The 100mm cavity debate

energy saving trust®

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1. Executive summary

This report seeks to investigate why cavity masonry construction is so predominant in mainstream housing; why the industry appears so keen to stick to the 100mm cavity; and what are the potential routes to achieve the improved thermal performance that is necessary at higher levels of the Code for Sustainable Homes.

In 2008 participants were invited to express their opinions on five of the key issues, and suggest the type of construction they view as most appropriate in achieving better thermal performance. The technical and commercial rationale underpinning the suggested construction was described, and extensive further information about their choice was then entered into an accompanying matrix.

Four key industry experts were invited to comment, each specialising in a different type of construction - masonry, timber frame, light-gauge steel frame and alternative construction techniques. Of these, three provided input, with the timber frame expert failing to comment. Sadly this means that considerations of timber frame had to be omitted from this report.

The results of the survey indicate that externally insulated solid walls could potentially provide a suitable way of increasing thermal performance whilst utilising the existing skills base. These would gradually be replaced in turn by Modern Methods of Construction (MMC) systems, which offer further benefits in terms of build speed and economy, as well as greater quality control.

Other findings of this report include:

- Cavity wall construction can only achieve Code performance levels 4, 5 and 6 with the cavity width significantly increased. This is commercially viable on all but the most inflexible urban sites.

- Planners can support the process of creating truly sustainable communities by placing more emphasis on thermal performance and innovation in housing.

- A clear focus on build quality will be key in meeting the challenges of higher thermal performance in housing. As this relies heavily on the skills of the site team and independent quality assessors, it brings potential for major training programmes and expansion in employment.

2. Introduction

This report investigates whether cavity masonry still has a role to play in the rapidly shifting world of domestic construction. The construction industry has been required by regulations to make frequent, incremental improvements in the thermal performance of new dwellings. And with the advent of the Code for Sustainable Homes and the 2016 zero carbon agenda, it is important to investigate whether the cavity wall is capable of meeting the new, higher thermal performance requirements.

The first part of the report analyses the history of the cavity wall and looks at the current market situation, where cavity construction typically accounts for the overwhelming majority of all new dwellings. It goes on to consider alternatives to the cavity wall before investigating some of the key considerations that apply when considering these alternative systems.

In the second section of the report, from section 7, p.18, contributors were asked what systems from within their particular field of expertise would in their view be most appropriate to reach the improved U-values required at levels 4, 5 and 6 of the Code for Sustainable Homes. The required specification was for a wall that achieves a U-value of 0.15 $W/m^2.K$, and contributors were invited to suggest their preferred construction on the basis of technical, financial and sustainable performance. Contributors then justified this choice by entering detailed performance parameters in the tables in section 7, which investigated a variety of issues including commercial, energy, sustainability, maintenance, and structural and performance issues. Finally contributors were asked to rank these areas in terms of perceived overall importance.

The report concludes with a summary of findings and recommendations for further work.

3. Questions to contributors

Contributors were asked five questions designed to analyse the current situation and point towards potential ways of future-proofing the cavity wall as a construction type. It was important to ask all contributors these questions, rather than the masonry expert alone, in order to highlight less familiar solutions which might nevertheless have a part to play in improving performance.

The questions asked were as follows:

1. **Why has cavity masonry been so dominant in mainstream housing?**
   - What advantages does it offer, and why does it still have a place in construction?
   - Would masonry construction benefit from adopting, for example, a zero-cavity, externally insulated approach?

2. **Why is industry reluctant to go beyond the 100mm cavity?**
   Is the reason:
   - Loss of liveable area, leading to lower profit per site?
   - Increased dwelling footprint, leading to loss of plots over large developments?
   - Investment in existing sound and structural calculations making the cost of change prohibitive?
   - Others?

3. **To achieve better U-values in masonry construction whilst still maintaining a 100mm cavity, insulated dry lining is often used. This effectively isolates the thermal mass in the structure.**
   - Is this a viable solution?
   - What other solutions are you looking at to improve masonry construction U-values?

4. **To achieve better U-values, would you consider switching to:**
   - Structural insulated panels (SIPs)?
   - Insulated concrete formwork?
   - Lightweight block with external insulation?
   - I-beam timber frame?

5. **How do you propose to get to the improved U-values (0.2 and below) required at levels 4, 5 and 6 of the Code for Sustainable Homes?**
   - What will the mainstream construction industry have to do to target this and what changes are necessary?
   - Does the zero carbon target spell the end of the line for traditional masonry construction?

The document which follows has been prepared by analysing all responses from contributors. In addition, where the Energy Saving Trust research (or other) adds usefully to the debate, this has been added and clearly referenced.

4. History and context of the cavity wall

Modern cavity wall construction developed in the wettest and windiest countries, with the UK, Ireland, Denmark, Belgium and the Netherlands the principal users of this construction system. Originally designed to prevent water ingress, accounts of cavity walls first appearance in the UK date back to 1805, with plans that show two leaves (wythes) of brick, bonded by brick headers, spanning across a six inch (152.4mm) cavity. A British publication from 1821 references cavity construction as a way of preventing rain penetration, whilst the first use of wrought iron wall ties can be dated back to Southern England, circa 1850[1]. In antiquity, examples of cavity construction have been found which date back to Roman times. For example, the sauna rooms within the Roman baths at Bath feature cavity construction, where the cavity was used for channelling steam in order to heat the walls.

However, as stated above, the primary purpose of the cavity wall was originally to prevent water ingress. As standard house-building bricks (particularly in older dwellings) are relatively porous, moisture can penetrate a solid brick wall in areas with frequent driving rain, leading to damp, mould and potentially even structural issues. The cavity wall was designed to provide a solution to this problem: the outer skin keeps the majority of moisture at bay, whilst the ventilated cavity allows any moisture that does penetrate to evaporate away.

The first experiments with cavity insulation occurred in the 1950s, with zonolite, vermiculite and perlite being used to insulate cavity walls. More modern products such as mineral wool were subsequently developed, and prompted by the 1970s energy crisis and changes to the building regulations, cavity insulation increased in popularity.

As the primary purpose of the cavity wall was originally to prevent water ingress, concerns were raised over the potential transfer of moisture from the 'wet' outer leaf to the 'dry' inner leaf in a filled cavity wall. An independent review carried out by BRE in 1993 found that such concerns were groundless.

It is now standard practice to fill cavities with insulation in order to improve the thermal performance of the wall. Historically, the size of the cavity has increased in accordance with insulation requirements, and this has led to an increase in width from 35mm to 50mm, and again to 100mm. With the UK Government having pledged to make all new housing zero carbon by 2016, the thermal performance of cavity walls will again need to be improved, raising questions about the continuing relevance of to this form of construction.

Today, cavity masonry is used in the vast majority of all new domestic construction. One of the key factors that has contributed to cavity masonry's popularity is the widespread availability of an experienced workforce. This means that house builders can rely on an existing skills base, whilst competition in the marketplace ensures that labour costs remain competitive. This factor may be key in influencing builders to continue using this form of construction, particularly with the Government's pledge to deliver three million new homes by 2020. That figure equates to 240,000 houses per year in England, up from 185,000 in 2006[2] (NHBC figures).

1. http://www.maconline.org/tech/rvalues/historyofinsulation/historyofinsulation.html
2. http://www.nhbcbuilder.co.uk/Newsevents/Library/filedownload,28928,en.pdf

Another factor that has contributed to the dominance of cavity construction is that masonry facades are often required by planners. This has led to a slightly bizarre situation in which even timber and steel frame systems often use a brick cladding. This is true for the majority of the UK, but not in Scotland, where rendered finishes are considered acceptable by planners. Nevertheless, across the majority of the UK, this requirement has meant that cavity masonry has remained the status quo, and has led some commentators to claim that the current planning system is anticompetitive and stifles innovation. It is certainly fair to say that the requirements affect on the economic viability of competing build systems, as all of these would be more competitive if the additional cost of a brick cladding were to be removed.

In addition to planning requirements, a large amount of anecdotal evidence has emerged from both the construction and financial industries, indicating that consumers prefer traditional forms of housing[3]. It is difficult to judge whether these opinions are based on objective evidence, but it is understandable that the industry should wish to continue with an approach that has already proven itself to be successful. Whilst commentators have blamed the construction industry for needless conservatism and identified it as a major factor in delaying new forms of construction, there are legitimate concerns over projected construction difficulties with new systems, which might necessitate expensive call-backs and reduce profits. In addition to this, profit is primarily derived from land transactions rather than construction itself, thus providing little incentive to invest in research and development.

3. Scott Sutherland School of Architecture and Environment: LINK project, http://www.rgu.ac.uk/files/developers.pdf

5. Alternatives to the cavity wall

Cavity construction is currently facing stiff competition from other construction types, which may capitalise on the uncertainty surrounding the cavity walls fitness for purpose in the context of zero carbon dwellings. Cavity construction presents a range of benefits, as well as shortcomings, in the context of meeting the UK's zero carbon agenda, but has historically proven to be flexible and adaptable enough to survive changes to building regulations. Coupled with the zero carbon driver, the introduction of Energy Performance Certificates (EPCs) may lead to shifts in public attitude, making energy efficiency a key selling point and driving demand for increased thermal performance.

The crux of the question is to what degree the industry needs to innovate and improve the performance of the building fabric, whilst achieving a good balance with microgeneration in order to achieve the most cost-effective overall solution. A variety of approaches may apply here: increased cavity width, internal insulation, external insulation, alternative masonry techniques (often derived from European experience) or MMC approaches. In the search to find a buildable and practical way to reach improved U-values, it seems likely that many builders will pilot a variety of these techniques, and it is expected that the construction types used by industry will become more varied over the next couple of years, before the market settles on the most cost-effective and practical route.

Projections of UK population growth and the trend for reductions in household size indicate that in addition to energy efficiency compliance, fast and efficient production techniques are crucial. The Government's targets will require an increase in annual house production of approximately 40%, and contemporary commentators have expressed incredulity that the industry is expected to achieve this whilst also achieving heightened energy performance. Build rates of this magnitude were seen in 1950s and 1960s, but quality suffered considerably as a result. Bearing in mind the enhanced build quality and site skills needed to achieve challenging thermal performance, airtightness and thermal bridging targets, the advantages of rationalising current approaches in search of a quicker, easier build system are clear.

The following three tables discuss the potential alternatives to cavity wall insulation. (Note that internally insulated examples have been excluded, as the technique is most appropriate for renovating existing properties.)

5.1 Externally insulated solid wall systems

Number	Mass wall	External insulation	Comments
1.	Dense aggregate concrete blocks, calcium silicate blocks or clay blocks. Usually 150-200mm thick if braced by intermediate concrete floors and/ or masonry partitions.	Plastic foam fixed with adhesive. Usually EPS of ordinary or Neopor type but can also be XPS or phenolic foam.	The version with calcium silicate or clay blocks is standard in new construction in Germany and Austria. Adhesive fixing of the insulation layer eliminates thermal bridging by fixings or wall ties and eliminates the risk of air movement behind the insulation, with resulting loss of thermal performance. In the UK the complete insulation and render system usually comes from a specialist supplier. Some suppliers are willing for the general builder to fix the insulation and for the specialist just to apply the render. This reduces the cost substantially.
2.	As above.	Rigid mineral fibre slabs.	Ditto. Needs mechanical fixings. If these are of stainless steel, they form a series of repeating point thermal bridges of similar magnitude to those in a cavity wall.
3.	As above.	Conventional lower-density mineral or cellulose fibre, contained within a non-load-bearing timber framework.	Has been used on many UK self-build houses and houses erected by small builders. Avoids need for a specialist supplier but thicker than walls 1 or 2.
4.	Calcium silicate storey-height elements, numbered in factory and craned into place.	As for walls 1, 2 or 3.	Very quick and precise way to build solid external walls. Low embodied energy. Not made in the UK yet; imported from Germany and the Netherlands.
5.	In situ dense concrete. Tunnel form.	As for walls 1, 2 or 3.	A method to cast in situ concrete flats and row houses very rapidly. Widespread in the Netherlands and Belgium where it is reportedly used to construct 40% of new dwellings and is very cost-effective for larger developments. Some UK projects also. http://www.concretecentre.com/main.asp?page=487
6.	In situ dense concrete. Tilt-up.	As for walls 1, 2 or 3.	Slabs cast on the ground, and needing no shuttering, are subsequently lifted into place. Widespread around the world. http://www.concretecentre.com/PDF/tiltup10.pdf
7.	Precast dense concrete.	As for walls 1, 2 or 3.	First used with thick external insulation - 200mm EPS - on the minimum energy houses in Schiedam, the Netherlands in 1982.
8.	Lightweight concrete blockwork with thin-joint mortar.	As for walls 1, 2 or 3.	A 400-450 mm thick wall gives a U-value of c.0.3, albeit very dependent on the in situ dampness and hence thermal conductivity of the masonry. More promising to use 150-200mm thick solid blockwork and add external insulation. At intermediate floor levels, where a concrete floor is needed to ensure airtightness, it seems best to use a prefabricated lightweight concrete reinforced floor.

Number	Mass wall	External insulation	Comments
9.	Lightweight concrete storey-height elements.	As for walls 1, 2 or 3.	Used on the demonstration House G built at Hjortekaer, Denmark in 1985. Project gave a 7% per year real rate of return on the reduction in wall U-value from 0.3 [then the Danish Building Regulations] to 0.15 W/m^2K.
10.	Ultra-low density fired clay blocks with thin mortar joints, plastered internally and externally.	As for walls 1, 2 or 3.	Refinement of the clay blocks widely used on mainland Europe. Supplied in UK by, e.g. NBT, http://www.natural-building.co.uk/tp.htm Reaches a U-value of 0.22 W/m^2K in a 450mm thick wall. NBT sells an external insulation system which enables the system to reach 0.15 W/m^2K. Given the energy involved in firing clay, embodied energy is likely to be higher per kg than many concrete or dense block walls. As with most walls which attempt to combine mass and insulation in the same layer, i.e. walls 8, 10 & 11, it is very thick for a given U-value.
11.	Hemcrete.	As for walls 1, 2 or 3.	A 300mm wall appears to give a U-value around 0.3 W/m^2K. To meet a U-value of 0.15 W/m^2K in a reasonable thickness it would need external insulation. An article in Building Design, 11 May 2007, stated that the air permeability of hemcrete walls was not yet known. http://www.bdonline.co.uk/story.asp?storycode=3086670
12.	Rammed earth or chalk.	Any in theory but point fixings are problematic because of the weakness of rammed earth. This favours the use of continuous adhesive.	Considerably thicker external walls than concrete. A recent UK building with external walls of 600mm rammed chalk needed further external insulation to reach c. 0.15 W/m^2K.

5.2 Mass in centre of wall

Number	Mass wall	Insulation	Comments
13.	*In situ* concrete. Insulated Concrete Formwork.	EPS or XPS.	Widely used in mainland Europe and North America. Used more by self-builders and one-off non-domestic buildings than by developers. Due to the limit on the height of individual pours, it cannot be built as quickly as some forms of in situ concrete, e.g. tunnel form, but it is much quicker than masonry walling. According to work in the USA it is quicker than site-built timber-frame.

5.3 Insulation in centre of wall

Number	Mass wall	Insulation	Comments
14.	Lightweight concrete storey-height sandwich elements with integral insulation.	Normally EPS. U-value calculations need to allow for the effect of the panel edges which are formed of lightweight concrete, not EPS.	One supplier is the Swedish company Thermonex, www.thermonex.co.uk. It is promoted in the UK as a basement construction system. The panels come complete with electrical sockets, to reduce site work. The normal 300mm thick element cannot reach a U-value of 0.15 but thicker elements could be made.
15.	Precast dense concrete storey-height sandwich elements with integral insulation.	Normally EPS.	Used for many decades in other countries, e.g, Sweden, typically faced with 75mm concrete and with a core of 150-200mm EPS. Such elements can also be used for separating walls between terraced or semi-detached houses where they avoid the high heat losses arising from current UK construction practice, i.e. with empty cavities.
16.	In situ concrete. Shotcrete.	Sprayed onto both sides of a slab of foam with integral reinforcement. Final thickness of concrete is c.100mm, i.e. 50mm on both sides.	When tested in the USA was shown to outperform timber-frame walls in terms of utilisation of winter passive solar gains or passive cooling in summer. Gives a very thin wall, especially if it can use rigid phenolic or PU/PI foam. The usual version uses EPS though.

6. Key considerations

6.1 Thermal performance and width of walls

Depending on the overall energy strategy used, a 100mm cavity can be adequate for compliance with Code for Sustainable Homes levels 3 and 4 requirements. However at levels 5 and 6, it will be necessary to improve the U-value further to reduce the amount of microgeneration required and to ensure that the overall build strategy is cost-effective. This might mean increasing the cavity to 150mm and beyond – the England and Wales Building Regulations Approved Document A allows for cavities up to 300mm in width. However, for a variety of reasons this is not seen as a preferred route by many in the construction industry.

Reasons commonly cited include the increase in overall wall thickness, leading to either a loss of internal liveable area or increased dwelling footprint. Both of these are commonly held to lead to a reduction in the number of plots in any particular development, reducing profits overall. This view was cited by some of the report's contributors; however, one response refuted it and claimed that only in extreme circumstances, where plot size is severely limited or inflexible, could an increased cavity result in loss of liveable area. It was also pointed out that in certain build types, for example terraced dwellings, an increase in cavity width would have a minimal impact as only the external, end walls would increase in thickness, whilst the internal party walls would remain constant, leading to a total increase of just 100mm in length.

Bearing this in mind, it appears that impacts of the increased dwelling footprint are likely to affect semi-detached and detached dwellings the most; terraced dwellings and flats will experience a minimal effect. Flats and maisonettes have been the dominant form of housing in England since 2003, and in the third quarter of 2007 (the latest statistics available) they made up over half of all new housing[4]. This suggests that the increased footprint argument is diminishing in significance, and it seems unlikely that an increase in cavity width would reduce development housing density significantly.

New anecdotal evidence from the Modern Masonry Alliance (MMA) suggests that 150mm cavities are gaining acceptance and being used more frequently by developers. In the self-build market, cavities of 125-150mm and beyond are common, largely due to the priority that self-builders commonly place on energy efficiency. If larger cavities do become commonplace, research and development will be necessary. Existing acoustic and structural calculations will need to be revised, which was felt by contributors to be relatively insignificant because on large developments, these costs are split over hundreds or thousands of dwellings and are therefore not prohibitive. More significant, for example, was the issue of thermal bridging across wall ties, which will require further research and development, as well as considerations of foundation design, which may be affected by increased cavity sizes.

6.2 Weather resistance

Cavity masonry construction provides excellent protection against moisture ingress in almost all conditions commonly found throughout the UK. The standard full fill cavity can be used in all but the most exposed areas; in particularly wet and windy areas (and notably, throughout all of Scotland) partial fill cavities are used in order to maintain convection and carry away any water that penetrates the outer leaf.

The introduction of insulation into cavities provoked concerns that filling the cavity might lead to a greater risk of dampness passing from the 'wet' outer leaf to the 'dry' inner leaf. A 1993 government-sponsored independent study carried out by BRE[5] showed that there was no evidence that filling the cavity with insulation resulted in any greater incidence of damp problems than occurred in cavity walls that had not been filled. The study's key finding showed that the structural condition of the walls was critical in

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4. http://www.nhbcbuilder.co.uk/Newsevents/UKnewhouse-buildingstatistics/Year2007/Name,32099,en.html

5. BRE Client Report 188/93 (1993)

avoiding the transfer of moisture to the inner leaf, and any cavity wall, if not correctly built, e.g. with poorly filled mortar joints or mortar droppings on wall ties, would be likely to have problems. This has implications for the UK construction industry, which sadly has a mixed reputation when it comes to build quality.

The implications of a switch to an alternative build type would include a thorough assessment of rain penetration risk, but with the adoption of suitable render or cladding it is likely that any alternative build type would be suitable for most areas of the UK, although exposed areas such as north-west Scotland, west Wales and south-west England may require further suitability checks. Therefore, even if another build type becomes predominant, the cavity wall may always have a role to play in the most exposed locations.

6.3 Build quality

Amongst the responses received, cavity construction came under fire for poor build quality. It was highlighted that workmanship defects such as mortar droppings and air gaps in insulation can significantly reduce the calculated thermal performance of walls.

Research in Sweden[6] has indicated that U-values increase markedly when gap sizes between sections of insulation exceed 10mm. While this research was carried out a number of years ago, it was recently re-examined by the committee responsible for ISO 6946 and was found to be still valid, suggesting that the critical gap between sections of insulation remains around 10mm. Air gaps are a serious issue with current forms of cavity construction, and can affect all types of insulation products. In fact, despite the superior thermal performance of foams (vs. full fill fibrous batts), it is likely that a far larger performance discrepancy is present with foam insulation, due to the potential occurrence of large air gaps between insulation and outer skin. If no improvements in on site checking and workmanship are made, this puts a question mark over the cavity wall's fitness for purpose as insulation standards increase into the future.

Research carried out between 1998 and 2000 showed that true (measured) U-values were higher than calculated U-values, even when thermal bridging and wall ties were taken into account. The difference depended upon the type of construction, and the differences were found to be as follows:

1. For internally insulated cavity walls, 0.05 W/m^2K (approx.).

2. For fully filled cavity walls, 0.05 W/m^2K (approx.).

3. For partially filled cavity walls, 0.10 W/m^2K (approx.).

4. For timber frame walls, agreement between measured U-values and calculated U-values tends to be close, but accurate cutting of mineral wool quilt at horizontal timbers is crucial.

5. For sloping ceilings with insulation in the slope of the ceiling, actual realised U-values can be extremely high.

These are major discrepancies and are highly significant in thermal terms. In addition to this, as insulation standards for new housing are nominally increasing, the difference between theoretical and actual U-values is likely to become greater and could have serious implications. At the heightened levels of thermal performance necessary to achieve Code levels 5 and 6, this disparity between designed and built thermal performance could affect the UK's ability to reach its carbon dioxide (CO_2) reduction targets.

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6. See figure 2.26 of ISO/TC 163/SC 2/WG 9 N33/N55, prepared by the ISO 6946 International Committee

Such discrepancies occur due to poorly trained site teams, and a lack of effective supervision. A 2005 report[7] carried out by BRE on behalf of the Energy Saving Trust investigated site inspection and build quality, and concluded that although loft insulation is normally subject to inspection prior to a completion certificate being provided, the insulation in walls and floors are not usually subject to systematic inspection.

In instances where insulation is inspected, those carrying out the inspection are not sure how to determine whether the insulation is likely to perform adequately and are therefore unsure of the level of standard that should be demanded. Thermographic images taken as part of the report show that insulation that looks only slightly untidy can have major consequences for thermal performance in practice.

The typical build process in the UK involves building both leafs of brick/block in parallel; insulation is either added as the wall is built, or injected in once the cavity is complete.

Altering the typical UK build process to the Scandinavian model could help provide better accountability – the inner skin is built to roof level and made watertight, with wall-ties exposed for building the outer skin at a later date. This technique allows for a complete inspection of the inner leaf to ensure airtightness, clean wall ties and lack of other foreign objects, before the insulation is added and the outer leaf constructed. Insulation can be fully inspected for continuity, and an added advantage is that internal fixings and finishes can begin earlier in the build process.

Thinner, externally insulated walls could not only address developer concerns over the wasting of development land through thicker walls – their ease and cost of construction may make them a superior choice in view of the UK's projected housing growth. They would also allow for detailed checking of insulation continuity. The use of external insulation might reopen the debate around masonry facades, and planners' acceptance of this technique will be key in ensuring its viability around the whole of the UK.

6.4 Thermal mass

One of the primary advantages of cavity masonry construction is its potential for achieving a good level of thermal mass. Thermal mass (generally comprised of dense blockwork, concrete or stone) acts like a sponge and absorbs heat during the hottest parts of the day, before radiating this stored heat back to the space at night. With the inclusion of a summer time overheating assessment in the 2006 Building Regulations, thermal mass has broken out of the self-build ghetto and is now very much a concern of the mainstream construction industry – becoming in the process the masonry industry's trump card. Low-mass houses, such as those constructed mainly from timber, will tend to overheat in peak summer conditions, because the materials have little capacity to absorb heat and attenuate internal air temperatures. However, this problem can be rectified by careful design and the integration of appropriate thermal mass into, for example, concrete floors. Phase change materials such as Du Pont Energain have been touted as a less space-intensive way of ensuring adequate thermal mass in such dwellings, but anecdotal evidence from dwellings on the BRE Innovation Park indicates that such materials are of limited effectiveness at this stage in their development.

Cavity masonry dwellings generally perform well in terms of thermal mass, but increasing thermal requirements have led to a trend to use insulated dry lining. This allows cavity constructions to achieve better U-values whilst still maintaining a 100mm cavity, but the solution is problematic for a number of reasons.

Firstly, the technique is relatively difficult to design and build if the interstitial condensation risk is not properly analysed. Unfortunately such calculations may not be a priority, particularly if builders and designers intuitively assume that condensation risk is naturally low in highly insulated dwellings.

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7. BRE Client Report 15921 (2005)

In addition, any dry lining will tend to isolate the thermal mass in the walls, and insulated dry lining in particular will heighten this effect, thereby losing one of the principle benefits of masonry construction. This is an important design issue, and can often be exacerbated by the use of low-mass timber intermediate flooring. These techniques are not suitable for the production of large numbers of dwellings with assured energy performance. Where one of these strategies must be used, it is essential to take a holistic approach to the design. The overheating risk may best be attenuated by either:

- Using concrete floors with dense finishes (e.g. tiles) to preserve some thermal mass in the structure.

- Integrating thermal mass into the internal walls.

6.5 Thermal bridging

Thermal bridging occurs when dense building elements (blocks, concrete lintels and brickwork, for example) abut each other, thus creating a 'quick way out' for internal heat. With careful design, cavity masonry can achieve very good levels of thermal bridging. For an example of this, see the Energy Saving Trust's Enhanced Construction Details, which will allow designers and builders to halve the current Accredited Details heat loss. Achieving this reduction in practice requires excellent site skills and supervision.

Typically, internal insulation will be subject to thermal bridging at many junctions, particularly where it meets intermediate concrete floors. This may lead to increased heat loss via junctions (there is a non-linear relationship between U-values and heat lost via thermal bridges), reducing the overall thermal efficiency of the building fabric.

A glued externally insulated approach would effectively eradicate thermal bridging in many areas of the building, by surrounding the entire structure with an uninterrupted layer of insulation. This would simplify the junction details required and speed up the overall build process.

6.6 Airtightness[8]

Typically, cavity construction doesn't tend to be particularly airtight; whereas timber and steel frame techniques rely on the installation of a continuous air barrier, airtightness in masonry construction is largely a function of build quality and attention to detail. As the requirement for pressure testing is relatively new, the level of site skills is still at a formative stage. However, build projects such as Stamford Brook have shown that it is possible to achieve highly airtight construction in masonry, and this learning will continue.

Of the available masonry options, a cavity construction is probably one of the most difficult to make airtight, particularly if internal dry lining is used. Experiences at Stamford Brook showed that using a parge coat could significantly help increase airtightness; using traditional wet plaster finishes is the optimum solution as it can provide an airtight layer as well as preserving the wall's thermal mass.

A simpler option would be to use a solid, externally insulated wall which can be more easily constructed, allowing greater attention to detail on site. Techniques from Europe may also be helpful in achieving airtightness. Glued panellised brickwork sections, such as those used in the Hanson House 2 at BRE's Innovation Park are highly airtight, meaning that attention on site can be focussed on ensuring the joints between panels are made airtight.

In all construction types, service penetrations and sealing around joists is critical; products such as joist shoes could usefully be used to augment the chosen airtightness strategy.

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8. See Airtightness Case Studies (CE248), http://www.energysavingtrust.org.uk/Global-Data/Publications/Achieving-airtightness-in-new-dwellings-case-studies-CE248

6.7 Anchor points

Cavity construction has traditionally provided excellent provision of suitable anchor points for internal fixtures and fittings. External insulation to solid walls, MMC solutions and most of the European techniques will continue to provide this; only internal insulation will be problematic here. Fixings can still be provided, via the use of timber members or Rawlbolts, but these can never be an ideal solution.

6.8 Flexibility on site

Hand-laid masonry has a distinct advantage over rival MMC techniques in that it can easily account for variations in ground levels and lack of fit. The current inflexibility of MMC in this regard might be highlighted should it be rolled out in great numbers across the country.

In addition, masonry can be used for internal and external walls as well as foundations, thus allowing for the delivery of a single product for the entire structure in many cases. This simplifies the supply chain and could also reduce the number of different skill sets needed on site.

Any form of masonry construction (save for MMC) is likely to maintain these benefits.

6.9 Cost and efficiency of build process

Market conditions mean that masonry construction is currently competitive, but this is largely due to lack of effective competition from rival build types rather than heightened levels of efficiency within the process itself. The efficiency of traditional block-laying techniques appears increasingly questionable, with Health and Safety restrictions hindering the process and alternatives such as smaller blocks or hollow-core blocks requiring a mortar filling.

To see some of the ways in which mainstream construction within the UK might develop, it is useful to examine the approaches taken in other European countries whose commercial environment and climate is similar to the UK's. The Netherlands is a country with a high proportion of dwelling units constructed by volume developers, as opposed to the self-build which predominates in Belgium, Germany or Austria. The Netherlands demonstrates the most promising techniques for the mass production of houses, including cheap shuttering systems for 'in-situ' concrete; precast concrete wall elements; and calcium silicate blocks factory-built to 2-3mm tolerances then lifted via crane and glued using thin-joint glue. These techniques are less affected by inclement weather than typical UK practices.

In order of abundance, dwelling construction systems in use by the Netherlands are:

- Tunnel-form (poured concrete) with in-situ concrete intermediate floors – the cheapest solution on large sites of around 150 dwelling units in a mixture of flats and terraced houses.

- Masonry (usually calcium silicate blocks or larger elements) with in-situ concrete intermediate floors, sometimes precast.

- Timber-frame (including timber intermediate flooring) is considerably less common given the scarcity of indigenous timber, but still significant.

Dutch housing construction costs are well below UK levels, reflecting the degree of building process mechanisation and rationalisation/standardisation of details. Energy efficiency levels are also higher, although not as high as Germany, Austria, Switzerland and Scandinavia. Dutch studies suggest Passivhaus performance or higher can be achieved with the construction techniques above. German Passivhaus production consists of 65% masonry, 20% insulated concrete formwork and 15% timber frame.

The evidence from the Netherlands suggests that zero carbon requirements will not necessarily bring an end to masonry building techniques, although hand-laying of large blocks may well become obsolete except in the heritage/vernacular market. Nevertheless, in the short term, builders are likely to retain familiar masonry techniques, such as thin mortar beds and adhesives, composite blocks that incorporate block insulation and brick finish bonded together to improve efficiency and quality.

To return to a point made earlier in this report – because profit is primarily derived from land transactions, the incentive to invest in research and development is low. The approach recommended by the Energy Saving Trust is that fabric heat loss should be reduced to zero before incorporating renewable energy technologies. But the current approach means that developers have a strong incentive to maintain existing current construction types, and compromise by adding more efficient systems and services to their existing designs. In practice this means that a U-value of 0.25 W/m^{2}K may be acceptable at Code level 4, provided that a suitable heating system and perhaps renewables are added. In the current market framework, a lower U-value can have a diminishing effect on emission levels relative to cost – and at this level, readily available forms of cavity masonry can continue to deliver.

This is a legitimate stand for the industry to take, but it runs counter to the Energy Saving Trust's 'fabric first' approach because efficient systems and services will inevitably fail and be replaced long before the building reaches the end of its life.

Despite the requirement in Approved Document L1B for replacement heating systems that have approximately equal or better efficiencies than the original, there is little evidence to show that this requirement is being enforced. In particular, given the high cost of renewable technologies, it is highly unlikely that government will be able to credibly require private householders to replace solar water heating or photovoltaic panels when they fail. The result will be a generation of houses which fail to meet their original design targets, and therefore a mechanism is urgently needed within the Code for Sustainable Homes to ensure that more thermally efficient building fabric is given primary importance.

7. The proposed constructions

Contributors were asked what systems from within their particular field of expertise would in their view be most appropriate to reach the improved U-values required at levels 4, 5 and 6 of the Code for Sustainable Homes. The required specification was for a wall that achieves a U-value of 0.15 W/m²K, and contributors were invited to suggest their preferred construction on the basis of technical, financial and sustainable performance. Contributors then justified this choice by entering detailed performance parameters (see tables in section 7) to investigate a variety of issues including commercial, energy, sustainability, maintenance, and structural and performance issues. Finally contributors were asked to rank these areas in terms of perceived overall importance. The table below summarises the systems suggested.

Aspect	Masonry	Steel frame	Alternative
Proposed construction	5mm gypsum plaster, 200mm aircrete skin, 180mm insulation, 15mm render. Solid masonry construction with external insulation and a range of render or cladding systems. This is the most cost-effective and thinnest of the masonry systems.	15mm plasterboard, 100mm steel flanges (studs and noggings) with mineral wool insulation in-between studs, 20mm plywood or OSB, 110mm expanded polystyrene, 50mm cavity, 100mm brickwork.	5mm gypsum plaster, 150mm cast in-situ concrete with light anti-crack reinforcement (2.1 W/m²K), 200mm Neopor-type EPS glued-on (0.030 W/m²K), 15mm Render system. Total thickness is 370mm, with a U-value of 0.15 W/m²K.
Total thickness	400mm	395mm	370mm
Technical advantages	This system meets structural requirements, whilst providing thermal mass, reductions in linear thermal bridging at junctions and stable background for fixings and fixtures. It is also simple to build, enables ease of insulation envelope inspection and high levels of air tightness – rendered and plastered solutions are known from Finnish work to provide superior airtightness and are used widely throughout Europe, particularly with PassivHaus.	Light steel frame (LSF) is a stable and strong material so a small mass of steel is required to build a house. The building system is now well established in the UK and can be used for off-site construction either in modular or panelised construction which can help to address site labour shortages and improve quality and speed of construction.	No internal condensation risk with high thermal mass for environmentally efficient attenuation of internal temperature and scope for increasing this by using concrete intermediate floors. Wall thickness is also minimal in comparison to alternatives, with glued-on insulation not thermally bridged and therefore fully utilised.
Financial advantages		LSF is well established in the UK and is now considered economically competitive compared to other construction methods. This construction does not vary significantly from commonly used constructions with only a thicker layer of external sheathing insulation which can readily be added. The slotted studs are not commonly used in the UK but could easily be introduced, or additional insulation added in their place. The cost of the steel frame is largely unchanged from current practice.	This system will probably be cheaper in mass production than manually laid masonry, as in the Netherlands and Switzerland. It is also considerably faster to produce – a four-storey block could be watertight within a week. Although currently expensive relative to current land costs, the following will become more viable in the future: • 100mm precast concrete elements, instead of 150mm cast in-situ concrete. • 150-160mm Phenolic foam (0.023 W/m2K), instead of 200mm Neopor-type EPS. • Future developments, such as aerogel and vacuum panels, could reduce insulation thickness to below 100mm and enable 200mm total wall thicknesses using precast concrete.
Sustainability advantages	Solid wall construction is likely to score well with BRE's Green Guide ratings, where masonry material can be separated and recycled. Whilst reduced foundation widths are possible in comparison to wider cavity solutions, using less concrete and associated excavation and haulage of material to land fill. Haulage is generally reduced with this system, with masonry sustainability ensured through third-party Environmental Management System plant accreditation.	Steel is a highly recycled material and its high value as scrap ensures that it is recycled. The use of mechanical fixings allows it to be readily dismantled for reuse or recycling. The XPS insulation is oil based but alternatives based on renewable resources are becoming available. The ability for off-site prefabrication offers potential sustainability benefits from improved quality, reduced waste, and better performance.	Although this external system would be evaluated poorly within most UK assessments, it should be considered, because: • Embodied energy of lightly reinforced concrete is lower than fired clay brick per unit volume or weight – based on UK government (DETR) issued table on embodied energy and CO_2. • This solution enables repeatability of thermal performance and airtightness standards, with insulation easily inspected prior to render application. • This solution addresses the UK skills shortage and difficulties with delivery of calculated energy performance, since it defaults to air tight and features insulation that is resistant to air movement and wind penetration. • PassivHaus Institute research indicates that over a 100-year period, embodied energy comprises 8-10% of total energy use, whilst operational energy is 90-92%. It is debateable if embodied energy should be reduced at the cost of shorter-lived buildings and those less able to attenuate temperature during summer heat waves – powerful heating, ventilation and air conditioning (HVAC) systems may become necessary in the future, negating benefits. • In the longer term, there is no reason that cement cannot be manufactured using renewable energy.

7.1 Commercial considerations

Aspect	Masonry	Steel frame	Alternative
Buildability, degree of site skills needed, speed of construction, etc	Solid masonry can draw on a huge existing skills base and can be constructed speedily. Often the external finishing can go on at the same time as first internal fix leading to significant build time savings.	Steel components are lightweight and easy to lift and carry. Wall panels can be moved around by two men; only about 2.5 to 3 tonnes of steel is required for a typical house in the UK. There is little waste in production, fabrication or assembly and benefits can be gained from off-site prefabrication in controlled conditions in a workshop. This minimises inefficient and disruptive work on site and improves quality control. LSF is suitable for use with a variety of claddings. For a traditional finish an external leaf of brickwork (or other masonry finish) with a 50mm clear cavity is used, connected to the light steel framing using stainless steel wall ties located into vertical runners fixed back to the light steel framework through the insulation. Lightweight claddings such as renders, metal claddings, timber T&G boarding or tiling can be fixed to the steel frame using appropriate fixings.	N/A
Mass market application	Masonry is desired by the consumer in most cases and with a range of finishes it can meet the demands of the local vernacular.	LSF is being used successfully for housing in many countries. In the USA, Japan, Canada, Sweden and Australia, increasing numbers of steel framed houses are being built. In the UK several systems are now available and significant numbers of projects are being built. The reasons for this are the inherent quality and durability of light steel framing when compared to the alternatives, and its suitability for off site construction of dwellings. Useable roof spaces and clear span internal spaces can be easily created without the need for internal load bearing walls, allowing for future adaptability and change.	A straightforward system which has proved to be commercially viable; see flats in the Netherlands, Germany and Switzerland.
Cost per m^2	Material cost of wall will be typically £10-15 per m^2.	The costs are competitive to other forms of construction.	In a mass market, with established systems of formwork, this is cheap - due to the speed of construction and the low cost of the raw materials.
Sensitivity to wind/ rain during build process	Masonry is rain resistant and in a solid wall construction is robust during construction.	Steel is a quality assured, accurate, high strength, long life, adaptable, recycled and recyclable material manufactured to tight specifications. It does not suffer from twisting, warping or movement due to changes in moisture content. This results in easier fixing of linings and higher quality finishes, avoiding problems such as cracking around doors architraves. This means that thermal and acoustic performance is less likely to be compromised by movement that occurs after construction. Call-backs to rectify cracking and other effects of movement are reduced. Steel lends itself to off-site fabrication and this is one of the reasons for the recent increase in interest in light steel framing for housing. Speed of erection on site is a major benefit. Prefabricated panels or even volumetric modules are used, thus significantly reducing on-site construction schedules. The steel is not damaged if it is exposed to moisture during construction as long as it is allowed to dry off. Modules can have insulation, finishes and services integrated before delivery to site.	Concrete can be built in light rain, both the formwork and the pouring itself are more tolerant of light rain than the construction of masonry walls is.
Wall thickness/floor area/development density?	The overall thickness will be some 400mm on average, just 100mm greater than most common form of current constructions. It will be highly competitive in thickness to other forms of construction.	A LSF construction that achieves a U-value of 0.15 W/m^2K will have an overall construction of about 400mm if a traditional 102mm brick outer skin is used or about 300mm with alternative lighter weight cladding systems.	This can achieve a U-value of 0.15 in about a 370mm wall, or less if one uses phenolic foam.

7.2 Structural and performance issues

Aspect	Masonry	Steel frame	Alternative
Structural issues/ calculations/ wind loading/progressive collapse	Masonry is an established form of construction with design codes (BS 5628 and Eurocode 6).	Light steel components are designed to BS 5950 Part 5 or Eurocode 3 Part 1.3. But may need the involvement of an engineer familiar with the technology. Light steel framing uses cold formed C or Z sections as its basic components. These sections are relatively thin (1.2 to 3.2mm thick) and are galvanised for corrosion protection. They can be pre-fabricated using dry assembly processes into storey-high panels. For walls, C sections are generally 75 to 150mm deep, at 600mm centres, in lengths typically 2.4 to 3.5 metres. Where necessary, back-to-back sections can be used for strengthening. For floors, 150 to 300 mm deep C sections can span from four to six metres. These sections can also be fabricated into long-span trusses. The galvanised steel is provided to EN 10147 with 275 g/m² zinc coating, and is by its nature, of guaranteed strength and dimensions. LSF can be located on a variety of foundations. Strip or trench footings are most commonly used with suitable levelling and locating devices to accommodate the tighter tolerances of LSF. Mini pile foundations are particularly suited to poor ground conditions and can achieve high levels of accuracy for line and level which enables the LSF to be more readily located.	Extremely resistant to wind loading. It is a monolithic form of construction, with no discrete joints. Mass wall is usually 140-150mm thick on buildings up to four to five storeys; may be thicker on high-rise. Precast concrete which is cross-braced by intermediate concrete floors or masonry partition walls may be c.50mm thinner.
Applicable to what dwelling types – low rise/high rise/both?	For low-rise construction up to four storeys, the construction can be loadbearing solid masonry. Above this level it can be used as an infill to steel or concrete frame construction.	LSF is usually used in a loadbearing capacity in two to three storey low rise dwellings. However it can be used in medium rise structures. In particular, modular volumetric installations have been built up to ten storeys using structural LSF. LSF is also used as secondary partitioning and cladding material in many medium and highrise buildings.	Both, but especially medium and high-rise.
Condensation risk	There is no significant risk of surface condensation risk with this form of highly insulated construction.	If 'cold frame' construction is used (with no insulation outside the steel frame) thermal bridging through the framing studs can cause local cool spots in the vicinity of the stud and create 'ghosting', where local condensation causes discolouration of the wall surface along the lines of the studs. Warm-frame construction (where a layer of insulation sheathing is added outside the steel frame) ensures that internal surface temperatures along the steel framing elements do not fall to below the dew point temperature. Interstitial condensation can be a risk, however the increased thermal conductivity of the light steel studs compared to the insulation alongside means that the temperature of the steel along the web and at the outer flange is greater than in the insulation alongside. This reduces the likelihood of condensation on the stud. With warm frame construction and an effective vapour barrier condensation risk is low, and monitoring data confirms this.	Not a problem.
Fire performance	Masonry construction is a well established and tested form of construction. Some consideration might be required to the external insulation used in some circumstances.	Clearly steel components must be protected in a fire to maintain structural integrity. A single layer of fire resistant plasterboard can achieve 30 minutes fire resistance, and two layers can achieve 60 minutes fire resistance for walls and floors. Often mineral wool is required for insulation purposes. Longer periods of fire resistance can be achieved by adding further layers of plasterboard. Measures to achieve fire performance also address acoustics, as plasterboard and insulation are also used for acoustic performance.	The mass wall is non-flammable. The insulant is flammable. Where this is an issue, a non-flammable insulant such as high-density min. fibre is substituted.
Acoustic performance, robust details (RD) and site testing	Initial site testing would be required to obtain RD status. However some test data does exist and shows that acoustic performance would not be adversley affected by the use of solid external walls. Insulation thickness is unlikely to be an issue.	Tests have shown that standards well above the current requirements of the building regulations for acoustic performance can readily be achieved in LSF. Generally, double-skin walls are used for separating walls, and these can achieve sound reductions over 60 dB, which can be enhanced by additional layers of plasterboard and insulation. For separating floors, a built up floor using several layers including resilient bars can achieve similar sound reduction and a impact sound transmission below 55 dB. Robust standard details have been developed for LSF that meet the requirements of Part E.	Can be good.
Resistance to driving rain	Solid masonry has a proven resistance to rain penetration (BS 5628-3). The application of external insulation plus finishes can act as an impermeable cladding and further enhance the resistance to rain penetration.	A rainscreen cladding approach is suitable for LSF construction. Although brick can be used as a cladding material with a clear 50mm cavity, lightweight cladding materials make better use of the prefabrication potential of this technology. A secondary water barrier behind the main cladding should be included to ensure the steel does not get consistently wet. Although steel will corrode if constantly wet, occasional wetting is not a problem. Furthermore the galvanising protects the steel for considerable periods even when wet. Considerable work has been carried out by SCI to develop guidelines for appropriate cladding systems for LSF, and in particular for the use of insulated rendered cladding systems which are often used on LSF walls.	Good.

7.3 Energy

Aspect	Masonry	Steel frame	Alternative
Thermal performance/ U-value	This construction achieves a U-value of 0.15 or significantly better with additional external insulation. Variation in U-values can be easily accommodated by altering insulation thickness without significant knock on effects to other parts of the building fabric design.	LSF construction allows high levels of insulation to be achieved relatively economically and without leading to excessively thick walls. Steel-framed walls with U-values of below 0.2 W/m²K have been built in the UK within tight budgets for social housing. In UK practice most of the insulation is placed on the outside of the structural frame to create a 'warm frame'. It is this approach which achieves excellent thermal performance and avoids 'thermal bridges' which lead to local heat loss and to risk of condensation. A variety of external finishes can be applied, while internally the frame is usually finished using dry lining plasterboard to provide suitable fire protection. Nevertheless the steel components do reduce the effectiveness of any insulation that is located between them. In the UK some manufacturers prefer to place all the insulation outside the steel layer, however this adds to the wall thickness. To achieve U-values as low as 0.15 W/m²K and keep wall thickness down generally requires some insulation between the studs. European research suggests that in most cases between 50% and 70% of the insulation should be on the outside of the light steel frame, with the remainder within the thickness of the frame. In America, however many light steel frame houses are built with smaller amounts of insulation outside the frame, and some UK manufacturers have found that with only 30% of insulation outside the frame the walls perform satisfactorily.	N/A
Airtightness	Based on similar builds in Europe this should be capable of achieving an air test result of 1m³/m²/h.	Airtightness is achieved in light steel framing by the creation of an air barrier. This can be the plasterboard lining, sealed appropriately at junctions and penetrations, but this method is not very reliable as penetrations through the plasterboard compromise the air barrier. More preferable is a membrane integrated within the construction. With a warm frame wall where much of the insulation is on the outside of the steel frame, the vapour barrier may be located on the outside of the steel frame but inside the external insulation sheathing layer. In this way it is not penetrated by the many potential services and fixings that inevitably pass through the plasterboard. A third option is to use a blown in polyurethane insulation rather than using mineral wool insulation between the steel framing components. This can seal in all the gaps and prevent air leakage as well as improving the U-value. It is, however, more expensive. Using blown cellulose may also have some benefits but some research from Scandinavia suggests that there may be problems with the corrosion effects of the boron in cellulose insulation and the galvanised steel.	Poured and vibrated in situ concrete defaults to airtight, unlike most other construction materials. Services can be recessed in external walls without special measures and without loss of airtightness. Tests in Scandinavia and North America showed much lower air permeability on concrete detached houses and flats than timber-frame buildings in the same region. Both types of construction can be made tighter by special care in design and workmanship, but in these efforts, concrete has a head start.
Thermal bridging	Has not been fully assessed but is likely to be very good with an external envelope of continuous insulation.	Clearly steel has a high thermal conductivity and thus leads to significant potential of thermal bridging. This can be alleviated by the use of warm frame construction (where most of the insulation is placed outside the steel frame as a sheathing layer). This is the accepted way of dealing with this in the UK. There has been considerable research in Scandinavia and North America about how to reduce the thermal conduction through the LSF studs. Slotted steel studs have been shown to have a much reduced thermal bridging effect and are used in Scandinavia. Combined steel and timber board studs have been suggested in the USA.	Virtually none unless cantilevered balconies are needed.
Thermal mass and summer time overheating	Overheating unlikely to be a problem even with plasterboard because of thickness of concrete walls.	If required, the thermal capacity of LSF buildings can be increased to suit different patterns of use by substituting lightweight floor structures with composite or concrete floors and including mass walls at a suitable point within the structure. Some UK LSF companies offer composite floors with the LSF structure which allows some thermal mass. Also the use of concrete ground floor slabs can help, and if necessary additional layers of plasterboard can be added. However, in many buildings the surface finishes and coatings insulate the available thermal mass from the internal spaces and this is a problem for all constructions.	Provides a high thermal capacity; expected to be able to provide very high summer comfort standards.

7.4 Sustainability

Aspect	Masonry	Steel frame	Alternative
Embodied energy	Concrete blocks have relatively low embodied energy. As with cavity wall constructions, the solid wall construction is likely to fare very well in the BRE's Green Guide ratings. Ongoing research is being conducted into the use of waste materials, such as sewage slag in the manufacture of bricks and blocks, which will reduce their embodied energy further.	The embodied energy of steel is higher per tonne than many other construction materials. However the relevant comparison is the embodied energy (and resultant emissions, etc.) from a like-for-like installation. A LSF house will only require a few tonnes of steel, compared to a masonry house that will require a higher weight of concrete. Also the structural material is only one small component of the embodied energy. The cladding material may be far more significant (particularly if brick is used) than the structural material. Thus when comparing a whole LSF house with a similar one using masonry construction (with similar thermal performances and cladding) I do not think the differences in embodied energy are significant. Furthermore, using dry assembly processes with LSF, there is little waste in production, fabrication or assembly and benefits can be gained from off-site prefabrication in controlled workshop conditions. Thus there is less embodied energy that goes to waste. Also the steel is likely to be recycled at the end of its life further leading to environmental benefit and reducing energy required.	Higher than timber, lower than concrete block, precast concrete or clay brick.
Scale of material resource/ease of availability	Concrete is available as a base material in the UK. Typical annual production of 9 million m^3.	There are many LSF manufacturers in the UK now, and the availability of steel as a resource in the medium term is not in doubt. In the longer term as we reach peak oil and beyond, the availability of any material is open to question.	Uses local sand and gravel from 3-12 miles away plus cement from typically 90 miles away.
Reusable materials?	Concrete can be reclaimed and crushed as aggregate for reuse in other concrete products.	Steel has a strong culture of recycling and is widely recycled. LSF is readily reused in individual component form or recycled into new steel compared to many other construction materials. I think it is important to use steel components in structures in such a way that they can be readily dismantled for reuse of the materials in future. This is a potential strong feature of LSF although largely as yet unrealised. It is important to consider the whole construction and its reusability. This has implications for the uses of cladding and internal finishing materials such as brick and plasterboard. I think it is important to develop alternatives that allow dry assembly and dismantling.	Not designed to be re-usable; is designed to last a very long time.

7.5 Maintenance

Aspect	Masonry	Steel frame	Alternative
Longevity	Masonry and concrete are highly durable materials, outlasting most other types.	Although there were problems with durability of steel frame housing built in the immediate post war period, the current LSF designs are very different and are designed to address issues of condensation and thermal bridging that cause problems in the earlier designs. The steel components are durable and have a service life that can be expected to be in excess of 100 years if correctly designed, installed and maintained. It is important to recognise the relevance of appropriate design of the whole building fabric, including the cladding system that keeps out rainwater, foundations, and condensation control.	Mass wall extremely long-lived. Insulation and render liable to need attention every century, according to German estimates.
Ease of maintenance and repair	Masonry can be easily and cost effectively repaired using existing knowledge and skills base.	The steel does not require any maintenance itself, so the maintenance issues are due to other components such as the cladding and the internal finishes. Service integration is important, as services usually have a shorter life than the building fabric. The space between the steel components allows for service integration, but access panels, or service routes should be considered to maximise potential for adaptability and upgrade.	May need the insulation to be stripped off in a century's time. If insulation is to be re-used, mineral fibre should be specified but this gives a thicker wall than EPS or phenolic.
Flood resistance	Solid wall masonry will have good flood resistance and will be a resilient form of construction - see CLG report. http://www.planningportal.gov.uk/uploads/br/flood_performance.pdf	Although steel corrodes when wet, intermittent wetting should not lead to corrosion. Flooding is likely to have significant impact on the cladding system and particularly on internal finishes rather than the steel itself. Details design of the LSF components should ensure that water is able to flow away in any flooding eventuality.	Properly vibrated concrete is almost waterproof and could withstand a hydrostatic head. But even so, dwellings should not be built on flood plains.
Adaptability to change of use/ occupants/addition of renewables	Solid masonry can be easily adapted and modified or extended using existing knowledge and skills base. This adaptability will mean that masonry buildings can be easily upgraded or altered to meet future requirements thus increasing options for change of use of building without having to demolish and rebuild.	The spanning capability of steel allows the creation of flexible internal spaces with large areas that are free from load-bearing structures. This provides flexibility for the designer and occupants. A significant issue for any adaptability of any system is the location of services (particularly drainage) as these are often most inflexible.	Concrete is not adaptable, but internal walls can be in a different material and capable of being dismantled.
Design for deconstruction/reuse	Masonry can be reclaimed and recycled after demolition.	For construction components to be reused requires buildings to be dismantled so that recovery is possible without damage. This already occurs for some valuable components such as cast metals and some hardwood timber components and to a much smaller degree for slates and bricks. Demolition methods are slowly changing, with the introduction of selective techniques which allow the sorting of materials that may be recycled – and architectural salvage is a growing business. In future buildings will need to be designed to be dismantled rather than demolished. Steel frame buildings are particularly suited to being dismantled, and therefore allow the components and sometimes whole buildings to have a further useful life. If bolting is used this is readily reversible, and the dry construction method that are often used with steel framing allow components to be dismantled. Examples from many temporary or movable buildings that use steel provide lessons in designing for deconstruction.	The construction is not designed for this. If a dwelling may have to be moved in 50 years, say due to rising sea levels, concrete is not very suitable. An alternative would be to build it from timber-frame, which allows the house to be moved in its entirety.

7.6 Overall rankings – perceived importance by area

	Masonry	Steel frame	Alternative
1.	**Commercial** Cost drives the use.	**Energy** It is imperative that we address the environmental issues resulting from fossil fuel use, the impact of peak oil and the likely future scarcity of energy resources.	**Structural and performance issues – joint 1st** We cannot avoid the need for construction to satisfy these criteria.
2.	**Structural and performance issues** If a construction does not perform, the other aspects become superfluous.	**Sustainability** Issues of sustainability must become far more prominent in our thinking and choice of systems.	**Energy - joint 1st** Supplies of oil and gas will be incapable of meeting demand within less than 15 years. Energy is the lifeblood of industrial society, and without appropriate action to invest in alternatives (energy efficiency is by far the cheapest, measured in p per kWh), industrial society will be seriously disrupted.
3.	**Energy** Dominated by building regulations and national requirements.	**Structural and performance issues** Systems must perform up to expectations and be safe and long lasting, otherwise the energy efficiency aims will not be met.	**Maintenance** Very important; some roof and wall finishes take too much maintenance.
4.	**Maintenance** Part of the life cycle cost.	**Maintenance** Systems need to be adaptable and easily maintained to extend their useful life and reduce the need for their replacement.	**Commercial – joint 4th** Unless peak oil and climate change are dealt with, the subsequent disruption to industrial society will render commercial issues irrelevant.
5.	**Sustainability** Energy covered elsewhere and minor aspects on life cycle assessment LCA less important.	**Commercial** We need to place less emphasis on commercial issues and put more value on other performance issues, otherwise we will continue to build to the lowest levels. I think that there is a need for demanding codes and for public education to value the needs of sustainability.	**Sustainability - joint 4th** Not a well-defined term but assuming it means environmental issues other than energy, it must be dealt with, along with securing sufficient access to energy in the future.

1 = most important 5 = least important

8. Conclusions and recommendations for further work

This report set out to investigate whether cavity construction is capable of meeting the higher levels of the Code for Sustainable Homes and achieving zero carbon performance. Although in theory the cavity could expand to greater widths to achieve the required thermal performance, this would involve a revision of existing practices and so the question becomes: what unique benefits does cavity construction have which mean we should keep it?

Developments in insulation materials and render mean that weathertight houses can be constructed without the use of a cavity, whilst alternative ways of integrating insulation mean that equivalent or better performance can be achieved without a cavity and with a reduced footprint. With the advent of modern approaches and materials, it seems like the days of the cavity wall may be numbered. In fact, one of the most persuasive reasons to keep it is to the large workforce skilled in cavity construction. This report sought optimum construction solutions from its contributors, and significantly, two out of three independently suggested an externally insulated solid wall. This would seem to be an ideal way forward for masonry construction, and one which could bridge the gap between the existing skills base and the need for increased thermal performance.

With the population growing and household sizes shrinking, the UK currently needs new housing that isn't just energy efficient but also fast to build. The process needs to be rationalised and streamlined, and key roadblocks which stand in the way of these twin goals need to be removed. Again, an externally insulated approach makes sense, because the build process is simplified by utilising solid walls, and simultaneously made more robust by allowing easy inspection of insulation continuity. The system shares many benefits with cavity construction, particularly practicality and liveability by allowing easy internal remodelling, and good levels of thermal mass. It also utilises the existing skills base and can be delivered using the existing supply chain.

One of the biggest obstacles to the widespread adoption of externally insulated construction will be planners' requirement for masonry facades. However, it is important to realise that masonry facades are just a trend, and that brickwork was originally a cheap replacement for stone. Dwellings can be rendered to disguise brickwork, whilst protecting the structural integrity, and planners should now turn their attention to creating truly sustainable communities rather than dealing with aesthetics at the expense of innovation. The prevailing opinion that buyers prefer a traditional appearance must also be tested if the industry is going to move forward in any meaningful way.

Delivering energy efficient housing in high volumes can be helped by external insulation, but to maintain progress the UK skills base needs to widen. A new generation of Clerks of Works is needed to ensure robust build quality and educate site teams. A greater requirement for parge coating, plastering and rendering could turn these into significant stages of the overall build with the potential for major training programmes and expansion in employment.

We should learn to walk before attempting to run, which is why externally insulated blockwork walls are a vital intermediate step. They also avoid some of the excessive technicality of certain steel and timber frame options. However, hand-laid block and brickwork has great potential for increases in efficiency and build speed, and European experiences point to MMC solutions which can serve to increase build speed further whilst reducing costs. Such systems have been tried and tested in real market situations and have proven themselves viable; it would be a missed opportunity if the UK didn't attempt to learn from lead that part of Europe has taken in energy efficient construction techniques. However, it is important to fully interrogate the applicability of such systems to the UK – and their flexibility in satisfying the demand for tight urban infill sites would need to be fully assessed.

Crucially, now is the time for innovation – not 2010. The next couple of years offer a chance for developers to use a variety of techniques in order to determine which techniques can achieve the necessary thermal performance. Unfortunately the Code for Sustainable Homes, although well intentioned, does not place appropriate emphasis on improving the building fabric, because renewable power and efficient heating systems can be added to offset emissions. Whilst such flexibility is desirable in theory, it has in practice given the construction industry a reason to be pragmatic and adopt a 'wait and see' attitude, when really there is a pressing need to get on with the job of developing energy efficient construction techniques.

There is currently little incentive for developers to invest in research and development into advanced fabric solutions, and this raises the risk of a whole generation of dwellings facing unoptimised energy efficiency in the future. It also risks a skills shortage when Code level 6 becomes mandatory and the building fabric has finally to be addressed. A revision of the Code to incorporate more binding requirements for fabric efficiency, would rationalise the legislative environment for developers, allowing them to concentrate on the fundamentals of energy efficient construction which would, in the long term, potentially do more towards hitting the UK's CO_2 reduction targets.

Further work recommended to follow up this report includes:

- Greater engagement with The Institute of Clerks of Works: this profession could make a significant impact on achieving the UK's zero carbon ambitions. An Energy Saving Trust training and accreditation scheme, coupled with ongoing education, could help get the important issues to workers on the ground without placing additional burden on the mainstream construction industry.
- A detailed investigation of the most promising European techniques, coupled with industry consultation to assess their applicability to the UK.
- A literature review of glued insulation techniques to investigate maintenance issues and durability, as well as fire performance.
- An investigation of the feasibility of replacing renewables and low carbon heating systems at the end of their life, along with UK emissions profiling for a variety of future outcomes.

Appendix A – Masonry response

Part A

1. Why has cavity masonry been so dominant in mainstream housing?

Masonry is a traditional, tried and tested construction technique which has longevity, durability and high sustainability credentials. It is constructed on site using a well-trained, established workforce and by a skill and trade that is now in ample supply. It is one of the most cost-effective forms of building, and despite being under attack from many other construction techniques, it is still by far the most popular form of construction in England and Wales.

Masonry continues to be popular as it offers flexible solutions, providing all of the necessary performance requirements of external and internal walls. In one material, designers have the complete solution to meet structural, fire, rain and water penetration, thermal and acoustic requirements. It is also flexible on site and is tolerant to changes in design and lack of fit. Unlike off-site manufactured components, it can accommodate changes and errors in ground levels and foundation setting-out. The materials used are indigenous to the UK and in abundant supply in a well-organised industry. This is a key aspect in the sustainability argument for masonry. There is generally no extended lead-in time and in many cases, completion of design to delivery on site can be a matter of days. Last-minute modifications to design are easily accommodated on site and masonry construction allows for extension or modifications to buildings at a later stage. Masonry materials can be used in foundations, thus allowing in many cases the delivery of a single product to use in all parts of the building structures. Fire resistance also remains a key feature both after and during construction.

For both internal and external walls, masonry provides the solutions to meet the current building regulations for acoustics and provides a high degree of sound insulation from outside noises. Flanking sound is minimised and Part E acoustic 'Robust Detail' constructions exist for a great number of masonry formats and will continue to do so in the future.

Cavity walls can be delivered in a wide range of formats. The inner skin can be constructed from many different formats of concrete components, ranging from heavy weight to lightweight aggregate concrete blocks, to aircrete. Block types are chosen to meet a balance of the desired design requirements, including high-strength varieties for multi-storey buildings to low-density types where high thermal performance is needed. Blocks and mortars now come in variety of sizes from common traditional formats in conventional mortar to the latest forms of 'jumbo blocks' constructed in thin layer mortars. Block thicknesses can be increased from the standard 100mm to virtually any size within reason if structural or other design requirements dictate. Masonry construction can incorporate many different types of thermal insulation, which can be used externally, in the cavity (full or part fill) or as an internal thermal board. Finally, the external skin can provide a range of finishes from the much-loved brick to rendered or clad masonry skins.

Would masonry benefit from adopting a 'solid' wall approach? Certainly up until the early part of the 20th century, solid walls were the most common form of construction. Cavity walls were later introduced to help, in the main, with the reduction of rain penetration. It was not until the 1980s that cavity was introduced as mainstream following regulatory changes in energy conservation. So might we go full circle? There are a number of considerations to take into account, including appearance and acceptability. However, new materials have been developed over the last century or so that will potentially make this form of construction attractive to use again. Advances in masonry material technology and from the ancillaries and thermal insulation manufacturers have all enhanced the debate about returning to this cost- effective and simple form of construction.

As we enter a new age of climate change and ever-higher performance requirements from thermal insulation, the risk of summer overheating becomes real. It has been shown that heavyweight forms of construction provide the required thermal mass to start to counteract the effect of rising internal temperatures and the need to provide a strategy of keeping the inside cool. Linked to climate change is the increasing threat of flooding and in recently published guidance documentation, masonry is given as the preferred solution for both flood resistance and resilience.

2. Why is industry reluctant to go beyond the 100mm cavity?

Historically, as changes to the energy conservation requirements of building regulations are made, the tendency has been to increase the cavity width and use a greater thickness of thermal insulation as either a full or partial fill. However, some parts of the house-building industry suggest that the 100mm cavity is the limit. We have to examine why this is the case. The first consideration is about cost effectiveness and the footprint of the building. It would appear that 100mm cavities are widely accepted by the industry as being cost effective and easily constructed. A few years ago this was not the case. Perhaps it is the fact that all forms of construction have had to increase in floor area owing to more stringent demands of energy efficiency. The case given in the past was that at the extreme, the result of increased wall thicknesses could be the loss of a house from the plot on a large building site. But does this really apply to a terraced housing? Take the case of increasing the cavity by an extra 50mm. Certainly the front and back elevations will increase the building's dimensions by 100mm to accommodate this change, but this increase need not apply to the separating walls between properties. The overall footprint will, therefore, only need to increase by 100mm in total length.

In other extreme cases where the plot size is limited, increased wall thickness could lead to loss of liveable area, leading to lower profit per site. But again, this is likely to be relatively small. So whilst there may well be extreme cases, there must be a significant number of projects where this is not the case.

Are builders really fixated on the 100mm maximum cavity? Certainly when looking at some options for houses built to Code level 3 and Code level 4 requirements (25% and 44% better CO_2 emissions from current Part L), indications from the industry are that 100mm cavities can be retained. Beyond these levels and particularly as we head towards Code level 6, the envelope of the house is restricted by the 'heat loss parameter', which effectively imposes low U-values on elements of construction. The house-building industry has intimated that it would therefore look at wider cavities and possibly other forms of masonry to meet the requirements. As far as technical issues are concerned, there is nothing that structurally prevents the use of wider cavities. Indeed Approved Document A to the Building Regulations allows design of walls with cavities up to 300mm. This form of construction has been built in low-energy housing with no reported difficulties. The main area to be addressed is that of thermal bridging across the wall tie itself. Certainly in the intervening period there is the opportunity for research and development in a number of areas, wall ties being just one of these.

Detailing of lintels may need addressing, but if the industry moves towards independent lintels, the issue starts to be resolved.

Are 150mm cavities out of the question? My suggestion is that this is probably not the case. Again the wall tie issue needs addressing, but very satisfactory U-values will be achieved. This form of construction will retain the benefits of thermal mass, an important issue for the future.

In all cases where change is necessary there will be a cost burden to bear on the redesign of the house type. This is true, however, for all forms of construction and although this is a real cost, a balance has to be achieved between the consequences for all of us if changes are not made.

3. To achieve better U-values in masonry construction, whilst still maintaining a 100mm cavity, insulated dry lining is often used. This effectively isolates the thermal mass in the structure.

Some have suggested that they will consider the option of a 100mm insulated cavity and a thermal board applied to the internal surface, although this form of construction is used by relatively few at the moment. This will provide a very comfortable level of thermal insulation, whilst providing a very beneficial option of reducing linear thermal bridging at junctions. By way of example, a board with an overall thickness of 30mm will typically achieve a U-value of 0.20W/m^{2}K, whilst at 70mm a value of 0.15W/m^{2}K is typically obtained. This is therefore a viable option, although it does come at the at the expense of some reduction in thermal mass and a reduced background for fixings that masonry beneficially offers the house occupiers.

4. To achieve better U-values, would you consider switching to:

As a supplier of masonry materials it is difficult to answer this one. I would suggest that most builders will try one of the options listed as a pilot study and many have; most however, have reverted back to masonry.

5. How do you propose to get to the improved U-values (0.2 and below) required at levels 4, 5 and 6 of the Code for Sustainable Homes?

Many have suggested that as we head towards the zero carbon era for new homes by 2016, this will be the death of masonry. I have lost count as to how many times I have heard this before. At every change to the energy regulations, commentators have argued that brick and block construction, as we know it, will cease.

Masonry has survived all of the attacks that can be thrown at it. It has been flexible enough in providing construction solutions that change and adapt with the times. Wall thicknesses have increased, along with all other forms of construction, to accommodate ever increasing thermal performance demands, and this is likely to continue. New forms of masonry products have been developed and will continue to do so, whilst still retaining a traditional flavour to the build.

How is masonry taking the agenda forward to 2016? Firstly we need to challenge the demands of the various Code levels in terms of fabric insulation. Ideally we would reduce the fabric heat loss to an absolute minimum before incorporating renewable energy technologies. But here again there lies a balance. It is possible to retain wall U-values of 0.25W/m^{2}K at Code level 4 and design in the required reduction in CO_2 emissions. When considering the overall emissions in a design calculation, it is soon found that the reduction of wall U-value below 0.25 has a diminishing effect on the total emission level. Up to this level, readily available forms of masonry construction can continue.

At a U-value of 0.20W/m^{2}K (using current forms of insulation materials) a cavity width of 130 to 160mm can achieve the targets. Future developments in materials will further reduce the overall thickness needed. Partial fills of insulation will provide construction options with a similar overall thickness.

We have already mentioned the use of a thermal board and this may become an attractive option to many.

Finally, perhaps designers will start considering other forms of masonry such as solid masonry with external or internal insulation? It may also stimulate the debate about the appearance required by planners and clients, but again maybe brick slip systems will start to appear as a viable option.

There is also the opportunity for new forms of higher performing insulation and here the designer will have to examine the balance required of cost of construction versus wall thickness.

Part B

Please suggest your preferred wall construction to reach a U-value of 0.15W/m^2.K, and explain why this is:

a) technically advantageous/attractive
b) financially advantageous/attractive
c) sustainable

A wall construction to meet a U-value of 0.15W/m^{2}K is that of a solid masonry wall with external insulation, which can have a range of finishes from a render to a cladding system. This form of construction is likely to be the most cost effective and thinnest overall of the masonry solutions on offer. Using typically a 200mm thick aircrete masonry skin, the external insulation required will be in the order of 130 to 180mm in thickness.

This form of construction meets the structural requirements for housing, whilst providing the thermal mass necessary for future developments to over come the overheating scenario. It is robust internally and provides a good level of reduction of linear thermal bridging at junctions with other parts of the construction. The house occupier also has the benefit having a stable background for fixings and fixtures.

From a buildability point of view, it is also simple. A single leaf of construction is simple to perform and the thermal insulation envelope is evident without trying to prove that it is present. This form of construction should also provide a good level of airtightness. When rendered and plastered solid walls are known from work in Finland to provide one of the best forms for construction as far as airtightness is concerned.

Solid wall construction is also widely used in other parts of Europe and is particularly popular as a 'PassivHaus' construction in Germany and elsewhere.

Solid wall constructions are likely to offer benefits due to reduced structural material costs (foundation widths, lintels, wall ties) but also use of thin joint systems will significantly improve the speed of construction allowing further savings to be made on the build programme and, consequently, build costs.

Solid wall construction is likely to fare extremely well in the BRE's Green Guide ratings. At the end of life the masonry material can be separated and recycled. There is also a case for reduced foundation widths (compared to wider cavity solutions), with less concrete, less excavated material to land fill and less haulage. Haulage in general is also significantly reduced from place of manufacture to site. Masonry provides the sustainability credentials needed under the Code for Sustainable Homes, with modern plants having third party accredited Environmental Management Systems.

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Appendix B – Light-gauge steel frame response

Part A

1. Why has cavity masonry been so dominant in mainstream housing?

First of all, we should be clear about whether we are actually discussing a cavity wall. I assume that we are referring to a space between an inner block leaf and an outer brick leaf filled with insulation. This is not really a cavity and in other countries such as Canada building scientists are surprised that in the UK there is acceptance of what we call full fill cavities. They regard it as good practice to maintain at least 50mm of clear (air filled) cavity. One of the reasons for the strong attachment to this form of construction is that the demand for traditional brick as an outer skin in many locations has stifled demand for alternative construction systems. Since many other construction systems such as timber or steel frame will need a clear cavity to ensure that no moisture crosses to the framing, this can lead to walls that are just as thick or thicker than masonry cavity construction.

The industry's hesitance to adopt new ideas is the main reason that it is so strongly attached to cavity masonry construction. This is due to a variety of factors. These include the negative reaction towards innovative construction methods used in the 1950s and 1960s (e.g. poorly detailed panel systems), which are now seen as a failure, and the dominance of marketing that encourages traditional designs and technologies. The planning system, which grants permissions for new buildings, also tends to limit new designs and technologies. A further problem is that private home builders in the UK make more money from land transactions than they do from construction, so there's little incentive to improve the product. These factors, together with the very low investment in research into alternative methods have limited the use of new construction technologies. This is beginning to change due to issues such as:

- The introduction of more demanding thermal regulations which lead to thicker walls and difficulties with airtightness of traditional cavity walls.
- Shortage of traditional construction skills required for masonry.
- The desire to remove more of the production process from the construction site to the more controlled conditions of a factory.

2. Why is industry reluctant to go beyond the 100mm cavity?

I think the industry is keen to keep the wall thickness minimal due to loss of net internal area and lower profit. In addition, there is some concern with the use of longer wall ties. I am not sure if there are issues related to codes and standards of going over 100mm. Many house builders are concerned with call backs and problems after construction as these are expensive to deal with. For this reason they prefer to stick with what they know and are less willing to change the technologies they adopt.

Going beyond 100mm cavities also may have knock-on implications on foundation design, and is seen to make handling of insulation more awkward.

3. To achieve better U-values in masonry construction, whilst still maintaining a 100mm cavity, insulated dry lining is often used. This effectively isolates the thermal mass in the structure.

Insulated dry lining reduces the benefits of one of the positive features of masonry construction – thermal mass. However, it may be possible to provide thermal mass in the floors and internal walls. Often the external walls use lightweight block that does not have as much mass as the internal block partitions which can be of heavier construction, so insulated dry lining may not be so negative. The design should be looked at as a holistic solution, so insulated dry lining may be appropriate if thermal mass is provided elsewhere. However, this will not address the problem of overall wall thickness. Also dry linings are difficult to make airtight.

If masonry is to be used, I would prefer to see a 100 or 150mm block leaf with a 200mm thick insulation layer on the outside and with a lightweight cladding such as render or thin brick cladding on the outside. This provides thermal mass inside the insulated envelope and a fully enclosed thermal insulation layer with minimal penetrations. If the inner surface is wet plastered or parged then air tightness can be achieved.

4. To achieve better U-values, would you consider switching to:
- Structural insulated panels (SIPs)?
- Insulated concrete formwork?
- Lightweight block with external insulation?
- I-beam timber frame?

I have worked with various alternative systems and I think there should be a range of options that are accepted by house builders in the UK. I designed one of the first SIP houses in the UK and was impressed with the technology. The house easily achieved wall U-values below 0.2 W/m^{2}K (and below 250mm thick) and air change rate of about 2 ach @50pa, and in use was very energy efficient, using less than 30kWh/m^2/yr for heating and hot water. This technology offers a lot of potential for airtight well insulated buildings.

Other technologies to consider are light steel framing, (slotted studs as used in Scandinavia are particularly interesting) and insulated concrete formwork.

In the short term, I think small builders are more likely to stick with the familiar masonry construction methods. However, block manufacturers are developing new technologies, such as thin mortar beds using adhesives rather than cement mortars and composite blocks that include the block, insulation and brick finish all bonded together into one unit. These are all intended to improve efficiency, speed, quality and cost. There is also increasing research into the use of waste materials (such as sewage slag) in the manufacture of bricks and blocks, for environmental reasons. The TRADIS system from Filcrete has attracted attention from many smaller house builders. This system, imported from Scandinavia, uses engineered timber I-beams in a prefabricated panel system, with cellulose insulation blown into the panel in the factory or on site. Window and door frames and surface finishes can be incorporated in the factory and the system has good environmental performance.

5. How do you propose to get to the improved U-values (0.2 and below) required at levels 4, 5 and 6 of the Code for Sustainable Homes?

I do not think there is one answer or solution. There are a variety of systems available and suitable – some may use masonry but others may not. It may be necessary to be more flexible about the use of brick as an external finish as this will allow thinner walls to be built. As explained above, the externally insulated masonry wall with a lightweight cladding may become more popular as it is readily achievable. Also SIP technology perhaps with additional insulation on the outside of the SIP is a viable option, as is the Tradis system. But all of these are more competitive if traditional brick is not the cladding material.

Part B

Please suggest your preferred wall construction to reach a U-value of 0.15W/m^2.K, and explain why this is:

a) technically advantageous/attractive
b) financially advantageous/attractive
c) sustainable

Light steel frame construction has the potential to create comfortable and highly energy efficient dwellings because the steel studs allow for a high standard of insulation to be incorporated. This construction method has been attracting interest in the UK in recent years and increasing in popularity for both individual houses and for apartment blocks. There are now several companies supplying light steel framing to the housing sector, and many developers and RSLs are actively using this technology. The use of light steel framing can help to address issues of skills shortage, provide high construction standards, achieve precise tolerances and increased off-site manufacture.

Light steel framing is now used successfully for housing in many countries. The reasons for this are the inherent quality and durability of light steel framing when compared to the alternatives, and its suitability for the design of well insulated dwellings. Concerns about the volatility of the timber market, the declining quality of structural timber, environmental issues such as sustainable forestry practices and quarrying for clay used for bricks and aggregates used in concrete blocks have affected the use of these materials. The American Institute of Architects, in its Environmental Resource Guide, recommends that steel may be considered less environmentally harmful than many other alternatives because many steel products are made totally or partially from recycled scrap.

Lightweight steel framing is a term commonly used to refer to light-gauge steel members with thicknesses ranging from 0.9 to 3.2mm that are produced by roll forming. These members may be wall studs, track, floor joists, roof rafters, bridging channels, furring channels or related accessories. Also included would be the non-load bearing drywall studs. Construction can use individual light steel components or sub frames; often prefabricated welded, bolted or rivetted panels are assembled on site using self tapping screws to create whole building structures.

Steel is manufactured to tight specifications and does not suffer from twisting, warping or movement due to changes in moisture content. This results in easier fixing of linings (sheathing) and higher quality finishes, avoiding problems such as opening up of cracks around architraves around doors due to movement. Steel components are lightweight and easy to lift and carry. Wall panels can be moved around by two men; only about 2.5 to 5 metric tons of steel is required for a typical steel house. There is little waste in production, fabrication or assembly and benefits can be gained from off-site prefabrication in controlled conditions in a workshop. This minimises inefficient and disruptive work on site and improves quality control. Useable roof spaces and clear span internal spaces can be easily created without the need for internal load bearing walls, allowing for future adaptability and change.

Steel is a highly recycled material and its high value as scrap ensures that it is recycled. The use of mechanical fixings allows it to be readily dismantled for reuse.

Modern light steel framing in the UK incorporates all or most of the insulation on the outside of the steel frame, leading to a 'warm frame' construction. This reduces the thermal bridging of the steel elements, thereby minimising the risk of cold spots occurring on the internal surface of the wall. It also maintains the steel above the dew point temperature, avoiding interstitial condensation. More innovative systems such as slotted steel studs reduce thermal bridging considerably.

The preferred construction

The preferred construction is a light steel frame wall preferably using slotted steel studs (but it can use standard LSF studs with additional insulation). The wall can have a brick or other cladding. Alternatives to brick cladding are preferred to keep the wall thickness down and reduce the embodied energy of brick. Also cladding materials that allow for deconstruction are preferred, such as timber cladding, thick brick tile systems, or thick layers of material such as modern render systems.

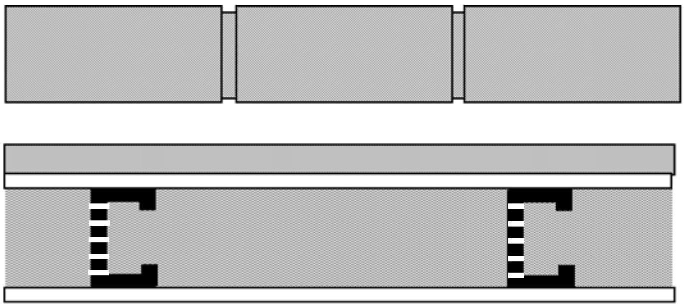

Figure 1: Slotted steel stud wall with insulating sheathing

Layer	Material	Material fraction	Thickness	Thermal conductivity	Thermal resistance
			(mm)	(W/mK)	(m^2K/W)
	External surface	-	-	-	0.040
1.	Brickwork	-	102	0.77	0.133
2.	Cavity	-	50	-	0.180
3.	XPS or similar insulation bridged only by fixings	-	110	0.03	3.667
4.	Plywood or OSB	-	20	0.13	0.154
5(a).	Insulation between steel flanges (studs and noggings)	0.9972 (99.72%)	100	0.04	2.500
5(b).	Steel flanges (studs and noggings)	0.0028	100	10	0.002
6.	Plasterboard	-	15	0.21	0.071
	Internal surface	-	-	-	0.130

The thermal conductivity of the steel in the above table has been estimated at 10 W/mK: this is about 20% of the actual conductivity of light steel framing. However research on the slotted studs (see above) suggests that thermal conductivity is much reduced by the studs. An alternative construction can include solid (not slotted) steel studs and a additional 15mm of sheathing insulation (layer 3).

Using the procedure set out in BRE Digest 465: U-values for light steel-frame construction, this construction gives a U-value of 0.15 W/m^2K.

Technical advantages

LSF is a stable and strong material so a small mass of steel is required to build a house. The building system is now well established in the UK and can be used for off-site construction either in modular or panelised construction which can help to address site labour shortages and improve quality and speed of construction.

Financial advantages

LSF is well established in the UK and is now considered economically competitive compared to other construction methods. This construction does not vary significantly from commonly used constructions with only a thicker layer of external sheathing insulation which can readily be added. The slotted studs are not commonly used in the UK but could easily be introduced, or additional insulation added in their place. The cost of the steel frame is largely unchanged from current practice.

Sustainability advantages

Steel is a highly recycled material and its high value as scrap ensures that it is recycled. The use of mechanical fixings allows it to be readily dismantled for reuse or recycling. The XPS insulation is oil based but alternatives based on renewable resources are becoming available. The off site prefabrication potential offers potential sustainability benefits from improved quality, reduced waste, and better performance.

Appendix C – Alternative construction techniques response

Part A

1. Why has cavity masonry been so dominant in mainstream housing?

A prevailing view is that cavity walls historically developed in the wettest, windiest countries of north-western Europe as a way to keep water out of masonry-walled buildings. This happened particularly early in wetter regions, such as the western UK and Ireland.

Only five small European countries appear to use the cavity wall widely. These are the UK, Ireland, Denmark, Belgium and the Netherlands. The rest of mainland Europe and indeed Asia uses mostly solid masonry and concrete walls. Norway, Sweden and Finland are mostly divided between solid masonry, concrete and timber-frame walls. The USA, Canada and Japan mostly build timber-frame, steel-frame and concrete walls.

It seems likely that externally insulated solid masonry walls could be used in many situations where cavity walls are used today. Since the most common types of externally insulated walls use a slab of plastic foam insulation and do not have a residual cavity, further checks on suitability may be needed for extremely exposed UK climates, including; e.g. north-west Scotland, west Wales and south-west England.

Cavity walls may continue to have a place where workmanship is excellent to superb. They may also be needed where new buildings must be finished in natural stone for planning reasons; it is relatively difficult to create a stone appearance using thin cladding on top of external insulation.

Where cavity walls are needed, alternative construction sequences should be assessed for buildability. One example is to build the inner skin of a masonry-walled, concrete-floored building to roof level and simply leave the wall ties sticking out. The wall is insulated and brick or stone-clad later at more leisure.

This sequence of construction is reportedly used in Scandinavia on many medium-rise buildings. It relies on the fact that a building braced by masonry partitions and concrete intermediate floors can be self-supporting even before the outer leaf is added.

An advantage of changing the construction sequence in this way is that the cavity insulation layer can be inspected for continuity from the outside.

There is a widespread view that the average standard of workmanship on UK insulated cavity walls is inadequate.

There is considerable concern over fully filled cavities containing mineral fibre. This is because of gaps being left in the insulation and covered up before any inspection occurs; also because of ‘foreign objects’, including mortar snots and worse, finding their way into the insulation layer.

There is even greater concern over partly filled cavities using as insulation various types of plastic foam slab. Figure 1 on page 40 shows typical gaps between the slabs as seen on most sites. It also shows another typical problem, the failure of the slabs to butt up tightly against the inner leaf, leading to air movement.

There is widespread suspicion that cavity walled housing, if monitored, would fail to perform as well as predicted in energy terms, and that the measured discrepancy would on average be greater for walls with partial fill foam slabs than for walls with full fill fibrous batts.

Accordingly, as we demand ever higher insulation standards, there must be questionmarks over the cavity walls' fitness for purpose. This is a separate matter from volume developers saying that they dislike thick walls because they take up valuable space. Even if wall thickness were not an issue, solid walls with external insulation might be preferred, because in a mature market they would be easier and cheaper to build - a major consideration, given the number of new dwellings that the UK now believes that it needs - and also because their expected energy performance is more easily achieved in practice.

2. Why is industry reluctant to go beyond the 100mm cavity?

With speculative developers, this author is unsure. Industry clearly fears loss of profit, since it has already purchased the development land which it will be building on in a few years' time and fewer (or smaller) housing units on that land inevitably means smaller profits.

On the other hand, if regulatory changes were announced in advance, and industry knew that it would be forced to make external walls say 100mm thicker in 2012, it is virtually certain that it would recalculate the residual value of the land which it buys now, from 2007 onwards, and pay less for it. Its profits would not then be materially affected. Indeed, all companies buying land would know that other companies were similarly affected and would presumably tolerate this relatively level playing field.

All clients of this practice since the 1980s who have used cavity walls in a new house have used cavities ranging from 125 to 300mm thick, i.e. 125mm was the minimum, not the maximum.

There is very little reluctance among self-builders to use thicker walls. They usually regard a house which uses less energy and emits less CO_2 as meeting their aspirations and indeed their self-interest (lower running costs). Also most planning authorities who have been asked in recent years for permission to make a house larger externally (in order to contain thicker insulation) have agreed to the change on grounds of sustainable development (this requirement is now contained in most development plans). This might be more difficult on tight urban sites.

It is unlikely that industry's wish to use existing structural or sound calculations could be a major factor. Even on one-off houses of timber or concrete, the structural calculations are not a huge cost (on masonry, the structural calculations are even lower, since many practices are deemed to satisfy the regulations by Building Control Departments). On a speculative development, these costs are spread over hundreds or thousands of dwelling units.

3. To achieve better U-values in masonry construction, whilst still maintaining a 100mm cavity, insulated dry lining is often used. This effectively isolates the thermal mass in the structure.

This is a problematic construction approach. It is relatively difficult to design and build if the interstitial condensation risk is analysed. The internal insulation is also subject to thermal bridging at many junctions, particularly; e.g. where it meets concrete intermediate floors, and is therefore only partially effective. One might be in effect paying for 75mm insulation and only obtaining the benefit of 45mm. This is not a good way forward.

Such an approach would not be favoured in new construction. It is mainly useful as a solution to retrofit existing listed solid-walled buildings, or sometimes a way to retrofit cavity-walled buildings which for some reason cannot be cavity-filled and/or externally-insulated.

4. To achieve better U-values, would you consider switching to:

- **Structural insulated panels (SIPs)?**
- **Insulated concrete formwork?**
- **Lightweight block with external insulation?**
- **I-beam timber frame?**

'Horses for courses' has to be the answer. The above is not a comprehensive list either. On the basis of experience and practice elsewhere in Europe, it is suggested that the most promising approaches may be those used for mass production of dwellings in countries such as the Netherlands. These include cheap shuttering systems for in situ concrete and calcium silicate blocks built in the factory to tolerances of 2-3 mm, lifted into place by crane and joined using thin-joint glue. These approaches are much quicker than laying masonry in mortar, and construction using in-situ concrete is less affected by inclement weather than construction of concrete blockwork.

The health and safety issues affecting block-laying in the UK have slowed down the build process. Solid 150mm dense blocks, as needed for a single-skin wall, either have to be made smaller, or lifted mechanically, or one must use 150mm hollow-core blocks and fill the cores with mortar.

This strengthens the case for considering quicker systems such as poured concrete, storey-height calcium silicate elements or precast concrete wall elements. Since these processes are mechanised, they are less affected by today's health and safety restrictions.

5. How do you propose to get to the improved U-values (0.2 and below) required at levels 4, 5 and 6 of the Code for Sustainable Homes?

Different construction systems will be used in parallel. Eventually, certain systems will become the most common. The author's best guess is that if the industry looks at the longer term and learns from experience elsewhere in Europe, i.e. does not just make incremental changes to the cavity wall or the average new 'masonry' house. The systems used in 20-30 years' time would be pretty similar to the systems now used, and still evolving, on the European mainland.

Take the Netherlands, another European country with a high proportion of its dwelling units constructed by speculative volume developers (i.e. by these rather than by self-builders, who predominate in countries such as Belgium, Germany or Austria). According to Trecodome (consultants), three main different dwelling construction systems are in use in the Netherlands. In descending order of abundance, they are:

1. Tunnel form (poured concrete) with in situ concrete intermediate floors. This is the cheapest solution on large sites with, say, a total of 150 dwelling units in a mixture of flats and row houses.

2. Masonry (usually calcium silicate blocks or larger elements), again with concrete (mostly in situ, sometimes precast) intermediate floors.

3. Timber-frame, with timber intermediate floors. This is considerably less common than 1 and 2, given that the Netherlands has little indigenous timber, but it nevertheless plays a modest role, as in all mainland European countries.

Housing construction costs in the Netherlands, expressed in £/m^2, appear to be well below UK levels. This reflects the degree of rationalisation of new house construction, including the degree of mechanisation and of standardisation of details. Their energy efficiency levels are somewhat higher than the UK, although they are not as high as in Switzerland, Germany and Austria (or in Denmark or the rest of Scandinavia).

All the above systems 1-3 were assessed in the Netherlands for the scope which they offer for reaching much higher energy efficiency. The finding was that Passivhaus performance or higher can easily be achieved using all three systems.

In Germany, the market shares in Passivhaus construction have reportedly been 65% masonry (as system 2 above), 20% concrete (ICF) and 15% timber-frame. Please note though that this sample was a few years ago and is likely to have been dominated by detached and row houses, as opposed to flats.

Zero carbon does not automatically spell the end for traditional UK masonry, if by that term we mean hand-laid concrete blocks. However, certain common aspects of UK masonry, such as the dry-lining and the timber upper floors, do make it unsuitable for the production of millions of new energy efficient dwellings with assured energy performance.

Various targets discussed in the media recently, such as a UK population perhaps rising to 70 million by 2050, and a household size continuing to fall slowly, reaching around two (the figure in Sweden today is already two), would need nearly a doubling of the rate of dwelling construction – up from 180,000 per year today to 330,000/yr over the 40 years from 2010 to 2050.

It seems obvious that if 'low to zero carbon' is an aim, and this rate of dwelling construction has to be achieved, current construction methods are lacking in respect not only of their typical energy performance, but the speed and efficiency of the construction process itself.

Note that the UK achieved a much higher construction rate than 330,000 dwellings/yr throughout the 1950s and the 1960s. However, the problems which arose in those decades have been discussed at length, and it seems a fair comment that the UK cannot afford to repeat them.

The Callcutt Review of Housebuilding Delivery[9] was published recently. Its second recommendation would have significant implications for the self-build market. To quote:

"2. Government and its agencies disposing of land should consider the opportunity for self-build and should aim to offer a proportion of the land in the form of small plots, where possible with ready access to services and other infrastructure, for sale to self-builders. Local planning authorities drawing up their strategic housing land assessments under PPS3 should similarly aim to identify a supply of small plots suitable for self-build and other smaller housebuilders."

This suggests that this review should be careful to cover construction systems suitable for self-build homes, where wall thickness is often of lesser importance.

9. See http://www.callcuttreview.co.uk/downloads/CallcuttReview-Recommendations.doc and http://www.callcuttreview.co.uk/downloads/callcuttreview_221107.pdf.

Part B

Please suggest your preferred wall construction to reach a U-value of 0.15W/m^2.K, and explain why this is:

a) technically advantageous/attractive
b) financially advantageous/attractive
c) sustainable

See the above discussion. No particular system can be expected to become predominant in the short term. There seems no sign of consensus or convergence yet, although others have reported to the author the observation that a high proportion of new UK flats appear to be constructed of in situ concrete.

In the long term, it is suggested that the preferred systems are quite likely to be similar to those which have proved most advantageous in the Netherlands – or indeed the many other continental European countries that have little indigenous timber.

Other wall construction systems should also be assessed.

Please note also that Passivhaus buildings do not all require a wall U-value of 0.15 W/m^{2}K. Some of them require a wall U-value of nearer 0.10 W/m^{2}K if they are to meet the upper limit to space heating energy use of 15 kWh/m^{2}yr.

0.15 W/m^{2}K is typical of what is likely to be needed on flats, offices or other developments with a favourable surface-volume ratio; e.g., some row houses. It is not adequate for the majority of detached and semi-detached houses. Some end-of-terrace houses may also have problems reaching 15 kWh/m^{2}yr if the wall U-value is 0.15 W/m^{2}K.

The tables supplied for section 7 were filled in for the following particular wall construction:

- 5mm painted skim coat of gypsum plaster (concrete is fairly flat and does not need a full coat of plaster unless wiring is to be hidden below the plaster)
- 150mm dense cast in situ concrete with light anti-crack reinforcement, 2.1 W/mK
- 200mm glued-on Neopor-type EPS, 0.030 W/mK
  [VARIANT: dense mineral fibre slab with stainless steel mechanical fixings]
  10-20mm render system
  TOTAL 370mm.
  U-value < 0.15 W/m^{2}K.

Fit for purpose is a phrase which should be borne in mind. In some situations, other wall constructions would be more appropriate.

Technical advantage

The above wall construction is free of internal condensation risks and it provides a high internal thermal capacity - concrete intermediate floors improve this further. If windows or ventilators are opened on heatwave nights, this degree of thermal capacity makes it easier to achieve high comfort standards without the need to fit air conditioning.

The ability of new dwellings to stay cool without fitting a refrigerated cooling system is particularly important in the south-east of England. In London, if we assume a 2K temperature rise, as forecast by DETR in 1996, the July mean temperature in 2050 is set to be as high as the July mean temperature in northern Portugal is today.

The wall also provides the thinnest possible wall, consistent with the use of heavyweight construction (NB it would be hard to design a timber-frame wall). If adhesive is used to fix the rigid insulation - as with most externally-insulated buildings in Germany today, the external insulation is not thermally-bridged and the benefit of each 1mm of insulation is maximised.

Financial advantages

The above system is likely to be cheaper in mass production than UK hand-laid masonry, as in the Netherlands and Switzerland today. It is certainly quicker to build. Barring heavy rain, a 4-storey block could probably be built from ground floor to roof level within a week. Once the windows and doors go on, the building is watertight and the internal construction work can proceed in parallel to the external insulation and rendering. Other factors - such as the total building cost - being equal, an increased speed of construction is advantageous, because it gives a better cash flow.

Sustainability

The above external wall system may come out poorly on most UK assessments. But the following should be borne in mind.

1. The embodied energy of lightly reinforced concrete is lower than fired clay brick per unit volume or unit weight. This statement relies on a table of embodied energy and CO_2 which the UK Government (DETR) issued in 1995. As such, the embodied energy of this wall, in kWh per m^2 wall, would be less than the embodied energy of a low-rise house wall of plasterboard, lightweight concrete blocks, 50mm foam insulation, stainless steel ties and a clay brick outer leaf.

2. The actual thermal performance of this wall is more easily predicted and controlled than many alternative wall systems.
   (a) Properly designed, poured and vibrated in situ concrete defaults to airtight. Unlike blockwork, no special airtightness details are needed if electrical services are to be buried in external walls.
   (b) As the insulation material is glued to the wall by continuous adhesive, the risk of air movement behind the insulation is eliminated. If such air movement occurred, it would reduce the wall's thermal performance (rather as it does with partial-fill cavity walls).
   (c) If needed, the continuity of the insulation layer can be quickly and easily inspected by an expert before the render goes on.

3. The UK has a skills shortage and a recent history of buildings which fail to deliver the calculated energy performance. Wall construction systems which default to airtight and whose insulation system is resistant to air movement or wind penetration appear to have significant advantages over other new or existing wall constructions.

4. Over 100 years, even in massive buildings meeting the Passivhaus standard, using normal German construction methods, embodied energy is approximately 8-10% of total energy use and operational energy is 90-92%. This finding emerged from work by the PassivHaus Institut. It is debatable if steps should be taken to reduce embodied energy if this is at the cost of:
   (a) Shorter-lived buildings; or
   (b) Buildings which would be more difficult to keep cool in future summer heatwaves and might need to fit electricity-consuming cooling systems.

5. This is not put forward as a wall construction system for temporary buildings or sites which we foresee might have to be abandoned to rising sea level in say 50 years time. However, over a longer timescale, such as 100 years or more, it is likely to come out equal to or better than alternatives. There is no reason why cement cannot be produced using renewable energy.

If a thin wall is the overriding objective, there are further possibilities to reduce it while still using the above basic wall construction, i.e. a high-mass, airtight load-bearing skin, clad with rigid insulation on the outside:

1. The wall thickness could be reduced from 370mm to about 320mm by using 100mm precast concrete elements instead of 150mm cast in situ concrete walls. Such a system was used in the well-known ‘minimum energy houses’ in Schiedam, the Netherlands in 1982.

2. Retaining the use of precast concrete, the wall thickness could be further reduced to 250-300mm by using 150-160mm of phenolic foam, with a conductivity of around 0.023 W/mK, instead of 200mm Neopor-type EPS with a conductivity of around 0.030 WmK.

3. In time, ‘exotic’ insulants such as aerogel and vacuum panels might be used, reducing the insulation to < 100mm thick. The resulting wall thickness would then be around 200mm using precast concrete and 250mm using in situ concrete.

Although steps 1-3 reduce wall thickness, they might have added costs. Precast concrete is usually more expensive than in situ concrete. Phenolic foam is an expensive insulant compared to EPS of the Neopor type. Aerogel and vacuum panels are at the early stage of commercial application, except perhaps for vacuum panels in the German-speaking world. Their indicative UK prices range from very expensive to extremely expensive, possibly making the resulting thinner walls only of interest at the land prices of, for example, central London, Manchester or Birmingham.

The wall thickness exceeds 370mm if dense mineral fibre slabs are used, with stainless steel mechanical fixings. However, this wall is fireproof. Also, the mineral fibre insulation is almost totally reusable if/when the insulation and render are replaced in c.100 years time. There is a trade-off between the wall thickness and this environmental benefit.

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