Technical Paper 18

HISTORIC SCOTLAND
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Evaluating energy modelling for traditionally constructed dwellings

Vicky Ingram & David Jenkins

HERIOT WATT UNIVERSITY

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This Technical Paper is available as web publication for free download from the Historic Scotland website:
www.historic-scotland.gov.uk/technicalpapers

This Technical Paper should be quoted as:
Historic Scotland Technical Paper 18

ISBN 978 1 84917 127 4

This paper was published by Historic Scotland, an executive agency of the Scottish Government.

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Introduction

by Historic Scotland

With the use of building modelling now mandatory, there is a need to understand the requirement, the types of evaluation packages available and how the apply to certain house types. The use of modelling tools to assess performance and give recommendations for thermal upgrade is an area of growth and constant change. The scope of the Scottish building stock is extensive, with a wide variety of property types and differing dates of construction. Historic Scotland is taking special interest in older properties, mainly inter war housing and properties that date from pre 1919. Some of these dwellings are historic and many of which are not.

However, they generally conform to standard construction techniques and the materials used, and as such the retrofit measures need to be configured with this fabric in mind. The Scottish House Condition Survey estimates that up to 20% of Scotland's housing stock is in the pre 1919 category and therefore represents a significant proportion of the stock. As much of the basic thermal upgrades will be delivered by Green Deal or ECO processes, which uses the modelling tool RdSAP, it is important to understand how this process assesses older properties and what sort of recommendations it will give for refurbishment.

No modelling system can cover all house types, and any system is a compromise of differing demands. This paper will seek to outline some of the characteristics of RdSAP and how it interprets this significant proportion of the pre 1919 stock. It will also consider areas where some improvement might assist in the modelling of older buildings and the consequent recommendations for improvement.

Executive Summary

by Urban Energy Research Group (UERG), Institute for Building & Urban Design, School of Built Environment, Heriot-Watt University

This study demonstrates, through chosen case studies, the use of building modelling in traditionally constructed dwellings in Scotland. The range of assumptions used by the SAP and RdSAP methodologies are investigated and recommendations are provided for how, with a focus on traditional Scottish homes, changes could be made to improve the validity of the advice provided by these tools.

The modelled case studies are not designed to be indicative of all traditionally constructed dwellings in Scotland. This section of the housing stock has a variety of modelling issues related to construction, listed status, and whether such characteristics are well-represented by building models, and therefore cannot be summarised by three examples. However, the case studies do demonstrate the difficulty in specifying energy-saving measures based on the currently available funding mechanisms. They also demonstrate the sensitivity of certain parameters within SAP and RdSAP models and, along with a background review of modelling, have been used to generate several key recommendations, specifically:

- The use of regional climate data should be encouraged in future iterations of both SAP and RdSAP
- An allowance for the difference in heating seasons throughout the UK should be accommodated within the methodology
- Specification of windows and doors could include more detail to account for differing dimensions, orientation and glazing type
- The default values used to describe thermal mass effects should be expanded to include, for example, uninsulated elements of traditional buildings
- The product characteristics database for heating technologies could be made more transparent and a more versatile approach to specification of different heating emitters added
- The nature and effect of draught lobbies could be better specified without making the SAP calculation any more arduous or resource-intensive
- Validating and calibrating SAP-based models with real data should be strongly encouraged as these models are now being used for applications that they, arguably, were not originally designed for
- With forms of solid-wall insulation being a potentially effective option for traditionally constructed homes, the target of 0.3W/m^{2}K for a refurbished solid-wall home to access ECO/Green Deal funds should be relaxed for homes with higher wall U-values

These recommendations do not deal with every aspect of building modelling, but are areas where improvements are feasible and are likely, in combination, to have a significant impact on the modelling of traditionally constructed homes.

About the authors

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Miss Ingram has a BSc (Hons) in Meteorology from the University of Reading and an MSc in Climate Change from the University of East Anglia. Her interests lie in the mitigation of further climate change, with particular focus on improving the efficiency of existing domestic buildings.
Prior to joining Heriot-Watt University, she worked in the private sector as an accredited energy assessor providing Energy Performance Certificates and strategies for reducing energy use in new-build properties. Her PhD, co-sponsored by Historic Scotland, is specifically concerned with assessing the energy performance of Scottish stone dwellings.

Dr. David Jenkins, PhD, MSc is a Research Fellow with the Urban Energy Research Group in Heriot-Watt's School of Built Environment. He has published over 50 articles in the area of low-energy buildings, building simulation, and climate change adaptation. This includes work on the Tarbase project, a nationally significant EPSRC/Carbon Trust project, which examined a wide range of low-carbon refurbishments for domestic and non-domestic buildings.
Dr. Jenkins holds an MSc in Physics and Astronomy from University College London, and a PhD in daylighting techniques and modelling from Edinburgh Napier University.

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1. Background

1.1. Policy

The requirement for building energy assessment originates in the European Energy Performance of Buildings Directive (EPBD). The EPBD (Directive 2002/91/EC) was originally adopted in 2006, recast in 2009, and requires a common methodology of energy assessment and implementation of energy certification of domestic and non-domestic buildings across all Member States (MS). In the UK, Energy Performance Certificates (EPCs) are provided to all buildings when sold or let, with nuances dependent on whether the building is domestic or non-domestic. Energy assessment methodologies are primarily concerned with providing these EPCs, and proving compliance with other aspects of Building Standards.

Other EU policies[1] are also shaping UK and Scottish legislation, through targets to:

- Reduce greenhouse gas emissions by 20% from 1990 levels by 2020;
- Supply 20% of Europe's energy from renewables by 2020; and
- Increase energy efficiency by 20% by 2020.

Each MS has specific targets, and while the UK has set legally binding targets to reduce emissions by 50% by 2027[2], Scotland has set ambitious targets to reduce emissions by 42% by 2020 with an 80% reduction over 1990 levels by 2050[3], inclusive of aviation and shipping (currently not included within the UK carbon budgets). To reach these targets, strong action is needed in all sectors, including the residential sector.

The UK Government has therefore introduced legislation to aid policies including:

- Renewable Heat Incentive (RHI) – Paying homeowners for every unit of renewable heat that is generated.
- Renewable Heat Premium Payments (RHPP) – Giving households a voucher towards the cost of installing renewable heat systems such as solar thermal or heat pumps.
- Feed in Tariffs (FITs) – Energy suppliers pay the homeowner for every unit of renewable electricity generated; the rate depending on whether the electricity is used in the home or sold back to the grid.
- Energy Company Obligation (ECO) – a levy on energy suppliers to generate £1.3bn each year in funds towards improving energy efficiency in homes. This is replacing the previous Warm Front, Carbon Emission Reduction Target (CERT) and Community Energy Saving Programme (CESP) schemes which ceased in January 2013, and will act through two schemes:

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[1] Summary of EU targets. http://ec.europa.eu/europe2020/targets/eu-targets/index_en.htm

[2] UK Government targets. https://www.gov.uk/government/policies/reducing-the-uk-s-greenhouse-gas-emissions-by-80-by-2050/supporting-pages/carbon-budgets

[3] Climate change targets by region of the UK. http://www.theccc.org.uk/topics/uk-and-regions/scotland

  - Carbon Saving – helping to subsidise improvement measures for dwellings
  - Affordable Warmth – subsiding improvements for target households (e.g. vulnerable and households in fuel poverty)
- Green Deal – a loan system to improve energy efficiency in homes in a cost effective manner through encouraging uptake of renewable energy and energy performance improvement measures.

These policy initiatives, whilst spear-headed from Westminster, are all available in the devolved nations. In Scotland, additional policy targets include[4]:

- 100% output equivalent of electricity from renewable sources by 2020[5]
- 11% of domestic heat from renewable sources by 2020 (aligned with a target for 51% reduction in emissions from domestic heat generation over 1990 levels) through the RHI
- Reduce energy consumption by 12% by 2020 through the Energy Efficiency Action Plan
- Eradication of fuel poverty by 2016, where reasonably practicable
- All homes to have smart meters by 2020
- All social housing to pass the Scottish Housing Quality Standard by 2015

The policy initiatives should work alongside one another; for example the introduction of smart meters may help reduce energy consumption, although concern has been noted within the Climate Change Delivery Plan4 that any increases in the cost of fuel will impact on those most vulnerable and may increase the level of fuel poverty.

What follows is a discussion around the calculation methodologies for domestic energy performance, the results of which contribute to proving compliance with many of the targets outlined above.

1.2. Energy assessment

Energy assessment can provide a basic understanding of building performance for the purpose of reducing bills and improving energy efficiency of (or in) the home. An awareness of energy use within a dwelling may be one of the barriers to lowering energy demand[6], therefore by understanding the dwelling's energy profile a homeowner or specifier can be better informed when considering refurbishments with respect to potential savings, either financial or environmental.

This research focuses solely on UK domestic energy assessment methods and, using a number of case studies, reviews their advantages and disadvantages over more complex energy modelling options.

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[4] Climate Change Delivery Plan. http://www.scotland.gov.uk/Resource/Doc/276273/0082934.pdf

[5] Scottish renewable energy policy summery. http://www.scotland.gov.uk/Topics/Business-Industry/Energy/Energy-sources/19185/17612

[6] Lomas, K., Oreszczyn, T., Shipworth, D., Wright, A., Summerfield, A. 2006. Carbon Reduction in Buildings (CaRB) - Understanding the social and technical factors that influence energy use in UK homes. Annual conference of the Royal Institute of Chartered Surveyors, UCL, London.

1.2.1. Standard Assessment Procedure (SAP)

In 1990 the Building Research Establishment (BRE) produced the Standard Assessment Procedure, a methodology designed to estimate the energy use in dwellings to prove compliance with Building Regulations. Over the past twenty years SAP has undergone many changes, the most recent change of significance in 2010 when the calculation moved from an annual calculation to a monthly calculation. Updates and addendums are now provided typically every six months, with major shifts in the method released alongside important changes to policy, such as the introduction and update of the EPBD and the introduction of the Green Deal.

The latest version of SAP is SAP 2009, v9.90, used from October 2010. This version has updated carbon emission factors, fuel prices, and climate information, and also now includes space cooling. The move from an annual calculation to a monthly calculation now recognises seasonal variations in weather and energy use.

An update is due in Spring 2013, which is anticipated to include regional rather than UK averaged weather data, bringing SAP in line with the method used for existing buildings (which has included this ability since October 2012).

1.2.2. Reduced data SAP (RdSAP)

Since 2007, to comply with the EPBD, existing buildings have needed to be energy assessed when sold or let. The BRE devised Reduced data SAP (RdSAP): a new edition of SAP to enable a single calculation methodology to be used for both new-builds and existing housing. RdSAP provides a database of values to be used in the calculation (such as wall construction, thickness, U-values) that is often unobtainable in a dwelling that is already built. The database of information is based upon the age of the dwelling and which country the dwelling is in, with slightly different information separating England & Wales, Scotland, and Northern Ireland. For example, all houses built between 1984 and 1991 in Scotland will use the same information from the databases. There are a number of bands within the 20th century, with a single age band for houses built pre-1919, and there is some concern that this single age band can lead to inaccurate dwelling assessment[7] (Barnham et al, 2008). Historic Scotland has commissioned much research in this area, including this Technical Paper, which will look at dwellings in both the pre-1919 age banding, and the 20th century.

The simplified nature of RdSAP makes an assessment easier and quicker for the assessor, keeping costs to the householder to a minimum. There is much discussion surrounding the accuracy and ability of RdSAP to represent a true assessment of energy in dwellings, both for[8] and against[9,10] such simplification.

[7] Barnham, B., Heath, N., Pearson, G. 2008. Technical Paper 3: Energy modelling analysis of a traditionally built Scottish tenement flat. Historic Scotland, Edinburgh.

[8] Spiekman, M. 2007. Applying the EPBD to improve the energy performance requirements to existing buildings – ENPER-EXIST WP1 Final Report. www.enper-exist.com

1.2.3. Alternative modelling techniques

The SAP and RdSAP methodologies are not the only method of energy assessment of buildings. There are a number of methods of energy assessment for non-domestic properties. The Simplified Building Energy Model (SBEM) is a steady state calculation, but Dynamic Simulation Models (DSMs) such as IES, Tas or Hevacomp are far more detailed, and can be applied to domestic buildings for research purposes (but not certification).

DSMs look at both high spatial resolution as well as high temporal resolution, to model the changes that occur over time using fundamental mathematics of the heat transfer processes that occur both inside and around a building. The model requires the building to be divided into multiple zones, with activity (e.g. office, kitchen, bathroom, restaurant, bar) assigned to each one, and can also use, for example, detailed Chartered Institution of Building Services Engineers (CIBSE) weather data, for 14 sites across the UK (in Scotland these are Glasgow and Edinburgh).

As well as the basic heat gains and losses calculations, DSMs also include convection, heat transfer by air movement, thermal radiation transmitted by surfaces, solar transmission, and absorption and reflection by any glazing. The heat gains utilised are both sensible heat (the temperature change in the air of the room) and latent heat (the change in humidity in the room). This is far more detail than is estimated in either of the domestic methodologies, a comparison of which is summarised in Table 1.1.

Table 1.1. Summary of main variables and differences between assessment methods

	SAP	RdSAP	Dynamic
Accredited for:	New-build Domestic	Existing Domestic	Non-domestic
Resolution	Monthly	Monthly	Hourly
Climate variables	UK average	UK average	Regional
Time to assess	0.5 - 2hrs	1-2hrs + site visit	1-2 days + site visit
Cost to assess	££	££	£££ upwards

Energy assessment should be as accurate as possible for informed decision making, but a balance needs to be found between simplicity and complexity. As shown in Table 1.1, dynamic simulation methods use detailed input data and assessments can be a lengthy process, whereas simplified

[9] Kelly, S., Crawford-Brown, D., Pollitt, M.G. 2012. Building performance evaluation and certification in the UK: Is SAP fit for purpose? Renewable and Sustainable Energy Reviews 16(9) p6861-6878.

[10] Kennett, S., 2010. Government's carbon compliance tool 'inadequate'. Building.co.uk. Available at: http://www.building.co.uk/5002377.article [Accessed 14 July 2010].

steady state methods use a less detailed approach which can be less time-consuming. The suggested difference in assessment time for SAP and RdSAP is partly related to the fact that the former is being applied to an existing building where a visit to the dwelling is required, rather than a difference in the calculation methodology itself. However, if the assessor is largely relying on default input values for RdSAP (due to lack of data); this process can be relatively quick.

As with any model or calculation, the detail of the output is related to the detail of the input as discussed in the following section.

1.3. Assessment parameters

Any energy assessment is strongly dependent on the assessor to input correct information. Some key input variables required for domestic energy assessment are explored here and, where significant, problems emanating from differences between inputted and actual parameters of Scottish dwellings are highlighted.

1.3.1. U-values

A U-value is a measure of heat loss through the building fabric (per unit area), dependent on the temperature either side of that building element. The elements assessed include floor, walls, roof, external doors, and windows. The level of heat loss is related to an element's construction, and therefore a database of defaults is available for use within RdSAP.

A selection of U-values to be assumed within RdSAP is shown in Table 1.2 for dwellings built prior to 1919.

Previous versions of RdSAP have used assumed values for wall thickness. Research by the Society for the Protection of Ancient Buildings[11] has shown this to be inaccurate. Therefore, to calculate the U-value of solid stone walls, a new method for v9.91 has been introduced to take account of the thickness of the wall:

Granite or whinstone: U = 3.3 – 0.002 × thickness of wall in mm
Sandstone: U = 3.0 – 0.002 × thickness of wall in mm

Additionally, where a stone or solid brick wall is dry-lined or has a lath and plaster finish, the U-value calculated is adjusted:

$$U = \frac{1}{\frac{1}{U_0} + R_{dl}}$$

Where:

U_0 is the value calculated above
R_{dl} is the additional thermal resistance from the internal finish = 0.17m^2K/W.

[11] http://www.spab.org.uk/downloads/SPABU-valueReport.Nov2012-v2.pdf

Table 1.2. U-values to be assumed, from RdSAP 2009, v9.91 (April 2012)

Element	U-value W/m^{2}K	Notes
Solid sandstone wall	1.40	Based on a 600mm wall with lath & plaster finish
Solid sandstone wall to stairwell	1.05	Unheated stairwell
Solid brick wall	2.10	No insulation
Cavity wall	2.10	No insulation
Filled cavity wall	0.50	Fully filled
Timber frame wall	2.50	No insulation
Timber frame wall (insulated)	0.60	Internal insulation
Party wall – solid	0.0	
Party wall – filled cavity	0.0	Sealed at all exposed edges
Party wall – unfilled cavity	0.5	Without effective edge sealing
Slate or tile roof	2.30	No insulation
Thatched roof	0.35	No insulation
Window – single glazed	4.80	All assumed to be wood frame
Window – double glazed	2.00	Installed after 2003
Window – secondary glazing	2.40	All assumed to be wood frame
Door – to outside	3.00	
Door – to unheated stairwell	1.40	If heated, zero heat loss

A U-value is not the sole measure of heat movement within a structure - moisture movement for example will aid thermal transfer, and is not yet included in any energy assessment methodologies.

1.3.2. Thermal Mass Parameter

Thermal mass is the measure of the heat capacity *within* the construction, rather than the heat flow *through* the construction. The thermal mass acts as a natural temperature dampener, absorbing warmth in the air, and releasing it when it is cooler in the room. The dampening effect also acts to delay the variation in temperature; therefore the coolest temperatures outside would be felt later on indoors (see Figure 1.1).

Previous versions of SAP and RdSAP have not included an input for thermal mass. The 2009 edition, which moved to a monthly calculation, includes the Thermal Mass Parameter (TMP), and is defined by SAP as the heat capacity within the construction, per unit of floor area of the dwelling. The heat capacity, C_m (kJ/m^{2}K), is calculated as the sum of the individual heat capacities of each element (floor, walls, roofs, and internal walls) multiplied by that element's area. The TMP is used to determine internal temperatures when calculating the space heating and cooling loads and likelihood of overheating in summer months.

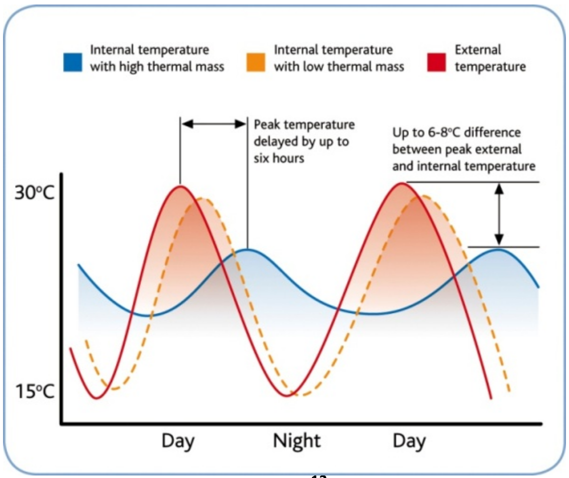

Figure 1.1. Thermal Mass effect[12]

1.3.3. Windows

The glazed area of a dwelling contributes in two ways to the energy demand for space heating; firstly through heat loss and secondly through solar gain.

The U-value of a window tends to be higher than that of the walls, and has been much discussed in Technical Papers 1 and 9[13], so the U-values of windows are not analysed here. However, the area of the window is an important factor in calculating the solar gain and heat loss, yet within RdSAP is currently a restricted input. Table 1.3 is taken from RdSAP 2009 v9.91 and indicates the assumptions to calculate window area.

Table 1.3. RdSAP 2009 v9.91 assumptions for window area

Age band of main dwelling	House or Bungalow	Flat or Maisonette
A, B, C	WA = 0.1220 TFA + 6.875	WA = 0.0801 TFA + 5.580
D	WA = 0.1294 TFA + 5.515	WA = 0.0341 TFA + 8.562
E	WA = 0.1239 TFA + 7.332	WA = 0.0717 TFA + 6.560
F	WA = 0.1252 TFA + 5.520	WA = 0.1199 TFA + 1.975
G	WA = 0.1356 TFA + 5.242	WA = 0.0510 TFA + 4.554
H	WA = 0.0948 TFA + 6.534	WA = 0.0813 TFA + 3.744
I	WA = 0.1382 TFA – 0.027	WA = 0.1148 TFA + 0.392
J, K	WA = 0.1435 TFA – 0.403	WA = 0.1148 TFA + 0.392

[12] Image courtesy of The Concrete Centre, originally from the publication "Thermal Mass Explained". 2009.

[13] Technical Papers - http://conservation.historic-scotland.gov.uk/home/publications.htm

In addition to the assumptions in the table, an assessor chooses whether the window area of the dwelling is: i) "less than" typical, ii) "much less than" typical, iii) "more than" typical, or iv) "much more than" typical, for the age and type of property. If the window area is less than typical, then the values in Table 1.3 are reduced by 25%; if more than typical, they are increased by 25%. If the assessor thinks the window area is much more or much less, then individual measurements of each window must be made, in which case orientation data must then also be collected. This enables the assessor to override the RdSAP assumption and enter accurate information; an option that would be more accurate but is a more lengthy process, depending on the number of windows in the dwelling.

Solar gains contribute towards lowering the heating demand, by heating the air and warming internal surfaces such as floors and furniture. The level of contribution that the sun can provide depends heavily on the window – its orientation, specification of glazing, and type of frame. It also depends on the incident surfaces, as darker smoother surfaces will absorb the incoming radiation to greater effect than lighter rougher surfaces.

The solar flux through a window differs depending on the orientation and the season. In RdSAP, the windows are all assumed to have 'average' overshading (from trees, other structures etc), and be east/west orientated, unless the assessor is entering the actual window details in which case orientation must also be recorded. This east/west assumption will limit the solar gain accuracy and underestimate gains if the dwelling has a large number of south facing windows and overestimate gains if the dwelling has a large number of north facing windows. The solar gains are an important variable within RdSAP, and the magnitude of its effect will be explored in Section 3.1.2.

1.3.4. Weather data

Every energy assessment model includes weather data, but its use can vary widely with methodology. For compliance calculations – e.g. Building Standards, Building Warrants and Energy Performance Certificates, the heating requirement uses UK average data. For Green Deal calculations however, the model uses regional data, allowing a more accurate assessment to better analyse potential savings of an improvement measure. The UK is split into 21 regions (Scotland is nine of these), each region having an average external temperature (Met Office average 1976-2005), wind speed and solar radiation (Figure 1.2). For the UK average, the model uses the same information as for Region 11 – Sheffield (East Pennines).

Dynamic modelling differs greatly to that of steady state methods, as the weather data does not just include temperature data. The IES software can use CIBSE Test Reference Years using historical weather data from the Met Office. This enables the model to incorporate hourly data over a year for the following variables: dry bulb temperature; wet bulb temperature; atmospheric pressure; wind speed; wind direction; cloud cover; total horizontal solar irradiation; and diffuse horizontal solar radiation. Therefore the diurnal temperature cycle is included, as is the effect of solar gains on each individual zone. It should be noted, however, that the regions within the CIBSE database do not match those used with domestic assessments.

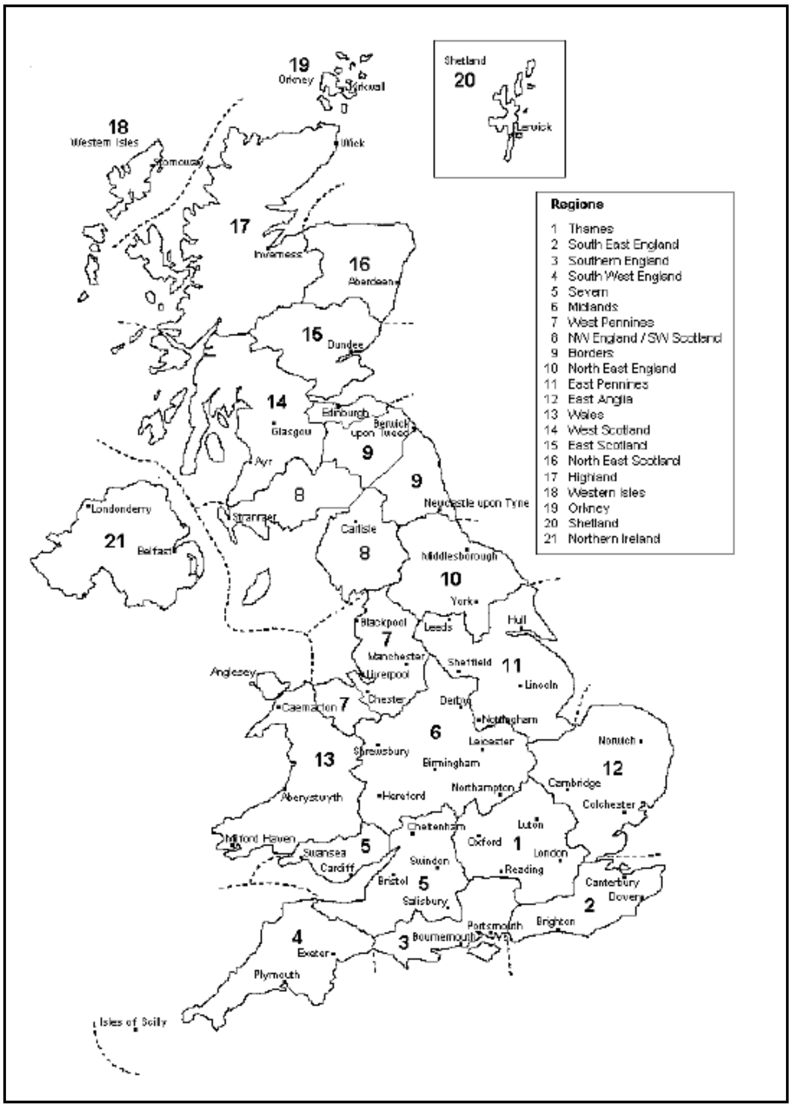

Figure 1.2. Climate regions as defined by RdSAP. Every UK postcode area is assigned a climate region.

1.3.5. Draught-proofing

A common perception, and perhaps stereotype, of older homes is that they are cold and draughty buildings. It is well known that air movement affects thermal comfort and that draught-proofing can be a cost-effective way of improving this in a leaky building during cold weather[14]. Accounting for the level of draught-proofing in a dwelling is included within the steady-state methodologies. In SAP 2009, this is entered as an integer representing the percentage of windows and doors draught-stripped. In RdSAP 2009, this integer is assumed as the percentage of windows classed as 'multiple glazing' – whether double, triple, or secondary. Doors are assumed not to be draught-stripped.

It is questionable what significance this integer has on the final energy requirement, and it may be an important consideration if SAP or RdSAP 2009 are to be used for refurbishment calculations.

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[14] CIBSE. 2006. Environment Design Guide A. ISBN-10: 1-903287-66-9

1.3.6. The 'draught lobby'

The SAP 2009 methodology has a strict definition of a draught-lobby:

> "A draught lobby is an arrangement of two doors that forms an airlock on the main entrance to the dwelling. To be included, the enclosed space should be at least 2m^2 (floor area), it should open into a circulation area, and the door arrangement should be such that a person with a push-chair or similar is able to close the outer door before opening the inner door"

In RdSAP 2009, the presence of a draught lobby is dependent on the dwelling type. Specifically, if the dwelling is a flat or maisonette a draught lobby is assumed to be present whether the corridor is heated or unheated. In a house or bungalow it is assumed there is no draught lobby.

1.4. The historic built environment

The Scottish House Condition Survey (SHCS) collects data from approximately 3,000 dwellings across Scotland every year, to assess housing and households. This is then extrapolated to provide a picture for the whole country. Table 1.4 provides an overview of the numbers, type and age of dwelling, from the 2011 Key Findings[15].

Table 1.4 Number of dwellings (000s), of dwelling types in Scotland, from the SHCS 2011

Age of dwelling	Detached	Semi-detached	Terraced	Tenement	Other flats	Total
Pre 1919	100	61	63	178	56	459
1919-1944	47	91	35	29	100	303
1945-1964	29	142	182	100	70	523
1965-1982	115	103	204	94	48	565
Post 1982	217	84	67	128	23	519
TOTAL	509	482	551	529	297	2,368

Using the SHCS provides a good summary of the Scottish housing stock, and the challenges facing it with respect to improving energy performance become clear, particularly:

- Urban/Rural divide
- Fuel poverty
- Type of dwelling

[15] Latest Scottish House Condition Survey. http://www.scotland.gov.uk/Topics/Statistics/SHCS/Downloads

- Protected buildings

Each of these is explained further below, using data from the SHCS from 2010 and 2011 (the most recent reports available at time of writing).

Urban and rural areas often have very different challenges to face in terms of: fuel availability, fuel delivery and cost; space for larger technology such as heat pumps or solid fuel systems requiring storage; and space for roof-based technology for shared roofs (e.g. tenement blocks). Of the whole Scottish housing stock 83% is in urban areas; for the pre 1919 age band[16] this value is slightly lower at 71%. As expected there are more detached dwellings in rural areas, with the majority (98%) of pre-1919 tenements in urban areas. A significant challenge in rural areas is sometimes the lack of access to cheap fuel, such as mains gas. In urban areas, 99% of dwellings are on the gas grid, compared to 48% in rural areas.

The more expensive a home is to heat, the more likely it is to be described as being in 'fuel poverty', defined as spending more than 10% of household income on fuel. Within the pre-1919 age band – using October 2011 fuel prices – 46% of households were fuel poor or extremely fuel poor (spending 20% of household income). The national average for Scotland is 34%, suggesting that this age of dwelling is either more expensive to heat, has lower income occupants, and/or is less efficient than newer buildings.

As introduced in section 1.3, the heating requirement of a dwelling is dependent on heat loss through the building fabric to the outside environment. Caution must therefore be given when analysing different types of dwelling: a small bungalow will have a larger area of heat loss per unit floor area in comparison to a large multiple storey dwelling; this is an area of research being carried out currently at Heriot-Watt University[17].

Every dwelling is likely to face multiple challenges to improve energy performance, from the accuracy of an assessment to the cost of recommended measures. These differences will depend on the location and type of dwelling and whether it is protected through being Listed, part of a Conservation Area, or part of a World Heritage Site, as is the case of Edinburgh, New Lanark and Orkney.

[16] Information specific to the pre-1919 age band comes from the 2010 SHCS, using data from an ad-hoc data request.

[17] V. Ingram and D.P. Jenkins, Analysing steady-state models for dwelling carbon performance, World Sustainable Energy Days, Wels, Austria, 27th Feb – 1st Mar, 2013

2. Methodology

To analyse the results of energy modelling in traditional Scottish dwellings, three case studies have been assessed using the three assessment methodologies introduced in Section 1.2: SAP 2009, RdSAP 2009 v9.91 and IES<VE>. An analysis of the differences between the methodologies and the impact this has on decision making is carried out. Further calculations have been carried out for a number of Green Deal scenarios to ascertain the ability of RdSAP 2009 to provide Green Deal measures that meet the Golden Rule. Because SAP and RdSAP software is available to accredited assessors only, the methodologies have been put into a bespoke spreadsheet model, allowing in-depth analysis and comparison of options currently not available through standardised software.

2.1. Case studies

2.1.1. CS1 – Large detached house

The large detached house is a four-storey, L-plan, former Laird's house in the heart of Edinburgh. Believed to have been constructed in the mid-16th Century and rebuilt significantly after fire in the 17th, the house has had a mixed history. Owned at one point by the Earl of Linlithgow, it was associated with the Regent Moray prior to his assassination in 1570, and has been used as a house for the gardeners at Holyrood Palace. It was later lodging for two families, and is now offices for Historic Scotland, following extensive refurbishment.

Figure 2.1. View of the rear of CS1 from the East (Source: Vicky Ingram)

This case study has many challenges in terms of it being accurately represented by RdSAP, with a large number of windows on multiple orientations, three different thicknesses of external stone rubble wall, turret spaces, and rooms in the roof. The turret spaces also provide challenges for the dynamic model, which is unable to apply windows to such tight curved walls. This is an area of development that the software providers are now considering.

2.1.2. CS2 – Small semi-detached bungalow

The semi-detached bungalow (Figure 2.2) was built at the end of the 19th century, as housing for farm labourers in a village just west of Edinburgh. Part of a larger development at the time, it is one of only two that have survived, the remainder having been rebuilt after falling into disrepair.

The village is off the mains gas grid, so the cottage is heated using bulk LPG from a tank in the neighbour's garden (as there is insufficient room in the dwelling's own garden). The LPG is delivered automatically when the tank reduces to a certain level, but there is no way of knowing the LPG usage until the annual statement outlines whether the monthly payments have been sufficient. The electricity is on a pre-pay system, the only case study to use this method of electricity payment.

Figure 2.2. View of CS2 from the South East (Source: Vicky Ingram)

Being a semi-detached bungalow, there is a large area of heat loss for CS2, and as such the EPC rating from an assessment in 2009 is a G. The two large front windows are south facing with no shading and the remaining windows are heavily overshaded by the neighbouring dwelling and tall hedges, implying the solar gains may differ from the calculated values. The windows were replaced in the last decade with PVC double glazing, the loft has 200mm of new mineral wool insulation, and the extension at the rear of the property has both floor and cavity wall insulation.

2.1.3. CS3 – 4-in-a-block flat

In an Edinburgh suburb, this upper ex-council flat built in the 1940s is of typical construction for Edinburgh's 4-in-a-block style of housing, with solid brick walls. The windows are PVC double glazed, and the accessible loft has mineral wool insulation added in the last 5 years. Similarly to the cottage of CS2, the flat is semi-detached but with a flat directly below, the heat loss area is reduced in relation to the floor area of the flat.

Figure 2.3. CS3 from the South East. (Image: Google Streetview.)

Additional types of housing (a traditional tenement and detached cottage) have been studied in Technical Paper 16.

2.2. Research applicability

Each case study has unique features and challenges with respect to energy modelling; for example, the relationship between area of heat loss and floor area, the orientation of the windows in the dwelling, or the construction assumptions that must be made.

As has been noted with regards to each case study, the domestic building stock in Scotland is not homogeneous and as such the results of this case study are specific to the dwellings investigated. The findings can, however, be used to add to the debate surrounding the energy performance of Scottish traditional dwellings, and the anticipated delivery of the Green Deal in Scotland and in other areas of the UK. Previous Technical Papers for Historic Scotland (3, 4, 5 and 8) have investigated energy assessment methods and the challenges that come with the Scottish housing stock. This Technical Paper uses the most recent version of the energy assessment methodology, v9.91 released in April 2012, and has a focus on the policy on which financial decisions may well be made.

It is hoped that the results of this research can inform homeowners and other stakeholders of the Scottish built environment as to the energy performance of dwellings, the policy driving home improvements, and the feasibility of such improvements.

3. Analysis

The primary methodology concerned in this Technical Paper is RdSAP 2009 (v9.91). The core calculation engine is the same as within SAP 2009, so comparison of the two methodologies enables an analysis of the assumptions and default values that RdSAP uses. Additional assessment using IES enables a further comparison across methodologies and highlights weaknesses of a steady state method when assessing energy use.

To assess the Green Deal policy, calculations using RdSAP 2009 only are used, as this is the methodology upon which decisions will be made.

3.1. Limitations of RdSAP

3.1.1. U-values

Previous assumptions concerning the thermal performance of traditional building materials have not always been seen in reality. The Society for the Protection of Ancient Buildings[18] has in recent years measured in-situ U-values of elements from 77 buildings across England finding, for example, in-situ sandstone wall U-values of 1.63 W/m^2K. Research for Historic Scotland investigated 67 in-Situ measurements across Scotland[19] finding in-situ U-values for 600mm solid sandstone walls of between 0.8 and 1.6 W/m^2K. The SPAB work found that in-situ measurements were on average lower (i.e. better) than those in RdSAP v9.90; both reports found, unsurprisingly, that the thicker the wall, the lower the U-value. Such studies have been reflected in the recent changes introduced for the current version of RdSAP, explained in Section 1.3.1.

To analyse the impact that U-values have on the energy performance of a dwelling, different U-values can be applied to each case study and the end result (in this case, SAP rating) examined. The results of the change in U-value calculation between versions of RdSAP are compared in Table 3.1, and show that the current RdSAP uses significantly better U-values than previously. This should therefore calculate a lower heating demand and give a better rating of energy performance for the same dwelling.

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[18] http://www.spab.org.uk/downloads/SPABU-valueReport.Nov2012-v2.pdf

[19] http://conservation.historic-scotland.gov.uk/publication-detail.htm?pubid=8341

Table 3.1. Impact of updates to RdSAP 2009

	RdSAP v9.90	RdSAP v9.91
Thickness of wall included	No	Yes
Internal finish included	No	Yes
U-value – 600mm stone wall (CS1, CS2)	1.5	1.4
U-value – 800mm stone wall (CS1)	1.5	1.1
U-value – 1090mm stone wall (CS1)	1.5	0.7
U-value – 220mm solid brick (CS3)	2.1	1.5

The impact of these changes is then shown in Table 3.2, giving the level of heat loss the dwelling is estimated to have through the building fabric, along with the space heating demand and SAP rating for each case study.

Table 3.2. Impact of RdSAP updates on SAP results

CS1	RdSAP v9.90	RdSAP v9.91 (as for compliance)	RdSAP v9.91 (as for GD)
Heat loss parameter (W/m^2K)	4.61	4.26	4.26
Space heating requirement (£/yr)	3,992	3,737	4,171
SAP rating	30.8 (F)	33.9 (F)	28.8 (F)
CS2			
Heat loss parameter (W/m^2K)	3.71	3.71	3.71
Space heating requirement (£/yr)	573	575	646
SAP rating	42.6 (E)	42.4 (E)	38.1 (E)
CS3			
Heat loss parameter (W/m^2K)	2.80	2.36	2.36
Space heating requirement (£/yr)	466	385	430
SAP rating	61.1 (D)	65.4 (D)	63.0 (D)

These results show that the lower (and probably more accurate) solid-wall U-values used for the v9.91 calculation methodology, provide lower heating bills and an improved SAP rating when running the RdSAP calculation in “compliance” mode. However, when in “Green Deal” mode and using regional climate data (discussed in section 4.1.3), the heating bill and ratings for the stone properties (CS1 and 2) are worse than v9.90. For the solid brick dwelling (CS3) the bill and rating for Green Deal mode is also worse than the “compliance” mode, but still better than version v9.90.

This may have implications for the success of the Green Deal: savings large enough to meet the Golden Rule from a new heating system, for example, would appear to be easier to achieve in v9.91 where the pre-improvement heating cost is larger than in previous versions of RdSAP.

3.1.1. Thermal mass

The space heating requirement in reality can be affected by the thermal mass of the construction acting on the internal temperature, as described in Section 1.3.2. RdSAP assumes a medium level of thermal mass (250kJ/m^{2}K) but using the aforementioned bespoke spreadsheet model, any level of thermal mass can be manually entered into the calculation. The variation in internal temperature associated with thermal mass in each case study is shown in Figure 3.1 to Figure 3.3.

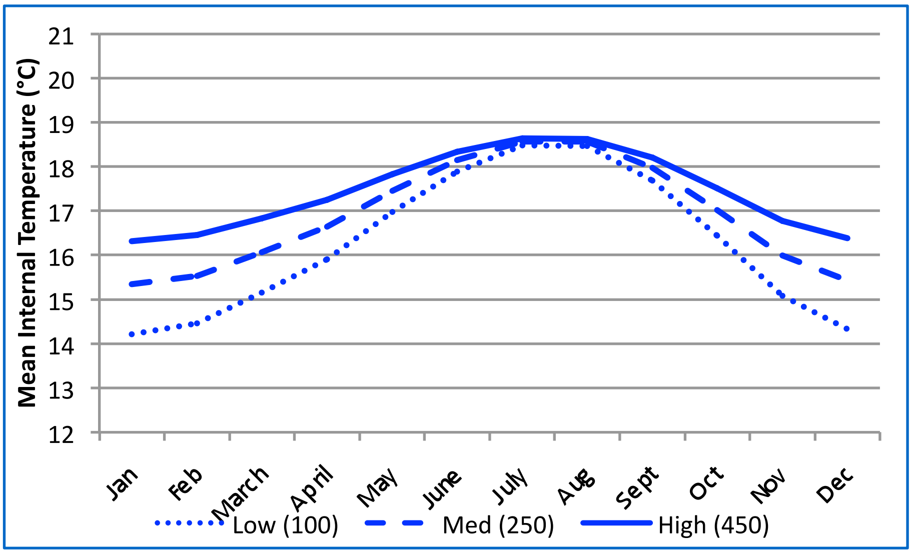


Figure 3.1. Thermal mass effect on internal temperature for CS1

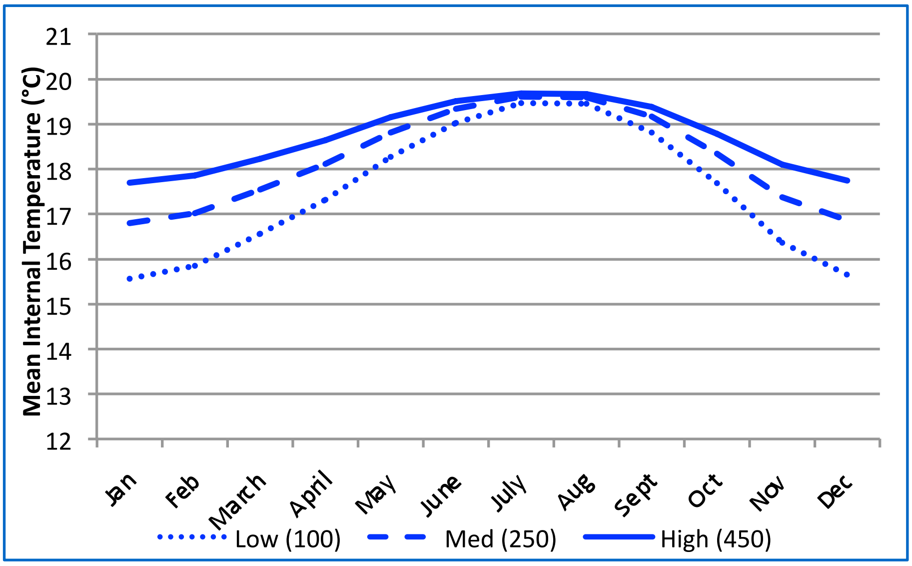


Figure 3.2 Thermal mass effect on internal temperature for CS2

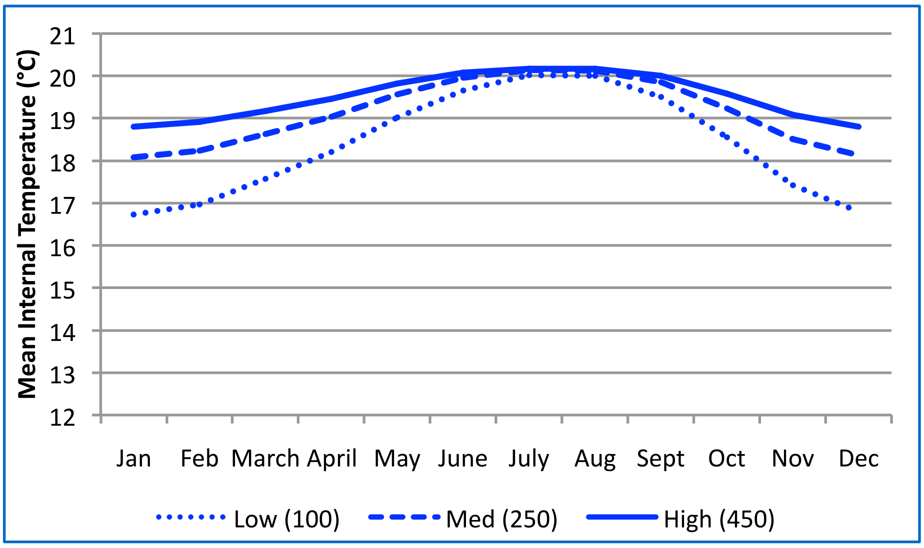


Figure 3.3 Thermal mass effect on internal temperature for CS3

It is immediately obvious looking at internal temperature that thermal mass has little effect on internal temperature during the summer months. However, during the heating season (defined in SAP as October to May), the thermal mass does affect the internal temperature, with higher thermal mass corresponding to higher internal temperatures. It can also be seen that the higher the thermal mass, the less fluctuation in temperature across the year. This suggests that the benefits of thermal mass outlined previously are being utilised within the calculation on a seasonal basis, though it is difficult to discern whether the magnitude of this effect is being accurately described without additional empirical data.

The internal temperature is significant in calculating the space heating demand, as the SAP methodology specifies the required room temperatures of 21°C for the living room and 18°C for the rest of the dwelling. The further the internal temperature is below these set points the more energy the space heating system will use. In this respect, a higher thermal mass is also beneficial, as is the case for CS1 and CS2. In CS3 the internal temperature is higher than the previous two case studies as the heat loss parameter associated with the construction materials is lower than the previous case studies. Therefore the heating system can use less energy to produce the desired temperatures.

Currently, for an assessor to input a level of thermal mass into SAP, they must input a heat capacity for each construction element from a table within the SAP technical guide, which currently does not include information regarding the heat capacity of a stone wall, nor that of an uninsulated solid brick wall. An assessment of thermal mass for an RdSAP assessment would rely on the assessor knowing the construction of the building elements.

3.1.2. Window size

As discussed in section 1.3.3, one of the significant assumptions within RdSAP is that of the window area. The assessor must make an assumption as to whether the area is typical, more than typical or less than typical. This section analyses the impact that has on the calculation, and how significant the window area is in relation to heat loss calculations.

From the data in Table 3.3, and using the RdSAP definitions of what constitutes a 'typical' window area, comparison with the measured window areas suggest that in CS1 the window area should be assumed as less than typical. In CS2 and CS3, the difference between assumed area and measured area is such that the assessor should measure each window. In v9.91, an assessment of each window is encouraged, therefore enabling an inclusion of orientation for a more accurate estimation of solar gains.

The heat loss through a window depends on the area and U-value, and the significance of that to an energy calculation relies on the area and U-value of the wall area in which the window sits.

Table 3.3. Impact of RdSAP window assumptions

		Window area as a		
		% of Total Floor Area	% external wall area	% total heat loss area
CS1 – Large detached 4-storey				
Size of dwelling	361 m^2			
External wall area	357.7 m^2			
Total heat loss area	654.4 m^2			
Measured window area	40.0 m^2	11.0%	11.1%	6.1%
RdSAP assumed window area	51.0 m^2	14.1%	14.2%	7.8%
Difference between RdSAP and measured window area			22%	
CS2 – Small semi-detached bungalow				
Size of dwelling	48 m^2			
External wall area	48.2 m^2			
Total heat loss area	160.6 m^2			
Measured window area	7.2 m^2	15.0%	14.9%	4.5%
RdSAP assumed window area	12.7 m^2	26.5%	26.3%	7.9%
Difference between RdSAP and measured window area			43%	
CS3 – Upper 4-in-a-block flat				
Size of dwelling	76.8 m^2			
External wall area	69.6 m^2			
Total heat loss area	146.4 m^2			
Measured window area	8.7 m^2	11.4	12.5	6.0
RdSAP assumed window area	11.7 m^2	15.2	16.8	8.0
Difference between RdSAP and measured window area			26%	

In CS1, the window area is 14% of the wall, and the U-value of the windows at 4.8 W/m^{2}K is significantly higher than the walls, with a U-value of 1.5 W/m^{2}K.

In CS2, the window area is larger at 26%, so the impact of the windows on the heat loss of the dwelling (with the same U-value as CS1) will be larger, although the windows in CS2 are double glazed so have an improved U-value of 2.0 W/m^{2}K.

In CS3, however, the window area is 15% of the wall area, the U-value of windows being 2.0 W/m^{2}K, and U-value of the walls 2.1 W/m^{2}K.

The most appropriate way to analyse the impact that window assumptions have on heat loss is to combine the U-value and the area, as in Table 3.4.

Table 3.4. Window heat loss

	A (m^2)		U (W/m^{2}K)		Heat loss (W/K)
CS1 – Large detached 4-storey					
Windows	50.97	×	4.8	=	205.24
Walls	277.02	×	1.1	=	304.72
	58.93	×	1.4	=	82.50
	31.70	×	0.7	=	22.19
					614.65
Windows are 33% of the façade heat loss					
CS2 – Small semi-detached bungalow					
Windows	2.55	×	4.8	=	10.25
	10.18	×	2.0	=	18.86
Walls	32.48	×	1.4	=	45.47
	15.76	×	0.5	=	7.09
					81.67
Windows are 36% of the façade heat loss					
CS3 – Upper 4-in-a-block flat					
Windows	11.73	×	2.0	=	23.46
Walls	55.99	×	1.5	=	83.99
					107.45
Windows are 22% of the façade heat loss					

If the results for CS1 had been calculated with a 'less than typical' window size, the window heat loss would have been 31% of the façade heat loss, suggesting that the 25% reduction in assumed window area would have made little difference. In CS2, the windows are a significant aspect of the heat loss, despite the double glazed proportion. In CS3 the windows are a fifth of the heat loss, despite being double glazed.

3.1.3. Weather data

The difference between the UK average data and the regional data can be seen in the difference between the "compliance" mode of RdSAP and the Green Deal mode. Figure 3.4 shows the external temperature for the two SAP climate regions used in this report.

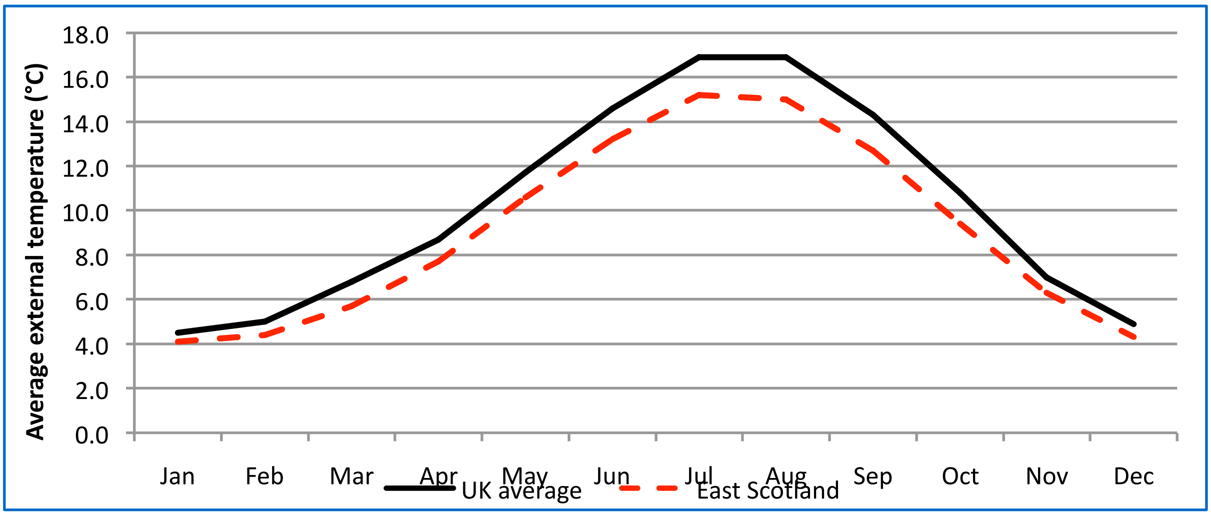


Figure 3.4. External temperature used in RdSAP

It is clear that the East Scotland climate is cooler than the UK average in the RdSAP calculation. These different climates lead the methodology to estimate different internal temperatures (Figure 3.5).

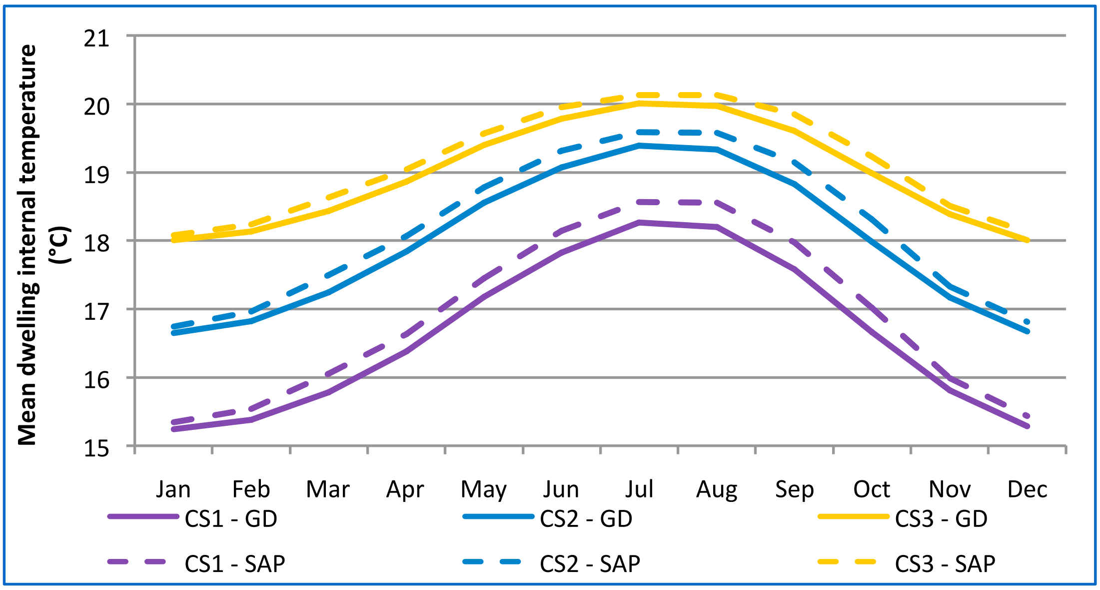


Figure 3.5 Mean internal temperatures in the Green Deal (GD) and (SAP) modes

These different internal temperatures are important in calculating the space heating requirement (and overall energy requirement) and therefore produce the different values shown in Table 3.2.

The differences between inputs in the three versions of RdSAP (v9.90, v9.91 “compliance” and v9.91 “GD”) have been shown to have an impact on the end results of the calculation. This will then impact on whether measures meet the Golden Rule.

3.1.4. Draught proofing

To ascertain the significance of the level of draught-proofing within the calculation, iterations have been carried out on CS2 assuming varying levels of draught-proofing from zero to 100%. The level of draught-proofing on the calculation impacts on the air exchange, and therefore the space heating demand, and it is this variable that is analysed in Figure 3.6.

The difference between zero draught-proofing and full draught-proofing in this particular case study is 342 kWh/year in SAP 2009, and 277 kWh/year in RdSAP 2009, indicating a cost difference of £20 over a year in SAP 2009 between worst and best case scenarios. Anecdotal evidence from the occupant of CS2 suggests that upon the implementation of draught-proofing of the doors, a minor improvement in the thermal comfort was experienced, noticeable through a warmer wooden floor surface, but no change was made to the heating system. This is an example of the rebound effect, when occupants choose to have a greater thermal comfort, than the opportunity to reduce energy bills.

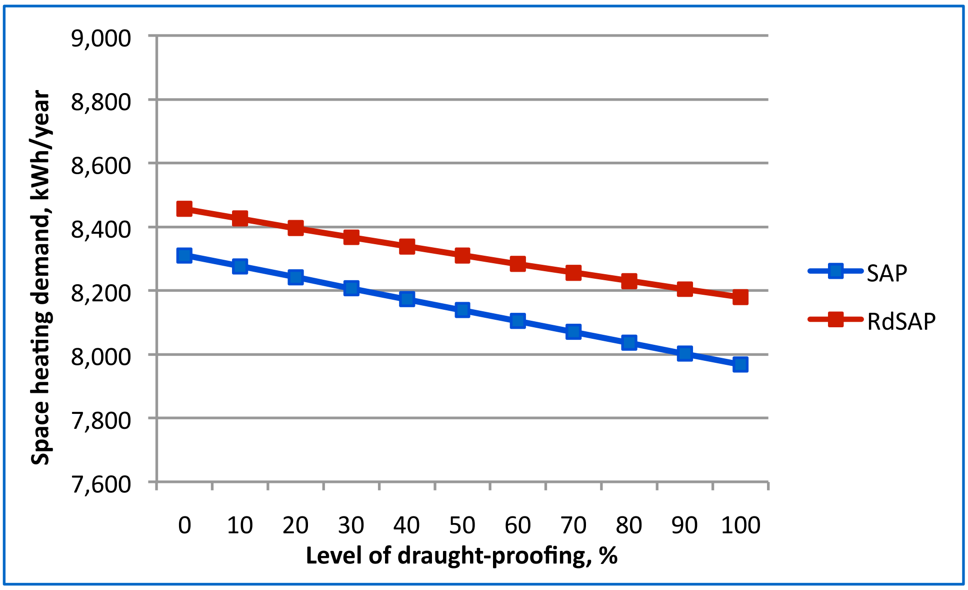


Figure 3.6 How draught-proofing impacts on end results, for CS2

Also investigated along with the space heating requirement was the EPC result. This remained unchanged, with an 'E' rating achieved across all levels of draught-proofing. In addition, the total *infiltration rate* was calculated in each case. The infiltration rate includes all aspects of incidental air exchange from the construction. In RdSAP 2009, the infiltration rate varied from 0.82 to 0.71 air changes per hour (ach), from 0 to 100% draught-proofing. In SAP 2009, the infiltration rate was calculated to be between 1.13ach with 0% draught-proofing and 0.94ach with 100% draught-proofing.

The calculation in which draught-proofing is included within SAP and RdSAP 2009 is shown within Figure 3.7, and details the relationship between draught-proofing and infiltration rate.

2. Ventilation rate

	main heating		secondary heating		other		total		m³ per hour	
Number of chimneys		+		+		=		× 40 =		(6a)
Number of open flues		+		+		=		× 20 =		(6b)
Number of intermittent fans								× 10 =		(7a)
Number of passive vents								× 10 =		(7b)
Number of flueless gas fires								× 40 =		(7c)

			Air changes per hour	
Infiltration due to chimneys, flues, fans, PSVs	(6a)+(6b)+(7a)+(7b)+(7c) =	÷ (5) =		(8)

If a pressurisation test has been carried out or is intended, proceed to (17), otherwise continue from (9) to (16)

Number of storeys in the dwelling (n_s)			(9)
Additional infiltration	[(9) – 1] × 0.1 =		(10)
Structural infiltration: *0.25 for steel or timber frame or 0.35 for masonry construction* *if both types of wall are present, use the value corresponding to the greater wall area (after deducting areas of openings); if equal use 0.35*			(11)
If suspended wooden floor, *enter 0.2 (unsealed) or 0.1 (sealed)*, else enter 0			(12)
If no draught lobby, enter 0.05, else enter 0			(13)
Percentage of windows and doors draught stripped			(14)
Window infiltration	0.25 - [0.2 × (14) ÷ 100] =		(15)
Infiltration rate	(8) + (10) + (11) + (12) + (13) + (15) =		(16)

Figure 3.7 Calculation towards infiltration rate in SAP 2009 v9.90

The level of draught-proofing, entered at box (14), when added to the other sources of infiltration – chimneys, fans, vents etc – provides a level of total infiltration in box (16). The infiltration due to windows (box 15) can only ever be between 0.05 and 0.25, with the additional sources of infiltration dependent on the specific dwelling. This limitation with respect to window infiltration leads to a limit on the reduction in space heating that can be gained through draught-proofing, as calculated by this methodology (though, physically, this will also be the case to some degree). Figure 3.8 highlights this limit, showing that the infiltration rate difference between zero and 100% draught-proofing is approximately 15%. Therefore, for CS2, the infiltration rate can only be reduced by a maximum of 15%, and this explains the relatively small savings in total space heating in Figure 4.6 due to draught-proofing.

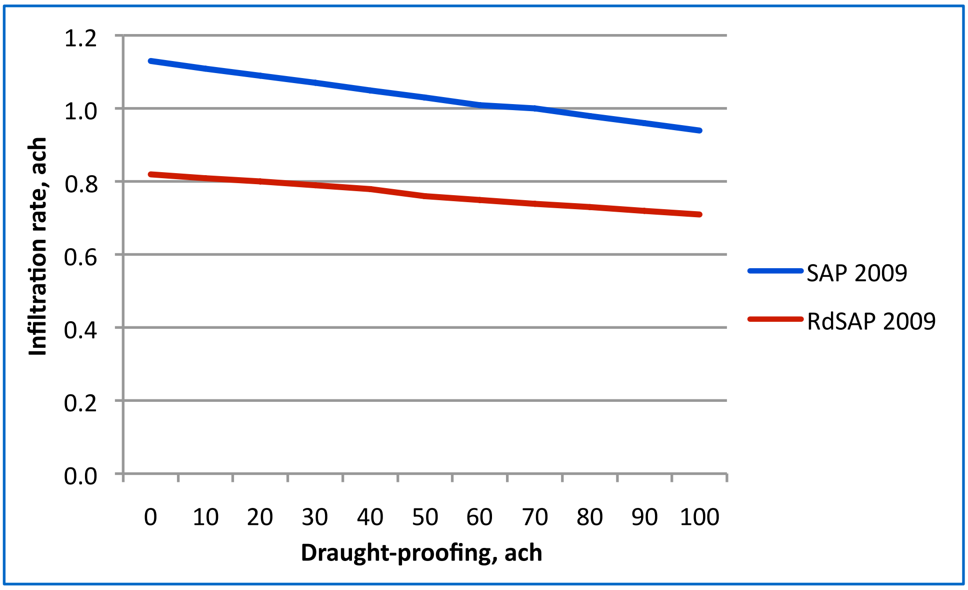


Figure 3.8 Relationship between draught-proofing and infiltration rate for CS2

3.1.5. The 'draught lobby'

An additional variable affecting the infiltration rate is that of the presence of a draught lobby. The second case study has a small area by the main door (Figure 3.9, 'Entrance') that acts as a draught lobby, but cannot be counted as such as it does not meet any of the three criteria in the definition in Section 1.3.6.

Anecdotal evidence from the occupant indicates the entrance is the coldest part of the house, despite new draught-proofing being recently added to the door, and that the temperature in the 'Entrance' is always cooler than the neighbouring living room. If this is the case, then this small room whilst not meeting the strict definition and therefore not being included in the calculation, does aid in keeping the living room warmer than it would be otherwise.

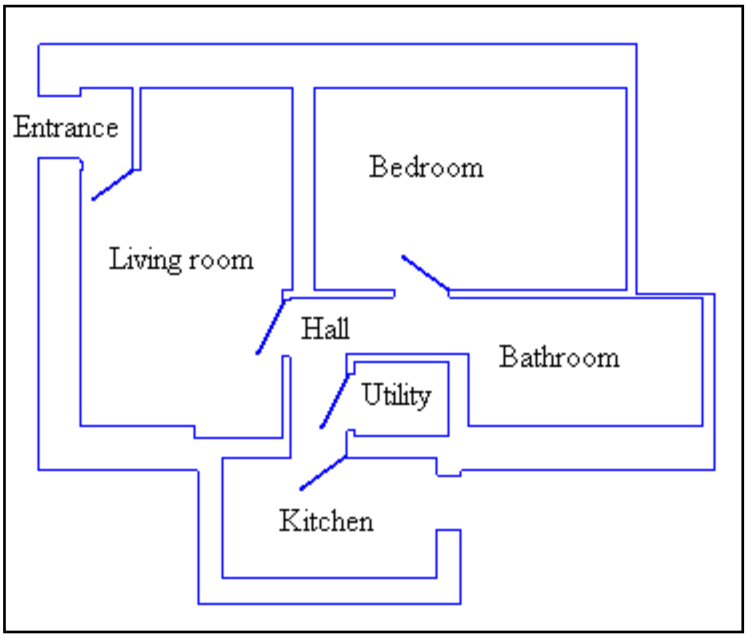


Figure 3.9 Floor plan of CS2

The SAP and RdSAP 2009 calculations have been repeated with and without a draught lobby, to investigate the level of effect this has on the dwelling annual average temperature and space heating demand.

Table 3.5 Impact of draught lobby assumptions on calculations for CS2

SAP 2009	**With draught lobby**	**Without draught lobby**
Average internal temperature (°C)	17.35	17.33
Space heating demand (kWh/year)	7,951	8,036
SAP rating	39.55 (E)	39.15 (E)
RdSAP 2009	**With draught lobby**	**Without draught lobby**
Average internal temperature (°C)	18.19	18.18
Space heating demand (kWh/year)	8,167	8,230.4
SAP rating	38.36 (F)	38.07 (F)

As Table 3.5 shows, the 'introduction' of a draught lobby acts to improve the internal temperature, reduce the demand for space heating, and improve the SAP rating, albeit marginally. In terms of final SAP rating, this is therefore only likely to be of importance for homes that are near the boundary of a SAP rating.

3.2. Green Deal

The changes to RdSAP for v9.91 have all been implemented in an effort to make the calculation more representative of a dwelling's actual energy performance, with the updated methodologies applied to energy saving calculations for the Green Deal. Understanding the energy assessment methodology provides greater understanding as to the effect improvement measures could have not only on the dwelling, but also in the calculations. This section therefore analyses the results of RdSAP calculations towards Green Deal improvement measures.

The Green Deal scheme provides loans to homeowners to purchase improvement measures. The savings from the improved energy performance of the dwellings are then used to pay the loan back over the (pre-determined) lifetime of the measure via the dwelling's electricity bill. The scheme relies on RdSAP assessments to calculate the potential financial savings of implementing certain measures and, if savings are modelled to exceed the annual loan-repayment costs – known as the 'Golden Rule' – then the measure is eligible for Green Deal finance.

To account for the potential performance gap between predicted savings and those actually experienced, (through modelling inaccuracies, the rebound effect, or a dwelling not conforming to the 'standard' against which technology is tested), a set of "in-use factors" have been identified. The analysis here applies these in use factors to the savings calculated using RdSAP v9.91.

The novel approach with the Green Deal is that the loan will stay with the dwelling, not the homeowner. If the occupants move before the loan is repaid, the future occupants will become responsible for the repayments. This concept was introduced to remove the financial barrier of implementing technologies with long paybacks, such as double glazing and photovoltaic panels.

The following table outlines the measures used in this Technical Paper, and their associated In-Use factors and cost[20].

Table 3.6 Improvement measures used in this Technical Paper

Improvement measure	In-use factor	Cost (£)
ASHP	25	8400
Attic insulation	35	500
Biomass boiler	25	9000
Boiler upgrade	25	2300
Double glazing	15	450 (per window)
Floor insulation	15	1200
GSHP	10	10000
Heating controls	50	300
Solar thermal	0	4000

A more in-depth review of the Green Deal process is available in the Historic Scotland Technical Paper 17: "Green Deal, ECO and Traditional Buildings". What follows is an analysis into how RdSAP treats the improvement measures, accounting for the limitations outlined in Section 3.1 in relation to the Golden Rule.

3.2.1. Cost savings

A number of improvement measures may be suitable for a dwelling, to improve the energy performance of both the building and the systems within it, reducing energy bills and improving the health and comfort of the occupants. The following figures give the savings predicted for each case study for each improvement measure. The measures have been chosen specifically for each property, i.e. only measures suitable for that property have been applied. In addition, where boiler upgrades have been modelled, boilers with similar capacities but far higher efficiencies have been selected, although in reality a smaller boiler may be sufficient due to reduced heating requirement. A negative saving indicates a cost to the occupant of that particular improvement measure. It should be noted that the costs in Figure 3.10 to Figure 3.12 relate to the annual loan repayment under the Green Deal, and therefore include an interest rate of 7.5%.

[20] DEMScot stock model. http://www.scotland.gov.uk/Topics/Built-Environment/Housing/supply-demand/chma/marketcontextmaterials/DEMSCOTversion2

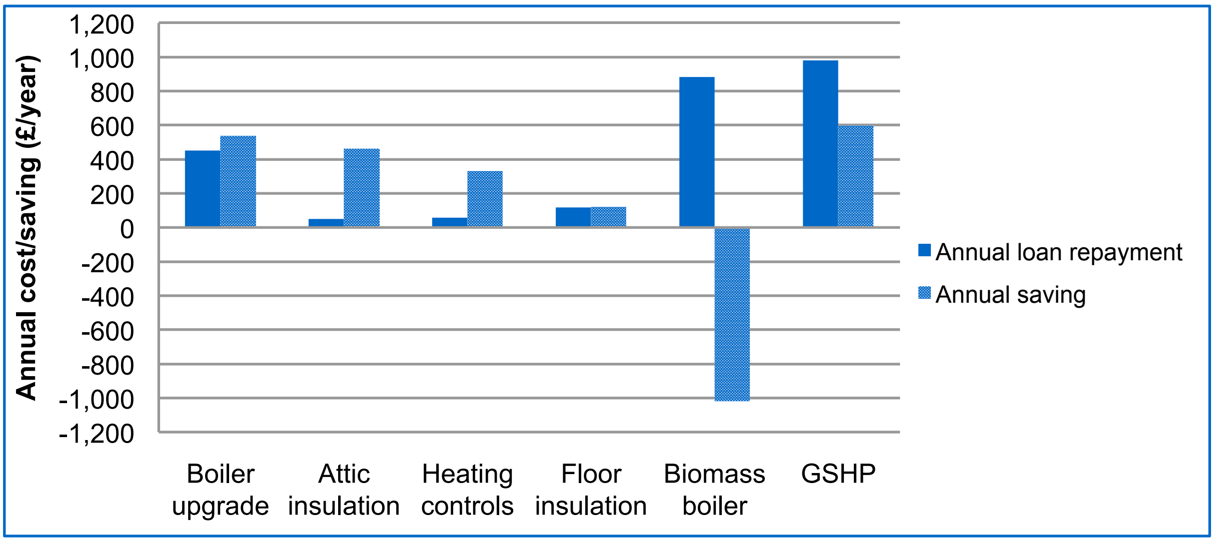


Figure 3.10 Green Deal measures applied to CS1

Using these charts it is clear which improvement measures meet the Golden Rule and which do not. Those measures that show a saving greater than the annual Green Deal loan repayment would be eligible for a Green Deal loan: in this case study, those measures would include a boiler upgrade, insulating the attic rooms, and upgrading the heating controls. It is also clear that insulating the attic and upgrading the heating controls are the cheapest options, and are likely to be completed first. This would in turn reduce the heating demand on the boiler, so a boiler with lower capacity – therefore cheaper – could be installed. Further calculations by a heating engineer would be required to calculate the precise sizing of any boiler upgrade, which would determine the size of loan. With a smaller heating demand after the insulation and heating controls however, it may be that a boiler upgrade no longer meets the golden rule, as the savings would be less.

The introduction of a biomass boiler for the heating system creates a negative cost saving for two primary reasons. Firstly, the efficiency of the biomass system is stipulated in SAP as 65% for this type of system. When this is applied to the calculation in comparison to the baseline mains gas boiler in CS1, with an efficiency of 72.9%, there is an increase in fuel requirement. In addition, the cost for mains gas in RdSAP 2009 is 3.10p/kWh, while the cost for a bulk supply of wood pellets is 4.93p/kWh. The increased fuel demand and the increased fuel price lead to a net cost for the biomass boiler. This finding may be seen across many case studies as the issue is primarily due to the low assumed efficiency and higher fuel cost relative to mains gas. If the biomass system were replacing an electric heating system, with a cost of 11.46p/kWh, the savings would be approximately 45% of the electric heating cost. This aspect of RdSAP is one where a low carbon fuel can be financially detrimental in the calculation, despite the reduction in emissions.

Similar issues regarding fuel cost can be seen in the improvement measures applied to CS2 (Figure 3.11). None of the suggested measures provide savings higher than the annual loan repayment, therefore would not be eligible for Green Deal funding without additional finance from elsewhere (such as ECO).

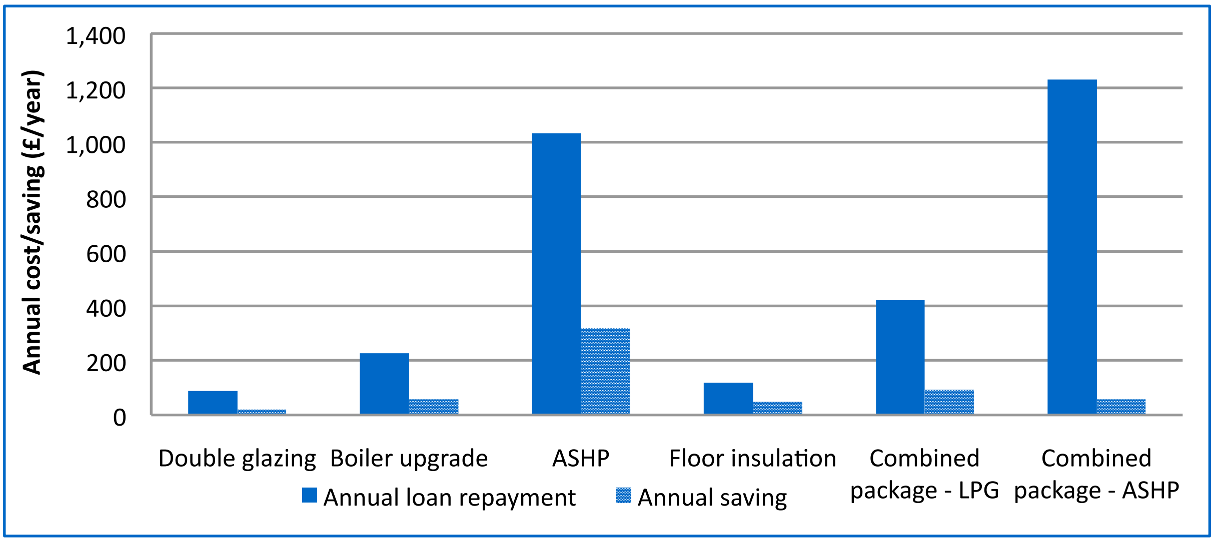


Figure 3.11 Green Deal measures applied to CS2

The dwelling is off the mains gas grid, so an upgrade to the existing LPG boiler is compared with switching the heating system to an ASHP. The ASHP provides the largest savings, again due to the baseline heating system. The improvement measure increases the efficiency from 82% to 250% (though, strictly speaking, this is a "coefficient of performance" of 2.5, not an efficiency), while the cost increases from 5.73p/kWh to 11.46p/kWh. Bulk supplies of LPG also include a £70 standing charge, while electricity has no standing charge. These factors combined provide the large cost savings for the ASHP measure.

The cost of an ASHP system at £8,400 is high, though in reality a smaller system might be cheaper leading to lower loan repayments. An ASHP system also introduces questions as to the lifetime of a product. The lifetime of an ASHP as specified in DEMScot documentation is 13 years, so payment should be made within that. However, the ramifications for the occupant if a product needs to be replaced before its "Green Deal life" are unclear.

For the third case study, there were two cheap improvement measures as well as two more expensive options. Of note is the scale used in the chart for CS3 - Figure 3.12, the lowest costs and savings of all three case studies. This is reflective of the low baseline space heating requirement, as any improvement measures would need to be significant and possibly expensive to produce a significant improvement. This in comparison to CS1, which started with a very high space heating requirement such that a small improvement could lead to a large change, suggests the worse a dwelling is to start with, the more likely it is to achieve Green Deal eligibility.

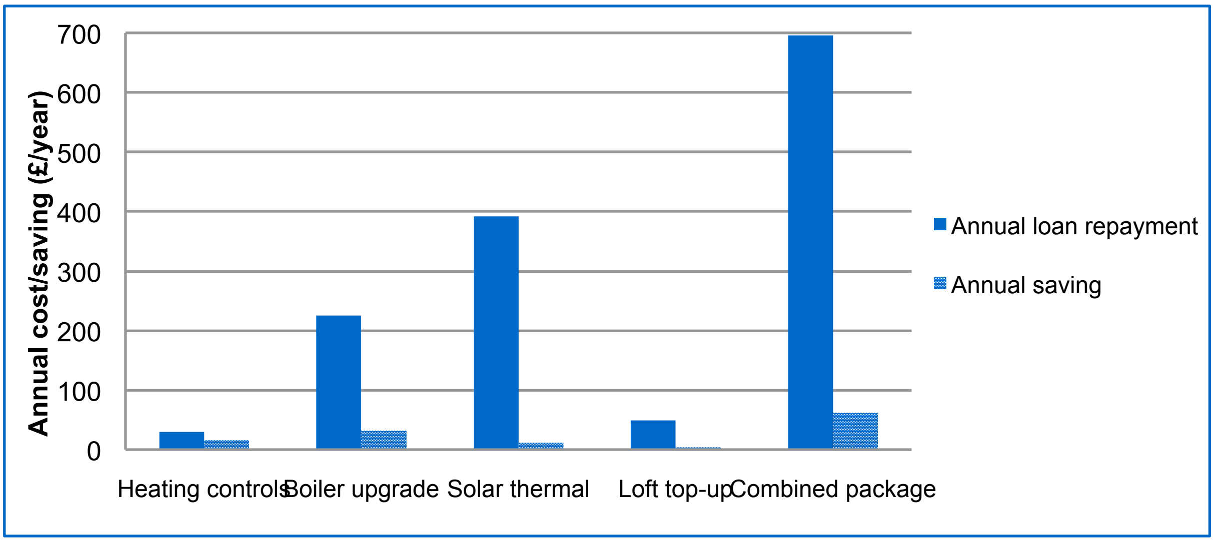


Figure 3.12 Green Deal measures applied to CS3

Unlike the previous two case studies, the use of a renewable energy technology has been selected for CS3. This technical paper has not focused on the inclusion of onsite generation, but it is included here as a viable measure for this particular case study. However, as Figure 3.12 highlights clearly, the cost benefits of implementing a solar thermal panel system are small in comparison to the costs such a measure would entail.

The costs and savings associated with a top-up of the loft insulation (from 260mm to 440mm) are relatively low. The savings according to RdSAP 2009 would amount to approximately £4 per year: again it is seen that the low baseline heating requirement provides little improvement potential when the loft is already insulated. A change from no insulation to 440mm insulation would produce a larger saving. According to the DEMScot model costs used, the cost to install loft insulation is £500 per dwelling. For a top-up, these costs could be lower, depending on the depth and type of insulation, reducing the amount of time it would take the measure to pay for itself. For these low cost measures, it could be argued that an occupant, if possible, would be better to purchase the measure independent of the Green Deal.

3.2.2. Carbon savings

The reduction in emissions of carbon dioxide, as distinct from simple energy savings, is a clear goal of current building legislation. The RdSAP methodology calculates CO_2 emissions from the modelled energy requirement, and the impact of the applied improvement measures from Section 3.2.1 are shown in Figure 3.13 to Figure 3.15.

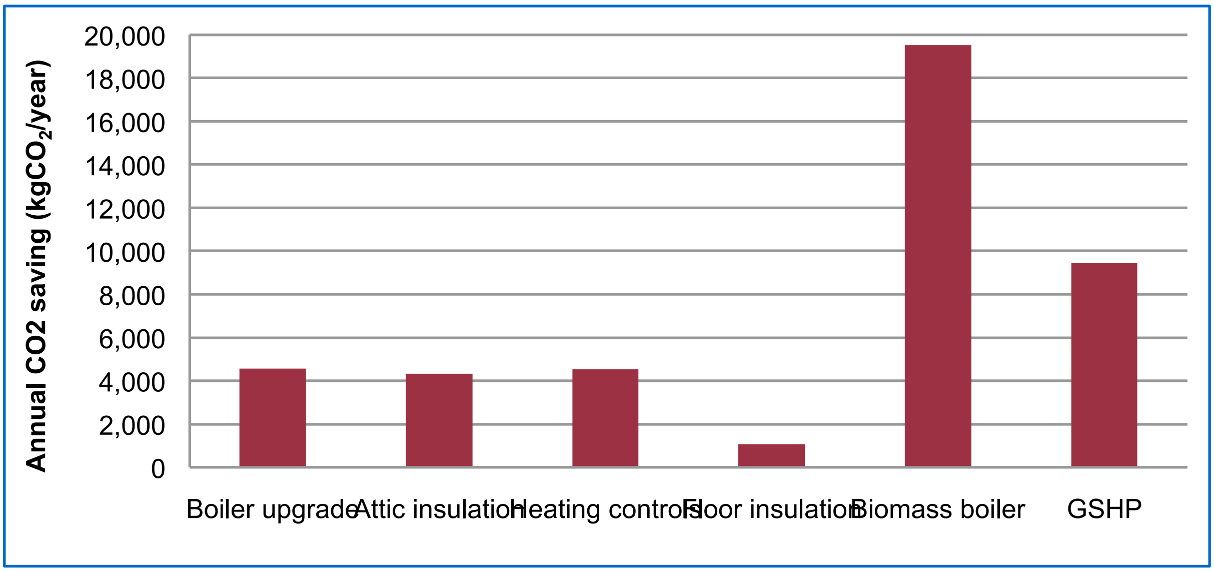


Figure 3.13 CO_2 savings for Green Deal measures applied to CS1

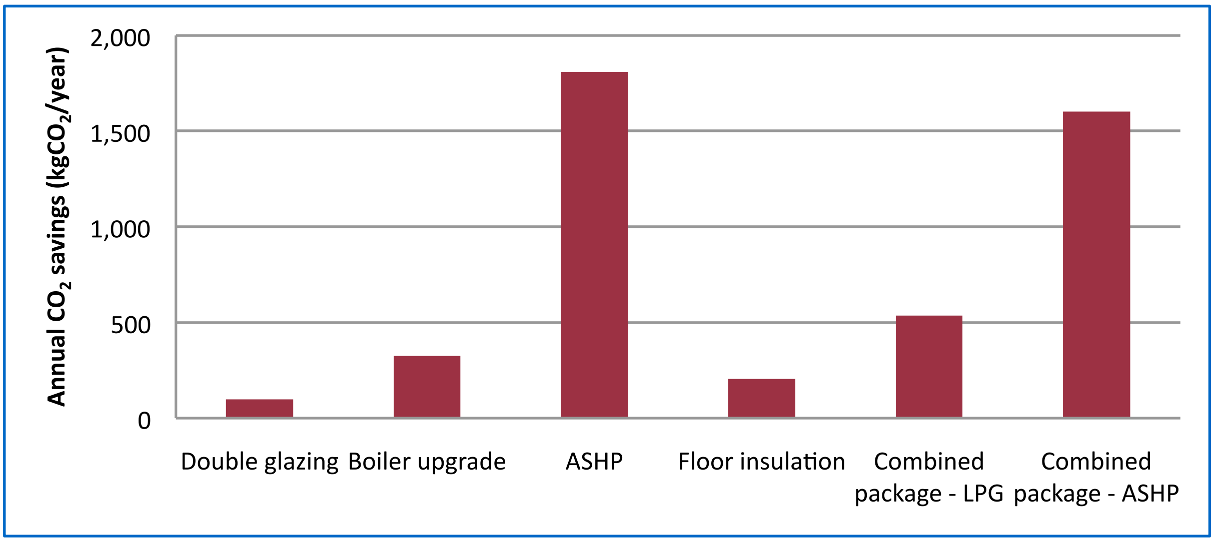


Figure 3.14 CO_2 savings for Green Deal measures applied to CS2

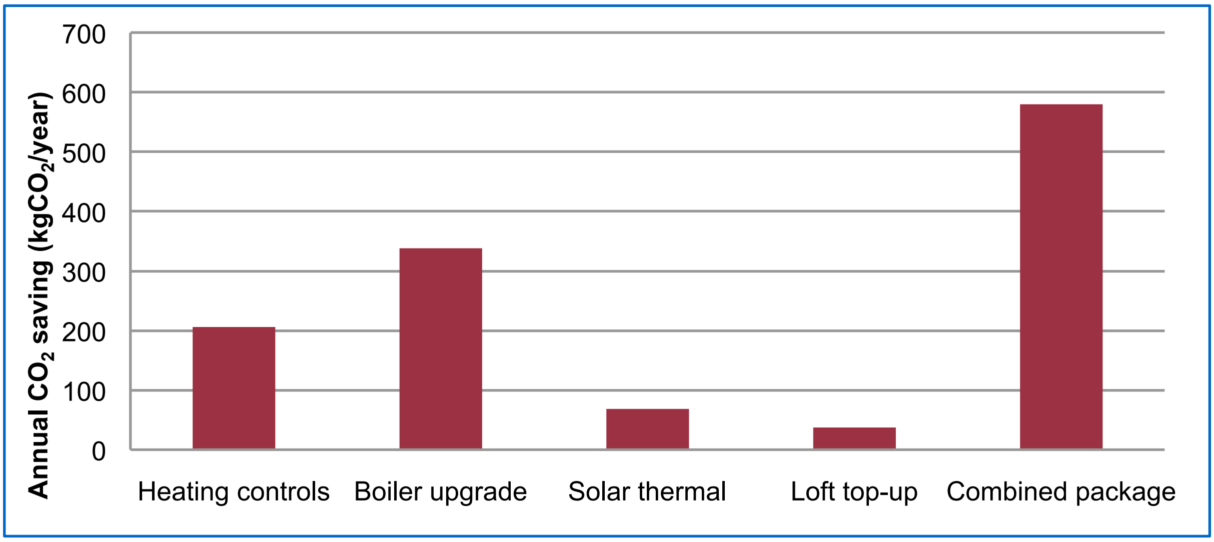


Figure 3.15 CO_2 savings for Green Deal measures applied to CS3

Similarly to the cost savings in Section 3.2.1, the CO_2 savings are highest for CS1 and lowest for CS3. It is indicative of the poor baseline of CS1 that the predicted savings from heating alone are larger than the baseline emissions from either CS2 or CS3.

While electricity is a far more expensive fuel than mains gas, it is also dirtier[21]:

- Mains gas (CS1, CS3) = 0.198 $kgCO_2$/kWh
- Bulk LPG (CS2) = 0.245 $kgCO_2$/kWh
- Bulk supply wood pellets = 0.028 $kgCO_2$/kWh
- Standard tariff electricity = 0.517 $kgCO_2$/kWh

The higher efficiency of heat pumps in comparison to biomass or conventional boilers nonetheless provides a net carbon saving, as seen in Figure 3.13 and Figure 3.14. It is clear that a biomass system might provide large CO_2 savings but, while the Green Deal aims to reduce CO_2 emissions, its primary calculation concern is based around cost, therefore the uptake of biomass systems may be limited.

[21] Values taken from Table 12, SAP 2009 v9.90. BRE. www.sap2009.co.uk

4. Improvements to SAP

4.1. Previous Improvements

Since its inception, a number of changes have been introduced to the Government's accredited energy assessment methodologies. The changes introduced after the introduction of the European Performance of Buildings Directive are outlined in Table 4.1.

Table 4.1 Changes to SAP and RdSAP since the EPBD

Model	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
SAP (new-builds)										
2005			2005 v9.80							
			2005 v9.81							
2009					**2009 v9.90**					
									2012 v9.92	
RdSAP (existing dwellings)										
Introduced		2005 v9.81								
2005			2005 v9.82							
2005				2005 v9.83						
2009					2009 v9.90					
2009								**2009 v9.91**		
2009									*2012 v9.92*	

The versions in **bold** are the current (as at March 2013) methodologies, those in *italic* are due for release spring 2013.

These changes have consistently been to improve the ability of the methodologies to be representative of energy use within dwellings. Each new version gives the relationship between that version and the previous edition, so comparison can be made between old and new assessments. In most cases there is little change, except in the case of dwellings with electric heating which would receive slightly worse ratings in SAP 2009 than SAP 2005.

Improvements such as the move to a monthly calculation in 2009 have allowed the calculation to recognise the heating season, to include thermal mass, and recognise the difference in solar gain across the year. The update in 2012 to include regional weather averages for calculations towards recommendations of improvements also makes the calculation more precise. Similarly, the change to calculation of solid wall U-values, as identified in Section 1.3.1, should enable the model to better represent in-situ building performance.

Despite such improvements to make the calculation more precise, there are still questions surrounding the accuracy of the SAP and RdSAP methodologies when comparing to real billing information.

4.2. Recommendations

What follows is a summary of suggested changes to the calculation methodology. A consultation on changes for the “SAP 2012 v9.92” took place in 2012, with the updated version due in 2013. Where the recommendations are already being suggested in the consultation, this is noted. The following key should be used:

	True for the Scottish stock
	True for historic dwellings in particular
	Recommended change to input
	Included in the draft version of v9.92 for 2013 release

4.2.1. Climate

Currently the use of regional climate data is restricted to Green Deal calculations and for energy advice. The use of UK average data is used for compliance calculations. It is recommended that one of the following be implemented to improve accuracy of the calculation:

a) Regional climate data used for all calculations, regardless of end use
b) UK average be obtained from the Met Office, rather than assuming the same as for region 11 of the BRE climate region map
c) Each nation to have its own average. This would improve the calculation for Scotland and Northern Ireland, while not detrimentally harming the calculation for England & Wales

This change not only ensures greater accuracy and a better informed occupant, but also ensures that (at a time when Governments must report energy generation, production and consumption to the EU) dwellings are represented more accurately in the reporting of the UK housing stock.

4.2.2. Heating season

Currently the heating system is designed to heat the living room to 21°C and the rest of the dwelling to 18°C, between October and May. The climate differences between the south coast of England and the islands of Scotland mean that the space heating demand can be significantly under- or over-estimated.

It is recommended that the heating season length be aligned with the climate region of the dwelling, perhaps as part of the same database.

4.2.3. Windows & Doors

In the current version of RdSAP, exact information for windows is only required when the assessor deems the window area to be 'much more' or 'much less' than typical. Only in these cases will the assessor provide the orientation of the windows. In addition, RdSAP assumes that the number of external doors is dependent on the type of dwelling; for example, a flat is deemed to have one door. In the Scottish 4-in-a-block style, it can be possible for the ground floor flat to have two doors, doubling the heat loss through doors, yet the calculation will not replicate that.

Additionally, if the assessor enters exact window information including type, this should also include whether the window is single, double or secondary glazing. This would provide more precise detail towards the infiltration rate, which includes draught-proofing based on the percentage of multiple glazed windows.

It is recommended that the exact window and door information be supplied by the assessor, including dimensions, orientation, type and number (for doors). This will improve the accuracy in solar gain, heat loss, and infiltration calculations.

4.2.4. Thermal mass


Currently the assessor enters information regarding the heat capacity of the construction materials using a table in the database of information within the Technical Guide. This table currently has no entries for uninsulated elements, and no entries for solid stone walls.

It is recommended that the SAP Table 1e is expanded to include more traditional and uninsulated elements to better reflect, in particular, the thermal mass effects in traditional homes.

4.2.5. Heating technologies


As has been noted within this Technical Paper, there is concern surrounding the efficiency values used in the Tables within SAP, specifically with respect to biomass.

It is recommended that further testing of such equipment be carried out, to expand the knowledgebase and ensure the efficiency values in the SAP guide and relevant to the current technology.

The database for heating and hot water system data uses the SEDBUK (Seasonal Efficiency of Domestic Boilers in the UK) method. The data from this method is available via a search facility on www.boilers.org.uk. This website is useful for homeowners to look up their own boiler, to ascertain how inefficient or out of date their boiler is. Assessors have access to the Product Characteristics Database, which is typically installed as part of the software for energy assessments, and is updated monthly. This database is not, however, in a particularly useable format for homeowners or specifiers. Unaccredited stakeholders therefore have to resort to alternative sources of information, which may not be up to date or accurate.

In addition, the SAP guidance applies a factor to the efficiency of the heating system dependent on the controls used, and the heating emitter. In the case of a mixed system (e.g. underfloor heating and radiators), the assessor is instructed to use the factor for radiators, rather than underfloor heating, as radiators have a higher flow temperature and therefore require more energy. If there was the ability to apply separate heating systems to each room (as currently is the practice in dynamic modelling), the dwelling volume heated by each source would be applied, improving the accuracy of the calculation. The heating emitters are something potentially less likely to be altered by future occupants (unless they were not functioning correctly), so the assessment should still be relevant to future occupants.

It is therefore recommended that

a) the Product Characteristics Database be made available in a more user-friendly format for both the public and assessors.
b) The SAP calculation methodology allows for a split in the heating emitters by volume

4.2.6. Draught lobby

Currently, as discussed earlier, the strict definition of draught lobby within SAP may lead to imprecision with respect to the air exchange through the main door, when the main door is separated by a second door to the main dwelling. Understandably, the definition requires the space between the two doors to be sufficient to close the first before opening the second, but that could only be significant to air exchange when the outer door is opened. For the remainder of the time, a second door does reduce heat loss through air exchange, thereby keeping the main dwelling warmer and reducing the space heating requirement.

It is therefore recommended that further research be carried out into the ability of a space to act as a draught lobby (although not meeting the SAP definition) by reducing air exchanges; the magnitude of that effect; and how to incorporate it into the SAP calculation methodology.

4.2.7. Calibration with data

Within the building modelling sector there is increased reliance on models, and – as seen with the Green Deal – these models are used to make recommendations, without checking the empirical validity of the model to begin with.

It is recommended that:

a) The capacity for testing existing and new technology, and construction elements, is increased, to ensure the most relevant values are used within any calculations; and
b) Post occupancy evaluation is used on a much larger scale than is currently the case, to ensure the operation meets the predicted performance. The results of these comparisons also need to find a visible place in the public domain

4.2.8. Solid wall insulation


To qualify under the Green Deal for ECO funding, solid wall insulation – internal or external – must improve the U-value of the wall to less than $0.30W/m^2K$ [22]. With initial U-values of $1.4W/m^2K$ (in this Technical Paper) it could take very expensive technologies to reach the low level of heat loss required. Organisations such as Historic Scotland and the National Trust for Scotland have carried out research into the use of alternative technologies to insulate solid walls[23].

It is therefore recommended that within 4.2.7 above, new technologies that have been proven in field trials are included in the appropriate testing regime for SAP, to ensure that those homes with solid stone walls, or hard-to-treat walls, are not excluded from the potential benefits of the Green Deal.

[22] OfGem guidance for the ECO consultation. Available at http://www.ofgem.gov.uk/Sustainability/Environment/ECO/Documents1/ECO%20Guidance%20for%20Consultation%20-%2023%20November%202012.pdf

[23] Historic Scotland. 2010. Technical Paper 8: Energy modelling of the Garden Bothy, Dumfries House.

5. Conclusions

This technical paper has reviewed RdSAP and SAP energy assessment methodologies, with a particular focus on traditional Scottish dwellings. With the current importance placed on the Green Deal, and this being a clear use of the latest version of RdSAP, calculations relating to this scheme have also been demonstrated for chosen case studies.

A series of recommendations have been proposed in Section 5 of the report that would allow this form of steady-state modelling to better represent the Scottish housing stock, both traditional and non-traditional. They would also provide slightly improved confidence for homeowners wishing to carry out energy-saving refurbishments.

A key recommendation relates to the use of climate and heating regime data. It is suggested that even relatively simple steady-state models could use more indicative local climate data and regional heating season durations. Although regional climate data is now introduced for Green Deal calculations, it is clear that the challenge of reducing heating demand in Scotland might be greater than in the South of the UK and models for building compliance should reflect this.

Specific assumptions within the calculation methodologies could also be improved, such as the specification of glazing and other openings. While a balance has to be found between simplicity of inputs and accuracy of outputs, it is possible that currently this balance leans towards simplicity too much. Similarly, the allowance for the thermal capacity of, in particular, traditional building materials through the thermal mass calculation could be updated. Even something as relatively minor as the definition of a draught lobby might not always reflect reality and ignoring the effect of this will result in an over-estimate of heat loss in a dwelling.

Of particular concern for historic dwellings are the assumptions behind solid wall insulation, and whether the requirement to reach a U-value of 0.3W/m^{2}K before accessing ECO/Green Deal funding might result in many homes choosing not to insulate a solid-wall, which may start at a pre-retrofit value in the region of 1.5W/m^{2}K. Large sections of the Scottish housing stock will therefore not have access to funding for what, in some cases, might be very effective insulation measures.

Having provided a path to demand reduction, the approach to specifying heating technologies might also be improved by better representing the efficiency of these technologies and also considering emitters in a more disaggregated way. However, amongst all this discussion of modelling, a far greater use of post-occupancy data should be encouraged for all refurbishment projects – and the emergence of the Green Deal makes this a particular area of importance. Being able to check, validate and calibrate models on real data should now be a priority as we use these models not just for “compliance” but for energy bill prediction. Obtaining such data for buildings that lie near the limits, or outside, the typical “average” home assumed within standardised models is of great importance.

In addition to the limitations and advantages of the methodology, homeowners should also be aware of the challenges with the Green Deal. The costs of improvement measures used in this report have been based on the DEMScot housing stock model indicative costs, however the repayment of the Green Deal loan would be based on the exact cost of the measure installed, which may be above or below the costs used here. This makes prediction of a measure meeting the Golden Rule more complex. For higher cost measures, where the cost goes beyond the Green Deal loan cap, additional funding would be required from ECO or private investment. For lower cost measures, homeowners might be better advised to purchase these through personal capital rather than the Green Deal.

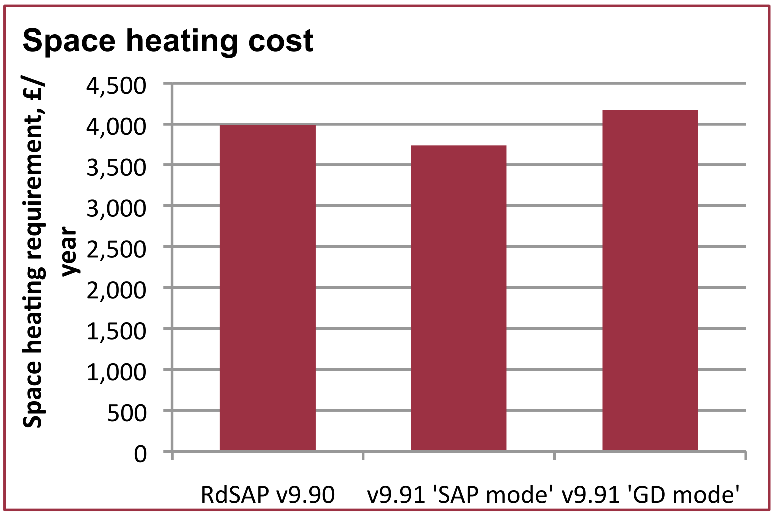
From the results within this Technical Paper, with respect to the savings available from technological interventions, it has been shown in all three case studies that savings could be made by ensuring a dwelling has a recent, efficient, condensing boiler. To reduce energy use the dwelling firstly should be as efficient as possible. This would include ensuring correctly fitted windows and doors, unused chimneys and flues blocked, and the construction elements insulated where possible. Secondly, the appliances and heating system used within the dwelling should be efficient. This would include correct heating emitters and controls for the room sizes, pipe insulation, correct placing of the boiler or hot water storage within the dwelling, and continuous maintenance of the heating systems, to ensure it is running efficiently. The use of renewable or low carbon technology should be the final step in reducing energy use, though may in some cases be a more readily available option than insulating a dwelling, especially in listed properties. There may also be cases where wall insulation, for example, is not possible.

The changes to RdSAP since its inception have been designed to make it a more useful tool for assessing a dwelling's energy performance in comparison against other similar dwellings of the same type and age. The latest version will be used to make financial decisions, and will be required to provide statistics to prove compliance with key EU policies; therefore the responsibility on the calculation and the assessor is far greater than it has been previously.

While the changes to the method should be encouraged, it is recommended that further and continuous changes be made to the model as data becomes available, to ensure a representative calculation is available towards energy assessment in Scotland's traditionally constructed homes.

Annex CS1

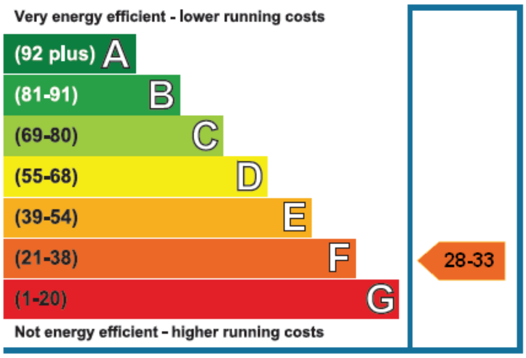
Dwelling type:	Detached house	**Storeys:**	4
Wall construction:	Stone rubble, lath and plaster	**Total floor area**	361m^2
Window type:	40m^2, single glazing		
Wall area	368 m^2	**Wall U-value**	0.7 – 1.4 W/m^{2}K
Floor area	90 m^2	**Floor U-value**	0.6 W/m^{2}K
Roof area	153 m^2	**Roof U-value**	2.3 W/m^{2}K

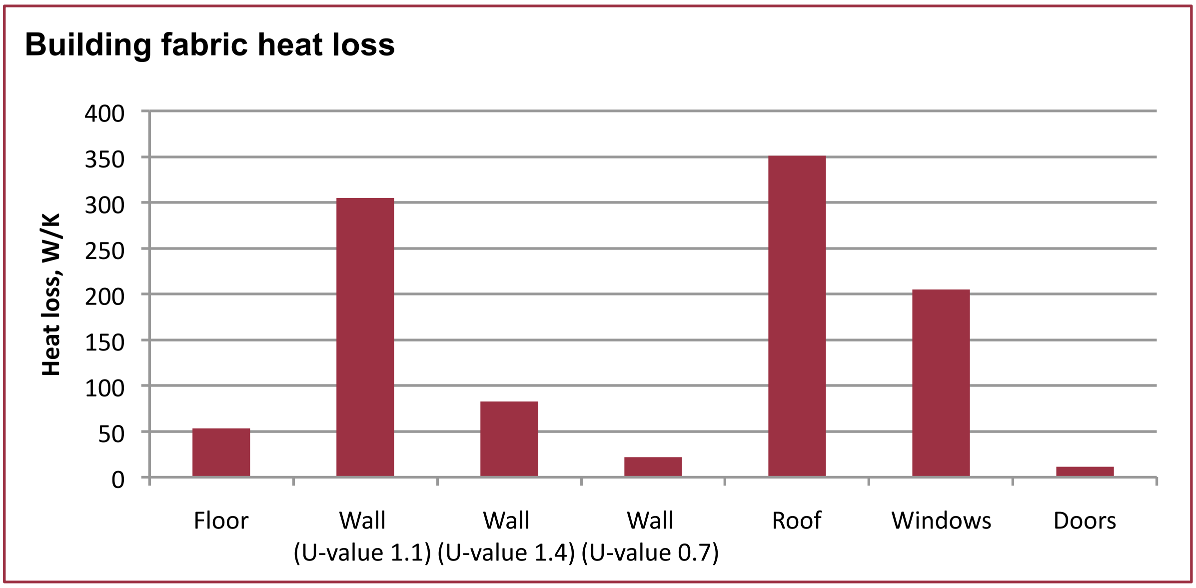


The improved accuracy of the wall U-value calculation reduces the heat loss and reduces the cost of space heating.

However, the regional variation in the 'Green Deal mode' dramatically increases the heating requirement and associated costs.

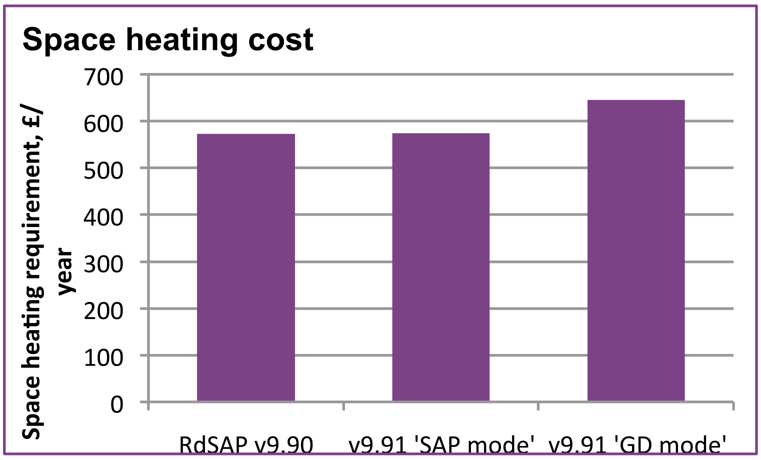
All three versions give CS1 an energy efficiency rating:





Annex CS2

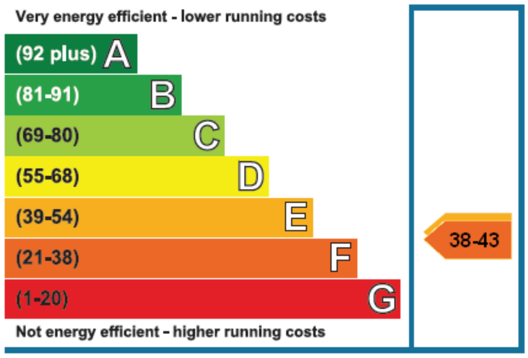
Dwelling type:	Semi-detached bungalow	**Storeys:**	1
Wall construction:	Solid stone, dry lining	**Total floor area**	48m^2
Window type:	7m^2, double glazing		
Wall area	48 m^2	**Wall U-value**	0.5 – 1.4 W/m^{2}K
Floor area	48 m^2	**Floor U-value**	0.53 W/m^{2}K
Roof area	48 m^2	**Roof U-value**	0.1 W/m^{2}K

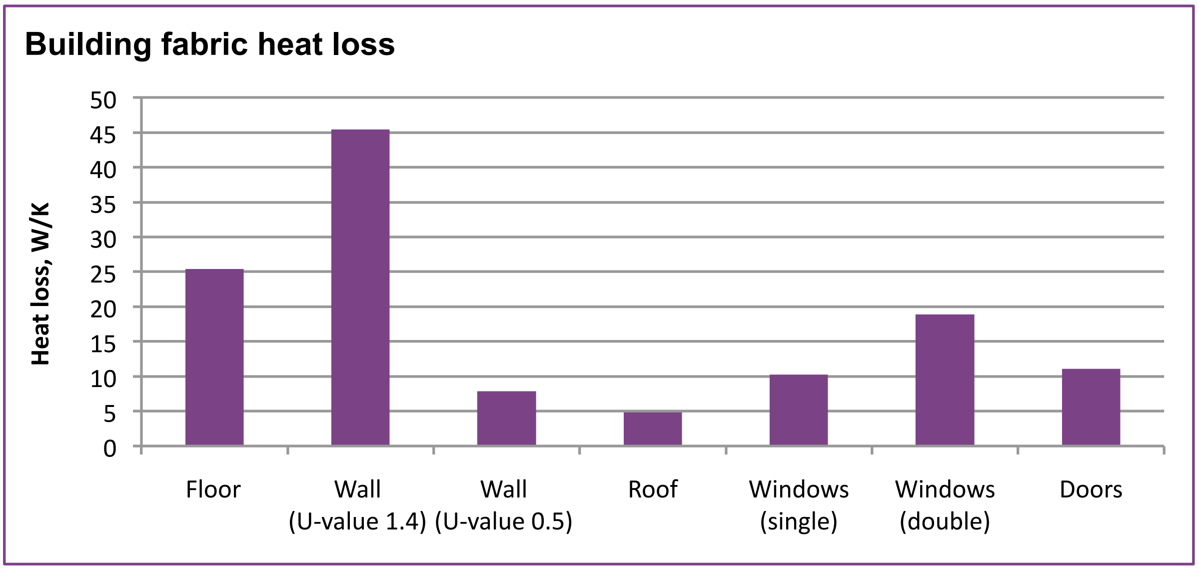


The regional variation in the 'Green Deal mode' slightly increases the heating requirement and associated costs.

Both the previous version and current version of RdSAP (in compliance 'SAP' mode') give CS2 an E rating.

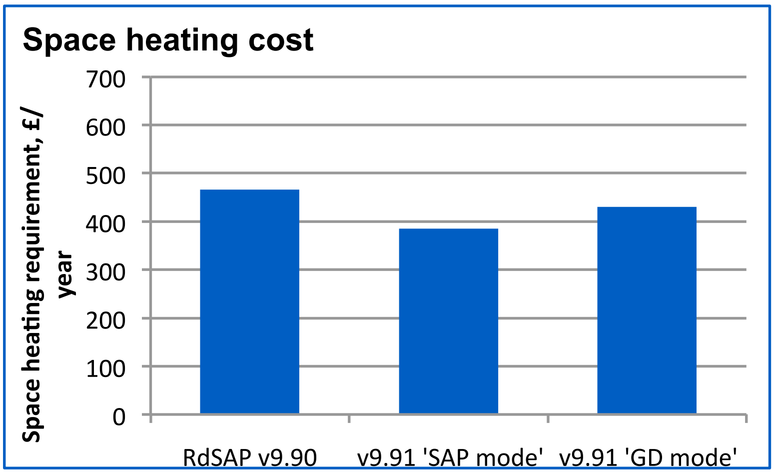
Running RdSAP v9.91 in 'Green Deal mode' gives CS2 an energy efficiency rating of F.





Annex CS3

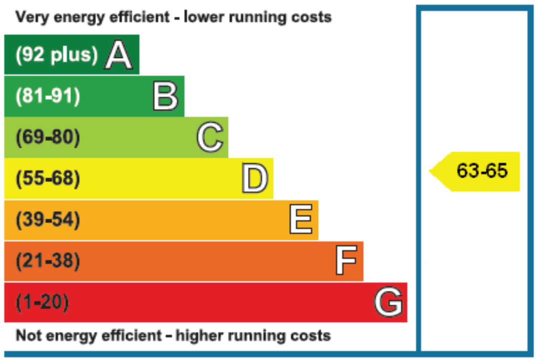
Dwelling type:	4-in-a-block flat	**Storeys:**	1
Wall construction:	Solid brick, dry lining	**Total floor area**	77m^2
Window type:	9m^2, double glazing		
Wall area	56 m^2	**Wall U-value**	1.5 W/m^{2}K
Floor area	77 m^2	**Floor U-value**	N/A
Roof area	77 m^2	**Roof U-value**	0.2 W/m^{2}K

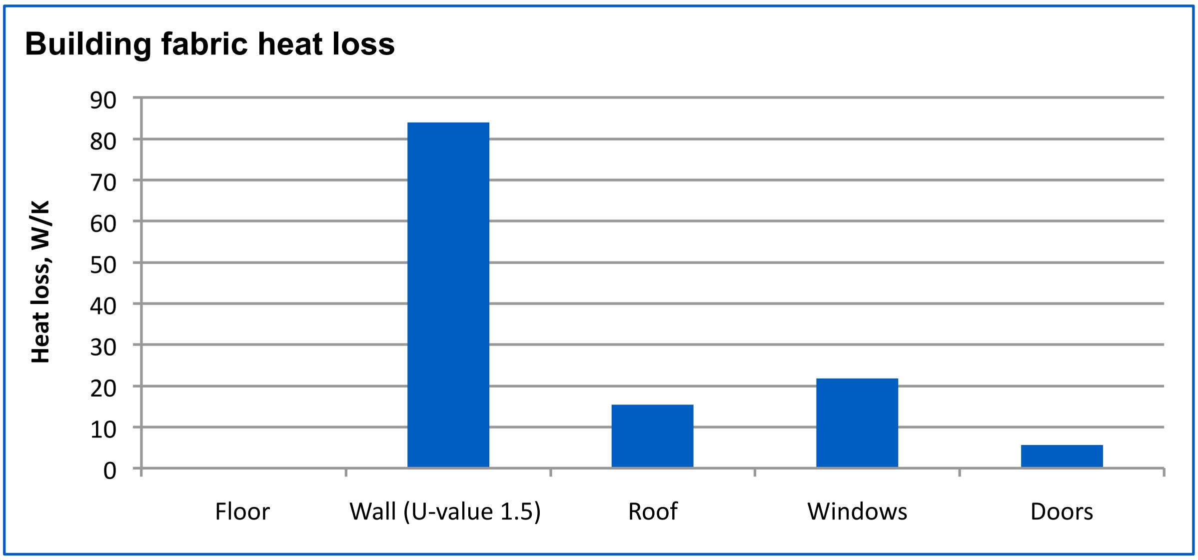


Both modes of v9.91 have reduced space heating costs than the previous version of RdSAP. This is due in part to the improved U-value of the solid brick walls in the newer calculation.

Again, the Green Deal regional difference calculates higher heating costs.

All three versions give CS3 an energy efficiency rating:





Historic Scotland Technical Papers

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1 Thermal performance of traditional windows

2 In situ U-value measurements in traditional buildings – *Preliminary results*

3 Energy modelling analysis of a traditionally built Scottish tenement flat

4 Energy modelling in traditional Scottish Houses (EMITSH)

5 Energy modelling of a mid 19th century villa

6 Indoor air quality and energy efficiency in traditional buildings

7 Embodied energy in natural building stone in Scotland

8 Energy modelling of the Garden Bothy, Dumfries House

9 Slim-profile double glazing – *Thermal performance and embodied energy*

10 U-values and traditional buildings – *In situ measurements and their comparison to calculated values*

11 Scottish Renaissance interiors – *Facings and adhesives for size-tempera painted wood*

12 Indoor environmental quality in refurbishment

13 Embodied energy considerations for existing buildings

14 Keeping warm in a cooler house – *Creating thermal comfort with background heating and locally used supplementary warmth*

15 Assessing insulation retrofits with hygrothermal simulations – *Heat and moisture transfer in insulated solid stone walls*

16 Green Deal financial modelling of a traditional cottage and tenement flat

17 Green Deal, Energy Company Obligation and traditional buildings

18 Evaluating energy modelling for traditionally constructed dwellings

19 Pre- and post-intervention monitoring of thermal upgrades on 10 traditional properties