REPORT FOR

Central Bedfordshire Council

Evidence base for feasibility and viability of carbon dioxide emission reduction measures

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Central Bedfordshire

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1. Introduction

As at March 2013 Central Bedfordshire Council is consulting on its new Development Strategy, for adoption in Spring 2014. The Development Strategy will be the main planning document for Central Bedfordshire, and sets out several new policies for development which will be used to determine planning applications.

The Council intends to set a policy target for all new residential development to achieve a minimum of 10% carbon dioxide emissions reduction as an improvement on the carbon dioxide emissions standard set by the Building Regulations.

Cutland Consulting Limited was appointed by the Council to explore alternative strategies for achieving the 10% reduction in carbon dioxide emissions for a variety of on- and off-gas grid dwelling types. This was carried out using 'NHER Plan Assessor' software, first modelling Regulations-compliant versions of the dwellings then undertaking multiple calculation runs with a range of carbon-reducing strategies.

A fundamental question addressed at the start of the project was, "Against which version of the Building Regulations should the analysis be carried out?" Ideally the study would have used whatever energy standards will be brought into force by the 2013 revisions to Approved Document L1A, but when this project started there was insufficient clarity from Government to predict that baseline with any confidence. We believe that it was originally Government's intention to bring the 2013 revisions into force by October of 2013, but by April 2013 (more than a year after the consultation closed) there had still been no feedback or confirmation.

The Building Regulations Minister said in public on 6 March 2013 that an announcement would be made "in the Spring". A common industry view at the time of writing is that due to the ongoing economic downturn for construction in particular, there is even a possibility that the Government may announce that there will be *no* uplift in the standards for 2013.

We therefore agreed with the Council that it would be prudent to carry out the 10% exercise against the in-force Approved Document 2010 (ADL1A 2010) rather than trying to second-guess the 2013 revisions, although of course the possibility remains open to repeat the exercise against an additional baseline.

The work was carried out during March and April 2013 by Cutland Consulting's director Dr Neil Cutland and associate Energy Consultant/Architectural Designer Hetal Shah.

2. UK Policy Context

In 2006 the UK Government introduced a revision to Approved Document L1A of the Building Regulations which improved the energy efficiency standard of newbuild dwellings by 20% from the previous standard. At the same time the Government set out a legislative 'route to zero carbon' based largely upon achieving emissions reductions by progressive tightening of the standards in ADL1A every few years. Zero carbon newbuild was proposed for 2016, and the intervening targets were aligned with Code for Sustainable Homes energy credit ENE1 as follows:

Proposed year	*Percentage emissions reduction over 2006*	*Code level (ENE1)*
2006	-	*n/a*
2010	25%	level 3
2013	44%	level 4
2016	≈150%	level 6

Table 1

The carbon emissions covered by Building Regulations are known as 'regulated' emissions, and include those arising from heating, cooling, ventilation and lighting. The definition of zero carbon proposed in 2006, however, also included 'unregulated' emissions (ie. those arising from household appliances), which is why the 2016 percentage reduction was 150% rather than 100%. This definition was subsequently changed, and as a result the 2016 reduction target became 100%, which reflects Code level 5:

Proposed year	*Percentage emissions reduction over 2006*	*Code level (ENE1)*
2006	-	*n/a*
2010	25%	level 3
2013	44%	level 4
2016	100%	level 5

Table 2

At that time, the Government indicated that social housing providers would be required to 'lead the way' by achieving the same percentage reductions but three years ahead of the private sector at each stage. Following the change of Government in May 2010, however, that requirement was dropped, and social housing providers are now bound by the same carbon reductions timetable as the private sector.

During 2011 Cutland Consulting sat on Working Group 1 (WG1) of the Building Regulations Advisory Committee (BRAC). DCLG officials informed WG1 that the 44% emissions reduction planned for 2013 would no longer be mandated, and as such the legislative landscape now had only two fixed points - 2010 and 2016. WG1 was further briefed to recommend for 2013 the best intermediate step for achieving zero carbon by 2016, ranging from ‘do nothing’ to a ‘fast-track’ approach. The Government released the resulting Building Regulations consultation on 31 January 2012, in which its preferred option for 2013 was essentially a near-FEES[1] level amounting to an 8% emissions reduction over 2010 (ie. 31% over 2006):

Proposed year	***Percentage emissions reduction over 2006***	***Code level (ENE1)***
2006	-	*n/a*
2010	25%	level 3
2013	31%	*n/a*
2016	100%	level 5

Table 3

At the time of writing (April 2013) the Government has reaffirmed its commitment to zero carbon homes by 2016, but its intentions regarding the detail in the timeline shown in Table 3 still remain unclear.

Due its intimate link with the carbon emissions which are regulated by Building Regulations, we have included in Appendix A a general discussion of the evolving definition of zero carbon.

[1] See Appendix A for definition and discussion of FEES.

3. Central Bedfordshire Council's Policy Targets

The Council recognises that the Earth's resources are limited and should be used in a sustainable manner. The resource efficiency policy seeks to reduce energy demand and carbon dioxide emissions in order to mitigate the effect of climate change and deliver sustainable and resource-efficient homes.

The Council intends to set a policy target for all new residential development to achieve a minimum of 10% carbon dioxide emissions reduction as an improvement on the carbon dioxide emissions standard set by the Building Regulations. The Council intends to allow a flexible approach to meeting this standard, including offsetting in the form of an 'Allowable Solution' as long as the benefitting scheme is located within Central Bedfordshire.

The Council's viability assessment allowed for a sum of £2,000 per dwelling to cover the increased cost of achieving the 10% target. At the time of writing the draft policy, the Council expected that the 2013 Building Regulations would increase energy efficiency and reduce carbon dioxide emission standards to the equivalent of Code for Sustainable Homes Level 4 (ie. 25% lower emissions than required by ADL1A 2010) and therefore allowed an additional £795 per dwelling.

The fundamental aim of this project was to verify that a 10% reduction in carbon emissions can in principle be achieved within the £2,795 cost constraint using a variety of practical strategies, both fabric-based and technology-based.

4. The Base Cases

We modelled four dwelling types which collectively represent the range of built forms and sizes which are typically built by developers for private sale. After discussion with the Council we agreed the following treated floor areas:

- 4-bed detached house: 125m^2
- 3-bed semi-detached house: 95m^2
- 2-bed mid-terraced house: 65m^2
- 1-bed top floor apartment with one external wall: 45m^2

The modelling was repeated for both a main gas-heated situation and an off-gas grid (rural) situation, using the same dwelling types in both cases. As discussed in section 1, *we agreed with the Council that it would be prudent to carry out the exercise against the 2010 Regulations rather than trying to second-guess the 2013 revisions*. The detailed dwelling type specifications are contained within Appendix B and are summarised in Tables 4-6 below.

The dwelling type data was transcribed into NHER Plan Assessor software v. 5.4.1.7, which contains a Government-approved implementation of SAP v. 9.90 (otherwise known as 'SAP 2009'). Using this software we calculated the following parameters for each dwelling type:

- Dwelling Emissions Rate (DER, in $kgCO_2/m^2/yr$)
- Target Emissions Rate (TER, in $kgCO_2/m^2/yr$) – the maximum DER value permitted for compliance with ADL1A 2010

We also recorded the following calculated parameters which are not strictly necessary for the analysis of the 10% strategies but which are of general interest to any carbon/energy strategy:

- SAP rating
- Fabric energy efficiency level (FEE) - which uses the same calculation method as the first 'slice' of the 2016 zero carbon triangle (FEES) described in Appendix A.

The base case specifications were chosen to reflect realistic developer sale homes of today, and were carefully tuned so that all dwellings 'just passed' Building Regs – ie. the DER was as close to the TER as was practically possible. In doing this we kept the basic fabric specification (U-values, air permeability and non-repeating thermal bridges) as consistent as possible across the dwelling types. Some combinations of built form, floor area and heating fuel gave rise to DER/TER results which allowed the overall specification to be 'relaxed' slightly. In these cases we generally adjusted the air permeability (and occasionally one or more U-values) in order to bring the DER to within a very small fraction of the TER.

In one gas-heated case it was necessary to add a flue gas heat recovery system (FGHRS) and in two cases a compensating control system was required.

Due to the carbon intensity of grid electricity in the UK, it is generally harder for electrically-heated homes to comply with ADL1A than gas-heated homes (even though the former are given a concession in ADL1A 2010 via an 'easier' TER). In keeping with our objective of using a consistent fabric specification across the dwelling types under study, if an electrically heated dwelling did not comply with ADL1A, we achieved a pass by adding a suitable area of photovoltaic (PV) panels - again aiming to bring its DER to within a very small fraction of the TER.

Note: *For the electrically-heated dwellings, the 10% strategies described in section 5 of this report were evaluated against this PV-inclusive base cases. At the Council's request, however, we also evaluated the technical viability of electrically-heated dwellings complying with ADL1A 2010 without PVs, and this alternative set of base cases is presented as an 'aside', in Table 6. The main conclusion is that it is possible for electric dwellings to comply with ADL1A 2010 without PVs, but only by adding mechanical ventilation with heat recovery (MVHR) as well as significantly tightening up the fabric specification. There is therefore unlikely to be any cost benefit for electrically-heated dwellings to comply with ADL1A via fabric rather than via PVs. Indeed, in all but the largest dwellings there will actually be a cost penalty.*

The detailed dwelling type specifications are shown in Appendix B, and are summarised in Tables 4-6 overleaf. Where a table cell is blank it signifies that the 'common specification' was used.

GAS-HEATED BASE CASE DWELLING TYPES

Common specification		**Changes to common specification in order to 'just pass'**			
		Gas detached *4B, 125m²*	***Gas semi-det*** *3B, 95m²*	***Gas mid-terrace*** *2B, 65m²*	***Gas top-floor flat*** *1B, 45m²*
U (wall) *W/m²K*	**0.25**				
U (floor) *W/m²K*	**0.17**	0.20			
U (roof) *W/m²K*	**0.13**				
U (windows) *W/m²K*	**1.40**	1.60			
U (doors) *W/m²K*	**1.40**				
Glazing solar factor, g	**0.63**				
Air perm. *m³/m²hr @50Pa*	**5.0**	7.3	6.5		6.4
Thermal bridging, y *W/m²K*	**0.08**				
Ventilation method	**Individual fans (as right)**	4 no.	4 no.	3 no.	2 no.
Heating system	**Gas condensing boiler (as right)**	Regular	Regular	Combi +FGHRS	Combi
Controls	**Temp + time, incl. zone control**		...plus compensator	...plus compensator	Programmer, roomstat + TRVs
Hot water	**As right**	Boiler to 200 litre cylinder	Boiler to 200 litre cylinder	From combi	From combi

Table 4

OFF-GAS GRID (RURAL) BASE CASE DWELLING TYPES

Common specification		Changes to common specification in order to 'just pass'			
		Electric detached *4B, 125m²*	*Electric semi-det* *3B, 95m²*	*Electric mid-terrace* *2B, 65m²*	*Electric top-floor flat* *1B, 45m²*
U (wall) *W/m²K*	**0.25**				
U (floor) *W/m²K*	**0.17**				
U (roof) *W/m²K*	**0.13**				
U (windows) *W/m²K*	**1.40**				
U (doors) *W/m²K*	**1.40**				
Glazing solar factor, g	**0.63**				
Air perm. *m³/m²hr @50Pa*	**5.0**	6.0	5.5		6.4
Thermal bridging, y *W/m²K*	**0.08**				
Ventilation method	**Individual fans (as right)**	4 no.	4 no.	3 no.	2 no.
Heating system	**Slimline storage heaters**				
Controls	**CELECT type**				
Hot water	**As right**	Dual immersion to cylinder	Dual immersion to cylinder	Electric instantaneous	Electric instantaneous
PV panels *kWp*	**As right**	2.41	1.75	0.6	0.34

Table 5

OFF-GAS GRID (RURAL) BASE CASE DWELLING TYPES *(ASIDE: NON-PV VERSIONS)*

Common specification		**Changes to common specification in order to 'just pass'**			
		Electric detached ***4B, 125m²***	***Electric semi-det*** ***3B, 95m²***	***Electric mid-terrace*** ***2B, 65m²***	***Electric top-floor flat*** ***1B, 45m²***
U (wall) *W/m²K*	**0.25**	0.15	0.17	0.24	0.18
U (floor) *W/m²K*	**0.17**				
U (roof) *W/m²K*	**0.13**				
U (windows) *W/m²K*	**1.40**				
U (doors) *W/m²K*	**1.40**				
Glazing solar factor, g	**0.63**				
Air perm. *m³/m²hr @50Pa*	**5.0**	4.0	4.0	4.0	4.0
Thermal bridging, y *W/m²K*	**0.08**	0.06	0.07		0.07
Ventilation method	**(Individual fans)**	MVHR	MVHR	MVHR	MVHR
Heating system	**Slimline storage heaters**				
Controls	**CELECT type**				
Hot water	**As right**	Dual immersion to cylinder	Dual immersion to cylinder	Electric instantaneous	Electric instantaneous
PV panels *kWp*	**As right**	None	None	None	None

Table 6

5. The 10% Strategies

The calculation sequence was applied to the eight dwelling/fuel combinations in a systematic way which enabled us to explore a variety of strategies, both fabric-focussed and technology-focussed, in order to formulate strategies which aim to optimise the benefits to the residents and the environment. The fundamental strategies were as follows:

- Photovoltaic panels (PVs)
- Solar hot water (SHW)
- Enhanced fabric specification
- Heat pumps - air source (ASHP) or ground source (GSHP) as appropriate
- Biomass heating - type appropriate to dwelling
- Allowable Solutions (as described in Appendix A)

Hence there are 48 theoretical combinations of dwelling type, heating fuel and 10% strategy. It was agreed with the Council that heat pumps and biomass heating are extremely unlikely to be considered by developers where mains gas is available, which narrows the number of scenarios to around 40. In the event, somewhat *more* than 40 scenarios were modelled, due to the nuances which only became apparent as the analysis proceeded.

For each strategy under investigation, each of the dwelling specifications was changed until the DER was reduced by 10% (or as close to 10% as practically possible). The fabric specification and services sizing was then noted, and the corresponding costs calculated as described in section 6 below.

In all cases we made assumptions typical of the Central Bedfordshire region, and erred on the conservative side (for example, by assuming average overshading and *not* assuming a strong southerly aspect).

The scenarios are summarised in Table 7 overleaf, with explanatory notes presented below the table.

The 10% strategies

	Gas det *4B, 125m²*	*Gas semi* *3B, 95m²*	*Gas terr* *2B, 65m²*	*Gas flat* *1B, 45m²*	*Elec det* *4B, 125m²*	*Elec semi* *3B, 95m²*	*Elec terr* *2B, 65m²*	*Elec flat* *1B, 45m²*
PVs	As required	As required	As required	As required	As required	As required	As required	As required
SHW	As required	As required	As required	As required	As required	As required	As required	As required
Fabric	***Ideally no tighter than:*** $U_W = 0.15$ $U_R = 0.13$ $U_F = 0.15$ $U_{Opngs} = 0.8$ Perm = 3.0 y = 0.04 ***…but as required.***	As left	As left	As left	As left	As left	As left	As left
Heat pumps	-	-	-	-	GSHP or ASHP (individual)	ASHP (individual)	ASHP (individual)	ASHP (individual)
Biomass	-	-	-	-	Auto-feed pellet boiler	Room heaters with back boiler	Communal	Communal
Allowable Solutions	Community energy fund (CEF)	Community energy fund (CEF)	Community energy fund (CEF)	Community energy fund (CEF)	Community energy fund (CEF)	Community energy fund (CEF)	Community energy fund (CEF)	Community energy fund (CEF)

Table 7

Notes to Table 7

- The enhanced fabric specification represents what might be termed good, practical low-energy design as found in mainstream projects today. The specification deliberately does *not* push the fabric to the extremes that might be found in, say, Passivhaus dwellings[2], simply because there is no need to do so in order to reduce emissions by 10%.

- Mechanical ventilation with heat recovery (MVHR) was added wherever the air permeability was 3.0 $m^3/m^2hr@50Pa$ or tighter. At this level ADL1A 2010 mandates that additional attention must be paid to ventilation, and the industry best practice in such cases is to install MVHR.

- The Zero Carbon Hub considers that the appropriate reference point for feasibility of roof-mounted solar technologies is a maximum area equivalent to 40% of the ground floor area[3]. If the area required exceeds this amount, other measures may also be needed which are not necessarily feasible or desirable. 1kWp of PV occupies an area of $10m^2$, and where PVs and SHW are used together the 40% criterion applies to the sum of their areas.

- In considering heat pumps for the smaller dwellings, it was agreed with the Council that developer sale homes would be far more likely to use individual ASHPs than communal GSHPs, in part due to the potential need for Environment Agency permission where water extraction is involved. An individual GSHP with a closed loop 'slinky' collector was nevertheless considered as an alternative to an ASHP for the larger, detached dwelling.

- In considering communal biomass heating for the smaller dwellings, two different scheme sizes were analysed: (a) 5-10 dwellings, and (b) 30-40 dwellings. This has an impact on the cost per dwelling.

- It was agreed with the Council that the Allowable Solutions analysis should be carried out in terms of a payment into a community energy fund (CEF), as described in Appendix A. This is a reasonable proxy for the cost of more specific investment in off-site technologies or third-party projects. The details of the specific technologies or projects that the Council could permit to be recipients of the CEF is the subject of the next phase of this study, but in anticipation of that phase of the work it seems likely that the technologies and projects might include:
    - community wind turbines
    - district heating and/or CHP
    - consequential improvements to existing dwellings
    - Green Deal contributions
    - Energy Companies Obligation (ECO) subsidies
    - local 'green' job creation

[2] For more information see www.passivhaustrust.org.uk/what_is_passivhaus.php
[3] 'Carbon Compliance: Setting an Appropriate Limit for Zero Carbon New Homes', Zero Carbon Hub, Feb 2011

6. The basis of the capital costs

The capital costs in this section should be regarded as indicative. It was agreed with the Council that since this study relates only to typical dwellings and covers a time period of several years, the analysis of capital costs would use generic cost data rather than employing a QS to carry out detailed cost calculations at this stage. Our philosophy was as far as possible to use technically robust and highly-regarded sources that are in the public domain[4].

The work was undertaken on a simple 'first capital cost' basis (ie. ignoring net present value considerations, product lifetimes, maintenance costs, feed-in-tariff benefits, etc). The results are generally shown rounded up to the next £50 or £100 as appropriate.

The fundamental cost assumptions were as follows.

Photovoltaics
The installed cost of a PV system, at scale and in the newbuild context, is £1,500/kW_p[5]

Solar hot water
The installed cost of a SHW system is £1,420 fixed cost plus £580/m^2.

Enhanced fabric
The costs of building to enhanced fabric and air permeability specifications are hard to ascertain. There are complex and interacting issues, such as the assumed specification and quality of the baseline insulation/services, the quality and performance of the enhanced services, and so on. The costing systems used by many volume builders are not sensitive enough to pick up the over-cost of a slightly increased width of insulation, and in any case the total cost is often dominated by the presence of MVHR in the enhanced dwelling. We used figures from a variety of real-life projects[6], as follows:

- Enhanced U-values: £7/m^2 treated floor area (TFA)
- Triple glazing: £8/m^2 TFA
- Improved air permeability: £zero (at the 3.0 m^3/m^2hr @50Pa level)
- MVHR: £3,500 fixed cost per dwelling

We also considered DCLG's published costs of moving between levels of the Code for Sustainable Homes. When the DCLG costs are pro-rated for TFA and for the percentage emissions reductions in question, they give results extremely close to those which we calculated independently. This provides additional assurance that our enhanced fabric cost assumptions are appropriate.

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4 Our main sources were: 'Domestic Low and Zero Carbon Technologies', Energy Saving Trust publication CE317, 2010; 'Cost of building to the Code for Sustainable Homes – updated cost review', DCLG, August 2011; 'Carbon Compliance: Setting an Appropriate Limit for Zero Carbon New Homes', Zero Carbon Hub, Feb 2011; 'Defining a Fabric Energy Efficiency Standard', Zero Carbon Hub, November 2009 .
5 Private communication with a national housebuilder and Central Bedfordshire Council. Note that one-off installations in the retrofit context (eg. FIT-driven householder installations) can cost 2-3 times more than in volume newbuild.
6 Private communication with experienced 'green' architects.

Heat pumps
The installed cost of an ASHP is £4,000 fixed cost plus £280/kW.
The installed cost of a trench (as opposed to borehole) GSHP is £3,170 fixed cost plus £560/kW.

Biomass heating
The installed cost of biomass heating is

a) for a 10kW individual biomass boiler: £10,000
b) for a communal system,
    - for a 50kW or smaller cluster: £10,000 fixed cost plus £250/kW
    - for a 200kW community scheme: £410/kW

Allowable Solutions
The size of the required payment into a community energy fund is calculated using the method recommended by the Zero Carbon Hub, ie. 10% of the annual carbon dioxide emissions of the dwelling[7] multiplied by 30 years, at an assumed price per tonne of carbon dioxide.

The tables in section 7 show the effect of the three following assumptions for the price of carbon dioxide:

a) the UK Government's current 'shadow price of carbon', £29/tonneCO_2
b) the Zero Carbon Hub's suggested working figure for Allowable Solutions, £46/tonneCO_2 [8]
c) the upper limit seen in the Energy Companies Obligation (ECO) brokerage auctions to date, £120/tonneCO_2

Note the extreme sensitivity of this strategy to the assumed price per tonne of carbon dioxide.

[7] The total emissions of a dwelling are equal to its DER multiplied by its treated floor area. Where the dwelling exactly complies with ADL1A 2010, this is the same as the dwelling's TER multiplied by its treated floor area.
[8] See Appendix A

7. Results

The input data and the detailed results of each of the calculation runs are presented in Appendix C. They are presented here in summary, with a commentary relating to each scenario.

7.1 Indicative costs for a 10% emissions reduction: *mains gas-heated dwelling types*

Strategy: Photovoltaics				
Dwelling type	***Gas detached*** *4B, 125m^2*	***Gas semi-det*** *3B, 95m^2*	***Gas mid-terrace*** *2B, 65m^2*	***Gas top-floor flat*** *1B, 45m^2*
Cost to reduce CO_2 by 10%	£850	£600	£450	£350

- Photovoltaics are clearly a straightforward way to achieve a 10% emissions reduction for all of the gas-heated dwelling types within the Council's cost criterion.

Strategy: Solar Hot Water				
Dwelling type	***Gas detached*** *4B, 125m^2*	***Gas semi-det*** *3B, 95m^2*	***Gas mid-terrace*** *2B, 65m^2*	***Gas top-floor flat*** *1B, 45m^2*
Cost to reduce CO_2 by 10%	£3,800	£2,600	£2,700	£2,600

- The two larger dwellings have regular boilers with hot water cylinders, whereas the two smaller dwellings have combi boilers. A dedicated solar store therefore has to be installed for the smaller dwellings, introducing losses that were not present in the base case and appearing to distort the results slightly.
- In the case of the gas-heated semi-detached, mid terrace and top-floor flat dwelling types, a solar hot water strategy appears to be viable according to the Council's cost criterion. This conclusion is, however, sensitive to the assumptions made about the solar system specification.
- Engineer to confirm domestic hot water usage calcs in each individual case.

Strategy: Enhanced Fabric				
Dwelling type	***Gas detached*** *4B, 125m^2*	***Gas semi-det*** *3B, 95m^2*	***Gas mid-terrace*** *2B, 65m^2*	***Gas top-floor flat*** *1B, 45m^2*
Cost to reduce CO_2 by 10%	£900	£1,500	£4,600	£4,300

- The detached house does not need triple glazing (which the others do).
- The mid-terrace and top-floor flat dwelling types cannot achieve 10% emissions reduction unless the air permeability is reduced to 3.0 m3/m2hr @50Pa. At this level

ADL1A 2010 mandates that additional attention must be paid to ventilation, and the industry best practice is to install MVHR at this level – which is reflected in the capital cost.

- In the case of the gas-heated detached and semi-detached dwelling types, an enhanced fabric strategy appears to be viable according to the Council's cost criterion.

Strategy: Allowable Solutions (CEF)				
Dwelling type	*Gas detached 4B, 125m^2*	*Gas semi-det 3B, 95m^2*	*Gas mid-terrace 2B, 65m^2*	*Gas top-floor flat 1B, 45m^2*
Cost to reduce CO_2 by 10% (at £29/tonne)	£200	£150	£100	£50
Cost to reduce CO_2 by 10% (at £46/tonne)	£350	£250	£200	£150
Cost to reduce CO_2 by 10% (at £120/tonne)	£850	£650	£450	£350

- £29/tonne CO_2 = UK Government's current 'shadow price of carbon'
- £46/tonne CO_2 = Zero Carbon Hub's suggested working figure for Allowable Solutions[9]
- £120/tonne CO_2 = upper limit seen at ECO brokerage auctions to date
- Using any of the above price assumptions, the council's cost criterion is met in all cases. The Council may, of course, wish to set a different price.

7.2 Indicative costs for a 10% emissions reduction: *off-gas grid (rural) dwelling types*

Strategy: Photovoltaics				
Dwelling type	*Electric detached 4B, 125m^2*	*Electric semi-det 3B, 95m^2*	*Electric mid-terrace 2B, 65m^2*	*Electric top-floor flat 1B, 45m^2*
Cost to reduce CO_2 by 10%	£1,500	£950	£750	£700

- The costs correspond to the amount of PV which is required additionally to that needed for compliance with ADL1A 2010 (as shown in Table 5).
- In purely cost terms, all of the off-gas grid dwelling types can achieve a 10% emissions reduction within the Council's cost criterion.
- However, the entries for the detached and semi-detached dwelling types are shaded grey because the area of PV required is greater than the '40% of TFA' technical viability limit suggested by the Zero Carbon Hub. It is therefore not considered to be a viable strategy in those cases.

[9] See Appendix A

Strategy: Solar Hot Water				
Dwelling type	*Electric detached 4B, 125m²*	*Electric semi-det 3B, 95m²*	*Electric mid-terrace 2B, 65m²*	*Electric top-floor flat 1B, 45m²*
Cost to reduce CO_2 by 10%	£3,200	£2,600	£2,700	£2,700

- For the detached, semi-detached and mid-terrace dwelling types, the majority of the PVs required for ADL1A 2010 compliance remained in place (see table 5). The small changes in PV area are reflected in the costs. If the PVs are omitted and just solar hot water is used, either the 10% emissions reduction is not possible or the '40% of TFA' criterion is violated (or both).
- For the top-floor flat, however, no PVs are required in order to achieve a 10% emissions reduction via SHW – and the costs reflect this (albeit small) capital saving.
- In the case of the off-gas grid semi-detached, mid-terrace and top-floor flat dwelling types, a solar hot water strategy appears to be viable according to the Council's cost criterion.
- The entry for the detached dwelling type is shaded grey because, in addition to not meeting the Council's cost criterion, the area of solar technologies required is marginally greater than the '40% of TFA' technical viability limit suggested by the Zero Carbon Hub.
- Engineer to confirm domestic hot water usage calcs in each individual case.

Strategy: Enhanced Fabric				
Dwelling type	*Electric detached 4B, 125m²*	*Electric semi-det 3B, 95m²*	*Electric mid-terrace 2B, 65m²*	*Electric top-floor flat 1B, 45m²*
Cost to reduce CO_2 by 10%	£5,500	£5,000	£4,600	£4,300

- The PVs required for ADL1A 2010 compliance remained in place for all cases (see Table 5).
- In order to achieve a 10% emissions reduction, all cases require enhanced U-values, low-emissivity triple glazing, reduced air permeability and MVHR.
- As a result of the MVHR in particular, an enhanced fabric strategy does not appear to be viable for any of the off-gas grid dwelling types according to the Council's cost criterion.

Strategy: Air Source Heat Pumps (ASHP)				
Dwelling type	*Electric detached 4B, 125m²*	*Electric semi-det 3B, 95m²*	*Electric mid-terrace 2B, 65m²*	*Electric top-floor flat 1B, 45m²*
Cost to reduce CO_2 by 10%	£2,100	£2,700	£4,300	£4,600

- In all cases the use of a heat pump achieved an emissions reduction greater than 10% (between 16-20%). We investigated the effect of relaxing the fabric specification until a 10% emissions reduction was only *just* achieved, but this has the undesirable side effect of increasing the overall capital cost, because (ironically) a larger heat pump becomes necessary.

- The PVs that were included for ADL1A 2010 compliance are no longer required in any of the cases. The costs reflect the capital saving.
- ASHPs have a relatively high fixed cost and a low cost per kW. Moreover the larger dwellings necessarily included significantly more PVs for ADL1A 2010 compliance than the smaller ones, so the capital savings are higher when they are removed. These two facts explain the apparently anomalous size-dependency of the costs.
- An ASHP may not be technically viable in the detached house due to the dwelling's relatively high heat load (engineer's calcs to confirm in each individual case). In this instance the indicative cost of an individual ground source heat pump (GSHP) with a closed loop trench-type collector would be £5,400 net of the PV capital savings. This achieves a 31% emissions reduction with the standard fabric specification.
- In the case of the off-gas grid semi-detached (and possibly also the detached) dwelling types, a heat pump strategy appears to be viable according to the Council's cost criterion.

Strategy: Biomass Heating				
Dwelling type	***Electric detached*** ***4B, 125m^2***	***Electric semi-det*** ***3B, 95m^2***	***Electric mid-terrace*** ***2B, 65m^2***	***Electric top-floor flat*** ***1B, 45m^2***
Cost to reduce CO_2 by 10%	£6,400	£7,400	(a) £1,900 or (b) £1,600	(a) £1,600 or (b) £1,300

- Where two costs are shown for a dwelling type, they represent the cost per dwelling for a communal heating scheme size of (a) 5-10 dwellings, or (b) 30-40 dwellings. Where a single cost is shown for a dwelling type it is for an individual heating system.
- In all cases the use of biomass heating achieved an emissions reduction greater than 10% (as much 49-65%). We investigated the effect of relaxing the fabric specification, even with a specification close to ADL1A 2010's backstop U-values the emissions reduction is still as much as 44%-60%. Moreover, this has the undesirable side effect of increasing the overall capital cost, because (ironically) a larger heating system becomes necessary.
- The PVs that were included for ADL1A 2010 compliance are no longer required in any of the cases. The costs reflect the capital saving.
- In the case of the off-gas grid mid-terrace and top-floor flat dwelling types, a biomass strategy appears to be viable according to the Council's cost criterion.

Strategy: Allowable Solutions (CEF)				
Dwelling type	***Electric detached*** ***4B, 125m^2***	***Electric semi-det*** ***3B, 95m^2***	***Electric mid-terrace*** ***2B, 65m^2***	***Electric top-floor flat*** ***1B, 45m^2***
Cost to reduce CO_2 by 10% (at £29/tonne)	£350	£250	£200	£150
Cost to reduce CO_2 by 10% (at £46/tonne)	£550	£400	£300	£250
Cost to reduce CO_2 by 10% (at £120/tonne)	£1,400	£1,100	£700	£600

- £29/tonne CO_2 = UK Government's current 'shadow price of carbon'
- £46/tonne CO_2 = Zero Carbon Hub's suggested working figure for Allowable Solutions[10]
- £120/tonne CO_2 = upper limit seen at ECO brokerage auctions to date
- Using any of the above price assumptions, the council's cost criterion is met in all cases. The Council may, of course, wish to set a different price.

[10] See Appendix A

8. Performance Gap Implications

8.1 General[11]

There appears to be a growing body of research evidence that new housing is failing to deliver the anticipated levels of CO_2 emissions, although there is relatively little understanding within the wider industry of what might be causing this. As zero carbon draws nearer it is increasingly important that a systematic approach is taken to understanding and eliminating any gap; this has not traditionally been the case.

There are seven key questions that need to be considered in order to reduce the performance gap:

1. Is the **assessment model** that was used to make the prediction accurate, and has it been correctly implemented in the software used by the designer?
2. Is the model's **input data** correct (and if not, is that due to the conventions or the user)?
3. Is the home's **design** overly complex, presenting unreasonable challenges to the construction team?
4. Are there fundamental **construction quality and skills** issues?
5. Do **building materials and mechanical and electrical (M&E) systems** perform as well in practice as laboratory tests predict?
6. Do changes in specifications get properly **communicated**?
7. Are the **post-construction tests and checks** appropriate and adequate?

All of these questions are relevant to the Council's development policy generally, with some having more significance than others. There are ways of mitigating the effect of all of them:

1. **The assessment model.** This is outside the Council's control, because use of SAP for ADL1A compliance is mandated by Government. However, BRE periodically validate the accuracy of the SAP, and the Zero Carbon Hub has concluded that (subject to a number of technical enhancements) SAP should continue to be used as the carbon compliance tool for new homes.
2. **Input data.** User errors can be reduced by employing an accredited On-Construction Domestic Energy Assessor (OCDEA). We presume that this is the Council's standard practice for Building Control, etc.
3. **The design**. As fabric and services specifications become more stringent, designers should aim to produce dwelling designs which (i) encourage site operatives to get the detailing right, (ii) aim to eliminate the need for improvisation on site, and (iii) make it easy for installers to route pipes and ducts. This point is arguably the most important of the seven, and impacts on several of the others.
4. **Construction quality and skills.** Passivhaus-like approaches, which include an airtightness champion, clerk of works, photographic recording, etc, clearly reduce the performance gap in low energy homes which require an increased attention to detail - but it has been argued that such practices are not workable in the volume housebuilding market.

[11] Some of the text is adapted from "Low and zero carbon homes: understanding the performance challenge", NHBC Foundation report NF41, February 2012, which was written by Cutland Consulting Ltd for the NHBC Foundation.

5. **Building materials and M&E systems.** New laboratory test methods are being introduced which can better simulate real-world conditions (eg. 'advanced hot box tests'). The performance of M&E systems can now be tested as an installed whole rather than as a kit of parts. The Passivhaus product certification process leads to the use of higher-performing insulation and M&E products.
6. **Communications.** Simple systems can be put in place to improve inter-team, as well as intra-team, communications. Design changes must be communicated to the construction team and vice versa. Basic rules such as "accept no substitutions on site" will help to reduce the instance of under-performing products being used. There is increasing interest in using building information modelling (BIM) for housing, as well as for larger projects, to improve communications.
7. **Post-construction tests and checks.** Specifying that basic monitoring should be carried out on all developments would enable the performance gap to be systematically diagnosed, and the learnings to be fed back to design and construction teams. Any prescribed methodology should be pragmatic – for example, simple fuel consumption monitoring via smart meters may be more workable at scale than co-heating tests.

A move towards simpler built forms and design features would not necessarily lead to architecturally uninteresting homes. Balconies, bays and projections can be designed as free-standing features which do not create thermal bridges. Simple built forms, if well-proportioned and detailed, can be visually pleasing.

8.2 Specific to Central Bedfordshire Council's 10% policy

Arguably a well-executed **fabric-led** approach is the simplest, most robust and some would say 'purest' way to design and build lower-energy homes. Points 3 – 7 above are most relevant to a fabric-centric element of any design strategy; all of them are addressable as discussed above.

For both **photovoltaic** and **solar hot water** systems it would be prudent for the developer to undertake a solar yield evaluation for each specific development at an early stage, to confirm that the assumptions built into the SAP routines are reasonable for that site.

Other than that, there are few performance issues which relate specifically to a **photovoltaic**-focussed strategy. PVs are inherently simple (having no moving parts), and as long as the dwellings are carefully laid out to avoid mutual overshading of roof pitches then it is a relatively foolproof technology. Clearly, different makes of panels have different generating efficiencies, but as long as the products actually used on site are the same as those specified during the design and modelling stages then there should be little, if any, performance gap relating to this aspect of the design.

Solar hot water is marginally more complex than PVs since it involves water as well as electricity and has a pumping and drainback system, but again is a relatively straightforward technology. Provided best plumbing practice is used, and the same potential problems of overshading and product substitutions are avoided, there should be few performance gap implications.

Heat pumps are at root relatively simple machines (fridge-like compressors). However, it has been reported in many studies that ASHPs in the UK climate can suffer from icing-up in midwinter which results in loss of heating performance and/or energy-intensive defrost cycles , and also from outdoor noise if not carefully sited. GSHPs suffer from neither problem, but skilful design of the ground loop is required if long-term build-up of permafrost is to be avoided.

Biomass heating systems generally suffer from few performance gap issues, but smoke control zones can obviously constrain their use. Biomass systems tend to be less responsive than gas or oil boilers, and individual appliances small enough for modern well-insulated homes can be hard to find. Communal systems can encounter issues about access for maintenance and refuelling, as well as logistical problems surrounding tenant billing.

The rules surrounding **community energy funds**, as the simplest form of Allowable Solution, are still to be finalised by Government and others. Issues include the sensitivity to the price of carbon; the potential for Administrations to use the CEF for general cashflow rather than ring-fencing it; the policing of the carbon calculations of the schemes which are permitted to take-out of the fund; the complexity of any regulatory process. But as a way of addressing the chronological and/or geographical challenges facing alternative offsite Allowable Solutions, CEFs are extremely practical.

9. Conclusions

This study considered the technical feasibility and financial viability of Central Bedfordshire Council's policy target of a 10% reduction in carbon dioxide emissions with respect to Approved Document L1A 2010 in newbuild housing. A wide variety of strategies were modelled, both fabric-based and technology-based as well as via Allowable Solutions, for a range of dwelling types and heating systems.

The broad conclusion is that, *within the degree of accuracy afforded by the dwelling types that were studied and the generic nature of the cost data used,* a 10% emissions reduction policy is viable according to the Council's cost criterion. This is the case in both mains gas and off-gas grid (rural) contexts in principle, although the number of strategies which can be used in practice depends on the context.

Outline summary of *cost* viability – mains gas-heated dwelling types				
	Gas detached 4B, 125m²	***Gas semi-det 3B, 95m²***	***Gas mid-terrace 2B, 65m²***	***Gas top-floor flat 1B, 45m²***
Photovoltaics	✓	✓	✓	✓
Solar Hot Water	✗	✓	✓	✓
Enhanced Fabric	✓	✓	✗	✗
Allowable Solutions	✓	✓	✓	✓

Outline summary of *cost* viability – off-gas grid (rural) dwelling types				
	Electric detached 4B, 125m²	***Electric semi-det 3B, 95m²***	***Electric mid-terrace 2B, 65m²***	***Electric top-floor flat 1B, 45m²***
Photovoltaics	(✓)	(✓)	✓	✓
Solar Hot Water	✗	✓	✓	✓
Enhanced Fabric	✗	✗	✗	✗
Heat Pumps	(✓)	✓	✗	✗
Biomass Heating	✗	✗	✓	✓
Allowable Solutions	✓	✓	✓	✓

(where symbols are in brackets, technical criteria may compromise the potential viability, as described in section 7)

Community energy fund and photovoltaic strategies (where technically feasible) are significantly cheaper than most other strategies at present – but the CEF concept in particular is very sensitive to the assumed price of carbon.

Depending on the Council's philosophical view of the community energy fund concept, it is recommended that the details of how a local CEF might operate are now explored. For example, it seems likely that technologies and projects permitted to be recipients of such a fund (either full or part contributions) could include:

- community wind turbines
- district heating
- CHP
- energy refurbishment of existing buildings
- consequential improvements to existing dwellings
- Green Deal contributions
- Energy Companies Obligation (ECO) subsidies
- local 'green' job creation
- …and many others.

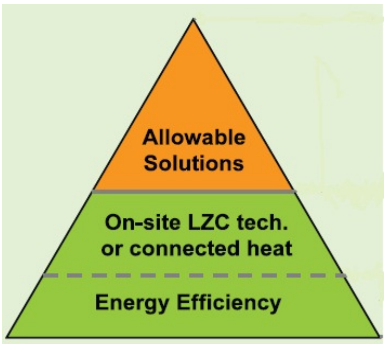
Appendix A

The Definition of Zero Carbon[12]

The original definition of zero carbon which included regulated as well as unregulated emissions also required the emissions to be reduced to zero through on-site means (ie. through a combination of fabric measures and low/zero carbon (LZC) heat and power). Some of these 'level 6' homes were built, but it was soon recognised that the cost of building to that definition, and its impracticability on many sites, meant that delivering zero carbon through an entirely on-site strategy was not the right approach for mainstream housing production.

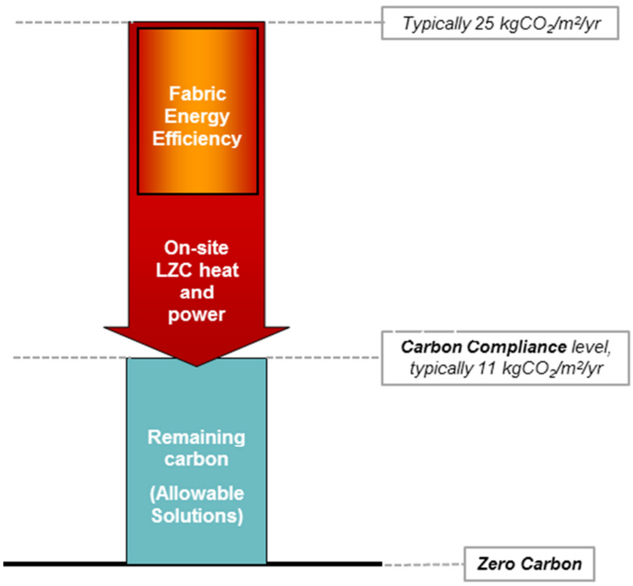
The concept of 'Allowable Solutions' was then proposed, whereby fewer emissions need to be eliminated by on-site means and an approved list of carbon-saving measures would be available to mitigate the remaining emissions. A further re-definition then took place, when unregulated emissions were excluded altogether.

The evolving definition has for some years been represented diagrammatically by an upward-pointing triangle:



However, we believe that the following graphic better illustrates exactly what designers, developers and housebuilders really have to *do* in order to meet the definition:

[12] Some of the text is adapted from "Zero carbon strategies for tomorrow's new homes", Zero Carbon Hub, February 2013, which was written by Cutland Consulting Ltd for the Zero Carbon Hub.



The 25kg/m^2/yr at the top of the diagram represents the emissions of a typical 2006 Building Regulations dwelling, and the graphic communicates the way that the strategy for emissions reductions works *downwards* towards zero. Also, the size of each box or arrow communicates the relative *quantity* of emissions.

The overall red arrow represents the carbon that is eliminated solely by on-site means, and also illustrates that this consists of a tightly-integrated combination of fabric improvements (U-values, thermal bridging, airtightness, etc), and low/zero carbon heat and power technologies (high-efficiency boilers, photovoltaic panels, solar hot water, etc). These on-site reductions amount to around 14 kg/m^2/yr in the example, which still leaves dwelling emissions of 11 kg/m^2/yr (shown in blue) remaining and needing to be eliminated in order to achieve zero carbon. This remaining CO_2 is formally known as the dwelling's 'Carbon Compliance' level.

It is important to realise that a dwelling's Carbon Compliance level is in fact the same as the Dwelling Emissions Rate (DER) which is calculated for Approved Document L1A compliance. In both cases it is simply the calculated CO_2 emissions of the dwelling in kilograms per square metre of floor area per annum, and it is calculated by precisely the same methodology in both cases.

Core requirements for zero carbon

There are three core requirements which must *all* be met for a dwelling to qualify as zero carbon:

1. the fabric performance must, at a minimum, comply with the defined standard known as the 'Fabric Energy Efficiency Standard', or FEES

and

2. whatever emissions remain must not exceed a certain defined level of Carbon Compliance

and

3. the remaining emissions (after requirements 1 and 2 have been met) must be reduced to zero.

Requirement 1, the Fabric Energy Efficiency Standard or FEES, is *the maximum allowed space heating and cooling energy demand, expressed in kWh/m^2/yr. The calculation is SAP-based, but uses set assumptions for the number of ventilation fans, internal gains and type of heating system.*

Requirement 2, the defined level of Carbon Compliance, is *the maximum permitted amount of CO_2 arising from heating, cooling, hot water, lighting and ventilation, expressed in kg/m^2/yr. It uses the same calculation methodology as the SAP and DER.*

The numerical values of the FEES standard and the defined level of Carbon Compliance are shown in the table below:

Built form	FEES, kWh/m²/yr	Carbon Compliance, kg/m²/yr
Detached houses	*46*	*10*
Semi-detached houses	*46*	*11*
End of terrace houses	*46*	*11*
Mid-terrace houses	*39*	*11*
Apartment blocks	*39*	*14* *(up to four storeys)*

Table 7

Requirement 3 may be met by deliberately 'over-performing' on requirements 1 and 2 so that there are in fact *no* remaining emissions, or it may be met by investing in 'Allowable Solutions'. In the latter case, the requirement may be met either

(i) by using Allowable Solutions alone,

or

(ii) by extending fabric and/or LZC energy technologies together with a smaller, possibly zero, contribution from Allowable Solutions[13].

There are many different types of Allowable Solution, and a full discussion of the framework is available elsewhere[14]. In practice, a developer will make a payment to an Allowable Solutions provider, who will take the responsibility and liability for implementing carbon-saving projects which deliver the required emissions reductions. The process will commonly include an 'energy fund' (with associated verification and certification procedures) to resolve situations where the housing development and the carbon-saving project are separated by geography and/or timing.

The total amount of remaining CO_2 that must be eliminated per dwelling when using Allowable Solutions is defined as the amount that accrues over 30 years. In our example above, the quantity is calculated as:

[13] It can therefore be seen that a dwelling's Carbon Compliance, its DER and the necessary amount of Allowable Solutions all consist of the same number (11 kg/m^2/yr in our example); they can in fact be thought of as the same thing.

[14] "Allowable Solutions – Evaluating Opportunities and Priorities", Zero Carbon Hub, Sept 2012; "Allowable Solutions for Tomorrow's New Homes", Zero Carbon Hub, July 2011.

11 kg/m^2/yr x habitable floor area of the dwelling x 30 years.
For (say) an 85m^2 home, this equates to 11 x 85 x 30 = **28 tonnes** of CO_2.

Variations on how to achieve zero carbon

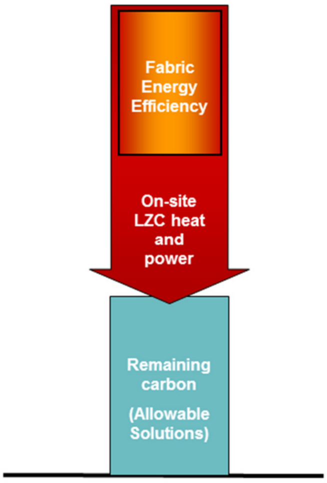
Developers will all have their individual preferences for how to comply with the core requirements of the zero carbon definition. The variants loosely fall into three categories:

- 'Balanced'
- 'Extreme fabric'
- 'Extreme low/zero carbon technology (LZCT)'

A typical **balanced** scheme comprises homes with:

- fabric performance approximately at the FEES level, and which…
- with a moderate but pragmatic focus on low/zero carbon technologies, achieve overall emissions at or below the defined Carbon Compliance level (ie. a DER no greater than 11 kg/m^2/yr in our example)

Schematically, this is shown with fabric energy efficiency and on-site LZC heat and power making roughly equivalent contributions to the overall emissions reduction:



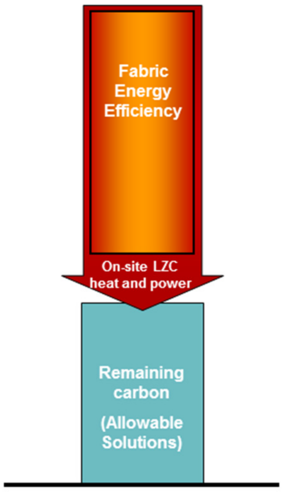
It can be seen that there is still a need for some Allowable Solutions to reduce the remaining carbon emissions to zero.

The balanced strategy represents a tried-and-tested approach for developers, one that is likely to be reasonably similar to schemes they have built before, and which could therefore be seen as a 'safe' or 'standard' approach. It is also very flexible, and readily allows trade-offs between fabric and services.

A typical **extreme fabric** scheme consists of homes with:

- fabric performance considerably in advance of FEES (usually at the equivalent of the Passivhaus level or better), and which…
- with little, if any, on-site low/zero carbon technology, has overall emissions at or below the Carbon Compliance level (ie. a DER no greater than 11 kg/m^2/yr in our example).

Schematically, this is shown with a much larger proportion of the overall emissions reduction being achieved by fabric energy efficiency:

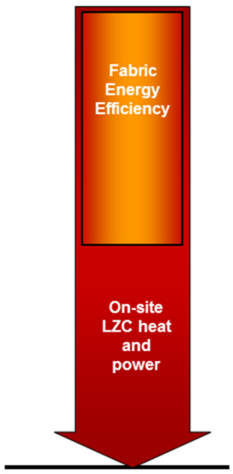


Again, there is still a need for some Allowable Solutions to reduce the remaining carbon emissions to zero.

The extreme fabric strategy represents a robust and durable approach to reducing emissions. It also achieves significant reductions in primary energy consumption, not just carbon. If the formal Passivhaus route in particular is followed (instead of an alternative, less formal extreme fabric approach), then designers have the added benefit of an established standard with an experienced UK support network and associated certification scheme.

Finally, a typical **extreme low/zero carbon technology (LZCT)** scheme comprises homes with:

- fabric performance considerably better than FEES (probably at or beyond the Passivhaus level), and which…
- exploit on-site low/zero carbon technology to the maximum, in order to reduce overall emissions far beyond the Carbon Compliance standard and ultimately to zero – ie. DER = 0.



Such a scheme immediately meets all three of the requirements of zero carbon, having no remaining CO_2 emissions needing to be eliminated. In other words, there is *no need whatsoever for any Allowable Solutions.* Designs which comply in this way will almost inevitably include an extreme fabric specification. They will also commonly include some form of solar design, to reduce space heating load using passive solar gain and/or to maximise the area of South-facing roof for photovoltaic panels or solar hot water.

An extreme LZCT scheme is most likely to be found where local needs or requirements dictate such an approach. It is a highly aspirational approach, which might for example be mandated by clients or local authorities who see themselves at the leading edge of sustainability. LZCT tends to be highly scalable, ie. once the site infrastructure is in place it is relatively simple to increase the capacity of the associated equipment. An extreme LZCT approach is arguably the most credible form of zero carbon, requiring no off-site measures in order to achieve zero emissions for the scheme.

The ‘energy fund’ Allowable Solution

It is currently anticipated that, where an Allowable Solutions approach to zero carbon compliance is chosen, the majority of developers will opt to pay the requisite sum into an official energy fund. An energy fund is essentially a mechanism which solves problems of ***timing*** (where the Allowable Solution project occurs at a future date to the associated housing development) or ***geography*** (where the Allowable Solution project is implemented in a different locality to the associated housing development).

The proposed mechanism is described in detail elsewhere[14], but a key concept is that the links between the developer’s contribution to the fund and the actual Allowable Solution project which draws on the fund will be sufficiently strong that the fund can be regarded as far more than just an esoteric offsetting scheme.

Discussions about the ‘abatement cost of carbon’ will continue ad infinitum. For obvious reasons developers prefer a lower cost, and Allowable Solutions providers prefer a higher cost; both parties produce robust evidence to support their case.

At the time of writing it is widely expected that the energy fund cost will be around £46 per tonne of carbon dioxide, so the payment in the example above would be 28 x 46 = £1,290 per dwelling. For a scheme of, say, 15 such homes the developer would therefore pay into the energy fund a total of 15 x £1,290 = £19,350 in order to eliminate the remaining CO_2 and make the scheme as a whole fully zero carbon compliant.

It will be interesting to see, where energy funds are controlled by individual Local Authorities, if the abatement cost of carbon that they set will determine where in the country developers decide to build houses.

In March 2013 the Government announced its intention to conduct a consultation on the ‘final details’ of the Allowable Solutions mechanism.

Appendix B
Base case full specifications

Gas		Detached House 125m²		Semi-detached House 95m²		Mid Terrace House 65m²		Top Floor Flat 45m²	
Fabric Specification									
Ext Wall U-value	(W/m²K)	0.25		0.25		0.25		0.25	
Party Wall U-value	(W/m²K)	n/a		0		0		0	
Semi exposed walls	(W/m²K)	n/a		n/a		n/a		0.2	
Floor U-value	(W/m²K)	0.2		0.17		0.17		n/a	
Roof U-value	(W/m²K)	0.13		0.13		0.13		0.13	
Door U-value	(W/m²K)	1.4		1.4		1.4		1.4	
Windows U-value	(W/m²K)	1.6	double glazed	1.4	double glazed	1.4	double glazed	1.4	double glazed
Window g-value		0.63		0.63		0.63		0.63	
Airtightness	(m³/m²/hr @ 50Pa)	**7.3**		**6.5**		**5**		**6.4**	
Thermal bridging	y-value (W/m²K)	0.08		0.08		0.08		0.08	
Services Specification									
Ventilation Type		natural		natural		natural		natural	
Number of extract fans		4		4		3		2	
Low energy lighting		100%		100%		100%		100%	
Electric tariff		standard		standard		standard		standard	
125ltrs/person/day, Water used ?		yes		yes		yes		yes	
Space Heating System (Gas)		Condensing (89%efficiency)		Condensing (89%efficiency)		Condensing combi (89%efficiency)		Condensing combi(89%efficiency)	
Space heating controls(individual)		Time temp zone		Time temp zone		Time temp zone		programmer, room thermostat & TRVs	
DHW cylinder size	(Litres)	200ltrs		200ltrs		n/a		n/a	
Declared loss factor	(KWh/day)	1.44		1.44		n/a		n/a	
compensator included ?		no		yes		yes		no	
FGHRS included ?		no		no		yes		no	
FEE (kWh/m²/yr)		59.8		49.7		43.4		46	
SAP		82		82		83		81	
DER (kgCO2/m2/yr)		17.65		17.86		18.02		20.64	
TER (kgCO2/m2/yr)		17.67		17.89		18.05		20.66	
DER/TER variance	%	**0.11%**		**0.17%**		**0.17%**		**0.10%**	

	Electric		Detached House 125m²		Semi-detached 95m²		Mid Terrace House 65m²		Top Floor Flat 45m²	
Fabric Specification	Ext Wall U-value	(W/m²K)	0.25		0.25		0.25		0.25	
	Party Wall U-value	(W/m²K)	n/a		0		0		0	
	Semi exposed walls	(W/m²K)	n/a		n/a		n/a		0.2	
	Floor U-value	(W/m²K)	0.17		0.17		0.17		0.17	
	Roof U-value	(W/m²K)	0.13		0.13		0.13		0.13	
	Door U-value	(W/m²K)	1.4		1.4		1.4		1.4	
	Windows U-value	(W/m²K)	1.4	double glazed	1.4	double glazed	1.4	double glazed	1.4	double glazed
	Window g-value		0.63		0.63		0.63		0.63	
	Airtightness	(m³/m²/hr @ 50Pa)	6		5.5		5		6.4	
	Thermal bridging	y-value (W/m²K)	0.08		0.08		0.08		0.08	
Services Specification	Ventilation Type		natural		natural		natural		natural	
	Number of extract fans		4		4		3		2	
	Low energy lighting		100%		100%		100%		100%	
	Electric tariff		off peak 7hrs		off peak 7hrs		off peak 7hrs		off peak 7hrs	
	125ltrs/person/day, Water used ?		yes		yes		yes		yes	
	Space Heating System (Electric)		Modern(slimline) Storage heaters		Modern(slimline) Storage heaters		Modern(slimline) Storage heaters		Modern(slimline) Storage heaters	
	Space heating controls(individual)		celect-type control		celect-type control		celect-type control		celect-type control	
	Water Heating System (Electric)		Dual Immersion		Dual Immersion		Electric Instantaneous		Electric Instantaneous	
	DHW cylinder size	(Litres)	200ltrs		200ltrs		n/a		n/a	
	Declared loss factor	(KWh/day)	1.44		1.44		n/a		n/a	

PV (kWp) to pass part L		2.41		1.78		0.6		0.34
(% of Ground floor Area for solar tech)		39%		37%		16%		15%
	without PV	with PV	without PV	with PV	without PV	with PV	without PV	with PV
FEE (kWh/m²/yr)	56.3	56.3	49.8	49.8	43.4	43.4	46	46
SAP	79	**88**	81	**88**	80	**83**	80	**82**
DER (kgCO2/m2/yr)	37.84	29.7	37.76	29.86	33.94	30.05	37.07	34.52
TER (kgCO2/m2/yr)	29.71	29.71	29.91	29.91	30.05	30.05	34.56	34.56
DER/TER variance %	-27.36%	**0.03%**	-26.25%	**0.17%**	-12.95%	**0.00%**	-7.26%	**0.12%**

Appendix C
Detailed results for the 10% strategies

10% improvement over Part L 2010

Gas

Total PVs for 10% improvement

	Detached House 125m²		Semi-detached House 95m²		Mid Terrace House 65m²		Top Floor Flat 45m²	
		with PV		with PV		with PV		with PV
PV (kWp) to achieve 10%		0.55		0.4		0.28		0.21
(% of Ground floor Area for solar tech)		9%		8%		8%		9%
FEE (kWh/m²/yr)		59.8		49.7		43.4		46
SAP		**84**		**84**		**84**		**83**
DER (kgCO2/m2/yr)		15.8		16.09		16.23		18.58
TER (kgCO2/m2/yr)		17.67		17.89		18.05		20.66
DER / TER variance %		**10.58%**		**10.06%**		**10.08%**		**10.07%**

Total SHW for 10% improvement

	Detached House		Semi-detached House		Mid Terrace House		Top Floor Flat	
Solar thermal panel area (m²)	4	sq.m	2	sq.m	2.2	sq.m	2	sq.m
(% of Ground floor Area for solar tech)		6%		4%		7%		9%
FEE (kWh/m²/yr)	**59.8**		**49.7**		**43.4**		**46**	
SAP	84		84		83		82	
DER (kgCO2/m2/yr)	15.88		16.05		16.23		18.56	
TER (kgCO2/m2/yr)	17.67		17.89		18.05		20.66	
DER / TER variance %	**10.13%**		**10.29%**		**10.08%**		**10.16%**	

FABRIC for 10% improvement

Ext Wall U-value	(W/m²K)	0.18	0.15	0.18	0.17 0.16 sheltered walls
Windows U-value	(W/m²K)		0.15	0.8 triple glazed low e	0.8 triple glazed low e
Door U-value	(W/m²K)		0.8 triple glazed low e		1
Airtightness	(m³/m²/hr @ 50Pa)		1	3	3
Ventilation		4	4	MVHR	MVHR
Thermal bridging	y-value (W/m²K)		0.06	0.05	0.04
FEE (kWh/m²/yr)		**50.7**	**38.5**	**34.2**	**32.8**
SAP		84	84	83	82
DER (kgCO2/m2/yr)		15.85	16.07	16.24	18.57
TER (kgCO2/m2/yr)		17.67	17.89	18.05	20.66
DER / TER variance	%	**10.30%**	**10.17%**	**10.03%**	**10.12%**

10% improvement over Part L 2010

Electric

		Detached House	125m²	Semi-detached House	95m²	Mid Terrace House	65m²	Top Floor Flat	45m²
Total PVs for 10% improvement	**PV (kWp) to achieve 10%**		3.4		2.4		1.07		0.8
	(% of Ground floor Area for solar tech)		54%		51%		29%		36%
			with PV		with PV		with PV		with PV
	FEE (kWh/m²/yr)		56.9		49.8		43.4		46
	SAP		**91**		**91**		**86**		**85**
	DER (kgCO2/m2/yr)		26.73		26.88		26.99		31.06
	TER (kgCO2/m2/yr)		29.71		29.91		30.05		34.56
	DER / TER variance %		**10.03%**		**10.13%**		**10.18%**		**10.13%**

		Detached House		Semi-detached House		Mid Terrace House		Top Floor Flat	
Total PV & SHW for 10% improvement	Solar thermal panel area (m²)	3	sq.m	3	sq.m	3	sq.m	3	sq.m
	PV (kWp) to achieve 10%		2.4		1.35		0.26		0
	(% of Ground floor Area for solar tech)		43%		35%		15%		13%
		without PV	with PV	without PV	with PV	without PV	with PV	without PV	
	FEE (kWh/m²/yr)	56.9	56.9	49.8	49.8	43.4	43.4	46	
	SAP	80	**89**	83	**89**	84	**86**	85	
	DER (kgCO2/m2/yr)	34.72	26.6	32.89	26.9	28.71	27.02	31.04	
	TER (kgCO2/m2/yr)	29.71	29.71	29.91	29.91	30.05	30.05	34.56	
	DER / TER variance %	-16.86%	**10.47%**	-9.96%	**10.06%**	4.46%	**10.08%**	10.19%	

FABRIC for 10% improvement

Ext Wall U-value	(W/m²K)	0.18	0.18	0.2	0.2
Windows U-value	(W/m²K)	0.8 triple glazed low e	0.8 triple glazed low e	1 triple glazed low e	1.4 double glazed low e
Airtightness	(m³/m²/hr @ 50Pa)	3	3	3	4
Ventilation		MVHR	MVHR	MVHR	MVHR
Thermal bridging	y-value (W/m²K)	0.06	0.06		
FEE (kWh/m²/yr)		**43.8**	**39.8**	**38.6**	**43.1**
SAP		84	85	82	82
DER (kgCO2/m2/yr)		26.53	26.84	26.82	30.81
TER (kgCO2/m2/yr)		29.71	29.91	30.05	34.56
DER/TER variance	%	**10.70%**	**10.26%**	**10.75%**	**10.85%**

ASHP for 10% improvement

Space heating controls(individual)		Time temp zone		Time temp zone		Time temp zone		programmer, room thermostat & TRVs	
			Air P = 9		Air P = 7		Air P = 8		Air P = 6.3
			y value = 0.15		y value = 0.15		y value = 0.15		y value = 0.15
		Same specs	reduced specs	Same specs	reduced specs	Same specs	reduced specs	Same specs	reduced specs
FEE (kWh/m²/yr)		56.9	68.3	49.8	57.4	43.4	51.9	46	76
SAP		77	**74**	79	**77**	80	**78**	78	**81**
DER (kgCO2/m2/yr)		23.66	26.72	24.6	26.81	24.75	27.03	28.93	31.07
TER (kgCO2/m2/yr)		29.71	29.71	29.91	29.91	30.05	30.05	34.56	34.56
DER / TER variance	%	**20.36%**	**10.06%**	**17.75%**	**10.36%**	**17.64%**	**10.05%**	**16.29%**	**10.10%**
Boiler size	(kW)	5.9	6.6	4.9	5.3	4.1	4.5	3.9	4.1

GSHP for 10% improvement

Space heating controls(individual)	Time temp zone	
		Air P = 10
		y value = 0.15
		reduced specs
FEE (kWh/m²/yr)	56.9	69.4
SAP	82	**79**
DER (kgCO2/m2/yr)	20.57	23.31
TER (kgCO2/m2/yr)	29.71	29.71
DER / TER variance %	**30.76%**	**21.54%**
Boiler size (kW)	5.3	5.9

Biomass for 10% improvement

Boiler Type	Wood pellet : Auto feed independent boiler to radiator		Wood chips : Closed room heater with boiler to radiator		Communal Biomass		Communal Biomass	
Efficiency	75%							
Flue type	Balanced & Fan assisted							
Space heating controls(individual)	Time temp zone		Time temp zone		Time temp zone		programmer, room thermostat & TRVs	
		Air P = 10		Air P = 10		Air P = 10		Air P = 10
		y value = 0.15		y value = 0.15		y value = 0.15		y value = 0.15
				windows = 1.6		windows = 1.6		windows = 1.6
	Same specs	reduced specs	Same specs	reduced specs	Same specs	reduced specs	Same specs	reduced specs
FEE (kWh/m²/yr)	56.9	69.4	49.8	61.6	43.4	55.4	46	58
SAP	76	**72**	83	**81**	76	**72**	75	**72**
DER (kgCO2/m2/yr)	7.37	8.42	9.11	9.98	6.69	7.74	7.25	8.3
TER (kgCO2/m2/yr)	17.67	17.67	17.89	17.89	18.05	18.05	20.66	20.66
DER / TER variance %	**58.29%**	**52.35%**	**49.08%**	**44.21%**	**62.94%**	**57.12%**	**64.91%**	**59.83%**
Boiler size (kW)	10.3	12.4	8.4	10.3	6.0	7.3	5.3	6.5