A Review of Domestic and Non-Domestic Energy Performance Certificates in Scotland

Research report for the Scottish Government, Heat, Energy Efficiency and Consumers Unit

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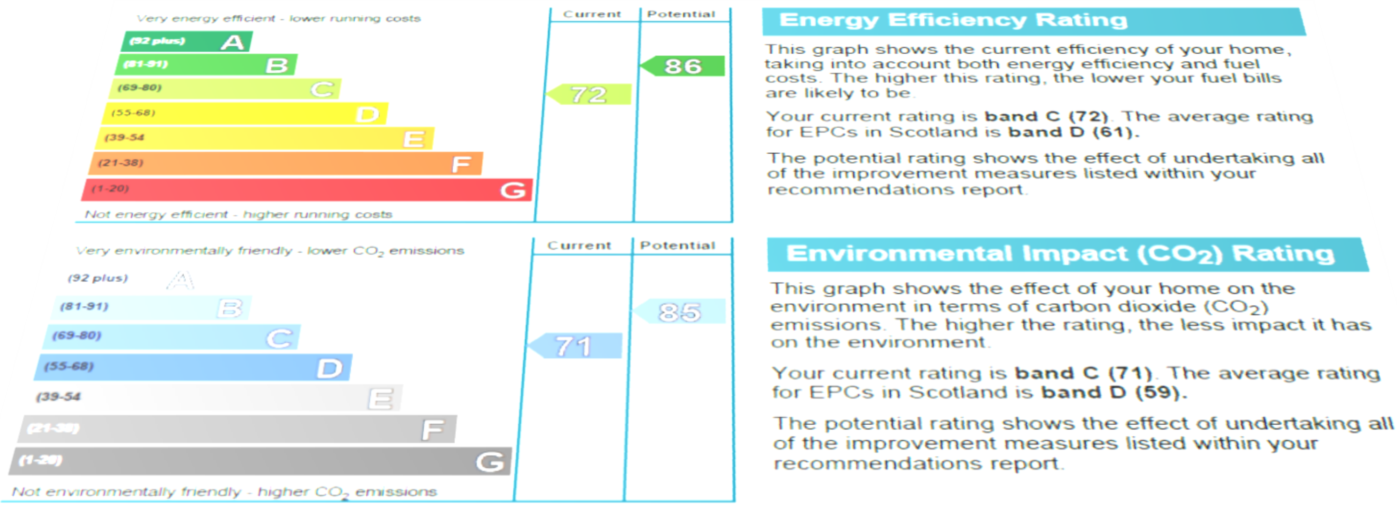
Alembic Research Ltd. in association with Energy Action Scotland and Dr Patrick Waterfield

Supplementary Topic Notes



in association with
Dr Patrick Waterfield

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1. Introduction

As part of the review of EPCs in Scotland, additional analysis was carried out as part of the research project into the methodology, calculations, and conventions underpinning the SAP and RdSAP methodologies.

This additional analysis was concerned specifically with six different topic areas identified through the main research programme:

- RdSAP and U-values
- Thermal Mass
- Rooms in the Roof
- Community heating
- Ventilation Sensitivity: draught lobbies, flues and extract fans
- Measuring Window Areas in RdSAP

The methods used in the additional analysis varied:

- in some instances, it was to carry out a more detailed technical analysis of a specific issue;
- in some instances, it was to compare directly the differences between an RdSAP assessment of a dwelling and a full SAP assessment of a dwelling, and examining the impact of the two different approaches; and,
- in some instances, it was to highlight confusion in the conventions and to seek clarity.

The additional analysis uses several case studies, and presents information not previously available publicly. However, the overall purpose of the additional analysis was to explore how the results from the RdSAP and EPC process could be improved.

The results of this additional analysis were used to inform the presentations at the four workshops that were help as part of the research programme for this project, and were openly discussed within the workshops. The results also informed the identification and impact assessment of various recommendations published in the main report.

The information within these supplementary topic notes was deemed too technical to include in the main report on the review of EPCs, but important and appropriate enough to publish as an addendum to the main report.

2. RdSAP and U-values

The default U-values defined with RdSAP have changed since RdSAP's introduction in Scotland in 2009. Up to October 2012, RdSAP in Scotland effectively had single, age band determined-default U-values for each of the 'as built' wall constructions (see Table UV1).

Wall Type	RdSAP Age Band										
	A	B	C	D	E	F	G	H	I	J	K
Stone: granite or whinstone (as built)	1.7	1.7	1.7	1.7	1.7	1.0	0.6	0.45	0.45	0.3	0.25
Stone: sandstone (as built)	1.5	1.5	1.5	1.5	1.5	1.0	0.6	0.45	0.45	0.3	0.25
Solid brick (as built)	2.1	2.1	2.1	2.1	1.7	1.0	0.6	0.45	0.45	0.3	0.25
Cob (as built)	0.8	0.8	0.8	0.8	0.8	0.8	0.6	0.45	0.45	0.3	0.25
Cavity (as built)	2.1	1.6	1.6	1.6	1.6	1.0	0.6	0.45	0.45	0.3	0.25
Timber frame (as built)	2.5	1.9	1.9	1.0	0.8	0.5	0.4	0.4	0.4	0.3	0.25
System build (as built)	2.0	2.0	2.0	2.0	1.7	1.0	0.6	0.45	0.45	0.3	0.25

Table UV1 – Default U-Values for Scottish 'as built' wall constructions – RdSAP v9.81,v9.83 and v9.90

With the changeover to RdSAP v9.91 in October 2012, while many of the 'as built' age-related U-values remained unchanged, the U-values for sandstone and granite or whinstone wall types were replaced by a footnote which referred the reader to equations in S5.1.1 of the SAP manual (see Table UV2 below). 'Limestone' was added to the sandstone wall type category with RdSAP v9.92 in December 2014, but there were no other changes to any of the 'as built' U-values.

Wall Type	RdSAP Age Band										
	A	B	C	D	E	F	G	H	I	J	K
Stone: granite or whinstone (as built)	a	a	a	a	1.7	1.0	0.6	0.45	0.45	0.3	0.25
Stone: sandstone or limestone (as built)	a	a	a	a	1.5	1.0	0.6	0.45	0.45	0.3	0.25
Solid brick (as built)	2.1	2.1	2.1	2.1	1.7	1.0	0.6	0.45	0.45	0.3	0.25
Cob (as built)	0.8	0.8	0.8	0.8	0.8	0.8	0.6	0.45	0.45	0.3	0.25
Cavity (as built)	2.1	1.6	1.6	1.6	1.6	1.0	0.6	0.45	0.45	0.3	0.25
Timber frame (as built)	2.5	1.9	1.9	1.0	0.8	0.5	0.4	0.4	0.4	0.3	0.25
System build (as built)	2.0	2.0	2.0	2.0	1.7	1.0	0.6	0.45	0.45	0.3	0.25

Table UV2 – Default U-Values for Scottish 'as built' wall constructions – RdSAP V9.91 and v9.92

The most recent manifestation of the default RdSAP U-values table for 'as built' has made changes to the U-values of both solid brick and cavity brick walls. These changes were introduced after on-site in-situ testing of walls found that solid brick walls and cavity walls performed better than the theoretical defaults[1], and as part of the UK Government's changes to SAP in the wake of the SAP 2016 consultation[2]. These changes to the default U-values were incorporated into RdSAP with v9.93 in November 2017 (see Table UV3).

Wall Type	RdSAP Age Band										
	A	B	C	D	E	F	G	H	I	J	K
Stone: granite or whinstone (as built)	a	a	a	a	1.7	1.0	0.6	0.45	0.45	0.3	0.25
Stone: sandstone (as built)	a	a	a	a	1.5	1.0	0.6	0.45	0.45	0.3	0.25
Solid brick (as built)	1.7	1.7	1.7	1.7	1.7	1.0	0.6	0.45	0.45	0.3	0.25
Cob (as built)	0.8	0.8	0.8	0.8	0.8	0.8	0.6	0.45	0.45	0.3	0.25
Cavity (as built)	1.5	1.5	1.5	1.5	1.5	1.0	0.6	0.45	0.45	0.3	0.25
Timber frame (as built)	2.5	1.9	1.9	1.0	0.8	0.5	0.4	0.4	0.4	0.3	0.25
System build (as built)	2.0	2.0	2.0	2.0	1.7	1.0	0.6	0.45	0.45	0.3	0.25

Table UV3 – Default U-Values for Scottish 'as built' wall constructions – RdSAP v9.93

2.1 Calculating Stone Wall U-values

With the changes to the default U-values introduced in RdSAP in October 2012, the respective single as-built U-values for the sandstone / limestone and the granite / whinstone wall types were replaced with equations. For these two stone wall type categories, these changes created infinitely variable U-values, as the thickness of the stone wall became a major determinant of the calculated U-value. The two equations were, respectively:

- for granite or whinstone, the U-value = 3.3 - 0.002 * thickness of wall in mm
- for sandstone or limestone, the U-value = 3.0 - 0.002 * thickness of wall in mm

[1] Review of default U-values for existing buildings in SAP, Consultation Paper: CONSP:16, available at https://www.bre.co.uk/filelibrary/SAP/2016/CONSP-16---Wall-U-values-for-existing-dwellings---V1_0.pdf

[2] Changes to the Government's Standard Assessment Procedure (SAP), November 2017, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/660478/Government_Response_-_Changes_to_SAP_FINAL-v2.pdf

Another variable was also introduced in the process: an additional shelter factor was applied to the calculated U-value if the stone walls in age bands A to E[3] had internal dry-lining or lath and plaster finish (that is, an airspace):

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

where R_{dl} is the additional thermal resistance introduced by the internal finish.
Use R_{dl} = 0.17 m²K/W.

So three factors now determine the stone wall U-value within RdSAP: the type of stone, the thickness of the stone wall, and the presence (or not) of an air space. A sample of the resultant U-values for stone walls is sent out in Table UV4.

	sandstone or limestone		granite or whinstone	
wall thickness in mm	plastered on the hard	with drylining or lath and plaster	plastered on the hard	with drylining or lath and plaster
200	2.60	1.80	2.90	1.94
300	2.40	1.70	2.70	1.85
400	2.20	1.60	2.50	1.75
500	2.00	1.49	2.30	1.65
600	1.80	1.38	2.10	1.55
700	1.60	1.26	1.90	1.44
900	1.20	1.00	1.50	1.20

Table UV4: Sample RdSAP U-values for sandstone or limestone and granite or whinstone walls

From Table UV4, the presence of the drylining or lath and plaster layer on the stone wall has a marked impact on the resultant U-value. In effect, if the stone wall was thick enough it would be give a U-value of 0.00 in RdSAP. For a drylined sandstone or limestone wall it would need to be 1498mm thick, and for a granite or whinstone wall it would have to be 1648mm thick.

In its current formulation, RdSAP does take into account the varying thickness of stone walls, and walls of different stone constructions, but does it go far enough?

Dr. Moses Jenkins of Historic Environment Scotland suggested in a paper presented at a recent seminar[4] that a minor adjustment to the RdSAP stone wall equations might produce a better alignment between the RdSAP U-values and the evidence collected through various in-situ testing projects. He suggested that rather than use a value of 0.002 in the equations set out above, that a value 0.0025 be used. The U-values in Table UV4 were recalculated using this modification and the results are set out in Table UV5 below.

[3] The additional resistance was also applied to as-built solid brick and as-built cavity walls across the same age bands.
[4] Critical Appraisal of EPC Certification in Scotland, the Engine Shed, Stirling, March 16, 2018. Paper available from Energy Action Scotland, Suite 4a, Ingram House, 227 Ingram Street, Glasgow G1 1DA

	sandstone or limestone		granite or whinstone	
wall thickness in mm	plastered on the hard	with drylining or lath and plaster	plastered on the hard	with drylining or lath and plaster
200	2.500	1.754	2.800	1.897
300	2.250	1.627	2.550	1.779
400	2.000	1.493	2.300	1.653
500	1.750	1.349	2.050	1.520
600	1.500	1.195	1.800	1.378
700	1.250	1.031	1.550	1.227
900	0.750	0.665	1.050	0.891

Table UV5: Sample RdSAP U-values for sandstone or limestone and granite or whinstone walls with adjusted to RdSAP calculation equation (0.0025 rather than 0.002)

This suggested adjustment does seem to align the 600mm and 700mm thick sandstone walls with his suggested actual performance of sandstone wall U-values of between 1.0 and 1.2 W/m^{2}K, but only when internal drylining or lath and plaster is included. Dr Jenkins's initial calculations presented at the seminar did not include for an internal lining. The resultant U-values for 900mm thick stone walls also appear to be 'too good'. Certainly, further empirical research work is required here to confirm and validate these possible changes to the RdSAP stone wall U-value equation.

2.2 Other Types of Stone Walls in Scotland

RdSAP is currently set up for four different stone wall types, grouped in two pairs: 'sandstone or limestone' and 'granite or whinstone'. Scotland has a rich diversity of stone used in the construction of its dwelling stock, though sandstone and granite are likely to be the most common. The RdSAP methodology advises assessors that if they come across other types of stone to categorise them as 'sandstone or limestone' if they are a sedimentary type of stone, or as 'granite or whinstone' if they are an igneous or metamorphic type of stone. The assessor is then to select Addenda note 1 from the software which states that the assessor has chosen the closest match to the actual wall construction. Thus, mudstone from the Orkneys would be recorded as 'sandstone or limestone', while basalt around Bathgate would go through as 'granite or whinstone'. Some work could go into collating more information on the energy performance of other types of Scottish stone, or undertaking in-situ testing, to broaden the range of stone wall U-values that are available in RdSAP[5].

[5] See: Butcher, Craig, Butcher, Ken., Craig, Bonnie, & Chartered Institution of Building Services Engineers, issuing body. (2015). Environmental design: CIBSE guide A (Eighth ed.).

2.3 Solid Brick Walls

It was noted above that with the introduction of RdSAP v9.93 in November 2017, that the RdSAP default U-values for solid brick walls up to Age Band E were revised downwards (that is, effectively improved). The basis of this change was an empirical data exercise whereby in-situ monitoring of wall U-values was completed on a significant number of dwellings (i.e. 300 dwellings)[6]. The results found that the actual U-values measured on site were lower (that is, losing heat slower) than calculated theoretically, or assumed by the RdSAP default U-value of 2.1 W/m^{2}K for solid brick walls. The range of measured results is shown in the graph in Figure UV1. The RdSAP default of 2.1 W/m^{2}K is shown at edge of high side of the distribution curve.

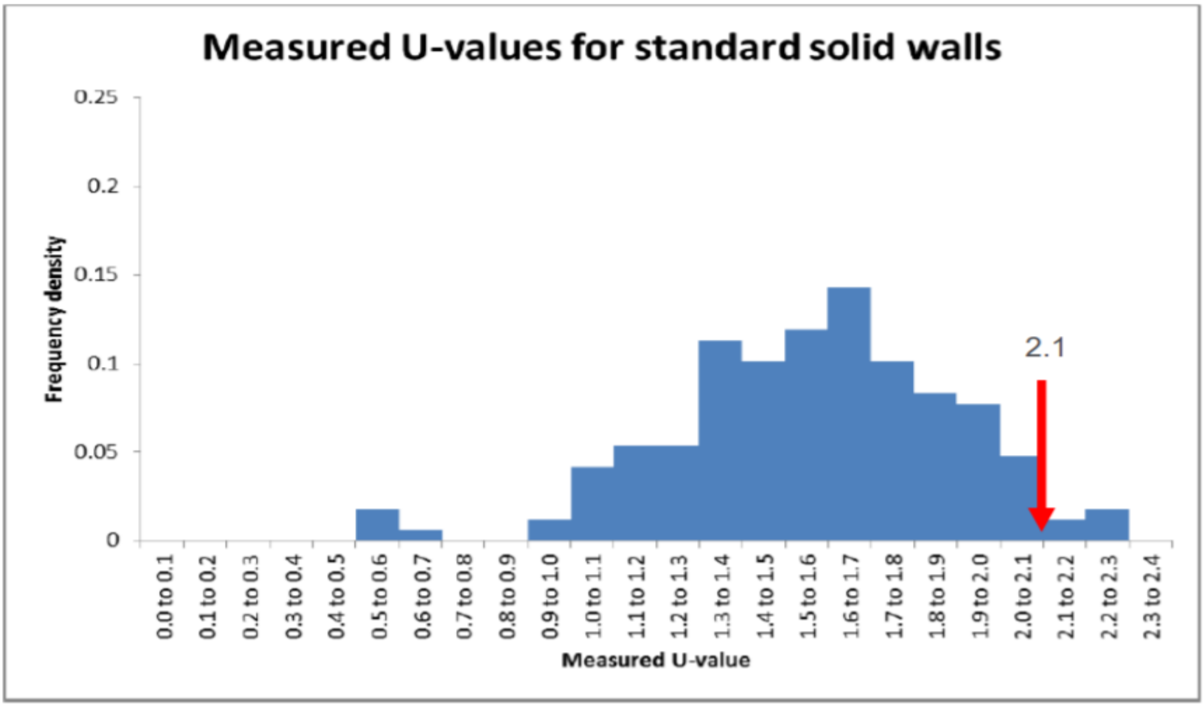

Figure UV1 – Distribution of measure U-values in standard (i.e. <330mm) solid brick walls (source: BRE (2014) In-situ measurements of wall U-values in English housing, BRE, Garston)

While the empirical evidence presented certainly supports such a change, the technical background paper to the SAP 2016 consultation on this topic noted “There are also likely to be other factors, such as air voids in nominally solid walls leading to (fortuitously) better U-values.”[7] What the supporting research did not identify was the impact of such factors, aggregating all standard solid walls together and noting that there could be other factors in play. This research would have been more robust if it had identified these various factors, and displayed the distribution of the measured U-values for different factors rather than amalgamating them all into one graph.

[6] BRE (2014) In-situ measurements of wall U-values in English housing, BRE, Garston, available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/409428/In-situ_u-values_final_report.pdf
[7] Op cit. 1, p6

The result of this research was to reduce the RdSAP default U-value for solid brick walls from 2.1 to1.7 W/m^{2}K. However, in RdSAP, one of the wall construction items to be identified as part of the assessment survey is whether there is an internal drylining or lath and plaster internal finish because of the airspace (a fortuitous air void?). If present, indicating this in the previous version of the RdSAP software changed the default U-value from 2.1 to 1.55, that is, better than the revised 1.7 W/m^{2}K value.

The same original research[8] also identified that 'non-standard solid walls' which were defined as solid walls greater than 330mm in thickness, were also performing significantly better than predicted or accounted for by the RdSAP default (see Table UV6 below). For the non-standard solid walls, the mean and median values were 1.28 W/m^{2}K compared to the RdSAP default of 2.1. Yet, there was no proposal in the SAP 2016 changes to revise RdSAP to include dimensional components into the solid wall U-values.

Wall type	Number of cases	**Measured U-values: mean (standard deviation) W/m²K***	**Measured U-values: median W/m²K**	*Calculated U-values: mean (standard deviation), W/m²K*	*Calculated U-values: Median W/m²K*	**Typical RdSAP U-values[a] W/m²K**
Solid wall, standard [b)]	85	**1.57 (0.32)**	**1.59**	*1.90 (0.20)*	*1.92*	**2.1**
Solid wall, non-standard [b)]	33	**1.28 (0.42)**	**1.28**	*1.91 (0.49)*	*1.68*	**2.1**

Table UV6: Summary of Results: Classification of wall and calculation of U-values[9]

While a brick-thick solid wall is the norm for many houses, in the pre-1919 tenements in Scotland, the close walls are often only a half-brick thick (i.e. 150-180mm thick), while the external walls of the lower levels of the tenement can be 1.5 or 2 bricks thick to support the weight of the upper levels of the tenement. The result is that the close walls are given too much benefit by the RdSAP defaults; the external walls not given enough.

Introducing a dimensional component for solid brick walls would differentiate solid brick walls by the wall thickness and assign default U-values: for example:

- a half-brick thick (approximately 150-170mm) (so anything less than 200mm)
- a brick thick wall (usually between 220-230mm) (so anything more than 200mm up to 300mm)
- a 1.5-brick thick wall (usually between 330-350mm (so anything more than 300mm up to 400mm)
- a two-brick thick wall (usually between 450-500mm) (so anything more than 400mm)

[8] Op cit. 5
[9] Ibid. extract of Table 4 p13 of report

This task would not require any more effort from the assessor: RdSAP assessors already measure the thickness of the wall as part of the survey. Identifying solid brick walls is also part of the survey. All of this change could be managed as a software issue.

2.4 Non-traditional and System-Built dwellings

Scotland has a large legacy on non-traditional and system-built dwellings. Much research has been completed on these dwellings to catalogue and describe these constructions in great detail. The Guide to Non-traditional housing in Scotland[10] gives descriptions of the constructions, the numbers of dwelling units built, the locations, as well as floor plans and section drawings. Behind this summary book were a series of detailed BRE reports on many of the individual non-traditional dwelling types. These dwellings encompass a wide diversity of metal, concrete and timber constructions. Yet, despite the availability of all this information, RdSAP aggregates them under a single, age-related, default U-value. Then, because RdSAP treats “system-built” as a catch-all categorisation, it does not recommend improvements to such wall types under Appendix T. They are not included in the type of walls that can be insulated under RdSAP conventions.

A major effort should be carried out to produce different defaults for known ’system built’ wall constructions, and Appendix T be opened-up to recommend external or internal wall insulation to defined non-traditionally constructed walls.

There is much published research on different types of ‘non-traditional’ and ‘system built’ walls so that default U-values could be calculated and built into a database within RdSAP so that they could be selected where the ‘system built’ type can be identified. Databases and records still exist indicating where many of these dwellings were built in Scotland. This information could be utilised to a produce a guide for RdSAP assessors. If the ‘non-traditional’ and ‘system built’ wall type could not be identified then the catch-all default would still prevail.

Where RdSAP assessors / DEA’s would be required to positively identify stone wall types or ‘non-traditional’ building elements, this change may require additional certification, and training provided by professional bodies e.g. HES or CIBSE.

[10] Scottish Office Building Directorate (1987) A Guide to Non-traditional Housing in Scotland 1923 - 1955, HMSO, Edinburgh

2.5 Accounting for Insulation that you can measure

The SAP 2016 consultation document noted that “the energy consumption of a dwelling predicted using SAP is very sensitive to a wall U-value”. With cavity wall insulation, the current assumption is that the cavity walls are being insulated with blown fibre or bead with a thermal conductivity of 0.04 W/mK. A number of companies however are using types of bead insulation with a thermal conductivity of 0.032 (i.e. about 25% better than blown fibre or traditional bead insulation) but get no added benefit to carbon savings or improved SAP scores, even if this can be identified or certified.

Similarly, this approach should be extended to internal and external wall insulation so that better modelling of the impact of the actual thickness of the insulation and the material being used is include within the RdSAP assessment. Currently RdSAP offers default insulation thicknesses of 50, 100, 150, and 200mm thicknesses of insulation (and again, this insulation is assumed to be the equivalent of Expanded Polystyrene (EPS)) with a thermal conductivity of 0.04 W/mK. However, many properties were retro-insulated in the past with 25 to 40mm of EPS or similar insulation materials – currently they would get no benefit for this insulation as the actual thickness is less than the minimum 50mm thickness, and assessors are advised by their membership schemes to ignore it[11]. Currently, many properties are receiving 70 – 90 mm of external or internal wall insulation (which under RdSAP convention should be rounded down to 50mm).

If the concern is getting to the right U-value, then we need to move RdSAP away from rigid standard thicknesses of insulation to allowing actual materials and thicknesses to be specified where these can be identified.

[11] personal experience of one of the authors of this report

3. Thermal Mass

The thermal Mass, or the internal heat capacitance, of a material reflects its ability of to absorb and store heat. Materials with high thermal mass will take longer to warm up, but longer to cool down. Thermal mass is not a substitute for insulation. Many materials with a high thermal mass are very poor insulators, for example, dense stone and concrete; many materials with good insulation properties have a low thermal mass.

Within building design and construction, thermal mass provides a buffer against rapid fluctuations in temperature: the thermal mass will absorb thermal energy when the surroundings are higher in temperature than the mass, and then transfer the stored thermal energy back when the surroundings are cooler. The appropriate use of thermal mass can make a considerable difference to internal comfort, and heating and cooling bills. In the winter, it can help the dwelling maintain comfortable temperatures, and in the summer, thermal mass can assist in preventing a building over-heating. However, thermal mass is not a ‘free’ heat source. If there is no heat input into the thermal mass, there is no heat to transfer back into the surrounding environment.

How effective thermal mass is at improving comfort conditions represents a trade-off between the type of heating in the property, the use of the heating, and the position of any insulation. It is not a simple equation that high thermal mass is good. For example, the benefits of the thermal mass may be negated by the placement of insulation or other low thermal capacitance materials between the heat source and the thermal mass. So, carrying out internal wall insulation in an otherwise high thermal mass stone-built property will effectively negate any benefits that the thermal mass may offer.

3.1 Temperature Profile

The modern common practice of intermittently heating the home works against realising the benefits of the thermal mass, as the heating system may not be used for long enough for the building fabric to warm up (i.e. to fill the thermal store of the fabric), despite the air temperature coming up to a desired temperature. Dwellings of low thermal mass (i.e. they warm up quickly when the heating is turned on) are more suited to use of intermittent heating. By contrast, the use of heating in stone-built dwellings in the past, where open fires were common, and which may have been kept burning continuously (if only in a dampened down state when the occupants were out or overnight to avoid the laborious task of having to re-light the fire from scratch) provided sufficient heat input to keep the fabric warm.

SAP and RdSAP are based on a model of intermittent use of heating in the home. This is shown in Figure TM1: the temperature trace shows the effect of heating coming on in the morning, the internal temperature rises; the heating then goes off, and the internal temperature drops through the day though benefiting from incidental solar gains; the heating comes on again in the evening, the internal temperatures rise again and are maintained through the evening until the heating goes off, and the temperature falls overnight. The whole process starts again the next day.

Unresponsive systems (e.g. electric storage heating or solid fuel systems) work better with dwellings with high thermal mass in SAP and RdSAP because they are assumed to provide a heat input into the dwelling outside of the defined heating period.

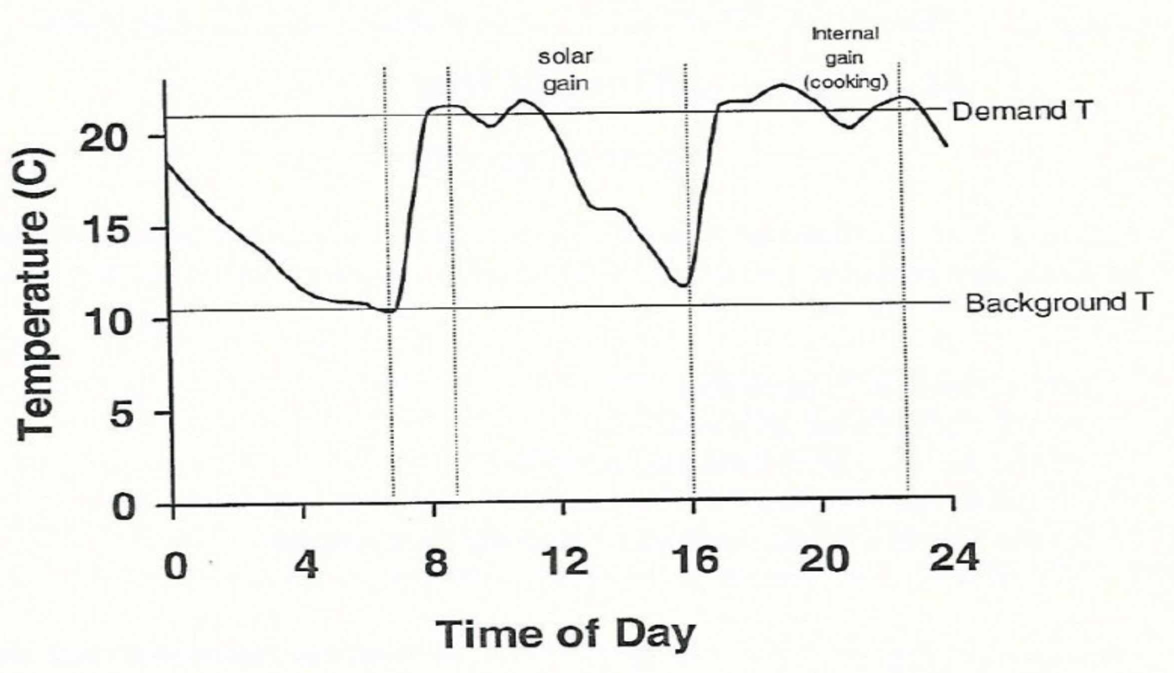

Figure TM1: Intermittent Heating Daily outside the formal heating period

3.2 Calculating the Thermal Mass Parameter

Within RdSAP, the heat loss calculation assumes a default Thermal Mass Parameter of 250 kJ/m^{2}K for all dwellings, that is, medium thermal mass. In the full SAP program, you can select high, medium, or low thermal mass, or choose to calculate the thermal mass parameter. The SAP 2012 manual provides the description and equations to carry out the calculation (see Figure TM2 and Figure TM3 below)

Table 1f: Thermal mass parameter

The κ values are used to calculate the TMP variable (Thermal Mass Parameter), worksheet (35), which is used to characterise the thermal mass of the building. It is:

$$TMP = \frac{\sum \kappa \times A}{TFA}$$

where the summation is over all walls, floors and roofs bounding the dwelling (including party walls and floors/ceilings) together with both sides of all internal walls and floors/ceilings.

Figure TM2: Calculating the Thermal mass parameter (source: SAP 2012)

Heat capacity per unit area, κ in kJ/m²K, for a construction element can be calculated from:[29]

$$\kappa = 10^{-6} \times \Sigma (d_j \rho_j c_j)$$

where:

the summation is over all layers in the element, starting at the inside surface and stopping at whichever of these conditions occurs first (which may mean part way through a layer):

- half way through the element;
- an insulation layer (thermal conductivity <= 0.08 W/m·K);
- total thickness of 100 mm.

d_j is the thickness of layer (mm)

ρ_j is density of layer (kg/m³)

c_j is specific heat capacity of layer (J/kg·K)

The elements to be included are walls, floors and roofs (windows and doors have negligible capacity), including all internal and party walls and floors. In the case of internal walls and floors, the capacity is needed for each side of the element.

Figure TM3: Calculating the Heat capacity per unit area (source SAP 2012)

In Figure TM3, the guidance sets out some quite explicit considerations when calculating the heat capacity per unit area of a material, for example, when the internal heat capacity of a stone wall was being calculated. Ending the calculation at 100mm of the wall is likely to occur before you were halfway through a common stone wall of 600mm thickness or more. If the stone wall had a lath and plaster internal finish, then very little of the actual stone would be taken into account as much of the 100mm in the calculation of the heat capacity per unit area of the wall would be taken up by the more lightweight lathe and plaster components of the wall construction.

Importantly, when it comes to calculating the thermal mass parameter for the whole dwelling, it is not just the external wall(s) that is/are taken into consideration, but also the internal partition walls within the dwelling, the party walls, the ground floor, any intermediate floors, and the roof. So even if stone walls were plastered on the hard with a dense plaster, the high thermal mass of this part of the fabric would be mitigated against by the suspended timber floor construction and the ceiling to the loft. It can be seen from Figure TM4 over the page, that it takes more than the external walls having a high thermal mass for a dwelling to be scored as high thermal mass overall.

Mass of construction elements

Ground floor	External Walls	Separating walls	Internal Partitions	Illustrative construction	Thermal Mass Category
light	light	Light	light	suspended timber floor, timber/steel frame walls, plasterboard on timber/steel stud internal partitions	Low
light	light	Light	medium	suspended timber floor, timber/steel frame walls, masonry internal partitions with plasterboard on dabs	Low
medium	light	light	light	solid floor, timber/steel frame walls, plasterboard on timber/steel stud internal partitions	Low
light	light	medium	light	suspended timber floor, timber/steel frame walls, masonry separating walls with plasterboard on dabs, plasterboard on timber/steel stud internal partitions	Low
light	medium	medium	light	suspended timber floor, masonry external and separating walls (cavity fill or external insulation on external walls) with plasterboard on dabs, plasterboard on timber/steel stud internal partitions	Medium-Low
medium	light	medium	light	solid floor, masonry external walls (internal insulation), masonry separating walls with plasterboard on dabs, plasterboard on timber/steel stud internal partitions	Medium-Low
medium	medium	medium	light	solid floor, masonry external walls (cavity fill or external insulation) with plasterboard on dabs, masonry separating walls with plasterboard on dabs, plasterboard on timber/steel stud internal partitions	Medium-Low
medium	medium	heavy	light	solid floor, masonry external walls (cavity fill or external insulation) with plasterboard on dabs, masonry separating walls dense plaster, plasterboard on timber/steel stud internal partitions	Medium
medium	heavy	medium	light	solid floor, masonry external walls (cavity fill or external insulation) with dense plaster, masonry separating walls with plasterboard on dabs, plasterboard on timber/steel stud internal partitions	Medium
medium	light	medium	medium	solid floor, masonry external walls (internal insulation), masonry separating walls with plasterboard on dabs, masonry internal partitions with plasterboard on dabs	Medium
medium	light	heavy	light	Solid floor, masonry external walls (internal insulation), masonry separating walls dense plaster, plasterboard on timber/steel stud internal partitions	Medium
medium	heavy	heavy	light	solid floor, masonry external walls (cavity fill or external insulation) with dense plaster, masonry separating walls with dense plaster, plasterboard on timber/steel stud internal partitions	Medium
light	heavy	heavy	light	Suspended timber floor, masonry external walls (cavity fill or external insulation) with dense plaster, masonry separating walls with dense plaster, plasterboard on timber/steel stud internal partitions	Medium
medium	medium	medium	medium	solid floor, masonry external walls (cavity fill or external insulation) with plasterboard on dabs, masonry separating walls plasterboard on dabs, masonry internal partitions with plasterboard on dabs	Medium
medium	medium	heavy	heavy	solid floor, masonry external walls (cavity fill or external insulation) with plasterboard on dabs, masonry separating walls dense plaster, masonry internal walls with dense plaster	Medium-High
light	heavy	heavy	heavy	Suspended timber floor, masonry external walls (cavity fill or external insulation) with dense plaster, masonry separating walls with dense plaster, masonry internal walls with dense plaster	Medium-high
medium	heavy	heavy	heavy	solid floor, masonry external walls (cavity fill or external insulation) with dense plaster, masonry separating walls with dense plaster, masonry internal walls with dense plaster	High

Figure TM4: Categorising a Dwelling's Overall Thermal Mass Source: DEAP 3.2.1 – Table S10[12]

[12] Sustainable Energy Agency of Ireland (2012) Dwelling Energy Assessment Procedure (DEAP) Version 3.2.1 available from http://www.seai.ie/resources/publications/DEAP_Manual.pdf

3.3 The Impact of Changing the Thermal Mass Parameter

Utilising one of the archetypes[13] from the REEPS analysis[14], the thermal mass parameter was assessed respectively as being high, medium, and low for two different heating scenarios – a gas boiler wet central heating system, and an electric storage heating system. The results are set out in Table TM1.

	Gas Condensing Combi Boiler			Electric Storage Heating		
	High TMF=450	**Medium TMF=250**	**Low TMF=100**	**High TMF=450**	**Medium TMF=250**	**Low TMF=100**
SAP	**48**	**51**	**55**	**24**	**26**	**27**
EI	**41**	**44**	**47**	**11**	**12**	**13**
Space Heating Consumption (kWh/year)	**26869**	**24649**	**22329**	**25823**	**25025**	**24430**
Space heating Fuel Costs (£/year)	**£935.05**	**£857.76**	**£777.03**	**£1799.50**	**£1743.87**	**£1702.38**

Table TMI: Summary of the impact of changing the thermal mass parameter on a property for two different types of heating

Changing from medium to low thermal capacitance increased the SAP and EI scores, and reduced the space heating fuel consumption and fuel costs for both heating scenarios. Switching from medium to high capacitance resulted in lower SAP and EI scores, and higher fuel consumption and fuel costs for both heating scenarios. The difference between the results for the two heating systems (i.e. the magnitude of the increases and decreases as thermal capacitance changed) was within a much narrower range with the electric storage heating than with the gas central heating: ±2 points on the SAP score compared to ±4 points for the gas system; ±1 point on the EI rating compared to ±3 points with the gas system; ±803 kWh on energy consumption compared to ±2320 kWh with the gas system; and ±£46 on the fuel bill compared to ±£80 with the gas system.

[13] archetype 1120110 – pre-1919,detached bungalow, 1.5 storeys, sandstone wall construction. The full specification of this archetype can be found at http://www.gov.scot/Topics/Statistics/SHCS/REEPSArchetypes

[14]Developing regulation of energy efficiency of private sector housing (REEPS): modelling improvements to the target stock, available at http://www.gov.scot/Publications/2015/11/4536/downloads

The thermal pass parameter was varied across the top 105 archetypes from the REEPS analysis (in terms of the number of dwellings of each archetype represented), which included all of the archetypes representing 1300 dwellings or more, and over 62% of the private sector dwelling stock scoring less than SAP Band D as derived from the SHCS surveys between 2010 and 2013. Only 2 of the 105 archetypes did not follow the pattern seen in Table TM1, that is, switching to low thermal mass improved the energy performance indicators, while switching to high thermal mass made them all poorer. Both of these properties were sandstone flats with electric heating. An overall summary of the impact of changing the thermal capacitance is set out in Table TM2.

	Range of impact	Mean impact
SAP medium TM to low	**-0.18 to +5.52**	**+2.828**
SAP medium TM to high	**-0.12 to -4.87**	**-2.619**
EI medium TM to low	**-0.19 to +4.39**	**+2.523**
EI medium TM to high	**-0.12 to -3.65**	**-2.272**
kg CO_2 medium TM to low	**-1560 to +21.6 kg CO_2**	**-555 kg CO_2/year**
Kg CO_2 medium TM to high	**-13.6 to +2103 Kg CO_2**	**+554 kg CO_2/year**
Total £ medium TM to low	**-£294.00 to +£2.89**	**-£93.15/year**
Total £ medium TM to high	**+£1.89 to +£351.00**	**+£89.88/year**
kWh medium TM to low	**-7765 to +127 kWh**	**-2684 kWh/year**
kWh medium TM to high	**-81 to +8126 kWh**	**+2643 kWh/year**

Table TM2: Summary of the Impact of switching the thermal mass parameter (n=105)

The heating systems in these archetypes was categorised by either being responsive (i.e. gas, LPG or oil central heating system with radiators) or unresponsive (i.e. electric storage heating, or solid fuel wet central heating or coal fires. As seen in the results for the single archetype in Table TM1, there is a much narrower range of change across all the indicators in the dwellings with the unresponsive heating systems (see Table TM2).

	Mean Impact Wet Central heating	Mean Impact Unresponsive Heating
SAP medium TM to low	**+3.61**	**+0.85**
SAP medium TM to high	**-3.29**	**-1.03**
EI medium TM to low	**+3.20**	**+0.75**
EI medium TM to high	**-2.86**	**-0.90**
kg CO_2 medium TM to low	**-735 kg CO_2/year**	**-171 kg CO_2/year**
Kg CO_2 medium TM to high	**+721 kg CO_2/year**	**+219 kg CO_2/year**
Total £ medium TM to low	**-£124.18/year**	**-£21.41/year**
Total £ medium TM to high	**+£118.63/year**	**+£26.92/year**
kWh medium TM to low	**-3495 kWh/year**	**-885 kWh/year**
kWh medium TM to high	**+3373 kWh/year**	**+1137 kWh/year**

Table TM3: Summary of Impact of switching thermal mass parameter (n=105): heating system type

Rather than adopt a single thermal mass parameter in the full SAP analysis of these archetypes, a variable thermal mass parameter was used. All stone dwellings (both sandstone and granite) were assumed to be of high thermal mass as were the two system-built dwellings; the solid and cavity brick dwellings were assumed to be medium thermal mass; and the timber frame dwellings were assumed to be low thermal mass. The effects of using a variable thermal mass parameter are compared against the results of the default medium thermal mass parameter (see Table TM4).

	Medium Thermal Mass mean	Variable Thermal Mass mean	Impact
SAP	**41.00**	**39.64**	**-1.35**
EI	**31.97**	**30.83**	**-1.14**
kg CO_2	**9154 kg CO_2/year**	**9467 Kg CO_2/year**	**+312.8 kg CO_2/year**
Total £	**£1558 /year**	**£1609/year**	**+£51.47/year**
kWh	**45648 kWh /year**	**47081 kWh/year**	**+1433 kWh/year**

Table TM4: Comparing results for Medium Thermal Mass Parameter against Variable Thermal Mass Parameter (n=105)

For the dwellings assessed, using a variable Thermal Mass Parameter would reduce the SAP score by 1.35 points, reduce the EI rating by 1.14 points, and increase the CO_2 emission figures, fuel costs and energy consumption figures. However, it must be noted that this sample of archetypes was heavily biased towards dwellings with stone constructions, and therefore with a heavy thermal mass (50 of the 100 archetypes were stone built). By contrast only 5 of the 100 were timber frame, and therefore considered to be of low thermal mass. In the Scottish dwelling stock there is a considerable larger share of timber frame dwellings than 5%.

Switching to a variable Thermal Mass parameter could be done in one of two ways:

- first, it could be built as a default into the RdSAP software. The identification of the wall construction in RdSAP includes all of the options here and a few more, that by selecting it, RdSAP would assign an appropriate Thermal Mass parameter automatically.

- alternatively, the assessors could identify the thermal mass from something like the Thermal Mass Category Table presented above in Figure TM4.

4. Rooms in Roof

Do assessors need to measure rooms in the roof in detail? It would appear that depends. The RdSAP guidance has become more confusing on these issues. Maybe the question should be rephrased and split into two: ‘what do you need to measure in rooms in the roof?’ and ‘when do you need to measure them?’.

4.1 What is a room in the roof?

Appendix S of the SAP 2012 methodology[15] sets out that attic rooms and roof rooms are to be included within an RdSAP assessment of a property when they are accessed via a permanent fixed staircase such that one is able to walk downwards facing forwards. They do not need necessarily to contain habitable rooms – which is defined in RdSAP as a room with a window. To assist with the identification of rooms in the roof space, Appendix S and the RdSAP conventions contain illustrations of typical rooms (see Figure RIR1).

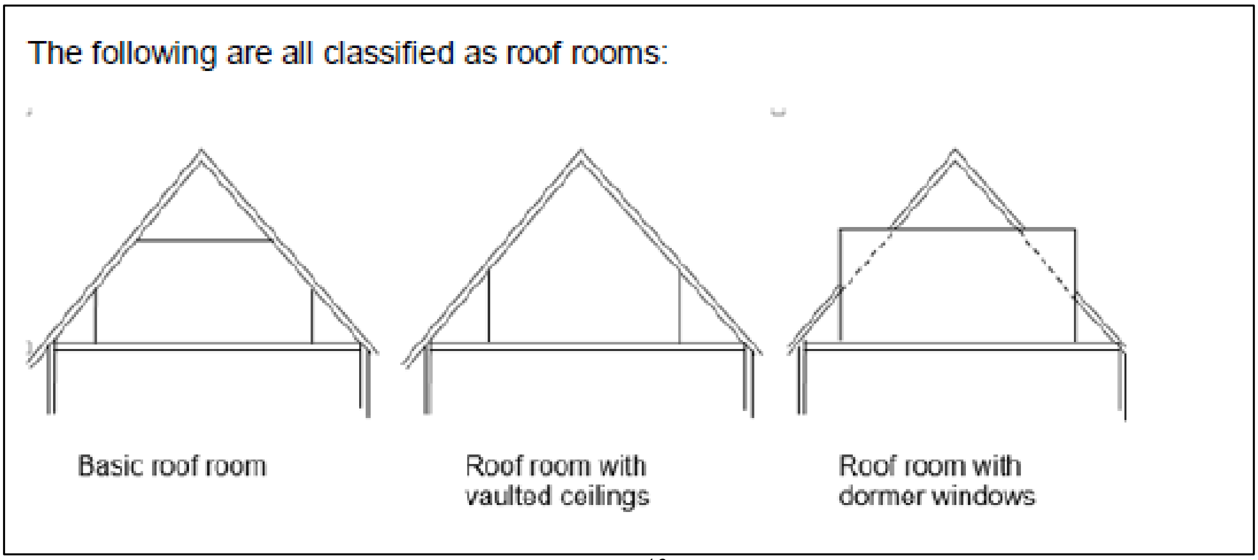

Figure RIR1: Illustrations of rooms in the roof[16]

RdSAP has been designed so that the areas of the room in the roof components may be calculated using one of two default formulae:

“Where the roof room is not connected to another part of the dwelling:

$$A_{rw} = 11\sqrt{(F_{rr}/1.5)}$$

where A_{rw} is the area of roof wall and F_{rr} the total floor area of the roof room

[15] RdSAP 2012 version 9.93 (19 November 2017) available at https://www.bre.co.uk/filelibrary/SAP/2012/RdSAP-9.93/RdSAP_2012_9.93.pdf
[16] Taken from “Conventions (v 10.0) for RdSAP 9.92 and RdSAP 9.93” available at https://www.bre.co.uk/filelibrary/SAP/2012/RdSAP-Conventions-10_0---from-31-December-2017.pdf

Where the roof room is connected to another part of the dwelling:

$$A_{rw} = 8.25 \sqrt{(F_{rr}/1.5)}$$

where A_{rw} is the area of roof wall and F_{rr} the total floor area of the roof room"

These formulae calculate the areas of the stud walls (i.e. verticals), the slopes and gable ends that make up the room in the roof (see Figure RIR2). The flat ceiling area of the room in the roof is taken to be the same as the room in the roof area in RdSAP[17] so in reality the room in the roof as calculated by RdSAP would look more like the one in Figure RIR3 rather than the example set out in Figure RIR2, and is in keeping with the right hand illustration in Figure RIR1 above.

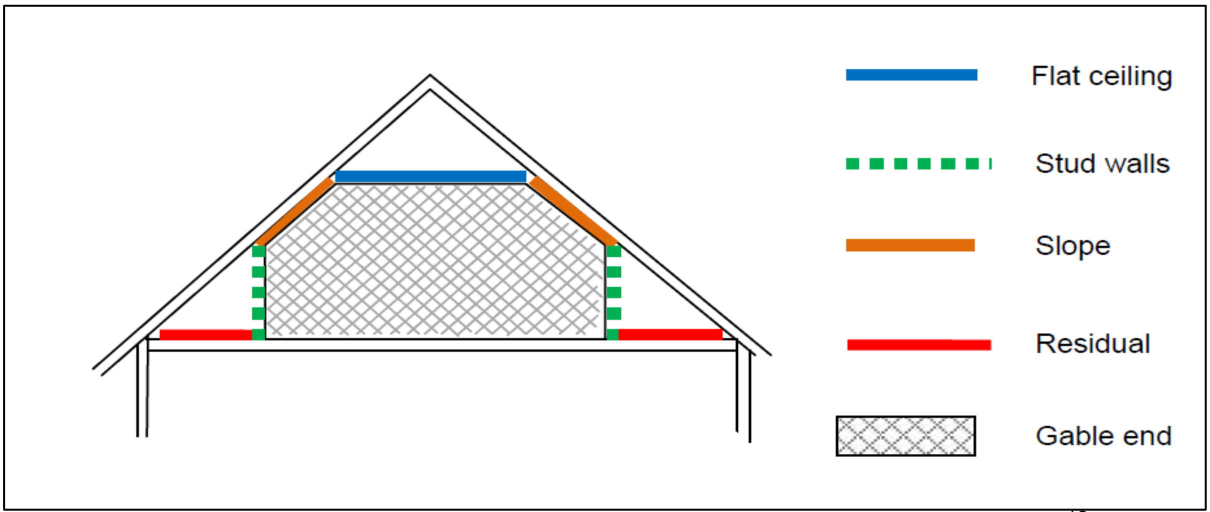

Figure RIR2: Illustration of the components that make up a room in the roof[18]

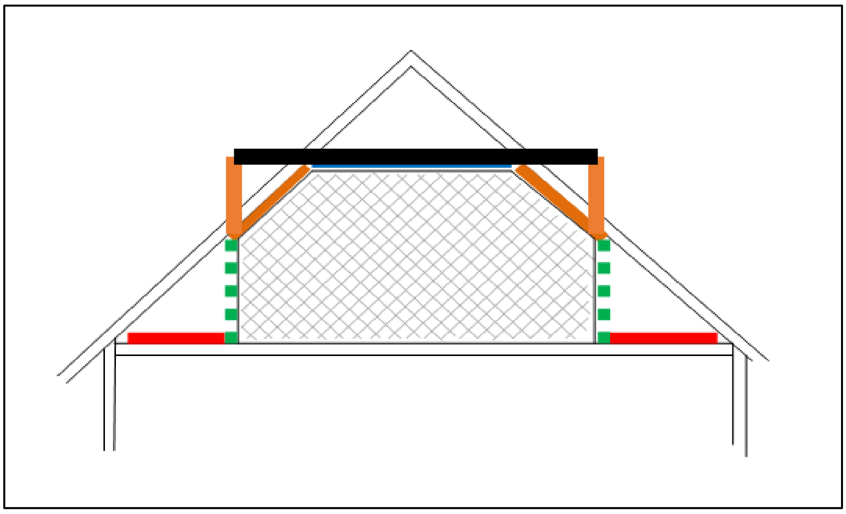

Figure RIR3: Re-marked illustration of the components that make up of the room as derived from Room in Roof algorithms

[17] See S3.9 on p12 of RdSAP 2012 version 9.93 (19 November 2017) available at https://www.bre.co.uk/filelibrary/SAP/2012/RdSAP-9.93/RdSAP_2012_9.93.pdf
[18] Taken from "RdSAP Conventions for RdSAP 9.92" available at https://www.bre.co.uk/filelibrary/SAP/2012/RdSAP-Conventions.pdf

Under the Convention 2.06 of the December 2017 RdSAP Conventions (i.e. Conventions v10),

"Detailed measurements of all elements are required only if evidence exists that the flat roof/slope/stud wall/gable wall have different levels of insulation or their U-values are known"[19].

A subtle change was made to this December 2017 statement compared to previous versions of the RdSAP conventions with the insertion of 'flat roof' into the list components where evidence of different levels of insulation triggers the need for detailed measurements. Convention 2.06 before December 2017 did not include 'flat roof' into the list:

"Detailed measurements are required only if evidence exists that the slope/stud wall/gable wall have differing levels of insulation or their U-values are known."

The revised December 2017 convention also inserted the words 'of all elements', so the convention reads to the effect that if any part of the roof room components has different levels of insulation then all elements now have to be measured, where previously, detailed measurements were not required if the flat ceiling had a different level of insulation from the other room in the roof components.

As many dwellings have had the area above the flat ceiling insulated as part of one of the many loft insulation programmes or grant schemes, this convention would appear to now require the need for all the components of the room in the roof to be measured. Was this the intended implication of this change in the wording – to increase the number of roof rooms where detailed measurements were required? If so, the unintended consequences may be negative if assessors stop evidencing any insulation in the flat ceiling area so they are not then held to account for not measuring all the components in the roof room which can be quite time consuming.

Another potential source of different levels of insulation, is where the gable ends of the roof room are the gables of the dwelling, and these gables have been cavity filled.

Further confusion about when to measure the components of the room in the roof is introduced by the wording of another part of RdSAP Convention 2.06:

"Where detailed measurements are made and the floor area of the parts of the dormer windows protruding beyond the roof-line is less than 20% of the floor area of the roof room, measure the elements of the roof room as if the dormers were not there. Otherwise total the vertical elements of all dormers in that building part and enter as stud wall and the flat ceiling elements as flat ceiling."[20]

[19] Op cit. 1, p4
[20] Op cit. 1, p4

So, if the floor area protruding beyond the roof-line is less than 20% of the total roof room floor area, you do not have to separately account for the dormer elements. If the floor area protruding beyond the roof-line is more 20% or more of the total roof room, does the assessor have to measure all the components of the roof room and account for the dormer? This is where the wording of this part of the convention is confusing, as it states, ‘where detailed measurements are made’, so if the assessor is not making detailed measurements or chooses not to make detailed measurements (because there are no different insulation levels within the roof room elements) then it would appear that the assessor would not have an account for the dormer. Nowhere in this convention statement does it state specifically or require that the assessor measure all the roof room components where the floor area protruding beyond the roof-line is 20% or more.

4.2 Half wall / 1.5 storey dwellings

So far, this note has confined the discussion to rooms built into the attic / loft space.

Within RdSAP, another type of roof room defined, and that is where the common wall of the dwelling extends upwards into an upper level of the dwelling but the height of this wall is less than 1.8m high where the plane of the roof meets the wall head for at least 50% of the common wall (excluding gable ends or party walls) (see Figure RIR4 below). This type of room in the roof construction was known as a ‘half wall’ room in the roof under the previous NHER methodology, but is referred to more colloquially in Scotland as a 1.5 storey cottage (or it would if the illustration included dormers).

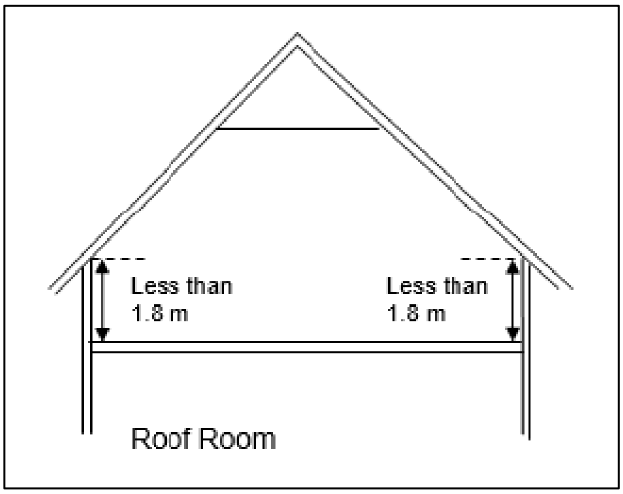

Figure RIR4: Illustration of Common Wall Room in the Roof

In RdSAP, once this structure is ‘defined’ as a roof room, the program will assume the common walls of the upper level are a timber stud wall construction and, without any other information, will assume the default U-values for a timber stud wall for the relevant age band, rather than assume the ‘stud’ wall is actually a continuation of the main wall construction of the dwelling with the same U-value. In a pre-1919, stone built 1.5 storey detached cottage with a 600mm sandstone wall with drylining and no other insulation, the default external wall U-value would be 1.38 W/m^{2}K in RdSAP; on the upper level, i.e. the roof room, RdSAP would assume this same wall has a U-value of 2.3 W/m^{2}K – a rather significant difference[21].

In such a dwelling, under RdSAP Convention 2.06, an assessor would be expected to measure all of the room in the roof components if the external wall had been insulated. As RdSAP does not take note of the fact that the roof room is a continuation of the half wall, it also does not automatically insulate the this upper level wall of the room in the roof (i.e. the continuation of the common wall) if the external walls of the property are insulated. Nor does it automatically insulate the gable wall of the room in the roof.

Would it not be better to separate out this type of a room in the roof construction into a separate category, or to allow for a half storey to be entered in the dimensional calculations? Assessors already measure the roof room total floor area so will have the basic dimensional data to calculate the perimeter. They may have measured the height of the common wall to demonstrate to their membership scheme that the common wall is less than 1.8m high. Why not use the perimeter length of the common wall, and the storey height of the common wall on the upper level, and overwrite the stud wall area calculated by the room in the roof algorithm, and use the U-value of the main external wall of the dwelling? If the main external wall was insulated, then so would be this vertical extension of the common wall.

It also seems such an easy question to ask if the gable walls of a room in the roof are of the same construction as the main external walls of the dwelling and if so, to use the external wall U-values instead of assuming the walls are timber stud walls with very different U-values.

Using the pre-1919, 1.5 storey detached sandstone cottage from above, adjusting the default RdSAP U-values of 2.3 W/m^{2}K for the stud and gable wall to match those for the external wall (i.e. 1.38 W/m^{2}K) improved the energy performance indicators across the board (see Table RIR1 below).

[21] As modelled in Elmhurst Energy RdSAP software v9.93

Roof room Dwelling	SAP score	EI score	CO_2 emissions (tonnes / year)	Space heating fuel costs (£/year)
1.5 storey pre-1919 detached cottage with RdSAP roof room default U-values of 2.3 W/m^{2}K for flat ceiling, stud walls, slopes, and gable walls	51	43	5.9	£1049
1.5 storey pre-1919 detached cottage with RdSAP roof room default U-values of 2.3 W/m^{2}K for flat ceiling and slopes. Overwritten U-values of 1.38 for stud walls and gable walls	54	46	5.6	£982

Table RIR1: RdSAP results for changing roof room default U-values to match external wall U-values

Without requiring that all the components of the roof rooms are measured for the purposes of RdSAP, there seems to be straightforward modelling solutions that could be adopted within the RdSAP software to improve the calculation of the energy performance of such room in the roof dwellings. It is not that 1.5 storey cottages are rare in Scotland

4.3 Roof Room with Large Dormer Windows (chalet style)

Up to and including RdSAP Convention v9, the three roof room illustrations set out in Figure RIR1 above included a fourth illustration – the Roof Room with Large Dormer Windows (chalet style) see Figure RIR5 below.

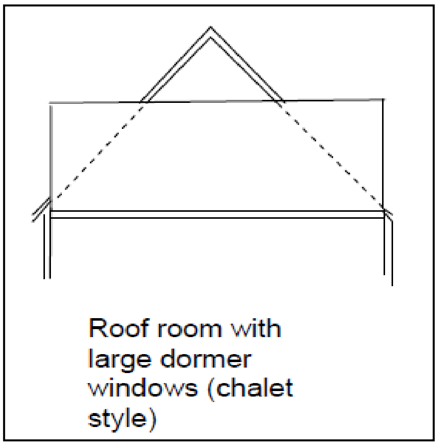

Figure RIR5: Roof Room with Large Dormer Windows (chalet style)

However, in RdSAP Convention V10, this diagram has been removed, with no explanatory text of why it is no longer included. Is this structure no longer deemed to be a room in the roof? Is this type of structure now to be treated as a vertical extension?

5. Community Heating

Community heating is defined in RdSAP under Convention 4.05:

"A system in which a heat generator provides heat and/or hot water to more than one premises."[22]

The convention then notes that "each dwelling to be assessed individually."

5.1 Community Heating in RdSAP

In RdSAP, community heating is entered into the program via four considerations:

- **the heat source**: boilers / CHP / heat pump
- **the system fuel**: mains gas / LPG / oil / mineral oil or biodiesel / biodiesel from any vegetable source / biodiesel from vegetable oil only / B30D / coal / biomass / electricity / waste combustion / biogas / waste heat / geothermal heat source
- **the main heating controls**: none / programmer only / room thermostat only / TRVs only / programmer and room thermostat / programmer and TRVs / two or more room thermostats
- **the method of charging for consumption**: whether flat rate charging or consumption-based charging

All other variables used in the RdSAP calculation are defaulted to in the program, for example, the system efficiency, the characteristics of the distribution network, and the price of the system fuel, regardless of the actual age of the system, the system's efficiency, its distribution system, or the actual fuel used. It also appears that RdSAP uses a single default value for most of these variables.

Table DH1 presents the results of an RdSAP assessment for a single, multi-storey flat heated by a community heating boiler system[23] where only the main fuel was changed in each iteration. What is evident from Table DH1 is that regardless of the main heating fuel selected, the results are identical for the SAP score and various calculated fuel costs. The Environmental Impact (EI) rating and the CO_2 emissions change depending on the fuel, but nothing else.

[22] Conventions (v 10.0) for RdSAP 9.92 and RdSAP 9.93, p17, available from https://www.bre.co.uk/filelibrary/SAP/2012/RdSAP-Conventions-10_0---from-31-December-2017.pdf

[23] note: results from assessing a community heating boiler with flat rate charging with programmer and TRVs assessed on same property. Hot water provided directly from system; no stored hot water in dwelling. Only change is the community heating boiler fuel. Results assessed using Elmhurst Energy's currently approved RdSAP v9.93 software.

	Community Heating Boiler Fuel			
	Mains gas	**LPG**	**Coal**	**Biomass**
SAP rating	**73**	**73**	**73**	**73**
EI rating	**62**	**58**	**37**	**98**
CO_2 tonnes/year	**6.3**	**7.1**	**11**	**0.6**
Lighting £/year	**£134**	**£134**	**£134**	**£134**
Space heating £/year	**£1190**	**£1190**	**£1190**	**£1190**
Water heating £/year	**£128**	**£128**	**£128**	**£128**

Table DH1: Results of an RdSAP Assessment of Flat heated by Community Heating

When the RdSAP assessment was repeated for the same multi-storey flat but assuming a combined heat and power (CHP) system[24] instead of community heating boiler system[25], and the changing of the main system fuel repeated, the SAP score improved, and the space and water heating fuel costs reduced, but they remained constant across all four system fuels. Again, the EI rating and the CO_2 emissions changed depending on the system fuel (see Table DH2).

	Combined Heat and Power System Fuel			
	Mains gas	**LPG**	**Coal**	**Biomass**
SAP rating	**76**	**76**	**76**	**76**
EI rating	**68**	**62**	**37**	**111**
CO_2 tonnes/year	**5.5**	**6.4**	**12.0**	**-1.6**
Lighting £/year	**£134**	**£134**	**£134**	**£134**
Space heating £/year	**£1074**	**£1074**	**£1074**	**£1074**
Water heating £/year	**£115**	**£115**	**£115**	**£115**

[24] note: results from assessing a combined heat and power system with flat rate charging with programmer and TRVs assessed on same property. Hot water provided directly from system; no stored hot water in dwelling. Only change is the CHP system fuel. Results assessed using Elmhurst Energy's currently approved RdSAP v9.93 software.
[25] That is, producing heat and electricity as opposed to just producing only heat and / or hot water.

Table DH2: Results of an RdSAP Assessment of Flat heated by Combined Heat and Power scheme

The problem here is that if you were to upgrade an existing community heating or CHP scheme with a newer more efficient boiler plant, or a better insulated distribution system, you would get exactly the same SAP and EI rating and CO_2 and fuel cost results as before, as long as the system fuel did not change. There would be no improvement in any of the energy performance indicators - not exactly an incentive for investing in a system upgrade. If you changed the system fuel (for example, switched from mains gas to biomass) then the rating and fuel costs would remain the same although the CO_2 emissions would change.

5.2 Community Heating in Full SAP

A full SAP assessment requires more information on a community heating / CHP system to complete an assessment on a dwelling:

- **the source of data**: SAP Table / manufacturer declared
- **the type of System**: CHP / boilers / heat pump / geothermal heat source / waste heat from power station
- **the system fuel**: mains gas / LPG / oil / mineral oil or biodiesel / biodiesel from any vegetable source / biodiesel from vegetable oil only / B30D / coal / biomass / waste combustion / biogas
- **the fraction of heat:** the fraction of dwelling heat coming from the community heating system
- **the efficiency of the system**: the efficiency of the community heating system (if from manufacturer declared or system records, it can be whatever values is declared; if from the SAP table: community heating and CHP are deemed to be 75% efficient, geothermal heat source and waste heat from power station are deemed to be 100% efficient, and a heat pump is deemed to be 300% efficient)
- **the Heat to Power ratio**: the efficiency of the thermal generation divided by the efficiency of the electricity generation
- **the Distribution Loss Factor**: the distribution Loss Factor can be calculated using equations in the SAP manual or selected in certain instances from Table 12c of the SAP 2012 manual – see over the page for both approaches taken from the SAP 2012 manual.
- **the main heating controls**: none / programmer only / room thermostat only / TRVs only / programmer and Room thermostat / programmer and TRVs / two or more room thermostats
- **the method of charging for consumption**: whether flat rate charging or consumption-based charging
- **the heat emitter in the dwelling**: radiators, underfloor (timber) / underfloor (concrete) / underfloor (timber) and radiators / underfloor (concrete) and radiators / underfloor (screed) / underfloor (screed) and radiators / warm air by fan coil

A full SAP assessment needs all of the data of RdSAP and much more, with consequential implications for the calculated SAP score and space and water heating costs. However, even within the SAP process, the system fuel does not affect the fuel cost calculations (see Table DH3), but does affect the EI rating and CO_2 emission results. If the efficiency of the boiler, the fraction of heat, the heat to power ratio, Distribution Loss Factor, and controls remain the same changing the system fuel will have no effect on the SAP-calculated rating. However, in a full SAP assessment the efficiency of the boiler plant and the heat to power ratio are unlikely to remain the same for different community heating or CHP schemes, so the actual results will vary in practice.

	Combined Heat and Power System Fuel			
	Mains gas	**LPG**	**Coal**	**Biomass**
SAP rating	**80**	**80**	**80**	**80**
EI rating	**89**	**85**	**63**	**98**
CO_2 tonnes/year	**0.709**	**0.978**	**2.475**	**0.134**
Lighting £/year	**£37**	**£37**	**£37**	**£37**
Space heating £/year	**£208**	**£208**	**£208**	**£208**
Water heating £/year	**£60**	**£60**	**£60**	**£60**

Table DH3: Results of a full SAP Assessment[26] of Flat heated by Combined Heat and Power scheme

[26] The various CHP system factors needed to complete the SAP calculation were obtained as part of an assessment for a specific project in carried out for by Alembic Research for Aberdeen City Council: “Full SAP Calculation for CHP in Aberdeen Multi-story Blocks: Final Report (revised March 2015)” – unpublished report.

In Table DH4, the difference between the full SAP and RdSAP results for the same multi-storey flat are compared directly. As can be seen, RdSAP results in a lower SAP score being calculated, a lower EI rating, higher CO_2 emissions, and higher space and water heating costs.

	Combined Heat and Power System Fuel				
	Mains gas	**LPG**	**Coal**	**Biomass**	**RdSAP[27]**
SAP rating	**80**	**80**	**80**	**80**	**76**
EI rating	**89**	**85**	**63**	**98**	**78**
CO_2 tonnes/year	**0.709**	**0.978**	**2.475**	**0.134**	**1.60**
Lighting £/year	**£37**	**£37**	**£37**	**£37**	**£48**
Space heating £/year	**£208**	**£208**	**£208**	**£208**	**£263**
Water heating £/year	**£60**	**£60**	**£60**	**£60**	**£92**

Table DH4: Comparative Results of a full SAP Assessment and RdSAP assessment of the of same multi-storey flat being heated with a Combined Heat and Power scheme

5.3 Distribution Loss Factor

A significant factor in determining the overall efficiency of a community heating / CHP system is the distribution loss factor, that is, how much heat is wasted in getting the heat from the boiler plant to the heat emitters. This is an area of the SAP methodology that appears to be well-outdated. The default distribution loss factors, as can be seen in Figure DH1, differentiate between systems installed either before or after 1991. Have there been no improvements in distribution systems in the almost 30 years since?

However, in RdSAP, as there is no allowance to select the Distribution Loss Factor for a community heating / CHP system, it is defaulted to the value for a pre-1990 pre-insulated system, that is, a factor of 1.10[28]

[27] Results from RdSAP assuming mains gas as the system fuel
[28] see SAP 2012: The Government's Standard Assessment Procedure for the Energy Rating of Dwellings https://www.bre.co.uk/filelibrary/SAP/2012/SAP-2012_9-92.pdf , p147

Table 12c: Distribution loss factor for group and community heating schemes

The following factors are used when one of the conditions stated in section C3.1 in Appendix C apply. Otherwise the factor is calculated as described in section C3.1.

Heat distribution system	Factor
Mains piping system installed in 1990 or earlier, not pre-insulated medium or high temperature distribution (120-140ºC), full flow system	1.20
Pre-insulated mains piping system installed in 1990 or earlier, low temperature distribution (100ºC or below), full flow system.	1.10
Modern higher temperature system (up to 120ºC), using pre-insulated mains installed in 1991 or later, variable flow system.	1.10
Modern pre-insulated piping system operating at 100ºC or below, full control system installed in 1991 or later, variable flow system	1.05

Figure DH1: Default Distribution loss factors – Table 12c, SAP 2012 methodology[29]

The use of these default values are specifically limited to situations where any of the following conditions are met:

1) The only dwellings connected to any part of the network are flats, or
2) The total trench length of the network is no longer than 100 metres, or
3) The linear heat density is not less than 2 MWh/year per metre of network[30].

Where these SAP Table 12c values cannot be used , the calculation of the Distribution Loss Factor is set out section C3.1 of the SAP methodology (see Figure DH2 below).

Where the linear heat density is less than 2 MWh/m/year or is unknown methods that may be employed by the scheme manager or designer to determine the distribution loss factor are:

(a) if the scheme has full heat metering at all connections to the distribution network, then the total heat supplied to the network from the energy centre(s) divided by the sum of the heat delivered from all the network connections (either to whole buildings or individual apartments), measured over a one year period (the same period for both), or

(b) by the formula

$$1 + \text{linear loss} \times \text{total length of pipework} \div (\text{total heat supplied} \times 114)$$

where:

'linear loss' is the average heat loss per metre run of pipework in W/m, calculated in accordance with ISO 12241:2008, equations (8) and (9);

'total length of pipework' is the length of the distribution system pipes for the whole scheme in metres;

'total heat supplied' is the heat supplied from the energy centre(s) to the distribution network over a whole year, in MWh/year;

114 converts MWh/year to W.

If the distribution loss factor cannot be calculated from scheme data a value of 1.5 should be used.

Figure DH2: Calculating the Distribution loss factor – Section C3.1, SAP 2012 methodology[31]

[29] SAP 2012: The Government's Standard Assessment Procedure for the Energy Rating of Dwellings https://www.bre.co.uk/filelibrary/SAP/2012/SAP-2012_9-92.pdf
[30] ibid, p49

Regardless of how the Distribution Loss Factor is derived in a full SAP assessment, there is no opportunity to change it all in RdSAP.

5.4 An Aberdeen Case Study

Differences in the results calculated by full SAP and RdSAP can be magnified because community heating and CHP systems usually impact on significantly more than 2 dwellings.

For a specific 55-flat, multi-storey dwelling block in Aberdeen being considered at the time of these assessments for connection to a CHP system, all of the different flat types were surveyed, and full SAP assessments completed to assess the potential CO_2 emissions associated with switching from electric storage heating to CHP. These assessments have been reworked in a current full SAP program[32] and the sample results set out in Table DH5.

		CHP - full SAP analysis – pre-install EPC data				
Flat	position	Full SAP SAP score	Full SAP Space heating _hot water + lighting costs (£/year)	Full SAP CO_2 tonnes / year	Full SAP EI score	Full SAP Space Heating demand kWh/year
1 meadow	GF	75	563	1.58	83	8749
5 meadow	FF	79	350	0.868	88	3928
6 meadow	FF	79	348	0.86	88	3862
7 meadow	FF	76	402	1.059	85	5411
8 meadow	FF	76	401	1.042	86	5287
9 meadow	FF	76	394	1.017	86	5096
10 meadow	FF	76	402	1.059	85	5411
11 meadow	MF	80	324	0.779	89	3227
42 meadow	MF	82	276	0.619	91	1968
28 meadow	MF	80	328	0.793	89	3356
56 meadow	TF	77	384	0.985	87	4809
57 meadow	TF	79	339	0.83	89	3629
55 meadow	TF	77	385	1.001	86	4954

Table DH5 – Sample audits for multi-story block in Aberdeen: Full SAP analysis

The same dwellings were also assessed using an approved RdSAP v9.93[33]. These results are set in Table DH6.

[31] ibid.
[32] Plan Assessor 6.4.3
[33] Elmhurst Energy's RdSAP v9.93 program

Flat	position	CHP RdSAP analysis – pre-install EPC data				
		RdSAP SAP score	RdSAP Space heating _hot water + lighting costs (£/year)	RdSAP CO_2 tonnes / year	RdSAP EI score	RdSAP Space Heating demand kWh/year
1 meadow	GF	70	682	3.1	67	8336
5 meadow	FF	75	411	1.7	77	3656
6 meadow	FF	78	364	1.4	81	2712
7 meadow	FF	71	493	2.1	71	5363
8 meadow	FF	72	482	2.1	72	5072
9 meadow	FF	74	438	1.8	75	4171
10 meadow	FF	71	493	2.1	71	5363
11 meadow	MF	77	375	1.5	80	2954
42 meadow	MF	80	328	1.2	84	1990
28 meadow	MF	76	393	1.6	79	3278
56 meadow	TF	73	461	1.9	73	4650
57 meadow	TF	75	416	1.7	77	3736
55 meadow	TF	72	472	2	72	4949

Table DH6 – Sample audits for multi-story block in Aberdeen: RdSAP analysis

The differences between the full SAP and RdSAP assessment for these same flats are set out in Table DH7. The SAP scores vary between 1 SAP and 5 SAP points less in the RDSAP assessment than in full SAP assessment; the EI scores vary by between 7 and 16 rating points less in the RdSAP assessment; the CO_2 emissions vary by between 0.54 and 1.52 tonnes more per year in the RdSAP analysis; and the fuel costs vary by between £16 and £119 more per year in the RdSAP analysis.

Flat	position	SAP score difference	Fuel Cost difference (£/year)	CO_2 emissions difference (tonnes of CO_2/year)	EI difference	Space heating demand difference (kWh/year)
1 meadow	GF	-5	119	1.52	-16	-413
5 meadow	FF	-4	61	0.832	-11	-272
6 meadow	FF	-1	16	0.54	-7	-1150
7 meadow	FF	-5	91	1.041	-14	-48
8 meadow	FF	-4	81	1.058	-14	-215
9 meadow	FF	-2	44	0.783	-11	-925
10 meadow	FF	-5	91	1.041	-14	-48
11 meadow	MF	-3	51	0.721	-9	-273
42 meadow	MF	-2	52	0.581	-7	22
28 meadow	MF	-4	65	0.807	-10	-78
56 meadow	TF	-4	77	0.915	-14	-159
57 meadow	TF	-4	77	0.87	-12	107
55 meadow	TF	-5	87	0.999	-14	-5

Table DH7: Summary of differences between full SAP assessment in Table DH5 and RdSAP assessment in Table DH6

Some of these individual assessments were representative of other dwellings within the same block. The multipliers are provided in Table DH 8, along with the aggregated total differences in CO_2 emissions, space heating consumption, and fuel costs for the different flat types respectively.

Flat	position	Multiplier	Total CO_2 emissions difference (tonnes of CO_2/year)	Total Fuel Cost difference (£/year)	Total Space heating demand difference (kWh/year)
1 meadow	GF	1	1.52	119	-413
5 meadow	FF	1	0.832	61	-272
6 meadow	FF	1	0.54	16	-1150
7 meadow	FF	1	1.041	91	-48
8 meadow	FF	1	1.058	81	-215
9 meadow	FF	1	0.783	44	-925
10 meadow	FF	1	1.041	91	-48
11 meadow	MF	14	10.094	714	-3822
42 meadow	MF	14	8.134	728	308
28 meadow	MF	14	11.298	910	-1092
56 meadow	TF	2	1.83	154	-318
57 meadow	TF	2	1.74	154	214
55 meadow	TF	2	1.998	174	-10
Total			41.909	£3337	-7791

Table DH8: Aggregated differences between full SAP assessment in Table DH5 and RdSAP assessment in Table DH6 for CO_2 emissions, fuel costs and space heating energy consumption

When aggregated across the whole of the 55 flats within this multi-storey block, when compared to the full SAP assessment, RdSAP over-estimates the CO_2 emissions by 41.909 tonnes per year; it over estimates the fuel bill by £3,337 per year; and it over estimates space heating consumption by 7791 kWh per year.

5.5 Community Heating and CHP Data Availability

The differences between the results in a full SAP and an RdSAP assessment for community heating and CHP have important implications in the assessing of local heat networks. Would it be possible to complete a full SAP analysis on each dwelling connected to a community heating or CHP scheme? The likelihood is not, as the detailed information required on the operational parameters of the community heating or CHP scheme are not necessarily readily available. Further you would currently need to use a full SAP program to complete the assessment. Under current arrangements of lodging EPCs, it is possible for a full SAP assessment to be lodged in the Scottish Register for an existing dwelling. However, to do so you may need to be both a qualified RdSAP assessor and a qualified assessor for new build (what is called an on-construction dwelling energy assessor).

A way around the need to use a full SAP program would be to allow extended data entry for community heating and CHP schemes within RdSAP. The precedent exists in that there are several areas where an assessor can ‘turn on’ extended data entry with RdSAP (for example, with rooms in the roof and windows). However, allowing extended data entry does not provide all of the necessary data to complete the SAP assessment.

The PCDF has introduced extended data into the information that assessors can select from the PCDF in a full SAP and RdSAP assessments. The extended boiler database is a good example of this and very useful. A recent development was to include information on community heating schemes. To date, however, there is only one such scheme in the PCDF that may be selected – the Lerwick community heating scheme (see Figure DH3 below). More community and CHP schemes need to be encouraged to supply their data to the PCDF.

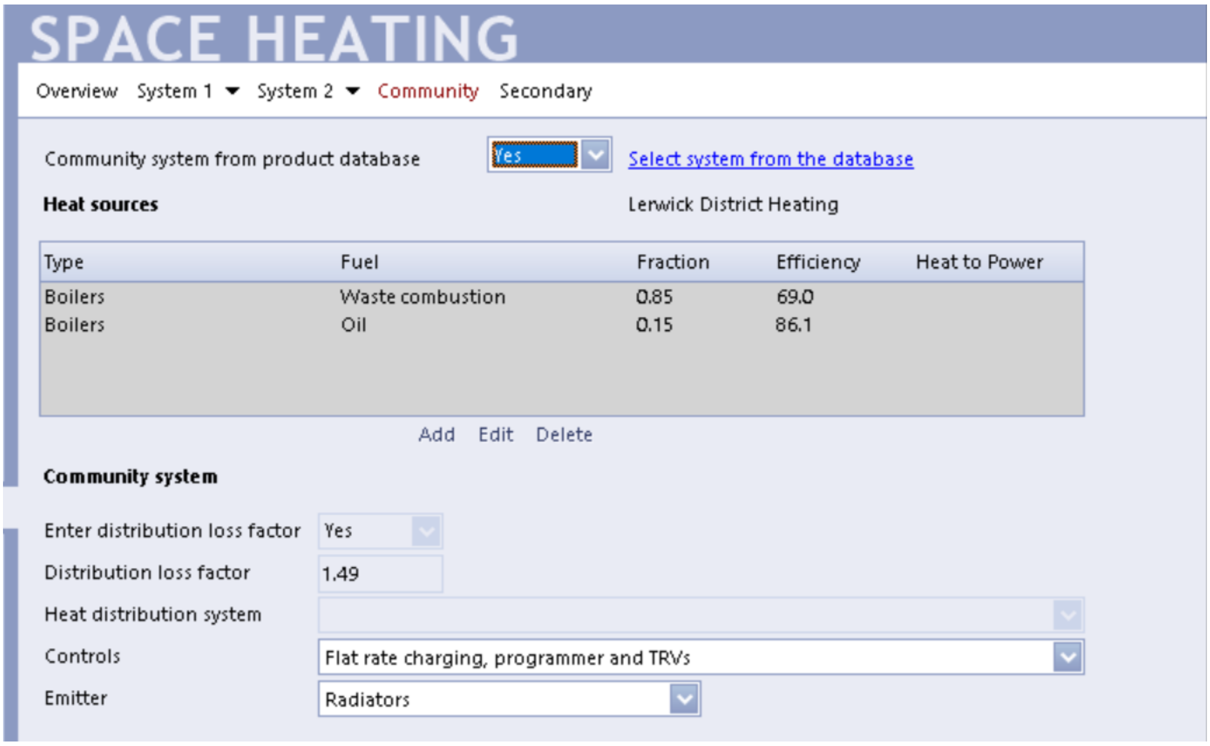

Figure DH3: PCDF data for Lerwick District Heating scheme

The Lerwick scheme appears to be available in RdSAP – it can certainly be selected, but when selected, the RdSAP software tested stated[34] it did not recognise this data in the context of an RdSAP assessment. This may be a software bug, or it may reflect that the necessary data items are not fully implemented within the RdSAP software yet.

The type of data needed within a full SAP type assessment could use the approach of Display Energy Certificates, whereby the necessary data was collated and put on display outside the boiler house.

[34] assessed using Elmhurst Energy RdSAP software v9.93 as of March 2018

6. Ventilation Sensitivity: Draught lobbies, Flues, and Extract Fans

The calculation of the air infiltration rate in a full SAP assessment is a function of many individual building. construction, location and climatic variables:

- number of storeys
- floor construction
- wall construction
- draughtproofing of the doors and windows
- the presence of a draught lobby
- number of open fireplaces
- number of flues
- number of extract fans
- number of passive vents (e.g. air bricks)
- presence and type of mechanical ventilation system
- number of sides sheltered
- wind speed region

Some of these items are inferred from other data entry items in the full SAP assessment, for example, the description of the wall construction and the floor construction is used to assign the appropriate ventilation factor for different wall types and floor types respectively. Other ventilation factors are direct inputs, for example, the number of open fireplaces, extract fans, and sides of the dwelling sheltered. The wind speed region is derived from the post code of the property. Mechanical ventilation systems, if present, are split into 6 different system types (currently), and once the type of system is selected, there are subsequent details to be provided.

Alternatively, rather than deriving the air infiltration rate from all of these variables, the ventilation rate may be measured on-site, and the results of an Air Permeability Test may be entered directly into the full SAP program.

By way of contrast, in RdSAP, only three ventilation variables are entered directly into the program:

- the percentage of draughtproofing of the doors and windows
- number of open fireplaces
- presence and type of mechanical ventilation system

Mechanical ventilations systems are reduced from 6 different system types in full SAP down to one of 2 types in RdSAP, with no additional system descriptors needed.

It is not that RdSAP ignores all the other ventilation factors included within the full SAP calculation; rather, the values are either inferred from other data entry items such as the wall and floor construction description selected (as occurs in full SAP) or use default values as set out in Table S5 of Appendix S of the SAP 2012 methodology (see Figure V1 over the page). It can be seen from this table that RdSAP:

- defaults to no draught lobby for houses and bungalows;
- assumes no extract fans for any dwelling built before 1975 in Scotland;
- makes no allowance for flues for any dwelling; and,
- includes no allowance for air bricks.

A sensitivity analysis was carried using an approved full SAP 2012 program[35] to assess the impact of these defaults on the SAP and Environmental Impact scores, as well as the SAP-calculated CO_2 emissions, primary energy and fuel costs.

Table S5 : Ventilation parameters

Parameter	Value
Chimneys	Number of open fireplaces
Flues	Number of open flues (main and secondary heating systems). Flue for solid fuel boiler in unheated space is not counted.
Ventilation system	Natural with intermittent extract fans, unless mechanical system clearly identified
Extract fans	Not park home: Age bands A to E — all cases — 0 Age bands F to G — all cases — 1 Age bands H to L — up to 2 habitable rooms — 1 " — 3 to 5 habitable rooms — 2 " — 6 to 8 habitable rooms — 3 " — more than 8 habitable rooms — 4 Park home: Age band F — all cases — 0 Age bands G, I, K — all cases — 2
Wall infiltration	According to the largest area of wall, system build treated as masonry, and infiltration according to masonry if equal. Net wall area after deduction of openings is used for this purpose, walls of roof rooms are not included. Park home: timber frame.
Floor infiltration (suspended timber ground floor only)	- Age band of main dwelling A to E: if floor U-value entered by assessor is < 0.5, sealed; if floor insulation is 'retro-fitted' and no U-value is supplied, sealed; otherwise unsealed - Age band of main dwelling F to L: sealed (the floor infiltration for the whole dwelling is determined by the floor type of the main dwelling) - Park home: unsealed suspended timber
Draught lobby	House, bungalow or park home: no Flat or maisonette: yes if heated or unheated corridor, otherwise no
Number of storeys	Greater of the number of storeys in the main part of the dwelling and in any extension. If an extension is above another part, no account of this is taken in calculating the storey count.
Sheltered sides	4 for flat/maisonette up to third storey above ground level 2 in other cases
Number of wet rooms (required for an exhaust air heat pump)	1 to 2 habitable rooms: Kitchen + 1 3 to 4 habitable rooms: Kitchen + 2 5 to 6 habitable rooms: Kitchen + 3 7 to 8 habitable rooms: Kitchen + 4 9 to 10 habitable rooms: Kitchen + 5 11 or more habitable rooms: Kitchen + 6

Figure V1: RdSAP Ventilation Defaults (source Table S5 from Appendix S of the SAP 2012 methodology[36])

[35] Plan Assessor v6.3.4
[36] op cit. 29

This sensitivity analysis used 183 of the 355 archetypes that were produced for the research that underpinned the report for the Scottish Government on “Developing regulation of energy efficiency of private sector housing: modelling improvements to the target stock” that was published in November 2015[37]. These archetypes were produced using the data collected on each dwelling by the Scottish House Condition Survey (SHCS), as a representative sample of the 400,000 private sector properties within the Scottish dwelling stock scoring below SAP Band D (that is, achieving a SAP score of less than 55) as surveyed by the SHCS between 2010 and 2013. The 183 archetypes used here represented over 50% of all of the archetypes, included all the archetypes that represented more than 1300 properties each, and in total represented over 75% of the 400,000 properties scoring below SAP Band D.

A full SAP2012 analysis was undertaken originally on each of the archetypes, and included within the energy performance assessment, the presence or not of a draught lobby, the count of the number of flues in the dwelling, and a count of the number of extract fans – as these are data items collected by the SHCS.
The analysis of these 183 archetypes was rerun to update the results for each archetype to current version of the SAP 2012 software, and the SAP and Environmental Impact scores, as well as the SAP-calculated CO_2 emissions, primary energy and fuel costs were recorded. The SAP analysis was then rerun for each of the 183 archetypes with the actual draught lobby, extract fans and flue variables being replaced with the RdSAP defaults as set out in Table S5 from the SAP methodology (see Figure V1 above).

Of the 183 archetypes assessed, change from the actual variables in the full SAP assessment to the RdSAP defaults, found that

- 35 of the 183 archetypes (i.e. 19.1%) resulted in no change as the actual variables used in the full SAP analysis were the same as the defaults used in the RdSAP analysis;
- 5 of the 183 archetypes (i.e. 2.7%) resulted in a negative impact; that is, they have a draught lobby that would be ignored in RdSAP, and as a result the air infiltration rate increased, along with the SAP-calculated primary energy consumption, CO_2 emissions, and fuel costs. The SAP and Environmental Impact scores both decreased;
- 114 of the 183 archetypes (i.e. 62.3%) resulted in a positive impact. These archetypes have either flues or extract fans or both, but no draught lobby, that would be ignored in RdSAP. As a result, the air infiltration rate decreased, along with the SAP-calculated primary energy consumption, CO_2 emissions, and fuel costs. The SAP and Environmental Impact scores increased.
- 29 of the 183 archetypes (15.8%) showed a mixed response. These archetypes have a draught lobby and either flues or extract fans or both. The

[37] see http://www.gov.scot/Topics/Statistics/SHCS/REEPSArchetypes and Developing regulation of energy efficiency of private sector housing (REEPS): modelling improvements to the target stock, available at http://www.gov.scot/Publications/2015/11/4536/downloads

RdSAP result could be either positive or negative compared to the full SAP analysis depending on the actual counts of the flues and / or extract fans.

Overall, switching from the actual ventilation variables in the full SAP assessment to the RdSAP defaults, results in a reduction in the mean air infiltration rate of 0.08 air changes per hour (that is, a lower ventilation loss) with a consequent improvement in the SAP score of 0.62 points and the Environmental Impact score of 0.55 points. Fuel costs, CO_2 emissions and energy consumption are all reduced respectively by £17.81 per year, 107 kg of CO_2 per year, and 535 kWh per year (see Table V1 below). Within this sample of dwellings, RdSAP underestimates the ventilation losses overall because it defaults on the draught lobby, flues and extract fans, and therefore overestimates the SAP and Environmental Impact score, and underestimates the SAP calculated fuel bill, CO_2 emissions and energy consumption.

	Change in Air Infiltration Rate (ach)	Change in SAP score	Change in Environmental Impact score	Change in SAP fuel costs (£/year)	Change in CO_2 emissions (kg of CO_2 /year)	Change in Primary Energy (kWh/year)
All 183 ATs	-0.08	0.62	0.55	-17.81	-106.58	-535.03
Draught lobby only (n=5 ATs)	0.042	-0.342	-0.3	13.716	90.586	411.25
Flues and/or extract fans - no draught lobbies (n=114 ATs)	-0.12	0.90	0.79	-25.29	-155.17	-764.47
Mixed (draught lobby and flues and or extract fans) (n=29 ATs)	-0.05	0.45	0.38	-15.35	-78.20	-441.97

Table V1: Impact on energy performance indicators by change from actual ventilation factors to RdSAP defaults

This sample of 183 archetypes is not a representative sample of the total Scottish dwelling stock as it was only drawn from a sample of those dwellings surveyed by the SHCS scoring below SAP Band D. It was not representative of all dwellings scoring below SAP Band D as it was only concerned with the private sector (both owner occupier and private rented). The 183 archetypes were also heavily biased towards older properties, with 133 of the 183 falling into the pre-1919 age category. That said, these dwellings should feature in future programmes to improve the worst performing dwellings in the country.

No single ventilation factor on its own is going to make a significant impact on the ventilation rate because of the many variables that contribute to the derivation on the air infiltration rate.

However, it can be seen in Table V2 and Table V3 that the number of flues and extract fans can add up. There were 2 properties with 5 flues recorded and 1 property with 5 extract fans. As the number of flues and fans in a property increase the change in the air infiltration rate becomes more significant, with a consequential impact on all of the energy performance indicators assessed here. With 4 or 5 flues, present RdSAP is underestimating the SAP score by more than 2.5 points, and with 2 and 3 flues, the underestimate is between 1 and 2 points.

	Change in Air Infiltration Rate (ach)	Change in SAP score	Change in Environmental Impact score	Change in SAP fuel costs (£/year)	Change in CO_2 emissions (kg of CO_2 /year)	Change in Primary Energy (kWh/year)
5 flues (n=2)	-0.38	2.63	2.41	-68.52	-425.27	-2401.99
4 flues (n=4)	-0.30	2.55	2.20	-76.68	-351.70	-1856.48
3 flues (n=10)	-0.24	1.75	1.58	-51.17	-275.89	-1505.63
2 flues (n=15)	-0.17	1.49	1.33	-48.59	-331.01	-1479.65
1 flue (n=53)	-0.10	0.72	0.59	-19.84	-117.15	-603.89
all flues (n=84)	-0.14	1.11	0.96	-32.56	-192.74	-970.08

Table V2: Change from actual full SAP ventilation factors to RdSAP defaults on number of flues

Flues have a bigger impact than extract fans. In SAP ventilation rates, 1 flue is the equivalent of 2 extract fans.

As both extract fans and flues are a straight count within full SAP, RdSAP could be revised to allow the count of fans and flues to be included rather than use defaults than may underestimate considerably the number of fans and flues present in a dwelling. It would add a minimal amount of time to the survey.

	Change in Air Infiltration Rate (ach)	Change in SAP score	Change in Environmental Impact score	Change in SAP fuel costs (£/year)	Change in CO_2 emissions (kg of CO_2 /year)	Change in Primary Energy (kWh/year)
5 extract fans (n=1)	-0.12	1.17	0.94	-48.36	-301.24	-1026.44
3 extract fans (n=15)	-0.16	1.42	1.27	-48.46	-230.22	-1282.96
2 extract fans (n=34)	-0.10	0.76	0.69	-23.34	-135.46	-722.59
1 extract fans (n=57)	-0.08	0.61	0.51	-14.72	-99.32	-458.73
all extract fans (n=107)	-0.10	0.78	0.68	-22.50	-131.04	-663.43

Table V3: Change from actual full SAP ventilation factors to RdSAP defaults on number of extract fans

7. Measuring Windows in RdSAP

For most dwellings, there is no requirement under the RdSAP conventions to measure windows sizes when completing a survey, but should there be?

7.1 Default Algorithms

In RdSAP, "window areas are obtained by application of the appropriate equation from Table S4"[38] of the SAP methodology)see Figure W1 below). These algorithms use three factors to calculate the respective window areas of a property:

- the dwelling type (that is, a flat / maisonette or a house / bungalow),
- the age band of the dwelling,
- and the total floor area of the dwelling.

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, L	WA = 0.1435 TFA – 0.403	WA = 0.1148 TFA + 0.392
WA = window area TFA = total floor area of main part plus any extension		

Figure W1: RdSAP window algorithms (Table S4 from RdSAP 2012 version 9.93 (19 November 2017))[39]

Within the RdSAP methodology, window areas are deemed to fall into one of five categories:

- typical
- more than typical
- less than typical
- much more than typical
- much less than typical

[38] RdSAP 2012 version 9.93 (19 November 2017) available from https://www.bre.co.uk/filelibrary/SAP/2012/RdSAP-9.93/RdSAP_2012_9.93.pdf
[39] Op cit. 1, p11

While these algorithms calculate the typical window area for the dwelling, Appendix S states:

"The window areas calculated using Table S4 are to be reduced by 25% if it is assessed as being less than typical for the age and type of property, and increased by 25% if assessed as being more than typical for the age and type of property."[40]

Additional guidance on window area calculations in Appendix S notes:

***"Typical** applies if the surface area of the glazing in the dwelling is essentially as would be expected of a typical property of that age, type, size and character. Even if there is slightly more or less glazing than would be expected, up to 10% more or less.*

***More than typical** applies if there is significantly more surface area of glazing than would be expected (15%-30% more), perhaps because there is a large sun room or numerous patio doors have been added.*

***Less than typical** applies if there is significantly less glazing than would be expected. This is rare as homeowners tend not to take out windows, but a property may have an unusual design with few windows."*[41]

If the window area in the dwelling is assessed as being '**much more** than typical' or as '**much less** than typical' (emboldment added), "the total window area should be obtained from measurements of each individual window"[42] … along with:

- the glazing type (i.e., whether single, unknown age, double glazed pre-2003, double glazed 2003 onwards, triple glazed, or secondary glazed)
- the frame type and glazing gap in pre-2003 or of unknown age uPVC double glazed windows
- the U-value, if known
- a note of whether it is a window or roof light;
- a note of whether it is located in the main dwelling or an extension,
- its orientation

Where window areas are measured and entered into RdSAP, the results from the default algorithms are overwritten by the actual measurements.

So, within RdSAP, window areas in a dwelling do not have to be measured if they are assessed as typical, more than typical or less than typical. Except that nowhere in the RdSAP methodology, does it set out what is 'typical'. Effectively, the only way for an assessor to confirm whether a window area is typical, more than typical or less than typical, or not, is to measure all the window areas, aggregate the results, calculate the typical window area from the appropriate Table S4 algorithm, and compare the two. In other words, the assessor needs to measure the windows to confirm that the assessor does not need to measure them – Catch 22! The assessor is not helped in this process by the software, as the authors of this report are not

[40] ibid
[41] ibid
[42] Op cit. 1, p12

aware of any currently available approved RdSAP software program that assists the assessor in this process by displaying what the typical window area would be for a given dwelling type, age and total floor area.

The question then is, how appropriate / accurate are the RdSAP window area algorithms Scotland? It would appear, not very accurate.

7.2 Comparative study of RdSAP Default Measured Window Areas

In 2009, Alembic Research was commissioned by the Scottish House Condition Survey team of the Scottish Government to prepare a background paper on the appropriateness of the RdSAP window area algorithms for Scotland[43]. Alembic Research had previously completed full energy audits of 1398 properties across Scotland as part of the research into assessing the impact of the first three years of the Scottish Government's Central Heating Programme on reducing fuel poverty. These energy audits included identifying the property type, measuring the total floor area in each property, and identifying the age of each property – that is, collecting the three data items used by the RdSAP window algorithms to calculate the typical window area of a dwelling. These energy audit surveys also measured all of the individual window areas in each property (as that was required by the then-NHER software being used in the assessments), so provided the data to allow the areas calculated by the RdSAP Table S4 algorithms to be compared with the actual measured areas for the dwellings. The overall results from this comparison are set out in Table W1 over the page.

What emerged from the overall assessment, and from breaking the data down by the RdSAP age bands, was the consistent over-estimation of window area across all Scottish age bands by the RdSAP algorithms. Overall, more than 62% of all the dwellings compared, were found to have their window area over-estimated by more than 25%. On average RdSAP was found to over-estimate the window areas by 44.9%.

The greatest variation occurred within the pre-1919 dwelling age band, both in terms of the extreme variation in the accuracy of the predicted area, as well as in the overall over-estimation of the predicted window areas. RdSAP predicted 59% more window area per dwelling than measured on site on average. There was also a variability by a factor of 10 between the two extremes of over and under-estimated window area,

[43] Sheldrick, B and Hepburn, D (2009) *Assessing the Appropriateness of the RdSAP Window Area Algorithms for Scotland*, prepared for the Scottish House Condition Survey Team, unpublished report.

RdSAP Age band	% RdSAP under-estimated by >25% of actual m^2	% RdSAP estimated within ±25% of actual m^2	% RdSAP over-estimated by >25% of actual m^2	% Range of RdSAP predicted m^2 vs actual window area	Average % difference per dwelling
Pre-1919 (n=358)	4.5	33.8	61.7	43.8 - 496.2%	59.0
1919-29 (n=104)	1.0	40.4	58.6	56.6 – 286.5%	45.4
1930-49 (n=180)	1.7	48.3	50.0	57.5 – 259.4%	30.3
1950-64 (n=430)	0.9	34.3	64.7	64.7 – 311.2%	40.4
1965-75 (n=242)	1.6	31.0	67.4	61.8 – 382.1%	41.1
1976-83 (n=40)	2.5	27.5	70.0	58.0 – 240.2%	50.5
1984-91 (n=41)	0	29.3	70.7	81.7 – 252.7%	50.2
Overall dataset (n=1398)	2.1	35.6	62.3	43.8-496.2%	44.9

Table W1: Summary of Comparison of RdSAP predicted Window Areas with actual Measured Window Areas in Scotland

The smallest over-estimation of window area occurred amongst the 1930 – 1949 age banding. Even then, the range of variability in the RdSAP predicted window area varied by a factor of 4, and the over-estimation of the window area by RdSAP was 30.3% on average.

When the data was disaggregated between flats and maisonettes, and houses and bungalows, there were differences between the two dwelling categories in the accuracy of the predicted window area. Generally, the RdSAP algorithms predicted considerably more window area amongst houses and bungalows than it did amongst the flats and maisonettes. There was only one age band where this pattern was not repeated, and that was amongst the 1976 – 1983 flats and maisonettes age band. Amongst this age band of flats and maisonettes, 83% had a predicted area that was more than 25% greater than the actual area, compared with only 64.3% of the houses and bungalows (see Table W2).

Age band	Flats and Maisonettes (n=716)				Houses and Bungalows (n=681)			
	% >25% less than actual	% within ±25% of actual	% >25% more than actual	Average % difference between predicted and actual m^2	% >25% less than actual	% within ±25% of actual	% >25% more than actual	Average % difference between predicted and actual m^2
Pre -1919 (F+M n= 239 H+B n=119)	6.3	45.2	48.5	43.3	0.8	5.9	93.3	120.2
1919 – 1929 (F+M n= 63 H+B n=41)	1.6	54.0	44.4	30.3	0	19.5	80.5	68.6
1930 – 1949 (F+M n= 114 H+B n=66)	1.8	64.9	33.3	15.1	1.5	18.2	80.3	62.6
1950 – 1964 (F+M n= 146 H+B n=282)	0.7	55.4	43.9	25.5	1.1	23.4	75.5	48.4
1965 – 1975 (F+M n= 115 H+B n=127)	0	43.5	56.5	31.3	3.1	19.7	77.2	50.6
1976 – 1983 (F+M n= 12 H+B n=28)	0	16.72	83.3	41.7	3.6	32.1	64.3	54.2
1984 - 1991 (F+M n= 23 H+B n=18)	0	43.5	56.5	26.4	1.1	11.1	88.9	80.5
All dwellings (F+M n= 716 H+B n=681)	2.7	50.6	46.8	31.3	1.5	18.8	79.7	65.2

Table W2: Summary of Comparison of RdSAP predicted Window Areas with Actual Measured Window Areas in Scotland – Disaggregated by Flats and Maisonettes, and Houses and Bungalows

Amongst flats and maisonettes, four of the seven age-band groupings had a greater percentage of dwellings amongst those where SAP over-estimated the window area by more than 25% compared against those where the SAP-predicted area was within ±25% of actual window area. Overall, however, the number of dwellings where the SAP-predicted window area was within ±25% of actual window area accounted for a slightly higher percentage of the total sample than did those where SAP over-estimated the window area more than 25%. Overall, RdSAP still over-estimated the window area by 31.3% across all flats and maisonettes.

Amongst the houses and bungalow, the difference between the predicted and the actual window area was much larger. All age bands had more than 60 percent of the dwellings amongst those where the over-estimation of the window area by SAP was by more than 25% compared to those within the ±25% of actual predicted window area. For the pre-1919 houses and bungalows, the over-estimation of the window area by RdSAP was 120.2% on average, that is, RdSAP over-estimated the window area by more than double the actual area. For only one age band of houses and bungalows was the over-estimation by less than 50% (i.e. the 1950-64 age band). Overall, amongst these Scottish houses and bungalows, RdSAP over-estimated the window area by 65.2%.

The sample of dwellings in this comparison was representative of the households that received new heating under the Central Heating Programme in Scotland between 2001 and 2004[44], both in the private sector as well as the local authority and housing association sectors. It was not representative, nor intended to be representative of the Scottish dwelling stock overall. However, it is a large sample of dwellings. Further, the sample included dwellings from across Scotland, including the three island groups. It included dwellings occupied by owner occupiers, private renters, as well as social tenants. This is a significantly larger sample of dwellings, and a more representative sample across the country than appears to have been used in deriving the RdSAP algorithms in Table S4, which appears to have been derived from surveys of 400 dwellings in Cambridge[45].

The RdSAP conventions is that assessors should measure individual windows when there is more than 30% more than typical window area, or more than 30% less than typical window area. These results indicate that in Scotland, RdSAP over-estimates the window area across most Scottish dwelling types when broken down by dwelling type and age band by more than 30%. In only three age band by house type groupings (1930-49 flats and maisonettes, 1950-64 flats and maisonettes, and 1984-91 flats and maisonettes) did RdSAP overestimate the window area by less than 30%, and in two of these it was still more than 25% out.

These results indicate that default position for RdSAP assessors in Scotland should not be to assume that the window areas are typical and not measure, but rather, they should assume that window areas are much less than typical compared to what the RdSAP window algorithms would predict, and measure all windows in the dwellings being surveyed, particularly in houses and bungalows.

[44] Sheldrick, B. and Hepburn, D. (2007) *Assessing the Impact of the Central Heating Programme on Tackling Fuel Poverty: The First Three Years of the Programme 2001-2004 Final Report*, available at https://www2.gov.scot/Publications/2007/03/23133305/18

[45] see "*A geometrical model of dwellings for use in simple energy calculations*" by P.F.Chapman, Energy and Buildings **21** (1994) p 83 – 91

A very limited assessment of the impact of these differences on the SAP scores for 28 instances[46], when the SAP assessments were adjusted for actual window areas, indicated a potential impact ranging between -4 SAP points to +3 SAP points, all within the ±4 SAP points error band that SAP uses, with most (i.e. 22 of the 28, 78.6%) falling within ±2 SAP points calculated using the typical window areas.

7.3 Glasgow East End Case Study

During 2013 and 2014, 26 pre-1919 sandstone tenemental flats in the east end of Glasgow were assessed using RdSAP for the purposes of assessing their CO_2 emissions. These flats were going to receive internal wall insulation under a utility funded ECO project, where the contractor received funding on the life-time carbon savings as calculated using the ECO rules published by Ofgem, so maximising the CO_2 savings was deemed crucial to the financial viability of the project. The flats themselves ranged in size from 1-bed bedsits to 2-bedroom flats, and comprised varying internal layouts - some only had one external orientation, while others spanned through the tenement. Initial assessments highlighted that RdSAP over-estimated the window areas for these flats by between 17% and 56% (see Table W3 below). The windows had pre-2003 uPVC double glazing units with 12mm gaps. Overall, RdSAP over-estimated the window area by 33%

Under the RdSAP convention, only 18 of the 26 properties should have had their window areas measured as being more than 30% less than predicted by RdSAP, so classified as ‘much less than typical’.

The impact of using the actual window dimensions in RdSAP over the default calculation, whether positive or negative, will in part be determined by the type of glazing and its orientation. The default orientation is East-West in RdSAP for all windows: the greater the window area facing south or in a southerly direction (that is, south east through south west on a compass), the bigger the positive impact. Conversely, if the majority of window area faces north or in a northerly direction (that is, north east through north west on the compass), the impact will be negative. These tenements were on a south east to north west axis: the windows in the 1-bed bedsits all faced south east; but in the flats running through the tenement, some had more glazing on the south east and some had more on the north west. The differences in the SAP, EI, CO_2 emissions, the Space heating costs and Space heating energy consumption from switching from default window areas to measured window areas is set out in Table W4.

[46] Only 7 properties were assessed, one from each age band, where the window area was adjusted for the extremes in the under-estimated and the over-estimated measurements given the pre-Central Heating Improvement condition. This analysis was repeated taking account of the improvements completed in them under the Central Heating Programme: in total, 28 impact assessments.

Flat	default window area (m^2)	actual window area (m^2)	% difference between default and actual m^2
F12-18B pre	8.55	4.05	0.526
F13-18B pre	8.42	4.59	0.455
F21-18B pre	9.18	6.21	0.324
F23-18B pre	8.42	4.59	0.455
F31-18B pre	9.18	6.21	0.324
F33-18B pre	8.42	4.59	0.455
FO2-24B pre	8.14	4.59	0.436
F21-24B pre	8.42	4.59	0.455
F22-24B pre	9.67	8.37	0.134
F32-24B pre	9.79	8.37	0.145
F01-32B pre	9.69	7.3	0.247
F02-32B pre	10.5	7.11	0.323
F12-32B pre	8.12	3.56	0.562
F22-32B pre	7.64	3.96	0.482
F32-32B pre	8.12	3.56	0.562
F33-32B pre	8.92	6.21	0.304
F01-34B pre	7.96	4.61	0.421
F21-34B pre	11.61	9.84	0.152
F11-34B pre	11.61	9.84	0.152
F31-34B pre	11.61	9.84	0.152
F12-34B pre	9	6.28	0.302
F22-34B pre	9	6.28	0.302
F32-34B pre	9	6.28	0.302
F11-24B pre	8.41	4.59	0.454
F11-32B pre	8.98	6.48	0.278
F02-18B pre	10.81	9	0.167

Table W3: Comparison of RdSAP default window areas with measured window areas in 26 pre-1919 tenemental properties

Flat	SAP	EI	CO_2 (tonnes/year)	Space heating cost (£/year)	Space heating consumption (kWh/year)
F12-18B pre	-1	0	0.1	-2	-51
F13-18B pre	0	0	0	-4	-74
F21-18B pre	-1	-1	0	0	6
F23-18B pre	0	0	0	-4	-74
F31-18B pre	-1	-1	0	1	6
F33-18B pre	-1	-1	0	-3	-54
FO2-24B pre	0	0	0	0	-14
F21-24B pre	0	-1	0	-4	-66
F22-24B pre	0	1	0	-16	-95
F32-24B pre	0	0	0	-3	-76
F01-32B pre	0	0	0	0	-1
F02-32B pre	0	0	0	-5	-95
F12-32B pre	0	0	0	-2	-35
F22-32B pre	0	1	0	-6	-116
F32-32B pre	0	0	0	-5	-100
F33-32B pre	0	0	0	1	30
F01-34B pre	0	1	0	-5	-122
F21-34B pre	0	0	0	-5	-90
F11-34B pre	0	1	-0.1	-4	-83
F31-34B pre	0	0	0	-4	-80
F12-34B pre	0	-1	0	1	7
F22-34B pre	0	0	0.1	1	14
F32-34B pre	0	0	0	1	22
F11-24B pre	0	0	0	-3	-74
F11-32B pre	0	0	0	0	1
F02-18B pre	0	1	0	-4	-93

Table W4: Comparing Energy Performance Indicators from Default Window Areas with those Calculated using Actual Window Area

As can be seen in Table W4, changing from the default window areas to calculated areas has almost no impact on the SAP and EI scores, and very small changes on the CO_2 emissions, space heating costs and space heating consumption.

In Table W5 and Table W6 below, the energy performance indicators are set out showing the impact of installing 100 mm of internal wall insulation in these properties for both the default window areas and the actual window areas respectively. Not all of the external walls in these properties received internal wall insulation because of the additional costs associated with moving kitchen and / or bathroom fittings. Areas excluded were accounted for in these post-internal wall insulation assessments.

Flat	SAP	EI	CO_2 (tonnes/year)	Space heating cost (£/year)	Space heating consumption (kWh/year)
F12-18B pre	1	2	-0.1	-19	-424
F13-18B pre	1	2	-0.1	-26	-579
F21-18B pre	2	3	-0.2	-41	-891
F23-18B pre	1	2	-0.1	-26	-579
F31-18B pre	5	5	-0.6	-100	-1138
F33-18B pre	1	2	-0.2	-27	-585
FO2-24B pre	1	2	-0.2	-23	-498
F21-24B pre	1	2	-0.1	-26	-482
F22-24B pre	2	2	-0.2	-40	-1337
F32-24B pre	3	5	-0.4	-68	-1446
F01-32B pre	2	2	-0.2	-33	-735
F02-32B pre	3	4	-0.4	-71	-1337
F12-32B pre	2	2	-0.1	-25	-470
F22-32B pre	1	2	-0.1	-12	-228
F32-32B pre	1	1	0	-10	-225
F33-32B pre	2	3	-0.2	-38	-852
F01-34B pre	1	2	-0.1	-16	-363
F21-34B pre	4	5	-0.5	-85	-1619
F11-34B pre	3	5	-0.5	-80	-1619
F31-34B pre	3	5	-0.4	-78	-1534
F12-34B pre	3	4	-0.3	-49	-1117
F22-34B pre	3	4	-0.2	-53	-1144
F32-34B pre	3	4	-0.3	-52	-1099
F11-24B pre	0	1	-0.1	-12	-278
F11-32B pre	1	3	-0.1	-28	-611
F02-18B pre	3	4	-0.3	-59	-1283

Table W5: Impact of Internal Wall Insulation on Energy Performance Indicators for Default Window Areas

Flat	SAP	EI	CO_2 (tonnes/year)	Space heating cost (£/year)	Space heating consumption (kWh/year)
F12-18B pre	1	2	-0.1	-28	-608
F13-18B pre	2	3	-0.2	-41	-910
F21-18B pre	2	3	-0.2	-48	-1048
F23-18B pre	2	3	-0.2	-41	-910
F31-18B pre	5	6	-0.7	-118	-1333
F33-18B pre	2	3	-0.2	-41	-886
FO2-24B pre	2	2	-0.2	-32	-704
F21-24B pre	2	3	-0.2	-43	-798
F22-24B pre	2	3	-0.2	-47	-1552
F32-24B pre	3	5	-0.4	-76	-1607
F01-32B pre	2	2	-0.2	-37	-819
F02-32B pre	3	5	-0.4	-82	-1552
F12-32B pre	2	3	-0.1	-35	-646
F22-32B pre	1	3	-0.1	-26	-482
F32-32B pre	2	2	-0.1	-22	-481
F33-32B pre	2	3	-0.3	-41	-930
F01-34B pre	2	3	-0.2	-29	-658
F21-34B pre	4	5	-0.5	-95	-1809
F11-34B pre	3	5	-0.5	-89	-1802
F31-34B pre	3	5	-0.4	-87	-1705
F12-34B pre	3	4	-0.3	-56	-1255
F22-34B pre	4	4	-0.3	-59	-1273
F32-34B pre	4	5	-0.3	-58	-1208
F11-24B pre	1	2	-0.1	-26	-597
F11-32B pre	1	3	-0.2	-34	-734
F02-18B pre	3	5	-0.3	-67	-1475

Table W6: Impact of Internal Wall Insulation on Energy Performance Indicators for Actual Window Areas

As would be expected, regardless of how the window area is calculated, the impact of fitting internal wall insulation in all of these properties is positive: the SAP scores increase; the EI scores increase; the CO_2 emissions go down, the space heating fuel costs reduce, and the space heating energy consumption drops. However, the impact of these improvements is greater generally where the actual window area is measured (see Table W7).

For 16 of the 26 flats, there is no difference in the calculated SAP score between default window area and actual measured area; there is no difference in the calculated EI score; and there is no difference in the CO_2 emissions (at a scale of resolution of 0.1 of tonne of CO_2 for 17 of the 26 flats. The calculated fuel costs and energy consumption were lower across all 26 flats using actual window area compared to the default window area.

Flat	SAP	EI	CO_2 (tonnes/year)	Space heating cost (£/year)	Space heating consumption (kWh/year)
F12-18B pre	0	0	0	-9	-184
F13-18B pre	1	1	-0.1	-15	-331
F21-18B pre	0	0	0	-7	-157
F23-18B pre	1	1	-0.1	-15	-331
F31-18B pre	0	1	-0.1	-18	-195
F33-18B pre	1	1	0	-14	-301
FO2-24B pre	1	0	0	-9	-206
F21-24B pre	1	1	-0.1	-17	-316
F22-24B pre	0	1	0	-7	-215
F32-24B pre	0	0	0	-8	-161
F01-32B pre	0	0	0	-4	-84
F02-32B pre	0	1	0	-11	-215
F12-32B pre	0	1	0	-10	-176
F22-32B pre	0	1	0	-14	-254
F32-32B pre	1	1	-0.1	-12	-256
F33-32B pre	0	0	-0.1	-3	-78
F01-34B pre	1	1	-0.1	-13	-295
F21-34B pre	0	0	0	-10	-190
F11-34B pre	0	0	0	-9	-183
F31-34B pre	0	0	0	-9	-171
F12-34B pre	0	0	0	-7	-138
F22-34B pre	1	0	-0.1	-6	-129
F32-34B pre	1	1	0	-6	-109
F11-24B pre	1	1	0	-14	-319
F11-32B pre	0	0	-0.1	-6	-123
F02-18B pre	0	1	0	-8	-192

Table W7: Comparing Energy Performance Indicators AFTER Internal Wall Insulation from Default Window Areas with those calculated using Actual Window Area

Where the actual window areas are less than the areas calculated by the RdSAP algorithms, there will be bigger savings to be reaped from using actual areas when assessing the impact of the wall insulation – insulated walls will lose less heat than glazed areas. The converse is also true.

When the purpose of the EPC was to produce an asset rating within the A to G banding, being out by 1 SAP point or 1 point on the EI scale may not be noticed. Only in a small number of instances would this change impact upon the SAP banding. However, if the purposes of the EPC are being used for compliance, or being used as the basis to calculate payments associated with carbon savings, then this allows for the EPC / RdSAP to be 'gamed' by contractors or others. That is, they could choose to measure windows when it is in their interest, and choose to use the defaults when they were in their interest. This is not the basis of a 'consistently applied methodology'.

7.4 Mixed Glazing Types

Within RdSAP, under Convention 3.12b, it states "Where a mixture of glazing gaps is present, all window areas should be measured"[47]. If we are staying with default window calculations, would there be a significant difference of just selecting the window type that is most common? Not in these 26 properties. The difference in the energy performance indicators for 100% pre-2003 uPVC double glazing with a 12mm gap compared with 100% 2003 onwards double glazing is set out in table W8.

From the results, the maximum impact for a complete replacement of the pre-2003 double glazing with 2003-onwards double glazing would be at best +1 on the SAP scale, +2 on the EI scale, a reduction of -0.2 tonnes of CO_2, an annual saving of £20 on the SAP-calculated fuel bill, and annual saving of 375kWh of energy consumption. In the same cases, there is no change in the SAP, EI and CO_2 indicators. Where there is a mixture of units then the actual differences will be even less as they will be somewhere between these two extremes.

This comparison between the results for 100% pre-2003 double glazing with 100% 2003-onwards double glazing was repeated using the actual window areas (see Table W9), and the differences are even less than with using default data for the basis of the comparison.

[47] Conventions (v 10.0) for RdSAP 9.92 and RdSAP 9.93, available from https://www.bre.co.uk/filelibrary/SAP/2012/RdSAP-Conventions-10_0---from-31-December-2017.pdf

Flat	SAP	EI	CO_2 (tonnes/year)	Space heating cost (£/year)	Space heating consumption (kWh/year)
F12-18B pre	1	1	0	-14	-311
F13-18B pre	1	1	0	-13	-285
F21-18B pre	0	1	-0.1	-13	-279
F23-18B pre	1	1	0	-13	-285
F31-18B pre	1	1	-0.2	-31	-360
F33-18B pre	0	1	-0.1	-13	-275
FO2-24B pre	0	1	-0.1	-10	-233
F21-24B pre	1	1	0	-15	-282
F22-24B pre	0	0	0	-14	-284
F32-24B pre	0	1	-0.1	-14	-290
F01-32B pre	1	1	-0.1	-12	-263
F02-32B pre	0	1	-0.1	-15	-284
F12-32B pre	1	2	-0.1	-17	-372
F22-32B pre	1	2	-0.1	-15	-270
F32-32B pre	1	1	0	-12	-265
F33-32B pre	1	1	-0.1	-13	-282
F01-34B pre	1	1	-0.1	-11	-241
F21-34B pre	1	1	-0.1	-20	-375
F11-34B pre	1	1	-0.1	-19	-373
F31-34B pre	1	1	-0.1	-18	-351
F12-34B pre	1	1	-0.1	-13	-296
F22-34B pre	1	1	0	-13	-294
F32-34B pre	1	1	-0.1	-14	-281
F11-24B pre	0	1	-0.1	-13	-286
F11-32B pre	1	2	-0.1	-13	-296
F02-18B pre	0	1	0	-18	-292

Table W8: Comparing Energy Performance Indicators for 100% pre2003 uPVC Double Glazing with 12mm gap and 100% 2003-onwards Double Glazing for Default Window Areas

Flat	SAP	EI	CO_2 (tonnes/year)	Space heating cost (£/year)	Space heating consumption (kWh/year)
F12-18B pre	1	0	-0.1	-6	-144
F13-18B pre	0	0	0	-7	-157
F21-18B pre	1	1	0	-8	-188
F23-18B pre	0	0	0	-7	-157
F31-18B pre	1	1	-0.1	-18	-204
F33-18B pre	1	1	-0.1	-15	-150
FO2-24B pre	0	0	-0.1	-6	-129
F21-24B pre	0	1	0	-8	-155
F22-24B pre	0	-1	0	-12	-261
F32-24B pre	0	1	-0.1	-12	-248
F01-32B pre	1	0	0	-9	-199
F02-32B pre	1	0	0	-7	-127
F12-32B pre	0	1	0	-11	-208
F22-32B pre	1	1	-0.1	-8	-139
F32-32B pre	1	1	0	-5	-121
F33-32B pre	1	1	-0.1	-8	-197
F01-34B pre	1	0	-0.1	-7	-144
F21-34B pre	1	1	-0.1	-16	-314
F11-34B pre	1	0	0	-16	-312
F31-34B pre	1	1	-0.1	-15	-293
F12-34B pre	0	1	-0.1	-10	-208
F22-34B pre	1	1	-0.1	-10	-206
F32-34B pre	1	1	0	-9	-196
F11-24B pre	0	1	0	-7	-158
F11-32B pre	0	1	0	-10	-214
F02-18B pre	0	0	0	-11	-237

Table W9: Comparing Energy Performance Indicators for 100% pre2003 uPVC Double Glazing with 12mm gap and 100% 2003-onwards Double Glazing for Actual Window Areas

The results in Table W10 for these 26 flats indicate only very small differences in the energy performance indicators whether calculated using the default window areas or measured window areas when assessing the differences in energy performance when assuming either 100% pre2003 uPVC Double Glazing with 12mm gap or 100% 2003-onwards Double Glazing. These differences will be even less as the actual split of glazing will be somewhere between the two extremes used here, depending upon the actual split in the different types of glazing.

Flat	SAP	EI	CO_2 (tonnes/year)	Space heating cost (£/year)	Space heating consumption (kWh/year)
F12-18B pre	0	-1	-0.1	8	167
F13-18B pre	-1	-1	0	6	128
F21-18B pre	1	0	0.1	5	91
F23-18B pre	-1	-1	0	6	128
F31-18B pre	0	0	0.1	13	156
F33-18B pre	1	0	0	-2	125
FO2-24B pre	0	-1	0	4	104
F21-24B pre	-1	0	0	7	127
F22-24B pre	0	-1	0	2	44
F32-24B pre	0	0	0	2	42
F01-32B pre	0	-1	0.1	3	64
F02-32B pre	1	-1	0.1	8	157
F12-32B pre	-1	-1	0.1	6	164
F22-32B pre	0	-1	0	7	131
F32-32B pre	0	0	0	7	144
F33-32B pre	0	0	0	5	85
F01-34B pre	0	-1	0	4	97
F21-34B pre	0	0	0	4	61
F11-34B pre	0	-1	0.1	3	61
F31-34B pre	0	0	0	3	58
F12-34B pre	-1	0	0	3	88
F22-34B pre	0	0	-0.1	3	88
F32-34B pre	0	0	0.1	5	85
F11-24B pre	0	0	0.1	6	128
F11-32B pre	-1	-1	0.1	3	82
F02-18B pre	0	-1	0	7	55

Table W10: Comparing Energy Performance Indicators between 100% pre2003 uPVC Double Glazing with 12mm gap and 100% 2003-onwards Double Glazing: Actual Window Areas compared to Default Window Area differences

Overall, the results for mixed glazing suggest as an asset rating it does not matter much if there are mixed types of glazing present. Either measure or use defaults across all surveys. Requiring assessors to measure because of the presence of different types of glazing seems an unnecessary demand, and one that an assessor can easily 'game' quality assurance anyway, by only providing evidence of one type of glazing being present in the dwelling.

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