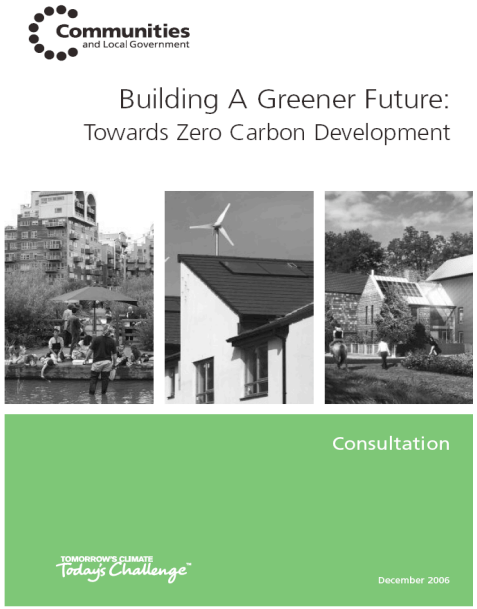
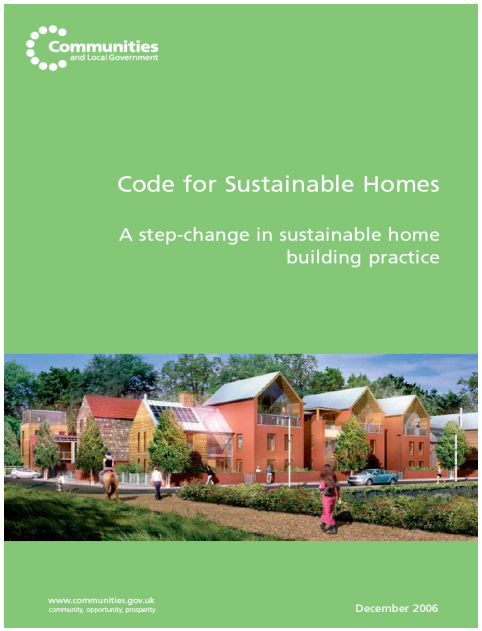
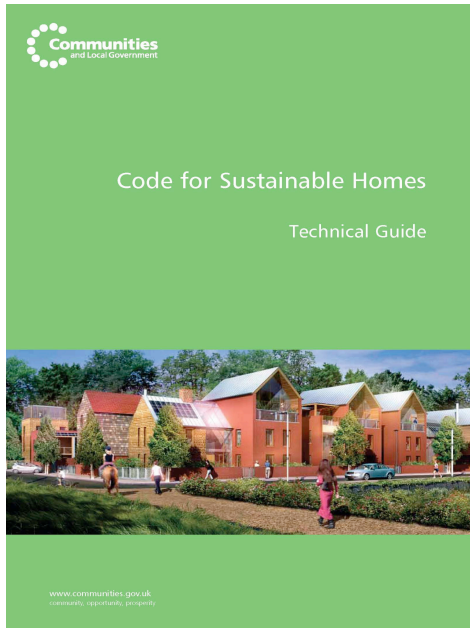
A solutions-based simulation approach to test the technical and economic feasibility of achieving low and zero carbon homes in the UK







Dr. Rajat Gupta and Smita Chandiwala

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ECEEE 2009 Summer Study, La Colle sur Loup, France, 1-6 June 2009.

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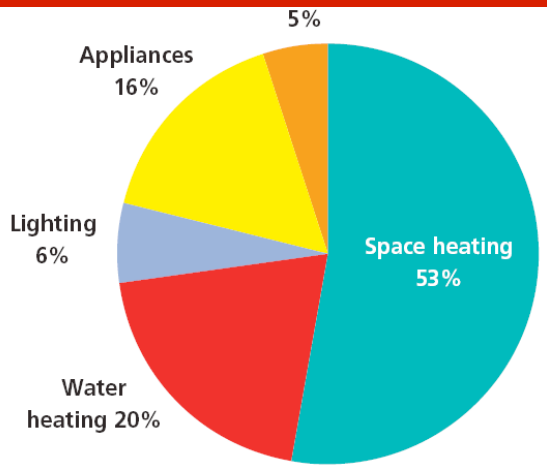
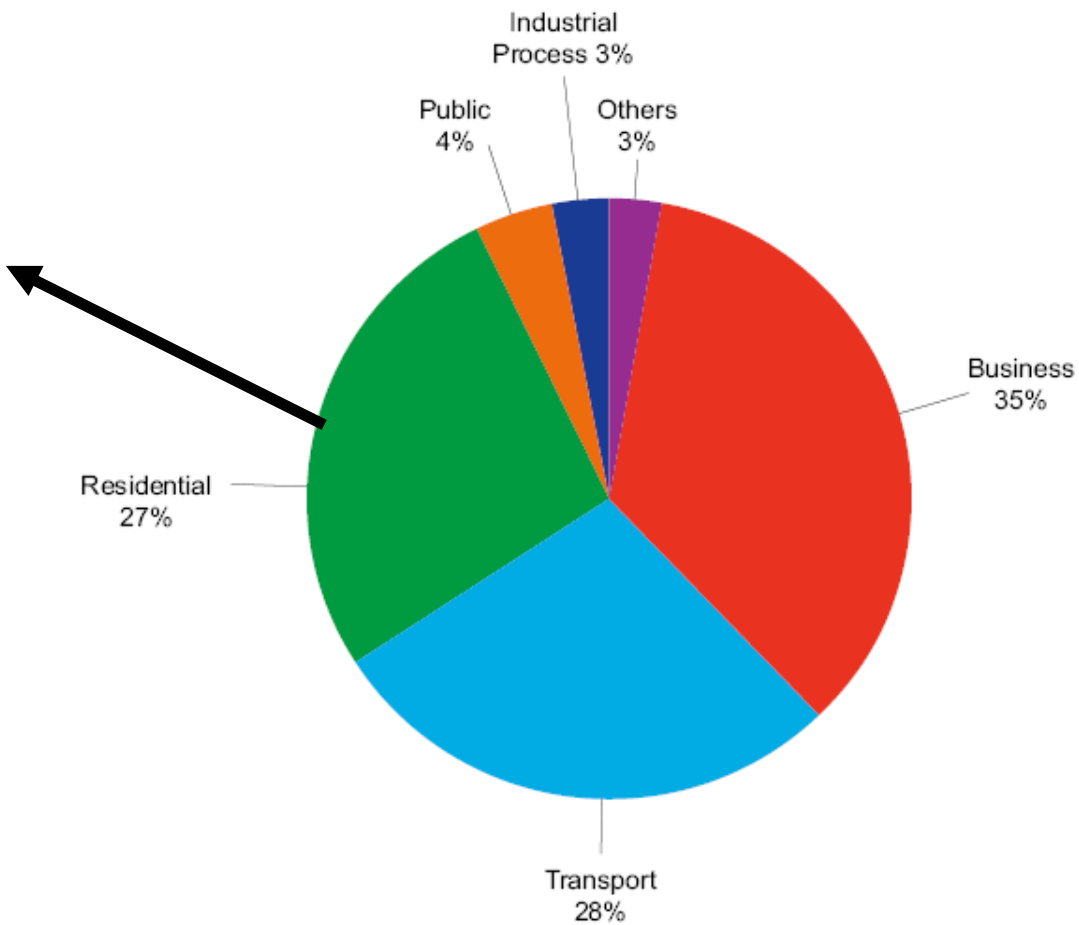
Structure

- Background - key legislative drivers for low carbon dwellings in the UK
- Code for sustainable homes guidance
- Project: economic and technical feasibility of achieving CSH levels
  - Developing SAT toolkit and appraisal options
  - Key results
- Barriers and future direction

Background

CO_2 emissions from the UK housing sector are significant…





73% of household emissions arise from space and water heating, and 27% from lighting, appliances and cooking.

2006 CO_2 emissions by final user

(Source: DEFRA (2008). 'e-Digest Statistics about: Climate Change')

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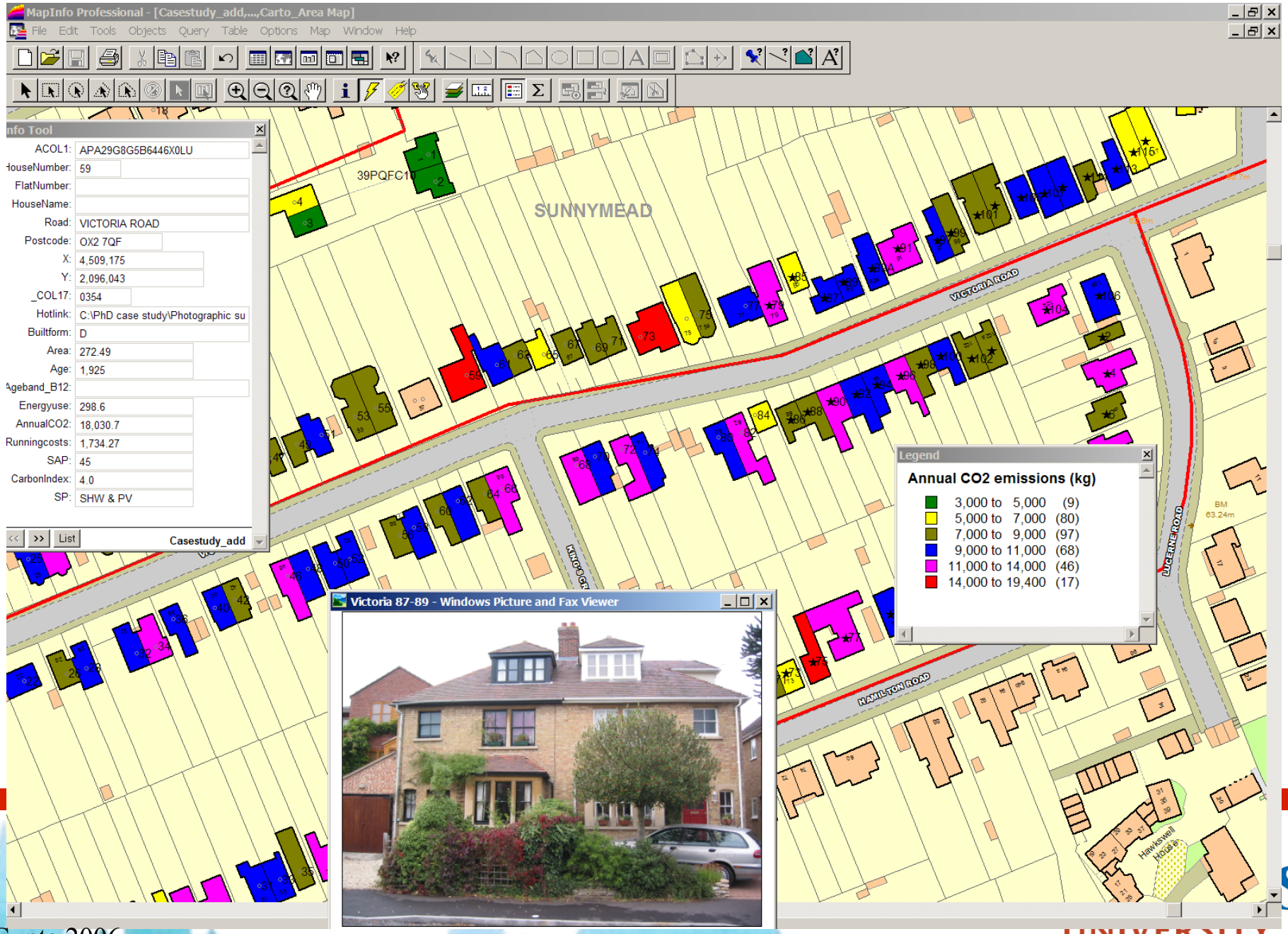
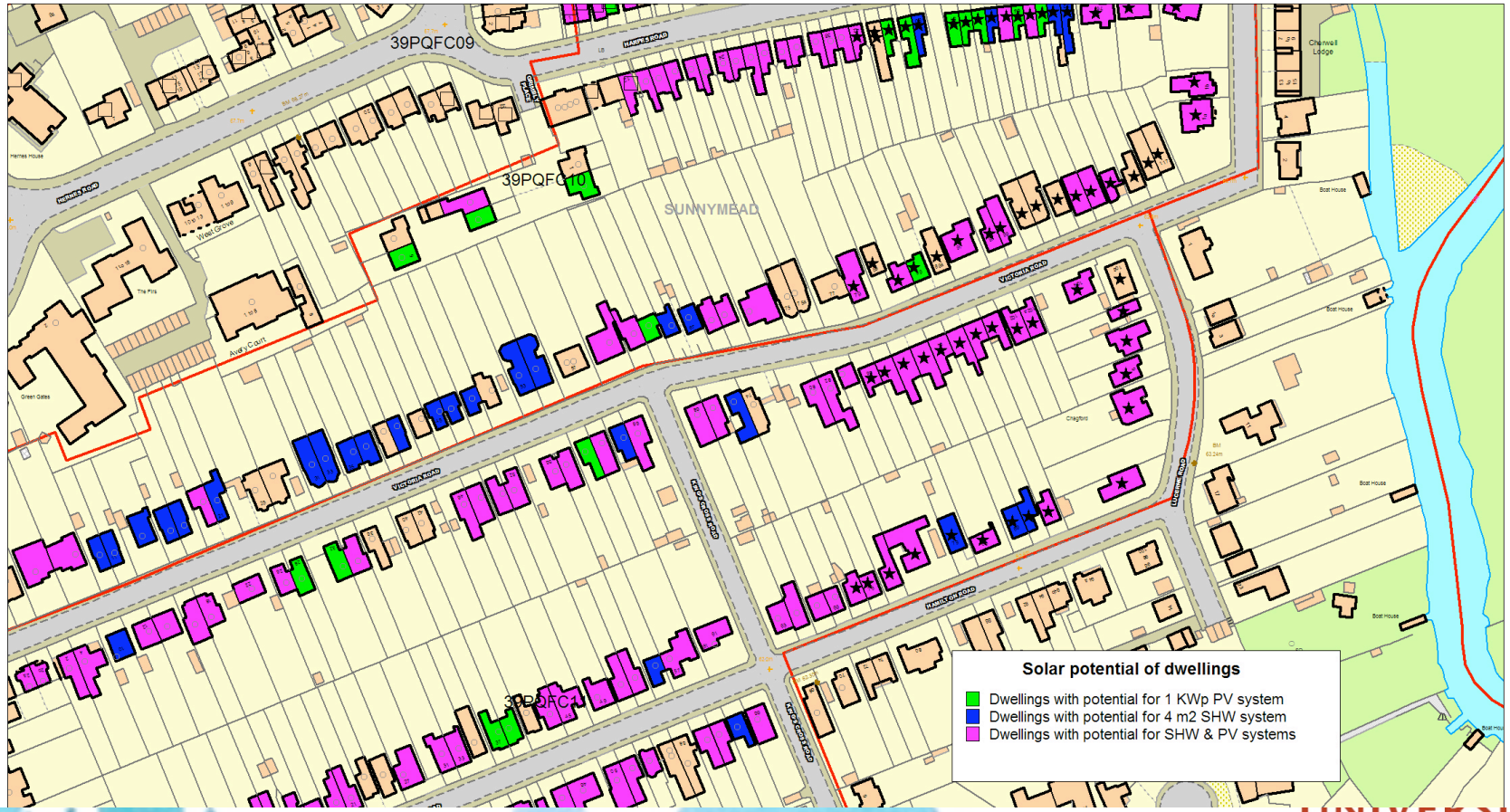
DECoRuM energy & CO_2 model: Bottom-up carbon counting



DECoRuM CO_2 reduction model: estimating solar potential

87% of the dwellings in the case study were suitable for installing either a SHW or a PV system or both.

Dwellings with potential for	Number of dwellings	Percentage
4 m^2 flat plate SHW (available roof area: 4.0 m^2- 9.9 m^2)	38	11.9%
PV (available roof area: 10.0 m^2-13.9 m^2)	46	14.5%
SHW & PV (available roof area: >13.9 m^2)	192	60.4%
None	42	13.2%
TOTAL	**318**	**100.0%**



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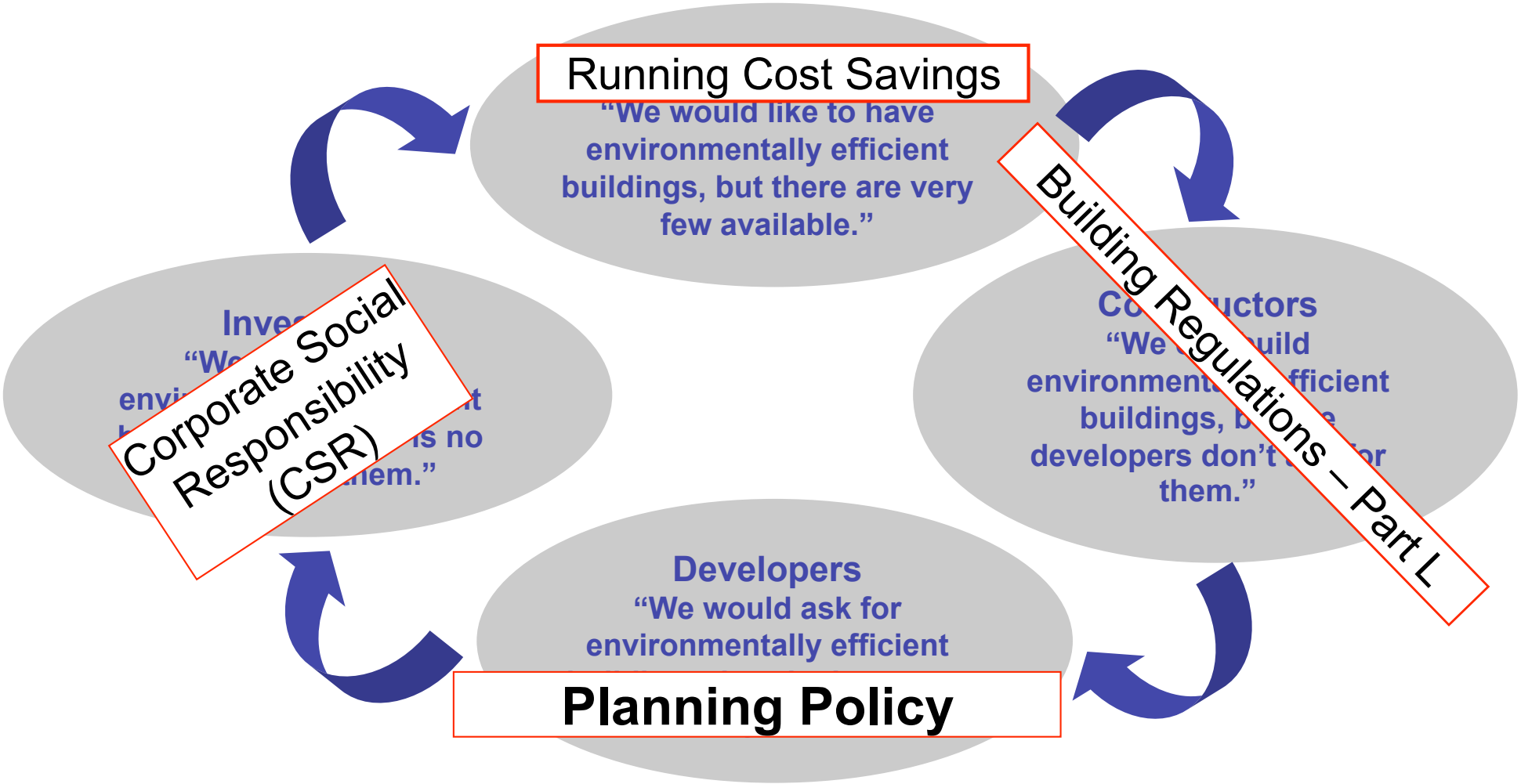
PAST: Why have low carbon buildings been adopted so slowly?



Towards sustainability – a strategy for the construction sector

CSH as a key legislative driver

- Government's announcement in Dec 2006: all new homes to be zero carbon by 2016.
  - Time-limited stamp duty tax exemption for zero carbon homes
  - Code for Sustainable Homes launched:
    - National standard for the sustainable design and construction of new homes comprising of 6 levels for new-build homes
    - Does not include refurbishment.
    - Mandatory rating for all new houses from 2008, even if no level is achieved.
    - Mandatory level 3 (Housing Corporation and English Partnerships) from 2008. Housing Corporation bids level 4 or above score more highly.
    - Serves as a guide to the direction of future Building Regulations, level 4 mandatory by 2013, level 6 (zero carbon) by 2016.

Code levels and point score

Code Levels	Total Points Score out of 100 (equal to or greater than):	Equivalent EcoHomes rating
Level 1 (★)	36 Points	Pass
Level 2 (★★)	48 Points	Good
Level 3 (★★★)	57 Points	Very Good
Level 4 (★★★★)	68 Points	Excellent
Level 5 (★★★★★)	84 Points	
Level 6 (★★★★★★)	90 Points	

Structure and Flexibility of the Code

Categories	Flexibility
Energy Efficiency	6 levels of minimum standards one for each level of the Code
Water Efficiency	Three levels of minimum standards each covering two levels of the Code
Materials	A single basic standard at Code entry level
Surface Water Run Off	
Waste	
Pollution	No minimum standards
Health & Well-Being	
Management	
Ecology	

Categories and Weightings

Issue category	Credits available	Weighting factor	Points score for each credit
Energy	29	36.4%	1.26
Water	6	9%	1.5
Materials	24	7.2%	0.3
Surface water run-off	4	2.2%	0.55
Waste	7	6.4%	0.91
Pollution	4	2.8%	0.7
Health & well being	12	14%	1.17
Management	9	10%	1.11
Ecology	9	12%	1.33

Minimum standard at each level

	Minimum Standards				
	Energy		Water		
Code Level	Standard (Percentage better than Part L[1] 2006)	Points Awarded	Standard (litres per person per day)	Points Awarded	Other Points[4] Required
1(★)	10	1.2	120	1.5	33.3
2(★★)	18	3.5	120	1.5	43.0
3(★★★)	25	5.8	105	4.5	46.7
4(★★★★)	44	9.4	105	4.5	54.1
5(★★★★★)	100[2]	16.4	80	7.5	60.1
6(★★★★★★)	A zero carbon home[3]	17.6	80	7.5	64.9

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What does CSH mean by zero carbon?

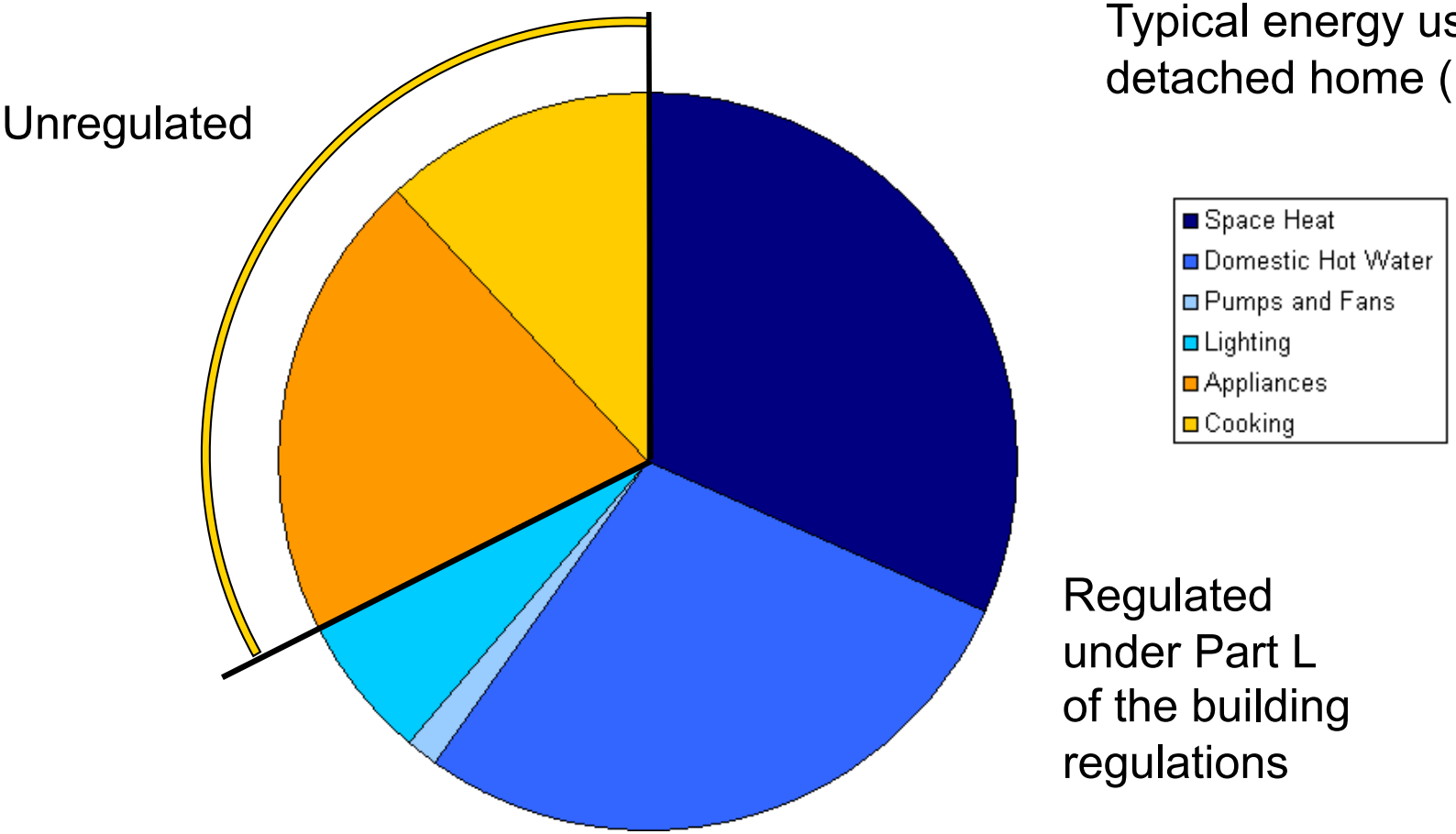
Zero carbon: Level 6

- Zero net carbon emissions from all energy uses within the building, including space and water heating, lighting, cooking and appliances.
- Carbon-emitting fuels are burnt on site, but locally-generated renewable energy is exported to the grid to make up for this.
- If offsite, the renewable energy source should be linked via private wires to the dwelling.

Source: BRE and DCLG

Regulated and Unregulated energy use

Typical energy use from a detached home (kWh)



(Source: Ben Smith, FaberMaunsell)

Unregulated

ZERO CARBON!!

Net zero carbon emissions over the year! i.e. equivalent CO_2 emissions from all energy use should be offset by generation from onsite LZC technologies.

Regulated under Part L of the building regulations

(Source: Ben Smith, FaberMaunsell)

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CSH assessment

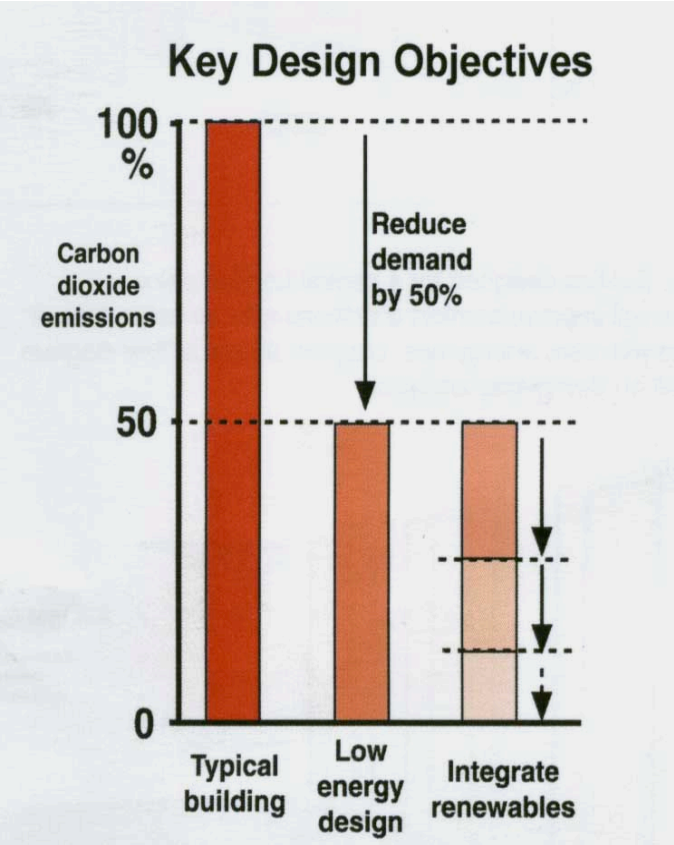
- Individual dwelling assessment
- Assessed in two stages –
  - Design stage and post construction review
- Fixed minimum standards for some categories
- Energy performance is measured based on percentage improvement over building regulations as opposed to absolute targets.

Our project

What is a low carbon building?

Low-carbon buildings result from the:

- Careful design of the building form and construction to reduce energy demand.
- Combined with highly-efficient heating and cooling systems.
- Energy-efficient appliances
- Reduction of the carbon intensity of energy input by:
    - Low carbon technologies such as: heat pumps, micro-CHP
    - Renewable energy technologies: solar PV, solar thermal, wind
    - Near-site renewables.
- Subtle human control systems that empower occupants to become part of the building energy operation systems.



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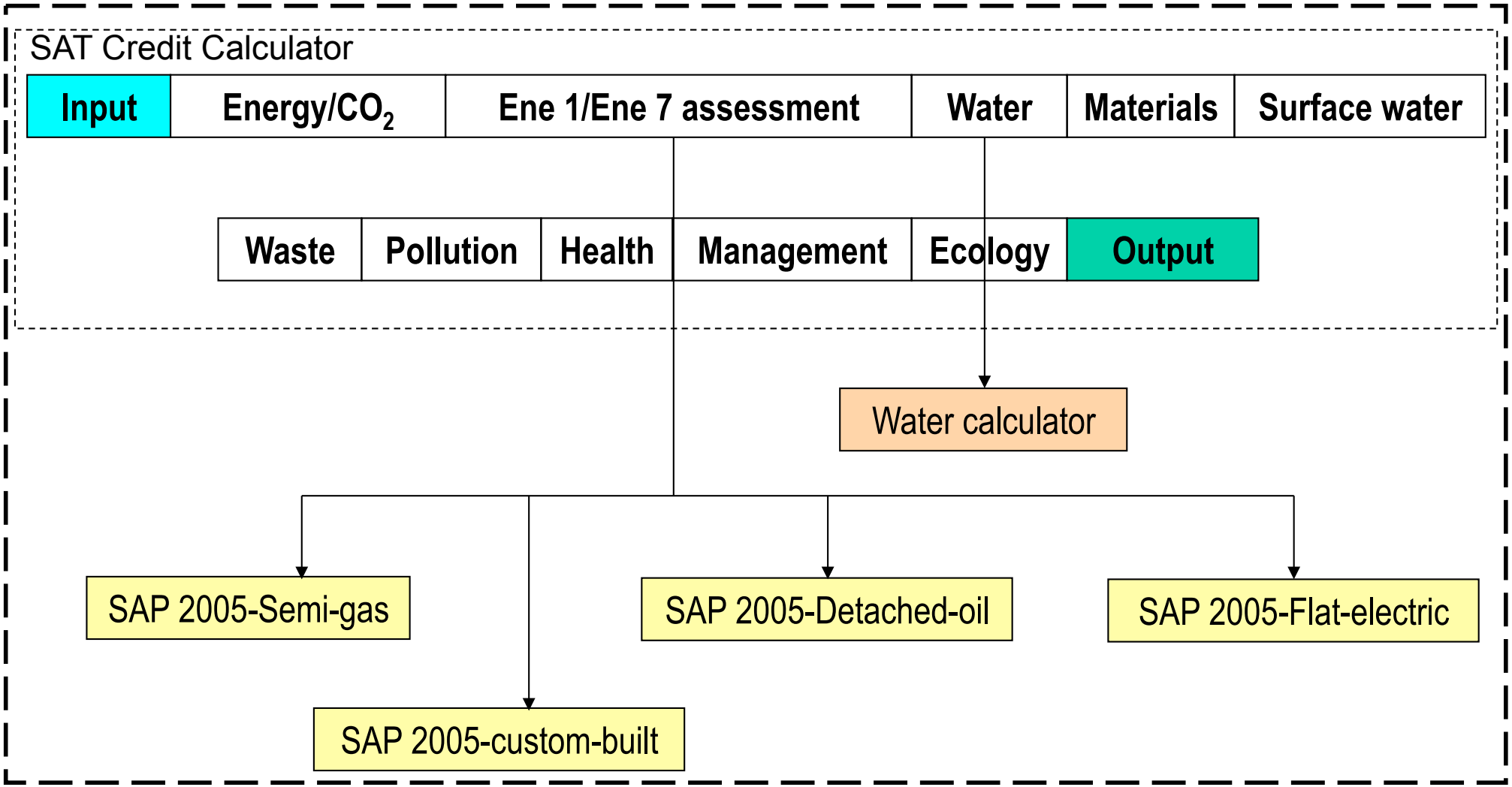
Methodological approach to develop a CSH-based SAT

1. Development of an interactive Sustainability Appraisal Toolkit to assess dwellings for CSH ratings.
2. 3 typical new-built dwelling forms were assessed – detached, mid-terrace and flats.
3. Each house type was further assessed for 3 scales of development – single house, 25 houses and 250 houses to allow assessment of community level strategies.
4. Use the toolkit to evaluate different options to achieve Code levels 4, 5 and 6
5. Cost the selected options

Architecture of SAT



Input sheet

Code for Sustainable Homes - Sustainability Appraisal Tool

This toolkit is based on the technical guidance released in 2008 and enables a pre-assessment of the probabale code level that can be achieved.

The tool is divided into 9 categories to achieve levels 1-6, with 6 being the highest level acievable.

There are three types of credits that are required -

Energy and water categories have mandatory credits required to meet each successive level (levels 1-6) of the code.

Waste, surface water run-off & materials have a mandatory entry level credit requirement (level 1) for any code level.

All other credits are tradable or flexible and add to the total credits for achieving a code level.

The code for sustainable homes should be evaluated separately for each 'dwelling type' in the development where the possible scoring for each dwelling may be different.

Name of the development	
Dwelling type (ID)	
Dwelling form	Semi-detached
Dwelling description	

Input / Energy / Energy credit 1&7 / Water / Materials / Surface water run-off / Waste / Pollution / Health & well-being

Typical category worksheet

Energy

Ene 1 Dwelling Emission Rate

Maximum number of available credits : 15
Mandatory Elements :Yes

Criteria		*Credits*	*Code level achieved*
Credits are awarded based on the % improvement of Dwelling Emission rate (DER) over Target Emission Rate (TER) based on SAP 2005 calculations. Minimum Code standards apply as well for each level.			
0% improvement	○		
10% improvement	○		
14% improvement	○		
18% improvement	○		
22% improvement	○		
25% improvement	○		
31% improvement	◉	**6**	Level 3
37% improvement	○		
44% improvement	○		
52% improvement	○		
60% improvement	○		
69% improvement	○		
79% improvement	○		
89% improvement	○		
100% improvement	○		
True Zero Carbon	○		

Total Credits (Ene 1) = 6 Level 3

Ene 2 Building Fabric

Maximum number of available credits : 2
Mandatory Elements :No

Criteria		*Credits*
Heat loss parameter achieved based on SAP 2005 calculations		
Greater than 1.30	○	
Less than or equal to 1.30	◉	**1**
Less than or equal to 1.10	○	

Total Credits (Ene 2) = 1

Input | Energy | Energy credit 1&7 | Water | Materials | Surface water run-off | Waste | Pollution | Health & well-being | Manag

Water calculator

Water Calculator (Wat 1)

Installation Type		Capacity / flow rate		Use factor		Number of uses/person/d	Total number within the	Litres water used/person/d
WC	Fixed flush	Litres (capacity)						
	Type 1			1.00		4.80		0.00
	Type 2							
	Type 3							
	Dual flush	Full flush	Part flush	Full flush	Part flush			
	Type 1			0.33	0.67	4.80		0.00
	Type 2							
	Type 3							
							Total use for WC flushing =	0.00
Bidet		Litres per use						
	Present	2.64		1.00		2.00		0.00
Wash hand basin taps		Litres/minute						
	Type 1			0.67		7.90		0.00
	Type 2							
	Type 3							
Shower		Litres/minute						
	Type 1			0.60 (Bath & Shower) 1.00 (Shower		5.00		0.00
	Type 2							
	Type 3							
Bath		Litres (Overflow)						
	Type 1			0.40 (Bath & Shower) 1.00 (Bath only)		0.40		0.00
	Type 2							
	Type 3							
Kitchen sink taps		Litres/minute						
	Type 1			0.67		7.90		0.00
	Type 2							
	Type 3							
White goods		Litres/use						
	Washing machines	Typical practice		1.00		0.34		0.00
		49						
		Actual Litres/use						
	Dish washers	Typical practice		1.00		0.30		0.00
		13						
		Actual Litres/use						
Water softener		Litres/use						
	Present	12.5		1.00		1.00		0.00
							Total Internal Use =	0.00
							Collection of grey water =	0.00
							Collection of rain water =	0.00
							Final water consumption (l/person/day) (Wat 1)=	0.00

Standard fittings to assume if details are unspecified –

water

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Output sheet

Overall points score and Code level achieved

Issue categories		Credits available	Weighting Factor	Probable No. of credits	% Score for Probable	Code level achieved
Mandatory Standards	Energy	29	0.364	9	11.2966	Level 3
	Water	6	0.09	0		No level
	Materials	24	0.072	0		
	Surface Water Run-off	4	0.025	2	1.2500	
	Waste	7	0.064	0		Not met
Tradable Credits	Pollution	4	0.025	0		
	Health and well-being	12	0.14	0		
	Management	9	0.10	0		
	Ecology	9	0.12	0		
				Total Points =	12.55	

Kg CO_2/m^2/year =	18.74
Tonnes CO_2/year =	1.48
Energy code level -	Level 3
Water code level -	No level
Mandatory criteria -	Not met
% credit score level -	No level achieved
Predicted overall code score:	**No level achieved**

Code Levels	Total Points Required
Level 1	36
Level 2	48
Level 3	57
Level 4	68
Level 5	84
Level 6	90

Energy / Energy credit 1&7 / Water / Materials / Surface water run-off / Waste / Pollution / Health &

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Energy/ CO_2 analysis

- CSH does not have many absolute targets
  - defines criteria in terms of % reduction of CO_2 emissions as compared to building regulations
- Low energy first and then low carbon approach was followed for the analysis
  - reducing energy use before using any renewable technologies.
- Houses were successively modelled to stringent fabric performance targets
  - such as, lower U-values for walls and openings, air tight fabric and efficient services
  - based on Energy Saving Trust's best and advanced practice targets.

Specifications of the three EST targets

Criteria	Building regulations	Good practice	Best practice	Advanced practice
Target emission rate (TER)	DER<= TER (SAP 2005)	$TER_{(good\ practice)} = TER_{(national\ regulations)} \times 0.90$	$TER_{(best\ practice)} = TER_{(national\ regulations)} \times 0.75$	$TER_{(advanced\ practice)} = TER_{(national\ regulations)} \times 0.40$
Limits on design flexibility				
U-values	Roof: 0.25 W/m^2K Walls: 0.35 W/m^2K Exposed floors: 0.25W/m^2K	Roof: 0.16 W/m^2K Walls: 0.30 W/m^2K Exposed floors: 0.22W/m^2K	Roof: 0.13 W/m^2K Walls: 0.25 W/m^2K Exposed floors: 0.20W/m^2K	Opaque <=0.15 W/m^2K
Windows and doors	U-values <=2.2 W/m^2K	Windows: BFRC rating band D or better Doors: U-values <=2.2 W/m^2K	Windows: BFRC rating band C or better Doors: U-values <=1.5 W/m^2K (glazed) & 1.0 W/m^2K (solid).	Openings (glazing and frames) <=0.8 W/m^2K

Predicted results for a detached house (gas heating)

Results

Detached house TER = 23.35	DER	Heat loss ratio	Space heating			Water heating		Regulated Electricity (Pumps & lighting)		% improve-ment 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	16.48	0.98	2578	554	**24.79**	3209	622.55	1276	538.47	**29.40%**
Advanced practice 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 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%**

- Best practice standards lead to Level 3 energy target (25% improvement)
- Advanced practice targets can achieve 38- 42% improvement (level 4, 44% improvement)

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Results

- Energy and carbon emission savings can be maximised if stringent energy standards are followed for the fabric performance.
- Large to mid sized house types such as detached and terraced houses achieved a level 3 and close to a level 4 (25-40%) CO_2 reduction target by following stringent building fabric targets mostly.
- For smaller, efficient dwellings such as flats, stringent fabric targets only achieve a maximum of level 3 or a 25% improvement over building regulations.
- Level 5 and 6 require use of renewable technologies in addition to very efficient building fabric.

Comparing gas vs. electric space and water heating

(with advanced practice building fabric standard)

Results

Detached house	DER	Heat loss ratio	Space heating		Water heating		Regulated Electricity (Pumps & lights)		Percentage improvement over TER	
			kWh/yr	$kgCO_2/yr$	kWh/yr	$kgCO_2/yr$	kWh/yr	$kgCO_2/yr$	Actual (Elec.)	*Compared to Gas*
Advanced practice **TER = 23.25** (Gas heated)	14.29	0.73	1514	325	3209	622.55	1276	538.47	**38.81%**	
Advanced practice **TER = 33.12** (electrically heated)	20.54	0.73	1428	602	2535	1069.8	1101	464.62	**37.98%**	***12.03***

For both advanced practice scenarios, AP=AP= $3m^3/m^2hr$, ψ = 0.03W/mK

- The target emission rate is much higher for electrically heated house
- A similar % improvement target is met by both scenarios, around 38%, but the absolute carbon emissions in each category are much higher
- As compared to the Gas TER, the % improvement achieved by the electricity use is only 12.03%

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Results

- Using electric heating instead of gas heating, even for a marginal space heating demand increases the TER.
- This 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.
- However, the absolute carbon emissions remain considerably more in case of electricity heated houses.

Key findings: Energy/ CO2

- Energy and carbon emission savings can be maximised if stringent energy standards are followed for the fabric performance.

- A percentage improvement of TER as the energy target has various consequences:
  - Smaller, efficient dwellings, find it harder to achieve higher code level targets as compared to bigger houses, as the TER is smaller to start with.
  - Changing the fuel to electricity, (common strategy in flats) increases the TER, making it easier to achieve a greater % improvement.
- Absolute carbon targets are required in the Code to counter this.

Cost of achieving level 4, 5 and 6

	Additional capital cost (Pounds)		
	Detached (104m2)	Mid-terrace (79m2)	Flats (61m2)
Level 4: single house	**4500**	**3375**	**-**
Level 4: 25 houses	**2889**	**2889**	**2600**
Level 4: 250 houses	Site specific		
Level 5: single house	**26,100**	**20,175**	**-**
Level 5: 25 houses	Site specific+7800	Site specific+5850	Site specific+6500
Level 5: 250 houses	Site specific+2800	Site specific+1140	Site specific+1750
Level 6: single house	**46,500**	**38,575**	**-**
Level 6: 25 houses	Site specific+15,750	Site specific+13,800	Site specific+12,750
Level 6: 250 houses	Site specific+15,340	Site specific+13,340	Site specific+10,938

Barriers and future direction

Barriers to achieving higher Code levels

- Lack of expertise within the building industry to fulfill code criteria in terms of build quality.

- Substantial additional costs over construction costs for typical dwelling types to achieve level 4, 5 & 6.

- Move towards absolute energy/CO2 targets (taking account of occupant density)

UK: AECB: Carbon Lite: Domestic buildings

Energy standards applied to a typical dwelling

Standard	Gas, oil or LPG	Electricity	CO_2 emissions
Average of UK dwelling stock*	239 kWh/m²yr	37kWh/m²yr	73kg/m²yr
UK Building Regulations ADL1 2006**	146kWh/m²yr	37kWh/m²yr	57kg/ m²yr
Silver	58 kWh/m²yr	22 kWh/m²yr	23kg/m²yr
Gold	23 kWh/m²yr	15 kWh/m²yr	4kg/m²yr

Domestic sector figures based on an 80m² semi-detached dwelling.

Summary – future directions

- Scale of development is crucial to strategies employed and hence, cost.

  Site wide strategies are more effective and allow the cost to be shared by a number of houses. This applies to both energy and water criteria.

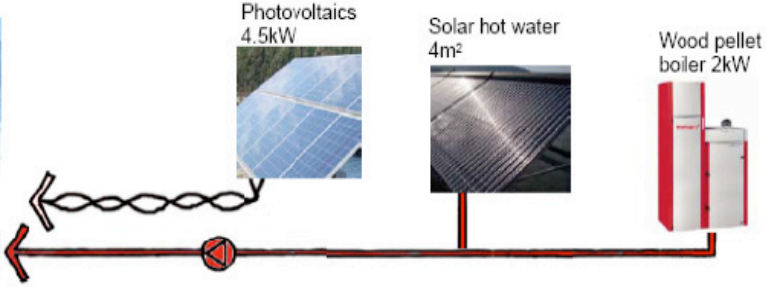
- Strategy for refurbishing and upgrading existing stock.

  Substantial additional costs for level 5 and 6 need to be examined within this framework.

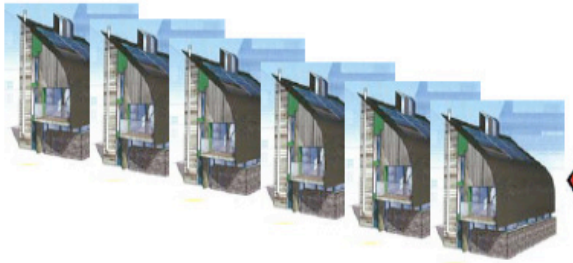
Energy supply options for Level 6

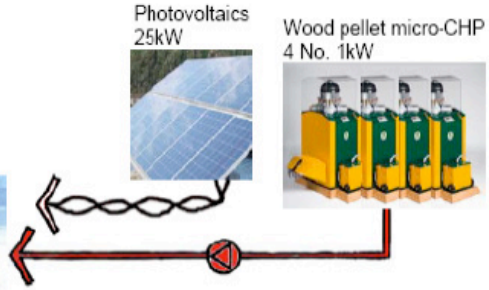
lighthouse
Kingspan

Single home



25 home development





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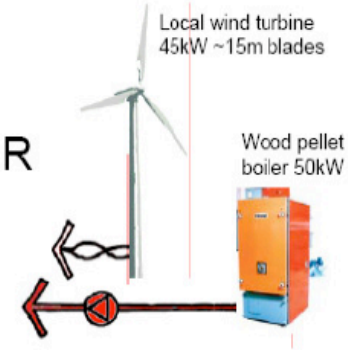
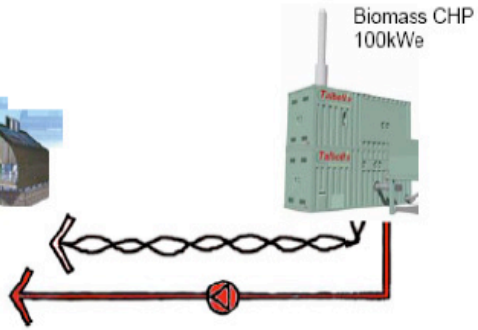


250 home development



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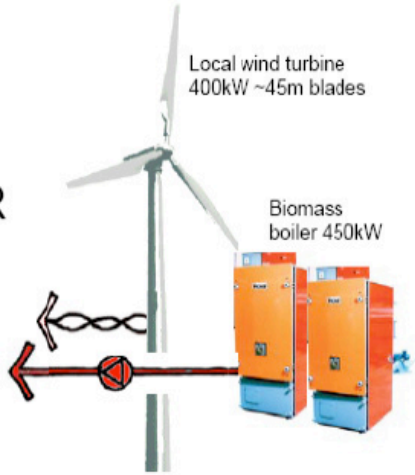

Kingspan ARUP SHEPPARDROBSON

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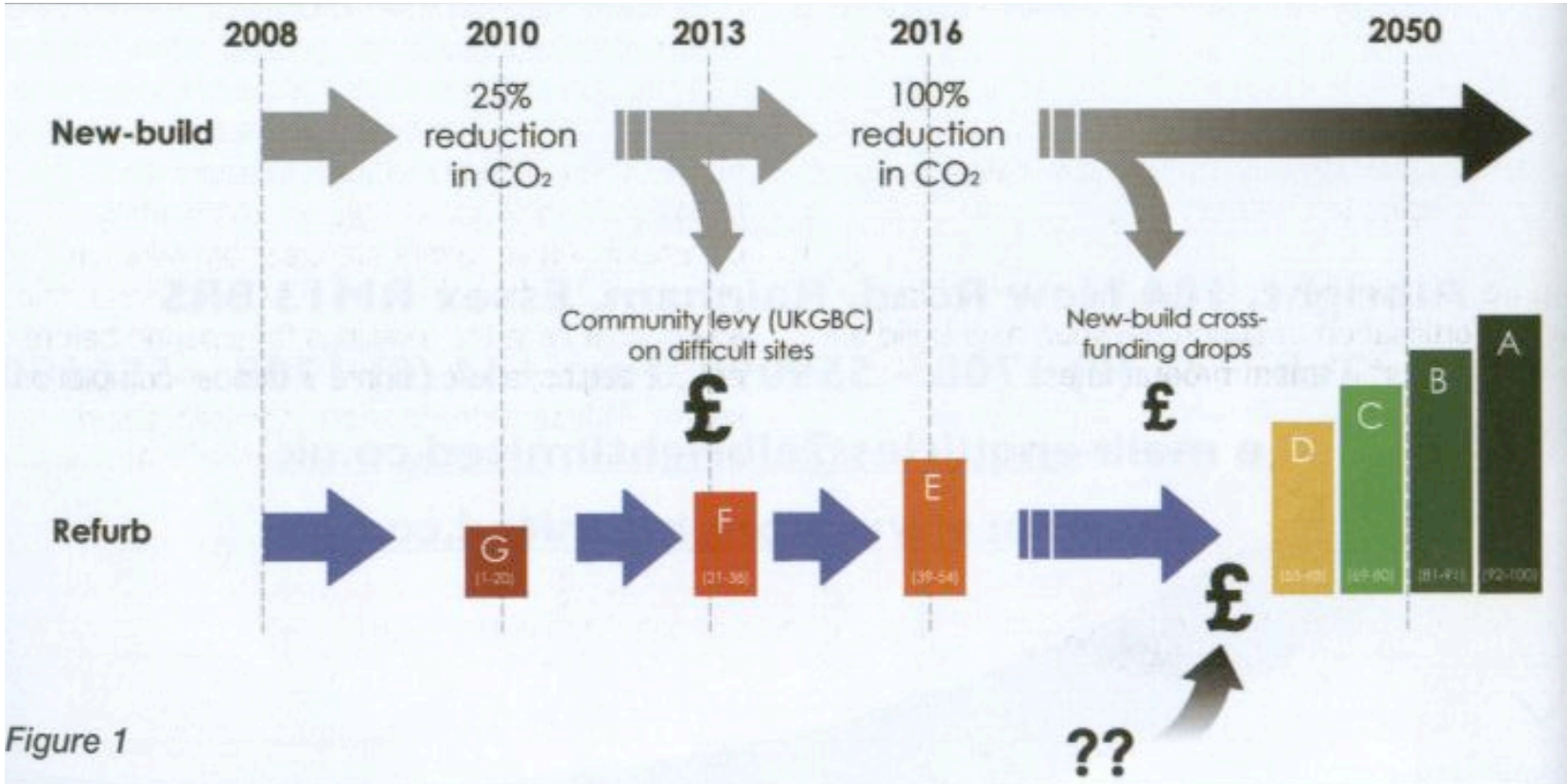
Cross-fertilisation of new-build and refurbishment



(Source: Dr David Strong, Inbuilt consulting, 2008)

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Low and zero carbon buildings: a reality

living on the planet as if we intended to stay