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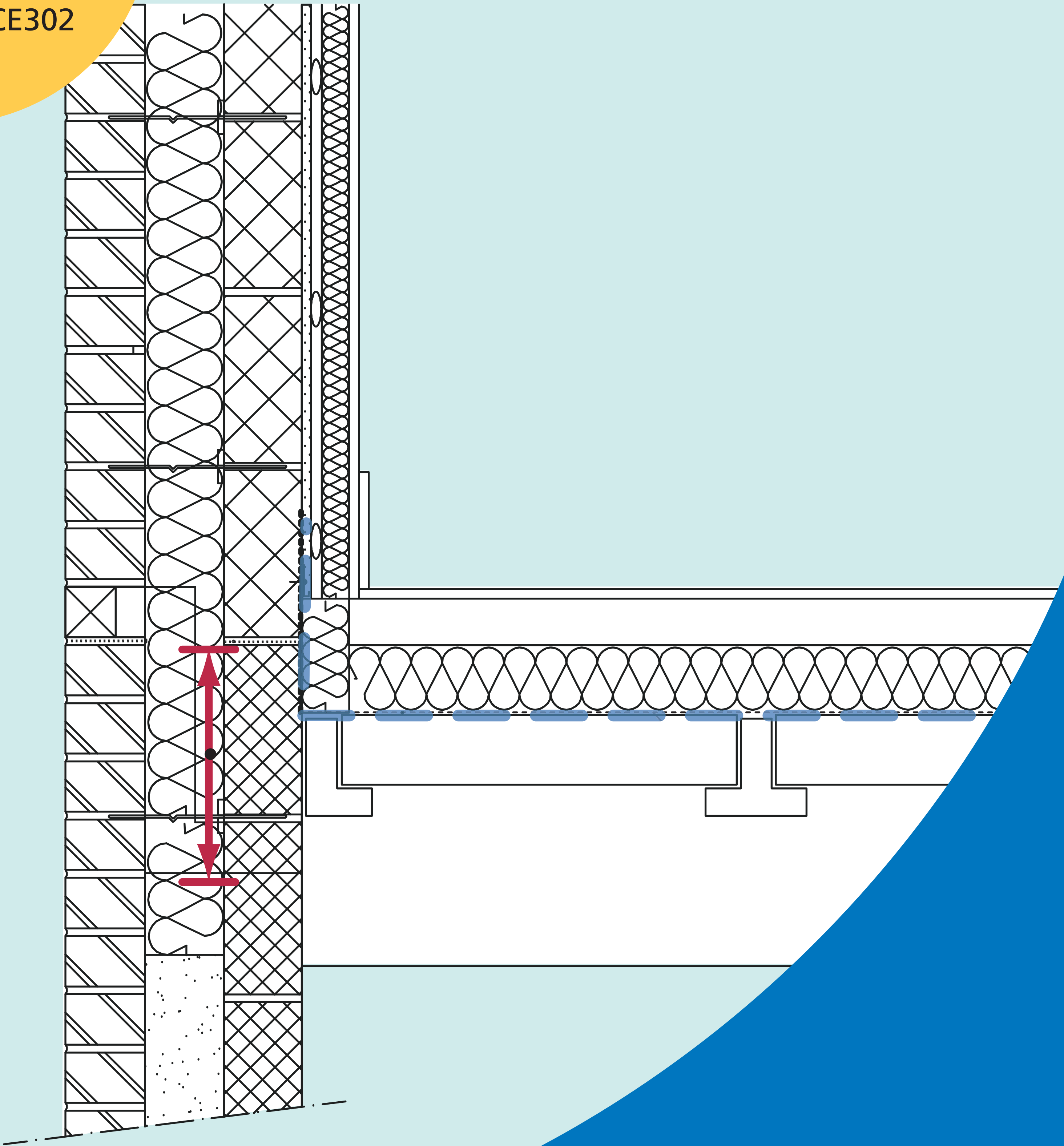

Enhanced Construction Details: Thermal bridging and airtightness

energy saving trust®

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Executive summary

This guide provides information and guidance relating to thermal bridging for use with the Enhanced Construction Details. It is a supplement to 'Enhanced Construction Details: introduction and use'.[1]

It aims to help housing designers, specifiers and builders reduce heat loss through the non-repeating thermal bridges that occur between building elements, at corners and around openings. Non-repeating thermal bridging is specifically included in SAP[2] and therefore forms part of building regulations compliance in England, Wales, Northern Ireland and Scotland.

Around 30% of the total heat loss through a building's fabric can be caused by thermal bridging. Indications are that better detailing and improved airtightness can reduce a dwelling's annual carbon dioxide (CO_2) emissions by up to 10%.

Simple design principles can improve the thermal performance of key details such as lintels, wall to floor junctions and ceiling to gable wall junctions by over 85%. Furthermore, improving fabric thermal performance with better detailing and improved airtightness can increase opportunities for design flexibility.

Site construction activities are key to realising these designed improvements in thermal bridging performance and improved airtightness.

Using the Energy Saving Trust Enhanced Construction Details and other details that conform to at least the standard of Accredited Construction Details will allow for the use of the Energy Saving Trust default y-value of 0.04 W/m^{2}K in SAP.

1. See the Helpful Tools section of our website www.energysavingtrust.org.uk/housing/tools/ECD
2. Specifically in SAP2005 and in its successor SAP2009.

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1. Introduction

Home energy use is responsible for over a quarter of UK carbon dioxide (CO_2) emissions which contribute to climate change. To help mitigate the effects of climate change, the Energy Saving Trust has a range of technical solutions to help UK housing professionals build to higher levels of energy efficiency.

To achieve overall energy efficiency, our housing guidance promotes high levels of insulation and airtightness in new dwellings as part of an integrated approach to housing design embracing the building fabric, heating and hot water systems, ventilation and lighting. All our information is available from www.energysavingtrust.org.uk/housing

The Energy Saving Trust developed the Enhanced Construction Details (ECDs) set with an industry working group to improve on the existing Accredited Construction Details (ACDs) and enable designers and developers to achieve further reductions in heat losses from dwellings.

This guide is intended for those involved in refurbishment with previous knowledge of:

- Approved Document L1 – Conservation of fuel and power, in England and Wales[3].
- Technical Booklet F1 – Conservation of fuel and power, in Northern Ireland[4].
- Section 6: Energy, of the Domestic Technical Handbook, in Scotland[5].

Focusing mainly on thermal bridging, this document explains the key principles associated with construction detailing of dwellings. It shows how to reduce heat losses at the junctions between elements, at corners and around openings. An associated and complementary aim of the ECDs is to improve the airtightness of a building's fabric.

This guide follows the introductory document and sets out how to use ECDs and gain credit in SAP for the improved thermal performance they deliver.

2. Development of Enhanced Construction Details

Following the publication of the Code for Sustainable Homes by the Department of Communities and Local Government (CLG) in December 2006, it became apparent that meeting the Code's energy requirement would require a significant reduction in the amount of heat loss from dwellings.

This can be achieved by reducing the fabric U-values of thermal elements further. But it is also necessary to reduce the impact of thermal bridging and uncontrolled ventilation heat losses.

To this end, the Energy Saving Trust has published a series of design guides covering how to meet the energy requirements of Code levels 3, 4 and 5&6. The design principles for meeting Code level 3 in the Energy Saving Trust guide *Energy efficiency and the Code for Sustainable Homes Level 3 (CE290)*[6] can be summarised as follows.

- Use design backstop fabric U-values of:

Roof	**0.13 W/m²K**
Walls	**0.25 W/m²K**
Floors	**0.20 W/m²K**

- Add improvements to the heating system (including its controls).
- Reduce heat losses through thermal bridges.
- Improve fabric airtightness to reduced uncontrolled ventilation.
- Provide whole-house mechanical ventilation.

The combination of all these factors provides a holistic approach to reducing CO_2 emissions from dwellings. Leading on from the guidance given in CE290, it was decided that the Energy Saving Trust Enhanced Construction Details project should focus on three types of junction detail with the significantly higher Ψ-values from Accredited Construction Details: lintels, gable/ceiling junction and the wall/ground-floor junction (see table 1).

3. England and Wales: The Building Regulations 2000, Conservation and power, are detailed in Approved Document L1A (2006 Edition). See www.planningportal.gov.uk
4. Northern Ireland: Building Regulations (Northern Ireland) 2000, are detailed in Technical booklet F1 2006, Conservation of fuel and power in dwellings. See www.dfpni.gov.uk
5. Scotland: Section 6: Energy, of the Domestic Technical Handbook outlines possible ways of complying with the Building (Scotland) Regulations 2007. See www.sbsa.gov.uk
6. See www.energysavingtrust.org.uk/housing/thecode

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Table 1: Default values of Ψ for junctions in wall constructions in Accredited Construction Details

Junction detail in external wall	Default Ψ-value (W/m²K)
Steel lintel with perforated steel base plate	**0.50**[3]
Other lintels (including other metal lintels)	**0.30**
Ground floor	**0.16**
Balcony between dwellings[1] [2]	0.04
Eaves: insulation at ceiling level	0.06
Eaves: insulation at rafter level	0.04
Gable: insulation at ceiling level	**0.24**
Gable: insulation at rafter level	0.04
Corner: normal	0.09
Corner: inverted	-0.09
Party wall between dwellings [1]	0.06

(1) For these junctions half of the Ψ-value is applied to each dwelling.

(2) This is an externally supported balcony (i.e. the balcony slab is not a continuation of the floor slab) where the wall insulation is continuous and not bridged by the balcony slab.

(3) Details in **bold** are the worst performing details and have been improved in the set of ECDs.

In the context of determining (from numerical modelling) the Ψ-values of enhanced junction details of these identified types, it was further decided to use fabric U-values that were lower than the design backstops suggested in CE290. The thermal modelling of the ECDs has demonstrated that a y-value of 0.04 W/m²K can be claimed with the following set of U-values. These are compatible with the published Energy Saving Trust design guidance on Code levels 4 (CE291) and 5&6 (CE292) and are:

Roof	**0.13 W/m²K**
Walls	**0.15 W/m²K**
Floors	**0.15 W/m²K**

You can confidently use these ECDs for all dwelling designs that are required to comply with the current building regulations, or those that need to comply with higher levels of the Code for Sustainable Homes.

3. Thermal bridging

In general, thermal bridges can occur at any junction between building elements or where the building structure changes. Compared with an un-bridged structure, the two primary effects associated with a thermal bridge where a building is being heated are reduced internal surface temperature and increased heat loss.

Thermal bridges fall into two categories:

(a) *repeating* thermal bridges (such as timber joists, mortar joints, mullions in curtain walling). The additional heat flow due to this type of thermal bridge is included when determining the U-value of the particular building element which contains these bridges (for further details see BR 443[7]);

(b) *non-repeating* thermal bridges (such as junctions of floor and roof with the external wall and details around window and door openings) where the additional heat flow due to the presence of this type of thermal bridge is determined separately.

This publication deals with thermal bridges from category (b), i.e. non-repeating thermal bridging.

7. Conventions for U-value calculations 2006 Edition (BR443). See www.bre.co.uk/filelibrary/rpts/uvalue/BR_443_(2006_Edition).pdf

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Linear thermal transmittance
Each construction detail within which a non-repeating thermal bridge occurs has an associated heat flow through that thermal bridge, which is represented by its linear thermal transmittance, or **Ψ-value** (psi value - pronounced 'si') in W/m^2K. The **Ψ-value** represents the extra heat flow through the linear thermal bridge over and above that through the adjoining thermal element(s). These **Ψ values** should be calculated by following the guidance contained in the publication "*Conventions for calculating Linear thermal transmittance and Temperature factors" – BR 497*[8].

4. Overall design principles and thermal modelling process

As can be seen from the list of Ψ-values contained in table 1 (the defaults for Accredited Construction Details), apart from lintels, ground-floor/wall, and gable/ceiling junctions, all other junctions have Ψ-values that are less than 0.10 W/m^2K.

So the ECDs have focused on designing lintel, gable and ground-floor details that resulted in significant reductions in their Ψ-values. Improving these details will have a major impact of the subsequent default y-value for use in SAP calculations.

Table 2: Description of each construction type

Construction Type	Type Code	Brief Description
Cavity Masonry	**MV01**	100mm block inner leaf internally plastered*. 150mm fully filled insulated cavity. Brick outer leaf.
	MV02	100mm block inner leaf, internally lined with laminated plasterboard on horizontal continuous dabs on parge coat. 100mm fully filled insulated cavity. Brick outer leaf.
	MV03	100mm block inner leaf, internally lined with laminated plasterboard on horizontal continuous dabs on parge coat. 100mm partially filled insulated cavity. Brick outer leaf.
Timber Frame	**TF01**	140mm fully filled timber frame, sheeted externally, air barrier/vapour control layer and insulated lining internally. Service void and plasterboard. Clear cavity with brick outer leaf.
	TF02	140mm fully filled timber frame, sheeted both sides, air barrier/vapour control layer. Service void and plasterboard. Partially filled insulated cavity with brick outer leaf.
Light Steel Frame	**SF01**	70mm fully filled light steel frame, air barrier/vapour control layer. Service void and plasterboard. Partially filled insulated cavity with brick outer leaf.
Ceiling	**-**	Attic trusses with insulation laid above, between and below, air barrier/vapour control layer. Service void and plasterboard.
Beam and Block	**F01**	Beam and block floor with insulation and air barrier above, with screeded finish.
Slab on ground	**F02**	100mm concrete slab on insulation on damp proof membrane/air barrier.
Suspended Timber	**F03**	Floor decking on insulation on air barrier on sheeting on suspended timber floor joists off joist hangers.

*NB. Internally plastered finish could be replaced by plasterboard on continuous horizontal dabs on parge coat.

8. www.bre.co.uk/page.jsp?id=677

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Table 3: Summary of modelled U-values

Energy Saving Trust Enhanced Construction Details - summary of U-values					
	Wall	**Roof**	**Slab on ground**	**Beam and block**	**Suspended timber**
MV01	0.22	0.11	0.15	0.14	0.15
MV02	0.20	0.11	0.15	0.14	0.15
MV03	0.22	0.11	0.15	0.14	0.15
TF01	0.22	0.11	-	0.14	0.15
TF02	0.19	0.11	-	0.14	0.15
SF01	0.18	0.11	-	0.14	-

An initial scoping study found that it was possible to aim for a much lower ECDs default y-value of 0.04, as long as the Ψ-values of lintels, ground-floor/wall, and gable/ceiling junctions were no greater than about 0.07 W/m^2K.

The details themselves were developed and designed in association with an industry working group made up of house builders, designers, product manufacturers, and building physics theorists. The aim was to design out possible problems and provide buildable details that the house-building industry could readily incorporate into its existing designs, therefore reducing thermal bridging heat losses without radically altering current build forms.

To focus the efforts of the working group, the construction forms were restricted to the main types currently used. For walls this meant cavity masonry (three variants), timber frame (two variants), and light steel frame. For floors, it covered slab on ground, suspended block and beam, and suspended timber.

Although some additional options were explored during this development process, these alternative details failed to achieve a low enough Ψ-value to be acceptable as ECDs. However, for completeness, these details and their resulting Ψ-values are discussed later in this guidance. Although not part of the ECDs (such that a default y of 0.04 can be used), they could be incorporated into a design for which a user defined y-value will be used.

Table 2 gives a brief summary of each specification for the various elements that make up the final ECDs set.

The junction details were modelled based on building elements of wall, roof and floor which achieved the following fabric U-values shown in table 3. These U-values are significantly lower than the suggested backstop U-values contained in the Energy Saving Trust Code level 3 guidance and should be considered as the target U-values for building elements when using the ECDs.

5. Consideration with other design criteria

The interaction between the thermal requirements and any other design criteria of any thermal element has to be considered from the start. The ECDs themselves only consider thermal and airtightness criteria. However, other design criteria need to be considered on their own merits. Below is some general guidance on determining if a detail is equivalent to an ECD.

5.1 Structural issues

The thickness of the masonry inner leaf described in table 2 is not significant for either of the MV02 or MV03 wall types. However, its thickness is more significant for the MV01 wall type when considering flanking heat losses through the wall/gable junctions and the wall/ground-floor junctions.

The declared Ψ-values for all MV01 details assume an inner leaf thickness of 100mm. For this declared Ψ-value (and hence the ECD y-value of 0.04) to be valid for inner leaf wall thickness up to 125mm, the thermal conductivity of the inner leaf masonry, demanded as a consequence of meeting the required thermal resistance limit, should be further adjusted as follows:

$$\lambda'_m = \lambda_m \times \frac{100}{d}$$

where

λ'_m is the adjusted thermal conductivity of the masonry inner leaf in W/m²K.

λ_m is the unadjusted thermal conductivity of the masonry inner leaf in W/m²K.

d is the thickness of the inner leaf in mm.

For inner leaf thickness greater than 125mm, the particular MV01 type detail would need to be numerically modelled in order to determine its Ψ-value and hence its equivalence (or not) to an ECD.

The size/spacing of timber or steel framing members is not thermally significant (since this has already been incorporated into the wall's U-value), as long as any required minimum thermal resistance is achieved for any critical thermal layers.

5.2 Fire resistance

The integrity/stability of timber framed structures in a fire situation is a result of their inherent properties and any applied layers of fire-resistant boarding. If a timber frame design requires additional layers of fire resistant material, these should be placed directly against the timber framing prior to the application of any further layers of thermal insulation.

Because the finished layer of plasterboard is penetrated by services, it is unlikely that it can be considered to offer any significant degree of fire resistance.

The steel frame solution presented here should be considered similarly to timber frames. Indeed, the ECD for a steel frame wall already includes a layer of plasterboard placed adjacent to the frames. This should be considered a minimum level of fire resistance.

5.3 Sound insulation

None of the ECDs show the junction between the external wall with a party wall. Nonetheless, this junction may be critical in terms of sound insulation as well as thermal bridging. It is therefore important to choose a suitable party wall design that is compatible with a chosen external wall. Further guidance on this interaction can be found in ACDs, as well as from Robust Construction Details Ltd.

The following sections offer a step-by-step approach to tackling thermal bridging and airtightness, from the design through to construction on site.

6. Design process – thermal bridging

Construction detailing needs particular attention and in order to minimise thermal bridging, this must start at the design stage. All of the following locations are key to limiting heat loss through thermal bridging:

- Window and door openings (cills, jambs and lintels).
- External wall/ground floor junctions.
- External wall/roof junctions.
- Separating wall/roof junctions.
- Junctions of external walls with upper floors.
- Internal and external corners in external walls.
- External wall/balcony junctions.
- Chimneys in external walls.
- Meter boxes in external walls.
- Internal walls that pass through the insulation plane of the ground floor.

A number of key principles encourage a holistic design method:

Adopt a strategic approach

Modern building construction is often complex, so achieving continuity of insulation should be considered at an early stage in the design process. The choice of construction method dictates how insulation continuity is approached. Components that form the principal insulation layers should be clearly identified on drawings, and their details developed to ensure continuity of these layers between elements of the construction.

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Encourage continual communication
It is important that the approach for achieving continuity of insulation is clearly communicated to the entire construction team via drawings, product specifications and site briefings. All parties should ensure any proposed changes to the design or product selection are widely communicated, because these may have a significant impact on detailing performance.

Keep the construction simple
Simple designs are more likely to be designed and built correctly. Minimise the number of different types of construction within the thermal envelope, because problems are most likely to occur where one type of construction meets another. Consider the construction sequence of each detail, and be prepared to modify details if it becomes apparent that they are difficult to achieve, or if the construction team identifies a better method.

Position windows and door frames to overlap the insulation plane
At openings the insulation layer should be continued to the rear of the window and door frame. Rebating the frame within the full thickness of the insulation layer will help to reduce the thermal bridge further.

Specify and detail lintels carefully
The choice and detailing of steel lintels needs careful consideration if thermal bridging is to be minimised. Although the steel used in lintels is only a few millimetres thick, its high conductivity can lead to high heat loss. This is true in all situations where a steel lintel supports both leafs, but is particularly true where there is a continuous lower flange. The addition of insulation within the lintel does not significantly reduce the heat flow through the steel.

For cavity masonry construction it is best to use two separate lintels to support the inner and outer masonry leaves and to carry the cavity insulation down between the lintels (which may also involve placing preformed insulating material beneath the cavity tray). An insulated soffit board should also be used to finish the opening.

Maintain the continuity of insulation as far as possible
Ideally one would design a continuous unbroken layer of insulation around the dwelling to avoid all thermal bridging. Although in reality many traditional construction details involve bridging the insulation layer.

It is often possible to amend these details to reduce the magnitude of thermal bridging. For example, using insulated cavity closers at jambs and cills in cavity masonry construction has become common practice in order to reduce the bridging associated with returning the inner leaf of block work against the outer brickwork leaf.

Overlap insulating layers to reduce the bridging paths
Some construction details include areas that interrupt the insulation layer. These are often structural at junctions. Although these thermal bridges cannot be completely removed, they can be reduced by overlapping the insulating layers of the main elements, even though these will not necessarily be in direct contact.

One such significant location is where the ceiling meets the gable wall. Figure 1 shows it is possible that insulation between the gable wall and the last truss might be omitted or overlooked simply because there is insufficient space to physically fit insulation into that gap.

There are often opportunities to reduce these unavoidable thermal bridges further by using other low thermal conductivity materials in the gap between the overlapping layers of insulation.

Design out difficult balcony penetrations
If the design includes cantilevered balconies, a simple way to eliminate the thermal bridge is to amend the design to include balconies supported on posts, or on brackets that can be fixed into the outer leaf of the external wall without penetrating the insulation layer.

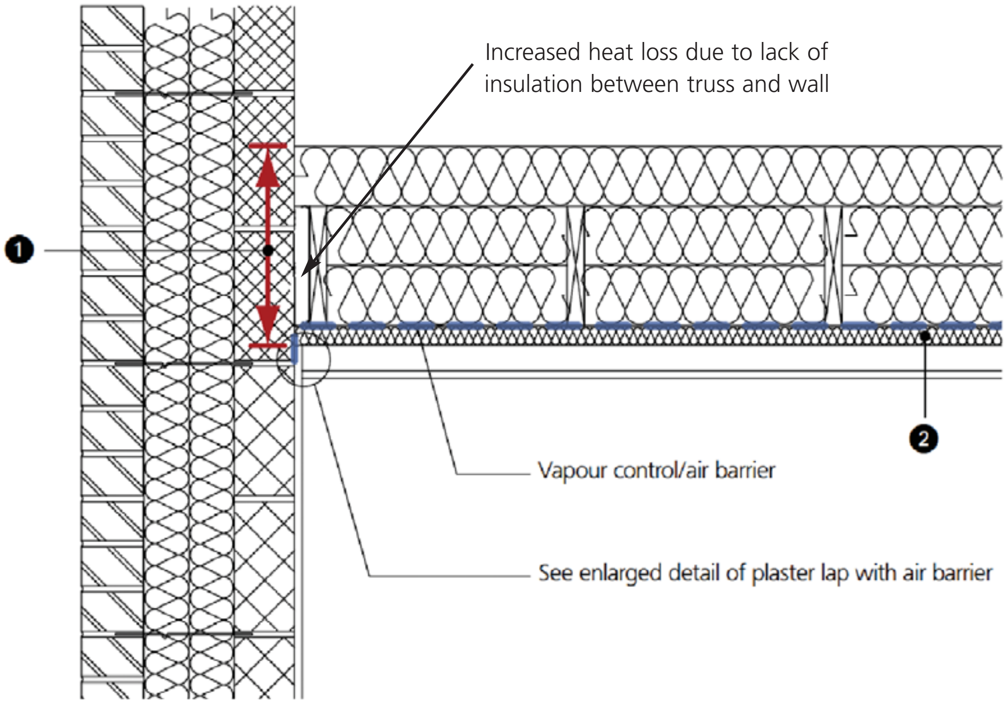

Figure 1: Enlarged view of ECD MV01 gable detail, showing the insulation omitted between the gable and the last truss at ceiling level. Without this section of insulation there will be a significant increase in heat flow at this junction. It is essential that where such a gap exists, insulation must be installed correctly. One way of ensuring sufficient space would be to pack out the last truss from the gable, at the location of the lateral restraint straps, to provide a sufficiently wide gap of say 50-75mm.

7. Construction process – thermal bridging

Site practice and construction quality are key factors in minimising thermal bridging in construction. This latest generation of building regulations emphasise this by requiring that construction quality be inspected and documented to confirm that the as-built thermal performance will be consistent with the design intention.

As explained in section 6, it is vital that the construction team – including management and supervisory staff concerned with the procurement of materials and components or with the construction of the building, and all tradesmen – are aware of the requirement to maintain the continuity of insulation and the equally important air barrier[9].

A key requirement is to ensure the construction programme is consistent with the intended assembly sequence of the continuous insulation layer. On-site quality management procedures should ensure that the continuity of insulation layers and air barriers is regularly documented and inspected before work is covered up.

9. The air barrier is the layer within the external envelope that will restrict the passage of air between the internal and external environments. See section 9 on airtightness.

8. Key practices for minimising thermal bridging

- In walls, floors and roofs, insulation materials should be continuous. Components should be butted together tightly, with no gaps between them and no gaps at the perimeters or corners. Failure to achieve accurate installation will result in breaks within the insulation layer and increase the potential for both unintended thermal bridging and air circulation, which will further increase unintended heat loss.
- Insulation should be cut to fit closely around openings and other features, and correctly cut and fitted to the front faces of any lintels, with no gaps.
- At openings, insulation should be built into window jambs, not pushed in after the wall has been completed; cill insulation should be supported on wall ties and should extend the full height of any sub-cill.
- Insulation that is exposed during the construction process should be protected against damage. In masonry cavity wall construction, cavity battens should be used to protect the top of insulation batts from mortar build up as the wall is raised. This build up can compress the insulation, which is particularly significant in materials such as mineral fibre that use the airspaces within their structure to reduce heat loss. Any mortar build up could also lead to rain water penetrating through to the inner leaf.
- Wall constructions such as masonry cavity or timber frame featuring site blown insulation should be conducted by a specialist contractor to ensure all areas of the cavity are insulated. Incorrect installation techniques can leave gaps within the structure, for example around complex openings or behind large noggins.
- Partial-fill cavity insulation boards should be coursed with the wall ties and securely fixed back to the inner leaf of masonry so that air cannot circulate behind them.
- Rigid insulation boards should be of the mitred and/or tongue and grooved type, where available, and should be securely fixed to the face of the inner leaf in accordance with the manufacturers' instructions to prevent air circulating behind the insulation layer.
- Loft insulation should be placed at the eaves early in the construction process, so that it does not have to be pushed into the eaves gap from inside the roof space after the roof has been constructed.
- Where services penetrate through fire compartment walls, floors and roofs and at meter boxes, the resulting holes should be sealed with the appropriate fire stopping system so that the fire resistance, insulation continuity and airtightness of the element is not impaired. If services penetrate through non fire compartment elements, a similarly robust seal should be created using a product that does not add to the fire load of the building, enhance the spread of flame, generate smoke or toxic fumes, or increase the rate of the propagation of fire, flame or heat across its surface.

9. Design process – airtightness

Air leakage is the uncontrolled flow of air through gaps and cracks in the fabric of a building (sometimes referred to as infiltration or draughts – see figure 2). It should not be confused with ventilation, which is the controlled flow of air into and out of the building for the comfort and health of the occupants. Too much air leakage leads to unnecessary heat loss and discomfort from cold draughts. It uses additional energy, not only to heat the air that leaks out through the fabric, but also because this is replaced by cold air from outside which also then needs to be heated. In a well insulated dwelling with a poor standard of airtightness, air leakage can account for up to 50% of the total heat loss (and exposed sites and elevated positions increase air leakage). The aim should be to *'Build tight – ventilate right'*. Taking this approach means that buildings cannot be too airtight, but it is essential to ensure that appropriate, controlled ventilation is provided.

9.1 Air leakage paths

Three main types of air leakage paths are found in dwellings (see figure 2):

- Joints around components (e.g. windows in walls).
- Gaps between one element and another.
- Holes where services pass through the construction.

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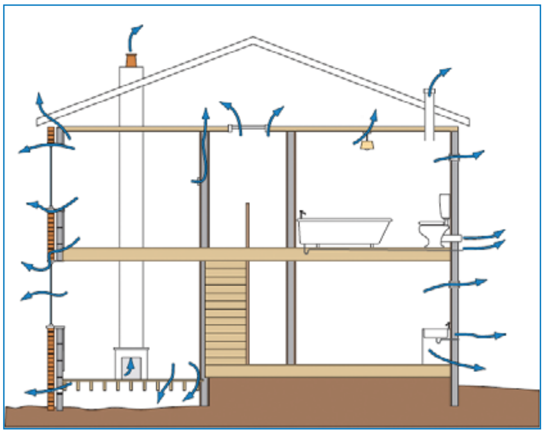

Figure 2: The many locations where uncontrolled air leakage can occur

The potential leakage paths are:

- External walls:
  - joints between masonry units.
  - the space behind dry linings.
  - at service entries behind meter boxes.
  - where electric wiring penetrates dry lining.
  - at other service penetrations (e.g. extract fans and overflows).
- Window and door openings:
  - between the frame and the wall.
  - beneath door thresholds.
  - beneath and at the sides of window boards.
  - at junctions with dry lining.
  - around steel lintels.
- Timber floors:
  - where timber joists are built into masonry walls.
  - at the perimeter of timber intermediate floors (and ceilings).
  - where holes are cut for services to run beneath the floor.
  - at ground floor service entries and soil and vent pipes (SVPs).
- Ceilings to roof spaces:
  - around the loft hatch and around its frame.
  - at the junction between the external wall and the ceiling, particularly when dry linings are present.
  - where piped services penetrate the ceiling.
  - at electrical outlets in ceilings or in walls to a room-in-the-roof.

The air barrier line

The air barrier is a term used to describe a layer within the building envelope which will adequately restrict the passage of air between the internal and external environments. The air barrier should closely follow the line of the inside face of the insulation in the exposed elements of the fabric of the building.

Consideration should be given at an early stage in the design as to which layer of each exposed element of the fabric will form the primary air barrier, and to the junctions between them.

Pen-on-section drawings

It is good practice for the air barrier line to be marked up on the architectural general arrangement and main section drawings as a bold distinguishable line. If the air barrier is continuous, it should be possible to trace around the whole section without lifting the pen. If you have to lift the pen, you have a discontinuity and a potential air leak. If the designer is not sure where the air barrier is located, it is unlikely that anybody else will know where it is either.

Larger scale drawings

It is also good practice for the design team to prepare large scale drawings (1:10 or 1:5) of sensitive points in their design. These drawings should clearly identify the insulation components and the air barrier line. The drawings should also be disseminated to all relevant parties, showing how the integrity of the insulation layer and air barrier is to be maintained at particularly complex interfaces.

The following general approach to design will help to achieve improved airtightness:

- Keep it simple. Simple designs are more likely to get designed and built right. Complex ones mean more junctions within the thermal envelope, each of which increases the likelihood of discontinuities.
- Decide which layer of the construction provides the air barrier and stick with this strategic decision as far as possible. Use the pen-on-section test to check continuity and to identify key details.
- Minimise the number of different types of construction within the thermal envelope – wherever one form of construction meets another, problems are likely to occur.

- Pay careful attention to the design of junctions between elements to ensure continuity of the air barrier. Think through the construction sequence of each detail, to ensure that it can be built. Be prepared to modify particular details if it becomes apparent that they do not work, or if site operatives identify better ways of doing them.
- Minimise the number of penetrations of the thermal envelope, whether by services or by the construction itself.
- Where penetrations are unavoidable (SVPs, ventilation exhausts and intakes, water supply, electricity and gas supplies), develop appropriate details and strategies for their proper execution. Adopt appropriate details for making good any damage to insulation and re-seal pipes and ducts to the surrounding air barrier.
- A good airtightness strategy is one which does not require the use of many tubes of mastic in an attempt to seal every visible penetration of the finished layers. All gaps should be properly sealed before applying finishes.

10. Construction process – airtightness

It is suggested that three basic principles should be addressed throughout the construction stage to ensure insulation continuity and the formation of an effective air barrier - management, communication and education, and quality control.

10.1 Management

- An ongoing review of the design is required throughout the construction phase. Project managers should ensure that details of all design changes involving elements of the external envelope are distributed throughout the design, procurement and construction teams.
- It is important that the project programme reflects the sequence needed to form the air barrier and install the insulation effectively. All trades must be allowed access to form not only the part of the insulation layer or air barrier for which they are responsible, but also to ensure that continuity is achieved between their works and that of other contractors.
- When compiling the programme of works, it may be prudent to include an ‘Air Tight’ milestone. Knowledge of this date may permit managers to schedule thorough envelope pre-test inspections and test dates in advance of the end of the project. Experience shows that these activities are of benefit to projects, relieving the inherent panic and potential penalties encountered as the completion date approaches.

10.2 Communication and education

- It is important that all managers and operatives procuring building materials and components and constructing the building fabric are aware of the need to ensure insulation continuity and airtightness. The more aware the team is of the issues, the less likely it is that essential components will be engineered out of the design for cost savings, and the more receptive site people will be to requests for a higher standard of workmanship.
- Awareness may be raised at key stages by briefing procurement offices and arranging site tool-box talks. Detailed pen-on-section drawings may be issued to all parties, clearly identifying where and how insulation continuity and the air barrier will be maintained.
- Operatives directly involved in building the elements (including the insulation and air barrier) should be encouraged to draw attention to difficulties and request direction rather than to bodge.
- Operatives not directly involved in procuring building fabric should also be made aware of the importance of maintaining insulation continuity and the air barrier line and of flagging up any breaches through these lines of defence. They should also be required to remedy any potential thermal bridges or air leakage routes brought about by their own activities, or to seek help from other trades, depending on the nature of the breach.

10.3 Quality control

- Most contractors now have systems in place for monitoring the quality of their processes and products. Experience again shows that the quality assurance (QA) system may be developed and extended to include checks for insulation continuity and airtightness.
- An essential QA control is that the issues of insulation continuity and airtightness are considered during all design changes or material substitutions affecting the external envelope. An ill-informed design change may jeopardise the final performance of the building envelope.

- The QA process should ideally involve a process of inspection of finished works. This will enable managers to check that all works are being properly constructed prior to being covered over.

11. Key practices for minimising air leakage

- Ensure that air barriers in wall, roof and floor constructions are continuous, with joints lapped at least 150 mm and joints and edges taped. Service penetrations should be avoided if possible, or sealed. The introduction of service voids can greatly reduce the risk of air leakage through the air barrier due to penetrations.

  In traditional masonry construction, floor joists should be supported on joist hangers, not built into external walls or separating walls.

- In masonry construction, blockwork inner leaves should be parged, or at the very least properly pointed up with mortar before plasterboard dry linings are fixed.
- Dry-lining boards should be fixed on continuous ribbons of plaster, not on intermittent 'dabs', especially at the head and foot of the wall, around openings, at room corners and at electrical boxes. Joints in lining boards should be taped and skimmed. Holes for services should be accurately cut with a sharp knife, and sealed after the installation has been completed.
- Openings for windows and doors should be accurately sized and square; damp proof courses should be properly fixed to window and door frames before they are built into the walls.
- Gaps around window and door frames should be properly filled with suitable sealant. Cills and thresholds should be properly bedded and sealed.
- Holes for services should not be over sized. They should be sleeved if necessary (to allow for movement) and properly sealed with expanding polyurethane foam or another suitable sealant.
- It is essential that the air barrier is inspected prior to the fixing of any finishes, and any damage repaired.

12. Design examples for compliance with ADL1A

The purpose of the ECDs is to reduce heat losses through thermal bridges, as well as improving airtightness and hence reducing heat losses through uncontrolled air leakage. The importance of this can be clearly demonstrated through the following series of SAP 2005 results.

For various typical house types complying with ADL1A, the SAP 2005 results presented here are based upon the following fabric U-values and other design criteria:

Wall U-value	**0.29 W/m²K**
Floor U-value	**0.22 W/m²K**
Roof U-value	**0.16 W/m²K**
Window U-value	**1.50 W/m²K**
Door U-value	**0.80 W/m²K**

(Total openings ~20% of floor area for dwellings and ~17% for flats)

Boiler efficiency 90%, including weather compensation and delayed start features.

Water storage vessel with 80mm factory fitted insulation.

Natural ventilation with intermittent extract fans.

Table 4 gives the set of SAP 2005 results for a design that does not include Accredited or Enhanced Construction Details. Thus the thermal bridging is estimated using the default of y = 0.15 W/m²K, and an airtightness of 10 m³/m²/h @ 50 Pa. This design represents the worst case in terms of thermal bridging and airtightness that will comply with ADL1A.

Table 5 gives the set of SAP 2005 results for a design whose junction details conform with ACDs, thus allowing a default y-value of 0.08 W/m²K to be claimed, and a design airtightness of 7 m³/m²/h @ 50 Pa to be assumed.

Comparing the two sets of results presented in tables 4 and 5, clearly there will be no difference in fabric heat losses via plane elements for any specific house type, since both use the same fabric U-values. But there is a 45% reduction in thermal bridging heat losses for each house type, and ventilation heat losses are reduced by about 9%. This means that when using ACDs for any of these house types, it is possible to achieve reductions in total heat losses of between 10% to 13%.

Enhanced Construction Details: Thermal bridging and airtightness

Table 4: SAP 2005 results for a range of house types to a default ADL1A specification

House type	Floor area (m^2)	% reduction of DER below TER	Fabric heat losses (W/K) (U-values)	Thermal bridging fabric heat losses (W/K)	Ventilation heat losses (W/K)	Total fabric and ventil-ation heat losses (W/K)
Detached	104	0.4	84.1	37.3	53.2	174.6
Semi-detached	90	0.7	67.1	29.3	46.4	142.8
End Terrace	78	2.9	58.7	26.0	40.6	125.3
Mid Terrace	78	3.5	50.4	21.5	40.6	112.5
Ground Flat	59.5	5.9	41.0	17.6	30.5	89.1
Mid Flat	59.5	7.4	29.7	9.5	33.4	72.6
Top Flat	59.5	3.2	39.2	18.5	33.4	91.1

Table 5: SAP 2005 results for a range of house types to an improved ADL1A specification

House type	Floor area (m^2)	% reduction of DER below TER	Fabric heat losses (W/K) (U-values)	Thermal bridging fabric heat losses (W/K)	Ventilation heat losses (W/K)	Total fabric and ventil-ation heat losses (W/K)
Detached	104	11.1	84.1	19.9	48.5	152.5
Semi-detached	90	10.6	67.1	15.6	42.3	125
End Terrace	78	12.7	58.7	13.8	36.9	109.4
Mid Terrace	78	12.3	50.4	11.4	36.9	98.7
Ground Flat	59.5	14.8	41.0	9.4	27.7	78.1
Mid Flat	59.5	13.6	29.7	5.1	30.3	65.1
Top Flat	59.5	12.7	39.2	9.8	30.3	79.3

Table 6: SAP 2005 results for a range of house types to an enhanced ADL1A specification

House type	Floor area (m^2)	% reduction of DER below TER	Fabric heat losses (W/K) (U-values)	Thermal bridging fabric heat losses (W/K)	Ventilation heat losses (W/K)	Total fabric and ventil-ation heat losses (W/K)
Detached	104	23.1	84.1	10.0	19.8	113.9
Semi-detached	90	21.5	67.1	7.8	17.1	92.0
End Terrace	78	23.5	58.7	6.9	14.9	80.5
Mid Terrace	78	22.4	50.4	5.7	14.9	71.0
Ground Flat	59.5	25.1	41.0	4.7	10.9	56.6
Mid Flat	59.5	22.2	29.7	2.5	12.0	44.2
Top Flat	59.5	23.7	39.2	4.9	12.0	56.1

Enhanced Construction Details: Thermal bridging and airtightness

So without radically changing any of the construction of the thermal elements it is possible to achieve at least a 10% reduction of the DER below the TER and so achieve the energy requirements of Code level 1, or the equivalent to a Merton Rule requirement that may be applied by a planning authority. Alternatively, it is possible to trade some of these savings in heat losses to reduce the fabric U-values, thus increasing design flexibility for compliance with ADL1A.

Table 6 gives the set of SAP 2005 results for a design whose junction details conform with ECDs, thus allowing a default y-value of 0.04 W/m^2K to be claimed, and a design airtightness of 3 $m^3/m^2/h$ @ 50 Pa to be assumed. For this set of results, natural ventilation is changed to mechanical ventilation with heat recovery (SFP 1.0 W/l/s, and 85% efficiency).

When comparing the results from table 6 with the results from table 4, there is about a 73% reduction in thermal bridging heat losses for each house type, and ventilation heat losses are reduced by about 63%. This means that when using ECDs for any of these house types, it is possible to achieve reductions in total heat losses of between 35% to 39%. Although it is necessary to meet certain thermal resistance rules for each individual ECD, these rules will not impact fundamentally on the typical constructions that are currently used. So when applying the ECDs philosophy to a default ADL1A design, it is possible readily to achieve the energy requirements of Code level 2, which requires an 18% reduction of the DER below the TER, and still have room for considerable design flexibility.

13. Design examples for compliance with Code for Sustainable Homes level 3 for energy

It is now a planning requirement that a certain proportion of all housing on a new development needs to be affordable. This element of the development would normally have to achieve a Code level 3 rating for energy which means a dwelling's DER should be reduced to at least 25% below its TER. Additionally, proposed changes to Part L of the Building Regulations due in 2010 will require all dwellings to achieve this 25% reduction in their CO_2 emissions.

The SAP 2005 results presented below for various typical house types complying with Code level 3 are based upon the following fabric U-values and other design criteria:

Wall U-value	**0.20 W/m^2K**
Floor U-value	**0.20 W/m^2K**
Roof U-value	**0.11 W/m^2K**
Window U-value	**1.50 W/m^2K**
Door U-value	**0.80 W/m^2K**

(Total openings ~20% of floor area for dwellings and ~17% for flats)

Boiler efficiency 90%, including weather compensation and delayed start features.

Water storage vessel with 80mm factory fitted insulation.

Mechanical ventilation with heat recovery - SFP 1.0 W/l/s, and 85% efficiency.

As for the previous design (table 6 results), table 7 gives the set of SAP 2005 results for a design whose junction details conform with ECDs, again allowing a default y-value of 0.04 W/m^2K to be claimed, and a design airtightness of 3 $m^3/m^2/h$ @ 50 Pa to be assumed, but in this set of results the fabric U-values have been reduced.

These results show that Code level 3 compliance for energy has been readily achieved, with only the mid-level flat being a marginal pass. However, it should be borne in mind that the Code for Sustainable Homes allows for 'energy averaging' for flats that are enclosed in the same construction and have the same energy design provision throughout. Energy averaging would provide for a 27.4% reduction of the DER below the TER for a three storey block of flats, and a 26.8% reduction for a four storey block. As all house types have DER savings that are more than 25%, this would allow for some degree of design flexibility while still achieving a Code level 3 rating for energy.

Table 8 gives SAP 2005 results as for the previous (table 6) set of data except that we revert to using only ACDs and the default thermal bridging y-value of 0.08 W/m2K, and an airtightness of 7 $m^3/m^2/h$ @ 50 Pa. At an airtightness level of about 7 $m^3/m^2/h$ @ 50 Pa, there is only a marginal improvement in the DER achieved by using a whole house ventilation system compared to natural ventilation, so here we revert to using natural ventilation with intermittent extractor fans.

Enhanced Construction Details: Thermal bridging and airtightness

Table 7: SAP 2005 results for a range of house types to a typical Code level 3 specification

House type	Floor area (m^2)	% reduction of DER below TER	Fabric heat losses (W/K) (U-values)	Thermal bridging fabric heat losses (W/K)	Ventilation heat losses (W/K)	Total fabric and ventil-ation heat losses (W/K)
Detached	104	29.2	69.3	10.0	19.8	99.1
Semi-detached	90	26.5	56.1	7.8	17.1	81.0
End Terrace	78	28.6	48.8	6.9	14.9	70.6
Mid Terrace	78	26.0	43.2	5.7	14.9	63.8
Ground Flat	59.5	28.7	35.6	4.7	10.9	51.2
Mid Flat	59.5	25.1	24.9	2.5	12.0	39.4
Top Flat	59.5	28.6	31.4	4.9	12.0	48.3

Table 8: SAP 2005 results for a range of house types to a reduced specification

House type	Floor area (m^2)	% reduction of DER below TER	Fabric heat losses (W/K) (U-values)	Thermal bridging fabric heat losses (W/K)	Ventilation heat losses (W/K)	Total fabric and ventil-ation heat losses (W/K)
Detached	104	18.2	69.3	19.9	48.5	137.7
Semi-detached	90	16.4	56.1	15.6	42.3	114.0
End Terrace	78	18.6	48.8	13.8	36.9	99.5
Mid Terrace	78	16.7	43.2	11.4	36.9	91.5
Ground Flat	59.5	19.0	35.6	9.4	27.7	72.7
Mid Flat	59.5	17.4	24.9	5.1	30.3	60.3
Top Flat	59.5	18.6	31.4	9.8	30.3	71.5

Comparing the results in table 8 to those of table 7, clearly again there is no difference in fabric heat losses for any specific house type as they have the same fabric U-values, but there is a 100% increase in thermal bridging heat losses for each house type, and ventilation heat losses have increased by about 150%. This means when using only ACDs and not ECDs for any of these house types, there will be an increase in total heat losses of between 39% to 53%. These results clearly demonstrate that not only would it be difficult to achieve a Code level 3 rating for energy (without either radically reducing the fabric U-values or using some form of renewable energy generation such as solar thermal), but also that most house types would not even achieve a Code level 2 rating.

The one exception to achieving Code level 2 with the design are developments containing flats, since energy averaging would allow a three or four-storey block of flats to achieve a Code level 2 rating. Note that energy averaging is not allowed for semi-detached or a block of terraced houses. So since the semi-detached and the mid-terrace house types used in this example only achieve a 16.4% and 16.7% reduction in their DERs respectively, any development including these house types would need to have the specification redesigned, i.e. the U-values of the thermal elements reduced further, to achieve a Code level 2 rating.

Enhanced Construction Details: Thermal bridging and airtightness

Table 9 shows the final set of SAP 2005 results, where it is now assumed that little or no attention is given to the detailing of junctions nor to airtightness and hence a default y-value of 0.15 W/m^2K for the thermal bridging and an airtightness level of 10 $m^3/m^2/h$ @ 50 Pa have to be assumed. Otherwise the design is as for the table 8 results.

This final set of results show what will be achieved in terms of heat loss if designers only consider reducing fabric U-values rather than adopting a holistic design strategy to reduce CO_2 emissions. This table probably reflects the current position adopted by the house building industry for its designs, i.e. not using ACDs, and not attempting to improve airtightness significantly above that allowed by the current building regulations. This situation is a consequence of how the building industry responded in the past to energy conservation and previous legislation.

However, as a consequence of the demand to use ever lower fabric U-values, it is now essential for the building industry to recognise that thermal bridging and ventilation heat losses are becoming more and more significant, as these sets of SAP 2005 results show. In particular, the final set of SAP 2005 results (table 9) show clearly that most house types do not even achieve a Code level 1 rating just by reducing fabric U-values to improve overall energy efficiency.

Indeed using these house designs rather than ones that incorporate ECDs will result in an increase in total heat losses of between 61% and 72%. Total heat losses of this order cannot be reduced significantly by simply focusing on reducing fabric U-values. For instance, taking just the results of the detached house, the combined heat losses from thermal bridging and ventilation alone account for 90.5 W/K of heat loss, which is comparable with the total heat losses of the Code level 3 compliant detached dwelling (table 7 results) of 99.1 W/K. So a building fabric with radically reduced U-values would be needed to achieve a Code level 3 rating without considering thermal bridging and airtightness.

14. Alternative Enhanced Construction Details considered that failed to achieve sufficiently low Ψ values

During the design process, a number of details, when thermally modelled, failed to achieve a Ψ-value that was low enough to merit their inclusion in the Energy Saving Trust Enhanced Construction Details. The initial scoping study calculated that no detail should have a Ψ value greater than about 0.07 W/m^2K in order for an enhanced y-value of 0.04 to be used with any house type. The following are design options that were explored but ultimately abandoned because the Ψ value of the details in question could not be reduced sufficiently to meet this criterion. For each of these details, an individual Ψ value is provided so that they can be used in the context of inputting a user-defined y-value in a SAP calculation. **However, note that none of these details (or variants) can be used to claim an Energy Saving Trust Enhanced Construction Details y-value of 0.04.**

Table 9: SAP 2005 results for a range of house types where no attempt is made to improve thermal bridging or airtightness

House type	Floor area (m^2)	% reduction of DER below TER	Fabric heat losses (W/K) (U-values)	Thermal bridging fabric heat losses (W/K)	Ventilation heat losses (W/K)	Total fabric and ventil-ation heat losses (W/K)
Detached	104	7.6	69.3	37.3	53.2	159.8
Semi-detached	90	6.9	56.1	29.3	46.4	131.8
End Terrace	78	9.1	48.8	26.0	40.6	115.4
Mid Terrace	78	8.2	43.2	21.5	40.6	105.3
Ground Flat	59.5	10.4	35.6	17.6	30.5	83.7
Mid Flat	59.5	11.4	24.9	9.5	33.4	67.8
Top Flat	59.5	9.6	31.4	18.5	33.4	83.3

Enhanced Construction Details: Thermal bridging and airtightness

14.1 Combined steel lintels in masonry construction

During the consultation process with the extended industry working group, a number of requests where received to thermally model the use of insulated combined steel lintels for two of the three masonry variants: MV02 and MV03. Masonry variant MV01 was not remodelled, as the use of the combined lintel for this detail is one of the existing ACDs.

The lintel types modelled were proprietary insulated combined lintels without a continuous steel base plate, and these are shown below in figure 3.

Although this configuration is thermally the best that can currently be achieved for a combined steel lintel, the resultant Ψ-values achieved for each detail were 0.099 W/m²K for MV02, and 0.124 W/m²K for MV03, respectively. Whilst both of these alternate details are significantly above the acceptable 0.07 W/m²K Ψ-value for an ECD (and so cannot be included as an ECD), they are nevertheless included in this publication together with their Ψ-values (which are lower than the ACDs: see table 1 previously) so that they can be used in the context of inputting a user defined y-value in a SAP calculation.

14.2 Use of blockwork sleeper walls to support block and beam, and in-situ suspended concrete slab

During the first phase of the thermal modelling process, difficulties were encountered with regards to two floor types - the beam and block floor, and the in-situ suspended concrete slab.

This was because that the Ψ value of some of these floor types used with any wall type was in some instances significantly above the 0.07 W/m²K threshold set for the ECDs. And some exceeded the Accredited Details default Ψ-value of 0.16 W/m²K (see table 1). Various options were explored, including reducing the thermal conductivity of the substructure blockwork, to extending additional layers of insulation inside the footings to attempt to improve the details thermally. Although these measures did help some of the wall/floor type combinations to achieve a reasonably low Ψ-value, the in-situ suspended concrete slab could not be sufficiently improved.

This floor type was considered to be an important option by the working group as it provided an alternative to using beam and block floors where ground conditions did not allow the use of fully ground-bearing slabs. Analysis of the heat flow paths in the thermal modelling of an in-situ

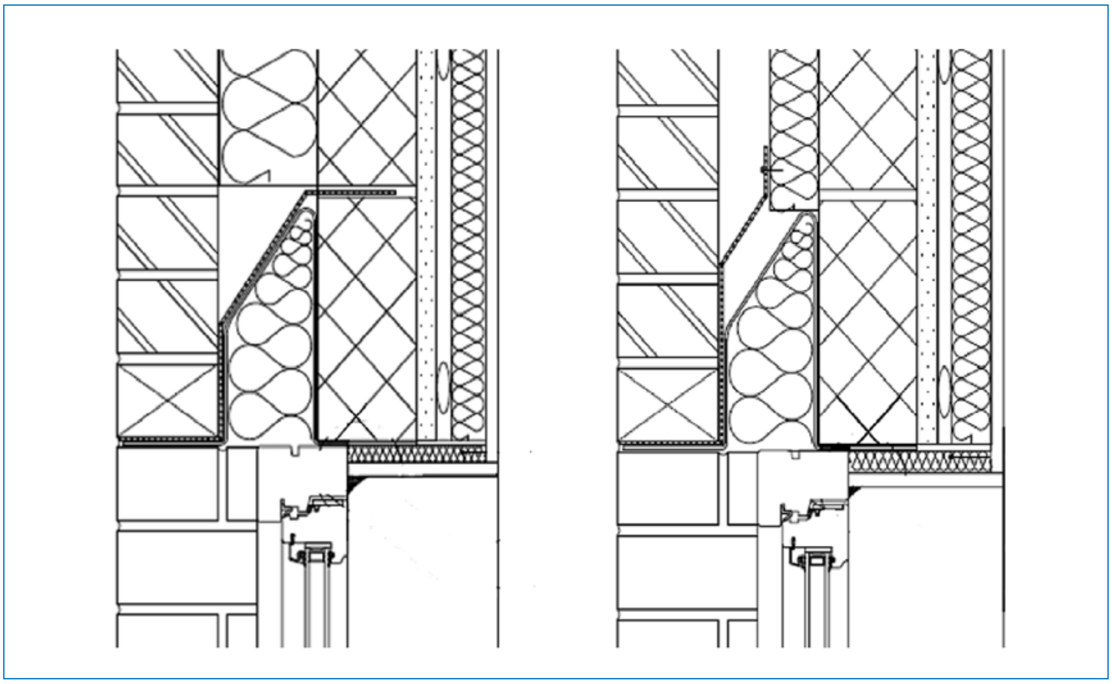

Figure 3: Alternative lintel details for masonry variants MV02 and MV03

suspended concrete slab showed that the main problem was associated with the need to fully support the floor edge directly onto the inner leaf of the footings.

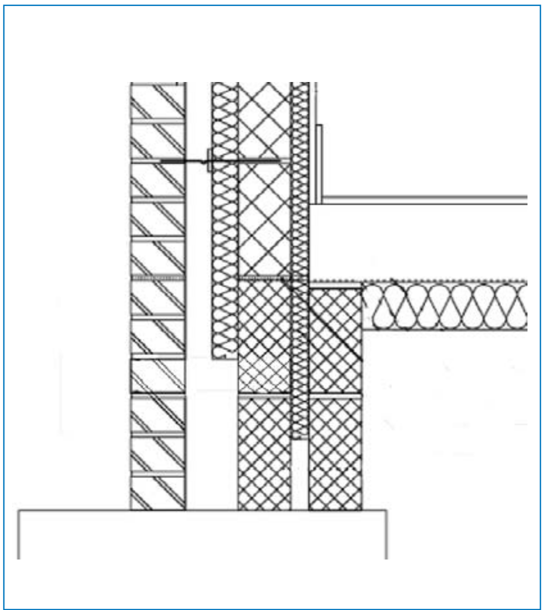

Figure 4: Typical sleeper wall arrangement for supporting the in-situ suspended concrete slab

One radical idea that was thermally modelled was the use of independent blockwork sleeper walls provided to the inside of the footings. A typical detail for this situation is shown in figure 4, and although this shows wall type MV03, details involving other wall types were similar.

However, even this modification was insufficient to reduce the Ψ-values for the in-situ suspended concrete slab when combined with any masonry wall type for inclusion in the set of ECDs. No other wall type was thermally modelled.

A slight improvement was gained for a beam and block floor when modelled with a sleeper wall compared to the first set of modelling for this floor type. However, it was decided that it was still insufficient to include a beam and block floor supported on sleeper walls as an option in the ECDs, so the sleeper wall solution was abandoned for all floor types. The beam and block floor type was improved by including a screeded floor finish together with perimeter insulation as shown in the final set of ECDs presented here.

As no method of support could be found to provide a sufficiently low Ψ-value to achieve the overall y-value of 0.04, the in-situ suspended concrete slab floor type has not been included in the set of ECDs.

Further information

The Energy Saving Trust provides free technical guidance and solutions to help UK housing professionals design, build and refurbish to high levels of energy efficiency. These cover all aspects of energy efficiency in domestic new build and renovation. They are made available through the provision of training seminars, downloadable guides, online tools and a dedicated helpline.

A complete list of guidance, categorised by subject area, can be found in *Energy Efficiency is best practice (CE279)*. To download this and to browse all available Energy Saving Trust publications, please visit www.energysavingtrust.org.uk/housing

The following publications may also be of interest:

- Energy efficiency and the Code for Sustainable Homes – Level 3 (CE290)
- Energy efficiency and the Code for Sustainable Homes – Level 4 (CE291)
- Energy efficiency and the Code for Sustainable Homes – Levels 5 & 6 (CE292)
- Energy efficient ventilation in dwellings – a guide for specifiers (CE124/GPG268)
- Improving airtightness in dwellings (CE137/GPG224)
- Enhanced Construction Details: introduction and use (CE297)
- Energy Saving Trust Enhanced Construction Details. See www.energysavingtrust.org.uk/housing/tools/ECD

To obtain these publications or for more information, call 0845 120 7799, email bestpractice@est.org.uk or visit www.energysavingtrust.org.uk/housing

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