



EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future



HISTORIC SCOTLAND
ALBA AOSMHOR



Scottish Construction Centre

S-RR3

MODELLING TOOLS TO ASSESS CO₂ IN DWELLINGS

TARGET AUDIENCE & DESCRIPTION:

This information paper is intended for anyone with an interest in measuring and calculating carbon performance of dwellings. What follows is an overview of the current method used to assess the energy performance of dwellings in Scotland, the benefits and shortfalls, and the potential improvements that could be made to the methods and systems in place.

1. INTRODUCTION

As the global consensus on climate change grows ever stronger, the need to reduce carbon emissions and fossil fuel use is now imperative. Emissions from housing in Scotland are responsible for 22% of Scotland’s total emissions¹, and therefore housing has a significant role to play in successfully meeting Scotland’s carbon emission targets; namely, to reduce emissions of greenhouse gases by 42% by 2020, and 80% by 2050, compared to 1990 base levels.

In 2006, the EU adopted Directive 2002/91/EC, the European Performance of Buildings Directive (EPBD), now recast as Directive 2010/31/EU. It requires a common methodology of energy assessment and implementation of energy certification of domestic and non-domestic dwellings across all Member States (MS). Each MS has different housing qualities, standards, expectations, and construction methods and materials, therefore while each MS requires energy assessments using a common methodology, there are slight variations in the detail used and calculation of energy assessment in each MS.

2. ENERGY ASSESSMENT METHODS

Section 6 of the Building Standards requires that when a dwelling is sold or let, an Energy Performance Certificate is produced, providing the future tenant information on the predicted costs associated with heating and lighting the home. There are two types of energy assessment: 1) the accredited method to calculate Energy Performance Certificate (EPC) ratings; and 2) experimental non-accredited models used in research and for stock-wide dwelling energy assessments.



2.1 STANDARD ASSESSMENT PROCEDURE (SAP)

SAP was introduced in 1990 to assess fuel costs of a dwelling. In 2007 SAP was given an offshoot model, Reduced Data SAP (RdSAP), for use with existing dwellings only, while SAP continued to be used for new-build dwellings only. The RdSAP uses a database of information to be used in the calculation where information is missing or unobtainable (such as wall construction, thickness, U-values) based on building age. The assessment method is the same throughout the UK; however the devolved nations have slightly different graphics and information on the output pages.

Both SAP and RdSAP have undergone many changes over the past twenty years, the most recent being in April 2010. With the recast of the EPBD in 2010, an update to SAP was needed to ensure consistency in energy assessment methods across the EU. The updated SAP 2009 v9.90 was released in April 2010, to be used from October 2010. (At the time of writing, the release of software to calculate EPC ratings under the revised Part L had been delayed until April 2011 affecting England & Wales, but not Scotland. It is unclear how this delay will affect calculation of SAP ratings). This new model has updated carbon emission factors, fuel prices, and climate information, and also now includes space cooling. The biggest difference to v9.90 is that it has moved from an annual calculation to a monthly calculation. The model is still steady-state (the conditions do not change over time, e.g. the model assumes the temperature throughout May is the same), but there is now slightly more detail than in previous versions. From October 2010, while new-build dwellings will be required to use SAP 2009, v9.90, existing buildings will continue to use SAP 2005, v9.83.

2.2 ALTERNATIVES

The National Energy Foundation established software not only for SAP, but also for their own rating system, the National Home Energy Rating². The NHER includes energy and fuel use of cooking equipment, and can assess overheating risk, where SAP assesses these only as an option when required by the assessor.

The Tarbase model³ was designed by the Urban Energy Research Group at Heriot-Watt University as part of a multi-partner project investigating energy use in buildings, and is recognised by Ofgem to assess energy use in various buildings, climates and locations around the UK. The tool calculates the cost, payback and emissions reductions expected from technology retrofits. Tarbase can be tailored by the assessor to get the required output type (graphs, tables, trends etc).

For more detailed modelling, energy assessment can be carried out using a dynamic simulation model (DSM), which uses a far higher temporal and spatial resolution. As well as the basic heat gains and losses calculations included in SAP, 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), and can be variable throughout the day.

Traditionally, DSMs are used for non-domestic properties only, due to their larger size and greater complexity; however it is possible to use a DSM for a domestic property, although it couldn't be used to produce an EPC. The disadvantages of using DSMs for domestic energy assessment include the greater complexity of the model and therefore the additional skill level required by assessors, the time taken to complete the assessment, and therefore the cost of completing the assessment.

3. INPUT FOR STEADY-STATE MODELS

The EPBD requires that each member state provide a National Calculation Method (NCM), the method used to demonstrate compliance with Building Standards and, through them, the EPBD. In the UK the NCM has a method for domestic and non-domestic properties, requiring that each building is assessed in the same way.

For domestic buildings across the UK, SAP is the NCM for assessing dwellings for Building Standards compliance and for calculating EPC ratings. What follows is a summary of the model input required for SAP calculations, and where this differs significantly from DSMs.

Dimensions used are the internal floor areas, as the focus is on the area through which heat is lost. This means that the internal partition walls are not included. Dynamic simulation models use dimensions to the centre of the partition wall so the heat transfer between each room is included.



The U-values are either those calculated using BS EN ISO 6946:2007⁴ "Building components and building elements – Thermal resistance and thermal transmittance – Calculation method", or those in the RdSAP construction database (for existing dwellings only). U-values are required for the floors, walls, roof, ceilings, doors, and glazing. The calculation does include correction factors if an element is exposed to an unheated space (such as a communal stairwell or underground car park), and one of SAP 2009's changes considers the heat transfer between two heated spaces (e.g. between terraced housing, or between different storeys within blocks of flats), while SAP 2005 considers heat transfer to be negligible.

Heat can be lost from the building envelope in two ways – through the walls, and by travelling across the junctions where materials meet such as corners and around openings. Thermal bridging is the term used to define the heat transfer between elements at these junctions, giving a numeric value to the way in which heat travels across the building fabric. Each 'route' of heat transfer has a linear transmittance: the heat flow for every degree of temperature difference across the junction, across the length of the bridge. The thermal bridging (γ) for the dwelling is the sum of the transmittance values multiplied by the length over which that bridge occurs, divided by the total area of the exposed external elements. If no information is available then a default value of $\gamma = 0.15$ is used. This is approximately twice that which is considered best practice in the UK for new-build housing⁵.

A new variable included in SAP 2009 is 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, and is used when calculating the space heating and cooling loads.

The TMP signifies the ability of the material to absorb heat, store it, and release it at a later time⁶. Materials with high thermal mass, or 'heavyweight', react slower as there is greater resistance in the material, while lightweight materials react much quicker, and their temperature follows the temperature of the air outside the building much more closely⁷. A building with high thermal mass therefore enables a building to better self-regulate the internal temperature (Figure 1).

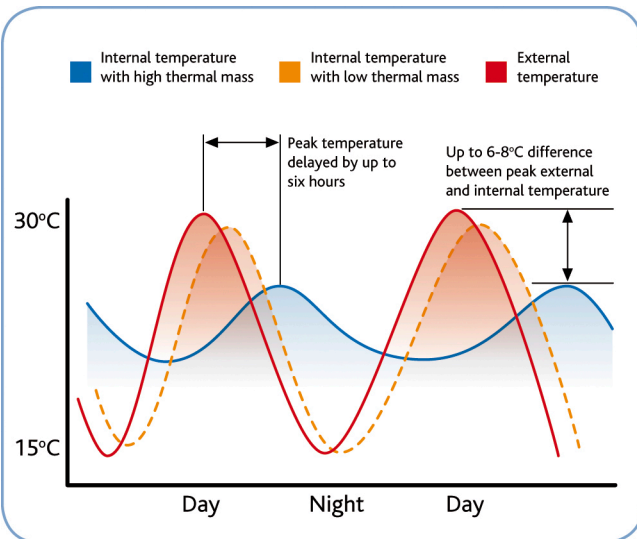


Figure 1. Time and temperature response of materials with different thermal mass⁸.

Traditional solid stone construction has high levels of thermal mass, timber frame construction less so, but as seen at Scotland's Housing Expo⁹ the concept of high thermal mass in walls is being combined with timber frame constructions in designs for new housing in Scotland.

In SAP 2009, the TMP is included in the calculations for both heating and cooling demand. Previous versions of SAP have not included TMP, in part because an annual steady state calculation will not allow for thermal interaction on timescales seen in Figure 1 above. A monthly calculation will use the TMP from a seasonal perspective; however a dynamic simulation model will be able to include short-timescale thermal mass effects as it uses an hourly resolution, and will also include diurnal temperature effects.

Ventilation is important to keep the internal air quality healthy for the occupants. However, poorly-sized ventilation can lead to excess heat loss, such as heating being on when windows are left open. There are two variables that provide a building with air changes: ventilation and infiltration. The ventilation air change rate describes the rate of air flow between

the internal and external environments, and is affected by many variables, such as the number of chimneys, flues, vents and fans. Infiltration is the measure of air tightness of the dwelling, and assesses the effect of gaps within the construction which may be within the envelope, or more commonly, draughts through poorly fitted or unmaintained openings. Ventilation can thus be thought of as intentional air change, with infiltration the unintentional air change through building fabric – though sensible design will consider both these factors in providing suitable air quality in a home.

When combining the fabric heat loss (U-values and thermal bridging) and ventilation heat loss, the heat loss coefficient is produced. The heat loss coefficient divided by the total floor area gives the Heat Loss Parameter (HLP, W/m²K). The HLP has the same units as a U-value, and can be thought of as a whole house U-value, and is used towards the heating and cooling requirement calculations.

The energy required for domestic hot water (DHW) is taken from a table within SAP and is a function of the total floor area. The methods used differ between SAP 2005 and 2009, with SAP 2009 using varying DHW usage each month: lower in the summer, higher in the winter.

Both versions of SAP calculate the hot water usage, energy content of the water used, and the losses incurred across the storage and distribution system. Similarly to the effect of ventilation losses on the heating system, the higher the losses incurred in the DHW system, the harder the system has to work, increasing energy consumption, bills, and emissions. However, the losses from the DHW system are fed back into the heating and cooling calculations: for example, if pipework was to be insulated, the DHW system would work less, while the heating system would work harder. These gains are included when calculating internal gains.

Internal gains, sometimes called casual gains, describe the heat emitted within the dwelling, which act to reduce the heating demand and increase the cooling demand. In SAP 2005, the heat gains from lighting, cooking, appliances, and the gains from the occupants (metabolic gains) are calculated using the standardised number of occupants and total floor area, through simple equations within SAP. (NB. If low energy lighting is used, the internal gains are reduced, as low energy lighting emits less heat from the bulb than traditional older lighting). In SAP 2009, the same heat gains are calculated using slightly different equations, and utilise two sets of equations, one for typical gains in existing dwellings, and the other for 'reduced gains' in new-build dwellings.

Solar gains also contribute towards lowering the heating demand by heating the air and through 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, but also on the surfaces it is hitting, as darker smoother surfaces will absorb the incoming radiation to a greater effect than lighter rougher surfaces. SAP 2005 and SAP 2009 again differ in calculation method, with SAP 2005 using a set of simple values whereas SAP 2009 uses a series of equations enabling the latitude of the site, the horizontal flux, and the vertical flux to be included in addition to the orientation. While each window type on each orientation is considered, the windows are not attributed to an individual room in steady-state modelling, whereas dynamic modelling does attribute windows to a particular room (as per zoning requirements).

In SAP 2005 the ratio between total useful gains (casual plus solar) and the heat loss coefficient is calculated and used to provide a utilisation factor which contributes to the space heating requirement calculations. In SAP 2009 the utilisation factor for space heating is also a factor of the internal and external temperatures and the Thermal Mass Parameter. In DSMs, the heat gains are considered as sensible heat (the temperature change in the air of the room) and latent heat (the change in humidity in the room).

To calculate the internal temperatures of a dwelling, the steady-state and dynamic methods differ significantly. The steady-state models require the dwelling to be split into two zones: the living room, and the rest of the house, whereas dynamic models require numerous zones to be defined, and each has different properties. The mean internal temperatures are assumed by SAP 2005 as a function of the HLP and the responsiveness and controls of the heating system, and vary between 18 and 21°C. In SAP 2009, the living room temperature is taken as 21°C, and the temperature in the rest of the house is dependent on the HLP and the controls on the heating system. However, the temperatures vary month by month.

The internal and solar gains in a dwelling contribute towards the thermal comfort of the occupants, as well as the temperature of surfaces, and any draughts. Overheating is directly connected to thermal comfort, and it is the gains just discussed that contribute to overheating. DSMs are more reliable in assessing thermal comfort as they assess the air movement between zones, and better replicate the internal conditions due to the better spatial resolution given by the numerous zones defined. However, SAP 2005 and

2009 both include a calculation of the risk of overheating (levels of risk defined by particular temperatures) as an optional Appendix calculation.

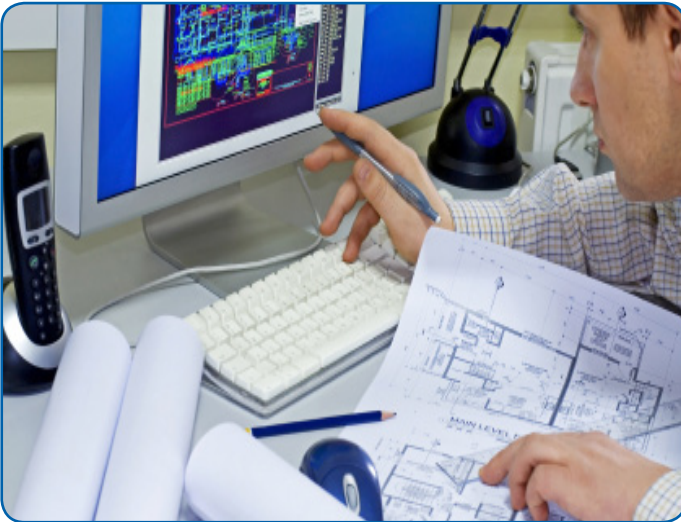
The space heating requirement in any building is a balance of heat gains and losses¹⁰. In SAP 2005 the temperature rise due to gains is subtracted from the mean internal temperature to give a base temperature, which is used to define the number of 'degree-days', a numeric value which represents when the external temperature falls below the base temperature. The number of degree days is then multiplied by a factor of 0.024 to provide the space heating requirement of the dwelling. The method used by SAP 2009 is very different. The level of gains, the mean internal and external temperatures, the utilisation factor, and the rate of heat loss all differ on a month by month basis, combined to provide a monthly space heating requirement.

Every energy assessment model includes weather data, but how specific and how much data is available depends on the model. The 2005 model used 20-year UK-average weather data from the 1960s and 1970s¹¹. SAP 2009 has updated this information by using more recent averages from the Met Office. For cooling demand calculations, the UK is split into 21 regions, with the temperature varying by location. However for heating requirement calculations, SAP 2009 still uses a whole-UK average external temperature. SAP 2009 now also includes wind speed and solar radiation.

Again, dynamic modelling differs greatly to that of steady state modelling, as the weather data does not just include temperature data. CIBSE weather guides¹² use historical weather data from the Met Office for a much larger number of locations, with hourly data available for:

- Dry bulb temperature
- Wet bulb temperature
- Atmospheric pressure
- Wind speed
- Wind direction
- Cloud cover
- Total irradiation on the horizontal surface
- Diffuse radiation on the horizontal

This allows the model to look at the effects of the weather on energy consumption more precisely, and over shorter timescales than a month or year.



4. MODEL OUTPUT

Each model type provides the assessor with different types and levels of results, summarised in Table 1. Dynamic simulation models can provide a more detailed assessment of a building than all other methods, with results including comfort statistics, hourly room temperatures (air temperature, mean radiant temperature, and dry resultant temperature), humidity, air exchanges, surface temperatures, internal gains, in addition to the standard energy consumption and carbon dioxide emissions. This is due to the more detailed input outlined earlier.

Table 1. Summary of output from different assessment methods

	SAP 2009	RdSAP 2005	Dynamic
Electricity consumption	✓	✓	✓
Fossil fuel consumption	✓	✓	✓
CO2 emissions	✓	✓	✓
Asset ratings (e.g. EPC)	✓	✓	Non-domestic only
Energy use by end use	✓	✓	✓
Hourly room temperature	✗	✗	✓
Casual gains	✗	✗	✓
Air exchanges	✗	✗	✓
Comfort statistics	✗	✗	✓

Where an asset rating is required for an EPC, a certain

level of accuracy and quality should be expected. The quality assurance aspect is required to ensure the simulation is as close to reality as possible, even though precision will not necessarily lead to an assessment that matches reality¹³. In Scotland, no such quality checks are required by the Building Standards Directorate¹⁴. However, EPCs can only be produced by qualified assessors who must belong to an accreditation scheme, and it is the accreditation scheme that controls the quality of the assessments, through continuous assessment via random sampling of EPCs.

5. SUMMARY

Updates to RdSAP are expected in March 2011, but it is unknown what they will consist of. With the new monthly variables aspect of SAP, and ongoing strengthening of carbon emission targets in the Building Standards (Scotland) and Regulations (England & Wales), it is expected that the revised RdSAP will be aligned with its parent model.

The move to a monthly steady-state calculation and the additional inclusion of heat transfer across party walls implies that a more representative view of dwelling energy use is desired. A monthly steady-state calculation is better than an annual steady-state calculation as it provides higher disaggregation of heating (and, where evident, cooling) loads throughout the year. However if a simple model could be devised that included the diurnal temperature cycle, the effects of thermal inertia in the construction could truly be recognised, which may be of some benefit to solid wall constructions, common across Scotland.

If used correctly, energy performance modelling tools can be useful for design decision making when looking to either build new, retrofit, or refurbish a dwelling. Such models can lead designers and engineers towards the correct choice of technologies and approaches for creating a low-carbon building stock. While such aims can only truly be borne out through analysis of post-occupancy data, modelling and simulation still has an important role to play, and thus it is vital the correct tools are used in the correct way.

Authors:



Vicky Ingram and Prof. Phil Banfill,
Urban Energy Research Group,
School of Built Environment, Heriot-Watt University



Dr. Craig Kennedy,
Head of Science for
the Conservation
Group, Historic Scotland

TITLE/DESCRIPTION	LINKS
Standard Assessment Procedure 2005, previous version of SAP, still used for RdSAP	http://www.bre.co.uk/sap2005
Standard Assessment Procedure 2009, current version of SAP, used from 1 October 2010.	http://www.bre.co.uk/sap2009
National Calculation Method (NCM), overview of the non-domestic NCM	http://www.ncm.bre.co.uk
EPBD, the Energy Performance of Buildings Directive, recast, 2010.	http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:FULL:EN:PDF
Building Standards Directorate	http://www.scotland.gov.uk/Topics/Built-Environment/Building/Building-standards
Building Standards, Section 6 – Energy	http://www.scotland.gov.uk/Topics/Built-Environment/Building/Building-standards/publications/pubtech
Scotland's Action on Climate Change, portal for the Climate Change Act (Scotland) 2009, the action being taken in Scotland and abroad	http://www.scotland.gov.uk/Topics/Environment/climatechange
Met Office, UK climate and weather statistics.	http://www.metoffice.gov.uk/weather/uk/climate.html

REFERENCES

1	Sneddon, S., Brophy, N., Li, Y., MacCarthy, J., Martinez, C., Murrells, T., Passant, N., Thomas, J., Thistlethwaite, G., Tsagatakis, I., Walker, H., Thomson, A., Cardenas, L. 2010. Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland: 1990 – 2008. Prepared by AEA for the Department of Energy and Climate Change, London.
2	National Energy Services. http://www.nesltd.co.uk/
3	Tarbase – to reduce CO2 emissions in the built environment by 2030. http://www.tarbase.com
4	BS EN ISO 6946-2007. 2007. Building components and building elements – Thermal resistance and thermal transmittance – Calculation method.
5	DCLG. 2007. Accredited Construction Details. http://www.planningportal.gov.uk/uploads/br/accredconbk.pdf
6	Wheatley, C. 2008. Thermal mass in traditional buildings. Historic Scotland, Edinburgh.
7	Wheatley, C. 2008. Thermal mass in traditional buildings. Historic Scotland, Edinburgh.
8	The Concrete Centre. 2009. Thermal mass explained. The Concrete Centre, Camberley
9	Scotland's Housing Expo. http://www.scotlandshousingexpo.com/
10	Lundin, M., Andersson, S., Östin, R. 2004. Development and validation of a method aimed at estimating building performance parameters. Energy & Buildings 36(9) pp905-914
11	BRE, 2009. Background and Consultation Questions http://www.bre.co.uk/filelibrary/SAP/2009/Background_and_consultation_questions.doc
12	CIBSE/Met Office. 2005. Hourly Weather Data, CIBSE/Met Office, October 2005.
13	Hand, J.W., Crawley, D.B., Donn, M., Lawrie, L.K. 2008. Improving non-geometric data available to simulation programs. Building & Environment 43(4) pp674-685
14	Hughes, A.M. 2010. Discussion on QA/Audit process for Scottish energy assessments. [Telephone conversation] (Personal communication, 05 May 2010)