A solutions-based simulation approach to test the technical and economic feasibility of achieving low and zero carbon homes in the UK

Dr. Rajat Gupta
Reader, Oxford Brookes University,
Department of architecture,
Headington campus, Gipsy lane
United Kingdom
rgupta@brookes.ac.uk

Smita Chandiwala
Researcher, Oxford Brookes University,
Department of architecture,
Headington campus, Gipsy lane
United Kingdom
schandiwala@brookes.ac.uk

Keywords

Code for Sustainable Homes, low/zero carbon homes, zero carbon technologies, energy efficiency, renewable energy

Abstract

This paper describes the development, application and analysis of an interactive user-friendly Code for Sustainable Homes-based Sustainability Appraisal Toolkit (SAT). SAT runs on MS Excel and is used to evaluate the technical and economical feasibility of achieving Code levels 3, 4, 5 and 6 for a representative sample of new-build dwellings in UK for different scales of development (single-home, 25 homes and 250 homes). The scenarios are modelled using three standard housing types: detached house (104m^2), mid-terraced house (79m^2) and a low-rise flat (61m^2).

A range of strategies are evaluated on both demand and supply sides of energy to meet different Code levels. The analysis reveals that if the fabric performance is improved, level 3 and 4 targets can be easily met with minimal low and zero carbon (LZC) technology for detached and mid-terrace houses. The study shows a considerable reduction in additional capital cost per dwelling (ACD) for LZC technologies to meet code level 4, which ranges from £4500 (Euro 4785) for a detached house to £2889 (Euro 3072) for 25 houses. To achieve level 5, ACD is estimated to be £26,000 (Euro 27,645) and £20,000 (Euro 21,265) for a detached and mid-terraced house respectively. Level 6 (zero-carbon) is the most prohibitive and ACD is predicted to be £46,500 (Euro 49,442) for a detached house and around £38,500 (Euro 40,936) for a mid-terraced home. Higher levels of cost savings can be expected for both levels 5 and 6 at community-level strategies. The research shows that it is difficult to achieve the required percentage improvement target in smaller, efficient dwellings such as flats due to the % reduction scale.

The research emphasises the importance of maximising energy efficiency improvements to the fabric and form of a dwelling, before adding low/zero carbon systems, and promotes a 'low-energy first and then low-carbon' approach. Also, a mix of energy technologies is required depending upon the site and scale of development, and the cost varies with scale to meet different Code levels.

Introduction

Scientific evidence shows that climate change is real and happening already, and that urgent action is needed now (Stern, 2006). At the same time Kate Barker's (2004) report into housing affordability has made it clear, that additional housing provision is required in the UK. The current housing stock is growing at a lesser pace than the projected requirement, including many single person households. To meet this requirement, the government has a set a target of increasing the housing provision to provide a total of two million new homes by 2016, and another million by 2020 (CLG, 2007). If the houses needed are built, then by 2050 as much as one-third of the total housing stock is yet to be built. It is vital that these homes are built in a way that minimises the use of energy and reduces their harmful CO_2 emissions, given that about 27% of UK's carbon emissions arise from the energy used to heat, light and run our homes (Roaf, et al, 2004). Reduction of emissions from the housing sector will be necessary if UK has to meet its revised target of 80% reduction from 1990 levels by 2050.

Also, we need to build and use our homes in a way that minimises their other environmental impacts, such as the wa-

Table 1.Mandatory targets for energy and water

Levels	Standard (percentage better than Part L)	Standard (litres/person/day)
Level 1	10%	120
Level 2	18%	120
Level 3	25%	105
Level 4	44%	105
Level 5*	100%	80
Level 6**	True zero carbon	80

Note:

**100% improvement implies zero emissions in relation to building regulations, i.e. zero emissions from heating, hot water and lighting.*

***A true zero carbon home for level 6 also takes into account energy use for appliances and cooking.*

ter they use, the waste they generate, and the materials they are built from. The Communities and Local Government launched a new guidance in December 2006 called the Code for Sustainable Homes (CSH), which defines sustainability criteria for new dwellings. It is essential to minimise carbon emissions from the additional, new housing for achieving overall reductions of green house gas emissions by the housing sector. The Code is the first step in this direction and decides the timeline to bring about a structured change in reducing carbon emissions.

CSH defines six levels of sustainability, ranging from level 1 which is the lowest to the highest level 6, also known as the zero carbon target. All new houses are expected to achieve the zero carbon status by 2016. The future housing provision also includes plans for five eco-towns, each to provide between 5000-20,000 new homes setting benchmarks for exemplary sustainable and zero carbon developments. The industry, currently, is grappling with not only the cost required to meet the Code levels but also the skill and the technical knowledge as CSH requires detailed assessment criteria for credits towards the requisite levels.

Within this context, the research objectives of this paper are to address the evaluation of new dwellings based on the criteria set out by the code. The paper explains the methodological approach for the development of a user-friendly, interactive tool, Sustainability Appraisal toolkit (SAT) that allows quick evaluations of CSH criteria at various stages of design. The tool has been used to assess the technical and economic feasibility of 24 options to achieve code levels 4, 5 & 6 for typical UK housing types. Three typical UK housing types; a detached house, a mid-terrace and a traditional low rise flat, were modelled at different scales of development; a single house, as a part of a 25-house development and a 250-house development.

Based on the analysis and findings, CSH guidance requirements (for energy) to meet higher code levels are critically evaluated, and an approach based on the principle of 'low energy and then low carbon' is suggested.

CODE FOR SUSTAINABLE HOMES

The Code for Sustainable Homes (CSH) came into effect on 10 April 2007 and acts as the vehicle to facilitate the government's goal of ensuring that every new house built in England is 'zero-carbon' by 2016. It serves as a guide to the direction of future Building Regulations (CLG, 2007) and currently defines the national standard for sustainable design and construction of new homes. CSH took over from BRE's EcoHomes scheme (England only) and defines six levels of sustainable development assigned through a detailed review at design and post-construction stages. Since, May 2008, all new homes require a mandatory assessment against the code, even if no specific level is targeted. Mandatory code level 3 is however, required to secure any government funding for housing projects on all Housing Corporation and English Partnerships funded projects from 2008 (Cyrill Sweett, 2007). Housing Corporation bids achieving a possible level 4 or above will score more favourably. Needless to say, CSH is an essential guidance, which directs the future of housing in the UK.

There are nine sustainability related categories in CSH, each subdivided into a number of criteria. At every level, there are mandatory performance targets for energy and water consumption standards, recognised as integral to any sustainable development. Three more categories (materials, surface water run-off and waste) have entry-level mandatory targets, and the remaining four (Pollution, Health and well-being, Management and Ecology) are entirely flexible credits. Credits gained in each category are then multiplied with their environmental weighting factor to count as 'point scores' for each credit received. Each of the six code levels are defined by the total number of 'points score' required to achieve that level. Unlike EcoHomes, to attain any code level, all mandatory targets including the water and energy target for that level must also be met, which cannot be compensated by more points in other categories towards fulfilling the total number of point scores required. Table 1 shows the minimum mandatory energy and water criteria required for each level.

Developing the SAT toolkit

A Sustainability Appraisal Toolkit (SAT) was developed as the first step towards assessing various scenarios of achieving different code levels. The architecture of the toolkit allows quick evaluations of design specifications to see how they affect code credits. The toolkit comprises of the following elements:

- SAT Credit Calculator
- Water Calculator

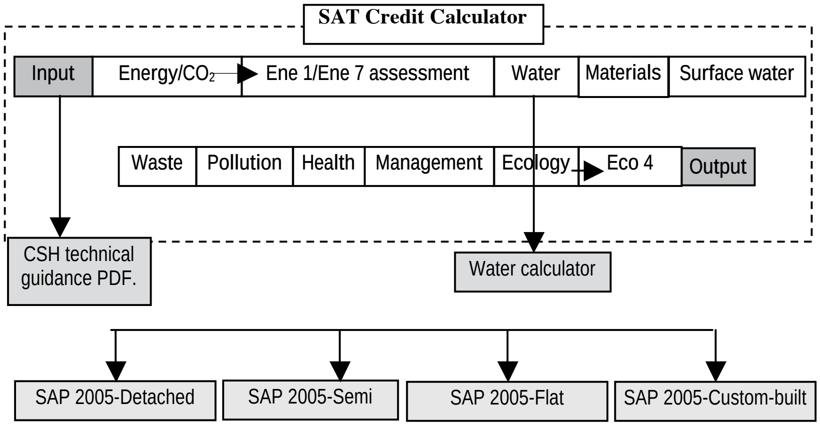


Figure 1. Architecture of the SAT toolkit

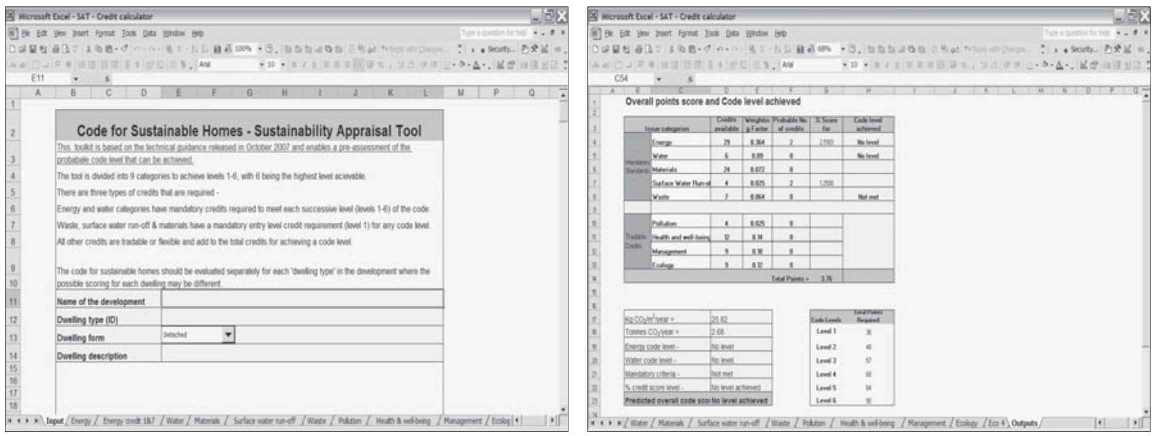


Figure 2. The Input and Output sheet of the SAT toolkit

- SAP worksheet, which is chosen according to the dwelling's built form:
  SAP-Detached
  SAP-Mid-terrace
  SAP-Flats
  SAP-custom-built
- CSH-technical guidance document

The '*SAT Credit calculator*' is the main file, which is linked directly or indirectly to all other files in the SAT toolkit. The credit calculator has 13 sub-worksheets in all: one for each of the nine CSH categories, an *Input* worksheet to select the type of house being evaluated, and an *Output* worksheet which displays the results. The *Energy 1 & 7* calculation file is further linked to an integrated dynamic *Standard Assessment Procedure (SAP)* 2005 worksheet, while the *Water calculator* provides the underlying calculation for assessing the water related credits.

The SAT toolkit works on an individual house level. It allows the user to select the type of house (detached, mid-terraced, flat, customise as per user input) being evaluated in the *Input sheet* (*SAT Credit calculator*); fill in the required data in a corresponding SAP 2005 worksheet, followed by the *Water calculator* linked to the *Water* worksheet; and then complete the remaining worksheets for other CSH categories. Apart from *Energy 1 & 7* and *Water,* all other CSH categories are implemented in SAT as a checklist of measures. Based on completed worksheets (from *Input* worksheet to *Eco4*), the final results are displayed in the *Output* worksheet, stating what level of CSH has been achieved for the overall dwelling. In addition, the *SAT-custom-built* worksheet also allows the evaluation of any custom built house, requiring specific data to be input in the linked SAP files.

The results from the '*SAT Credit calculator*' and '*Water calculator*' worksheets were validated against excel worksheets provided by the BRE for evaluation of CSH level ratings - this instils confidence in the outputs from SAT. A unique feature of the SAT toolkit is its dynamic linkage to an integrated SAP 2005 worksheet (detached, mid-terraced, flat, custom-built) and as a result, even minor changes made in the SAP 2005 worksheet enables designers to see the effect on achieving target code levels. The transparency of the toolkit allows the user to see absolute figures and compare one strategy against the other in terms of energy savings.

Once the SAT toolkit was developed and validated, it was used to appraise options for achieving levels 4, 5 & 6 of the CSH. Given the weightage and importance of energy/CO_2 credits (*ENE 1*) in CSH, this paper primarily focuses on achieving the mandatory energy criteria (*ENE 1*) for percentage improvement achieved over the target emission rate of a 2006 Part L building regulations compliant house. All other sustainability criteria were analysed as a part of the wider research project and can be accessed from a published report by Gupta and Chandiwala (2008).

Methodology for SAT appraisal options

The code puts forward demanding energy targets for future housing developments. For evaluating options, this paper focuses on achieving the mandatory energy target *ENE 1*. The Energy 1 credit – '*Energy and CO_2 emissions*' is calculated based on the SAP worksheet and specifies percentage improvement in the Dwelling Emission Rate (DER) over the current building regulations Part L, 2006 standards, specified in SAP as the Target Emission Rate (TER). Each level is achieved by improving the energy performance of the dwelling by a required percentage (Table 1). The percentage improvement is met by first, increased energy efficiency measures followed by renewable technologies if required.

It is realised that CSH guidance does not specify any absolute targets for either energy use or carbon emissions and barring a few exceptions, such as the maximum heat loss parameter for a code 6 house to be less than 0.08W/m^{2}K, no design limits are specified to be met at each level, as long as the dwelling is building regulations compliant and achieves the specified percentage improvement target for the code level. In this paper, to achieve technically and economically-feasible options, dwellings were modelled first, to maximise an energy-efficient fabric to reduce demand for energy, and then low and zero carbon technologies added to achieve percentage reduction of CO_2 emissions, for a respective code level. This is in line with our proposed 'low-energy first and then low-carbon' approach, in contrast with a 'low-carbon' approach which could jump over low-energy and concentrate too much on low-carbon supplies (both renewables on-site and fuel supplies from outside) that purport to have low carbon factors.

Three typical house types in the UK were chosen as a representative sample for this study from the Standard Dwellings Configuration Report (BEPAC, 1990). The report provides a set of standard benchmark dwellings representing typical UK house types. The three chosen house-types were: Detached house (2 storeys) - 104m^2; Mid-terrace house (2 storeys) - 79m^2; Traditional low rise flat (up to 4 storeys) - 61m^2. Building drawings for each dwelling type can be accessed from appendix A, at the end of the paper. Each dwelling type is assessed as an individual dwelling, as part of a 25-house development and as part of a 250-dwellings development. The different scales of development allow assessment of the feasibility of using community schemes towards achieving different code levels. In all, 24 options were evaluated across three levels of the code. Each option was first evaluated in the linked SAP worksheets specifying figures for fabric U-values, ventilation rates, air tightness, thermal bridging, space and water heating type with controls, and low and zero carbon (LZC) technologies. The results were then evaluated through the *SAT Credit calculator* sheet to assess the level reached for *ENE 1*.

BUILDING FABRIC

CSH specifies a percentage reduction in emissions over the notional baseline building regulations for energy use in new houses, and the levels are defined from 10% reduction to 100% reduction for a level 5 house that includes energy use for all space and water heating, and electricity for lighting (regulated energy use). For a level 6 house, electricity for cooking and appliances is also taken into account and this leads to a 150-170% improvement above a baseline complaint house. CSH does not specify detailed design criteria. However for this research, a number of available UK energy efficient standards were compared, to formulate a building energy standard for a low-energy low carbon-home. Notably, there are three main standards available in the UK.

1. Passiv haus Institut – Passiv-Haus standard
2. Association of Environment Conscious Builders (AECB) – Silver, Passiv haus and Gold standards.
3. Energy Saving Trust (EST) – Good, Best and Advanced practice standards

The Passiv-haus target is the most commonly known Eurospean energy standard and defines a house in which a comfortable interior climate can be maintained without active heating and cooling systems. The house is built to a specification where it can heat or cool itself and hence 'Passive'. The design space-heating load is limited to around 15 kWh/m^2/yr (can be between 10-20 kWh/m^2/yr, depending on climate) and the total primary energy for all uses is limited to around 120 kWh/m^2/yr. The Association of Environment Conscious Builders (AECB) has also outlined a set of standards as a result of their Carbonlite programme, bringing together expertise from the mainstream construction sector. Their *Silver standard* corresponds to readily available and tested strategies, the *Passive-haus standard* as the name suggests, requires a stringent fabric performance target matching the original standard. The *Gold standard* follows the Passiv-haus standards for the building fabric, but also includes additional criteria for more renewables to offset electricity related CO_2 emissions. The standards have a prescriptive as well as a performance-oriented approach to it. Similar to AECB's performance-based standards, the UK Government's Energy Saving Trust also defines three standards, specifying a percentage reduction over the building regulations TER (EST, 2006). In addition, EST also specifies design limits for a range of other criteria as part of achieving the standard. Their *Good practice* target and the *Best practice* target relate to a 10% and 25% improvement respectively. The *Advanced practice* target defines absolute targets based on the Passiv-haus target, in addition to a percentage target.

As seen, all the standards reviewed refer to the Passiv-haus standard but differ in the range of criteria that they specify. Therefore in this research, simulation results in SAT toolkit are based on EST targets due to their detailed specifications and reference to absolute targets specified by Passiv-haus. Firstly, selected house types (detached house -104m^2, mid-terraced house-79m^2 and a low-rise flat-61m^2) are assumed to have typical specifications meeting the building regulations Part L 2006 criteria as their baseline performance standard for energy, also called the *base case* scenario. These dwellings are then modelled in SAT to progressively stricter standards for fabric performance to analyse their effect on space heating and other energy end-use demands relative to attaining the higher code levels. Since the analysis primarily looks at achieving code levels 4 and higher, EST's *good practice* standard (close to 2006 Part L Building Regulation) has not been appraised. Instead the *base case* scenario is tested for EST's *best-practice* standard, followed by the *advanced-practice* (selective criteria) standards. Table 2

Table 2. Specifications of building regulations and EST standards

Criteria	Building regulations	Best practice	Advanced practice (Similar to PassivHaus)
Target emission rate (TER)	DER<=TER	TER (best practice) = TER x 0.75	TER (advanced practice) = TER x 0.40
U-values	Roof: 0.25 W/m^{2}K (0.20 W/m^{2}K) Walls: 0.35 W/m^{2}K (0.30 W/m^{2}K) Exposed floors: 0.25 W/m^{2}K (0.20 W/m^{2}K)	Roof: 0.13 W/m^{2}K Walls: 0.25 W/m^{2}K Exposed floors: 0.20 W/m^{2}K	Opaque <=0.15 W/m^{2}K (Roof: Roof: 0.13 W/m^{2}K)
Windows and doors	U-values <=2.2 W/m^{2}K (Windows=1.9 W/m^{2}K) (Solid doors=2.0 W/m^{2}K)	Windows: BFRC rating band C or better (1.2 W/m^{2}K) Doors: U-values <=1.0 W/m^{2}K (solid)	Openings (glazing and frames) <=0.8 W/m^{2}K
Space heating	Should conform to 'domestic Heating Compliance Guide'	Should conform to CHeSS HR6 or HC6 (2005)	Space heating <=15 kWh/m^2/yr Primary energy demand (all end uses) <=120 kWh/m^2/yr
Air permeability	Less than 10 m^3/m^{2}hr at 50 Pa (7 m^3/m^{2}hr)	Less than 3 m^3/m^{2}hr at 50 Pa	Less than 1m^3/m^{2}hr at 50Pa
Limiting of Thermal bridging	Accredited construction details	Accredited construction details (<=0.04 W/mK)	Practically eliminated, <=0.01 W/mK
Ventilation	Purpose provided ventilation	MVHR 85% efficiency, 1 W/(l.s) Specific fan power (SPF)	MVHR 85% efficiency, 1 W/(l.s) Specific fan power (SPF)

Note: U-values mentioned are the limiting values for the standard. The value inside the parenthesis is the value used while modelling the baseline scenarios.

The advanced practice target has also been modelled with slightly higher air permeability (3m3/m2hr) and thermal bridging (0.03 W/mK) values to keep the target close to what is 'practically' achievable within the industry currently and not overestimate savings.

Table 3. Indicative Costs for low and zero carbon technologies

Technologies	Cost – Low (£) (250 houses)	Cost – Average (£) (25 houses)	Cost – High (£) (single house)
Solar thermal panel 4m^2	3200	3850	4500
PV 1kWp system	5000	6500	8000
Wind turbine per kW*	3500	5000	-
Biomass wood pellet boiler - 20kW	5500	8750	12000

Note: All costs have been derived from the Low Carbon Buildings Programme.

**Cost for wind has been derived from British Wind Energy Association*

specifies the main criteria for these two EST standards and how they compare with the 2006 Part L building regulations.

COSTS

As recognised widely, exact capital costs are difficult to estimate, especially, costs for fabric-related changes such as increased insulation, high performance glazing etc as they are dependent on contractor costs, supplier chains, location aspects and development scales amongst other things. However to assess feasibility of different options in this study, it is important to relate to capital costs, as a key challenges in achieving higher code levels is the increase in capital costs (Cyrill Sweett, 2007). One of the more substantial costs for achieving higher code levels is that of the low and zero carbon technologies. Indicative costs for these systems have been provided (Table 3) to give an idea about additional costs that may be involved at each successive level of the code.

Appraisal options to achieve code levels

The SAT toolkit was used to develop 24 appraisal options for achieving levels 4, 5 and 6 of the Code for Sustainable homes. Detailed energy criteria were defined for three typical dwelling types as explained in the sub-sections below. Each dwelling type was assessed as an individual house, as a part of 25-house development and as a 250-house development. This allowed SAT toolkit to assess the feasibility of using community schemes to achieve the different code levels.

ENERGY EFFICIENCY

Detached house

The table below shows how successive stringent standards affect the space, water heating and the regulated electricity demand for a detached house (104 m^2). It also shows percentage improvement achieved over 2006 Part L building regulations in comparison with the EST targets.

Table 4. Predicted energy use (Gas and electricity) for detached house

Detached house TER = 23.35	DER	Heat loss ratio	Space heating			Water heating		Regulated Electricity (Pumps & lighting)		Percentage improvement over TER
			kWh/yr	$kgCO_2$/yr	$kWh/m^2/yr$	kWh/yr	$kgCO_2$/yr	kWh/yr	$kgCO_2$/yr	
Baseline building regulation	22.02	1.57	5855	1257	56.30	3209	622.55	971	409.76	5.71%
Best practice (TER*0.75 = 17.51)*	16.48	0.98	2578	554	24.79	3209	622.55	1276	538.47	29.40%
Advanced practice (TER*0.4 =9.34) AP= $3m^3/m^2hr$, ψ = 0.03W/mK	14.29	0.73	1514	325	14.56	3209	622.55	1276	538.47	38.81%
Advanced practice (TER*0.4 =9.34)* AP= $1m^3/m^2hr$, ψ = 0.01W/mK	13.34	0.61	1057	227	10.16	3209	622.55	1276	538.47	42.85%

Note: all specifications are based as per the EST standard. Any exceptions are mentioned below the target.

AP =Air permeability value

ψ = limiting of thermal bridging value

** Value in parenthesis is the TER requirement as per the specific EST standard.*

EST's *best practice* standard used for building fabric specifications is able to achieve code level 3 requirements, with a 29.40% reduction in CO_2 emissions over building regulations. The space-heating requirement is almost halved when compared to the building regulations compliant house and the annual space heating demand per unit area is reduced by half to 25 $kWh/m^2/yr$ as against 56.3 $kWh/m^2/yr$ (Table 4). The additional 300 kWh/yr (1276 kWh – 971kWh) of regulated electricity use is due to the introduction of mechanical ventilation with heat recovery (MVHR) system. The *advanced practice* standard has been modelled with two sets of values: for air permeability and thermal bridging that can be practically achieved through robust construction details. It is important to remember that modelling should not provide results from only a purely theoretical model, but also consider the 'achievability' factor to keep savings realistic. For example, current UK construction practices generally do not achieve elimination of thermal bridging and air permeability rates less than 1 $m^3/m^2/hr$ on a mass scale. This is why air permeability rates up to 1 $m^3/m^2/hr$ have been considered in this research, in line with expected skills and practices.

In both *advanced practice* scenarios, the heat loss parameter (HLP) is reduced to less than 0.8, which is a mandatory design requirement to achieve a level 6 house (CLG, 2007). The space heating is greatly reduced, to less than 15 $kWh/m^2/yr$ requirement of Passiv haus standard. All other end uses remain the same. This leads to almost a 38% reduction in emissions. Reducing the ventilation rate to 1 m^3/m^2hr and practically eliminating thermal bridging by reducing it to 0.01 W/mK, leads to an overall improvement of 42.85% which is close to the Code level 4 requirement of 44% improvement. As a result, the space-heating requirement is reduced to a marginal 10 $kWh/m^2/yr$. Given that the CO_2 factor of grid electricity in UK (1 kWh of grid electricity = 0.422 $kgCO_2/m^2$/year) is two and a half times dirtier than gas (1 kWh of grid electricity = 0.194 $kgCO_2/m^2$/year), these scenarios assume a central gas heating system with 90.2% efficiency. Although houses built to a Passiv-haus standard (requiring less than 15 $kWh/m^2/yr$ of space heating) do not require a central heating system, as for such a small heating load the fabric is capable of maintaining comfortable internal temperatures. This marginal heating load may be met in Passiv houses by a compact services unit combining heating, hot water with the mechanical ventilation unit (Passivhaus Institut). This requires some form of additional heating to be accounted for, provided with electricity.

Therefore further scenarios assessing the variation in CO2 emissions and percentage improvement over TER, were modelled by assuming that the (small) heating component is derived from electricity including water heating, as per SAP assumptions, in the absence of a central heating system. Another scenario was modelled where, in the absence of a central heating system, the primary space-heating component is reduced to 10% of the total demand, which is met by electricity. Although it should be noted that in a SAP 2005 model, a fuel factor correction figure of 1.47 is applied for electrically-heated homes (compared to the base case of 1 for gas) to make it slightly easier for an electric (or oil) heated house to pass the CO2 emissions target (CLG, 2007). This raises the maximum allowable CO2 emissions per unit floor area by that factor, such that a home with electric heating is allowed to have nearly 50% higher CO2 emissions than if it had gas heating. If this factor wasn't there it would be very difficult to build a new house with electric heating.

This is why as shown in Table 5, for an electrically-heated detached house, the TER increases to 33.12% as compared to 23.35% for a detached house with gas central heating system. Assuming that the entire heat load is met by electricity, it gives a percentage improvement of 38%, which is similar to the percentage improvement when gas is used as a fuel (Table 4). However, if the two scenarios (gas boiler and electric heating) are compared in absolute carbon emissions; the DER for electrical heating is much higher at 20.54. This compares with only a 12% improvement over the gas based TER. A similar trend is observed when only additional electrical heating is provided (assumed to be 10%) and solar thermal panels meet part of the water-heating load.

It is important to note, that even a small requirement of space heating and hot water, if met only by electricity, leads to

Table 5. Predicted energy use for detached house: Electrically heated

	Detached house TER = 33.12	DER	Heat loss ratio	Space heating			Water heating		Regulated Electricity (Pumps & lighting)		Percentage improvement over TER	
				kWh/yr	$kgCO_2$/yr	kWh/m^2/yr	kWh/yr	$kgCO_2$/yr	kWh/yr	$kgCO_2$/yr	Actual (Elec.)	*Compared to Gas*
1	**Advanced practice** (TER*0.4= 13.25) (All heating by electricity)	20.54	0.73	1428	602	13.73	2535	1069.8	1101	464.62	37.98	*12.03*
2	**Level 4** (only secondary heating and water heating by electricity)	15.33	0.73	143	60	-	2535	1069.8	1101	464.62	53.72	*34.33*
3	**Level 4** (as option (2)+ $4m^2$ solar thermal)	11.94	0.73	143	60	-	1624	685.8	1176	496.27	63.96	*43.25*
4	**Level 5** (as option (2)+ $4m^2$ solar thermal + 2.75 kWp PV)	-0.08	0.73	143	60	-	1624	685.8	1176	496.27	100.24	*100.34*
5	**Level 6** (as option (2)+ $4m^2$ solar thermal + 5.25kWp PV)	-12.31	0.73	149	60	-	1624	685.8	848	496.27	137.84	*152.7*

Note: all options are based on advanced practice standard and have been modelled without a central gas heating system. The TER is different due to the change of fuel to electricity which has a higher carbon factor than gas. The air ventilation rate is $3m^3/m^2$/hr, thermal bridging ψ=0.03 W/mK and 30% EE lighting (except level 6, 100% EE)

Further details of all options are listed below.

Includes all primary, secondary space heating and hot water requirement with electricity as SAP assumes in absence of a central heating system.

The primary heating component is eliminated, only secondary space heating and water heating by electricity.

Secondary space heating and water heating by electricity, and 4 m^2 of flat plate solar thermal panels,

Secondary space heating and water heating by electricity, 4 m^2 of flat plate solar thermal panels, 2.75 kWp of PV

Secondary space heating and water heating by electricity, 4 m^2 of flat plate solar thermal panels, 5.6 kWp of PV, 100% EE lighting

a greater TER and facilitates a higher percentage improvement leading to a higher code level target. But, in absolute terms, it also leads to greater CO_2 emissions, especially for code levels 3 and 4. Since, code level 5 and 6 require 100% or greater improvements to the TER, in both scenarios, the entire CO_2 emissions requirement is offset. Even at higher code levels, it is worthwhile to consider, that post-occupancy evaluations of buildings, have often shown actual consumption levels to be much higher than those considered at design simulation levels. Assuming, this to be the case, it will be beneficial to provide the additional heating demand, however small, by a fuel with a lesser carbon factor. A similar level of analysis was done for the mid-terrace and the same trend was observed. Further details can be accessed from appendix B at the end of the paper. For flats, the analysis shows a different trend and is discussed in the later section under low-rise flats.

Mid-terrace house

Modelling using the SAT toolkit for a mid-terrace house shows that a 27% improvement over TER can be achieved by *best practice* standards alone as shown in scenario 2 of Table 6. *Advanced practice* EST standards achieve a 33-36% improvement (scenarios 3 and 4) based on values of air permeability and limiting of thermal bridging. For a mid-terrace house, *best practice* standards are able to achieve a low heat loss coefficient of less than 0.8, which reduces further to 0.51 by using advanced practice standards. There is a marginal annual space-heating load of 6.4kWh/m²/yr, which is well below the Passiv haus standard of 15 kWh/m²/yr.

Low-rise Flat

The EST targets applied to a low-rise flat demonstrate that achieving higher code level target becomes difficult for houses with smaller area. *Best practice* standards just manage to achieve a 22.75% improvement above the baseline TER even though the heating requirement is only about 16 kWh/m²/yr. The *advanced practice* target varies between a 27-30% improvement hence, just above the level 3 target of 25% improvement.

Since the space-heating requirement is marginal in flats, it was replaced entirely with electrical heating to see the effect on DER. The following table shows that *advanced practice* targets and electrical heating lead to a 34% improvement. However, when compared in absolute terms for carbon emissions, the improvement in the DER for electrically heated houses is found to be marginal at 8% than the gas TER. This is similar to the baseline building regulation compliance case if gas is used as the main fuel (table 7). This shows, that smaller, more efficient dwellings might be penalised and may find it harder to achieve the percentage improvement targets as per the CSH guidance.

The energy efficiency analysis to achieve a well-performing fabric shows that substantial savings in space heating energy and a greater percentage improvement over the Baseline TER

Table 6. Predicted energy use (Gas and electricity) for mid-terrace house

	Mid-terrace house TER = 21.38	DER	Heat loss ratio	Space heating			Water heating		Regulated Electricity (Pumps & lighting)		Percentage improvement over TER
				kWh/yr	kgCO_2/yr	kWh/m^2/yr	kWh/yr	kgCO_2/yr	kWh/yr	kgCO_2/yr	
1	**Baseline building regulation**	19.39	1.33	3062	658	38.76	2791	541.45	782	330.00	9.31
2	**Best practice** (TER*0.75=16.04)	15.45	0.79	1178	253	14.91	2791	541.45	1003	423.27	27.76
3	**Advanced practice** (TER*0.4=8.55) (AP= 3 m^3/m^{2}hr, ψ = 0.03W/mK)	14.19	0.61	717	155	9.1	2791	541.45	1003	423.27	33.63
4	**Advanced practice** (TER*0.4=8.55) (AP= 1 m^3/m^{2}hr, ψ = 0.01W/mK)	13.60	0.51	502	107	6.35	2791	541.45	1125	474.75	36.38

Note: all specifications are based as per the EST standard. Any exceptions are mentioned below the target.

AP =Air permeability value

ψ = limiting of thermal bridging value

** Value in parenthesis is the TER requirement as per the specific EST standard.*

Table 7. Predicted energy use (Gas and electricity) for low-rise flat

	Low –rise Flat TER=22.30	DER	Heat loss ratio	Space heating			Water heating		Regulated Electricity (Pumps & lighting)		Percentage improvement over TER
				kWh/yr	kgCO^2/yr	kWh/m^2/yr	kWh/yr	kgCO^2/yr	kWh/yr	kgCO^2/yr	
1	**Baseline building regulation**	20.44	1.22	2248	482	36.85	2476	480	670	283	8.35
2	**Best practice** (TER*0.75 = 16.7)	17.23	0.78	986	212	16.16	2476	480	848	358	22.75
3	**Advanced practice** (TER*0.4=8.92) (AP= 3m3/m2hr, ψ = 0.03W/mK)	16.09	0.63	662	142	10.85	2476	480	848	358	27.86
4	**Advanced practice** (TER*0.4=8.92) (AP= 1m3/m2hr, ψ = 0.01W/mK)	15.45	0.53	481	103	7.88	2476	480	848	358	30.73

Note: all specifications are based as per the EST standard. Any exceptions are mentioned below the target.

AP =Air permeability value

ψ = limiting of thermal bridging value

** Value in parenthesis is the TER requirement as per the specific EST standard.*

Table 8. Predicted energy use for low-rise flat: Electrically heated

Low rise flat Electrical heating TER = 31.58	DER	Heat loss ratio	Space heating			Water heating		Regulated Electricity (Pumps & lighting		Percentage improvement over TER	
			kWh/yr	kgCO_2/yr	kWh/m^2/yr	kWh/yr	kgCO_2/yr	kWh/yr	kgCO_2/yr	Actual (Elec.)	*Compared to Gas*
Advanced practice (TER*0.4=12.63) (AP= 1m^3/m^{2}hr, ψ = 0.01 W/mK)	20.85	0.53	464	197	7.6	1874	791	673	284	33.96%	8.1%

Table 9: Indicative strategies and costs for Low and zero carbon technologies

	Detached		Mid-terrace		Low rise flats	
	Key strategies	Cost (£) /house	Key strategies	Cost(£) /house	Key strategies	Cost(£) /flat
Level 4						
Single house	4 m^2 flat plate solar thermal	4500	3 m^2 flat plate solar thermal	3375	_	
25 houses *(24 flats)*	75m^2 flat plate solar thermal (3 m^2 each)	2889	75m^2 flat plate solar thermal (3m^2 each)	2889	9.6 kWp of PV panels shared (0.40 kWp each)	2600
250 houses *(240 flats)*	Communal CHP with gas fired boilers	Site specific	Communal CHP with gas fired boilers	Site specific	Communal CHP with gas fired boilers	Site specific
Level 5						
Single house	4m^2 flat plate solar thermal+2.7 kWp of PV	26,100	3 m^2 flat plate solar thermal+2.1 kWp of PV	20,175	_	
25 houses *(24 flats)*	Communal biomass boiler+30 kWp PV panels	Site specific +7800	Communal biomass boiler+22.5 kWp PV panels	Site specific+ 5850	Communal biomass boiler +24 kWp PV panels (1 kWp each)	Site specific+ 6500
250 houses *(240 flats)*	Communal biomass CHP+140 kWp PV panels	Site specific+ 2800	Communal biomass CHP 57 kWp PV panels	Site specific+ 1140	Communal biomass CHP 84 kWp PV panels (0.35 kWp each)	Site specific+ 1750
Level 6						
Single house	4 m^2 flat plate solar thermal+5.25 kWp of PV	46,500	3 m^2 flat plate solar thermal+4.4 kWp of PV	38,575	_	
25 houses *(24 flats)*	Communal biomass boiler+37.5 Kwp of PV + 2x15 kw wind turbines	Site specific+ 15,750	Communal biomass boiler+30 Kwp of PV + 2x 15kw wind turbines	Site specific+ 13,800	Communal biomass boiler+24 kWp of PV + 2x15 kw wind turbines	Site specific+ 12,750
250 houses *(24 flats)*	Communal biomass CHP+750 kWp of PV + 4x15 kw wind turbine	Site specific+ 15,840	Communal biomass CHP +625 kWp of PV + 4x15 kw wind turbine	Site specific+ 13,340	Communal biomass CHP +483 kWp of PV + 4x15 kw wind turbine	Site specific+ 10,938

can be achieved if stringent standards are followed. In detached and mid-terrace houses, EST best practice standard met the criterion for level 3 energy requirements and advanced practice achieved about 40% improvement over baseline. If rigorous construction procedures and detailing are followed, these savings can be replicated across developments maximising carbon emission reductions. The analysis also shows that using the percentage improvement target from TER makes it easier for larger houses to achieve higher code level targets (104 m^2 detached house), as compared to smaller efficient houses such as flats (61 m^2) with a lower space heating demand.

Using electric heating instead of gas heating, even for a marginal space heating demand increases the TER and makes it easier for dwellings to achieve a greater percentage improvement and hence code levels 3 and 4. For level 5 and 6, this is negated due to a 100% improvement target, which means all regulated and unregulated energy use respectively must be accounted for.

In all dwellings, the EST's *advanced practice* standard achieves considerable savings in energy end use. However, the absolute targets defined by the EST standard (TER*0.4) is not met, implying, that building fabric improvement should be used in combination with low and zero carbon (LZC) reductions to achieve further reductions in the dwelling emission rates.

Low and zero carbon (LZC) technologies

To meet the requirements of ENE 1 criteria, for code levels 4, 5 and 6, low and zero carbon (LZC) technologies are deployed in the SAT toolkit. LZC are defined as development-wide, onsite or building integrated technologies that use, fossil fuels very efficiently to have low CO_2 emissions (ground source heat pumps, combined heat and power), or renewable sources having zero operational CO_2 emissions. LZC technologies can be used to offset the energy requirements in dwellings by generating heat, electricity or both. Table 8 provides a comparative assessment of additional LZC strategies deployed in this research to achieve levels 4, 5 and 6 using the SAT toolkit. For all dwelling types, fabric performance relative to the EST's *advanced practice* has been taken as the base case. Each dwelling type except a low-rise flat is assessed as a single dwelling, as well as a part of a mid and large-scale development allowing the use of community level solutions. The table also provides 'additional capital cost per dwelling' (ACD) for each option.

Level 4

Level 4 requires a 44% improvement over 2006 building regulations for the dwelling. Housing Corporation in the UK has already announced preference for schemes aiming to achieve level 4, though it is not expected to be a requirement of mainstream funding till after 2010. For a single dwelling, about 44% improvement is achieved by incorporating solar thermal panels with a well-performing fabric. The cost is reduced when the strategy is used over a larger number of houses; the ACD varies from £4500 (Euro 4785) for a single dwelling to about £2889 (Euro 3072) for a 25-house development. For low-rise flats, ACD amounts to £2600 (Euro 2765) of additional capital cost. For larger developments, communal CHP gas fired boilers can achieve the target percentage improvement. The costs for such systems are specific to the site. Moreover, SAP methodology only accounts for the energy provided by a communal system but does not indicate a system size, hence, community systems have not been provided with an indicative cost.

Level 5

Level 5 of the CSH, requires a 100% improvement over the 2006 building regulations. This means, that all energy accounted for in SAP, including, space and water heating and lighting must be either equal to zero or negative. Level 5 represents a much higher target when compared to level 4. Cost for level 5 in individual dwellings varies from £26,000 (Euro 27,645) for a detached to £20,000 (Euro 21,265) for a smaller mid-terrace house. For larger development, it was found, that while it was possible to achieve level 4 by savings through a communal heating systems, a 100% reduction necessarily required a combination of more than one technology.

Level 6

Level 6 is the highest and the most difficult level to achieve for the construction industry, requiring stringent standards for the building envelope and accounting for all the energy the house uses, including the energy used for appliances. On an average, this represents a 150-170% improvement over the 2006 building regulations. This is mostly reflective of the electricity use for appliances being highly carbon intensive. Level 6 defines the 'Zero carbon house' that the government aims to achieve as the standard for all houses built from 2016 onwards. As can be seen from the table, the additional cost for a single detached house to achieve level 6 is estimated to be about £46,500 (Euro 49,442) and around £38,500 (Euro 40,936) for a mid-terrace.

Currently, there is an ongoing debate about the definition of true zero carbon, as CSH only allows renewable energy to be counted towards reducing emissions for the house if it is directly connected by a private wire. Hence, any offsite renewables at present do not count towards CO_2 savings and cannot be used to achieve level 6. The policy is highly unlikely to be achievable for a large majority of the houses, especially those built in cities, where the provision of space and other natural sources such as the effectiveness of wind energy, might be limited. The modelled solutions for flats (table 8) reiterate this fact. A recently-published report by the UK Green Building Council (2008) points out that based on their study, around 10-80% of the new homes being built may not be able to meet the zero carbon targets as defined currently, and the government might need to reconsider the definition by allowing off-site renewables where on-site solutions are either very expensive or not possible.

To put the ACD results from the SAT toolkit analysis into context, the following table compares those results with research undertaken by English partnerships (2007) and CLG (2008) in terms of the estimated additional capital costs for each Code level.

Table 9 highlights the similarities in the results of all three evaluations, based on the proposed technological strategy for achieving specific code levels. Differences in costs in the three reports can be attributed to the energy efficiency criteria considered for each level and the cost as well as the sizing of renewable technologies while modelling. As discussed before, solutions modelled in SAT have followed the approach of maximising the performance of the building fabric to the most stringent standards to reduce the demand for energy first, and hence, the capital cost for LZC technologies for level 4 is greatly reduced. This is line with a 'low energy first, then low-carbon' approach.

Whilst the reports by English partnerships (2007) and CLG (2008) include cumulative cost of fabric performance and low carbon systems, the SAT modelled options only include the additional capital cost of deploying renewable technologies. The higher end costs in all scenarios are for the larger detached houses, and costs are reduced greatly for smaller dwellings such as the mid-terrace.

Conclusions

Code for sustainable homes currently defines the national standard for sustainability of new homes and serves as a guide to the future building regulations. The construction industry is gearing itself to address the demands of achieving higher CSH levels, which specify detailed sustainability criteria. It is imperative that this leads towards long-term strategic solutions resulting in CO_2 emissions reductions with minimal costs. An interactive and user-friendly tool, the Sustainability Appraisal Toolkit (SAT), was developed to enable evaluation of design and construction specifications for achieving target code levels and 24 appraisal options were analysed to achieve code levels 4,5 and 6 through a range of strategies.

Applying the SAT toolkit to achieve the mandatory energy target *(ENE1)*, for three typical UK dwelling types, it was found that energy and carbon emission savings can be maximised if stringent energy standards are followed for the fabric performance. The Code level 3 for detached and mid-terrace dwelling types can be achieved by using EST best practice standards. For all other levels, using demand-side advanced practice standards considerably reduces the requirement for supply-side low and zero carbon technologies. This is in line with a 'low energy first, then low carbon approach'.

For flats, however, advanced practice standards are required to achieve level 3 due to a limited exposed building fabric which minimises the possibility of heat losses. The analysis shows that using the percentage improvement target from TER makes it easier for larger houses or inefficient forms with a higher exposed surface area to achieve higher code level targets, especially, level 3 and 4, as compared to smaller houses with a lower TER. Replacing the type of fuel in the house from gas to electricity, which has a higher CO_2 factor, also has a similar effect, by increasing (easing) the dwelling TER. However in effect, the DER for such houses is much higher than a gas-heated dwelling, even with marginal heating loads. Therefore providing absolute energy (kWh/m^2/yr) and CO_2 targets (kgCO_2/m^2/yr) for specific levels of the code (taking into account occupant density), can be useful to address this issue, to ensure, houses

Table 10. Comparison of additional capital costs and technology options for achieving CSH levels

Criteria	English Partnerships & Housing Corporation 2007	Communities and Local Government 2008	SAT toolkit, Oxford Brookes University 2008
House types	1. Detached -116 m^2 2. Semi-detached/ end terrace– 101 m^2 3. Low rise Flats – 59 m^2 4. Medium/high rise flats – 75 m^2 5. 3 other house types built using MMC (house types 4 & 5 is not compared in the table)	1. Detached House -104 m^2 2. End terrace/Semi– 76 m^2 3. Mid-terrace – 76 m^2 4. Flats – 60 m^2	1. Detached -104 m^2 2. Mid-terrace – 79 m^2 3. Flats – 61 m^2
Different packages used for energy	1. Energy efficiency (EE) + solar thermal+ PV + biomass 2. Energy efficiency +Small scale wind turbines + biomass. 3. Development with shared energy services, CHP, costs per unit are averaged for a theoretical 200 home development. 4. Increased energy efficiency, whole house mechanical ventilation and no renewable energy.	No energy package but house types are further grouped to make development types'. Strategies chosen are based on these – defined by location and density. 1. Small scale – 30 dwelling/hectare 2. City infill – 180 dwelling/ha 3. Market town – 50 dwelling/ha 4. Urban regeneration – 160 dwelling/ha	No particular packages that are tried for each house to achieve specific level, 30 options are evaluated for achieving levels 3,4,5,6 1. Each level for a single house, 2. 25 home development, 3. 250 home development.
Code levels	Level 1-5	Level 1-6	Level 3,4,5 &6
Level 3 Technology	EE+ solar thermal/ Wind/ EE	EE+ solar thermal and/ or PV	Energy efficiency, EE +PV
Level 3 Costs	**Detached** £1693-4481 **End-terrace** £1693-3971 **Low-rise flat** £1600-2907	**Detached** £3916-5536 **End-terrace** £3692-4020 **Mid- terrace** £3581-3916 **Flat** £2622	**Detached** Efficient (Best practice) building fabric **Mid-terrace:** Efficient (Best practice) building fabric **Low-rise flat**: Efficient (Advanced practice) building fabric
Level 4 Technology	EE+ solar thermal and PV / Wind/ CHP	EE+Solar thermal and PV /Biomass	EE+ Solar thermal and PV / gas CHP
Level 4	**Detached** £2622-13,525 **End-terrace** £1349-7590 **Low-rise flat** £1600-2907	**Detached** £8223-10,914 **End-terrace** £5880-7115 **Mid- terrace** £5133-6187 **Flat** £4782-5054	**Detached** Site specific - £4500 **Mid-terrace** Site specific -£3375 **Low-rise flat** Site specific - £2600
Level 5 Technology	EE+ solar thermal +PV +Biomass/ EE+Wind+Biomass	EE+PV+Biomass / EE+Biomass CHP	EE+ solar thermal +PV / EE+ Biomass CHP+ PV+ Wind
Level 5	**Detached** £14943-20270 **End-terrace** £14365-19962 **Low-rise flat** £21,742-29951	**Detached** £14,254-22,367 **End-terrace** £10,278-13292 **Mid-terrace** £8938-11,933 **Flat** £8289-12,055	**Detached** Site specific- £26,100 **Mid terrace** Site specific -£20,175 **Low-rise flat** £Site specific
Level 6 Technology	Not assessed	Advanced EE+PV+Biomass / EE+Biomass CHP	EE+ solar thermal +PV / EE+ Biomass CHP+ PV
Level 6	Not assessed	**Detached** £31125-40,228 **End-terrace** £23,631-29,393 **Mid-terrace** £23,569-29,172 **Flat** £16,775-18,996	**Detached** £Site specific-46800 **Mid-terrace** £ Site specific -38,575 **Low-rise flat** £Site specific

built to the same level are comparable in the amount of CO_2 they emit.

It was found; code levels 3 and 4 are achievable with a well-performing fabric combined with some low and zero carbon technologies for detached and semi-detached houses. Levels 5 and 6 require a 100% improvement over building levels, with level 6 accounting for even appliance use. The cost for a single detached house to achieve level 5 is around £26,000. For level 6, it increases to £46,500. This shows, how prohibitively expensive the higher code levels become due to additional LZC costs. It is hence, imperative to reduce energy use in the building to as much as possible before using LZC technologies for energy generation. Higher levels of savings can be expected from community-level strategies. It is concluded that a mix of energy technologies is required, especially to achieve higher code levels, depending on the site for different scales of development and the cost varies greatly in each scenario. It is hoped that these solution-based findings provide guidance to both public and private housing providers in achieving different levels of CSH in the coming years.

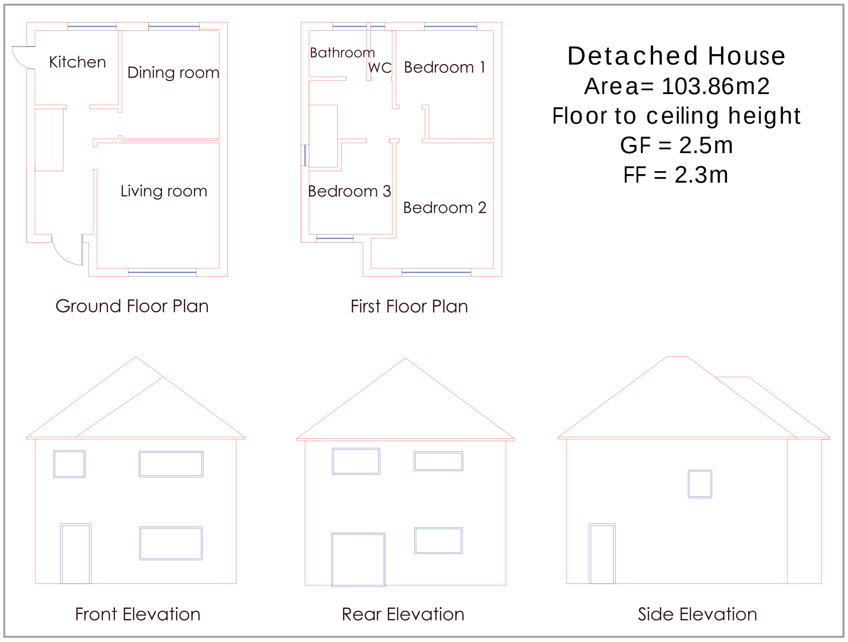
References

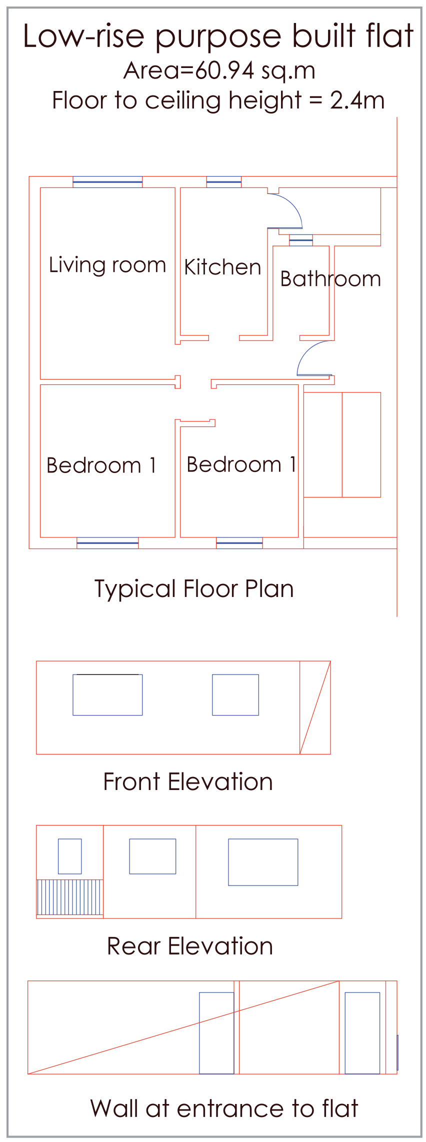
1. Stern, *Stern review: the economics of climate change*. 2006, The Stationery Office: London.
2. Barker, K., *Review of Housing Supply: Delivering Stability-Securing our Future Housing Needs*. 2004.
3. Roaf, S., A. Horsley, and R. Gupta, *Closing the loop: benchmarks for sustainable buildings*. 2004, London: RIBA Enterprises.
4. CLG, C.a.L.G., *Building a Greener Future: Towards Zero Carbon Development*. 2007, Department for Communities and Local Government, London.
5. BEPAC, *Standard dwellings for modelling: details of dimensions, construction and occupancy schedules*. 1990, BRE.
6. CLG, Building *a Greener Future: Policy Statement*. 2007.
7. CLG, *Building Regulations: Energy efficiency requirements for new dwellings* 2007, Department for Communities and Local Government, London.
8. Cyrill Sweett, *A cost review of the Code for Sustainable Homes* 2007, English Partnerships, Housing Corporation.
9. Energy Saving Trust, *Demonstrating Compliance: Best Practice*. 2006, EST.
10. Energy Saving Trust, *Demonstrating Compliance: Advanced Practice*. 2006, EST.
11. Environment Agency, *Assessing the cost of compliance with the Code for Sustainable Homes*. 2007, Environment Agency.
12. Cyrill Sweett, *A cost review of the Code for Sustainable Homes* 2007, English Partnerships, Housing Corporation.
13. DEFRA, *The Government's Standard Assessment Procedure for Energy Rating of Dwellings*. 2005, BRE.
14. CLG, *Code for Sustainable Homes - Technical Guide*. 2008, Department for Communities and Local Government, London
15. English Partnerships, *English Partnerships' Quality Standards: Delivering quality spaces*. 2007.
16. Gupta R, Chandiwala, S, Development and Application of Sustainability Appraisal Toolkit (SAT), Oxford Brookes University
17. Housing Corporation, *Design and Quality Strategy*. 2007, Housing Corporation: London.
18. Department for Business Enterprise and Regulatory Reform. *Low Carbon Buildings Programme: Microgeneration technologies*. [Cited 2008 7 March]; Available from: http://www.lowcarbonbuildings.org.uk/micro/.
19. BWEA. *British Wind Energy Association*. [Cited 2008 6 march]; Available from: http://www.bwea.com/index.html.
20. UKGBC, *The definition of Zero Carbon*. 2008, UK Green Building Council.
21. EST, *Energy Efficiency and the Code for Sustainable Homes: Level 3*. 2008, Energy Saving Trust.
22. EST, *Energy Efficiency and the Code for Sustainable Homes: Level 4*. 2008, Energy Saving Trust.
23. EST, *Energy Efficiency and the Code for Sustainable Homes: Level 5 & 6*. 2008, Energy Saving Trust.
24. Passiv Haus Intitut, what is a Passive house? (cited 2009 5 January); Available from http://www.passiv.de/
25. AECB Carbon lite, Energy Performance Standards, ((cited 2009 5 January), Available from http://www.carbonlite.org.uk/carbonlite/energystandards.php
26. CLG, Cost analysis of the Code for Sustainable Homes, 2008, Department for Communities and Local Government, London
27. CLG, Research to assess the costs and benefits of the Government's proposals to reduce the carbon footprint of new housing development, 2008, Department for Communities and Local Government, London
28. CLG, Definition of zero carbon homes and non-domestic buildings, 2008, Department for Communities and Local Government, London
29. BRE, Applying the code for sustainable homes on the BRE innovation park, Lessons learnt about building fabric, 2008, IP 9/08, BRE, London

Acknowledgements

The authors gratefully acknowledge the guidance documents provided by Energy Saving Trust and BRE. The authors are also grateful to Homegroup Ltd for commissioning Oxford Brookes University to undertake this research.

Appendix A: Building drawings of typical houses





Appendix B: Mid terrace house

The table below shows modelled scenario without a central heating system. The 10% secondary heating by electricity is provided for additional heating requirements.

Table 11: Predicted energy use for mid-terrace house: Electrically heated

	Mid-terrace house Electrical heating TER =30.23	DER	Heat loss ratio	Space heating		Water heating		Regulated Electricity (Pumps & lighting)		Percentage improvement over TER	
				kWh/yr	$kgCO_2$/yr	kWh/yr	$kgCO_2$/yr	kWh/yr	$kgCO_2$/yr	Actual (Elec.)	*Compared to Gas*
1	**Level 4** (only secondary heating and water heating by electricity)	16.21	0.46	42	18	2158	910.68	828	349.42	46.38	24.18
2	**Level 4** (as option (1)+ 3m^2 solar thermal)	12.52	0.46	42	18	1394	588.27	903	381.07	58.57	41.4
3	**Level 5** (as option (2)+ 4m^2 solar thermal+ 2.2 kWp PV)	-0.16	0.46	42	18	1394	588.27	903	381.07	100.58	100.74
4	**Level 6** (as option (2)+ 4m^2 solar thermal+ 4.65 kWp PV)	-14.28	0.46	42	18	1394	588.27	903	381.07	147.23	166.79