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Improving the efficiency and performance of the residential building stock is necessary for meeting future energy and climate change targets. Building Performance Evaluation and Certification (BPEC) tools are vital for estimating and recommending cost effective improvements to building energy efficiency. In the UK, building performance is estimated using the Standard Assessment Procedure (SAP) for new dwellings and Reduced SAP (RdSAP) for existing dwellings. Using a systems based approach we show there are many opportunities for improving the effectiveness of BPEC tools. Building performance standards across Europe are compared and successful strategies highlighted. It is shown that the large variance between estimated and actual energy performance from dwellings may be preventing the broader adoption of bottom-up energy efficiency measures. it is shown that despite popular belief, SAP and RdSAP do not estimate building energy efficiency but instead attempt to estimate the cost-effective performance of a building and thus create perverse incentives that may lead to additional CO2 emissions. In this regard, the SAP standard confounds cost-effectiveness, energy efficiency and environmental performance giving an inadequate estimate of all three policy objectives. Important contributions for improving measurement, analysis, synthesis and certification criterra for buildings is offered.

Keywords UK, Dwellings; Building Stock; Buildings; SAP; EPC;

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Building performance evaluation and certification in the UK: a critical review of SAP?

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24 October 2011

Abstract

Improving the efficiency and performance of the UK residential sector is now necessary for meeting future energy and climate change targets. Building Performance Evaluation and Certification (BPEC) tools are vital for estimating and recommending cost effective improvements to building energy efficiency and lowering overall emissions. In the UK, building performance is estimated using the Standard Assessment Procedure (SAP) for new dwellings and Reduced SAP (RdSAP) for existing dwellings. Using a systems based approach we show there are many opportunities for improving the effectiveness of BPEC tools. In particular, if the building stock is going to meet future energy and climate change targets the system driving building energy efficiency will need to become more efficient. In order to achieve this goal, building performance standards across Europe are compared highlighting the most effective strategies where they are found. It is shown that the large variance between estimated and actual energy performance from dwellings in the UK may be preventing the adoption of bottom-up energy efficiency measures. We show that despite popular belief, SAP and RdSAP do not estimate building energy efficiency but instead attempt to estimate the cost-effective performance of a building and thus create perverse incentives that may lead to additional CO_2 emissions. In this regard, the SAP standard confounds cost-effectiveness, energy efficiency and environmental performance giving an inadequate estimate of all three policy objectives. Important contributions for improving measurement, analysis, synthesis and certification of building performance characteristics are offered.

Keywords: Dwellings; Building Stock; Buildings; SAP; Energy Performance Certificates; Efficiency, Energy Demand.

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Nomenclature

BPEC	Building Performance Evaluation and Certification
BRE	Building Research Establishment
BREDEM	Building Research Establishment Domestic Energy Model
CCC	Committee for Climate Change
DEA	Domestic Energy Assessor
DECC	Department of Energy and Climate Change
DER	Dwelling Emission Rate
DOE	Department Of Environment
ECF	Energy Cost Factor
EHCS	English House Condition Survey
EI	Environmental Impact Rate
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificates
EST	Energy Saving Trust
EU	European Union
FES	Fuel and Energy Survey
FIT	Feed In Tariff
GDP	Gross Domestic Product
PV	Photovoltaic
RdSAP	Reduced Data Standard Assessment Procedure
RHI	Renewable Heat Incentive
SAP	Standard Assessment Procedure
SDLT	Stamp Duty Land Tax
SHWS	Solar Hot Water Systems
UK	United Kingdom
U-Value	The overall heat transfer coefficient representing the rate of heat transfer through a physical boundary

1 Introduction

1.1 Background

In the UK, buildings account for 46% of total CO_2 emissions, with the residential sector responsible for 27% of total emissions (BRE 2007). While space and water heating account for over half of total end use emissions (WWF 2007), demand for electricity, driven by increased plug load, is growing faster than any other final energy source (Trust 2006) (see Figure 5). Such statistics emphasise the importance of reducing emissions from buildings for meeting future energy and climate change targets. This conclusion is defended by many international studies produced by multilateral organisations (WWF 2007; Mckinsey 2008; World Business Council for Sustainable Development 2009; United Nations Environment Programme 2008; IEA 2008a; IEA 2008b; IPCC 2008) and by government departments (DECC 2008; DECC 2009; Department for Communities and Local Government 2007; Committee on Climate Change 2008; Committee on Climate Change 2011). Moreover, there is overwhelming evidence from the extant literature, that some of the largest potential for emissions reductions are from buildings (Swan and Ugursal 2008; Yun and K. Steemers 2011; Sandberg et al. 2011; Lomas 2010; Kannan and N. Strachan 2009; Druckman and Jackson 2009; Wright 2008; Clarke et al. 2008; Natarajan and Levermore 2007). At the same time, improving the efficiency of buildings gives some of the lowest cost forms of CO2 mitigation (L. D. Shorrock, J. Henderson, Utley and Establishment 2005a; Levine and Urge-Vorsatz 2008, p.389; ECI 2005; Horton 2005; Barker 2008). Yet, significant barriers and market failures undermine much needed investment in energy efficiency measures in the buildings sector (IEA 2008c, p.33).

In 2008, the UK introduced The Climate Change Act and thus became the first country to pass legislation for reducing GHG emissions. The UK is now legally bound to reduce emissions by 80% on 1990 levels by 2050 (UK Government 2008). Interim budgets established by the Committee on Climate Change (CCC) require 50% cuts by 2027; 35% cuts by 2022; and 29% cuts by 2017. While it is likely the interim budget to reduce emissions by 23% on 1990 levels by 2012 will be met, this did not occur directly due to climate related policy. Rather, the emissions reductions came from the ‘dash for gas’ during the 1990’s (UKERC 2009, p.17) and the recent financial crisis that saw total emissions drop by some 10% in 2009 alone (CCC 2011, p.4). For the UK to meet the longer term carbon budgets, reductions in emissions from the residential sector are pivotal. This position is acutely expressed by the CCC declaring net emissions from buildings in 2050 will have to be zero if future emissions targets are going to be met (CCC 2010, p.237). It is therefore evident that policies targeted at removing and overcoming market failures and barriers to investment are essential if progress for reducing emissions from buildings is to be made.

1.2 Aim and scope of paper

The objective of this paper is to identify what characteristics of existing policy instruments are working well, and what factors may lead to larger and more rapid improvement of the energy efficiency of the building stock. A systems approach is applied requiring an assessment of the components within the system but also an assessment of the system as a whole. For example, existing government targets require all new buildings to be zero carbon by 2016 whilst simultaneously making significant improvements to the existing building stock (although there are no concrete targets yet in place for the existing stock). The effectiveness of policy therefore relies on the following system components:

- a universally accepted definition of zero carbon;
- accurate calculation procedures for assessing the performance of buildings;
- a widely understood building rating standard for the comparison and assessment of different buildings;
- a sufficient number of well trained and competent assessors to carry out inspections;
- a credible certification programme that when implemented will result in the rapid transformation of the building sector; and,
- high calibre research aimed at understanding the social and technical performance of the building stock resulting in new technological improvements and the development of more well informed policy.

Thus, a successful national BPEC strategy will have at its heart an accurate and reliable set of calculation procedures for assessing buildings; trained and competent assessors; an understandable and well-respected building performance and certification standard, and research with access to rich datasets to close the loop and further improve present BPEC standards. The need for a reliable measurement and verification system was demonstrated in the US through an analysis of the wide variance of energy and carbon performance of buildings under the LEED programme. In a study by Wedding and Brown (2007, 2008) it was found the variance between estimated and actual energy consumption was caused precisely by the lack of measurement and verification in assigning green credentials.

The current paper is novel in its outlook and presents an original critique of building performance standards in the UK. It therefore offers an important but timely contribution to the development of policy for improving BPEC, thus leading to a deeper and more rapid transformation of the UK building stock. This paper is separated into four main sections. The first section looks at the development of BPEC calculation procedures in the UK. Here, we show how the evolution of BREDEM led to the creation of SAP and RdSAP and question the power of existing SAP calculation routines to deliver the changes necessary for meeting energy and climate change targets. The second section looks at the development of the EPBD and compares the different building standards that have been implemented across Europe. Several improvements and strategies are identified for implementation in a UK context. Thirdly, we discuss Energy Performance Certificates (EPCs) and the central role they play for driving bottom-up transformation of the building stock. Finally, we review the weaknesses of SAP and RdSAP and offer suggestions for how the underlying calculation procedures may be improved, increasing the reliability of the estimates and therefore the predictability of end-use energy savings.

1.3 The importance of building performance evaluation and certification

Not only is it important that the potential contribution in emissions reductions from the residential sector is understood and quantifiable, but also, the right policies and incentives are in place to ensure such reductions are achieved. One of the first steps required to meet future emissions related targets is to ensure a robust measurement and certification procedure is in place. There are many benefits for implementing a national BPEC and certification scheme several of these are discussed below.

- When a large sample of statistically robust data is collected from a population of dwellings, it allows for detailed and accurate modelling of the existing building stock. With detailed information about the performance of a large number of discrete heterogeneous buildings, data can be aggregated in different ways to determine the performance of buildings belonging to different groups. For example buildings can be broken into income deciles, building typology, ownership category or location etc. When only a small sample is collected it prohibits the segmentation of the building stock into sub-groups for in depth targeted analysis.

- A large database containing information about each specific dwelling thus makes it possible to target whole boroughs, communities and streets for simultaneous improvement. Targeting the best improvements on a street-by-street basis means that resources can be pooled, transaction costs reduced and the benefits from economies of scale realised. Street-by-street transformation of the existing stock is a clear strategy supported by several existing studies (GFC 2009; Kirklees Council 2009; DECC 2009; Lomas 2011)

- A national building performance and certification scheme provides a common standard from which all buildings can be compared and measured against. This reduces confusion in the sector and creates a level-playing field for market competition (BSRIA 2011) .

- National certification schemes expose previously hidden information about building performance. In Europe, it was not until the European Performance of Buildings Directive (EPBD) that certification requirements were extended to existing buildings across the EU. A primary function of building certification is to address the issue of imperfect information and encourage much needed investment in building energy efficiency (European Commission 2002). In the EU, an EPC needs to be produced every time a new occupier purchases or leases a building. Through the provision of information about a buildings' energy performance, new occupiers are given the opportunity to make well-informed choices about the property thus changing the characteristics that drive value in the property market.

- Fuel poverty in the UK is an increasing concern. In 2009, it was estimated that at least one-fifth (5.5 million) of UK homes were in fuel poverty (DECC 2011a). This is only exacerbated by the forecasted increase to energy prices (DECC 2011b). Without detailed information about the performance of buildings classified as being in fuel poverty, it is difficult to determine what strategies may alleviate these pressures. It is only through robust BPEC standards that the most effective strategies for reducing fuel poverty can be targeted.

In sum, the successful implementation of BPEC standards is central to any national strategy for reducing emissions. However, such benefits only accrue when the BPEC standards are trusted by the users of the information. This can only occur if the standards represent an accurate picture of building performance through the buildings' consumption of energy and emissions. In this paper we show how BPEC and certification standards can be improved through the provision of better evidence, incentives and targeted policy design.

1.4 Evolution of building performance evaluation procedures in the UK

Presently, the UK relies on a group of models (BREDEM) developed and maintained by BRE for estimating the energy consumption of UK buildings. BREDEM was established as an engineering simulation tool for estimating individual building performance. Typically a trained engineer or energy assessor performs an audit on the physical characteristics of a building through measurement and identification of energy relevant characteristics within the home. Parameters recorded include the surface area of all floors, walls windows and roofs as well as the materiality of the structure (e.g. insulation thickness and double glazing). Details about the energy system are also required to determine heating system efficiency. The calculation routines thus use internal and external temperatures to estimate energy demand from a set of heat balance equations (B Anderson et al. 2001). As BREDEM is essentially a physical simulation model the data requirements are substantial.

It is from the early suite of BREDEM models that the Standard Assessment Procedure (SAP) for assessing the performance of new dwellings was first created. The energy performance of existing buildings is estimated using the Reduced Standard Assessment Procedure (RdSAP) and is based primarily on SAP procedures. In RdSAP, additional standard data tables (using default values) are added to the model to replace missing or incomplete information. This greatly reduces the data requirements and the time required for carrying out building performance assessments on existing buildings. Unfortunately this often comes at the expense of accuracy when a building's performance is different from that of the category on which default values were obtained.

Although building regulations have been in place for newly constructed buildings for several decades, it is only relatively recently that existing buildings have come under much deeper scrutiny. This introduces its own set of complex issues. The UK suffers from an aging building stock where approximately 40% of buildings were built before 1944 (Dixon and Gupta 2008). Moreover, it is estimated that over 75% of buildings in use today will still be standing in 2050 (ECI 2005; Sustainable Development Commission 2007, p.41). Thus, transforming the existing building stock whilst maintaining high standards for the construction of new buildings will be central to any national decarbonisation strategy. The importance of existing buildings is emphasised in Figure 1 where the cumulative number of EPC lodgements from new dwellings and existing dwellings is compared. If present trends continue, all buildings will have an EPC by the early twenties.

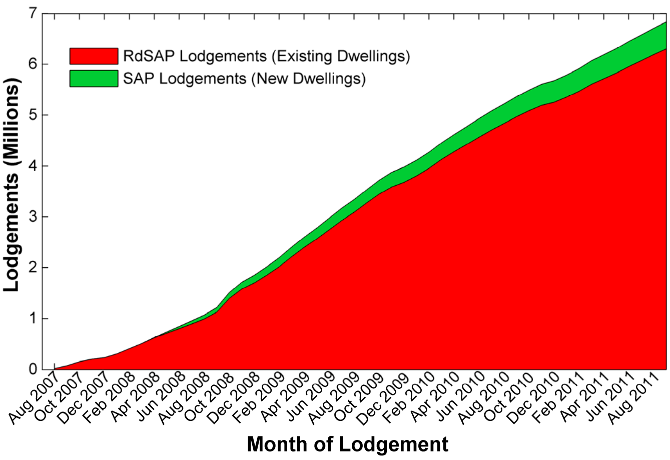

Figure 1: Cumulative EPC lodgements in England

(Data Source: Freedom of Information Request from Communities and Local Government)

The UK Governments Standard Assessment Procedure (SAP) was first developed in 1993 as an independent calculation methodology for estimating the performance of buildings across the UK. SAP is now at the heart of Government policy concerning the measurement, identification and improvement of the UK building stock. The SAP routines have been incorporated into the UK building regulations for meeting the energy requirements of newly constructed buildings (Part L1A) and for measuring the energy performance of existing buildings (Part L1B). It is the chosen methodology for delivering the EU Energy Performance of Building Directive (EPBD) and is used in the calculation and creation of Energy Performance Certificates (EPCs). It is used widely for the delivery of many Government policies such as Warm Front, the Carbon Calculator, Stamp Duty Exemption for Zero Carbon homes and The Code for Sustainable Homes among others. In future SAP will increasingly be used for the delivery of new Government policy targeting a reduction in emissions from dwellings across the UK. For example, SAP will likely play a central role in policy instruments such as the GreenDeal and the Renewable Heat Incentive (RHI), where the effectiveness of strategies to reduce energy and carbon will need to be assessed. Additionally, it will be an important measure for identifying and targeting homes requiring priority attention, such as those dwellings classified as being in Fuel Poverty.

The estimated performance of the building stock is also changing. Below, two histograms represent how the estimated performance of the English building stock has evolved over a 10 year period from 1996 to 2006. While it is clear both the mean and the median estimated performance of dwellings have improved, there has been very little increase within the category of high performance buildings (A or B)[2]. Clearly this must change all buildings must be zero carbon by 2050 as estimated by the Committee on Climate Change (CCC 2010, p.237).

[2] Changes to the SAP calculation methodology between 1996 and 2006 may be responsible for some of the variation in estimates.

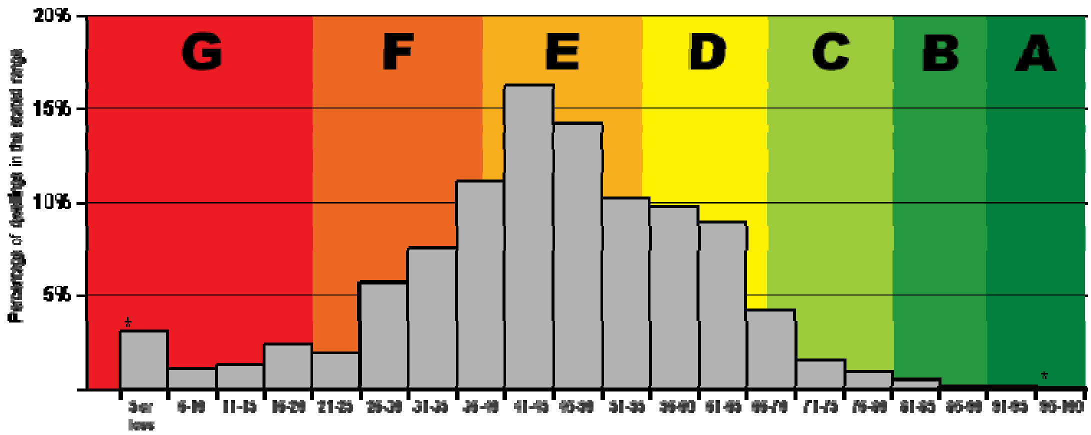

Figure 2: Distribution of UK SAP ratings in 1996

(Data Source: EHCS 1996, after grossing weights have been applied)

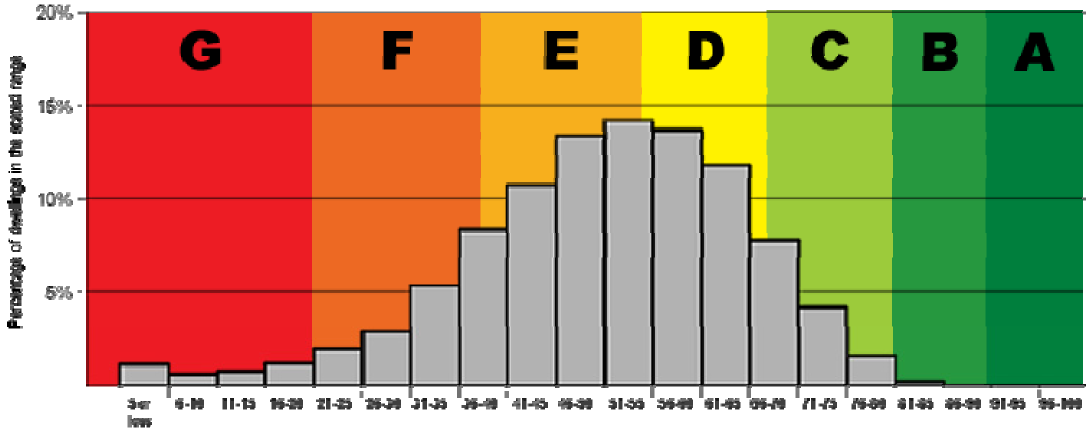

Figure 3: Distribution of UK SAP ratings in 2006. Note that the shift to higher efficiency is primarily in the lower-to-middle performing buildings from 1996, not at the upper end of the distribution.

(Data Source: EHCS 2006, after grossing weights have been applied)

Given the importance of meeting future energy and climate change targets and the central role of buildings for meeting these goals, it is crucial that the underlying data and calculation procedures used by SAP are understood, validated and reflect the range of strategies that might be adopted to improve performance. Whilst anecdotal evidence from professional and academic circles suggests the efficacy of SAP for measuring building performance may be outdated and inadequate (BRE 2006; AECB 2006), there is a gap within peer-reviewed literature providing an independent critique for the effectiveness of BPEC for improving building stock emissions. There is also a serious lack of recent experimental analyses testing the validity and robustness of BREDEM and SAP (at least since 1990's) in regard to calculating building performance, especially for low energy buildings (L. Shorrock 2011). Such validation tests need to correctly estimate the effect of new efficiency measures on energy consumption while controlling for behavioural and other climatic factors. Furthermore, many newly constructed homes do not meet minimum regulatory compliance standards (Energy Saving Trust 2004). This is owed to design errors, building defects and failures in enforcement. This is largely because of poorly developed policy, low understanding from those implementing the regulations and a lack of verification of performance (AECB 2006).

As shown by Figure 4, there has been tremendous growth in the relative SAP rating, rising from an average of just 18 in 1970 to 54 in 2010. If this trend continues, the average SAP rating of the UK building stock will increase to 88 by 2050. This is equivalent to an average dwelling reducing its energy bill from £720/annum to £192/annum in real terms using SAP2009 standard assumptions[3]. Although the trend for increasing SAP rates is promising, the corresponding rate of increase in energy consumption remains uncertain especially as real household disposable income is expected to rise. Furthermore, electricity is the fastest growing end-use energy carrier and presently has the highest carbon intensity (Figure 5). Not surprisingly, the growth in residential energy consumption is largely matched by the growth in new dwellings for the period 1970-2004. From 2004 onwards however, residential energy consumption appears to decouple from growth in new dwellings. One plausible explanation for this sudden decoupling was the rapid rise in the real price of gas and electricity, motivating consumers to cut energy spending. Another point worth noting is that the real price of energy (gas and electricity) is only 20%-30% more expensive in real terms than it was in 1970, with the majority increase in energy prices having occurred in the last five years.

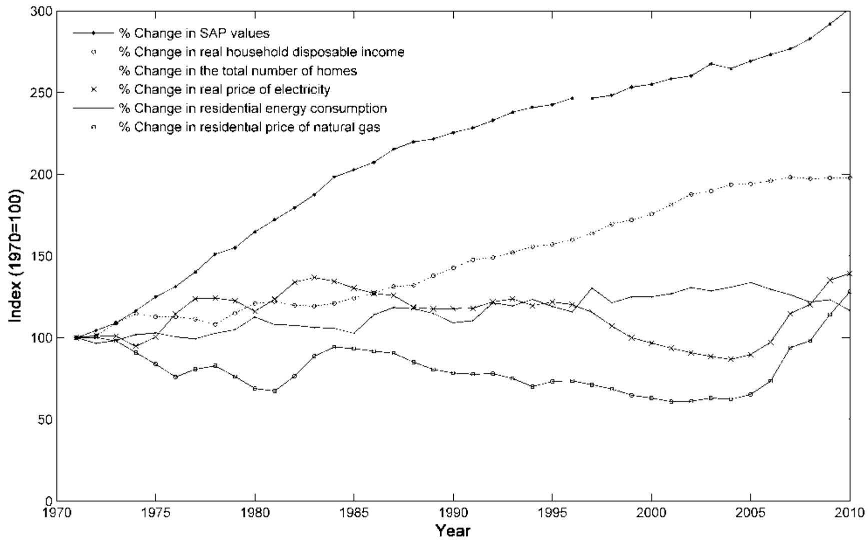

Figure 4: Relative changes in factors that effect household energy consumption and SAP (Data Source: DECC Domestic Energy Consumption in the UK Tables)

[3] Using the SAP2009 standard assumptions, an average dwelling in 2011 with a SAP rate of 55 and floor area of 60m² consumes 15.5MWh/annum for heating using natural gas @ 3.1p/kWh and 1.55MWh/annum of electricity @ 11.46 p/kWh. By 2050 the same home will improve its SAP rate to 88 consuming 4.2MWh/annum for heating using natural gas and 0.5MWh/annum for electricity at the same prices (£2005).

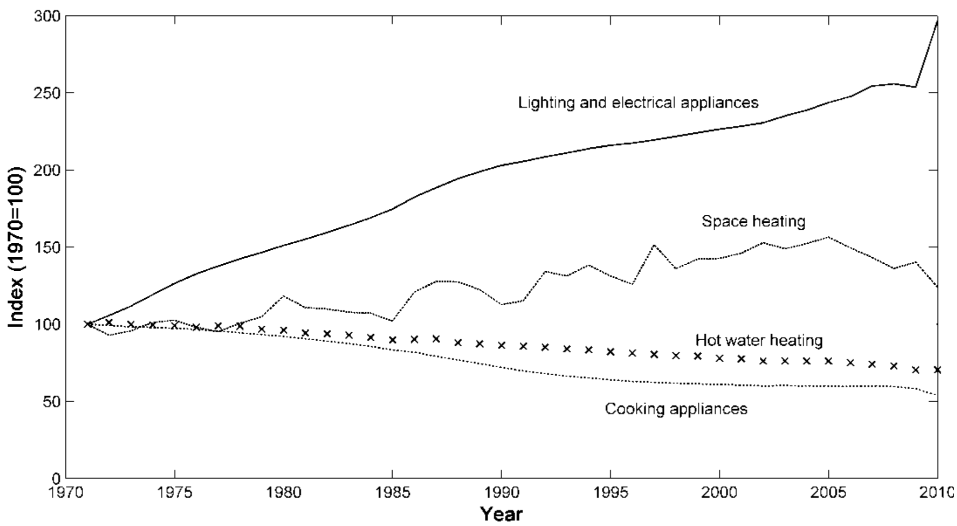

Figure 5: Change in net energy consumption for different end use types

(Data Source: DECC Domestic Energy Consumption in the UK Data Tables)

In conclusion, SAP calculation procedures now form the backbone of government policy for estimating building performance in the UK (Dickson et al. 1996). It is the primary method for assessing the efficiency of the building stock and for meeting EU policy directives regarding improvements to building efficiency (Audit Commission 2009; DECC 2010; DEFRA 2008). SAP is widely used by government departments, local authorities, architectural practices energy auditors and energy companies for estimating building performance and for meeting minimum compliance regulations. Accordingly, the calculation procedures underpinning SAP are crucial to get right.

1.5 The early BREDEM Models

During the 1980's an Energy World Demonstration project was initiated where 51 homes in the Milton Keynes Energy Park were designed and constructed to be at least 30% more efficient than the building codes of the time. These new building endeavours led to advanced trial and monitoring programmes and the construction of over a thousand new low energy homes across the UK. It represented a milestone in the design and construction of energy efficient buildings and important developments in the evaluation of whole-house energy calculation procedures now incorporated in the BREDEM model.

An early successor to BREDEM was a single zone; bi-seasonal building physics model that utilised mean seasonal temperatures for the calculation of energy demand (Uglow 1981). This approximation simply found the average external temperature over the entire heating season (October to April inclusive [5.5-7.5°C]) for use in a heat balance equation. Similar approximations were adopted for internal temperatures, estimated to be 16.4°C for homes using full central heating and 13°C otherwise. Clearly, these crude temperature approximations introduce significant uncertainty adversely affecting the model's ability to predict energy use in homes. Although these approximations simplified the calculation procedure, it is now widely accepted that internal energy demand is highly sensitive to small changes to both internal and external temperature, and that internal temperature is affected significantly by occupant behaviour, raising questions about the accuracy of this model for predicting energy demand (Cheng and Koen Steemers 2011). Furthermore, the sensitivity of this model to varying climatic conditions was never validated, as dwellings used to construct the model were taken from the same geographical location (Uglow 1981).

Another shortcoming of this early model was its sensitivity to the estimated length of the heating season, producing dramatically different demand estimations for small changes in heating season length. Although the temperatures used in this model were long-term averages and no considerations were made for the behavioural effects of occupants, an investigation into the validity[4] of the model showed model estimations were roughly within 20% of measured energy consumption values (Uglow 1982). Unfortunately, the sample of homes used for this validation consisted of just 42 dwellings and had similar characteristics to the homes used during model development, limiting the statistical power of the model to be used for different building typologies and locations (Uglow 1982). The homes modelled thus differ markedly in their characteristics from homes in the population.

A later version of BREDEM was extended to include two zones and incorporate changes to the way internal and external temperatures were handled. Specifically, the model incorporated the degree-day method instead of the mean temperature method (G. Henderson and L. D. Shorrock 1986). The degree-day method is a better approximation of heating demand than the mean temperature method as it more accurately estimates climatic factors from both the duration and extremes of seasonal temperature profiles. Henderson (1986) tested the two-zone version in BREDEM-5 against earlier versions of BREDEM and showed that the two-zone model improved the scatter of model estimates of energy consumption, reducing the average standard error from 33MWh to 28MWh. As noted by Shorrock (2011) these improvements may have also been explained by other changes that were incorporated in the model at the same time. A further shortcoming of this validation process was that it used the same building dataset used by Uglow (1982), and therefore is subject to the same limitations as discussed earlier. Such validation exercises raise important questions about the robustness of these early models for estimating building performance more generally. Furthermore, Henderson (1986) notes:

"The sample used for this study was dominated by medium to large dwellings with a good standard of heating, so that the good agreement observed should be extrapolated cautiously to other situations"

Henderson remarks the model should be expanded and validated against a more varied range of dwellings. The paper proposes that fabric heat loss is only loosely related to energy consumption and calls for an assessment method that accounts for the demand for heating instead of an analysis of only building fabric (i.e. a model incorporating human behaviour). A description on the development of the BREDEM prior to 1985 is available in a report produced by Anderson et al (1985).

In BREDEM-8 the model was upgraded from a two-zone bi-seasonal version to a monthly model. Another validation exercise was completed by Dickson et al (1996)

[4] The model was validated against 42 homes belonging to BRE staff near Garston

and involved comparing the results of the monthly model and the seasonal model against metered energy measurements and detailed simulation models. The metered energy measurement dataset used for this validation exercise consisted of 19 intensively monitored dwellings from the Milton Keynes Energy Park over two consecutive years (Dickson et al. 1996). All dwellings participating in this study used natural gas for central heating and were designed to consume 30% less energy than typical buildings constructed in the UK at the time. Once again, due to the confined geographic location of the sample and the limited sample size, the results from this validation exercise can only be cautiously extrapolated to model buildings in the rest of the UK.

Dickson et al (1996) found very little difference in results from the bi-seasonal version and the monthly version of BREDEM. The reason for such agreement in model results is most likely due to the similar assumptions made by the two models. For example, the monthly model adopted the same calculation procedure for estimating electricity demand as the seasonal model and simply divided the estimated annual electricity demand evenly over each month in the twelve-month period. Dickson (1996) also showed that BREDEM compared well with more detailed simulation models. Agreement between Dickson's BREDEM model and other building simulation models can be explained by similar assumptions common to most physical building simulation models. For example, building simulation models fail to account for human behaviour and usually just include the physical properties of the building.

The most recent and comprehensive BREDEM-9 model has incorporated several much needed improvements. The model now allows different heating profiles for weekdays and weekends, a more thorough allowance of renewable resources, it incorporates monthly demand for electricity from lights and appliances, it allows for the responsiveness of the heating systems and it makes important corrections for the utilisation of hot water. Given the significant developments that have now been incorporated into BREDEM it is unfortunate that robust validation projects of the model have not been carried out for over fifteen years. As discussed already, even the initial validation exercises conducted on BREDEM raise important questions about their applicability for extrapolation to the rest of the UK building sector. For example, in order for BREDEM to reproduce a statistically significant model estimate of energy consumption for the UK building sector, BREDEM would have to be validated against a sample of approximately 384 dwellings[5]. This has significant implications for the validation of SAP rates based on the same calculation routines used in BREDEM, where the most recent validation exercise was completed on just 19 dwellings. As far as the authors are aware there has never been a validation exercise conducted for BREDEM on a sample more than 45 dwellings or for a sample spanning any significant geographic-climatic region in the UK. Moreover, recent improvements to buildings codes have resulted in the construction of many high performance buildings. The energy consumption from this new generation of buildings has never been tested against BREDEM and SAP energy performance estimations (L. Shorrock 2011).

[5] This assumes a confidence level of 95% and a confidence interval of +/-5%.

Figure 6 summarises data on the relationship between actual and modelled energy consumption, using the 1996 English House Condition Survey (EHCS) and the 1996 Fuel and Energy Survey (FES). The SAP estimates of energy consumption were taken directly from the 1996 EHCS. The scatter plot shows 3,756 data-points clearly showing the large variance between estimated and actual energy costs taken from metered energy use. It is expected that some of the variance can be explained by climatic and behavioural effects not included in the SAP calculations. However, with such a wide confidence interval[3] and weak statistical significance of slope, the error bars of the model estimates cannot be ignored in determining whether SAP is truly predictive of actual energy consumption. In sum, the homogeneity and limited sample size of these early building models severely limits the accuracy and robustness of the models for predicting energy demand from a large cross-section of homes in the UK. It is concluded that a more accurate energy-demand estimation model is urgently required.

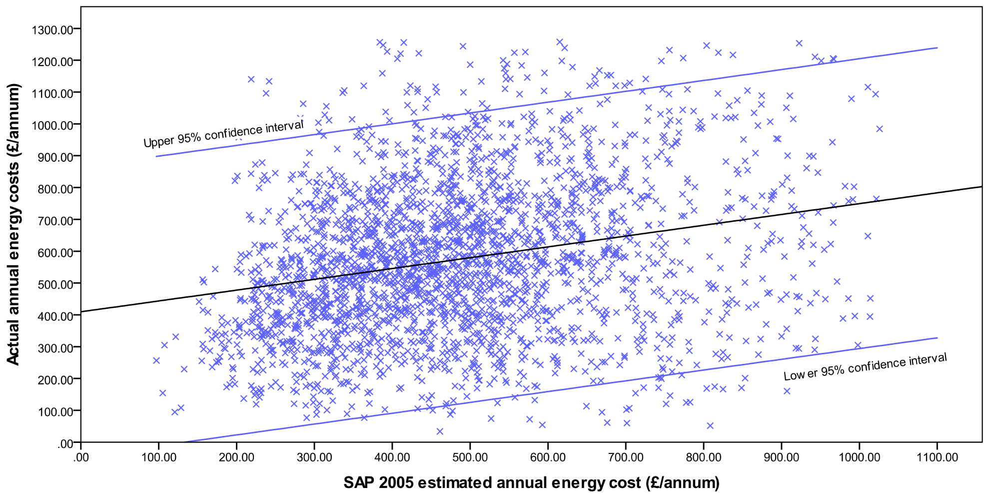

Figure 6: Actual versus SAP estimated energy consumption

1.6 The development of SAP for new buildings

One of the most important outcomes from BREDEM was the establishment of a national rating scheme for buildings, now known as the Standard Assessment Procedure (SAP). The development of SAP was conceived from a desire to provide a national energy-rating label for buildings and to address the confusion that had arisen from several private-sector energy rating schemes (Killip 2005, p.9). The original purpose of SAP aimed to address the following issues:

- enhance the role of building energy efficiency for all buildings sold and let;
- use the SAP rate as a trigger for improving the energy efficiency of buildings; and,
- introduce minimum SAP rates into the building regulations for new buildings;

Although SAP is calculated using very similar algorithms included in BREDEM, there are several important distinctions between these two models. First, BREDEM is foremost a tool for estimating the energy demand from a dwelling. This requires the input of physical building characteristics but also details about occupancy and weather that are generally location specific. The purpose of SAP however, is to give a standardised measure from which the energy performance of a building can be compared with other buildings in the UK. Therefore, as an indicator of relative building energy performance (as opposed to estimating energy consumption directly) SAP rates are estimated independent from occupancy, behaviour and weather characteristics, although, other European countries make very different assumptions about the standardisation of different factors (e.g. France has three different climatic zones).

The first version of SAP was developed in 1993 as a joint project by the Department for the Environment (DOE) and the Building Research Establishment (BRE). It was developed using the annual BREDEM-9 model to independently rate, assess and compare the energy performance of a heterogeneous building stock. By 1994, SAP had been incorporated into part L of the building regulations and marked a step change in the way newly constructed buildings were rated and assessed. One of the main outputs of the new rating system was an energy efficiency index, ranging from 1-100, known as the buildings SAP rate. The SAP rate represents an estimate of the annual cost in £/m^2 for providing heating, hot water and lighting to a dwelling. The higher the SAP rate the lower the expected energy cost. As well as being independent of demographic, social and cultural factors, SAP is also independent of the ownership and efficiency of appliances and individual heating patterns and temperature set points applied by the occupants (DEFRA 2005). Such factors are known to contribute significantly to actual energy consumption (S. Kelly 2011).

A consolidated version of SAP1995 was published in 1998 (SAP1998) with improvements to the methodology being introduced in SAP2001, SAP2005 and SAP2009. In SAP2001 a carbon index was introduced to demonstrate compliance with new building regulations (BRE et al. 2001); this was later adapted in SAP2005 as the dwelling CO_2 Emission Rate (DER) and the Environmental Impact Rating (EI)(RICS 2005). The dwelling emission rate is calculated from a notional dwelling benchmark based on Part L of the 2002 Building Regulations (HM Government 2002). The Environmental Impact (EI) rating is based on a dwelling's CO_2 emissions from heating, hot water, ventilation and lighting less any emissions saved from onsite energy generation technologies. The EI rating is calculated using the emissions factors for different fuel types. Like SAP, it is normalised to unit floor area and expressed on a scale from 0-100 so that the building's EI rating is essentially independent of dwelling size. In SAP2005, a supplementary calculation for Stamp Duty Land Tax (SDLT) was added giving exemption of stamp duty for zero carbon homes. In this new version several improvements were made including: additional allowances for the effects of thermal bridging; an update to solar hot water heating calculations; new allowances for renewable energy technologies; the addition of energy used for lighting; and, a change was made to adopt more widely understood energy units (i.e. GJ to kWh).

From April 2006, new building regulations stipulated the use of SAP2005 for all newly constructed buildings. Among other things, the new building regulations replaced the requirement of U-values for estimating household energy efficiency with the Dwelling Carbon Dioxide Emission Rate (DER). At the same time, the new regulations necessitated the need for SAP rates to be displayed inside newly constructed buildings. It was hoped that by conspicuously displaying the energy performance rating of newly constructed buildings, the awareness of energy efficiency for purchasers, sellers, and occupants would increase, and therefore be an important factor in the sale of new dwellings. The intention of this new policy was to ensure that energy efficiency ceased being a hidden factor that was difficult and expensive to determine and would become a transferable, transparent, and simple measurement for making investment decisions in buildings. This principle was extended to existing dwellings and led to the implementation of RdSAP and later Energy Performance Certificates (EPCs).

Up until 2006, the focus of building regulations had been on the construction of new buildings, or those buildings undergoing major renovation. With legislation for the construction of new buildings firmly in place, a new rating scheme for existing buildings was urgently needed. In 2006, the building regulations were once again amended to comply with the new EPBD (EU Parliament 2002). This led to the introduction of approved document L1A for new build and L1B for existing homes including extensions. The outcome was a new version of SAP specifically targeting existing dwellings. The new assessment procedure, now known as RdSAP (Reduced Data SAP) substantially lowered the overall data requirements from previous versions of SAP. With this new rating system, average values about the building stock can be used when physical data for a dwelling is either missing or incomplete. Theoretically, this means that every home, no matter how old, can be given a SAP rating from which it is possible to create an energy performance certificate (EPC). Under new legislation (HM Government 2007), an EPC must be completed whenever a building is sold, constructed or rented out, showing the energy performance of the property and how it can be improved. This is typically carried out by an independently certified professional who visits the dwelling and gathers the required information to make an assessment. The purpose of the new law was to allow buyers to make informed choices about the purchase or rent of a property during the early stages of the transaction, thereby affecting the decision of purchase.

The most recent modifications to SAP2009 include: monthly estimates for the demand of space and water heating; allowance for space cooling; explicit inclusion of parameter estimates for the thermal mass of a dwelling; improved methods for the calculation of boiler and heat pump efficiencies; improved calculation of thermal bridging; and updated weather data tables and CO_2 emission factors.

Despite widespread use, there is still much confusion about what BREDEM, SAP and RdSAP actually measure. BREDEM is a building physics model that estimates the energy requirements of a dwelling while ignoring the behavioural effects of occupants. SAP uses BREDEM algorithms and therefore also ignores human behaviour but estimates the economic efficiency of a dwelling using standardised data for climate, the number of occupants as a function of floor area, internal temperature characteristics and energy prices. RdSAP is similar to SAP but uses a standardised set of assumptions about building characteristics such as age, typology, and heating systems for estimating building performance. Even so, the input data requirements for RdSAP are still significant and can take a trained assessor one day to complete approximately four assessments (Banks 2008). In sum, BREDEM is used to estimate building energy consumption while SAP and RdSAP are used to estimate building performance.

SAP remains the central procedure for assessing and certifying the energy performance of new buildings in the UK. It is therefore, imperative that SAP and RdSAP give the right signals for transforming the building sector. This will require methodologies that fairly and accurately measure building performance in an open, transparent and transferable way. Figure 1 is a timeline showing how BREDEM and SAP have evolved over the last forty years. Instruments such as the GreenDeal, RHI, and FIT's will only lead to greater reliance on BPEC tools and standards.

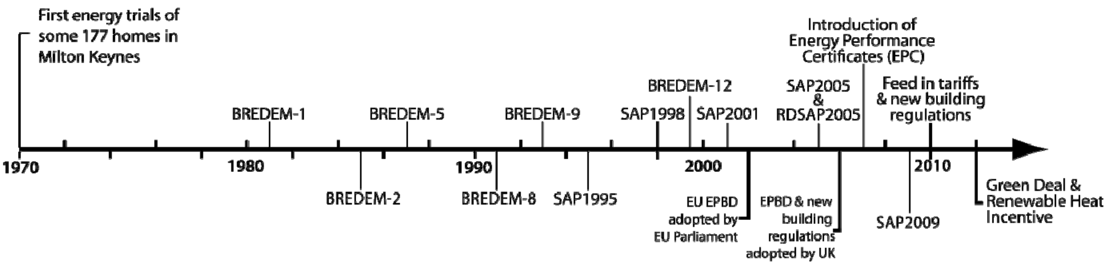

Figure 7: Evolution of BREDEM and SAP

2 Inter-European comparison of building performance and certification

The Energy Performance of Buildings Directive (EPBD) was introduced by the EU Parliament in 2002 and has had a significant influence in bringing about much needed changes to building regulations in many member states and remains the most important legislative instrument at the EU level for reducing energy consumption from EU buildings (EU Parliament 2002). Despite concerted efforts from EU officials, the long-term trend across the EU27 has remained relatively unchanged. The large difference in emissions between countries as shown by Figure 8, can be explained by differences in climate, relative per capita wealth, the size of dwellings and the number of occupants per dwelling, varying widely from country to country.

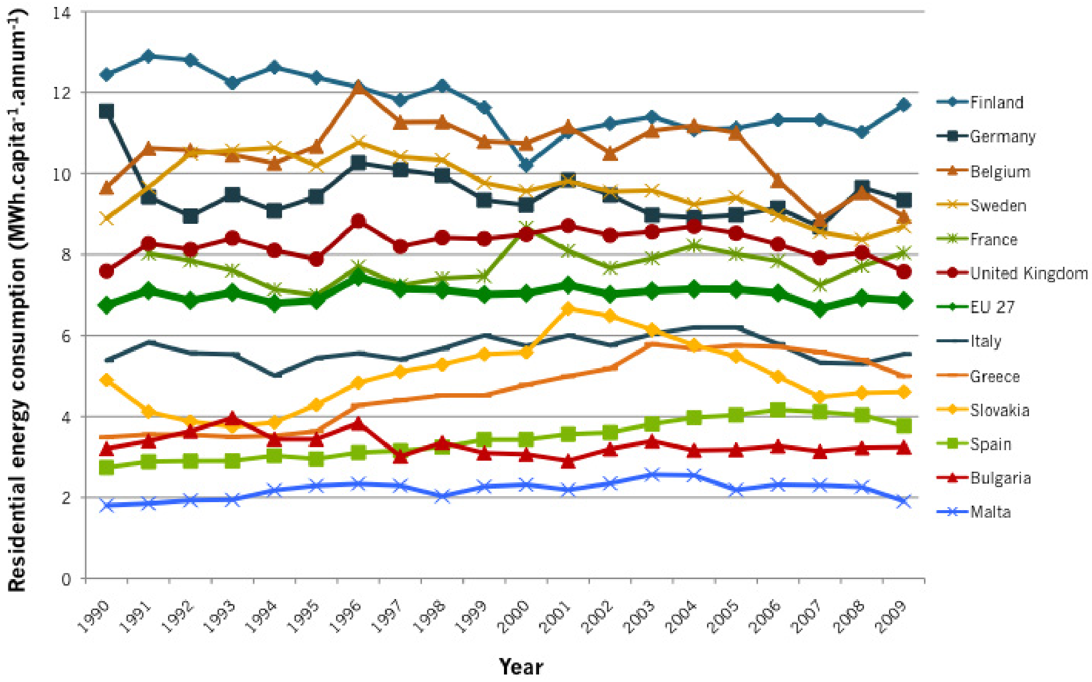

Figure 8: Residential annual emissions for a per-capita basis for selected EU countries (Data source: Eurostat 2011)

In the UK, the introduction of the EPBD came at a time when public awareness of climate change was increasing, as was political pressure to deal with fuel poverty. Thus, the introduction of a reliable rating scheme for both new and existing dwellings was acutely needed. The following section will compare and contrast policy, and regulations implemented in the building sector for different EU member states, with particular focus on how the UK may learn from European experience.

As outlined by the European Parliament, the EPBD was designed to go beyond simply being a tool for the analysis and comparison of buildings to something that would form the basis of transforming the built environment across Europe. Under the principle of subsidiarity and proportionality member states were required to develop and implement measurement and certification standards for improving the energy performance of their building stock. Each member states was therefore given freedom to implement their own BPEC standards (EU Parliament 2002), the result was a plethora of different BPEC standards across all member states. Some 30 European (EN) and 24 International standards were drafted (Roulet and Brian Anderson 2008). With the benefit hindsight since implementation, the strategies adopted by different member states can now be assessed and compared.

A review of these schemes has highlighted some important differences. For example, some countries only consider heating while other countries include cooling needs as well as hot water, plug load, and lighting in calculation procedures. There are also important differences in the level and type of information being collected. For instance, some member states use primary energy while others use final energy. Germany gives both primary energy and final energy statistics on the EPC (European Union 2011). While most member states give a grade in energy units (i.e. kWh/m^2 per year) some give additional units (i.e. CO_2/m^2 per year). The UK is somewhat unique in that it uses the final cost of energy to create a relative scale of building performance from 0-100. All these factors make it difficult to compare ratings across different member states. However, it is possible to look at different schemes across Europe and identify what instruments appear to work well.

When innovative products and technologies are not included in BPEC, it acts as a barrier to market uptake (Heijmans et al. 2010). If a new technology or innovative system does not contribute to the calculation of the SAP rate, there is no motivation to include it in design, construction or renovation of a building (Xing et al. 2011). It is therefore important that SAP procedures explicitly foresee the possibility of new technologies and innovative systems, which are not covered by the standard procedure. Countries like Portugal and Denmark offer loose frameworks, making it much simpler for new and innovative systems to be incorporated. However, there are disadvantages to this approach that include inaccuracies between anticipated versus realised energy savings. A further method of dealing with new and complex technologies is the 'equivalence approach' where equivalent technologies are used as proxies for unspecified technologies. To minimise the disadvantages it is beneficial for any building performance standard to regularly make improvements to the calculation procedure or alternatively make allowance for technologies to 'prove' their efficiency levels to be better than the performance of the equivalent technology. If both calculated and metered energy consumption data were to be collected, the difference between these two values could assist in the determination of actual efficiency improvements offered by the new technologies.

An important distinction between several EU schemes is the methodology used in the calculation of building performance. There are two methods. The first method is known as the 'estimation method' and is derived from the physical properties of the building. Average values for buildings of a similar type are sometimes used when information is missing. The second method is the 'measurement method' and uses actual energy consumption data to estimate building performance. Both methods have their own advantages and disadvantages. The estimation method is based on the physical properties of the building envelope and the efficiency of heating systems, thus detailed information about the building allows improvement diagnostics to be carried out. Another advantage of this calculation procedure is that standardised calculation procedures mean the calculated energy performance from buildings can be immediately compared. The time required to collect sufficient information about a building for this type of analysis is not negligible, thus making it a much more costly process to implement. The price for carrying out an energy performance evaluation in Europe ranges from €100-€1000 (European Union 2011, p.26). In the UK, the estimated cost is much less, estimated to be around £40 making it one of the most affordable schemes in Europe.

The measurement method, on the other hand, is quick and energy saving recommendations directly relate to the real energy consumption of the dwelling. This method however is adversely affected by occupant behaviour and because building certification supposedly represents an independent estimate of building performance and not the behaviour of occupants, standardisation of certification for comparison purposes across different buildings becomes problematic. A further complication of this method is that it makes the identification of building improvements difficult to assess as much less information about the physical properties of the building is collected and so the contributions of building characteristics and occupant behaviour cannot be separated. Clearly, the best approach is to combine both methods. There are presently four countries in the EU that allow users to choose between methods, these are: Finland, Germany, Luxembourg and Latvia. However, the full potential of combining estimated and measured energy consumption readings has not yet been fully exploited.

Given the apparent success of the EPBD since it was introduced in 2002, and the huge potential remaining for improving the performance of buildings across Europe, a new version of the EPBD was recast and ratified by the EU Parliament (2010). The Recast of the EPBD clarified, strengthened and extended the scope of the existing directive, requiring all new buildings to be "nearly zero" energy by 2020. The definition of 'nearly zero energy' requires newly constructed buildings to have very high-energy performance with energy sourced from renewable sources produced on-site or in proximity to where the final energy is consumed. This is in stark contrast to the strategy adopted in the UK requiring all new buildings to be zero-carbon by 2016. Given the controversy surrounding the definition of zero-carbon in the UK (Goodchild and Walshaw 2011) and the difficulty in measurement and certification of zero-carbon policies (Kennedy and Sgouridis 2011), it is not surprising why the EU chose to use energy consumption as the measurement instrument instead of CO2 emissions.

The subtle differences in policy and implementation strategies across Europe raises important questions about the availability of different schemes for meeting energy and climate change targets. While the UK methodology gives a certain amount of freedom for developers to source low carbon energy, it does not necessarily provide sufficient motivation to improve the efficiency of the building. Put another way, a building in the UK may continue to use energy inefficiently as long as it is taken from a low carbon source. This is in contrast to the Recast of the EPBD that calls for clear strategies that focus on energy demand reduction and on-site renewable energy production. Although there are no specific targets for existing dwellings, the Recast of the EPBD expects member states to develop policies and take measures that will stimulate the refurbishment of existing buildings and to inform the commission of these national plans.

3 Evaluation of Energy Performance Certificates (EPCs)

A necessary and important output of carrying out building performance evaluations is the Energy Performance Certificate (EPC). In the preamble of the EPBD it states that the EPC is to form the basis of a package of integrated policy measures designed to transform the building stock across Europe. The EPC system therefore goes beyond being a simple tool for the comparison of buildings and serves as a policy instrument for reducing carbon emissions and transforming European buildings. One of the key principles of the EPBD is the stipulation that any building sold, leased or undergoing major renovations within the EU must have an energy performance evaluation and an up-to-date EPC.

The scheme is now functional in all member states and is regarded as being successful in stimulating the transition to a more efficient building stock (European Union 2011). There are however, still logistical and economic considerations that are being closely scrutinised by several member states. In the UK, SAP calculations have been mandatory for new buildings since 1995 and from 2007 it became compulsory for all buildings sold or leased to have an EPC (Bell and Robert Lowe 2000). The following section will therefore discuss the benefits and disadvantages of different strategies. Figure 9 shows the layout of an EPC for England and Wales showing both the SAP rate and the Environmental Impact Rating. It is a discrete normalised scale with no connection to real units. This is in contrast to the both the German (Figure 10) and Italian (Figure 11) versions that give a single continuous scale quoting actual energy consumption in (kWh/m^2). The German scale also gives estimates for the energy consumption for both new and old buildings of the same building type. The Italian EPC shows a range of different building performance measures; (i) cooling performance, (ii) heating performance, (iii) hot water performance, (iv) overall performance. Both give an estimate for the annual CO2 emissions and the average performance of the building stock.

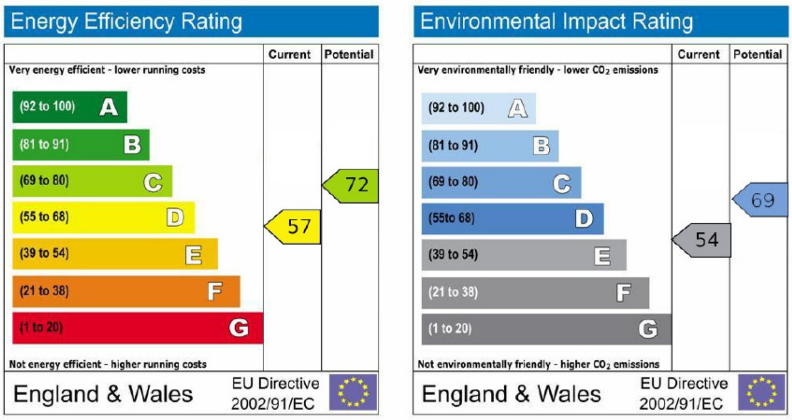

Figure 9: SAP and EI rating for Energy Performance Certificates (EPC) in England and Wales

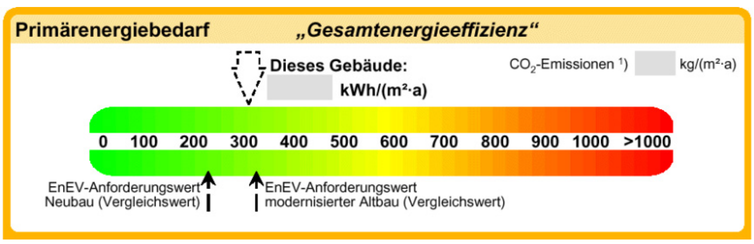

Figure 10: German Energy Performance Certificates

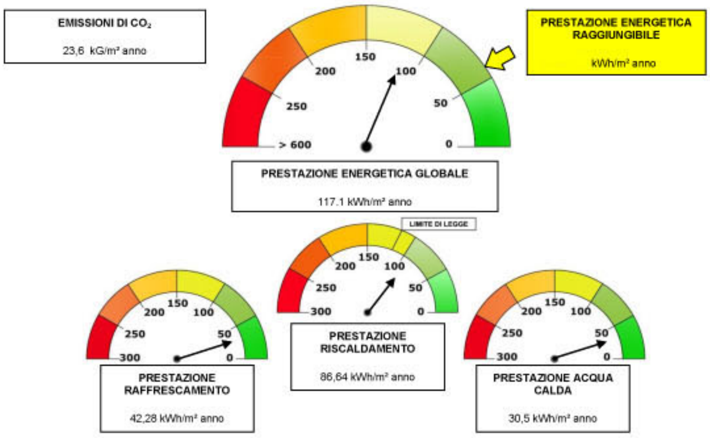

Figure 11: Italian Energy Performance Certificate showing a range of different measurements

In the UK, EPCs have been mandatory since October 2007, and provide important information to purchasers and renters about the performance of a building from which informed choices can be made. In essence, an EPC overcomes information asymmetry between the seller (who generally has good information about a building) and the buyer (who has limited information). Thus, EPCs act to facilitate the exchange of information between the buyer and the seller reducing the disparity between the *market price* and the *fair value* paid for a property (Sandmo 1999). This is a significant point considering research by *Wolseley (UK)* has shown over two-thirds of respondents would pay more for an energy-efficient home (Wolseley 2006). Even in cases where the seller may not have a good grasp of the energy performance of the property, an EPC may encourage the seller to improve the building performance in the hope it might increase the attractiveness of the property to buyers or renters who do place value on this type of information.

The way in which EPCs are delivered and the information that they contain has considerable relation to the success of the policy instrument and ultimately whether the proposed measures are eventually adopted. The perception of the EPC is as important to its effectiveness as the accuracy of the information contained on the certificate. In a study by Banks (2008) it was found that the majority of sellers had a negative attitude towards EPCs. The common attitude was resigned acceptance, with misgivings about the whole process and speculation that EPCs were just another stealth tax applied by the government. Banks (2008) found that estate agents had a similar view, speculating that the process was just a “big con” where they were left wondering what was gained from the process. As this type of attitude is so widespread, it may have an overall detrimental effect on the scheme. For example, homeowners are less likely to improve the performance of their home if they place no value on the results of the EPC and buyers will be less likely to consider EPC ratings when purchasing a home. User buy-in is thus essential for achieving market transformation, which in turn means there must be a clearly established relationship between the numerical value on the EPC and actual energy savings.

Banks (2008) argues the costs associated with carrying out the assessments are one of the root causes of dissatisfaction. Once overheads are factored in, the cost of carrying out an EPC is estimated to be around £100. Banks (2008) suggests that reducing the VAT rate from the full rate of 20% may go some way to reducing such apprehension.

Somewhat perversely, the VAT on energy consumed for home heating in the UK, such as natural gas, is set at 5%, while costs associated with improving building efficiency (like EPC evaluations) are taxed at the full rate. This is a simple example where government policy is clearly sending the wrong message to consumers. Similarly, if building performance were linked to council tax rebates, the attitudes of buyers and sellers would likely favour improved energy efficiency.

In the UK, the full EPC contains more information than just the categorical A-G SAP scale. The certificate also includes an EI rating and information on the estimated running costs of the building broken down by service type. Average building performance of all UK dwellings is also included (grade E), but such information is only vaguely helpful. If the average performance of a building in the same building category (i.e. same building type, age and construction material) were given instead (similar to the German standard), it would give owners a better indication if their property was over or under-performing for that particular building category. Such an addition might stimulate an increase in energy efficiency, as buyers and letters tend to make comparisons within a category of buildings rather than across them.

As stipulated in the EPBD, EPCs are required to include recommendations for cost-effective building improvements. This is probably the most valuable information contained on the EPC. These are separated into 'lower cost measures', 'higher cost measures' and 'other solutions'. Lower cost measures typically cost less than £500 while higher cost measures typically cost more than £500. The 'potential' column in the EPC certificate only includes improvements from lower cost measures. The category 'other solutions' generally includes options that are more expensive and have much longer payback periods. The cost-effectiveness of options is estimated using a simple payback calculation. Although this is the easiest approach, it does have several drawbacks. Simple Payback is sensitive to changes in costs and is a poor estimate for costs that arise in the present and savings that accrue in the future. A more accurate method would use net present value (NPV) or internal rate of return (IRR) calculations to allow for the time value of money. In addition, the anticipated future prices for fuels needs to be included in calculations as the effect of rising (changing) energy prices has a significant effect on the cost-effectiveness of different energy efficiency measures. A government certified annual forecast of future energy prices could be used to improve the cost estimates of different efficiency measures. Simply assuming existing energy prices continue at current prices is incorrect and leads to erroneous results that underestimate the cost effectiveness of building improvements.

An important component of the EPC is the list of cost-effective improvements listed on the certificate. Research by Oxera has shown that most residents have little or no knowledge about the characteristics of energy efficiency, including costs (Oxera 2006). For example Oxera showed that only 8% of respondents were aware of accreditation schemes for existing domestic insulation installers and significantly over estimated both the time and cost of installations. This highlights the importance of providing an indication for the true costs and savings to a dwelling. Information concerning actual building running costs salient to new building occupiers. Unfortunately, only the estimated running costs are provided for a dwelling on the present EPC. Providing new occupiers with information on the actual energy consumption of a dwelling based on metered energy consumption readings will give new occupiers a much better picture of the real performance of a dwelling. With information about a dwelling's actual energy consumption, improved estimates about anticipated savings can be made and therefore more accurate recommendations for the most cost-effective energy efficiency measures given.

In order to work effectively the EPC must be available to new occupiers as early as possible in the decision making process. Because many responsibilities for carrying out EPC duties fall on estate agents, solicitors and private landlords, the success or failure of the scheme lies with these professionals. In a study by Banks (2008) it was found that many professionals were not fully adhering to the scheme guidelines or simply doing the bare minimum to meet regulatory compliance. Banks (2008) found statutory regulations were too relaxed, reducing the potential effectiveness of the scheme. One prime example is the absence of any requirement to show the EPC until right before a new contract is signed, at which point the decision to purchase or lease the property has already been made. This reduces the power of the market to discriminate between homes with different energy performance characteristics. One way to overcome this shortcoming is for the energy performance rating to be included with any advertisement, or marketing material aimed at selling or leasing a property. With the introduction of the Recast of the EPBD (European Parliament 2010) due to be enforced by all member states by January 2013, building performance ratings will be mandatory on all property advertisements. This will likely lead to greater awareness and use of EPC ratings for comparing building performance values and altering the demand for energy efficient dwellings (Amecke 2011).

The evidence presented suggests that actual energy consumption and calculated energy consumption are very different. It is not unusual for the calculated energy consumption on an EPC to up or down of estimated consumption by a factor two to three. Although much of the variance can be explained by missing variables included the calculation procedures, this may have damaging effects on the credibility of BPEC giving the misconception that certificate estimates are accurately estimating energy consumption, energy efficiency and environmental impact when they are not. Providing sufficient detail on the certificate for what the indicators are actually measuring will go a long way to alleviating this situation.

4 A critique of SAP

In previous sections, we discussed the evolution of building simulation models in the UK aimed at developing summary measures of building performance. We then looked at the introduction of the EPBD and the effect this was having on transforming the built environment across Europe. Our attention then focused on the importance of EPC and the differences in certification across EU countries. Next, we will discuss the strengths and weaknesses of the SAP methodology adopted in the UK and highlight how BPEC might be improved so such evaluations better predict actual performance and hence can be used to identify the most cost-effective improvements.

SAP ratings measure the annual unit cost of space and water heating from notional assumptions about heating patterns and internal temperatures. Fuel prices used by the present RdSAP model are averaged over three years and across regions in the UK. Because SAP is an index calculated from a collection of many different building elements it allows developers to mix and match different building components to meet SAP requirements, often resulting in sub-optimal outcomes. For example, improvement to the building fabric might be sacrificed for an improved heating system, such as a condensing boiler. Although, in theory, this leads to cost-optimal solutions at the time of construction for meeting minimum SAP requirements, it results in sub-optimal solutions for building performance over the life of the building. This is emphasised in Table 1 where the additional cost of a condensing boiler at the time of construction is negligible, making it an obvious choice for a developer wishing to meet minimum SAP requirements. If on the other hand, the lifetime emissions from competing energy efficiency measures are compared, cavity wall insulation and roof insulation offer the most cost-effective CO_2 savings over the life of the measure. Nevertheless, a developer trying to minimise costs whilst meeting minimum SAP compliance, will always choose the option that has the least capital cost at the time of construction in order to meet compliance. Alternatively, if the Net Annual Cost (NAC) method were used to assess and compare technologies over the life of different measures, it would be possible to compare the most cost-effective and the most carbon efficient technologies.

Table 1: Typical costs and CO_2 savings for UK dwelling[6]

Data source: (L. D. Shorrock, J. Henderson, Utley and Establishment 2005b)

	Energy consumption	Difference in cost at installation	Annual energy savings	Lifetime	End of life carbon savings	Net Annual Cost[7]
	kWh/year	£	£/year	years	$kgCO_2$/year	£/year
A/B Rated Boiler	14,623	£50	57	15	5,610	-£53
With Roof Insulation	11,687	£339	87	40	27,840	-£71
With Cavity Insulation	10,783	£406	133	40	35,480	-£114
Glazing E to C rated	14,542	£253	14	20	1,760	-£4
Hot Water Cylinder Insulation	14,059	£20	29	10	1,945	-£27

The main reason for the large differences in the NAC between different technologies (Table 1) is that different building efficiency measures have differently estimated working lives (e.g. a condensing gas boiler has an expected life of 15 years while the installation of cavity wall insulation is expected to last more than 40 years). These factors are left out of present SAP calculation procedures that only estimate the building's present day performance and incentivise investment calculated from the cost difference at the time of installation. Table 1 also neglects to include the additional savings for making refurbishments at the time of construction. For example, a study by the Energy Saving Trust (EST 2006) shows that it is more cost-effective to install efficiency measures during construction or refurbishment than doing so haphazardly over the life of the building. This is due to the added costs of time and labour owed to piecemeal improvements. If the additional savings made by installing efficiency measures at one time (as opposed to haphazardly) the overall

[6] This assumes the building has an annual energy demand of 15MWh/year with annual discount rate,r, of 3.5%.

[7] Net Annual Cost (NAC) is a measure of cost-effectiveness. A negative NAC indicates that a measure is cost effective (i.e. over the life of the technology the return on the investment is greater than cost of the initial investment), whilst a positive value indicates the investment is not cost-effective.

$NAC = EAC - S$; where: S is the annual savings of the measure and $EAC = \left[\frac{Cr}{1 - (1 + r)^{-n}} \right]$; where: C is the capital cost of the measure, r is the annual discount rate (3.5%) and n is the life of the measure in years.

economic performance of carbon saving measures will improve and reduce the total cost of investment. Such benefits need to be included cost effectiveness calculations.

In Figure 12, three dwellings are chosen to represent the building stock in England. Dwelling 1 represents a home at the 25th percentile of energy consumption, Dwelling 2 is taken from the 50th percentile and Dwelling 3 is taken from the highest 75% percentile. The SAP value for each home is calculated using the SAP2009 methodology with a standard typical floor area of 90m^2 for each dwelling. One-third of each dwelling's total energy consumption is assumed to be met by electricity with the remainder being supplied by coal, natural gas, wood, community waste (i.e. waste-to-energy) or bio diesel (Figure 12). The only exception is for homes that use electricity for heating, where it is assumed electrical resistance heaters supply all the heat in the dwelling.

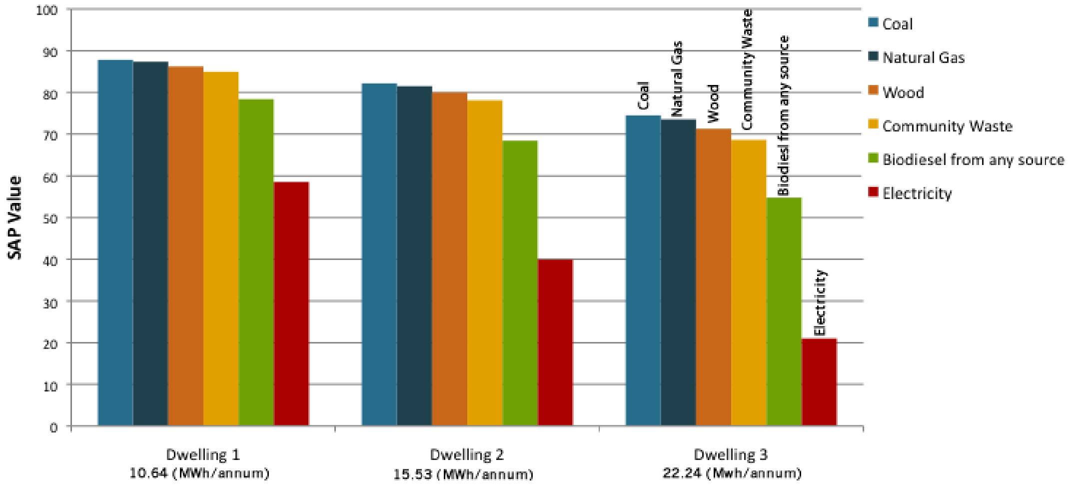

Figure 12: Effect of fuel type on SAP

The main conclusion from Figure 12 is that fuel type plays a very important role in determining a building's overall SAP rate. Strikingly, fuel type appears to make even more difference to SAP than improving building efficiency reducing total energy consumption, in large part because the more carbon intensive fuels tend to be less expensive per unit energy. Unfortunately, this situation may lead to perverse incentives where it is possible to improve a building's SAP value by switching to coal from a less carbon intensive fuel such as wood or bio diesel. In this example, Dwelling 3 can jump from an SAP rating of F to C simply by switching from electricity to coal for heating. In fact, because coal is one of the cheapest fuels used for heating it gives the highest SAP rate when compared with all non-renewable fuel types. This occurs because SAP is a measure of the economic performance of a building and not a direct measure of energy efficiency. It uses energy cost as a surrogate for energy consumption and/or carbon emissions, making it better suited to policies aimed at reducing fuel poverty than at reducing energy or carbon. Within the SAP calculation procedure, energy consumption is estimated from space heating, water heating and electrical lights and appliances. The annual fuel bill is then estimated using standard prices in SAP2009 (Table 2). It is from the total annual fuel bill that the Energy Cost Factor (ECF) is calculated using Equation (1.1).

$$ECF = \frac{C.\mu}{(45 + A)} \tag{1.1}$$

$$\begin{aligned} &\text{for } ECF \geq 3.5, \quad SAP2009 = 117 - 121 \times LOG_{10}(ECF) \\ &ECF < 3.5, \quad SAP2009 = 100 - 13.95 \times ECF \end{aligned} \tag{1.2}$$

In Equation (1.1) ECF is the Energy Cost Factor; C is the estimated annual energy bill for a property, μ is the GDP deflator that allows SAP values to be compared across different years, and A is the total floor area for the dwelling. Thus, the ECF is proportional to the anticipated annual fuel bill on a per m^2 basis. A log transformation is then applied to the ECF to convert it into a SAP rate and put it on a scale from 0-100 (Equation 1.2).

Table 2: Fuel prices and emissions factors used in SAP2009

Fuel Type	Fuel price (p/kWh)	Carbon intensity (kgCO2/kWh)
Coal	2.97	0.301
Natural Gas	3.1	0.198
Wood	3.42	0.008
Community Waste	3.78	0.040
Bio diesel from any source	5.7	0.047
Electricity (standard)	11.46	0.517

The effect of including prices in the calculation of SAP distorts the overall assessment of building efficiency and may undermine legitimate intentions to make buildings more energy efficient. Another unintended consequence of using energy prices is that energy prices fluctuate, sometimes dramatically. Although changes to energy prices over time, within a basket of different fuel-types are captured by the GDP deflator, the relative price difference between fuels is not captured. For example, if the price difference between electricity and other fuels increase, the relative difference in SAP rates will also increase[8]. The result is that SAP values may fluctuate between successive SAP models, not because of changes to building performance but simply because of differences in the market price of fuels assigned. Another downside of the present SAP methodology is that it fails to consider the relative CO_2 emissions from different fuels. From Figure 12 renewable fuels such as wood and bio diesel only contribute to SAP values through price; thus, if the prices of renewable fuels increase, the effect will be a subsequent decrease in the SAP score for dwellings that use these renewable fuels. Absent a significant tax on carbon emissions this problem with the SAP will remain.

Thus far, we have shown that SAP is actually a measure of the economic efficiency of a building and not energy efficiency *per se*. Now it will be shown that SAP is also a poor measure of economic efficiency. Recent changes introduced into SAP2009 allow

[8] Presently fuel prices are updated in the SAP calculation procedure every six months.

dwellings to offset their energy consumption through the generation of electricity through micro-generation technologies. If electricity produced on-site exceeds the energy requirements of the dwelling it is given a SAP rating over 100. Therefore, it is possible for a dwelling with very low building performance to get a high SAP rating if electricity is produced on-site from the installation of PV, micro wind or microCHP. The marginal abatement cost for generation of electricity from these technologies is known to be higher than that of energy saving measures (Scarpa and Willis 2010). Moreover, as the cost of electricity produced by micro-generation technologies is not included in SAP calculations, SAP does not accurately estimate the cost of energy coming from micro-generation. By allowing such technologies to contribute to the overall SAP rating, SAP moves even further from being about efficiency and cost. However, this undermines the purpose of the Environmental Impact Rate (EI) established for the purpose of giving feedback on carbon emissions. Furthermore, as SAP is inherently designed to be independent of geographic location and human behaviour, the estimated cost of energy is even further distorted.

At present, SAP is not set up to handle reimbursements for FIT's or the RHI from micro-generation technologies. Incorporating the financial benefits of FIT and the RHI into SAP will require significant changes to the way SAP is presently calculated and would be unhelpful as SAP would then reflect subsidy levels. Cost rebates for different technologies vary, complicating energy cost estimates, and therefore complicating the estimated SAP rating. Moreover, most technologies qualified to receive a financial rebate under FIT and the RHI are subject to degression rates[9] thus changing the level of subsidy available depending on the year the technology was first installed. This unnecessarily adds several layers of avoidable complication to SAP calculations. If SAP removed energy prices from its calculation procedure altogether (like most other European countries) SAP would be a much better estimate of a building's energy efficiency rate represented in (kWh/m^2) and would be a better means for identifying strategies for reducing energy use and carbon emissions.

The SAP calculation procedure also assumes that electricity generated from PV is co-incident with average demand, therefore reducing net electricity consumption. This is not always true, as solar energy occurs during the day when occupants are typically at work requiring electricity to be exported to the grid. Simply assuming average solar capacity factors across the country also leads to erroneous results, as different parts of the country receive different amounts of sunshine. Another peculiarity of allowing on-site electricity production to contribute to SAP is that there is no allowance for on-site heat production, aside from energy produced through CHP district heating schemes (S. Kelly and Pollitt 2010). The effect of recognising onsite electricity production but not heat is that it benefits expensive electricity technologies and therefore wealthy households that can afford to invest in micro-electricity generating technologies. In addition, there is no account given to dwellings that may be on a renewable electricity tariff. If SAP aimed to be internally consistent, it would be possible to offset energy consumption using other forms of renewable heat such as homes heated by wood stoves, biomass or community heating supplied by renewable sources. At present, the combustion of these fuels contributes to energy consumption and therefore has a negative effect on SAP rates.

[9] Degression is the rate at which the levels of a tariff reduce over time allowing for the cost reductions of a technology as volumes build over time.

The present SAP calculation procedure also does not allow Solar Hot Water Systems (SHWS) to be used in central heating systems, only in hot water systems. This is despite the significant potential for central heating during autumn and spring. Because of this, any additional solar hot water produced over and above the hot water demand requirements cannot be used within the SAP calculation for central heating and therefore limits the overall contribution that SHWS can make to improve the overall SAP rating of a dwelling. Unlike PV, SHWS have the advantage of storing heat in hot water cylinders until heating is required. Lastly, Banks (2008) revealed that SAP calculations were only capturing 25% of the potential energy savings from SHWS. SAP calculation procedures would therefore benefit from improved handling of renewable hot water heating systems.

In order to overcome the limitations of SAP, the Environmental Impact Rating (EI) was created and designed to sit beside the building's SAP rate on the EPC. Instead of using energy prices (like in SAP) the EI rating uses emissions factors from different fuel types. Using the same dwellings from Figure 12, we have recalculated the EI rating[10]. An advantage of EI ratings over SAP ratings is that they include CO_2 emissions factors, but a disadvantage is that they fail to give an accurate measure of building efficiency. For example, in Figure 13 homes that use renewable fuels such as wood, will receive a high EI rating despite how much energy is consumed overall. For homes that use electricity from the grid, the EI rate is even more problematic as it completely depends on the carbon intensity of the national grid (presently estimated at 0.517 $kgCO_2/kWh$), which is predicted to change markedly over the coming several decades. Finally, having two indicators on the EPC adds to the confusion about what these indicators measure and which ones should be used as a measure of energy efficiency or as a means to identify strategies of reduction of energy costs, energy use or carbon emissions, all of which are distinct policy aims.

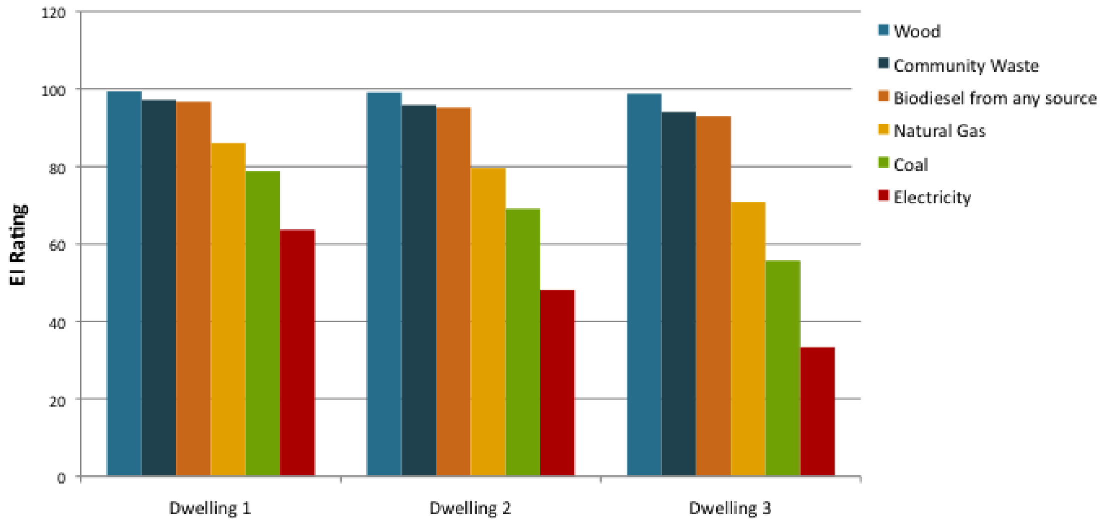

Figure 13: EI ratings for different fuel types

[10] For ease of comparison, we assume that the physical properties of each home are the same, each home has a floor area of $90m^2$ and one-third of total energy consumption derived from electricity.

The effect of human behaviour on household energy consumption is known to be significant (Yun and K. Steemers 2011; S. Kelly 2011; Lomas 2010) and estimated to account for 51% of the variance in heat demand and 37% of the variance electricity demand for different energy users (Gill et al. 2010). Behaviour is also one of the biggest uncertainties in estimating household energy consumption. Even so, most building performance models do not incorporate human behaviour in their analysis. With the rollout of smart-meters and other technologies that integrate with human behaviour, it will be increasingly important to allow for the effects of these new technologies when estimating building performance. In addition, the time of day that energy is consumed is also important (R. Lowe 2007). For example, electricity consumed during peak periods will have different carbon emissions factors as the electricity generation mix fluctuates. As new demand is placed on the electricity system, the electricity mix changes as does the marginal generating plant. The more demand on the grid fluctuates the more important it will be to allow for this effect in calculating the emissions from discrete homes, each having varying energy demand profiles. The incorporation of emission factors for different demand profiles into building calculation procedures could incentivise people to shift their demand and therefore reduce overall emissions (James 2011).

5 A critique of RdSAP

While SAP is primarily designed for assessing the performance of newly constructed buildings, RdSAP is designed for assessing the performance of existing buildings. RdSAP uses the same underlying algorithms as SAP, and therefore suffers many of the same criticisms. Unlike SAP where energy prices are updated every six months, energy prices in RdSAP are updated every three years. But what makes RdSAP significantly different from SAP is that it is designed for use by someone with limited knowledge about building energy analysis and with limited information about physical properties of the building. This means RdSAP requires assumptions to be made about the energy consumption based on the type and age of the building; hence it is an indication of energy consumption across large populations of buildings with similar general characteristics, rather than being specific to a particular building. All buildings assessed in RdSAP are assumed to be located in the middle of England and have typical occupancy rates calculated as a function of floor area. There are also assumptions about heating requirements, where all rooms are heated to a comfortable level (21° in living areas and 18° elsewhere) with a high standard of hot-water heating. Thus, there is a trade-off between model simplicity, accuracy and comparability with other dwellings that may lead to confusion and produce anomalous estimates about building performance for specific buildings (see Figure 6). Given the assumptions made by RdSAP and the large variance between different householders' actual energy use even within a building energy category, errors can be introduced for specific buildings even when estimates of means across categories are correct. For example, dwellings in colder parts of the country should expect their heating bills to be higher than that predicted by RdSAP.

This use of category averages of performance limits the potential of RdSAP to make sound recommendations for improvements. For example, within RdSAP all homes constructed after 1983 are assumed to have cavity wall insulation; if a domestic energy assessor learns this is not the case, there is no opportunity for including this as a recommendation for improvement. Allowing assessors to enter known information about a dwelling will give better insights into recommendations for improvements. Allowing full SAP assessments to be carried out on existing dwellings, will provide more accurate estimates of building performance when required. Additionally, some of the default assumptions in RdSAP are the most cost-efficient options, giving no motivation for assessors to enter the correct energy characteristics. Defaults should be set to be the poorest alternative; thus rewarding occupiers and developers for making the extra effort to calculate the true performance of property. This is similar in principle to the PHPP (pasivhaus standard) in Germany (AECB 2008).

6 Discussion and conclusions

In this paper, we have shown the calculation procedures used within SAP and BREDEM have never been robustly validated against a statistically significant sample of dwellings that represent the UK residential building stock. Moreover, the few studies that have been completed use a relatively homogenous sample of dwellings from a confined geographic-climatic area. Although some of the variance between SAP measured and actual energy consumption can be explained by differences in behaviour and geographic location, the unexplained variance remains substantial. As both the SAP rate and the EI rates are provided on a scale ranging from 0-100 with no evident link to physical measures of performance, there is no relevant feedback to the user about what this means in terms of their relative energy consumption or emissions and how this may compare to other dwellings of a similar building type with different kinds of strategies applied. Many member states in Europe have opted to retain the original energy units on EPCs (i.e. in kWh/m^2 see Figure 10) so that occupiers of dwellings are encouraged to think about energy consumption in original units, therefore increasing awareness and perhaps changing energy practices. The EI rating on the other hand only considers the emissions factors of different fuel types, and provides these as an areal density (emissions per square metre) that is of limited use in assessing movement towards national emissions reduction targets. This measure therefore allows profligate energy consumption as long as it is low carbon, ignoring issues of resource conservation and fuel poverty.

Energy Performance Certificates are a critical component of the BPEC system. The energy rating of a dwelling needs to be made explicit at the earliest stages of the leasing and buying process. Certificates need to be clear and well trusted by owners and new tenants or their effectiveness as a policy instrument is reduced. At present recommendations on an EPC for improving building performance are based on estimated energy consumption and crude assumptions about the future price of different fuels. Including actual energy consumption data on the EPC will act as a reality check against which calculated energy performance could be compared. Using metered energy consumption data, for cost-effective efficiency recommendations (instead of estimated performance) will improve the accuracy of estimating the cost of energy saving technologies. Building performance recommendations can also be improved by using government approved energy price forecasts and the lifetime cost effectiveness calculations by using the Net Annual Cost method.

It is argued that SAP and RdSAP confound cost-effectiveness, energy efficiency, environmental performance and GHG emissions adding unnecessary complexity and confusion to the SAP calculation procedure. As a result it is not clear which of the many national policy aims – reducing fuel poverty, increasing energy efficiency, decreasing overall energy use, or reducing carbon emissions – is being captured by the various performance measures. This then leads to confusion and disconnect between performance measures, policy instruments and policy objectives and which of the policy aims is being improved by a particular strategy. Inconsistency across different approaches then leads to perverse incentives. For example, dwellings that switch to low cost fuels such as coal are rewarded with higher SAP rates despite the implications for carbon emissions reduction.

As clearly shown in Table 3, there are large differences across policy instruments for the affects they have on policy objectives. As it stands policy instruments are used haphazardly to meet multiple policy objectives. Unfortunately this approach leads to unpredictable and possibly ineffectual outcomes. Redesigning BPEC tools so that they target specific policy objectives may lead to more cohesive and productive outcomes. For example, an EPC would contain separate indicators for energy consumption (kWh/m^2), CO2 emissions ($kgCO2\ /m^2$), and energy costs (£/dwelling). Matching measurements with policy objectives reduces confusion and may improve the effectiveness of policy instruments. If required, an additional aggregate indicator that transparently combines each of the three sub-indicators could then be used to assess the overall performance of a dwelling against a combined set of policy objectives. Using this approach it is also possible to transparently represent the importance of each sub-indicator using predetermined weightings.

Table 3: Effect of policy instrument on policy objective

	Impact on policy objective					
Policy instrument	Lower CO2 Emissions	Improve fabric efficiency	Lower energy consumption	Reduce fuel poverty	Increase renewables	Improve security of energy supply
EPC	Medium	Medium	Low	Medium	Low	Low
SAP	Low	Medium	Low	Medium	Medium	Low
RdSAP	Low	Medium	Low	Medium	Medium	Low
EI	**High**	Medium	Low	Low	Medium	Medium
FIT	**High**	Low	Low	Low	**High**	**High**
RHI	**High**	Low	Low	Low	**High**	**High**
GreenDeal	**High**	**High**	**High**	**High**	Low	Low

In addition to targeting policy instruments to match policy objectives there is also a clear need for more detailed information about the building stock to be made publicly available for research purposes. This is particularly true for data at the dwelling level representing actual energy consumption data along with the physical characteristics and social demographic or behavioural factors. These data will allow comparison of estimated and actual performance of buildings, enhancing confidence that such performance measures are useful in identifying the most cost-effective strategies for energy and carbon reduction. Such a statistical database will allow a set of criteria to be established so that buildings can be benchmarked against buildings of the same type. It will also allow researchers to monitor the progress being made in the transformation of the buildings sector.

In conclusion, SAP, RdSAP and EPCs are critical for the transformation to a zero-carbon building stock. It is important that these indicators accurately measure building performance, and that the measurements directly relate to policy objectives. This requires calculation procedures that are robustly validated; standards that measure and compare the right factors; EPCs that are understandable and reliable and drive decision making; and finally, a system of data gathering and research methods that provide feedback into understanding and transforming the efficiency of the building stock.

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