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Analysing steady state models for dwelling carbon performance

Vicky Ingram & Dr David Jenkins

Urban Energy Research Group, Heriot-Watt University

Abstract

In the UK, 24% of all carbon dioxide emissions are from the residential sector (Office for National Statistics, 2010), and of those only 4% have been built since 2002 (Office for National Statistics, 2010), under EPBD-compliant Building Regulations requiring greater energy efficiency. Therefore, the UK *existing* building stock must be improved to meet the UK and EU emissions targets.

The current Government's flagship policy is the Green Deal: a loan scheme offering homeowners finance to improve the energy efficiency of their home, paid back through electricity bills. These payments must cover the full cost of the work within 25 years: known as the Golden Rule. The loan stays with the home, not the homeowner, so it does not prohibit the purchasing of measures that have a long payback.

To estimate emissions from the residential sector, the UK uses the Standard Assessment Procedure (SAP), a compliance tool designed originally to provide Building Control and Planning Authorities with proof of compliance. It is a simple steady state calculation that estimates fuel costs and emissions associated with heating and lighting a home. The Green Deal will use SAP methodology to estimate savings of chosen options, to decide eligibility for finance (the aforementioned Golden Rule).

This research identifies some of the flaws with this approach and investigates the weaknesses and sensitivities of the model, when compared with dynamic simulation tools such as the IES<Virtual Environment>.

1. Background

It is widely accepted that the global climate is changing (Jones, et al., 2009), and the European Union has implemented policies and targets that have cascaded through to individual Member States, requiring mitigation measures by reducing emissions of greenhouse gases. In the UK, 24% of the greenhouse gas emissions are from residential buildings (Office for National Statistics, 2010) and reducing this has become a key focus area for the UK Government. The European Performance of Buildings Directive (EPBD) requires each Member State to have a National Calculation Methodology (NCM) in place to assess the energy use and carbon dioxide emissions of the building stock, and to have a plan in place to reduce the emissions of both new build and existing homes. It is the UK NCM that is discussed in this paper.

The current method of assessing energy use within a dwelling in the UK focuses on the heat loss through the building fabric (and due to ventilation conductance), and the resulting demand for space heating. The UK Government's Standard Assessment Procedure (SAP) and the Reduced Data version (RdSAP) are steady-state models run using monthly parameter inputs, and it has been questioned whether the models have the ability to adequately quantify the real-world space heating in a dwelling (Jenkins, et al., 2013) and (Kennett, 2010). For existing dwellings - the focus of this paper - the RdSAP methodology is used, which provides a number of assumptions and defaults that must be used in the calculation, making the calculation quicker and easier than for a new-build dwelling. The current version of RdSAP uses a single set of climate variables: an average for the UK given by Met Office station records in the Sheffield region of the UK for the period 1987-2006 (Anderson, 2010), see also 'region 11' Figure 1. It is firstly questioned if this single UK climate is adequate for the end purposes of the energy assessment.

A second question of the steady state model when applied to UK dwellings is its adequacy when assessing and utilising the level of thermal mass in a construction. Thermal mass is defined in SAP as the heat capacity within the construction per unit of floor area of the dwelling, and is used when calculating the space heating loads. The Thermal Mass Parameter (TMP) signifies the ability of the material to absorb heat, store it, and release it at a later time. Materials with higher thermal mass react slower to changes in temperature.

Across the UK there are various construction types in domestic buildings with varying levels of thermal mass, such as solid stone, solid brick, timber frame, slate roof, thatched roof, and cavity wall construction. These constructions have different levels of thermal mass and should therefore require different heating patterns and demands. The use of RdSAP however, assumes that all existing homes have a medium-weight construction and the calculation applies the same heating regime in every dwelling.

To encompass building characteristics that are more complex than can be applied within a steady-state methodology, dynamic simulation software is also available: whilst only accredited for non-domestic properties, such software is often utilised in research for more detailed investigations of dwellings. There are several benefits of using dynamic simulation, one of which is temporal resolution: calculations can typically be performed at a 10 minute resolution, though output is often used in half-hourly or hourly format, (with similar resolution for the climate data from a regional weather station). This high resolution enables a more adequate assessment of the thermal behaviour of the indoor environment, and the diurnal temperature cycle is recognised (a feature lacking in monthly calculations). The dynamic calculation requires significantly more skill from the user than a steady state calculation, and takes significantly longer to complete, therefore it is not always seen as practical to use in the domestic sector on buildings that are more numerous and relatively simple in comparison with their non-domestic counterparts.

2. Method

A number of dwelling case studies were subjected to three energy assessment methodologies to assess their energy performance. Iterations of the standard assessment were carried out to ascertain the sensitivity of the methodology to changes in certain variables, namely, the climate and the level of thermal mass.

2.1 The Case Studies

2.1.1 CS1 – Tenement Flat

This flat is a solid-stone walled, mid-storey, mid-terrace tenement in Edinburgh, believed to have been constructed in the mid-19th century.

2.1.2 CS2 – Large detached house

This house is a large solid rubble walled four-storey building in Edinburgh, believed to have been constructed in the mid-16th Century and rebuilt significantly after fire in the 17th.

2.1.3 CS3 and 4 – small detached house

This is a simple 19th century house in Western Scotland, with kitchen and living room downstairs and two bedrooms plus small bathroom upstairs. The house pre-interventions (CS3) was of typical construction, with solid stone walls with a lath and plaster internal finish, no roof insulation, and timber and solid concrete floors both present.

The CS4 case-study refers to the refurbished version of the house. The refurbishments were:

- Upgrading the heating system from coal fires and electric room heaters, to a biomass central heating system
- Insulating behind the lath and plaster with Expanded Polystyrene beads upstairs
- Lining the kitchen walls with a hemp-lime mixture and living room walls with insulated clay boards
- Insulating the ground floor
- Replacing the single glazing with double glazing

2.1.4 CS5 – Semi-detached bungalow

The semi-detached bungalow was built with solid stone walls at the end of the 19th century, just outside of Edinburgh.

2.1.5 CS6 – New-build flat

This new-build flat was constructed in 2006 in a large redevelopment area within Edinburgh. On the second floor, it is a corner flat and as such has three external wall surfaces. The development uses a steel frame with concrete blocks but does feature stone cladding, deemed to be sensitive to the architectural surroundings of Edinburgh.

2.1.6 Case Study Summary

The differences between case studies are highlighted in Table 1.

Table 1 Case Study summary

Dwelling type		Constructed	Primary wall construction	Heated floor Area (m^2)
CS1	Tenement flat	Late 19th century	Solid stone, lath and plaster	65
CS2	Detached house	Mid 16th century	Stone rubble, lath and plaster	341
CS3	Detached house	Mid 19th century	Solid stone, lath and plaster	63
CS4	Detached house	Mid 19th century	As CS3 but with energy efficiency interventions	63
CS5	Semi-detached bungalow	1899	Solid stone, lath and plaster	48
CS6	New-build flat	2006	Steel frame, concrete block	61

The dwellings in Table 1 were reviewed and compared across the following energy assessment methods to ascertain an understanding of the sensitivity of the energy calculation methods to changes in two specific input characteristics, namely: climate and thermal mass.

2.2 The models

There are a number of building performance simulation models available globally and in the UK. To maintain relevance for the widest audience, the project uses models that are accredited in the UK to carry out Building Standards compliance checks and produce energy performance certificates to comply with the EPBD.

Standard Assessment Procedure (SAP) is used for new-build dwellings, Reduced Data SAP (RdSAP) is used for existing dwellings, and IES<VE> is dynamic simulation software used for non-domestic buildings. The background to each model used is explained here, with a summary of how the model was used and the assumptions made.

2.2.1 SAP 2009

The primary purpose of energy assessment in the UK is producing Energy Performance Certificates (EPCs) for both domestic and non-domestic buildings, at the point of sale or rent for compliance with the EPBD. The methodology is a monthly steady-state calculation, using average values to represent a fixed time-period, in this case, each month. While the technical guide and calculation methodology for SAP are open to anyone to view and download (BRE, 2011), the majority of software providers allow access to their SAP programmes only to qualified assessors. A minority allow unlimited or academic access. The SAP methodology has therefore been put into a bespoke spreadsheet model to enable detailed examination of the calculations and relationship between variables.

2.2.2 RdSAP 2009

The most significant change to SAP was the introduction of RdSAP in 2007, used for predicting the energy demand in existing dwellings. It does this through a database of information (BRE, 2011) to be used in the calculation where the assessor finds information unobtainable (such as wall construction, or U-values), based on the age of the dwellings.

The defined RdSAP methodology has also been put into a bespoke spreadsheet model, enabling in-depth examination of the calculations and relationships between variables. This method also allows direct comparison between entering known values and those from the construction database.

2.2.3 Dynamic Simulation Models

In addition to the standard domestic (SAP and RdSAP) and non-domestic methods, the UK National Calculation Methodology (NCM) includes Dynamic Simulation Models (DSMs). These DSMs have the potential to look at both higher spatial resolution as well as higher temporal resolution to model the changes that occur over time using fundamental mathematics of the heat transfer processes that occur both inside and around a building.

As well as the basic heat gains and losses calculations, DSMs also include convection, heat transfer by air movement, thermal radiation transmitted by surfaces, solar transmission, and absorption and reflection by any glazing. Dynamic models are most effective when the building is divided into multiple zones to reflect different activities and conditions, and use much more detailed weather data than in SAP and RdSAP, from the Chartered Institute of Building Services Engineers (CIBSE) (CIBSE, 2013). In the UK, there are two DSMs accredited to produce EPCs for non-domestic buildings: this research uses the IES<Virtual Environment>, referred to from here as IES<VE>.

2.3 Green Deal

Using the RdSAP 2009 methodology, Green Deal-type calculations have been carried out on each case study property, having selected a single intervention measure from the Green Deal 'Measures' list (DECC, 2011). Interventions across the UK include: technologies such as heat pumps, biomass heating systems, photo voltaic panels and solar water heating; building controls such as the introduction of room thermostats or hot water controls; or building fabric solutions such as double glazing or cavity wall insulation. As each case study is different and interventions are not suitable for every case study, measures were chosen that are suitable for the particular case study. For example, CS2 is unlikely to utilise double glazing, due to its status as a listed property and the expense involved with the large number of windows. A replacement heating system has therefore been chosen. Table 2 indicates the chosen measures and associated cost of that measure.

Table 2 Example Green Deal measures

	Measure	Indicative cost, £ *
CS1	Replace single glazing with double glazing	3,150
CS2	Replace existing D-rated gas boilers with A-rated boilers plus thermal store	2,300
CS3	Replace old room heaters with biomass central heating	3,150
CS4	Combined measures used in the dwelling:	
	Biomass boiler	9,000
	Heating controls	300
	Replacement glazing	3,150
	Underfloor heating	1,200
		Total = 13,650
CS5	Replace LPG D-rated boiler with Air Source Heat Pump	8,400
CS6	Apply PV panels, electricity sold to grid	8,000

* Indicative costs from the DEMSCOT model (Scottish Government, 2010)

For a measure to receive Green Deal finance, it must pass the 'Golden Rule', that the savings over the lifetime of the measure are greater than the cost of the measure. To calculate this, RdSAP is used to calculate a *before* and *after* cost of running the home, and the savings compared with the payment that would be required to pay back the loan over its lifetime. To take account of the difference between predicted savings and those experienced by the homeowner, whether through errors in modelling, the rebound effect (where occupants enjoy warmer conditions due to improved efficiencies, and do not reap the financial benefits), or a dwelling not conforming to the 'standard' against which technology is tested, a set of "In Use Factors" have been identified. These In Use Factors are applied to the modelled savings: for example, the In Use Factor for a ground source heat pump is 10, so if the modelled saving was £1000, the payment required would be compared to a saving of £900.

3. Results

Results for specific case-studies are highlighted in this section, with an overall summary in Section 4.

3.1 Climate

Despite being a relatively small landmass, the UK experiences very different weather dependent on location. While SAP assumes a monthly UK average temperature within the calculation, Figure 1 (a) highlights the need for regional variations to be taken into consideration when assessing the cost of heating a UK dwelling with a 3°C difference between the north and south of the country. Using CS1, regional climates have been applied and space heating cost calculated. The impact this regional data would have on space heating cost, if it were utilised in the calculation can clearly be seen as the cooler the climate the more expensive the cost to heat the dwelling to the SAP-specified temperature. As seen in Figure 1(b), two identical dwellings would be assessed as costing £206 per annum to heat in south east England, yet £370 per annum for Shetland. (NB. The importance of a dwelling's occupants and their behaviour towards the heating would alter these findings, possibly significantly, and has not been included in this paper but is a topic of research within the overall project.)

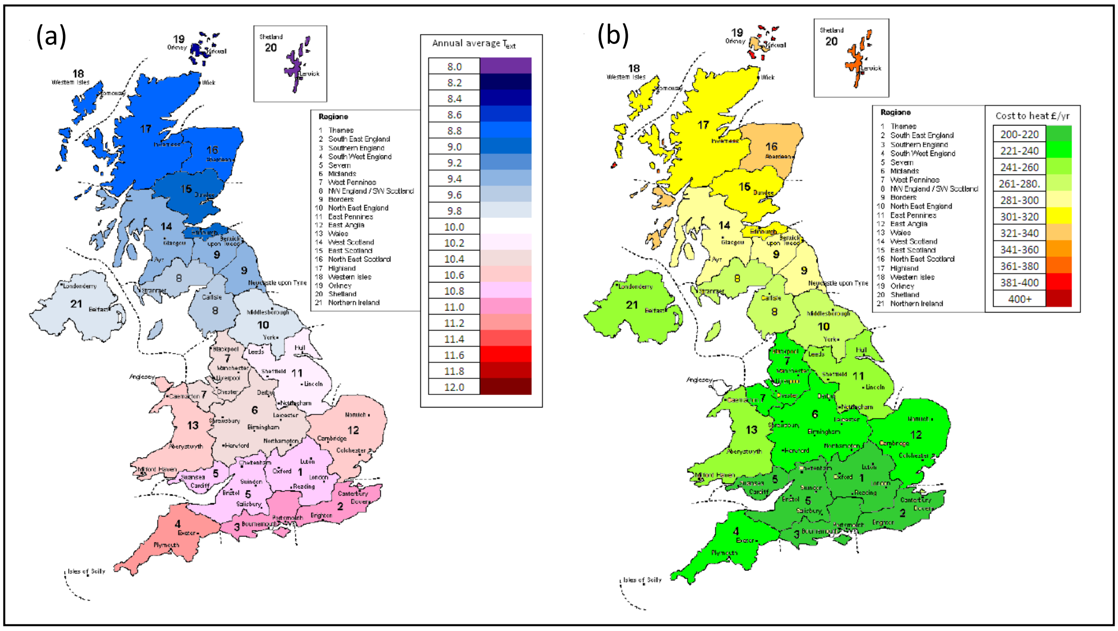

Figure 1. The (a) mean external temperature and (b) associated space heating cost, for CS1

An update is expected to the SAP methodology in April 2013, which *may* allow regional climate data to be used for Green Deal calculations, but would still use UK "average" data for compliance calculations. At the time of writing it was unknown if this allowance would be introduced.

3.2 Thermal Mass

The inclusion of the Thermal Mass Parameter (TMP) in SAP and RdSAP 2009 was a new parameter from previous years. The assumed level of thermal mass in RdSAP 2009, as introduced previously, of 250kJ/m^{2}K can be significantly different to that as assessed in SAP 2009, impacting on the internal temperature and therefore demand for space heating.

One output that can be compared to assess the impact of thermal mass is that of the mean internal temperature, as there is an understanding that higher thermal mass regulates internal temperatures and dampens the variation across the year. For this research, the SAP calculation has been forced to use low and high levels of thermal mass, in addition to that recommended for that particular building construction, as indicated in Table 3, the results of which are shown in Figure 2.

Table 3. Indicative values for Thermal Mass Parameter (TMP) from SAP

Thermal mass	TMP (kJ/m^{2}K)
SAP 2009 Low	100
SAP 2009 Medium	250
SAP 2009 High	450
RdSAP 2009	250
SAP 2009 recommended – CS3	*197*
SAP 2009 recommended – CS4	*332*

The case studies used here are CS3 (Figure 2a) and CS4 (Figure 2b), as a direct comparison can be made between the otherwise identical dwellings.

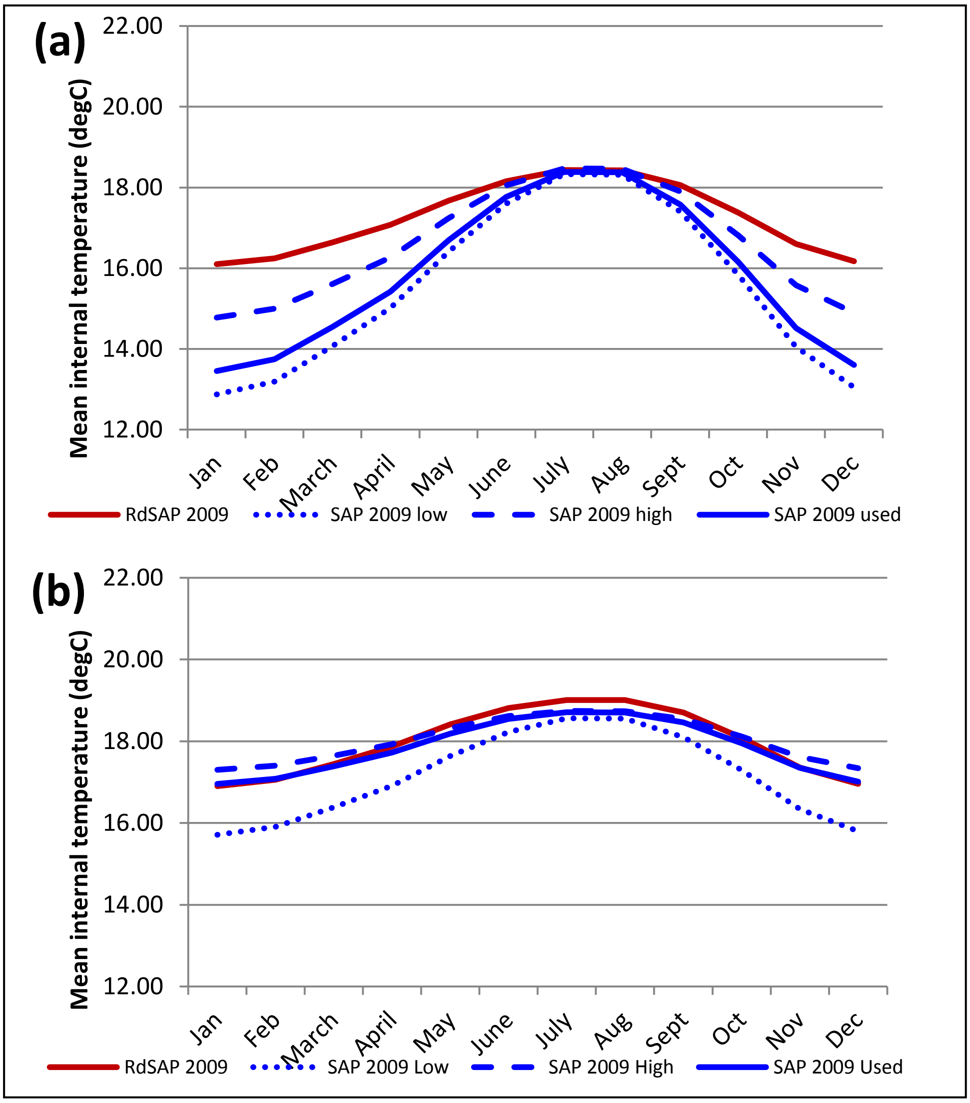

Figure 2 Mean internal temperatures for (a) CS3 and (b) CS4 with varying levels of thermal mass

The floor area, volume, heat loss areas, orientation and number of occupants are identical, as are the levels of TMP for the purposes of this investigation. Therefore, the difference between Figure 2(a) and CS4 Figure 2(b) is purely down to the U-value and air exchange differences between the pre and post-retrofit versions of the dwelling.

It is clear that the level of TMP does impact on the internal temperature, specifically during the winter months, and therefore it is suggested that if such discrepancies across the heating season reflect real internal environments, then it will impact on the demand for space heating and in turn the cost, EPC rating and perceived performance of the property. Also of note is that in the pre-retrofit (inefficient) case study, the assumed level of thermal mass in RdSAP gives significantly different internal temperatures across the heating season than even the SAP model with a high level of thermal mass. This would indicate that there is a discrepancy between the two methodologies despite using the same calculations and this warrants further investigation.

3.3 Green Deal

The measures in Table 2 were applied to the Case Studies and the breakdown of cost savings and whether the measure would pass the Golden Rule is shown in Table 4. The only case study to meet the Golden Rule is CS2, where a new boiler was the chosen measure.

Table 4 Green Deal assessment results

	Total running cost before (£/year)	Total running cost after (£/year)	Saving* (£/year)	Payment required (£/year)	Golden Rule
CS1	505	460	38	309	✗
CS2	4,458	3,172	964	451	✓
CS3	1,497	1,409	75	309	✗
CS4	1,497	787	524	981	✗
CS5	829	779	37	1,034	✗
CS6	375	358	17	785	✗

*Including In Use Factor

When analysing these results, it should be remembered that the costs of the measures are based on figures from the DEMSCOT stock model and as such are indicative only. As CS2 is such a large property, it currently has two boilers therefore two replacement boilers have been modelled and the payment required reflects that.

In addition, the primary concept to reduce energy use in buildings is to ensure the building envelope is efficient *before* applying technologies. In the calculations in this paper single measures are modelled, and it is proposed that if improving the building envelope were possible in CS2 (in reality this would depend on many variables, including its status as a Listed property), then the savings from the improved building envelope would reduce the large savings seen when improving the boilers. This may then lead to the measures not meeting the Golden Rule.

These sorts of calculations are incredibly useful to understand how the methodology works and what measures will give you the best savings, but a note of caution should be extended: no model will truly recreate a real-life situation, even with the In Use Factors, and variations between model inputs and the dwelling itself may lead to savings experienced not matching those predicted. In doing a Green Deal assessment and looking at different measures, it is obvious that some measures will be better suited to particular dwellings than others, and Green Deal assessors need to be aware of this.

4. Consequences

4.1 Energy Performance Ratings

Figure 3 shows the SAP rating calculated using the three different methodologies. As IES is a non-domestic tool, it does not calculate a SAP rating, therefore a value for SAP rating has been calculated outwith the software using the IES output in the SAP rating calculation.

The tenement flat is the only property unaffected by which method is used, all other case studies could have one of two ratings, depending on which method was used. A policy initiative discussed and due for implementation in 2017 is that buildings will need to receive an E rating before they can be sold or let (HMSO, 2011) and (DECC, 2010). If this policy is implemented, Figure 3 suggests that further research be done into this area, to ensure that homeowners are not restricted because an innacurate methodology has been used.

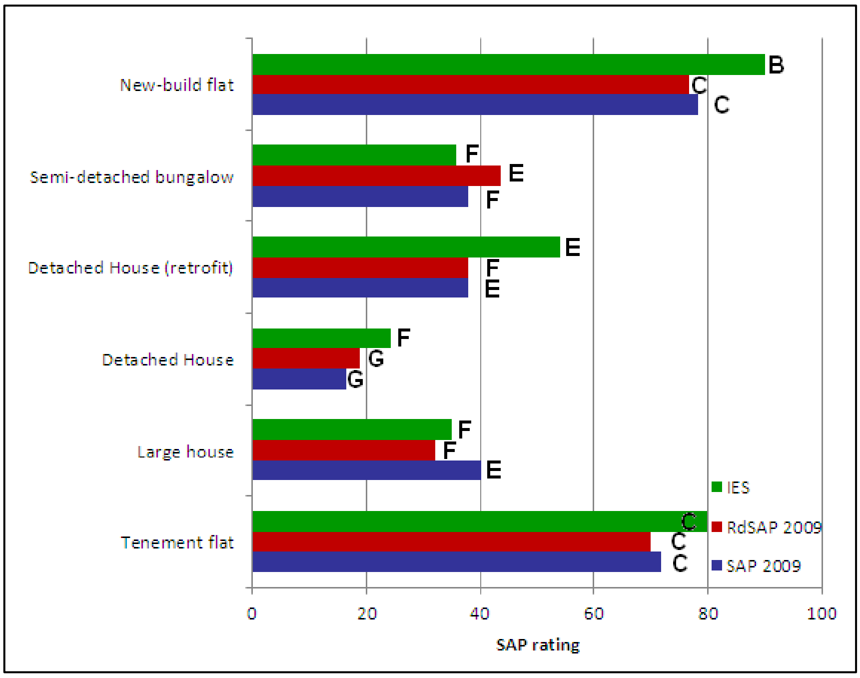

Figure 3 The SAP rating by method for each case study

4.2 Green Deal

The Green Deal is run in parallel with the Energy Companies Obligation (ECO). The ECO levies a charge against energy providers, which in turn supplies funds for installation of measures under the Green Deal through partial or full subsidy dependant on dwelling circumstance and measure.

The Government costing papers, consultation documents and Impact Assessments on the schemes have all been based on SAP and RdSAP methodologies, using 'typical dwellings'. In a country with 26 million homes, no two of which will be the same, there will be a large number of homes that are not considered to be typical. The findings in Section 3.3 suggest this could be a significant issue, with predicted savings not being realised. While the ECO fund is expected to amount to £1.3billion per year, it is unclear as to the level of uptake. What is clear is that there are a lot of ‘known unknowns’ within the scheme and the methodology used to calculate its success.

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Communication should be directed to Vicky Ingram, v.ingram@hw.ac.uk, +44(0)131 451 4637.

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