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CAN FUTURE UK HOUSING MEET ITS ENERGY NEEDS FROM ZERO OR LOW CARBON SOURCES?

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Abstract. From 2016 every new home in Britain must supply all of its energy needs from zero or low carbon (ZLC) energy sources such as solar and wind - under the Code for Sustainable Homes (CSH) Level 6. This is not just the heating of the space and the water but also the lighting, cooking and all of the energy sapping devices such as TVs and fridges that are so much a feature of modern life. Social landlords must comply a full year earlier, in 2015. Fortunately, this does not represent a standing start for many developers as 'Merton Rules' have been widely adopted by local authorities since 2003. These typically require 10% of the energy use in the home (excluding lighting, appliances etc) to come from onsite renewable resources. In practice even this level has proved pretty challenging. This paper uses studies of Merton Rule-style policies, and case histories from around Britain and Europe, to evaluate the main ZLC technologies and their potential to deliver onsite energy cost-effectively.

The paper also examines the experience of low energy homes in North European climates to identify how much electricity and heat a Code Level 6 home is likely to consume and how much can realistically be harvested onsite. The author concludes that the CSH Level 6 policy is impractical using renewable energy harvested onsite, and only becomes practicable when energy can be imported from elsewhere. The policy condemns developers to investing in ineffective technologies such as wind or solar that are highly inefficient and expensive when deployed on a micro-scale in urban areas; or other technologies of questionable environmental benefit. It also condemns local authorities to an unnecessary and highly complex assessment and monitoring regime. The author argues that a far simpler and more logical solution is to allow wind and solar energy also to be harvested offsite– through large-scale, developer-funded, farms. These are relatively cheap, zero carbon in operation; easy to regulate; and can in principle supply any development from the very largest to individual units.

Keywords: 'Merton', 'renewables', Code for Sustainable Homes', 'onsite energy', 'ZLC'

1. Introduction

As governments in many countries struggle to reduce their countries' carbon emissions, the built environment has been highlighted as a major source of emissions.

Progressively tighter building regulations and improving building practices have reduced energy usage, in some cases dramatically. Much effort is now being expended in identifying how much energy can realistically be harvested from renewable sources to reduce or eliminate carbon emissions from the remaining energy usage.

In the UK this approach has been pioneered by local government and latterly taken up nationally through the Code for Sustainable Homes.

The Code has major financial and logistical implications but is based only upon an emerging understanding of the various factors involved.

This paper discusses the options available to the developers; how feasible and cost-effective they are likely to be in practice;

and the lessons that are can be learned as a result.

2. Policy Evolution

2.1 The ‘Merton Rule’

When Merton Council instituted the original ‘Merton Rule’ in 2003, it did so in the face of significant opposition. It also specifically *excluded* residential developments.

The neighbouring borough of Croydon swiftly followed Merton’s lead by adopting the Rule in 2003, but with the important addition of new residential developments – ‘comprising 10 or more units’. The requirement was ‘to incorporate renewable energy production equipment to off-set at least 10% of predicted carbon emissions, except where:

1. the technology would be inappropriate;
2. it would have an adverse visual or amenity impact that would clearly outweigh the benefits of the technology; and
3. renewable energy cannot be incorporated to achieve the full 10%.

In 2004 the Mayor’s London Plan explicitly took up the policy and added further precision by producing a Renewables Toolkit to help developers to implement it. The Scottish Executive followed (requiring 15%) in 2007 and the policy was taken up widely by local authorities throughout the country.

From 2016 however, this voluntary policy will be replaced by a single national scheme and all new housing – not just that in relatively large developments as in the Merton Rule - will be required to meet Level 6 of the Code for Sustainable Homes and fulfill *all* of their energy requirements from ZLC energy produced on-site.

2.2 The Code for Sustainable Homes

In 2006 the new Code provided a comprehensive measure of the sustainability of new homes – not just energy efficiency.

The Government’s ambition for the Code was that it should become ‘the single national standard for the design and construction of sustainable homes, and that it drives improvements in home building practice.’

The Code awards points for nine assessment criteria, from energy to ecology. Category 1 (Energy and CO_2 emissions) is by far the most important, representing 36% of the total. A numerical score is thus developed for each building, and so a ‘star rating’ from 1 to 6 – with Level 6 being the ‘zero carbon home’.

At Level 6 all of the energy used by appliances in the home, as well as by the heating and lighting, must be directly sourced from onsite ZLC sources (or from a ‘private wire’ to such a source).

The requirement is not that the development must go ‘off grid’ or even be capable of doing so, it is that an *equivalent* amount of ZLC energy is delivered onsite to that which the site consumes –so allowing for the fluctuations in supply levels to which most renewable technologies are subject.

2.3 Acceptable technologies

Renewable energy is generally considered to be energy that can be derived from sources without, for practical purposes, depleting them. Low carbon technologies are, by definition, those that use little carbon in the conversion of energy for use, although fossil fuels are usually permitted in the construction of the equipment used to harvest the energy.

There is significant discussion about the boundaries of the terms – is biomass (usually wood) really sustainable; do heat pumps – which require electricity to run them qualify? And so on.

The Merton Rule specifically focused on ‘renewables’ – but avoided defining exactly what was included and excluded.

The later London Toolkit took a broader view by including biomass and heat pumps, neither of which is strictly renewable; and, later again, the Code for Sustainable Homes broadened the permitted onsite energy sources much further, notably with the introduction of natural gas-fired Combined Heat and Power as a low carbon technology. This technology delivers usable electricity and heat in a single process (rather than wasting the heat as is the usual practice in the UK). Low carbon it may be, but fossil fuel derived it is, and renewable energy it certainly is not.

2.4 What can onsite mean?

The Code for Sustainable Homes defines onsite as:

> The installation of Low or Zero Carbon technologies which directly supply the dwelling with heat and/or electricity through a direct connection to the property or through a private wire arrangement.
>
> > These installations can be located on/in the dwelling, its curtilage or elsewhere on/off site provided that there is a direct connection to the dwelling.[i]

2.5 How effective are these policies?

In July 2007 a team from London South Bank University (LSBU) carried out a review for the Greater London Authority (GLA) on the impact of the energy policies in the London Plan for applications referred to the Mayor. They concluded that a 5.8% saving in CO_2 emissions was attributable to the use of onsite ‘renewables’ – with energy efficiency measures contributing a further 21.3%. However the authors’ reservations on the quantity and quality of the available data were substantial - ‘many statements [have] limited data, [and] sometimes [are] of questionable accuracy’; and only 30% of the applications approved (113) were analysed. It is thus highly possible that the achievement was overstated.

The study also noted that:

- ‘SHW [Solar hot water], biomass, PV [photovoltaics] and GSHP [ground source heat pumps] provided the majority of the renewables installations (in that order)’.
- ‘the most carbon effective technologies are CHP [combined heat and power] and CCHP [combined cooling heating and power], particularly where biomass fuel is specified’.

thus highlighting a major challenge – that the most widely adopted technologies were far from the most effective at reducing energy use.

When the two principal councils behind the Merton Rule – Merton and Croydon – carried out a similar study in 2008, based upon planning submissions in their boroughs, their findings were similar.

The data again showed the relative popularity of solar hot water installations - 29 of the 84 installations examined, followed by photovoltaics and wind turbines at 15 and 14 respectively (Cotterill, 2009).

However 76% of the projected CO_2 savings came from biomass heating and biomass CHP, with solar hot water providing just 6% of the benefit.

3. Energy use per home

Clearly the amount of energy generation required depends on the amount of energy consumed - and much of the impact of the Merton Rules has been to improve overall energy efficiency.

There are several models of very low carbon homes in existence that provide an idea of what can be achieved. These rely on minimizing energy wastage – especially on heat lost through the fabric of the building - and on the capture of solar (and other) natural energy.

3.1 Hockerton Housing Project

This Nottinghamshire development comprises five earth-sheltered and super-insulated homes - with large south-facing glazed areas and high thermal mass to capture and store solar thermal energy.

This strategy is so effective that four of the five homes require no additional space heating with the internal temperature only varying between 18-20^{0}C in winter and 22-23^{0}C in summer (BRECSU/Energy Saving Trust, 2003).

The development achieves an independently audited energy use of around 3,000kWh/yr per home for space/water heating, cooking and appliances. This equates to just 24-32 kWh/m^2/yr[ii] depending on the household.

Hockerton is a rare example of a development that generates essentially all of its energy onsite from renewable sources – in this case from a PV array and two free-standing wind turbines.

It should of course be noted that this is a showcase project, in a rural area where optimal orientation was possible to maximise solar gain and wind could be used effectively.

3.2 Passivhaus

The principal standard for low energy homes in Europe is *Passivhaus*, which originated in Germany. To date some 2,069 buildings and 8,449 apartments have been certified to be completed to this standard[(] (PASS-NET).

These homes use a mechanical heat recovery ventilation system, and usually solar thermal panels to provide a proportion of the domestic hot water.

A core requirement is that the space heating should use less than 15kWh/m^2/yr and that the total *primary* energy use for all appliances, cooking, domestic hot water and space heating and cooling should be less than 120 kWh/m^2/yr.

3.3 BedZED

BedZED, an urban development of low carbon homes and businesses in south London, uses a similar approach to Passivhaus and Hockerton with well-insulated homes and solar gain.

For BedZED the average electricity consumption in 2007 was 34kWh/m^2/yr and for space and water heating 48kWh/m^2/yr – a total of 82kWh/m^2/yr (BioRegional).

3.4 A future energy requirement?

All three developments are of course largely occupied by enthusiasts for low carbon living – and in some cases there is active competition between occupants to show how little energy they use. For non-enthusiasts the consumption is likely to be significantly higher.

The Technology Strategy Board has set the bar at 125kWh/m^2/yr in 2009 for its ‘Retrofit for the Future’ competition to upgrade social housing. This seems to be a reasonable target given the experiences of these low carbon developments.

To calculate what the energy usage would be *per household* we have set the total dwelling size at 87m^2 (NAEH, 2004) - the average in 2001 – and so the total energy requirement is 10,875kWh/yr.

4. What can onsite ZLC technologies deliver?

The task is therefore to identify just how readily each technology can contribute to this figure, and with what limitations on its use.

4.1 Solar Hot Water

These systems transfer the sun's radiant energy into a fluid - which transfers the heat in a hot water store, such as a cylinder ('hot water tank') in an individual home; or unitary 'buffer storage' in a larger development.

This energy is 'low-grade' as in this context its only feasible use is to provide warmth – largely for domestic hot water (DHW).

Solar water heating technology is very well-established, widely deployed, and converts around 50% of the energy from irradiation into heat.

In the UK an obvious drawback is that in the winter we use more hot water, just at a time when the panels produce less. In a test a 3m^2 array met 93% of the relatively modest needs (100 litres of 60^{0}C water a day) of a house in July and just 15% in January (Viridian Solar, 2007).

To maximize energy capture solar hot water requires a southerly facing aspect; and space to site the panels safely and securely.

Although used only on a small scale in the UK, relatively large installations are being promoted through the SoLarge initiative in the EU. The case studies had an average collector yield of between 300kWh/m^2/yr (Potsdam, Germany) and 690 kWh/m^2/yr (La Rochelle, France) (SoLarge 2008).

A 3 to 4m^2 system in the UK is thus likely to produce in the region of 1000 to 1500kWh of heat per year. Assuming one unit per 87m^2 dwelling this would represent 11-17 kWh/m^2/yr of the anticipated heat usage.

This size of array is however likely only to be possible in relatively low-rise developments and in all cases an unshaded southerly-facing mounting area is required.

4.2 Photovoltaic cells – electricity

Photovoltaic (PV) cells convert radiant solar energy into DC electricity and require the same orientation and positioning as solar hot water. In many cases they will effectively compete for space.

The PV-Compare Project from the University of Oxford Environmental Change Institute identified annual energy yields from PV arrays ranging from c. 20 to almost 120kWh/m^{2}yr in Oxford. These results were achieved with as close to optimal orientation and management as possible. The range of efficiencies was considerable, with mono-crystalline silicon PV cells performing best.

A 3 to 4m^2 monocrystalline PV array in the UK is thus likely to produce at most 360 to 480kWh of electricity per year (4.5-6kWh/m^2/yr of the total electrical usage). This may improve in the future as new technologies come onstream.

3.3 Wind energy

Whilst well-sited large-scale wind turbines on land and at sea have been shown to be capable of generating substantial amounts of electricity, this is not true for the small-scale domestic turbine in urban areas.

The Energy Saving Trust's Domestic Small-scale Wind Field Trial report in 2009 – largely based upon the Warwick Wind Trials - found that 'no urban or suburban building-mounted sites generated more than 200kWh or £26 per annum' and some were actually net users of energy, not producers.

Whilst free-standing turbines in rural areas fared better for this study the best urban results will be used, as most new housing will be in these areas.

Thus at 200kWh per annum the most we could expect to generate from a building-mounted wind turbine would be 2.3kWh/m^2 for our 87m^2 house.

4.3 The total onsite energy opportunity

Thus, by taking optimistic assumptions that we have a southerly facing house with 6m^2 of solar arrays (half solar hot water and half PV) and the best performing building-mounted wind turbine we can expect to generate at maximum:

Source	Yield (kWh/m^2/yr)	Type
SH water	17	heat
PV	6	electricity
Wind	2	electricity
Total	25	

This represents just c.20% or one fifth of the target energy consumption. Clearly offsite ZLC energy sources are needed to make up the shortfall.

5. Offsite ZLC energy resources

The main options are summarized below.

5.1 Biomass/biofuels

Biomass and other biofuels are offsite resources in almost all urban cases as they require the extensive growth of combustible material – usually woody material in the UK.

Biomass, like fossil fuels, is essentially stored energy, although in a far less energy-dense form. Air-dried wood requires almost three times as much space as petroleum of the same energy value. This has an impact on boiler size, on the amount of fuel storage space required onsite and on the amount of transport required to move it to the site.

Biomass is also a limited resource – if every gas boiler was replaced by a biomass one we would run out of trees to burn very quickly.

Unlike solar and wind energy it also requires combustion, with consequent potential air quality problems. As the Biomass Energy Centre notes, good quality and well-run large woodchip installations may emit many more times as much nitrous oxides, particulate and sulphur dioxide than their gas-fueled equivalents.

Clearly this fuel is an option especially for large developments but there are serious sustainability, air quality and transport issues if it were to be used widely.in the UK.

5.2 Heat Pumps

Heat pumps use the same condensing/evaporating principle as a domestic fridge to extract heat energy – usually from the ground, the air or water. They are highly efficient and may deliver three or more times as much heat to the home than they could by directly heating for example an electric bar fire.

They do however require electricity to run and this will usually come from the familiar mix of gas, nuclear, coal and hydroelectric generators that supply the grid.

Ground source heat pumps require large areas of underground piping – usually either laid flat or drilled down vertically – to allow the heat transfer to take place – which will certainly provide challenges in many urban locations. Air source heat pumps are usually less efficient and have smaller capacity.

Assuming that the space is available however heat pumps can provide all of the space and water heating requirements – although, as noted above, they are rarely zero carbon as they almost always use grid electricity.

5.3 Combined Heat and Power (CHP)

The final significant option is Combined Heat and Power or ‘cogeneration’. This delivers usable heat and electricity in a single process. This can be extended to include cooling (‘trigeneration’ or Combined Cooling Heat and Power (CCHP)) - through the addition of an absorption cooling cycle.

Conventionally almost all of the heat generated as a by-product of electricity power production in the UK is rejected as waste. Indeed only c. 2% of UK homes are supplied by CHP (CHPA, 2008). By contrast this technology provides 98% of Helsinki’s and, in 2000, 63% of Denmark’s heating requirements. The technology is thus well-proven.

The challenge is how to move the heat from home to home – which is relatively easy if not very cheap in a highly concentrated inner city estate. The East London Barkantine Estate installed a system at a cost of about £10,000/dwelling (London Esco, 2008). Such work is much more difficult and expensive for dispersed or individual housing.

In the UK some of the largest CHP community heating schemes (Nottingham and Sheffield) are run from the incineration of waste – which is classed as compliant ZLC technology but is far from popular among nearby residents. CHP can of course be run from a variety of fuels but these are either fossil fuel or limited supply biomass with the limitations that we have noted above.

Technically however this resource can provide all of the heat and power that is needed – provided that there is sufficient investment and a suitable and sustained source of fuel.

5.4 The onsite ZLC resource in summary

In sum then little effective contribution can be expected from onsite wind and solar energy due to scale and location; at most one fifth of the likely requirement.

Some contribution for heating can be derived from heat pumps, although this will depend on the ability of the developers to run substantial arrays underground; and with the current grid generation make-up any carbon reductions are likely to be very limited

Biomass can certainly be used to provide heat and power, although there are issues with storage, operation and maintenance, carbon emissions and applicability to small schemes

Gas-fired CHP/ can provide substantial amounts of heat and electricity far more efficiently than current systems but involve using a fossil fuel and a substantial investment in building a distribution network for the heat

It is clear that none of the options presented by the CSH represents the silver bullet needed to resolve this complex challenge, and indeed all have substantial drawbacks.

6. Cost-efficient energy at scale

As with many processes, there are very considerable efficiencies when electricity and heat are produced at large scale.

The completed cost of a wind farm is typically estimated at less than £1,000/kW of capacity. A typical 600W building-mounted turbine (Ampair, 2009) is likely to cost c.£1,500 for the base unit, £500 for the regulator and possibly a further £500-1,000 for installation – a total of £3,000 - or £5,000/kW.

The physics of wind energy make it many times more efficient to generate with large, high turbines in areas with steady and strong winds than in urban areas with small, low turbines with little and gusty wind.

Thus large-scale wind may generate at costs as low as €0.07 or €0.08/kWh 'in the near future' (Hassan, 2009).

The four Ampairs used in the Warwick Wind Trials study (Encraft, 2009) that were building-mounted on low-rise buildings in urban areas generated from 54-179kWh/yr (average 94.8kWh/yr). Assuming a ten-year life this represents a cost of just over £3/kWh (over €3/kWh at time of writing) or generating at between 30 and 40 times the cost of upcoming big wind developments.

The cost-efficiencies for offsite large-scale solar and other technologies are less extreme but the difference is still very considerable.

It almost goes without saying that a small number of large professionally constructed and managed sites are far easier to manage and assess than a plethora of technologies deployed at very small scale locally.

7. Conclusions

It seems clear that genuinely zero carbon onsite sources can only supply about one fifth of even highly efficient future homes' energy needs. The remaining 80% must come from offsite through grid electricity, in gas or heating pipes, or as solid fuel on trucks.

The current policy allows much of this to be generated using fossil fuels - for gas CHP or grid electricity for example. By contrast it effectively forbids developers from investing in full-scale offsite renewables despite their being many times more cost-effective than trying to site them locally, easier to assess and monitor and genuinely zero carbon.

It is clearly possible for future UK homes to meet their energy needs from ZLC, and indeed from genuinely zero carbon, sources – but the most sensible and cost-efficient option seems specifically to be excluded by the current regulations.

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