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Whole building assessment for energy efficiency and zero direct emissions heat in multi-owner and mixed-use buildings

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March 2023

DOI: http://dx.doi.org/10.7488/era/3231

1 Executive summary

1.1 Aims

This report looks at different options for conducting whole building assessments of multi-owner and mixed-use buildings, through a literature review and structured conversations with stakeholders. These assessments are needed to plan the improvement of building fabric efficiency and installation of zero direct emissions heating systems.

This work is useful because most current building assessment methods in Scotland are used for single dwellings and not at a whole building level. Additionally, the most commonly used assessment methods for both domestic and non-domestic properties are intended to measure compliance with building regulations rather than retrofit design.

1.2 Findings

Current assessment methods cannot be used for the purpose of retrofit design because they are designed for comparison rather than absolute calculations of building performance. The assessment of multi-owner and mixed-use buildings requires two methods, which cannot currently be combined to produce a single assessment.

Based on analysis of whole building energy assessment approaches internationally, we found that:

- none of the examples have been developed specifically for multi-owner and mixed-use buildings
- several assessment approaches can co-exist and fulfil different functions (i.e., compliance and design), eg Denmark and France have additional assessment approaches beyond energy performance
- best practice assessment approaches go beyond energy modelling and use holistic frameworks; for example, PAS 2035 is a British framework for delivery of quality retrofits of domestic buildings.

We outline three options for how a whole building assessment methodology could be developed in Scotland. The options cover a range of costs both for conducting the assessment and for method development. For this reason, they range in the level of detail and accuracy.

Option 1 is a low-cost option, based primarily on assumed data rather than measured data. It involves updating existing methods to complete a whole building assessment.

Advantages:

- Low-cost option, for both assessment and development
- Utilises the existing workforce and the management arrangements associated with producing Energy Performance Certificates.

Limitations:

- The existing methodology must be modified in order to assess communal and non-domestic spaces
- An assumption-based assessment cannot adequately consider the risk associated with the retrofit of multi-owner or multi-use buildings.

Option 2 is a detailed assessment approach with PAS 2035.

Advantages:

- A holistic retrofit assessment rather than an energy performance assessment, designed to mitigate the risk of unintended consequences of retrofit
- Infrastructure for PAS 2035 training, qualifications and certification is already being put in place, although this must be scaled up.

Limitations:

- The supply chain is not yet capable of delivering PAS 2035 retrofit
- Changes to modelling approaches are required for this option, meaning higher development costs.

Option 3 presents an assessment approach that draws on best practice from the international examples we found.

Advantages:

- Like option 2, option 3 is designed as a holistic assessment approach, which aims to mitigate the risks of retrofitting multi-owner and mixed-use buildings

Limitations

- It has the highest associated development costs as it does not build on existing approaches already used in Scotland
- The Scottish context differs from the examples we have reviewed, particularly in terms of the lack of formal management structures in multi-owner buildings, low prevalence of communal heating and the current practice of assessing only individual flats.

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2 Glossary

Term	Definition
Building Envelope	The building envelope is the physical separation between the interior and exterior of a building. It includes walls, floor, roof, windows and doors.
Building Services	Building services are the systems installed in buildings to make them comfortable, functional, efficient, and safe. For example heating, ventilation and lighting.
Delivered Energy	The energy metered at point of use (i.e. in the home).
Domestic Energy Assessor (DEA)	Assesses the energy efficiency of existing residential buildings using RdSAP.
Dynamic Simulation Model (DSM)	Considers energy flows between spaces of the building and over a greater time-period than 24 hours. This type of energy modelling is time-consuming and is used for buildings with numerous temperature zones, occupancy profiles and servicing requirements.
Energy Consumption	The actual energy consumed by a building.
Energy Consumption Monitoring	An assessment of the actual energy consumed in a building. This can be done using energy data from bills or through smart meter readings.
Energy Model	A physics-based software simulation of building energy use. We use this term to describe the modelling methodologies used in regulatory compliance and retrofit design in the international examples. Examples used in Scotland include SAP and PHPP.
Energy Performance	The amount of energy a given building consumes over a defined period.
Framework	The regulation, guidance or best practice that surrounds a modelling methodology.
Heat Consumption	The amount of heat a building uses.
Heat Cost Efficiency	The cost efficiency of heating the building. This is based on the energy demand of the building and the efficiency of the heating systems in place. The efficiency of the heating systems can be measured (through energy consumption monitoring) or modelled (energy modelling).
Heat Demand	The amount of heat required by a building based on the difference between the desired indoor temperature and the outdoor air temperature.
Individual Building Renovation Roadmap	A tool outlining deep step-by-step renovation plans with customised recommendations for individual buildings.
Measured Data	Data that is gathered from an in-person visit or physical test.
Mixed-Use Building	A building with more than one use i.e., residential and commercial.
Modelled Data	Data already contained within a pre-defined calculation.
Modelling Methodology	Energy models and calculations used in regulatory compliance or voluntary frameworks.
Multi-Owner Building	A singular building with two or more dwellings (units) within it.

National Calculation Model (NCM)	Procedure for demonstrating compliance with the Building Regulations.
On Construction Domestic Energy Assessors (OCDEA)	Assesses the energy efficiency of new residential buildings. OCDEAs have the skills and knowledge to use full SAP (rather than RdSAP).
PAS 2035	A specification for 'whole-house' or 'whole building' retrofit. It is a framework that details how to deliver quality retrofits of existing domestic buildings. It aims to ensure the right measures are installed and to reduce the 'performance gap' of energy savings not being delivered in practice.
Performance Gap	The difference between how a building is designed to perform and how it actually performs.
Physical Testing	An on-site test to determine one or more characteristics related to the energy performance of the building following a specific procedure.
Primary Energy	Primary energy is the energy required to deliver energy to the point of use. It includes energy associated with extraction, processing, distribution and storage. It is the amount of energy required to produce 1kWh of delivered energy. It is used to compare the efficiency of different energy sources.
Reduced Data SAP (RdSAP)	A simplified version of SAP which is used to produce EPCs for existing dwellings. RdSAP uses a set of assumptions about the dwelling.
Regulated Energy Use	Energy used for fixed building services including space heating and cooling, hot water, ventilation, fans, pumps and lighting. These are regulated as part of Building Standards.
Standard Assessment Procedure (SAP)	The methodology used by the UK Government to assess and compare the energy and environmental performance of dwellings.
Simplified Building Energy Model (SBEM)	The methodology used by the UK Government to assess and compare the energy and environmental performance of non-domestic buildings.
Solar Gains	The increase in heat in a building resulting from absorbed solar radiation.
Steady-State Model	Energy consumption is assessed based on a simple energy balance calculation (heat loss vs gains) for each individual day of the year. This type of energy modelling works well in buildings where boundary conditions are constant (such as in dwellings) where analysis of variables such as solar gain is not required.
Thermal Bridging	The movement of heat across an object that is more conductive than the materials around it. Thermal (or cold) bridges are weak areas in the building envelope which allow heat to pass through.
Thermal Inertia	A building's capacity to absorb, store and release heat.
U-value	A measure of the rate of heat loss through a construction material. It measures how effective a material is as an insulator.
Unregulated Energy Use	Energy use for purposes such as appliances, cooking and additional lighting or heating.

3 Introduction

The Scottish Government aims to reduce emissions from buildings by 68% compared to 2020 levels by 2030 and reach net zero emissions in 2045, according to the Heat in Buildings Strategy. Achieving these targets requires retrofitting Scotland’s existing building stock, reducing energy demand by improving fabric efficiency and installing zero direct emissions heating - systems.

The retrofit of multi-owner and mixed-use buildings is challenging for a number of reasons. These include a lack of building management structures such as owners’ associations, endemic disrepair of tenement blocks (Robertson, 2019) and current property law arrangements. The Scottish Law Commission (Scottish Law Commission, 2022) is considering the law around compulsory owners’ associations and a draft Tenement Maintenance Bill which could introduce new provisions to facilitate common works by Spring 2026. One key challenge to the retrofit of these buildings is that currently we cannot undertake energy assessments at a whole building level. Whole Building Assessments will be required to assess and make appropriate recommendations for communal works for both energy efficiency work and communal heating systems.

This report presents results from a desk-based scoping exercise to identify options for developing an assessment method of multi-owner and mixed-use buildings in Scotland. The research findings are primarily based on published literature. This was supplemented by input from 14 stakeholders from 11 organisations (see Section 10).

The report contains:

- a summary of assessment methods that are currently used in the UK and their suitability for assessing multi-owner and mixed-use buildings
- an outline, analysis and comparison of eight international examples of whole building assessment methods
- three possible options for the development of an assessment method of multi-owner and mixed-use buildings in Scotland.

4 Existing assessment methods in Scotland

Two methodologies are currently used to produce Energy Performance Certificates (EPCs) in the UK. This section provides a brief overview of these energy models, as well as two other types of energy model currently in use in Scotland: Passivhaus Planning Package (PHPP) and Dynamic Simulation Models (DSM).

4.1 Standard Assessment Procedure (SAP)

4.1.1 Overview

SAP is a steady-state modelling method. This means it uses a simple energy balance calculation (heat loss vs gains) for each individual day of the year. This type of energy modelling is commonly used for domestic buildings. The calculation models heat loss, internal gains, solar gains, energy balance, carbon emissions, heating, ventilation, internal lighting, cooling and renewable energy sources.

SAP is used for both new and existing residential buildings. Full SAP is primarily used to generate an EPC for new dwellings whereas RdSAP (Reduced Data SAP) is used to generate an EPC for existing dwellings. RdSAP uses the same calculation as full SAP but uses a simplified data collection process. This enables the calculation to take place where a complete data set for a property is unavailable, and for a lower cost than full SAP.

4.1.2 Accuracy

Comparability rather than accuracy is the primary objective of an RdSAP assessment. In order to make fair comparisons between buildings it ignores factors such as local climate conditions and makes assumptions about the number of occupants.

There is evidence that steady-state tools such as SAP and RdSAP are inaccurate in predicting the energy consumption of dwellings (Sierra, et al., 2018). However, while SAP as a model is considered accurate, inaccuracies in its outputs are caused by the assumptions and default values used (AECB, 2008), such as for occupancy. Full SAP calculations rely on fewer inferred values than RdSAP. Tests conducted by Passivhaus Trust (Passivhaus Trust, 2020) found that SAP can accurately calculate space heating and hot water demand, although it is less accurate for aspects such as internal heat gains and the efficiency of Mechanical Ventilation with Heat Recovery systems. This is because the more a dwelling deviates from the standard assumptions within SAP, the less accurate the modelling is.

RdSAP contains too many assumptions to be of value when designing or installing retrofit measures. To aid its simplicity, RdSAP relies on a number of inferred values. These include assumptions for airtightness, thermal bridging, area of windows, wall thickness, wall u-value (based on age), ventilation type and heating efficiency. There is also evidence of low accuracy (in terms of reproducibility), errors and variable quality in RdSAP assessments (Hardy & Glew, 2019), (Jenkins, et al., 2017).

4.2 Simplified Building Energy Model (SBEM)

4.2.1 Overview

SBEM is used to produce EPCs for non-domestic buildings. SBEM utilises a different calculation methodology to SAP. For the generation of an EPC, the SBEM calculation utilises standardised information for several factors to allow comparability between similar building types. In an SBEM calculation, the actual building geometry is entered into the software and zones are defined for each of the spaces (e.g. swimming pool, small shop unit). SBEM then assigns a standardised occupancy profile to each zone based on figures derived from the Chartered Institute of Building Services Engineers. These occupancy profiles are contained within 'locked databases' which the user cannot change (BRE, 2015).

4.2.2 Accuracy

Like SAP, SBEM requires a certain amount of standardisation to enable comparability between buildings for benchmarking purposes. However, and as acknowledged by the standard, this is at the expense of accuracy. SBEM is more flexible than SAP. Some parameters are held in 'accessible databases' which allow the assessor to override default parameters and use their own measured or observed data. There are also a series of 'locked databases' within SBEM, the purpose of which is to enable allow fair and consistent comparison between buildings. This means that measuring and interrogating actual energy performance is not possible.

4.3 Limitations of SAP and SBEM

The background calculations used by SAP and SBEM could be used to assess multi-owner or mixed-use buildings for retrofit. However, both tools would need to be adapted to fulfil this purpose. In their current form neither methodology can be used for assessing multi-owner and mixed-use buildings for the purpose of retrofit design for two main reasons:

- **"multi-owner and mixed-use"**

In a multi-owner or mixed-use building, flats will be assessed using SAP. Non-domestic and communal circulation spaces will be assessed using SBEM. The results and outputs of the two calculations cannot (currently) be directly compared or aggregated.

To produce a single calculation for a whole building, a unified calculation methodology is required. Alternatively, the tools could be adapted so that they can be combined. The core calculations behind SAP and SBEM are very similar, and stakeholders explained that theoretically the two tools could be mixed if required.

- **"retrofit design"**

Both SAP and SBEM were designed as tools to demonstrate compliance with energy efficiency aspects of the building regulations. Therefore, both methods are intended for comparison rather than absolute calculations of building performance. SAP in particular, is now used in a range of other unintended ways, including as an assessment tool to inform retrofits, and as a design tool. These issues are discussed in more detail in (Etude, et al., 2021). However, as design is not the intended purpose of these tools, there are naturally limitations in how well they perform for this purpose.

They are also both carbon assessment tools, rather than energy performance tools. These factors limit their usefulness as a tool for assessing buildings for the purpose of retrofit design.

Despite their limitations, the ubiquity of these methods and their existing integration in legislation means there may be advantages in adapting one of them to be used for the purpose of assessing multi-owner and mixed-use buildings for retrofit.

4.4 Passivhaus Planning Package (PHPP)

4.4.1 Overview

PHPP is a similar calculation to SAP and is used to determine heat demand in buildings. However, PHPP can be used to calculate both domestic and non-domestic parts of buildings under the same methodology (albeit with separate calculations).

4.4.2 Accuracy

PHPP has a high level of flexibility as it allows users to alter parameters which are locked in RdSAP, full SAP and SBEM approved software. These include:

- More detailed inputs for window U-value calculations
- The installed efficiency of building services, ventilation, and domestic hot water
- The effect of shade on heat gains
- Occupancy characteristics, such as hours of use and internal heat gains (Essential for overheating assessment)
- Insertion and calculation of the energy consumption of small power and white goods

This greater flexibility and lower reliance on assumptions means that PHPP is a more appropriate design tool than SAP. The flexibility of the software means that greater accuracy can be obtained when modelling a building by inputting data from in-situ testing which may be required by a whole building assessment[1].

For example, heat demand is based on several inputs, which can be modelled using the software. A heat demand calculation can be performed without in-situ testing, but monitoring of actual heating costs, temperature and relative humidity can be used to better predict the impact of measures on heating costs.

4.5 Dynamic Simulation Models (DSM)

SAP, SBEM and PHPP are steady-state models. Dynamic simulation models (DSM) are an alternative approach to energy modelling. DSM is typically used in large and complex buildings. It is more accurate than steady-state approaches because it can account for more physical processes, such as energy flows between spaces of the building. DSM is more complex than the equivalent steady-state approaches as it requires more information inputs, and a greater amount of time to conduct an assessment.

The results of DSM are highly accurate. DSM produces a 3D model of a building and is used to simulate the impact of various retrofit upgrades.

There are various tools for DSM that are currently used in the UK such as IES, EnergyPlus and Sefaira, all suitable for both domestic, non-domestic and mixed-use buildings. No formal qualifications are required for DSM, although it is generally conducted by Mechanical

[1] Johnston, D. et al (2020) Are the energy savings of the passive house standard reliable? A review of the as-built thermal and space heating performance of passive house dwellings from 1990 to 2018

Engineers and some Architects. In comparison to a specialist tool such as PHPP, there is already a large workforce in Scotland undertaking DSM assessments.

5 International examples

Eight international examples of whole building assessments of multi-owner and mixed-use buildings are summarised in Table 1. Full details on our findings can be found in Section 11. The summary table allows for comparison between the assessment approaches and includes PHPP and SAP for comparison. International asessment approaches are further discussed in relation to options for whole building assessment for multi-owner and mixed use buildings in Section 6.

Table 1. Overview of international examples of energy frameworks and models

	Canada	Denmark		Flanders, Belgium	France		Germany	Sweden	International	UK
Energy model or tool	HOT2000	Be18	Be18	EPC Common Parts Software	3CL	TH-C-ex	DIN V 18599 iSFP software	Unspecified	PHPP	SAP
Framework	EnerGuide	EPC	BetterHome	EPC Common Parts	EPC	GTD	iSFP	EPC	PAS2035	EPC
Primary use	Both	Compliance	Design	Design	Compliance	Design	Design	Compliance	Design	Compliance
Heat demand[1]	WB	WB	WB	WB	WB + IF	WB + IF	WB	WB	WB + IF	IF
Actual consumption	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No
Detail of assessment	high	high	high	medium	high	high	high	medium	high	low
Consideration of building condition	medium	high	high	high	medium	high	high	medium	high	low
Number of visits	2	1	2+	1	1	1	2	1	1	1
Assessment cost[2]	medium	-	-	low	medium	medium	high	high	-	low
Recommendations	WB	WB	WB	WB	WB + IF	WB	WB	WB	WB	IF
Quality of recommendations	medium	medium	high	low	low	high	high	low	high	low
Building applicability[3]	MO + MU	MO + MU	MO	MO	MO + MU	MO	MO	MO + MU	MO + MU	SF

[1] WB = Whole Building, IF = Individual Flat

[2] Assessment costs have been standardised for comparison purposes. They are based on price per owner and converted using Xe Currency Converter (December 2022). Actual costs are provided in each summary.

[3] MO = multi-owner residential building, MU = mixed-use buildings, SF = single-family buildings

6 Considerations for developing an assessment approach

6.1 Scalability

There is a risk that data gathering for assessment purposes becomes disproportionate to the scale of the retrofit. A whole building assessment should be scalable. This means it should have the ability to identify relevant tests to be conducted prior to work commencing. It should not require all multi-owner and mixed-use buildings to undertake the same level of testing regardless of the complexity of the building and proposed improvements. This would ensure that information is collected when required and relevant. It would also gradually increase industry understanding of the Scottish multi-owner and mixed-use building stock over time.

6.2 Site visit and in-situ testing

A solely desk-based assessment is not appropriate for this purpose. A site visit is necessary to gather information such as:

- Detailed measurements of the building including the sizes and characteristics of all external openings.
- Where information exists on previous energy efficiency upgrades or building work, it should be possible and straightforward to include this information in the calculations.
- A visual check that building services have been properly commissioned and are operating as intended (such as trickle vents, boiler, extract vents). Signs of inadequate ventilation, such as mould, odours and condensation, should be recorded.

In-situ testing could also be carried out, determined by the complexity of the building. Tests may include:

- Thermography using a thermal imaging camera to identify areas of concentrated heat loss and building defects.
- Temperature, relative humidity, consumption monitoring and CO_2 monitoring. This is to determine how occupants currently use the building and the adequacy of ventilation.
- In-situ U-value monitoring to determine the actual performance of the building fabric.
- Moisture analysis of the existing fabric to determine the suitability of the building for certain types of insulation.

The tests above aim to reduce the risk of unintended consequences when upgrading a building. They can also identify maintenance issues and problems with the existing building services.

6.3 Occupant behaviour and consumption data

Energy assessments for benchmarking or compliance purposes intentionally exclude data on consumption or occupancy. This is to allow for meaningful comparisons between buildings. An assessment for the purpose of retrofit design will be more accurate if it considers how energy is used across the whole building. This is important because the sizing and design of ventilation systems to avoid summer overheating is dependent on developing an accurate picture of occupancy. Inferred occupancy data is likely to underestimate the number of occupants in small properties, particularly social housing.

Moreover, assessments should consider both regulated and unregulated energy use. In a multi-owner or mixed-use building this would require gathering data from each flat or non-domestic space. This would allow advisors to give recommendations on the efficiency of appliances, which make up a greater proportion of overall energy use in buildings with a high level of fabric efficiency.

The alternative to collecting operational data is to develop a series of profiles for different building types and household types, as is currently done with SBEM.

6.4 Development of retrofit recommendations

Based on the assessment, recommended retrofit measures and plans are either generated through software or specified by a professional (or a combination of the two). Due to the complexity of multi-owner and mixed-use buildings, software-generated measures alone are not appropriate for retrofit design and should be either checked or specifically recommended by a qualified professional.

6.5 Policy and regulatory landscape

A whole building assessment approach could fulfil both regulatory compliance and retrofit design functions. Alternatively, it could operate alongside the EPC system. Several internal examples (Denmark, Flanders, France, and Germany) have both a mandatory EPC-style assessment (though more advanced than RdSAP) as well as an optional and more tailored scheme focused on long-term retrofit design (sometimes called Building Renovation Roadmaps).

In Canada the EnerGuide assessment is used for both compliance and retrofit design. The tool uses normalised data for compliance, and inputs can be changed for design purposes.

6.6 Decision-making structures in multi-owner buildings

In the design of a whole building assessment approach for Scotland, it is important to consider the practical context of decision-making and organisation of multi-owner buildings. Most of the international examples exist in a context where multi-owner buildings have different decision-making structures to Scotland. For example, in Denmark, Sweden and Germany, it is a legal requirement for flat owners to be part of a building owner association. In some cases, this association acts as the legal owner of the building.

Whole building assessments and long-term retrofit plans are easier to implement into such structures where there are stricter regulations on building management and a stronger tradition of collective organising. In Scotland, the design of a whole building assessment approach will have to consider the current building management practice and policy, such as the role of property factors and need for owners' associations.

6.7 Existing heat infrastructure

It is also important to note that the reviewed countries have different heat infrastructure compared to Scotland. For example, most of the reviewed European assessment approaches are designed for a context where communal heating is the norm, in the form of communal oil or gas boilers in each building, or where district heating is more widespread.

7 Options for developing an assessment approach

The following section outlines three options for the development of an assessment approach for multi-owner and mixed-use buildings. The options provide a range of costs (both cost of assessment and method development costs) and a range in the level of detail and accuracy. The differences between the three options are illustrated in Table 2.

7.1 Option 1: Assumption-based

7.1.1 Overview

This option explores updating RdSAP to complete a whole building assessment. In its current form an RdSAP calculation excludes common areas and cannot be used for non-domestic spaces. This is because RdSAP includes background assumptions that only apply in residential properties which cannot be changed. To assess non-domestic or common areas, the background assumptions would need to be altered. This would allow assessment of all areas of a multi-owner and mixed-use building.

7.1.2 Data collection

Data collection for RdSAP involves a site visit. The assessor will:

- Take dimensional details of the entire property
- Look at heating and hot water systems
- Assess the building fabric (external walls, glazing, exposed floors and accessible roof space)

The survey normally takes 0.5-1 hour during which time photographs are also taken.

7.1.3 Assessor qualifications

The survey is conducted by a qualified Domestic Energy Assessor. No specific experience is required to undertake the 3-day course and test to become a DEA (Elmhurst Energy, 2023). It is uncommon for building professionals to qualify as DEAs as the assessments are not profitable for those with specific experience in construction.

7.1.4 Data input

The assessor inputs the data to an accredited online RdSAP software provided by the organisation that the DEA is accredited to (e.g. Elmhurst, Stroma). All software is approved by Building Research Establishment (BRE). The software generates an EPC and a report.

Data input involves inserting overall building dimensions for the gross internal area, external walls, roof and floors and information about the installed building services. Many inputs are assumed, for example wall insulation depth is assumed based on the construction date. U-values for wall insulation, loft or roof insulation, floor insulation and glazing are inferred, but can also be over-written by the assessor if actual values are known and evidenced. In practice it is rare to over-write inferred data with actual data. This is because there are no direct benefits to the client, it may often be beyond the competency of the assessor and incurs a higher cost for the assessment.

RdSAP has limited flexibility, for example values for airtightness, thermal bridging, ventilation, and occupancy cannot be changed. This means that the impact of these aspects on energy performance cannot be assessed. Ventilation and thermal bridging contribute significantly to a building's overall heat loss.

7.1.5 Output

RdSAP assessments produce an EPC which gives the property an energy rating. A report is also generated which details recommended steps to improve the property's SAP rating and the typical financial savings from each improvement. The recommended measures are algorithmically generated, and the software does not consider building condition or the interaction between different retrofit measures.

7.1.6 Cost of assessment estimate

Currently an RdSAP assessment can cost between £50 to £100[2], dependent on the scope and scale of the property. If a significant amount of work is required to modify SAP for the purpose of whole building assessments, this may increase the cost to building owners.

Estimated cost for a block with 6 flats:

- RdSAP costs for one flat @ £50 to £100 x 6 = £300 to £600

7.1.7 Limitations

Without modifications, SAP cannot be used to assess communal and non-domestic spaces. This means that it is unsuitable for the assessment of multi-owner and mixed-use buildings. SAP is owned by the UK Government. Development of SAP, including any modifications, is currently contracted to BRE, who collaborate with two advisory groups SAPIF (the SAP Industry Forum) and SAPSIG (the SAP Scientific Integrity Group).

The RdSAP assessment is based on an unobtrusive survey based on what the assessor can see at the time of survey. Assessors rarely have access to additional information such as detailed drawings. As such, RdSAP relies on assumptions at both input and output stage.

The recommended retrofit measures are intended to increase the SAP score of a building, rather than to reduce its overall energy use. SAP scores are an energy cost metric, not an energy efficiency or carbon metric. Therefore, an RdSAP assessment will not necessarily recommend measures which target an end goal of a net zero retrofit.

An assumption-based assessment such as RdSAP cannot accurately assess the interaction between recommended retrofit measures. Identifying potential interactions between

[2] The costs in this estimate are based on the experience of a certified Domestic Energy Assessor in Scotland.

measures is necessary to understand and predict the impact of retrofit on the movement of heat, air and moisture within a building. The use of an assumption-based tool creates the risk of poor outcomes such as damp or mould, and expensive remediation work. For example, insulation measures to reduce heat loss, air infiltration and air leakage may have unintended consequences for internal air quality and for the movement of moisture through the building fabric. This is a particular risk in pre-1919 buildings, and in non-traditional buildings constructed in the 1960s and 1970s (BSI, 2022).

An assumption-based tool also risks a 'performance gap' where predicted energy savings are not delivered in practice.

Currently RdSAP cannot recommend connection to communal or district heating, even when connection to a local heat network is possible (Alembic Research Ltd, 2019).

7.2 Option 2: Enhanced energy modelling with PAS 2035

7.2.1 Overview

Option 2 looks at a more detailed assessment approach using either full SAP or Passivhaus Planning Package (PHPP) modelling in conjunction with PAS 2035.

The UK Government has already invested in PAS 2035 as a holistic retrofit approach. By 'holistic' we mean an approach that considers a range of building performance issues such as comfort, maintenance, heritage and air quality, rather than energy performance only.

PAS 2035 permits the use of both full SAP and PHPP modelling methodologies when assessing the impact of retrofit measures on existing buildings. PAS 2035 is useful for whole building assessments because it identifies where more detail is required to mitigate the risk of unintended consequences in retrofit. The risk is primarily created by the interaction between existing and new building fabric and services. PAS 2035 tailors the requirement for an assessment based on building characteristics such as age, historic significance of the property, or the number and technical complexity of measures being installed. There is much in common with international examples of frameworks such as the Global Technical Diagnosis (GTD) in France.

PAS 2035 is currently used in the UK on retrofit schemes including ECO4 and is likely to be included in Scottish delivery programmes as part of the Heat in Buildings Strategy (Scottish Government, 2022)[3]. PAS 2035 has been developed with funding from the Department for Energy Security and Net Zero (DESNZ, formerly BEIS), meaning there is infrastructure in place for training, qualifications and certification in the UK. Additionally, there is a national body, Trustmark, which has been set up to oversee the certification and quality assurance of projects completed in accordance with PAS 2035. Certification is through an online portal which retains information from the building assessment and improvements. This data can inform future works and energy calculations.

7.2.2 Data collection

Using a PAS 2035 approach requires more data collection than an RdSAP assessment. A site visit may take 2-4 hours and is tailored to the construction type and planned measures. The

[3] Concerns have been raised about the applicability of some aspects of the PAS 2035/30 standards in Scotland, Scottish Government will set up a technical group to work with BSI to develop the standards.

assessment aims to develop a detailed understanding of the construction of the building, any previously installed energy efficiency measures and any defects.

7.2.3 Assessor qualifications

This assessment is carried out by a Retrofit Assessor (RA). This role is a Domestic Energy Assessor (DEA) with an additional RA qualification. The RA is overseen by a Retrofit Coordinator (RC). The RC is a construction professional who uses their judgement and the PAS 2035 framework to determine a suitable level of assessment for any given building.

For SAP modelling there is an existing workforce of qualified On Construction Domestic Energy Assessors (OCDEA). An additional training course for multi-owner and mixed-use buildings could be introduced, as is the case in Canada for EnerGuide assessments.

For PHPP modelling a professional background in buildings and a two-week training course is required. Currently, there are around 600 professionals (Passivhaus designers) qualified to use PHPP in the UK (Passive House Institute, 2023). Significant upskilling of the workforce is required to make PHPP the default calculation methodology.

7.2.4 Data input

Unlike RdSAP, full SAP and PHPP allow assessors to input a greater amount of information about the building, increasing the accuracy of the calculation. Examples of the additional information include details on calculated thermal bridging, measured air permeability and a requirement for thermal calculations for all elements of the building fabric. The two software packages are similar steady-state calculations, however, the user interface for most SAP software is more limited than PHPP. PHPP provides greater flexibility than SAP as it allows for additional data including occupancy, commissioned performance of building services, domestic hot water, appliances, internal heat gains, shading and components. This increased flexibility makes PHPP more suitable as a design tool which can be used by professionals, whereas currently SAP is primarily used for compliance in new buildings.

7.2.5 Output

The output of this approach is an ‘improvement option evaluation’ and a ‘medium term plan’. The improvement option evaluation under PAS 2035 is a report by a RC. The report outlines the current condition of the building, its suitability for receiving retrofit measures and a recommended package of measures to achieve an ‘intended outcome’. If the ‘intended outcome’ was to install a low temperature heating technology, such as a heat pump, the package would likely include significant fabric upgrades. It can be used to assess suitability for communal heating systems, but this is based on the experience of the assessor rather than an automatically generated results.

PAS 2035 requires assessments to present the cost implications of retrofit measures in a simple way, such as a payback calculation for each individual measure.

The medium-term plan sets out the sequencing of installation to ensure that retrofit measures do not impair critical functions of the building such as ventilation, moisture management or heating. If a heating system was proposed for a building, the medium-term plan would set out what preparatory work (such as insulation improvements) would need to occur prior to installation.

7.2.6 Cost of assessment estimate

A PAS 2035 retrofit assessment for a multi-owner or mixed-use building will require several days of time from a Retrofit Assessor, Retrofit Coordinator and possibly other professionals, for example for an air pressure test. It is likely to cost several thousand pounds. An indicative cost of for a block with six flats using PHPP is detailed below[4]:

- Desktop PHPP costs for one flat @ £500 x 6 = £3000
- Air pressure test for one flat @ £350 x 6 = £2100
- Thermography (all six flats) = £1250
- Temperature and relative humidity monitoring = £500
- In situ U-value monitoring = £500
- Moisture Analysis = varies

Approximate costs = £5000 to £7350

7.2.7 Limitations of PAS 2035 framework

The PAS 2035 approach was developed to improve the piecemeal approach to retrofit which has resulted from RdSAP assessments. However, a key limitation of this option is that the supply chain has not fully matured to deliver the requirements of the PAS 2035 standard. In comparison to DEAs there are relatively few RAs, RCs or installers. However, it is likely that this is a short-term challenge that will be alleviated as the approach becomes more mainstream.

The more detailed assessment is more expensive than an RdSAP assessment. However, it is well documented that increased assessment, design and quality assurance is critical to the success of retrofit measures (Bonfield, 2016).

7.2.8 Limitations of SAP modelling

Without modifications, SAP cannot be used to assess communal and non-domestic spaces. This is because SAP includes background assumptions that only apply in residential properties which cannot be changed.

If SAP were modified for these purposes, it would require more detailed inputs to be used as a design tool. Improvements such as accurate measurement of thermal bridges and better measurement of airtightness have been recommended to DESNZ (formerly BEIS) for SAP 11 (Etude, et al., 2021). However, fully assessing energy performance in buildings for design rather than compliance purposes would require modifications that allow experienced users to edit the default assumptions used by SAP. The changes required to make SAP compatible with whole building assessment calculation of multi-owner and mixed-use building buildings are significant. It would require extensive industry consultation.

7.2.9 Limitations of PHPP modelling

Unlike SAP and SBEM, PHPP cannot currently be used to generate an EPC for benchmarking or compliance. Therefore, buildings would require two separate assessments (one for retrofit design and one for compliance), unless PHPP was permitted as an approved

[4] The costs in this estimate are based on the experience of a certified Passivhaus Designer in Scotland

methodology for EPCs. There is currently a collaboration between the Association for Environment Conscious Building (AECB), Passivhaus Trust and Elmhurst Energy to develop a common energy reporting process capable of using either PHPP or SAP.

PHPP software cannot generate capital costs for retrofit measures. Costs could be generated as part of an assessment process if provided by the assessor. This would mean that costs would not be consistent across assessments, but they may be more realistic for the building owners.

7.3 Option 3: Best practice from international examples

7.3.1 Overview

Unlike options 1 and 2, this option does not present one specific approach to whole building assessments. Instead, it draws out best practice examples from the countries that were reviewed. Based on these suggestions, it would be possible to design an assessment approach which is tailored to the needs of multi-owner and mixed-use buildings in Scotland, and which would fulfil the identified requirements.

Most of the international examples assess the building as a whole with no distinction between communal and private areas (Table 1). As a result, there are limited examples of best practice for the assessment of individual flats within a whole building assessment.

7.3.2 Data collection

Data collection follows an approach similar to PAS 2035 and is more detailed than for RdSAP. In the examples we found (Section 11), site visits typically take between 1 and 4 hours, during which the assessor gathers information on the type, material, and condition of the building envelope and heating system. This option consists of a risk-based scalable approach to data collection, which ensures that the process is proportionate to the scale of the retrofit being undertaken. This is exemplified by the GTD approach in France, which consists of certain mandatory steps and a number of optional steps. The assessor determines which optional steps are required, based on the complexity of the building and whether it has communal heating. In old buildings an assessor may include the optional step of visiting all flats, rather than the standard approach of visiting a sample of flats. Another optional step is to undertake a week of temperature and humidity monitoring.

Following the approach used in Denmark's EPC and BetterHome plan, the assessor can also be required to collect secondary off-site data such as building plans or data on conservation areas from the local authorities.

An assessor could visit all flats or make general recommendation for flats on the assumptions that they are similar. Most international examples do not calculate heat loss of individual flats, though some assessments will include visits to a sample of flats. Both TH-C-ex and 3CL in France contain an option for calculations for flats in certain circumstances. For example, within TH-C-ex an individual flat would be assessed if it is arranged differently to the rest of the building. However, the focus of the assessment is communal improvements. Within 3CL there is an option for individual flats to pay extra for a specific assessment of the individual flat.

With the exception of Canada, none of the international examples we found appeared to have a post-installation assessment. Canada's EnerGuide assessment requires a post-installation assessment to validate that the work has been completed and provide a measure of energy saved and greenhouse gas emissions reduced as a result of the retrofit. The post-occupancy assessment is required before homeowners receive the Canada Greener Homes Grant (funding is provided as a reimbursement). Germany's Individueller Sanierungsfahrplan (iSFP) and Denmark's BetterHome plan can both include additional meetings as part of the retrofit development process, but only one data collection audit takes place.

7.3.3 Assessor qualifications

For a detailed approach to data collection and analysis, assessors will need to have experience to meet the complexity of the building. This would need to be regulated.

The requisite skills for a whole building assessment can be provided and assessed in several ways. The GTD in France is normally conducted by a multidisciplinary team consisting of both an architect and a heating engineer since the assessment requires a wide range of skills.

In countries where only one assessor is required, the training typically reflects the requirements for the role, for example by requiring an engineering degree or professional experience in a similar field (Denmark, Germany, Sweden). Canada has a robust training scheme for EnerGuide assessors, and early assessments are audited (which, if failed, can result in the assessor re-training) (Etude, et al., 2021).

7.3.4 Data input

Calculation software for this option is designed to allow assessors to input the relevant variables impacting on energy performance. An example of this is EnerGuide in Canada, which allows assessors to change standard assumptions around occupancy, hot water use or appliance use.

The assessment could also make use of data collected off-site through building drawings, as is done for BetterHome in Denmark.

In terms of assessing communal areas, Flanders stood out in this regard with the EPC Common Parts which is used to assess communal areas alone. A building assessment can also be designed to include considerations for multi-use buildings as exemplified by the Danish EPC assessment which divides multi-use buildings into three zones depending on use: Domestic, Office, and Storage. These zones are used to distinguish different temperature requirements and times of use. The assessment produces a single output based on all zones.

7.3.5 Output

Most of the reviewed international examples provide recommendations at building level rather than for individual flats. On this basis it is possible to make general recommendation for flats on the assumptions that they are similar. Recommendations for individual flats require more thorough assessment, as outlined under 'Data Collection'.

Option 3 will produce a highly detailed retrofit plan similar to the Building Renovation Roadmap produced in Denmark, Germany, Flanders and France. The assessment provides a staged plan for retrofit leading to a final low-carbon outcome for the building. It considers the interaction between recommended measures. We have not assessed the comparative risk mitigation of the different international models.

Several cost metrics can be included in the assessment output: capital costs of installations, running costs, cost savings and energy savings, cost-benefit over time. Running costs will depend largely on other potential measures that are installed. Cost savings can be less accurate than energy savings due to fluctuating energy prices.

It was not possible to make an assessment of the relative accuracy levels of the models due to lack of access to the specific costing methodologies. As an example, the Danish EPC provides costed recommendations, as well as annual cost savings. Germany's iSFP contains cost data for each package of measures and includes a comparison of current and future energy costs, as well as CO_2 emissions, energy demand and energy consumption.

EnerGuide in Canada includes energy savings rather than cost savings. Similarly, in France the focus of the GTD is energy savings rather than cost savings. Return on investment figures are provided to building owners, but at a later stage in the assessment process so that energy gains are the primary focus of retrofit decision-making (CoachCopro, 2020).

The examined models did not compare costs of different heating systems. This is likely because cost is not the most important factor in recommending appropriate heating systems. Most of the reviewed countries have more extensive heat network and communal heating infrastructure than Scotland. Therefore factors such as proximity to an existing network may influence recommendations.

Option 3 offers tailored guidance to the building owners. The iSFP assessment in Germany provides two documents for building owners: a renovation roadmap and an implementation guide for measures. BetterHome in Denmark can include an optional retrofit implementation ('project') phase where the adviser is responsible for coordinating installation works.

This option requires a framework to allow the assessment to be linked to the building in a national database. This could be achieved through a building passport scheme such as those in Germany, France and Flanders, or the UK's TrustMark scheme. None of the examples we reviewed appear to have all assessment data inputs available to the building owner. However, some models include more available data than others; for example, Flanders' building renovation roadmap, Woningpas, includes an online logbook featuring energy performance, renovation advice, and various housing data (BPIE, 2018).

Guidance for building owners could be designed to include information on permissions and warrants required. It is likely that assessors would input this information (as with BetterHome in Denmark), rather than an automated process. Whether a building is listed or in a conservation area could be flagged through an automated process, however a building professional would be required to detail which consents are needed for the proposed retrofit work. Similarly, the requirement for planning permission or building warrants are subjective. The assessment process could flag where these may be required.

7.3.6 Cost of assessment estimate

An assessment will likely cost several thousand pounds per building. Some typical costs for the international examples of assessments are provided below for reference[5]:

- Typical figures for an energy audit in France in 2011 were €2,500 to €6,000 (£2,219 to £5,326) for a building with 50 or fewer flats (ADEME, 2016). We would anticipate that these costs are now higher.

- The simplified DPE (French EPC) costs between €1,000 to €4,000 (£888 to £3,551) for the whole building (2016 figures) (ADEME, 2016).

- One assessor in Germany advertises the approximate cost of €2,300 (£2,042) for iSFP for a multi-owner building with four flats (Baupal, 2022).

7.3.7 Limitations

The specific methodology for option 3 would need to be designed, alongside work to identify or develop suitable software for the assessment. As a result, the cost of developing the assessment approach will be the highest of the three options. This option also requires significant upskilling of the workforce, similar to option 2.

As with PHPP, it unclear how option 3 would fit within the existing EPC framework. It is possible to draw inspiration from the reviewed countries to design a whole building assessment which is used either alongside an EPC to fulfil a separate purpose (this would require two building assessments) or to replace the existing EPC framework.

Finally, the reviewed international examples are designed for countries with different heating system landscapes. The installation of communal heating systems is less of a policy priority than in Scotland, and therefore there are limited lessons that can be drawn from the reviewed examples.

7.4 Summary of options

The differences between the three options are illustrated in Table 2. Explanatory notes are numbered and listed below.

We were unable to obtain any figures relating to the cost of developing an assessment approach. Table 2 indicates whether each option would have a high, medium or low cost of development based on the amount of work required to either modify an existing process or develop a process from scratch.

[5] All currency conversions are using xe currency converter (February 2023)

Table 2. Performance of the three options against parameters of interest

	Option 1	Option 2	Option 3
	Assumption-based (RdSAP)	Enhanced energy modelling + PAS 2035	International examples of best practice
Technical			
Suitable for whole building assessment without adaption	no	yes	yes
Assessors are suitably qualified to carry out a whole building assessment	no	yes	yes
Calculates the energy performance (heat loss) of communal areas	no	yes	yes
Calculates the energy performance (heat loss) of non-domestic areas	no	yes	yes
Calculates the energy performance (heat loss) of individual flats	~ 1	yes	yes
Allows assessors to input all variables impacting energy performance	no	yes	yes 10
Requires post-occupancy evaluation	no	yes	yes 11
Process of assessment is sufficient to mitigate risk in installation of retrofit measures	no	yes	yes 12
Management and Implementation			
Established oversight of the methodology in the UK	yes	yes	no
Able to produce an EPC	yes	no	no
Results of the assessment are linked to the building in a national database	yes	yes	yes 13
Input data is accessible to future building occupants/designers/installers	no	yes	yes 14
Available workforce in Scotland to carry out the assessment	yes	~ 5	no
Output			
Running cost estimates	~ 2	yes	~ 15

Capital cost estimates for heating systems	~ 3	yes	yes 16
Capital cost estimates for energy efficiency measures	~ 3	yes	yes
Cost comparisons for heating system options	no	~	~ 17
Guidance for homeowners	~ 4	~ 6	yes 18
Information on permissions and warrants required, potential legal issues relating to joint ownership or metering requirements	no	no	yes 19
Identifies technically feasible and cost-effective communal and/or individual zero direct emissions heating systems	no	~ 7	yes 20
Recommends energy efficiency measures in both individual flats and areas that are commonly owned	no	~ 8	yes 21
Calculation output is reliable to accurately size heating system/heating load	no	yes	yes 22
Scalability			
Assessment can be scaled based on complexity of the building	no	yes	yes 23
Cost			
Cost of assessment is equivalent to those currently used for single buildings	yes	no	no
Cost of development of the assessment approach	low	medium 9	high

Explanatory notes for Table 2

Option 1

1. This is an output of an RdSAP assessment but it has too many assumptions to be considered accurate (Etude, et al., 2021).
2. Running cost estimates are provided but are based on outdated energy costs.
3. Capital cost estimates are provided but are based on standardised figures which are only updated with a new EPC.
4. Guidance is for fabric and services only. It does not consider risk, interaction between measures or the adequacy of ventilation. This cannot be considered as a whole building approach.

Option 2

5. Limited workforce for such assessments as PAS 2035 is not yet a requirement in Scotland. There is a large workforce with transferrable skills (to become a Retrofit Coordinator) but this pool of professionals is smaller than the number of current DEAs.
6. Guidance is provided but is not standardised. Guidance is based on the experience of the Retrofit Coordinator and their professional judgement.
7. Communal or individual heating systems would be identified if specified as an ‘intended outcome’ of the assessment.
8. Energy efficiency measures would be recommended for both flats and commonly owned areas if this is specificed as an ‘intended outcome’ of the assessment.
9. Investment is required to facilitate PAS 2035. If PHPP were to be used for the assessment of multi-owner and mixed-use buildings, it would require national oversight in a similar way to SAP.

Option 3

10. We cannot specify an example of best practice as we did not review the data input and data processing of international energy models as part of this scoping research.
11. The only example of post-occupancy assessments we identified was the EnerGuide assessment in Canada.
12. All examples that include more detailed assessment are more likely to be low-regret.
13. Option 3 is designed to enable this. This could be achieved through a building passport scheme such as those in Germany, France, and Flanders (BPIE, 2016), or the UK’s TrustMark scheme.
14. Option 3 is designed to enable this; however we have not identified any examples where the raw input data is stored and available for future use.
15. We did not have access to specific costing methodologies and therefore cannot assess which example is the most accurate. Generally, cost or energy savings were more common than running costs.
16. Estimated capital costs are provided by most international examples. We have not examined the methodologies for calculating capital costs in the international examples.
17. We did not identify examples of this, but it would be possible to include.
18. The different models provide different level of guidance. Best practice examples include Danish BetterHome and German iSFP as these are centred around the customer experience.
19. In the Danish BetterHome, this is included in the practical design of energy efficiency measures, as the assessor investigates relevant legal requirements. It is not automated.

20. GTD in France contains an additional optional study for switching from individual heating systems to communal.
21. This is possible although not common in the reviewed examples.
22. This is possible depending on assessor skills/knowledge and requirements. For example, a heating engineer is involved in GTD assessment in France.
23. GTD in France is a good example of this.

8 Conclusions

8.1 Current assessment approaches

There are two main limitations that prevent SAP and SBEM from assessing multi-owner and mixed-use buildings for the purpose of retrofit design:

- Outputs from SAP and SBEM cannot currently be combined to produce a single calculation for whole multi-owner or mixed-use buildings
- Both SAP and SBEM were designed as tools to demonstrate compliance with energy efficiency aspects of the building regulations. Therefore, both methods are intended for comparative purposes rather than absolute calculations of building performance.

8.2 Lessons from international examples

The international examples we reviewed are not approaches that have been developed specifically for multi-owner and mixed-use buildings. In most cases, the approaches are used across all building types (single- and multi-owner). Some, such as EnerGuide in Canada, have additional assessments and training requirements for multi-owner and mixed-use buildings.

The international examples demonstrate that several assessment approaches can co-exist and fulfil different functions (i.e., compliance and design). This can be seen in Denmark and France, which have additional assessment approaches beyond EPCs.

Best practice assessment approaches go beyond energy modelling to consider aspects such as building condition, comfort and air quality. These additional elements should be considered if an approach is to be useful in informing retrofit to achieve net zero. Frameworks such as PAS 2035, iSFP (Germany) and GTD (France) encourage a holistic approach to retrofit planning in this way.

8.3 Key considerations for an assessment approach

A whole building assessment should be scalable. This removes the risk of data gathering for assessment purposes becoming disproportionate to the scale of the retrofit.

A solely desk-based assessment is not appropriate for this purpose. A site visit is necessary to gather information. In-situ testing could also be carried out, determined by the complexity of the building.

An assessment for the purpose of retrofit design cannot rely on generic inferred data on occupancy and energy consumption. The assessment could include operational data or use a series of detailed profiles for different building types and household types, similar to those currently used by SBEM.

Due to the complexity of multi-owner and mixed-use buildings, software-generated improvement measures alone are not appropriate for retrofit design. These should either be checked or specifically recommended by a qualified professional.

8.4 Developing an approach for Scotland

We outlined three options for how a whole building assessment methodology could be developed in Scotland. The options illustrate a range of costs, both of assessment and development, and a range in the level of detail and accuracy.

Option 1 is a low-cost option, based primarily on assumed data rather than measured data. It involves updating RdSAP to complete a whole building assessment. The advantages of this option are that it can use the existing DEA workforce and the management arrangements associated with producing EPCs.

However, SAP must be modified in order to assess communal and non-domestic spaces. Additionally, an assumption-based assessment such as RdSAP cannot adequately consider the risk associated with the retrofit of multi-owner or multi-use buildings. This may lead to defects, a ‘performance gap’ and unintended consequences such as damp or moud.

Option 2 is a detailed assessment approach using either full SAP or PHPP modelling alongside PAS 2035. This option is a holistic retrofit assessment, rather than an energy performance assessment, and is designed to mitigate the risk of unintended consequences of retrofit.

Infrastructure for PAS 2035 training, qualifications and certification is already being put in place by DESNZ (formerly BEIS) but must be scaled up. Changes to SAP and PHPP modelling approaches are also required for the development of option 2. SAP requires more detailed inputs to be used as a design tool and modifications to assess communal and non-domestic spaces. PHPP requires national oversight arrangements and significant upskilling of the workforce.

Option 3 draws on examples of best practice from the international examples that were reviewed. It has the highest associated development costs as it does not build on any approaches already used in Scotland. Like option 2, option 3 is designed as a holistic assessment approach, which aims to mitigate the risks of retrofitting multi-owner and mixed-use buildings. The main limitation of this option is that direct comparisons cannot be made between the international examples and Scotland, particularly in terms of the management of multi-owner buildings, the prevalence of communal heating and the need to assess individual flats as well as whole buildings. However, there are other areas of best practice that could be incorporated into a whole building assessment approach for Scotland.

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10 Research Methodology

1. Research Framework

We developed a research framework which contained specific research questions, appropriate search terms and evidence inclusion and exclusion criteria.

A large part of this task was identifying the different terminology for "multi-owner" and "mixed-use" buildings, as well as different terms for "whole building assessment". Search terms were developed to ensure that our searches would pick up as many international examples as possible, regardless of the different terminology used.

As part of the research framework we also defined "Whole Building Assessment" and identified the component parts and tools which might be used during an assessment (see Table 3).

Table 3. Research framework: parts of a whole building assessment

Whole Building Assessment		
"What needs to be measured"	"Ways of measuring it"	
	Methods for measured data	Methods for modelled data
Heat cost efficiency	• Energy consumption monitoring	• Energy modelling
Building condition	• Physical inspection • Thermal imaging • Air pressure testing • Moisture probes • Moisture analysis	• Industry agreed conventions • Technical modelling
Heat demand (fabric efficiency)	• Co-heating test • Triage of temperature, relative humidity, and energy consumption monitoring • Thermal imaging • Air pressure testing • In-Situ U-Value testing	• Energy modelling • Energy modelling • Technical modelling

2. Scoping

A long list of 22 'countries of interest' was developed. Based on relevance to the Scottish context and the availability of information on their building assessment process this list was distilled down to nine international examples (including PHPP).

'Similarity to the Scottish context' was defined in terms of:

- Age profile of the country's building stock.
- Multi-owner and mixed-use buildings proportion of building stock.
- Ownership and management structures in multi-owner and mixed-use buildings.

3. Data gathering

Data gathering was conducted as a desk-based review of literature available online. The aims of the data gathering exercise were to:

- Gain an understanding of the assessment approaches in the international examples identified.
- Understand potential costs of developing and managing methodologies.
- Gather stakeholder opinions on the options for developing a whole building. assessment approach in Scotland for multi-owner and mixed-use buildings.

We also sought input from expert stakeholders through calls and email correspondence. A total of 42 stakeholders, identified as industry experts, were contacted for input into the research, and 14 provided contributions.

10 Stakeholders from the following organisations contributed through a video call:

- Boverket (Swedish National Board of Housing, Building and Planning)
- Building Research Establishment (BRE)
- Building Research Solutions (BRS)
- Carbon Futures
- GreenGeneration
- Sustenic
- Royal Institution of Chartered Surveyors (RICS)

Stakeholders from the following organisations contributed via email correspondence:

- Danish Energy Agency
- EALA Impacts
- Frankfurt Energy Department
- The Paris Climate Agency

4. Analysis of international examples

Following the data gathering we conductive a comparative analysis of the international examples of assessment approaches. The analysis focussed on the following aspects of the approaches:

- Accuracy
- Reliability
- Cost
- Ease of use
- Necessary qualifications and workforce
- Adaptability (for multiple building types, or the ability to conduct more detailed assessments for complex cases)
- Detail of output for householders

5. Development of options for whole building assessment approach

Based on the research findings we developed three options for how a whole building assessment methodology could be developed. For each option we outlined:

- The types of skills and workforce required
- An estimate of the cost of the assessment for property owners
- The steps needed to develop and manage the assessment approach
- The limitations of the approach

Information on the four factors listed above was not available for every option.

11 International examples

To outline their relevance to the Scottish context we have highlighted the percentage of multi-owner buildings, and the age of the building stock. The age of building stock gives an indication of the construction type. For example, pre-1919 is used to determine 'Traditional' buildings which are associated with solid wall construction methods and materials such as wood and stone.

Different countries use different proxy dates to categorise national housing stock. Some of the reviewed countries had data available for pre-1919 and others pre-1945. In Scotland, 19% of all occupied dwellings (not buildings) were built pre-1919, and 30% pre-1945 (Scottish Government, 2020).

Without further analysis we were not able to access data on multi-owner and mixed-use buildings in Scotland. The available Scottish data relates to individual dwellings. Of all occupied dwellings in Scotland, 37% are tenements or other flats (i.e. the dwelling is one of multiple within one building), and 14% of these are pre-1945 (Scottish Government, 2020) (Table 4).

Of Scotland’s 2.6 million dwellings, 15% are private rented (or the household is living rent free), and 23% are social rented properties (Scottish Government, 2022).

We have also highlighted any relevant similarities or differences in terms of building management and ownership structures, and the prevalence of communal heating systems.

Table 4. Proportion of Occupied Dwellings in Scotland by age and type. Data from SHCS 2019

	Type of Dwelling					
Age of Dwelling	**Detached**	**Semi-detached**	**Terraced**	**Tenement**	**Other flats**	**Total**
Pre-1919	5%	2%	3%	7%	2%	**19%**
1919-1944	2%	3%	1%	1%	4%	**11%**
1945-1946	1%	6%	7%	4%	3%	**21%**
1965-1982	5%	4%	7%	4%	2%	**22%**
Post-1982	10%	5%	3%	7%	2%	**27%**
Total	**23%**	**20%**	**21%**	**24%**	**13%**	**100%**
Sample Size						2997

11.1 Canada

Framework: EnerGuide

EnerGuide Ratings (expressed in gigajoules per year) are used for national benchmarking of building performance. There is an additional level of service which is used to produce Renovation Upgrade Reports (Natural Resources Canada, 2023) for the purpose of retrofit.

Energy model: HOT2000

Strengths:

- Based on an energy usage metric rather than cost, which is more useful for the purpose of retrofit design.
- Considers both regulated and unregulated energy use.
- Uses specific efficiency values for systems, which improves the accuracy of energy calculations (in comparison to using assumed values).
- Includes consideration of thermal bridging (inferred from wall, floor and roof construction types) and overheating.
- Assessors provide comments and guidance specific to the property and based on building condition.

Limitations:

- Assessors' recommendations lack detail when compared to fuller energy audits (Wohngluck, 2022), (BPIE, 2018).
- Flats do not get an individual assessment.
- Prices for retrofit measures are not provided.
- Used for low rise multi-owner buildings only (three or fewer storeys). High rise buildings are assessed as commercial buildings using an ASHRAE energy audit.

Building stock and heating infrastructure: A similar number of multi-owner buildings to Scotland (34%) (Statistics Canada, 2017). The majority (70%) of multi-owner buildings are rented (Canada Mortgage and Housing Corporation, 2016). Most multi-owner buildings have individual heating and cooling systems in each flat, although some older buildings have communal gas boilers.

Building Management: Condominium associations are a legal requirement and are used to manage the repairs and maintenance of all common areas. They are managed by an elected board of directors ('Condo Board'). In practice most Condo Boards employ a management company.

Regulatory Context: There are no national energy requirements for buildings. City and provincial authorities may implement their own regulations. EnerGuide assessment is a requirement for accessing the national Greener Homes Grant. EnerGuide and HOT2000 are also used to assess compliance with voluntary standards such as BC Energy Step Code (a standard in British Columbia which seeks to go beyond legal Building Standards).

Assessment Process: The entire building structure, including all units and common areas, is assessed in a single assessment. Flats do not get an individual assessment. EnerGuide is only used for blocks with fewer than 6 apartments. Larger blocks are treated as commercial buildings and are assessed using ASHRAE Energy Audits (Canada Energy Audit, 2022).

The assessment includes:

- Visual inspection and measurement to determine surface area and insulation levels.
- Manufacturer efficiency values (from appliance manuals) for mechanical systems (heating system, air conditioning system, ventilation system, and domestic hot water). If manufacturer figures are not available default values from HOT2000 are used.
- Blower door test to detect air leakage and measure air changes per hour.
    - Depressurisation test where required. This is to test for combustion spillage which is the flow of harmful combustion gases (such as carbon monoxide) back into the home. This is a risk in buildings with high levels of air-tightness and inadequate ventilation.
- The EnerGuide rating (used for national benchmarking) rates the house independent of occupant behaviour. However, the occupancy and energy usage of households is incorporated for calculating the 'Estimated Household Energy Use' figures on the report for householders. These figures are also considered as part of the recommendations of measures.

Accuracy: Heat demand is modelled rather than measured. Where possible efficiency values of mechanical systems are used as inputs, rather than assumed values. However, the efficiency stated by manufacturers will differ from the actual in-use efficiency of appliances.

Intrusiveness: A pre- and post- assessment are carried out, each lasting 2-3 hours. Air blower test requires prior preparation from the householder, and for fuel-fired heating or water systems to be switched off. Householders are asked to provide appliance manuals and to comment on any existing problems and planned renovations.

Improvement Recommendations: A roadmap of improvements is provided. These are a combination of recommendations generated and prioritised by HOT2000, and some suggested by the assessor. Recommendations are prioritised to be fabric first based on house-as-a-system concept.

Costs for improvements are not provided in the Renovation Upgrade Reports. Potential energy reduction figures are given.

EnerGuide does not flag any legal requirements as part of its recommendations because building codes and by-laws differ by province in Canada.

Heating system considerations: EnerGuide is closely linked to the Greener Homes grant programme. Under the grant programme multi-owner buildings (known as MURBs) with three or more units are not eligible for heating upgrades, but all other measures are eligible. To make an assessment for communal heating a more in-depth survey would be required[6].

Adaptability: EnerGuide is used for both multi-owner and mixed-use buildings. In mixed-use building an additional risk assessment is required. This ensures that the non-domestic space can be appropriately assessed alongside domestic spaces. It highlights any precautions that

[6] Such as a commercial building energy analysis ASHRAE

may need to be taken in the assessment, for example to account for processes and equipment that generate a large amount of heat or building configurations which may impact on blower door tests (Natural Resources Canada, 2015)[7].

Costs: Not regulated and vary dependent on the assessment organisation. Based on the costs from one provider (Greener Homes, 2022) the pre and post assessment for a block with 5 flats would cost $2500 (+ tax) (approximately £1500).

Qualifications and Training: Assessments are completed by government registered energy advisors, who must pass two exams and be affiliated with a licensed Service Organisation. There is an additional exam for MURBs. There are no particular pre-requisites for training.

11.2 Denmark

In Denmark, the national energy calculation programme Be18 is used to produce two different outcomes: an EPC, and a BetterHome plan. These two frameworks each address different aspects of the energy efficiency improvement process.

Building stock and heating infrastructure: The building stock is similar to that of Scotland. 41% of dwellings are in multi-owner buildings (Entranze, 2008), and 21% of these dwellings were built before 1919 (Danmarks Statistik, 2020). Unlike Scotland, most multi-owner buildings are supplied by district heating (66% of the entire building stock) (Danmarks Statistik, 2022), (Quartz+Co, 2015). Two thirds of this heat come from combined heat and power plants.

Building management: In multi-owner buildings with individual ownership of the units, all owners are legally required to be part of an owners' association which is responsible for the maintenance of common spaces and heating systems. In urban areas it is also common for buildings to be owned by a housing cooperative, which in those cases are responsible for common spaces and heating systems.

Regulatory context: EPCs have been issued in Denmark since 1997. The current scheme has been in place since 2006 following the implementation of EPBD. Unlike Scotland, the whole building is assessed. EPCs are a legal requirement when a building is rented, sold, or built. An EPC is valid for 10 years. Access to and guidance on the calculation programme Be18 is delivered through SBi instruction 213.

11.3 Denmark: EPC

Framework: EPC (energimærkeordningen)

Energy model: Be18

Strengths:

- The calculation software is flexible and allows for data from in-situ testing to be included where it is available.
- Emphasis on heat-loss through thermal bridges results in a realistic account of the building's energy efficiency (similar to PHPP).

[7] see Appendix A: Risk Assessment of Mixed-Use Buildings

- Highly specific regulations ensure uniformity across buildings.
- Calculation programme allows detailed descriptions of individual building parts, such as distinct U-values for eight different window types (similar to PHPP).
- Recent framework changes have made the recommendations more specific and easier to implement.

Limitations:

- Recommended improvements and cost-savings may not match the experience of the householder.

Assessment process: The assessment covers the whole building and requires access to common spaces such as loft, basement, and stairwell. It is not necessary for the assessor to visit the individual flats if sufficient information is provided by the owner. The calculations account for a large number of parameters. The energy consultant must follow a strict set of rules outlined in 'Handbook for Energy Consultants' (Energistyrelsen, 2022).

Accuracy: The heat demand of the building is based on a visual inspection and standardised assumptions, rather than in-situ tests and consumption data. The calculation takes into account a large number of inputs relating to the material and condition of the building envelope. The consultant is required to assess whether the observed data matches the building drawings and registered data.

Intrusiveness: The assessment is carried out during one visit lasting one hour or more, depending on the size of the building. If there is not enough data available, and if the owner consents, a 'destructive' assessment may be carried out. This could include drilling into the wall to determine insulation type and thickness.

Improvement recommendations: Improvement recommendations are divided into 'cost-effective' and other improvements. 'Cost-effective' recommendations are defined as those where the associated savings cover the cost of the investment before the component must be replaced. As such, the definition includes an estimate of the lifespan of the components of the energy saving investments. Recommendations in this category are costed, and annual savings are estimated. The recommendations are considered to be highly tailored, with distinct recommendation for flooring, walls, loft, insulation, heating system, and electricity (X-tendo, 2022). Additionally, an EPC must include if there is potential to install solar PV and heat pumps. The assessor is not required to advise on potential required planning permissions.

Heating system considerations: If the building is not already part of a district heat network, the assessor must consider if it is possible to achieve energy improvements by upgrading the boiler, changing the boiler type, installing solar PV or heat pump, changing the heating system, or connecting to an existing district heat network. EPCs are not currently required to include considerations for other communal heating systems.

Adaptability: The same framework and calculation programme is used for residential, commercial, and mixed-use buildings. For mixed-use buildings, the EPC calculation can include different 'zones' to account for the different energy needs of the building. There are three zones: residential, office, and storage. EPCs are issued for both existing and new buildings.

Costs: The Danish authorities sets a maximum assessment cost for smaller buildings within different size brackets (Energistyrelsen, 2023). The figures below are converted based on Bank of England Exchange rates (Bank of England, 2022):

- <100 m^2: £724
- 100-199 m^2: £797
- 200-299 m^2: £869

There is no upper cost limit for larger residential and commercial buildings.

Qualifications and training: EPCs are carried out by a certified energy consultant who must be employed by a certified energy certification company. Energy consultant certification is achieved by attending course worth 10 ECTS (European Credit Transfer and Accumulation System) (European Education Area, 2023). Two years of experience in a relevant field is required.

11.4 Denmark: BetterHome

BetterHome is a one-stop-shop initiative with the aim to make it easier for building owners (such as home-owners, housing cooperatives, and owner associations) to retrofit of their home. It was initially designed for single-family buildings but has been expanded to include multi-owner buildings as of 2017. It is a voluntary, market-based scheme developed by four companies and the Danish Energy Agency. The scheme contains two parts: a plan, which provides an overview of potential improvements and costs, and a project, where the adviser coordinates the installations from start to finish (X-tendo, 2022).

Framework: BetterHome (BedreBolig)

Energy model: Be18

Strengths:

- Provides a very high quality of recommendations that are tailored to both the needs of both the householders and the building.
- The project phase of BetterHome makes the installation of retrofit measures more achievable and successful.
- Supports householders to achieve a higher EPC rating.

Limitations:

- BetterHome is more expensive and time-consuming than an EPC, and it requires a high level of engagement from the building owner.
- It is unclear how the process is carried out in larger multi-owner buildings with several owners with different priorities and energy usage.

Assessment process: The BetterHome assessment uses the same calculation programme (Be18) as an EPC assessment, and an existing EPC is commonly used as part of the assessment input. The process is longer and with a greater focus on the specific needs and interest of the building owner. If the BetterHome plan is approved by the owner, the advisor goes on to develop and coordinate the retrofit project from start to finish (NIRAS, 2016).

Accuracy: The assessment uses similar input to EPC (see above).

Intrusiveness: The duration of the assessment varies widely depending on the size of the building and the needs of the owner. Because a BetterHome plan is optional, the assessment is not required to consider all parts of the building unless requested by the building owner. Multiple meetings will follow the assessment if the building owner decides to pursue the project stage.

Improvement recommendations: The main output of the BetterHome plan is a list of recommended actions, such as insulation of pipes or certain parts of the building fabric. These are tailored to the priorities of the building owners and, unlike the EPC, can include recommendations related to energy use and habits.

Heating system considerations: There are no legal requirements for the heating system to be considered, but a BetterHome plan will typically include suggestions relating to the heating system. As noted above, most multi-owner buildings are already connected to a district heating network. If connection is not possible, ground- or air-source heat pumps may be recommended.

Adaptability: BetterHome was originally developed for single-family homes only. In 2017 it was expanded to include multi-owner buildings. It was difficult to find information about how larger multi-owner building owners and owner associations are engaging with the initiative. It appears that there is an option to request a BetterHome plan for only part of a building.

Cost: The cost of a BetterHome plan is around £700, though it may be higher for larger buildings (NIRAS, 2016).

Qualifications and training: The BetterHome plan and project is carried out by a certified BetterHome advisor. Certification is achieved by taking a specific BetterHome course, which requires at least two years of experience in the field.

11.5 Flanders, Belgium

Framework: EPC

Energy model: Software for EPC common parts

The Flemish Government and Climate Agency have an approved certification software programme for the calculation of the EPC common parts (Flemish Energy and Climate Agency, 2023). It takes into consideration the building envelope and any communal space heating, hot water, ventilation, lighting or solar (Solvari, 2023). The method is primarily used to encourage staged retrofit at the communal level.

Strengths:

- Supports co-owners to consider upgrades at the building level.
- Options to use known input data or standardised assumptions.
- Relatively inexpensive.
- Optional additional testing available.
- Woningpas (Building Passport) digital file stored on a government database (European Commission, 2023).

Limitations:

- Energy experts cannot amend the recommendations that are produced by the software.
- Prices are not provided.
- Does not consider how individual dwellings interact with communal areas.

Building stock and heating infrastructure: In both Scotland and Flanders approximately 14% of flats were built pre-1945 (European Commission, 2017)[8]. The average number of dwellings per multi-owner building in Flanders is 6.5 (European Commission, 2017). Most buildings are heated with natural gas boilers. Like in most other of the European countries we consulted, multi-owner buildings are usually heated by one boiler located in the basement (unless connected to a district heat network) – this system is called 'central heating' outside of the UK.

Building management: Owners of an apartment within a multi-owner building own their individual dwelling and a share of the common areas**.** An owners' assembly takes place at least once per year. It is common for the owners' association to contribute to a reserve fund to assist with large one-off works (DeLanghe, 2019).

Regulatory context: Upon selling or renting a property, both an individual apartment EPC and an 'EPC common parts' are required (Flemish Government, 2023). EPC common parts was introduced in 2022 to inform the owners of each residential unit about the collective steps they can take to make the building more energy efficient. An energy efficiency 'grade' or 'class' is not supplied.

Assessment processes: The heat demand and heat cost efficiency are calculated using the approved software. The energy expert must follow strict set of rules and working methods outlined in an 'inspection protocol' (Flemish Energy and Climate Agency, 2023).

Accuracy: Heat consumption is based on standardised assumptions and bills are not required from the householders. Heating demand is calculated from several inputs based on the actual condition and observed information from the building. For example, specific boiler types, window makes, insulation thickness etc. can be recorded or looked up using the software and included in the calculation. No physical testing takes place.

Intrusiveness: One visit takes place and although no physical testing is required detailed information on the characteristics of the insulating envelope of the building (walls, floors, ceilings etc) and building condition (year of construction, type of building, etc) are collected. Energy experts therefore request that, where possible, as much of this information is provided to them prior to the visit (Flemish Energy and Climate Agency, 2023). This data collection exercise could be time consuming for householders.

Improvement recommendations: Although no physical testing is required, due to the large number of inputs, recommendations are relatively detailed. However, they are generated automatically, and the energy expert cannot adjust, remove or change the order of the recommendations (Flemish Government, 2023). Capital costs are not included. The

[8] stats based on 2014 data

recommendations therefore provide a first level of information to owners regarding communal works, but it is recommended that as a next step owners get a construction professional or architect to use the EPC to assist them in planning the most logical execution of the necessary works.

Heating system considerations: It was unclear if the EPC Common Parts framework requires that the energy expert makes specific recommendation relating to the heating system and, in that case, what those recommendations could look like.

Adaptability: The model can be used for new and existing residential multi-owner buildings. Owners can request that additional measurements are taken (e.g., checking the type and thickness of internal wall insulation) but this is not a requirement and standard assumptions can be used instead.

Costs: Estimated costs for the EPC common parts assessment are as follows (Solvari, 2023):

- >16 units € 600 + € 10 per apartment
- 5-15 units € 300 + € 20 per apartment
- 2-4 units € 300 + € 15 per apartment

The certificate is valid for 10 years but expires if major retrofit is conducted (e.g., 15% of the building envelope is insulated, any collective heating is replaced). The cost of the assessment is not regulated.

Qualifications and training: only an energy expert 'type A' can carry out a residential EPC inspection (Flemish Government, 2023). The course and exam can be taken by anyone. Those with a 'relevant' background degree e.g., an engineer or architect can take an accelerated course (EPCInvest.be, 2023).

11.6 France

We identified two energy models being used for whole building assessments in France: 3CL and TH-C-ex, which are discussed in turn below.

Building stock and heating infrastructure: A similar proportion of buildings are multi-owner (44% of dwellings are multi-owner in France, and 37% of buildings in Scotland.) Multi-owner buildings are generally older in France than they are in Scotland. The average number of dwellings per multi-owner building is 7.6 (Entranze, 2008). Communal heating (known as collective heating) is widely used in multi-owner buildings.

Building management: The ownership structure differs to Scotland in that there is a legal requirement to form a 'copropriete' (co-ownership) (Smith, 2019). For buildings in co-ownership, retrofit measures such as heating upgrades must be voted on unanimously.

Regulatory context: Under the Energy Performance of Buildings Directive (EPBD) France developed the Diagnostic de Performance Energétique (DPE), the French equivalent of an EPC. Unlike Scotland, all DPEs are conducted at building scale (Ministère de la Transition énergétique, 2023). Additional regulations for multi-owner buildings are also in place. For example, a Global Technical Diagnosis (GTD) is mandatory if:

- The building presents a danger to the health or safety of occupants.
- A building is more than ten years old and is newly divided into flats.
- Co-owners vote for a GTD by a simple majority during their general meeting (Public Service France, 2023).

11.7 France: 3CL

The 3CL calculation is a steady-state energy model used for the DPE. It calculates the energy consumption of the building using a large amount of input data (Lartigue, et al., 2022). To make the calculation of the energy consumption easier, the French Government has certified several software packages which are based on the 3CL calculation.

Under the DPE, the calculation method is primarily used for benchmarking purposes. It can also be used for retrofit design under the GTD[9].

Framework: EPC (known as DPE)

Strengths:

- Provides a first level of information to owners for a low modelling cost (Senova, 2016).
- Offers the possibility to create an individual DPE from the DPE-collective but this is only possible where similar heating, cooling, domestic hot water and ventilation systems are in place (e.g., communal heating, or where all flats have the same heating systems).
- Includes a temperature profile based on geographical location. This means that calculations will be more accurate than models that rely on a standardised temperature profile for a large region or country.

Limitations:

- The method is based on standardised assumptions of occupancy and occupants' behaviour (Exacompare, 2020). This is only a limitation if the assumptions cannot be edited to inform further analysis.
- Does not provide sufficient accuracy to effectively improve the energy performance of buildings.

Assessment processes: To carry out a DPE at the building scale there are minimum requirements around the number and location of individual units in a building that must be visited as part of the assessment (AC Environnement, 2021). Heat demand is calculated for the whole building, rather than individual flats. This calculation accounts for a large variety of parameters including heat losses through the building envelope; heat transfer due to air exchange; energy consumption of the ventilation auxiliaries; solar gains; and thermal inertia. Heat consumption is calculated from the heating demand by considering the power

[9] 3CL can also be used for a "simplified version" of the Global Technical Diagnosis (when apartments have individual heating, less than 20 units, or collective heating with less than 50 units). However, it doesn't have to be used in these circumstances, the "complete" energy model (see TH-C-ex) can be used instead.

efficiency of the heating system(s) and the heating degree hours based on geographical location (Lartigue, et al., 2022), (Legifrance, 2021).

Accuracy: The 3CL method does not require in-situ testing or consumption monitoring. It uses a mix of measured and modelled data as observed information can be input in the software (e.g., the type of heating system and its age). The inclusion of geographical location is also included. This means that calculations will be more accurate than models that rely on a standardised temperature profile for a large region or country.

Intrusiveness: One visit takes place, and the assessment is relatively unintrusive as no in-situ tests are required. The accompanying building inspection is moderately detailed and considers characteristics of the insulating envelope of the building (walls, floors, thermal bridges etc.) and building properties (region, altitude, orientation etc). Approximately one hour per $100m^2$ is required by energy experts (Engie, 2018).

Improvement recommendations: Recommendations are made by the assessor based on the outputs from the software. They include estimated costs; cost savings and priority works (Ministère de la Transition énergétique, 2023). The recommendations provide a first level of information to owners but are not detailed enough to support significant improvements in the energy performance of the building (Acceo, 2022).

Heating system considerations: 3CL is used to assess buildings with communal heating. We could not ascertain whether 3CL would be used to recommend communal heating in a building where flats currently have individual heating systems.

Adaptability: The model is adaptable as it is used for all buildings receiving a DPE. This means new and existing domestic (including multi-owner) and non-domestic (including mixed-use) buildings are assessed using the same method. It can also be adapted for different heating set ups – both communal and individual systems.

Costs: The DPE costs between €1,000 and €4,000 for the whole co-ownership (ADEME, 2016). Assuming the average number of dwellings to be 7.6 this equates to €132 – €526 per owner. DPE is valid for 10 years and the price is not regulated.

Qualifications and training: The collective DPE must be carried out by a certified diagnostician. This expert must have professional liability insurance and hold a DPE certification "all types of buildings". The level of qualification required is higher than that of an individual apartment DPE (Hellio, 2023)[10]. In addition, diagnosticians must use the approved calculation software.

11.8 France: TH-C-ex

TH-C-ex was developed and defined by the Centre Scientifique et Technique du Bâtiment (CSTB) and is used for energy audits of existing buildings. The calculation is completed by

[10] Individual owners can request a separate apartment DPE if they want one, but this does not remove the requirement to have a building scale DPE

using approved software (Arobiz, 2023) and TH-C-ex is used for several types of energy audit including the Global Technical Diagnosis (GTD) (Public Service France, 2023)[11].

Under the GTD, TH-C-ex is used to support multi-owner property upgrades and retrofit. TH-C-ex is also used to assess if renovations meet the Passivhaus Standard or the BBC Label (low consumption building label).

Framework: Global Technical Diagnosis (GTD)

Strengths:

- The GTD is a more thorough process than that used to produce a DPE as behavioural calculations and physical measurements are considered (including an architectural audit).
- Recommendations are detailed and organised into staged packages of works.
- The framework outlines base and optional assessments and either steady-state or dynamic modelling can be used.
- It is a good example of targeting expertise in the most complex buildings to give retrofit advice.

Limitations:

- Building usage scenarios (e.g. assumed heating temperatures) are standardised. The values used do not reflect commonly observed heating practices (Senova, 2016).

Assessment processes: The assessment to conduct the GTD uses precise calculation formulas. These determine the primary energy consumption of an existing building accounting for heating, cooling, lighting, ventilation, auxiliaries and the preparation and storage of DHW. The heat demand and heat cost efficiency of the whole building are calculated using the software. Consumption is presented in both delivered and primary energy.

Accuracy: The GTD requires a complete analysis of the existing property and the software uses a mix of modelled and measured data (similar to PAS 2035). Physical tests and observed information are gathered to provide data on:

- indoor temperatures
- wall temperatures
- indoor humidity
- masonry thickness of exterior walls
- thickness of visible insulation
- height under ceilings
- measurement of ventilation flows (if ventilation has ducts)

[11] The GTD is a holistic tool designed to inform condominium owners in France about all key technical and thermal aspects in their buildings. The aim is to encourage owners to implement a programme of works, with a particular focus on energy efficiency. It includes a list of works necessary for the conservation of the building, their cost and summary of measures to be carried out over the next ten years. The GTD uses a methodology that is adaptable for all sizes of multi-owner building, including those with collective and individual heating.

- wall humidity level

Where possible, actual consumption is included in the software and owners supply energy bills from the past three years (CoachCopro, 2020). The model is more accurate than 3CL due to the ability to include data from physical tests.

Intrusiveness: One visit takes place (an energy and full architectural audit), and physical tests are required. Details from the architectural audit are not included in the TH-C-ex calculation however they are used to inform the recommendations made to householders. Owners can also opt for a more detailed weeklong 'measurement campaign' which would require two visits.

Improvement recommendations: Recommendations are automatically produced by the software. They include costs, return on investment and priority works. Potential financial aid is also indicated in a general manner without quantification. The recommendations are then tailored by the auditor to support significant improvements in the energy performance of the building over a ten-year period. They are organised into three categories (CoachCopro, 2020):

- Priority 1 - short term or urgent works
- Priority 2 - medium term
- Priority 3 - long term

Auditors are required to produce at least two different work plans for the ten-year period (CoachCopro, 2020).

Heating system considerations: TH-C-ex uses static thermal modelling as standard. There is an option of dynamic thermal modelling if required by the complexity of the building or intended outcomes. The methodology refers to an additional optional study for switching from individual heating systems to communal (and vice versa) (CoachCopro, 2020).

Adaptability: TH-C-ex is appropriate for existing buildings only, and a separate model is used for new buildings. This means that existing mixed-use and multi-owner buildings can be assessed using the same method. However, the GTD framework is specifically aimed at multi-owner residential buildings so it is unclear whether this could also be used for mixed-use or non-domestic properties.

Costs: Estimated costs for the full GTD assessment are extremely varied and depend on the number of dwellings as well as the type of firm or professional hired. The adaptability of the method with base and optional assessments also leads to variation in costs. The GTD was reported as more expensive than the DPE assessment. For smaller buildings (i.e., 4-7 units) the cost is approximately €1,200 and for larger buildings (i.e., 16-19 units) €2,700. Estimates include auditor fees, travel, and the submission of the report (Exacompare, 2021).

Qualifications and training: the TH-C-ex calculation must be carried out by a certified professional. The full GTD course is approximately 35 hours over five days, which is similar to the PAS 2035 Retrofit Coordinator course. A three-year diploma in a 'relevant' field (e.g., certified real estate diagnostician or thermal engineering qualification) is required as a pre-requisite for the course (Afnor competences, 2023).

11.9 Germany

Framework: Individueller Sanierungsfahrplan (iSFP)

Energy model: DIN V 18599 in iSFP software

DIN V 18599 is the national calculation methodology used in Germany to assess the energy performance of buildings[12]. It calculates the useful, final and primary energy requirements for heating, cooling, ventilation, domestic hot water and lighting (energy balance) of buildings (Beuth, 2018). Since 2017, it has also been used for iSFP software to produce an individual building renovation roadmap (iSFP).

Strengths

- Accessible and easy to understand documents (Wohngluck, 2022).
- Offers options for staged or one-off energy renovations.
- Financing available for the audits (BPIE, 2018).
- Strong focus on consultation with co-owners and designing for their needs.

Limitations:

- Lacks depth in comparison to more complete energy audits (which provide 150-page reports) (Wohngluck, 2022), (BPIE, 2018).
- It is unclear how many inputs are required for the calculation and how in-depth the measured data needs to be.
- It provides a snapshot that may become redundant over a short period of time.

Building stock and heating infrastructure: Around a fifth of multi-owner buildings are pre-1945, similar to Scotland (14%) (Entranze, 2008). The average number of dwellings per building is 7.7 (Entranze, 2008). Like in Scotland, natural gas boilers are the most common heating system (48%). 14% of dwellings are supplied by district heating (BDEW, 2019). Most buildings have a building-wide heating system and communal boiler, rather than individual boilers in each dwelling. This heating system is called 'central heating' (Zentralheizung) and can use either a gas or oil boiler.

Building management: Owners form a legally-required condominium association which is a self-governing body that meet on an annual basis to vote on any building related issues.

Regulatory context: In 2017 Germany introduced a new software-based tool for retrofit called an individual building renovation roadmap ("Individueller Sanierungsfahrplan" - iSFP). This is an optional assessment that can be used to improve the energy efficiency of buildings (Federal Ministry For Economic Affairs And Climate Action , 2023).

Assessment processes: the iSFP assessment follows a seven-step process.

1. Initial consultation with owners, data on the building condition and services are recorded and user requirements are discussed.

[12] DIN 4108-6 and DIN 4701-10 are alternative methodologies however these are due to expire.

2. The energy performance of the building is calculated using balancing software.

3. Based on the meeting with owners, the data and calculations, refurbishment proposals are drafted.

4. The proposals are discussed with the owners to agree on the final refurbishment concept.

5. The iSFP and the implementation instructions are elaborated in detail.

6. The iSFP is printed and handed over to the owners.

7. The iSFP and the individual documents are explained, and questions clarified in a final meeting with the owners. Two documents are provided – a renovation roadmap and guidelines for renovation measures (Gebaudeforum Klimaneutral, 2022).

Accuracy: The inputs are based on a mixture of modelled and measured data. Where actual data is available it can be inserted into the calculation. For example standard or specific indoor temperatures can be included in the model (i.e., room temperature set on the thermostat) (Bundesministerium für Wirtschaft und Klimaschutz, 2020). Detailed information in relation to the building condition is also gathered. It considers:

- the envelope (walls, roof, windows, floors)
- systems (heating, hot water preparation, heat and hot water distribution, including storage and transmission, ventilation)
- 'quality assurance' (thermal bridges and airtightness)

Where possible, bills are required from the householders; however, these are only used to calculate energy costs. Where bills are unavailable, "typical consumption" values are used (Gebaudeforum Klimaneutral, 2022)[13].

Intrusiveness: Two visits take place. One is for data collection and initial consultation, and the second is a meeting at handover stage. It is recommended that half a day is needed for the first visit. The assessment is relatively unintrusive.

Improvement recommendations: The iSFP has been designed to be a user-friendly tool that includes both short and long-term measures and suggests ways to avoid lock-in effects. Recommendations include estimated costs, cost savings and priority works. Auditors design a comprehensive package of measures to achieve deep renovation considering the owners' specific needs with the aim of successfully nudging them to initiate deep renovations. The recommendations are tailored to support significant improvements in the energy performance of the building over a fifteen-year period (Green Home, 2022).

Heating system considerations: It was unclear if there are specific requirements relating to heating system upgrades. Common heating system upgrades are from communal oil to communal gas boiler, or from communal gas boiler to district heating, if available (BDEW, 2019).

[13] "Typical consumption" was derived by the Institute for Housing and Environment from a sample of 1,700 buildings. It is based on the average heating energy consumption that a building of the same size and the same energy standards.

Adaptability: The calculation method (DIN V 18599) is adaptable as it is used for all buildings in Germany (Gebaudeforum Klimaneutral, 2023). However, the iSFP software is only used for residential buildings as it was developed to support the residential market to retrofit their properties (BPIE, 2018).

Costs: Estimated costs for the full iSFP assessment are extremely varied and depend on whether it is a single or multi-owner home. The German government currently offer up to 80% funding support for the assessment which is capped at €1,700 for multi-owner buildings. An assessment of a multi-owner building with four dwellings is around € 2,300 (Baupal, 2022).

Qualifications and training: The iSFP must be carried out by a building energy consultant who has completed specific training (Baupal, 2022). Those from a 'relevant' background e.g., electrical engineer, construction specialist, architect, real estate expert can apply to the course (this is similar to PAS 2035).

Sweden

Like in Denmark, EPCs are issued for the whole building. Unlike many other European countries, the Swedish EPC is based on measured delivered energy, rather than modelled heat demand.

Framework: EPC (energideklaration)

Energy model: Unspecified

Strengths:

- Reflects how energy is actually used in the property.
- Improvement recommendations are likely to have a clear impact on the householder.
- Includes a geographical adjustment factor to account for temperature differences across the country.

Limitations:

- The quality of the recommendations can vary widely depending on who carried out the EPC assessment.
- Relies on normalisation of values to enable comparisons between buildings.

Building stock and heating /infrastructure: Sweden has a large share of multi-owner dwellings (58%) (Entranze, 2008). 20% of multi-owner buildings were built before 1930 (European Commission, 2021). Most multi-owner buildings are already connected to district heat networks (90%). Electric heating including heat pumps account for 8% (Energimyndigheten, 2020).

Building management: Sweden's housing stock is characterised by a large degree of public and co-operative ownership (68%). Only 32% are under private ownership (Ministry of Infrastructure, 2019). Properties in Sweden typically have 'warm rent', where heating and hot water costs are included in the rent. This puts the incentive of energy efficiency improvements on the owner rather than the tenant[14].

Regulatory context: A valid EPC must be available when a building is sold, rented, or built. Guidance and regulations are set out by the National Board of Housing, Building, and Planning (Boverket). Boverket sets out a baseline of inputs required in an EPC assessment, but the full extent is up to the individual energy export and depends on the information provided by the building owner.

Assessment process: An assessment of the building's heat demand is carried out by an independent, certified energy expert. An in-situ inspection of the building is required and must consider the building's orientation, passive solar radiation, and the climate of the location (as outdoor temperatures vary greatly across Sweden). Thermal properties are taken into account, including U-values of roofs, walls, windows, and outer doors; cold bridges; and the airtightness of the building envelope. The energy expert also notes the type and condition of the heating, hot water, and ventilation systems. The general condition of the building is not considered.

Accuracy: The energy expert must verify that the information provided by the owner aligns with the visual inspection. There is no national calculation programme; it is up to the energy expert which programme is used. The assessment includes a geographical adjustment factor to account for different outdoor temperatures across Sweden. This means that buildings in some regions are allowed to have a higher heat demand compared to the requirements (Boverket, 2022). Additionally, different fuel types are weighted differently, with electricity being weighted higher. In 2020, the energy performance calculation methods were changed to make buildings more comparable regardless of the fuel type used for heating (Boverket, 2021).

Intrusiveness: The assessment is carried out during one visit, lasting from 30 minutes and up to a few hours depending on the size of the building. The data collected depends on where was accessible on the day, but the energy expert is not required to access individual units.

Improvement recommendations: Recommendations are made for the building as a whole, though some may be relevant to individual flats, such as recommendations regarding taps and radiators. As the regulations are limited, Swedish EPCs can contain either few or highly detailed recommendations. This is reflected in the cost of the EPC (Byggahus.se, 2019). A benefit of using actual consumption data in the assessment is that the recommended improvements have a clearer connection to the householder's energy use.

Heating system considerations: Under the EPBD a building's heating system must be inspected if it has a space heating output of more than 70 kilowatts. This inspection must include an assessment of the system's efficiency and recommendation of cost-effective measures to improve the system's efficiency. Only new buildings are required to consider alternative heating systems.

Adaptability: The Swedish EPC does not distinguish between building use, so it is also used for mixed-use buildings. It is used both for existing and new buildings.

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[14] Personal communication with a representative from Boverket

Costs: The cost of an EPC is not regulated and generally increases with the size of the building. An EPC for a multi-owner building typically costs between £900 and £1400[15].

Qualifications and training: Energy experts are certified through a certification body and work as independent contractors. Certification requires a relevant background (education or experience) and passing an exam. There are separate exam preparation courses, but they are not a requirement.

If you require the report in an alternative format such as a Word document, please contact info@climatexchange.org.uk or the following postal address: ClimateXChange, Edinburgh Climate Change Institute, High School Yards, Edinburgh EH1 1LZ

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[15] Estimated based on personal communication with a representative from Boverket, and costs from three EPC companies.