these factors - typified by a so-called bell-shaped curve. However, they also show an average performance that achieves the predicted energy target.

PHI states that using PHPP can predict the space heating energy of most building designs to within a margin of ± 2kWhr/m^{2}yr. The small remaining discrepancy is down to uncertainties in such matters as the exact thermal conductivity of the thermal insulation supplied to site, and so on.

It is often said in the UK that variability in the behaviour of a building 's occupants can confound the most careful projections of heat loss and final building energy use. The unspoken implication is that it is therefore not worth trying to further improve the accuracy of our projections. This is misleading. The benefits of a whole building emissions approach are that we get a clear picture of total actual emissions; it helps to improve the accuracy of the predominant UK building simulation methods; and it emphasises the importance and effectiveness of the 'passive measures '.

Citing human behaviour as a wild card is therefore unhelpful. It diverts attention away from what really matters – creating a built infrastructure that supports, rather than works against, low carbon behaviour patterns in particular, and human nature in general. Successfully applying integrated 'passive ' measures to the building as a whole - passive solar gain, adequate thermal capacity, passive cooling, extensive daylighting, thermal insulation and other demand reduction measures - achieve this aim, and will assist any building occupant to keep their energy demand to a minimum.

The passive measures focus largely on the form and fabric of the building. These are the elements of buildings that endure; the benefits of these measures can be optimised by an integrated design approach, producing buildings needing relatively minimal services.

The AECB 's approach is therefore to adopt rigorous methods for calculating whole building heat loss and CO_2 emissions during the design stage, to require clear evidence of careful on-site practice to provide building occupant guidance, and then to monitor, post-occupancy, a statistically significant number of projects, to track actual performance.

As explained in *Volume One: An Introduction to the CLP*, we have adopted the Passivhaus Planning Package (PHPP)[1] for both modelling projections of buildings ' energy and CO_2 performance and as the certification tool for CLP Steps One and Three. (PHPP is already used to certify Passivhaus / CLP Step Two buildings). Having been calibrated against the results of dynamic thermal simulations and checked against post-occupancy monitored data, PHPP is more useful for modelling very low-energy buildings than the UK 's current tools[2]. Occasionally, however, designs may be proposed which are outside the scope of PHPP and which need further analysis.

The AECB 's decision to adopt the Passivhaus software (used in combination with suitable design guidance) and to provide both a 'prescriptive ' and 'performance ' based route to CLP compliance, should provide:

- improved accuracy;
- more cost-effective solutions to low energy and low carbon buildings;
- an enhanced understanding of the individual impact on energy performance of a wide variety of design features;
- a wide degree of design choice for designers and builders, without compromising energy conservation and CO_2 emissions.

This document explains some of the areas where current UK calculation methodology and design and construction practices most adversely affect building energy performance. It aims to do three things:

- to explain important shortcomings of UK calculation methodologies and indicate the alternatives available, including how and why they are better, based on research to date;
- to explain the adverse effects of key design and construction practices;
- to describe the methods adopted by the AECB to underpin the CLP.

It is designed to accompany CLP detail design guidance documents (Volumes Four and Five), which focus mainly on thermal bridging and airtightness. These companion documents provide constructional examples for designers working to CLP Steps One, Two and Three (based around likely typical Silver, Passivhaus and Gold Standard building fabric design). The key design and construction principles illustrated in these guides will be useful to all those who are attempting to design more thermally-efficient building envelopes.

1 PHPP is available from www.carbonlite.net

2 The AECB, with NES, has commissioned a detailed comparison of PHPP and BREDEM12 for a range of dwelling types. The results of this research will be made available to those who manage the development of SAP to help ensure that improvements to the accuracy of SAP are made in time for the next revisions to the Building Regulations in 2010.

Calculating heat loss

SECTION 2

The thermal envelope

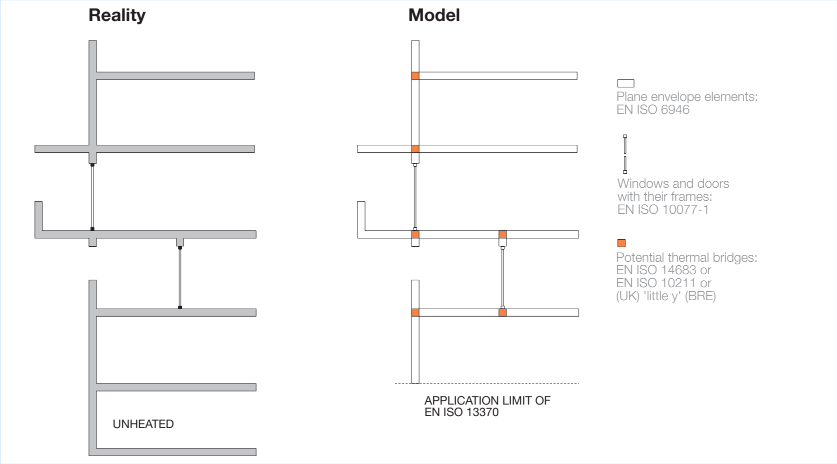
The UK has now adopted the European Standards for calculating heat losses from buildings; see the references at the end of this document. The EN standards ensure greater precision and define the total heat loss as being made up of:

- Heat losses through the fabric: roofs, walls, floors and windows. These heat losses are partly by conduction through solid materials such as brick, stone, timber and insulation materials and partly by radiation; plus
- Convective heat losses due to air infiltration / exfiltration and occupant-controlled ventilation. These losses are attributable to warm air leaving the building, carrying heat with it, and being replaced by cold outside air, which must be heated up.

TABLE 1

Standard	Year	Calculation method provided
BS EN ISO 13789	1999	details the 'transmission heat loss coefficient ' calculation and defines the boundary of a thermal envelope
BS EN ISO 14683 or BS EN ISO 10211		heat loss through thermal bridges
BS EN ISO 6946	1996	thermal resistance and transmittance of building components, excluding doors, windows and heat transfer to the ground
BS EN ISO 10077-1 BS EN ISO 10077-2	2002 2003	thermal transmittance through frames
BS EN ISO 13370	1998	heat transfer through the ground and unheated adjacent spaces

FIGURE 1
Clearly defined boundaries for applying the EN ISO standards



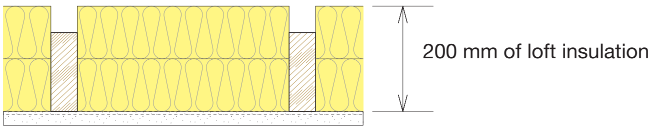
It also shows the application limit of EN ISO 13370 - concerning heat losses associated with unheated adjacent spaces. See Figure 1.

In calculations made decades ago, the conduction heat losses were taken simply as the one-dimensional heat loss through the insulation material. The impact of thermal bridges - conductive materials which interrupt the insulation layer and other imperfections in the construction - was ignored. With small thicknesses of insulation, such as loft insulation of 25 mm, and with external brick walls which had no insulation, these factors made little difference to overall heat loss calculations.

Now that much thicker levels of insulation are used, the impacts of thermal bridges have become much more significant. This is illustrated in Figure 2 which shows historically how the use of more sophisticated calculation techniques has provided increasingly accurate predictions of

FIGURE 2
U-values using three different calculation techniques

Changing U-values



U insulation = 0.18
U proportional = 0.20 (thermal bridging of joists taken into account)
U combined = 0.24 (gap above joist taken into account)
= 33% (increase in U-value)

More sophisticated calculation techniques give a better prediction of U-values

U-values. The three U-values shown are respectively the value for the insulation material alone, the value derived using the ‘Proportional Area ‘ method ‘ and the value derived using the ‘Combined ‘ method.

Calculation methods appropriate for highly energy-efficient designs should encourage and reward those using their detail design skills to develop cost-effective constructions that significantly reduce heat losses through the thermal fabric. At levels of insulation required by advanced building performance standards, it is essential to calculate the overall level of fabric heat loss accurately. This overall heat loss comprises the heat loss through the insulated structure, plus the extra heat loss due to all the different types of thermal bridge.

Treatment of different types of thermal bridge

Thermal bridges in a building can be broken down into three principal types:

- **Point thermal bridges - both repeating and non-repeating**. Examples of these include metal cavity wall ties, the points where steel beams are built into a lightweight aerated concrete block wall, and the nails, screws and other fixings in timber-frame construction. Point thermal bridges also occur at the corners of a building where three planar elements meet but these are usually ignored. Instead, the calculation is done using the individual heat losses of all the linear thermal bridges which meet at that point;

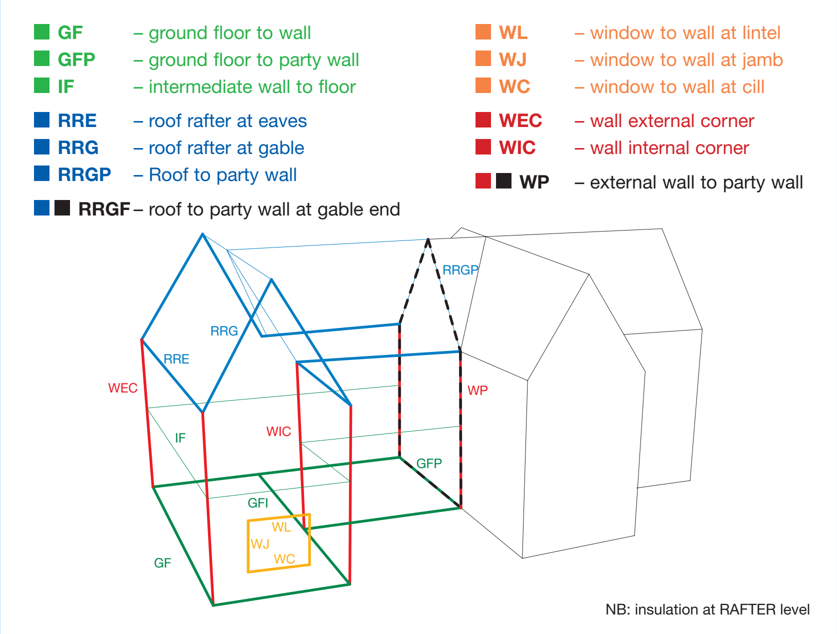
- **Repeating linear thermal bridges**. These occur regularly within the construction of some types of external wall, roof and ground floor. Examples include the solid wooden studs in timber-frame walls, joists in a suspended timber ground floor, rafters in a timber roof, metal studs in a light steel-frame wall and mortar joints in a wall of lightweight aerated concrete blockwork;

- **Non-repeating linear thermal bridges**. These can occur at the junctions between elements, within elements, and around window openings. For instance, there are linear thermal bridges at the joints between wall and floor, wall and roof, window and wall. They also occur at other locations; e.g., the upper floors in platform-framed wooden buildings form a thermal bridge around the building, as do reinforced concrete intermediate floors in a building with lightweight block walls. Other examples of linear thermal bridges are around loft hatches and rooflights, bed joint reinforcement in walls of lightweight concrete blockwork, and steel beams which are used to lengthen the span of timber roofs.

FIGURE 3

Locations of non-repeating linear thermal bridges

Non-repeating linear thermal bridges occur at all the junctions between elements. The figure shows most of the places where thermal bridges can cause extra heat loss. There will be a bridge between the floor and the wall along the exposed perimeter [GF] and also at the party wall [GFP]. There will also be a bridge at the wall to intermediate floor [IF]. A bridge will exist between the wall and the roof at the eaves [RRE], at the gable (where the insulation is at rafter line [RRG] and at the party wall [RRGP]. In addition there will be linear thermal bridges around the windows, which can be broken down into the lintels [WL], jambs [WJ] and cills [WC], and at the external [WEC] and internal [WIC] corners of the walls.



In theory, U-values quoted today in the UK should include the effect of the repeating point and linear thermal bridges, which have a major impact on U-values.

However, U-value tables provided by insulation and blockwork manufacturers do not usually take these common thermal bridges into account, and it is these values that designers often use without appreciating the additional heat loss which this entails.

This document concentrates on the effects of non-repeating linear thermal bridges. One of the main differences between PHI and UK methodology is in the convention for treating non-repeating linear thermal bridges (see below).

U-values

U-values quoted in the UK exclude the effects of the non-repeating linear and point thermal bridges, which designers are expected to add separately. The impact of these non-repeating thermal bridges is significant and it is essential to calculate it accurately. It is estimated that UK details – typically built in practice under the 2006 Building Regulations – lead to more than double the fabric heat loss compared to the details provided in the Step One (Silver Standard) guidance.

ADL1-2006 deals with non-repeating thermal bridges by promoting the use of ‘accredited details ‘. In addition, if designers do not adopt ‘accredited details ‘ and want to avoid calculating the effect of all the thermal bridges, they can add a standard allowance to cover the associated extra heat loss. The extra heat loss is denoted by a ‘y-value ‘. It represents a notional additional U-value, spread uniformly over the whole thermal envelope.

If ‘accredited details ‘ are used, a y-value of 0.08 W/m^{2}K is added to the overall heat loss of all the elements in the building thermal envelope. In a typical new dwelling, the average heat loss through the fabric, including the repeating point thermal bridges and linear thermal bridges, might correspond to a U-value of 0.3 W/m^{2}K. So the normal allowance for non-repeating linear thermal bridges raises this by 27% to 0.38 W/m^{2}K.

If other, non-accredited details are used - the tacit assumption is that these permit more thermal bridging - a y-value of 0.15 W/m^{2}K is added to the overall heat loss of all the elements in the thermal envelope. Thus, in the same new dwelling using non-accredited details, the allowance for non-repeating linear thermal bridges increases the conductive loss through the fabric by +50% to 0.45 W/m^{2}K. This method does not reward those designers who have reduced thermal bridging in their details relative to the accredited versions. An alternative to using y-values is for the designer to calculate the heat loss through each linear bridge separately and then add them together. To do this, ψ-(psi) values are used. Appendix K of SAP-2005 lists ψ-values for junctions in typical new UK buildings.

Once a ψ-value for a particular thermal bridge has been established, it is easy to calculate the heat loss. But working out the ψ-value for a proposed detail is complex and relies on computer modelling of two-dimensional or even three-dimensional heat flow.

Measuring conventions: internal versus external dimensions

Designers using PHPP can reduce their workload or circumvent the problem of needing to undertake detailed and complex calculations of heat loss associated with non-repeating linear thermal bridges by:

a) using “thermal bridge-free construction”; and

b) measuring elemental areas to the outside of the insulation layer.

“Thermal bridge-free construction” is where the building is surrounded by a continuous layer of thermal insulation, uninterrupted by more conductive materials. The PHI defines thermal bridge-free junctions as having a ψ-value of ≤ 0.01 W/mk, with reference to external dimensions. Avoiding thermal bridges is the simplest way to ensure that heat loss from the fabric is minimized. It also avoids the need to calculate the impact of each thermal bridge separately – a time-consuming process. This approach allows thinner walls – as losses due to the non-repeating linear thermal bridges do not have to be compensated for by an improved U-value.

The UK methodology for calculating heat loss involves measuring the internal envelope areas and adding all their heat losses together. However, on mainland Europe, it is common to measure the external envelope, i.e. the areas of the wall, roof, floor, etc are measured to the outer face of the thermal insulation layer, rather than to the inner face of the fabric. This is the approach applied by the PHI in PHPP.

The method adopted by the CLP for calculating window and door U-values is based on the PHI convention which includes the thermal bridge due to the installation detail of the window or door in the external wall or other building element *in the U-value of the windows or doors*. These maximum U-values are a weighted average for all the windows or opaque doors installed in a building. To avoid the need for further calculation, designers may use the default ψ-values for good window installation details, which are published by PHI in the PHPP Manual or the default y-values described above.

The CLP has adopted the practice of using external dimensions for heat loss calculations. It simplifies designers ‘ work and eliminates the need to allow for the geometrical thermal bridges at the corners of buildings.

Treatment of air infiltration and ventilation

The greater the volume of air that moves through the fabric of a building, the higher the heat loss will be if temperature differentials draw warm air from the inside to the outside and cold air is drawn into the warmed building. The air moves through the thermal envelope of the building either under wind pressure or as a result of the stack effect.

Energy performance of buildings significantly worsens with increasing air leakage through the thermal envelope. The convective heat loss associated with most party walls has also recently been identified as a significant factor. Calculating accurately the heat loss arising from air permeability

Text removed pending review and updating work

FIGURE 4

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Example calculation: comparing heat losses from buildings built to different standards

The level of heat loss arising from a semi-detached house built to different standards and design details is illustrated in Table 2.

The table compares the overall level of insulation allowed under the Silver standard and under Part L1A of the Building Regulations 2006. The intent is to demonstrate heat loss accurately. We have done this by defining ADL-1 2006 in a way that represent how the Building Regulations could be applied in order to comply with the TER and then applying accurate values for real heat losses in accord with the principles discussed earlier in this document.

THE METHODOLOGY USED FOR THE COMPARISON

Defining the Building Regulations 2006 standard

The parameters of the 2006 standard have been derived by meeting the 20% reduction in the TER in the following ways:

- the U-values for the building regulations are the maximum allowed, which are basically the same as the U-values in the 2002 regulations
- the reduction of 20% in the TER has been reached by including a more efficient boiler than the building regulations reference case (since this is now a separate regulatory requirement) and by improving the hot water tank insulation
- the higher window U-value is a typical weighted average for smaller windows and/or smaller individual lights than the standard-sized 1250 x 1500 mm. Smaller lights are typical of current UK dwelling designs
- the naturally-ventilated typical ADL1–2006 house has trickle vents and extract fans while the Silver Standard house has MVHR.

These changes are legitimate ways of reaching the target reduction but they do not improve the fundamental efficiency of the fabric.

Calculating the heat loss from the windows

Conventionally, the standard pane size is modelled with a central divider, with one opening and one non-opening light, which could be considered as equivalent to two 0.75 x1.25 windows. However, it is important to model the actual arrangement of glazing bars, as the heat loss through timber of window frames and edges of glazing units can equal or exceed the heat loss of the entire blockwork wall.

Calculating heat loss from linear thermal bridges

The losses from the non-repeating linear thermal bridges have been accurately calculated, rather than taking the assumed heat loss implied by the y-value. The major non-repeating linear thermal bridges in the example are the ground floor-to-wall junction and the lintels, sills and jambs. The window surrounds in the conventional dwelling have high ψ–values and add up to make a long linear thermal bridge.

We have calculated the heat loss from the linear thermal bridges in detail to demonstrate the difference between using the y-value, and calculating the sum of the actual linear thermal bridges. Although the SAP calculations say that if Accredited Details are used, an overall y-value of 0.08 may be applied, in this typical case, the real y-value is calculated to be 0.13 using the actual psi-values given for the Accredited Details in SAP Appendix K. Clearly the two figures are not equivalent, and demonstrate that the accredited details do not deliver the notional y-value of 0.08 W/m^{2}K and that, consequently, the overall heat loss will be higher than would implied by the notional value.

Using HLP

The Heat Loss Parameter is a building ‘s total specific heat loss in W/K per m^2 of internal floor area. The heat loss includes the sum of all areas multiplied by their U-values, the sum of all non-repeating thermal bridges, and the infiltration and ventilation heat losses.

Ventilation heat loss is calculated after allowing for any heat recovery, so the use of MVHR will reduce the HLP. The total heat loss in units of W/K is divided by the total internal floor area of the building, according to the UK definition of floor area, in m^2 to give the heat loss parameter in W/(K.m^2).

The HLP is the primary limiting factor in the AECB ‘s prescriptive standard; the U-values given are the maximum figures, but some built forms will need lower U-values, or improved ventilation to meet the HLP defined in the standard. It also has this role in the CSH level 6 standard. In the AECB ‘s standards the HLP must achieve different values, depending on:

1. The total heat capacity contained in the thermal envelope, in terms of Wh/K.m^2 of floor area, and
2. The total area of unshaded south-facing glazing relative to floor area.

Table 2 shows the heat losses attributed as follows:

- conductive heat loss (a) from the insulated structure, including the loss via repeating linear thermal bridges and point thermal bridges; (b)
- via the linear non-repeating linear thermal bridges; and
- convective heat loss via (a) air infiltration and (b) deliberate ventilation.

The Silver Standard:

- reduces conduction losses from the insulated structure (1) by 30% from 84 to 58 W/K
- reduces conduction losses via the linear non-repeating thermal bridges (1) b by 77%, from 23.2 W/K to 5.1 W/K
- reduces heat losses due to air infiltration plus ventilation by 77%, from 58.6 W/K to 13.7 W/K.

The Silver Standard achieves a 72% reduction in losses to 14 W/K in two ways:

- Infiltration heat losses are reduced by using construction details which are designed to be relatively airtight; reducing these losses by about 88%; and
- In most dwellings, a heat recovery ventilation system is used which recovers at least 70% of the heat in the stale exhaust air to preheat the cold fresh air. This relatively controllable air supply replaces the relatively uncontrollable ingress of cold fresh air in the conventional dwelling.

The example shown has slightly lower U-values, calculated using UK conventions, than the Silver Standard limits. However, when the non-repeating linear thermal bridges are taken account of, the sum of the U-values and the y-value, calculated using UK conventions, is just below the permitted limits.

Design for airtightness is not just about reducing heat losses. An important benefit of it is avoiding interstitial condensation. If warm moist internal air passes into a leaky structure, the water vapour will condense to liquid when it meets cold parts of the structure.

Interstitial condensation is usually thought of in terms of the diffusion of water vapour through vapour-permeable materials down a vapour pressure gradient. If this water vapour is blocked by layer(s) of relatively vapour-impermeable materials, it may condense out. But the bulk movement of warm moist air through leaky building envelopes, from the warm side to the cold side, usually accounts for tens or hundreds of times more transport of water vapour than vapour diffusion - and is a more common cause of condensation and damage to building structures. So it is very important to design construction details to be airtight.

TABLE 2. **Total heat loss from a semi-detached house to UK Building Regulations or Silver Standard ‘**

(1) HEAT LOSS VIA CONDUCTION		**Silver Standard House**		**2006 Building Regulations House**	
(a) From the insulated structure, including point and linear repeating thermal bridges					
Element	**Area**	**U-value**	**Specific heat loss**	**U-value**	**Specific heat loss**
	m^2	W/mK	W/K	W/mK	W/K
Roof	40	0.12	4.80	0.20	8.00
Walls	77	0.24	18.0	0.35	26.80
Windows	18	1.40	25.20	2.20	39.60
Doors	2	0.90	1.80	2.50	5.00
Floor	40	0.18	7.00	0.20	8.00
TOTAL	**179**		**56.80**		**87.40**
(b) Additional loss via linear non-repeating thermal bridges					
Element	**Length**	**ψ-value**	**Specific heat loss**	**U-value**	**Specific heat loss**
	m	W/mK	W/K	W/mK	W/K
Floor-wall junction	26	0.03	0.80	0.16	4.20
First floor	18	0.00	0.00	0.07	1.30
Eaves	10	0.03	0.30	0.04	0.40
Verge at gable end	9	0.03	0.30	0.24	2.20
Verge at party wall	9	0.03	0.30	0.24	2.20
Vertical at party wall	10	0.06	0.60	0.06	0.60
Vertical at external corners	10	0.06	0.60	0.09	0.90
Window heads	18	0.03	0.50	0.50	9.00
Window jambs	40	0.03	1.20	0.05	2.00
Window sills	15	0.03	0.50	0.04	0.60
TOTAL			**5.00**		**23.3**
(c) Total heat loss from the insulated structure via the above mechanisms, (a) plus (b)			**61.80**		**110.70**
y-value for building, in W/m^2K			**0.028**		**0.13**
(2) HEAT LOSS VIA AIR MOVEMENT					
Air infiltration	**1.5 m^3/m^2hr @ 50 Pa**		**6.20**	**13 m^3/m^2hr @ 50 Pa**	**53.60**
Deliberate ventilation	Continuous MVHR, mean 25 litres/sec and 75% heat recovery		7.50	Occasional use of extract fans	5.00
Total heat loss via air movement			14.00		54.00
(3) TOTAL BUILDING HEAT LOSS, (1)a + (1)b + (2)				**76.00**	**165.00**
DESIGN HEAT LOSS AT 20° C INSIDE, -4°C OUTSIDE			**1.80**	**kW**	**4.00**

NOTES TO TABLE 1:

a. Both dwellings are of cavity masonry construction.

b. The above ψ-values are expressed with reference to internal dimensions.

c. We assume that there are no point non-repeating thermal bridges and that the only non-repeating thermal bridges are linear ones.

d. The air movement measured in a pressure test at 50 Pa is multiplied by a factor of 0.07 to calculate the heating season average air exchange losses, following PHPP ‘s procedure for a typical level of exposure. The UK still uses an older factor of 0.05.

e. In the above example, our calculation includes figures of of 3 m^3/m^2hr for the separating walls, 13 m^3/m^2hr for the building thermal envelope and 10 m^3/m^2hr @ 50 Pa for building overall surface area. The 13 m^3/m^2hr figure is used in the heat loss calculation.

f. The calculation excludes the impact of other common thermal defects in new houses. For instance, typical separating wall details cause elevated heat loss. Work by Leeds Metropolitan University at Stamford Brook housing project in Cheshire suggests that masonry separating walls of current design have effective U-values of 0.5-0.6 W/m^2K, about twice the U-value of an ‘external ‘ wall.

Calculating CO_2 emissions

SECTION 3

UK official figures

UK published coefficients for the calculation of CO_2 emissions from different fuels, are not consistent across government departments. They are also widely regarded as leading to significant under-estimates of actual CO_2 emissions from the use of a unit of various forms of energy.

The CLP therefore seeks to provide more accurate figures for the emissions related to different fuels. These are based on the fundamental chemistry involved.

Primary energy consumption

Calculate primary energy consumption using overall efficiencies as follows, from primary to delivered energy:

- solid fuels, including coal or wood, delivered energy/primary energy 0.95;
- oil and LPG 0.91;
- natural gas 0.94;
- grid electricity 0.36

So if a building uses 33,000 kWh/yr of delivered mains gas, the corresponding consumption of primary energy is 33,000/0.94 = 35,000 kWh/yr. If it uses 18,000 kWh/yr of electricity, the corresponding primary energy consumption is 18,000/0.36 = 50,000 kWh/yr.

Examples of calculation procedure to use for non-domestic buildings

Open-plan office

The procedure for a new open-plan office is shown in Table 3. Typical energy use is given in ECG 19[1] as 151 kWh/m^{2}yr of gas, oil or LPG and 85 kWh/m^{2}yr of electricity. Using AECB conversion factors, this corresponds to CO_2 emissions of 76 kg/m^{2}yr. The allowed primary energy use and CO_2 emissions are reduced accordingly. For Step 3, primary energy use and CO_2 emissions are 80% less than typical of the stock.

As an actual case study, Table 3 includes early measured consumption figures and emissions for the Lamparter Office in southern Germany, built 1999-2000. The figures were later improved upon by the owners purchasing some more energy-efficient items of office equipment.

Secondary school without swimming pool

The procedure for a secondary school without swimming pool is shown in Table 4. Typical energy use is given in Carbon Trust report ECG 073 as 173 kWh/m^{2}yr of gas, oil or LPG and 34 kWh/m^{2}yr of electricity. Using AECB conversion factors, this corresponds to CO_2 emissions of 51 kg/m^{2}yr. For Step 3, primary energy consumption and CO_2 emissions are 75% less than typical of the existing stock.

As an actual case study, Table 4 includes the measured energy consumption for the Waldshut School in southern Germany, built 2002-

03. The space heating energy use figure reflects a rather high internal temperature. In other respects, it shows expected levels of performance for a CLP Step 2 secondary school with no swimming pool.

Other building types for which the Carbon Trust has published energy benchmarks should be treated similarly to offices or schools.

CO_2 emissions coefficients

CO_2-equivalent emissions are to be calculated using overall coefficients of:

- coal 0.32 kg per kWh of delivered energy;
- wood 0.05 kg/kWh;
- natural gas 0.195 kg/kWh;
- LPG 0.235 kg/kWh;
- light heating oil 0.26 kg/kWh;
- electricity from the national grid 0.55 kg/kWh (based on the annual average[3]).

So if a building uses 60,000 kWh of delivered mains gas, the corresponding CO_2-equivalent emissions are 60,000 x 0.195 = 11,700 kg = 11.7 tonnes.

If it uses 36,000 kWh of electricity, the CO_2-equivalent emissions are 36,000 x 0.55 = 19,800 kg = 19.8 tonnes.

AECB will review coefficients on a regular basis, particularly with respect to electricity.

No credit is given for ‘green tariffs ‘. The proportion of electricity from renewable systems is only 4% in 2007. Although a contract may appear to be for renewable electricity, the electricity delivered will be largely from fossil-fuelled electricity, with the attendant CO_2 emissions.

Assume that fossil fuel consumption, where unspecified in Carbon Trust energy benchmarks, is made up of 85% mains gas, 12% oil and 3% LPG.

Calculating the primary energy and CO_2 reductions for the standards

The primary energy and CO_2 reductions for dwellings in Building Regulations and the Code for Sustainable Homes are expressed relative to a reference dwelling. AD L1A 2006 sets a 20% reduction in energy and CO_2 emissions relative to an identical dwelling meetings AD L1 2002.

The AECB has chosen to express the primary energy and CO_2 reductions delivered by the energy standards against measured energy data, rather than notional energy consumption, to provide a more real sense of what can be achieved. This has been calculated by estimating energy and CO_2 emissions for the average dwelling based on the Digest of UK Energy Statistics for 2003, later updated to 2004. Its energy consumption and CO_2 emissions per m^2 of floor area represent the weighted average for the dwelling stock. For further details, see Appendix 1.

3. For electricity, the coefficient varies from year to year according to which power stations are used. It also varies from hour to hour. It is higher in winter, when most space heating is used, than in summer.

Calculating primary energy and CO_2 budgets for different buildings

The permitted energy and CO_2 budgets for dwellings of varying surface/volume ratio in the AECB energy standards were derived by the use of PHPP for a range of dwelling types and sizes. All variants modelled met or exceeded the useful space heating energy target of ≤15 kWh/m²yr and contained energy-efficient lighting, electrical appliances, central heating pumps, etc. There is a modest decline in the energy needed by larger, more compact buildings, assuming the same occupancy density, appliance ownership, solar exposure, etc. Hence the allowable energy use per unit floor area falls slowly as the building 's volume-to-surface area ratio rises.

A block of flats or maisonettes, or a row of attached houses, may be designed so that the building as a whole, but not all its constituent dwelling units, meet the stipulated energy and CO_2 budgets. So calculate the volume/surface area ratio for the whole block and then set the energy and CO_2 budget accordingly. Interpolate linearly where necessary and do not attempt to exceed three significant figures. For instance, if a row of houses has a volume/surface ratio of 1.25, measured internally, the performance version of the standards sets a limit to primary energy usage of 119.5 kWh/m²yr and a limit to CO_2 emissions of 23.5 kg/m²yr.

The target figure for space heating in the standards; e.g. ≤15 kWh/m²yr, is the annual output of the space heating system per unit of treated floor area, not the annual fuel input. For dwellings, calculate it assuming a standard occupancy for that dwelling 's treated floor area; i.e., a floorspace of 31 m² per person and a daily mean internal temperature of 20°C for normal buildings and 21.5°C for care homes, sheltered housing, hospitals or hotels. These temperatures are under review by PHI and may be raised.

Calculate winter ventilation for dwellings at a mean daily rate of 8 l/s. or 30 m³/hr.person, using the design occupancy for that dwelling; i.e., 31 m²/person.

TABLE 3. **OPEN-PLAN OFFICE**

Energy standard		Existing stock	Qualifying examples				
			Step 1	Step 2	Lamparter Office (Germany)	Step 3	
Delivered energy	Gas or oil	151	30	18	12	16	kWh/m²yr
	Electricity	85	26	20	25	20	kWh/m²yr
	Total	236	56	38	38	36	kWh/m²yr
	Index	100	24	16	16	15	
Primary energy	Gas or oil	161	32	19	13	17	kWh/m²yr
	Electricity	236	72	56	69	56	kWh/m²yr
	Total	397	104	75	83	73	kWh/m²yr
	Index	100	26	19	21	18	
CO² emissions	Gas or oil	29	6	4	3	3	kWh/m²yr
	Electricity	47	14	11	14	0	kWh/m²yr
	Total	76	20	15	16	3	kWh/m²yr
	Index	100	26	19	21	4	

1 Energy Consumption Guide 19 for Offices – www.cibse.org/pdfs/ECG019.pdf

TABLE 4. **SECONDARY SCHOOL WITHOUT POOL.**

Energy standard		Existing stock	Qualifying examples				
			Step 1	Step 2	Waldshut school	Step 3	
Delivered energy	Gas or oil	157	30	12	18	11	kWh/m²yr
	Electricity	34	29	18	19	20	kWh/m²yr
	Total	191	59	30	37	31	kWh/m²yr
	As index	100	31	16	19	16	
Primary energy	Gas or oil	168	32	13	19	12	kWh/m²yr
	Electricity	94	81	50	53	56	kWh/m²yr
	Total	262	113	63	72	67	kWh/m²yr
	As index	100	43	24	27	26	
CO_2 emissions	Gas or oil	32	6	2	4	2	kWh/m²yr
	Electricity	19	16	10	10	0	kWh/m²yr
	Total	51	22	12	14	2	kWh/m²yr
	As index	100	44	24	28	4	

References

1. ANDERSON B Conventions for U-value calculations. BRE report 443 - 2006 version
2. BRE IP 1/06 Assessing the effects of thermal bridges at junctions and around openings 2006
3. BS EN ISO 13789:1999 Thermal Performance of Buildings - Transmission Heat Loss - Calculation Method
4. BS EN ISO 6946 :1997 Building Components and Building Elements - Thermal Resistance and Thermal Transmittance - Calculation Methods
5. BS EN ISO 14683:1999 Thermal Bridges in Building Construction - Linear Thermal transmittance - Simplified methods and default values
6. BS EN ISO 10211 Thermal Bridges in Building Construction - Heat Flows and Surface Temperatures - Part 1 General Calculation Procedures 1995.
7. Ibid. Part 2 Calculation of Linear Thermal Bridges: 1999
8. BS EN ISO 13370:1998 Thermal Performance of Buildings - Heat Transfer via the Ground - Calculation Method
9. Accredited Construction details - from www.planningportal.gov.uk; see building regulations/approved documents/other.
10. KOBRA, KOBRU86, TRISCO - Thermal analysis programs from www.physibel.be 2006-082611.
11. Passivhaus Planning Package 2007: Specifications for Quality Approved Passivhaus buildings. PHI-2007/1(E)

SECTION 4

Appendix 1

Estimating the average energy use and co_2 emissions of the UK dwelling stock

Current estimates of the energy use and CO_2 emissions of the UK dwelling stock are as follows:

- delivered energy 288 kWh/m^{2}yr, comprising
  - 229 kWh/m^{2}yr fossil fuel (6 kWh solid fuel, 19 kWh oil or LPG and 203 kWh gas), and
  - 59 kWh/m^{2}yr electricity
- primary energy 409 kWh/m^{2}yr; and
- CO_2 emissions 78.8 kg/m^{2}yr

These were calculated using the following information and methodology:

- the DTI ‘s Digest of UK Energy Statistics 2005, whereby domestic delivered energy in 2004 was 12 TWh solid fuel, 42 TWh oil, 425 TWh gas and 124 TWh electricity;
- BRE ‘s Domestic Energy Fact Files, giving a total stock of 24.7 million dwellings in 2004 and stating that in 1996 the mean dwelling floor area in England was 85 m^2. To work out total floor area in 2004 we have assumed that new UK dwellings since 1996 have averaged 78 m^2 in floor area and were built at an average rate of 200,000/year.
- delivered energy is converted to primary energy using these factors: solid fuels including wood 0.95, oil 0.91, natural gas 0.94 and electricity 0.36. Delivered energy is converted to CO_2 emissions using these coefficients: solid fuel 0.32 kg/kWh, oil including LPG 0.25 kg/kWh, LPG 0.235 kg/kWh, mains gas 0.194 kg/kWh and electricity 0.55 kg/kWh.