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Defining 'Cost Effectiveness' for Energy Efficiency Improvements in Buildings

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Executive summary

This work is a review of definitions of cost effectiveness, carried out by Cambridge Energy, commissioned by ClimateXChange on behalf of the Scottish Government.

There are many different ways to define and assess cost effectiveness. The Scottish Government needs a sound, evidence-based definition of cost effectiveness to use in the Energy Efficient Scotland programme, which proposes to bring all Scottish homes up to an Energy Performance Certificate Band C by 2040, where technically feasible and cost effective. To inform this, our work aimed at understanding the pros and cons of using different definitions of cost effectiveness in relation to energy efficiency investments in homes and non-domestic buildings.

We found that cost effectiveness definitions vary in how energy savings are predicted or measured, in what other costs and benefits are included, and in the metrics used. We identified nine methods of evaluating cost effectiveness, summarised in the table below, along with our assessment of the pros and cons of each.

Table 1: A summary of cost effectiveness methods and the pros and cons of each.

Evaluation Method	Pros	Cons	How widely used?	Applied to buildings or programmes?
Simple payback: how many years does it take to recoup outlay?	Simple, widely used and understood.	Omits maintenance and replacement costs. Understates savings from long-life investments. Puts same value on benefits in future as benefits today (no discounting). Does not include non-cash costs and benefits.	Very widely	Buildings
Net annual savings: how much higher are yearly savings than yearly cost?	Relatively easy to understand.	Treats the initial investment as a loan with annual repayments, which may or may not be appropriate. Does not	Unusual except when upfront costs	Buildings

Evaluation Method	Pros	Cons	How widely used?	Applied to buildings or programmes?
(with cost based on loan costs)		include non-cash costs and benefits.	are met by a loan.	
Consumer cash flow: how much higher are yearly savings than yearly cost? (as above, but with separate cash flow figures calculated for each year)	Conveys lots of information Allows users to see deficit and 'profit' years easily.	Not a single figure, which makes comparisons difficult, although the cumulative cash flows in the final year can be compared. Sensitive to time horizon. Focuses only on cash flow and therefore does not include non-cash costs and benefits.	Unusual	Buildings
Discounted cash flow: as above, but with future benefits discounted to reflect time-value of money	As above, but in addition use of discounting means it is more appropriate for valuing investments with long time horizons.	As above but sensitive to discount rate chosen. Note that when comparing across investments DCF could be summed to give a single figure which would be the same as NPV.	Relatively common in business	Buildings
Net Present Value (NPV): how much higher is the total lifetime value than the lifetime costs? (with discounting)	As above, and commonly used in business. Can incorporate wider costs and benefits other than cash flow.	Sensitive to discount rate and time horizon.	Common in business	Both
Internal Rate of Return (IRR): what rate of interest would earn equivalent benefits to this investment?	As above, and easy to compare between investments of different durations.	Complex calculation requiring iterative method (a built-in Excel function exists).	Quite rare (never by households)	Buildings
Return on Investment (ROI): what is the net benefit, as a fraction of total costs? (with discounting)	Includes all costs and savings. Good for incorporating benefits far into the future. Facilitates comparisons	Sensitive to discount rate, and may overstate returns for long-life investments.	Quite rare (never by households)	Both

Evaluation Method	Pros	Cons	How widely used?	Applied to buildings or programmes?
	between different investments.			
Cost-Benefit Ratio (CBR): what is the ratio of total lifetime benefits to total costs?	Includes costs and benefits such as installation costs and reduced bills. Good for incorporating benefits far into the future. Facilitates comparisons between different investments.	As above.	Quite rare (never by households)	Both
Levelised cost (£/MWh): what is the cost of capital relative to annual energy savings?	Good for comparing measures with each other in terms of energy savings.	Indicates cost to achieve an energy-saving goal, not actually a measure of overall profitability, although can be compared to fuel prices to see if investment is likely to pay back.	Unusual (never by households)	Both

Cost caps are sometimes used as an alternative to a cost-effectiveness test, for example, in relation to the UK Government’s energy efficiency regulations which apply to the private-rented sector in England and Wales.

In addition to considering the relative merits and sectors of application of each definition, our review answered eight specific questions:

1. How do definitions consider packages of measures?
2. How do definitions take account of wider benefits to society?
3. Are different definitions used for the domestic and non-domestic sectors?
4. Are there variations in how definitions are applied?
5. How do definitions take account of funding sources?
6. What evidence is there regarding the acceptability of different payback periods?
7. What are the different ways definitions are used in practice?
8. What are the practical lessons from experiences of implementing definitions?

1. Packages versus single measures

All of the methods in the table can be applied to single measures or packages of measures, though the calculations for packages of measures require more information and are more complex as they involve calculating the total costs and savings from the combination of measures. More sophisticated methods account for the interactions between measures. We found that only the Salix Energy Efficiency Loan Scheme (2018) explicitly describes using its assessment method for packages of measures.

2. Wider benefits

In principle, if wider benefits can be given a money value then they can be incorporated into any of these methods. This tends to happen only for policy appraisal and not at the individual project/building level. For example, the value of lower greenhouse gas emissions and better air quality was converted into financial benefits in the UK Government’s assessment of the (now withdrawn) Green deal programme (DECC, 2012). However, for privately funded projects, standard practice is to only consider financial benefits. The International Energy Agency’s Annex 56 advocates incorporating wider benefits (Almeida & Ferreira, 2017) within these standard methods.

3. Differences in domestic and non-domestic sectors

Payback is by far the most common method for domestic buildings, and also very common in business. More sophisticated methods including discounting are very seldom used for dwellings, but more widely used in business – especially NPV, ROI and IRR.

4. Variations in application

We found no evidence that tenure or building type affects the choice of definition. Arguably, social housing is more likely to be evaluated for energy efficiency improvements as part of a programme than individual owner-occupied homes, so it is more likely to be assessed using a more sophisticated method involving discounting (NPV or IRR), whereas owner-occupied homes are more likely to use payback.

5. Sources of funding

Methods of calculating cost effectiveness often take some account of the source of funding. For example, as funding is often from loans, most methods use a discount rate related to the cost of borrowing. A ‘discount rate’ is an annual percentage reduction applied on future costs and benefits, to reflect the fact that money today is worth more than money next year. The UK Treasury’s Green Book (HMT, 2018) – used for assessing public sector investments – proposes 3.5% for the first 30 years, falling thereafter. However, in the private sector there is a consensus that this should match the cost of capital (which is different for different organisations). The Carbon Trust and others recommend using the weighted average cost of capital (WACC). The only measures that do not take discount rates into account in any way are simple payback and consumer cash flow.

Particular assessment methods are associated with particular funding programmes: the Green Book requires use of NPV, Salix Loans set a maximum payback time and maximum cost/£ saved, and the Green Deal used net annual savings. In the US, Efficiency Vermont dictates using NPV and payback.

6. Acceptability of payback periods

There is no clear consensus about how acceptable different payback periods are. Consumer Focus (which campaigns for fair deals for consumers in England, Wales and Scotland) suggested that up to 15 years can be an acceptable payback period (Consumer Focus, 2011). Others contend that households struggle to look further than five years ahead, so they prefer energy efficiency measures to pay for themselves within five to seven years (Accent, 2016). Research by Eunomia (BEIS, 2017) suggested that the same is true for companies, who often use payback as well, and often use a period of five to seven years.

7. Uses in practice

Definitions are most commonly used to assess investment decisions for individual buildings – comparing between different upgrade options, and sometimes comparing against non-energy investments. They are also used in regulations to define exemptions for minimum levels of action – such as the 15-year payback limit for improvements when other building work is carried out in English Building Regulations (MHCLG, 2018a). And they are used as a test to assess to energy efficiency loans (like the withdrawn

Green Deal or Salix Loans). The Green Book emphasises NPV as a yardstick to assess policies or interventions.

Cost effectiveness tests are also applied in assessments of regulatory standards, to determine incentives for energy efficiency programmes, in reviewing programmes post-hoc and in estimating economic potential for savings.

8. Practical lessons

We found very few case studies that covered practical issues of applying definitions, or included reflections about how successful they were. However, there is considerable evidence about how hard it is to predict actual energy savings for measures installed in buildings, and evidence that this uncertainty discourages investment, especially in the domestic sector. There are also guidelines for assessing savings in programmes.

Although there are examples of definitions being used in a regulatory context, we found no examples of definitions being used to take enforcement action.

Glossary of Terms

Term	Meaning
Anyway costs	The International Energy Agency term for costs that would be incurred with no energy efficiency improvement – often overlooked in decisions about energy efficiency. This is similar to 'business as usual'.
Consumer cash flow	A measure of whether an investment makes sense financially (though precise definitions vary, and this is often not spelt out). More commonly used in regulations.
Cost-benefit ratio	Shows the ratio of total lifetime benefits to total costs, allowing users to prioritise different investments.
Cost-effective	A measure of whether an investment makes sense financially (though precise definitions vary, and this is often not spelt out). More commonly used in regulations.
Cost-optimal	Lowest overall cost over the lifetime of the investment – usually lower energy savings than a cost-effective plan that just breaks even. Less commonly used in regulations.
Discounting/discount rate	An annual percentage reduction applied on costs and benefits incurred or accrued, to reflect the fact that money today is worth more than money next year. This is not the same as inflation.
Discounted cash flow	All costs and benefits calculated year-by-year into the future, with a discount factor applied to reduce the value of costs and benefits in future years.
EPC	Energy Performance Certificate – a rating system from A to G assessing energy efficiency, required by law for all buildings that are rented or sold. These must be displayed for public buildings in Scotland with a floor area greater than 250m^2.
ESOS	The Energy Savings Opportunities Scheme – a mandatory energy assessment scheme for organisations in the UK requiring them to audit their facilities and identify cost-effective energy saving measures.
Internal rate of return (IRR)	A complex calculation showing the rate of interest equivalent to the future benefits of a particular investment, expressed as a percentage.
Levelised costs	What is the cost of meeting a specific energy-saving target, expressed in pounds per unit of energy.
Net annual savings	The savings each year minus the annual costs, summed together (with costs including the cost of a loan to borrow the initial outlay).
Payback	How long, in years, the savings from an investment takes to repay the initial outlay.
Reference case	The comparison situation against which to compare investment opportunities. (Sometimes called the 'counterfactual', or 'business as usual'.)
Return on Investment (ROI)	The aggregate value of all future benefits, divided by the aggregate costs, with discounting applied to future costs and benefits.
Salix	Solving Energy Efficiency Investment in the Public Sector: Provides interest-free government funding to the public sector to support energy efficiency work. Funded by the UK, Scottish and Welsh Governments.
Wider benefits	Co-benefits associated with energy renovation work, for example thermal comfort, improved indoor air quality and reduced exposure to energy price fluctuations.

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Introduction

The Scottish Government has ambition to improve the energy efficiency of the entire Scottish building stock: domestic and non-domestic buildings.[1] For the domestic sector the stated goal is for all homes to be at least EPC Band C by 2040 – to the extent that this is technically feasible and cost effective. However, opinions were mixed about the definition of 'cost effective' proposed in the Government's consultation (Scottish Government, 2017): that measures should pay back within their lifetime. This research was commissioned by ClimateXChange, to conduct a thorough review of definitions that have been used elsewhere, summarising the pros and cons for each where evidence is available.

A simple alternative approach to assessing cost-effectiveness is to put a cap on the total costs incurred. This is the approach followed by the UK Government regulating energy efficiency in the private-rented sector, and proposed by the Scottish Government in its consultation about energy efficiency in the private-rented sector.[2] In contrast, this report focusses on definitions where both the cost and benefits are taken into account to derive a measure of cost effectiveness.

This report responds to the research questions below.

Table 2: A summary of the research questions explored in the report

Question	Answer
1. What definitions of cost effectiveness of energy efficiency improvements exist?	Cost effectiveness calculation methods vary in three main ways: • The metric used (e.g. payback time, net present value) • Costs and benefits included in the calculations • The 'counterfactual' or reference case There are also considerations to do with when they are applied – as a prediction or as a review – and different ways to calculate savings in each case. Different stakeholders tend to use different methods. These issues are discussed in separate sections in our report.
2. From the available evidence, what are the advantages and disadvantages for these definitions?	We found clear pros and cons for different definitions – largely to do with the trade-off between complexity, completeness, and how easy it is to compare between options and interpret the outcomes of these definitions. We discuss the advantages and disadvantages of each type of method in the section on methods. For individual dwellings, the advantage of simplicity and ease-of-understanding means that simple payback is almost always used. For non-domestic buildings, there is a wider range of definitions. Payback remains common, but in business the

[1] The terms "building" and "dwelling" are used interchangeably in this report with respect to the domestic sector, but depending on the regulatory context there may be a distinction, e.g. in the case of a block of flats the regulations may apply to each dwelling individually rather than to the block as a whole (and there may be different regulatory standards depending on the tenure of different flats in the block).

[2] https://www.gov.scot/publications/energy-efficiency-condition-standards-private-rented-housing-scotlands-energy-efficiency/

	advantage of including long-term costs and benefits which can vary over time, and being able to compare between options, mean that more sophisticated definitions are also commonly used.
3. Do any definitions consider the cost effectiveness of a package of energy efficiency measures versus single measures?	We found evidence that efficiency measures in single buildings may be assessed individually, or as a package. We discuss how, when packages of measures are considered, there is a subtle distinction between cost effective and cost optimal, and cost effective is usually more relevant for regulatory purposes.
4. Do any definitions take account of the wider benefits to society in determining the cost effectiveness of a particular measure / package of measures?	Social benefits are often considered in evaluation of energy efficiency programmes with public funding, although these are not always quantified or monetised (translated into money). There is almost nothing in the literature about single-building upgrades and wider social benefits – apart from carbon emissions (even this is not presented in social-benefit terms) and, less commonly, health benefits for people using that building. These are discussed in the section on energy efficiency programmes.
5. Are there examples of situations where different definitions of cost effectiveness apply for different sectors, for example varying according to tenure or type of building?	There are differences between domestic and non-domestic buildings in terms of what costs and benefits are included and also what metrics are used. Typically, broader and more complex methods are used for non-domestic buildings. These are discussed in sections about what is included and excluded, and about non-energy benefits. However, there was no evidence that different tenures or building types (e.g. retail, offices, sports centres) use different definitions. Rather, it depends on standard practice for the organisation.
6. Are there examples of different definitions for cost effectiveness relating to the domestic and non-domestic sectors?	As above.
7. Do any definitions take account of the source of the funding for the measure(s)?	Yes, public funding often requires particular methods of assessing cost effectiveness: the Green Book requires use of NPV, Salix Loans call for maximum payback and cost/£ saved, and the Green Deal used net annual savings. In the US, Efficiency Vermont dictates using NPV and payback. The source of funding is also an important driver of what is included in costs and benefits. This is discussed in the section on energy efficiency programmes.

Question	Answer
8. How are the definitions used in practice? For example, are they general definitions for guiding policy or are they used in creating incentives or taking enforcement action?	Definitions are used in several ways: • in decision making by building owners • in making policy, for example building regulations • in reviewing economic potential for energy saving • in determining the level of incentives provided to building owners • in reviewing the performance and energy efficiency programs. These contexts are discussed in the first section below.
9. Does the literature provide any evidence on the practicalities of implementing cost effectiveness measures or how well these have worked / could work in practice?	There are very few case studies included in the literature, and those that are available have incomplete descriptions, omitting practical issues or reflections on how successful they were. However, there is evidence on the difficulty of predicting energy savings from energy efficiency measures in general.

In our literature review we identified more than 200 articles and reports of relevance including government regulations and policy documents, advice to households, companies and energy assessors, research reports and journal articles. We filtered out those that did not relate to ClimateXChange’s research questions, leaving 58 articles and reports that we read and summarised. The bulk of these were from the USA (25), the UK (13) and other parts of Europe. Appendix I describes our method in more detail.

How cost effectiveness calculation methods are used

We found cost effectiveness tests applied in a variety of different contexts.

1. By building owners (residential and commercial)

Building owners make decisions on what energy efficiency measures to install. For example, a study about an office building in Italy (Aste & Pero, 2013) asked: “Would it be more cost effective to just repair or to install a package of energy efficiency measures at the same time?” Often it is a question of choosing between alternative measures, but sometimes, like this example, it is also the choice between energy efficiency improvements and improvements with no impact on energy or carbon emissions.

We also found advice (CEE, 2017) on how to market energy saving measures to residential customers where non-energy benefits such as comfort and control are a better strategy than relying on communicating energy savings.

For the commercial sector there are a number of schemes requiring commercial companies to audit their energy use, including in buildings, and consider energy efficiency measures that could make savings. Examples include ESOS in the UK (DECC, 2015), and a similar scheme in Berkeley, USA (BESO, 2018). There is also general advice on how to present a business case for energy savings from the Carbon Trust (Carbon Trust , 2013).

2. In Building Regulations

Energy efficiency is a key part of building regulations. In the USA, building codes are set locally but the Department of Energy publishes a methodology for how each change is evaluated in terms of cost effectiveness (BECP, 2015). The different regulations are compared by modelling on a set of building types using local weather conditions to evaluate the costs and benefits.

In England there are cost effectiveness tests used to determine when renovation in dwellings (MHCLG, 2018a) and other buildings (MHCLG, 2018b) may be reduced to comply with current regulations. Both of these use simple payback over 15 years as the test, but with different rules for calculating savings. Regulations in Wales are similar to England, with an economic feasibility test of 15 years simple payback. However, in Wales VAT is included in the payback calculations whereas in England it is excluded (Welsh Government, 2016).

Building regulations in Scotland do not apply a general cost-benefit test when determining the level of performance required for renovations to domestic and non-domestic buildings. However, the level of performance can be reduced where meeting the standards otherwise required would not be reasonably practicable having regard to all the circumstances, including the expense of carrying out the work. Moreover, where substantial work is being undertaken on non-domestic buildings (works affecting building services, requiring a building warrant and costing £50,000 or more), the regulations require that energy efficiency improvements (amounting to approximately 5% of the cost of the other work) should also be made. [3] In these cases, as one element of the test of whether the energy efficiency improvements are reasonably practicable, the regulations state that it is only necessary to consider improvements which, when combined, have a payback period of five years or less.[4]

3. In reviews of economic potential

We found a number of reviews of economic potential in housing stock in the UK for the Committee on Climate Change (Element Energy, 2011), by the UK Energy Research Centre (UKERC, 2017), and in the USA (Wilson et al, 2017). These reviews all differ slightly. The CCC study measures levelised costs (spread evenly over time) of carbon savings and ignores non-energy benefits. The USA study is strictly from a building-owner viewpoint and considers only energy bill savings as benefits. The UKERC study, however, shows how adding in non-energy benefits - such as for thermal comfort, air pollution and carbon emissions - increases the potential.

4. To determine incentives

Social and environmental benefits, such as health improvements or reducing carbon emissions, can be used to determine the level of incentive that can be provided to building owners. This is exemplified by rules in Vermont, where companies implementing an energy efficiency project on their buildings can claim some of the cost back based on the benefit of the project to society (Efficiency Vermont, 2017). The funding is claimed through Energy Efficiency Vermont, a non-profit organisation commissioned by the Vermont Public Utility Commission. It receives funding through a charge on electricity bills, and through selling carbon allowances.

5. In reviews of programmes

We also found annual reports and reviews of energy efficiency programmes along with a great deal of discussion on what costs and benefits should be included. These programmes are often part-funded by the state, either through performance incentives or direct funding. (Readers should note that most such

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[3] https://www.gov.scot/publications/building-standards-2017-non-domestic/6-energy/annex-6d-improvement-to-the-energy-performance-of-existing-building-services-when-carrying-out-building-work/

[4] The exception to this is the replacement of a boiler or chiller unit, where near the end of its useful life, as there will be additional cost benefit where replacing such equipment as part of more extensive works.

programmes are actually a series of decisions made at the level of individual buildings, evaluated together.) For example, we found a series of documents showing initial advice to Maryland Public Service Commission on what benefits should be included in calculating the cost effectiveness of programmes (Skumatz, 2014), followed by objections (State of Maryland, 2017) and a final ruling (Hogan, 2017). In the final text, explicit mention of benefits such as increased property values, improved comfort and reduced emissions were crossed out. Instead it included participant non-energy benefits in general, and social benefits such as impacts on jobs and the environment, but only where the benefits were ‘quantifiable and directly related to a program or service’.

Viewpoint

We would emphasise that from the literature it is clear that the definition of cost effectiveness chosen for a particular programme or study depends on your viewpoint. To a homeowner, an incentive may be a benefit, but to the programme administrator this may be a cost. Savings in energy costs are a benefit to householders or businesses, but costs (in terms of lost revenue) to utilities companies. Figure 1 below highlights how benefits for one particular group may be a cost for another group.

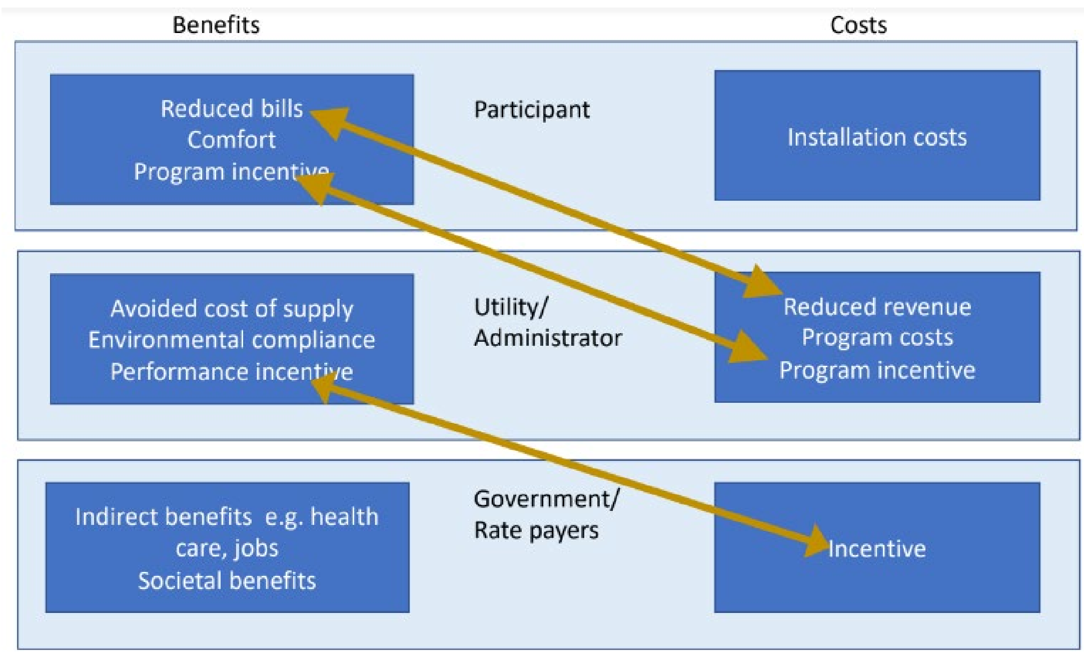

Figure 1: Definitions of cost effectiveness vary depending on the perspective and who makes decisions – benefits for one group are often costs for another.

Pros and cons of different methods

The table below shows methods used and typical examples of when they are used.

Table 3: A summary of cost effectiveness methods and examples of where they are used

Method	Brief description	Examples of use
Simple payback	Upfront costs divided by annual savings, in years. This shows how long it takes for an investment to pay for itself.	Building regulations in England and Wales for renovation Part L1b (MHCLG, 2018b) and in the USA (BECP, 2015) Salix energy efficiency loan scheme (Salix, 2018).
Net annual savings	Annual costs minus annual savings (where annual costs are based on the costs of borrowing capital, expressed as a series of annual loan repayments comprising interest and capital repayment, like a mortgage).	Advice to householders from Florida Energy Systems Consortium (Putnam, 2015).
Consumer cash flow	Year by year costs minus savings. This differs from net annual savings above in that it can incorporate costs varying from year to year – say, because of maintenance only needed every few years.	Used in the USA for building regulations (BECP, 2015).
Discounted cash flow	As above but with future costs and benefits discounted (where a fixed percentage is applied each year into the future to reduce costs and benefits in the future) to incorporate the time value of money.	Used by some UK companies surveyed by Eunomia (BEIS, 2017) and a case study on an office building in Italy (Aste & Pero, 2013). Advocated by IEA Annex 56 (Almeida & Farreira, 2017).
Net present value (NPV)	Total benefits minus total costs (both appropriately discounted) over a fixed period of time. More often used to incorporate wider costs and benefits (i.e. other than cash flow) than other methods. The result is a single figure that can be positive or negative, but a negative figure indicates the investment brings a loss, so by this measure it would not be viable. The magnitude of a positive figure indicates how attractive the investment is.	UK Treasury Green Book (BEIS, 2018) and hence UK policies such as the Green Deal and the Minimum Energy Efficiency Standards (MEES). Berkeley (2018) Building Energy Saving ordinance (commercial sector advice)
Internal rate of return (IRR)	This is the discount rate for which the NPV is zero. It is expressed as a percentage, and represents annualised return. Again, a positive figure indicates that the investment is attractive or profitable, and the magnitude how attractive it is.	Recommended by the Carbon Trust (2013) in their guidelines for how to make a business case

Return on investment (ROI)	(Total benefits minus Total costs) divided by Total costs (both appropriately discounted). Again, this is expressed as a percentage, allowing straightforward comparisons between different investment options. NPV, IRR, ROI and CBR are all similar, and they are all ways of presenting discounted costs and benefits.	Economic evaluation of a commercial building (Zheng & Lai, 2018)
Cost benefit ratio (CBR)	Total costs divided by total benefits (both appropriately discounted). This shows how many times less the costs are than the benefits – it is less than 1 for viable investments, but more than 1 if the discounted benefits do not repay the costs.	Most common in reviews of energy efficiency programs – very seldom used for single buildings.
Levelised cost (£/MWh)	Capital recovery factor multiplied by cost, divided by annual energy savings. Where the 'capital recovery factor' is derived from the discount rate. This gives a measure of costs per kWh saved.	Comparison of evaluation of energy efficiency programmes in the USA (Hoffman et al, 2015), and in Ontario (IESO, 2015). Not used for single buildings.

The following box provides worked up examples for each cost effectiveness method

Assumptions

Lifetime of measures	10	years
Upfront cost	400	£
Savings (kWh)	1500	kWh/year
Fuel price	0.05	£/kWh
Loan	60	£/year (10-year loan)
Maintenance every 3 years (for cashflow case:	20	£
Discount rate (where applied)	5	% p.a.

Simple Payback

This is the upfront cost divided by the yearly savings.
Additional savings or costs can be included in the annual calculation as long as they are tl same from year to year.

Upfront cost	400	£
Savings/year	1500	kWh/year
Fuel price	0.05	£/kWh
Savings/year (kWh * price)	75	£/year
Payback time (Upfront cost/savings)	**5.3**	**years**

Net annual savings

Instead of a capital investment at the start, there is a loan with equal annual payments. Then the net savings is savings minus costs. Additional savings or costs can be included in the annual calculation as long as they are the same from year to year

Upfront cost	400	£
Annual cost of loan for this (depends on interest rate and term)	60	£
Energy savings/year	1500	kWh/year
Fuel price	0.05	£/kWh
Energy savings/year	75	£/year
Net annual savings (savings - cost)	**15**	**£/year**

NB. The Green Deal Golden Rule said this mu be positive i.e. annual savings > annual costs

Consumer cash flow

This method can handle variable costs and savings from year to year. As an illustration this example has additional maintenance every three years.
The cash flow figure is the bottom line. In this example it is coloured according to whether it is positive (green) or negative (red). The intention is to see how many yea it takes for the balance to become reliably positive, as well as how far it goes into deficit.

Year	0	1	2	3	4	5	6	7	8	9	10
Opening balance (£)	0	-400	-329	-261	-213	-151	-93	-52	2	53	88
Costs (£)	-400	0	0	-20	0	0	-20	0	0	-20	0
Savings (£)	0	75	75	75	75	75	75	75	75	75	75
Net savings	-400	75	75	55	75	75	55	75	75	55	75
Discount factor multiply by 1/(1+discount rate) each year	1	0.952	0.907	0.864	0.823	0.784	0.746	0.711	0.677	0.645	0.614
Discounted costs (costs * discount factor	-400	0	0	-17	0	0	-15	0	0	-13	0
Discounted savings (savings * discount fa	0	71	68	65	62	59	56	53	51	48	46
Closing balance (£)	**-400**	**-329**	**-261**	**-213**	**-151**	**-93**	**-52**	**2**	**53**	**88**	**134**

Discounted consumer cash flow
This is the same as consumer cash flow, except that all the costs and savings are discounted. Each year, the previous discount factor is divided by (1+discount rate). The first three rows are the same as the basic cash flow. Then discounted costs and savings are calculated.

The discounting means that costs and savings in later years are worth less. This means it takes longer for the net cash flow to become positive. Higher discount rates mean longer payback times.

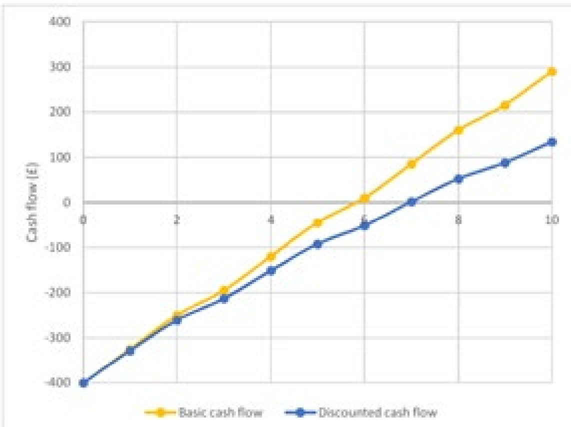

Figure 2: Worked example showing effect of discounting

NPV, ROI, CBR, IRR
These methods are based on discounted costs and benefits over a fixed term – in this example 10 years. The first three are all based on the total discounted savings and total discounted costs, obtained by adding up the appropriate rows from the discounted cash flow table. IRR is calculated by an Excel function on the Net savings row (without discounting).

Yellow cells above indicate values used for the calculations. The rows for opening and closing balance are not needed for these calculations but the rest is the same.

NPV	TotalDisSavings - TotalDisCosts	134	(negative would mean an overall loss)
Return on investment	(TotalDisSavings - TotalDisCosts)/TotalDisCosts	30.1%	(negative would mean an overall loss)
Cost benefit ratio	TotalDisCosts/TotalDisSavings	0.769	(> 1 would mean an overall loss)
Internal rate of return	IRR(NetSavings)	12%	(negative would mean an overall loss)

Levelised costs
This only takes upfront costs into account. It accounts for discounting and assumes a fixed term which is normally the lifetime of the measure. This value is independent of energy prices as it includes only investment costs. The overall plan is in profit if the levelised cost/kWh is less than the price/kWh.

Upfront costs	400	£
Energy savings	1500	kWh/year
Years (measure lifetime)	20	Years
Discount rate	5%	
Capital recovery factor (discount * POWER(1+discount,Years))/ (POWER(1+discount,Years)-1)	0.0802	
Levelised cost (factor x cost/annual savings)	**0.021**	**£/kWh**

The simple payback method is claimed to be well understood, including by households (Accent, 2016), and it is also often used in the commercial sector (Eunomia, 2017). However, it understates the savings of measures with long lifetimes. A measure that pays back in two years will actually generate profits after that and may payback many times over its lifetime, but this information is lost. Conversely, a measure with high upfront costs and a long payback period could fail a payback test where a maximum payback period is specified, but still pass other cost-effectiveness tests over its whole life. In its simplest form - simple payback - it ignores costs beyond installation so cannot allow for differences in maintenance and replacement costs for the measure over time. If these are included, then it is equivalent to consumer cash flow up to the point where accumulated benefits are equal to costs.

Net annual savings is useful when upfront investment is met by a loan – in fact, the only examples in the literature relate to cases where there is a loan. It would, however, be possible to use it in contexts where a loan is not in place, provided there was a reference interest rate. In this situation, it would be interpreted as testing whether the fuel bill savings from the upgrade exceed the opportunity cost of the capital used to pay for the upgrade

Consumer cash flow conveys a lot of information, and is usually calculated year-by-year, although it could be cumulated for a specific year. In the usual form, with yearly figures, comparisons are harder. Consumer cash flow is mainly used by businesses, and there is no evidence it has been used in a regulatory context.

We found discounted cash flow (DCF) used to good effect in a comparison of retrofit with basic repair on an office building. This too could be cumulated for a specific duration – this would be equivalent to the NPV of the cash flow. Figure 3 (below) of cumulative DCF over the years (i.e. NPV over longer and longer periods) indicates that the retrofit cost is less than the repair costs after 18 years.

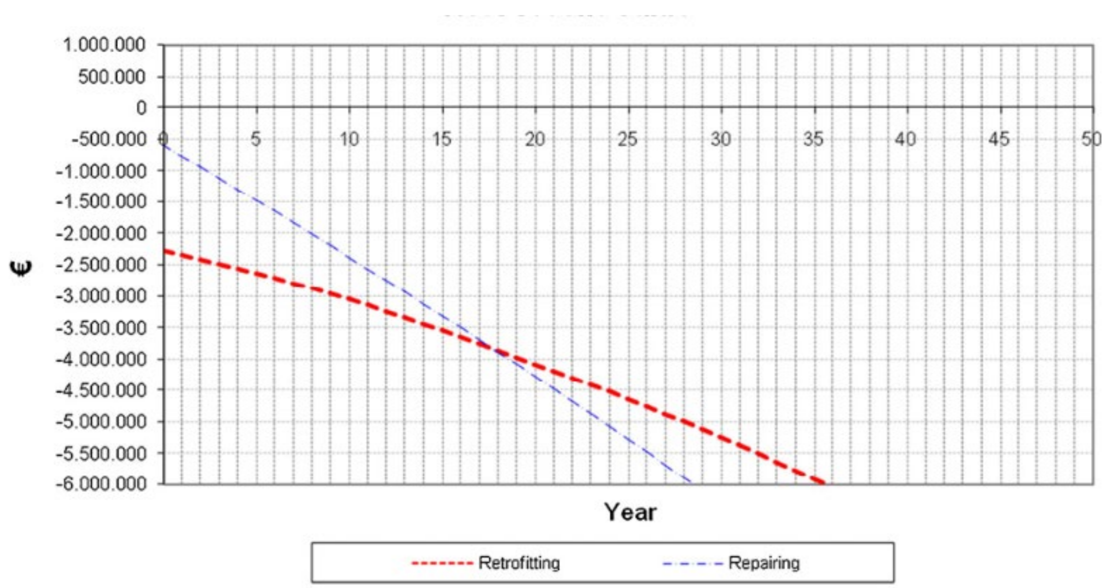

Figure 3: Cumulative DCF (or NPV over longer and longer periods) of the cost including operating and maintenance of a building retrofit compared to repair costs – from Aste, 2013

As discussed above, the Net Present Value (NPV) is equivalent to a cumulative discounted cashflow. However, it is often used in contexts where costs and benefits other than cashflow are taken into account, such as wider social costs and benefits. NPV is a good indicator of whether there is a net benefit or cost, but the result is sensitive to the discount rates chosen and the time horizon (how far into the future costs and benefits are included).

The Cost Benefit Ratio (CBR) and Return on Investment (ROI) are alternative ways of presenting the information contained in an NPV calculation. They are potentially more informative than NPV because they scale the benefits to the costs, which can allow the relative attractiveness of different investments to be compared. The close relationship between these methods is illustrated by the fact that CBR=1-NPV, while ROI = 1/CBR-1. If benefits exceed costs, CBR will be less than 1, while NPV and ROI are positive. These three methods will therefore provide the same answer if the proposed definition of cost effectiveness is that the benefits should exceed the costs.

Internal Rate of Return is recommended by the Carbon Trust because it is easy to compare with other investments of different durations. For example, an IRR of 20% means that it would do better than investment in a deposit account giving interest rates of less than 20%. The difference from ROI is that the IRR represents an average year, whereas the ROI is the return over the whole project duration. One disadvantage of the IRR is that it requires iterative searching to calculate it. However accounting tools (such as Excel) hide this complexity. IRR was not mentioned in any evaluations or reviews in our sources.

A summary of the pros and cons of the cost effectiveness methods is set out in Table 1 in the Executive Summary.

Considerations in applying the methods

Discount rates

There is no consensus in the literature about what discount rate to use, with different sources citing different rates. Sometimes different discount rates are applied to different parts of the analysis. Typically, social costs and benefits have a lower discount rate, reflecting consideration of intergenerational equity (fair shares for future generations), and in other contexts the rate reflects the cost of borrowing. The National Standard Practice Manual (NESP, 2017) suggests 0-3% for social costs and benefits, and higher rates for households and companies. For companies, the rates are based on the Weighted Average Cost of Capital (WACC) and can be up to 8%. The Carbon Trust (2013) also recommends that the cost of capital is used – this may be related to borrowing costs or alternative investment interest rates as appropriate.

The discount rate also can vary with the time horizon with lower rates for longer terms. The UK Treasury Green Book specifies 3.5% for the first 30 years and declining below 3.5% thereafter (HMT, 2018).

Which method to use when

There is no single answer to which is best - it depends on the intended audience and their expectation or normal practice. For home owners, payback time, despite its faults, is the only method that is widely used, because it is easy to understand and simple to calculate. For other stakeholders there is variation. The Carbon Trust recommends IRR is best for making a business case. The guidelines for the UK Energy Savings Opportunity Scheme indicate that savings should be expressed in whatever form is normally used by the company board for investment decisions (ESOS, 2015). Berkeley Building Energy Savings Ordnance specifies a report that is used similarly to ESOS or EPC – it stipulates that both simple payback and NPV are shown (BESO, 2018).

Accounting period

Our evidence review suggests domestic and non-domestic consumers are normally interested in quite short time horizons. Commercial companies in the UK surveyed by Eunomia most often used a simple payback criterion, often 5 years or less (BEIS, 2017). Household customers similarly prefer short payback times of no more than 5 – 7 years: “Many homeowners struggle to look further than five years ahead and accordingly want to see energy efficiency measures pay for themselves within a five to seven year time period. Beyond this, the future is so hard to imagine or project, it almost becomes theoretical and too difficult for many to contemplate. Uncertainty about future plans or moving home are also mentioned as additional barriers to acting.” (Accent, 2016). However, according to Consumer Focus (which campaigns for fair deals for consumers in England, Wales and Scotland) up to 15 years can be acceptable (Consumer Focus, 2011).[5]

Building regulations are based on longer time horizons. In the USA, federal guidelines use 30 years because this is a typical mortgage term (BECP, 2015). However, a review of building regulations in New Jersey considered several time spans: 7 years as the average home tenure, 15 years for a short term mortgage and 30 years for a long-term mortgage (Rutgers, 2011). Building Regulations in England have an exemption for renovations where the payback time is more than 15 years – they do not explain why 15 years is the threshold.

Most schemes for assessing energy efficiency programs use the lifetime of the measure as the accounting period for each installation. When a project or programme includes several measures – or when maintenance is a significant expense – then operation and maintenance costs are included, so that replacement costs and maintenance can be accounted for. The accounting period may be as long as 60 years (Denmark, 2016).

What is the reference case?

It is also important to consider what energy efficiency refurbishment costs are compared against - the so-called ‘counterfactual’ (IEA, 2017a). As the IEA’s (2017c) Annex 56 Methodology argues, buildings are upgraded over time anyway – regardless of energy efficiency – and this refurbishment work also incurs costs. The IEA report argued that costs should be compared against “anyway” costs. If this does not happen, it militates against energy retrofit and means that sound investment opportunities are not taken up.

For homeowners, high initial capital costs and long payback times are held to be the biggest barriers to investing in energy efficiency. These are exacerbated when costs are compared to ‘do nothing’, and according to the International Energy Agency Annex 56 (IEA, 2017a), these costs should always be compared against “anyway” renovation – usual maintenance and improvement costs that homeowners and other building owners would incur even without energy-orientated investments.

As an example of anyway costs, Aste (2013) reported on a case study of refurbishment of an office building where the impact of energy efficiency retrofit is compared with basic repair. This suggested that refurbishment was preferable over 18 years or longer. Similarly in the six case study buildings reported by IEA the base case was a normal programme of repair and refurbishment including replacement heating systems (Venus & Höfler, 2017).

In another example Suerkemper (2011) compared various heating measures such as a heat pump or wood stove with a reference case which is a low temperature condensing boiler. This is appropriate where the household does not already have one and would be expected to get one by default at the next replacement.

Wider benefits – owners and occupiers

Wider benefits to building occupants may be taken into account in cost effectiveness methodologies. IEA Annex 56 held that the biggest drawback of traditional approaches to cost-benefit analysis is the short-term focus. It says that traditional analysis (payback and annual savings) overlook and exclude increased asset values and improved occupant wellbeing.

Annex 56 also gives a long list of co-benefits of energy renovation work: thermal comfort, natural lighting and contact with outside, improved indoor air quality, reduction of ‘problems with building physics’, noise reduction, operational comfort, reduced exposure to energy price fluctuations, aesthetics and

[5] This figure was apparently obtained in polls conducted as part of the Great British Refurb campaign, with Energy Saving Trust and DECC in 2010. Unfortunately the detailed report for this is no longer online - it is referenced in the Consumer Focus report.

architectural integration, safety (intrusion and accidents), and pride, prestige, reputation. Ideally, full calculations of cost effectiveness will take these co-benefits into account as well as the direct savings in energy costs.

The list of direct benefits is shorter. IEA Annex 56 (IEA, 2017b) stated "Usually a private cost/benefit perspective [should be] assumed, comprising:

− initial investment cost (planning and construction costs, professional fees, taxes, etc.),

− replacement cost during the (remaining) lifetime of the building (periodic investments for replacement of building elements at the end of their lifetime)

− running costs: Energy costs (including existing energy-and CO_2-taxes), maintenance costs (repair, cleaning, inspection, etc.), operational costs (taxes insurance, regulatory costs, etc.)."

The description continued: "Subsidies for energy related measures are excluded from the assessment of costs and benefits to have an assessment which is undistorted by currently prevailing subsidy programs (owners or investors assessing a specific renovation project will take possible subsidies for energy related measures into account)."

This part of Annex 56 made the point that empirical data on co-benefits is scarce, and quantification and/or monetisation are time-consuming, with robust data often unavailable. Further, co-benefits are partly context specific. The report said this makes it difficult to add their contribution to a traditional cost-benefit analysis and to the assessment of renovation measures – with the result that these are often absent from cost-effectiveness assessments.

In practice, therefore, readers may not be surprised that wider benefits are seldom included in a regulatory context (such as building regulations for new buildings or upgrades).

However, in a market situation such co-benefits can be a greater motivation than reduced bills. Their value can be harder to quantify but is none the less real to the consumers concerned. Skumatz Economic Research Associates (Skumatz, 2014) suggested marketing only on cost savings is a fatal flaw (CO_2 reductions, for instance, are a 'saving', but very seldom measured in monetary terms). To buy based on this message requires trust that savings will occur and valuing future savings enough to justify the upfront cost. But those savings depend on unpredictable events such as energy price changes, rebound effects, and the weather. Marketing based on positives like improved comfort (which stands to be better in any weather conditions), hygiene or aesthetics are more powerful in the market place.

These recommendations are supported by research in the UK and in Germany. In 2011, researchers from the Climate Policy Initiative in Germany surveyed 2000 households that were either planning, not planning, or had undertaken a thermal retrofit (Novikova, 2011). The results showed that improving the building's appearance and thermal comfort were more important than high bills as drivers of renovation decisions, especially as the initial motivation, in households that actually took action. Another recent study in the UK involved interviews with 24 UK households that had undertaken an energy retrofit (Kerr et al, 2018). The most consistent reason for going ahead was to improve thermal comfort in the home. Other consistent drivers included wanting to do something that would be good for the value of the house and an expectation to be in the house for a long time. A desire to reduce energy bills was significant in half the households.

The value that different people allocate to these preferences varies (depending, for example, on disposable income) but surveys have been used to determine average values. In surveys for Massachusetts, low income households valued comfort almost as much as other households. However, they valued health rather less (NMR Group, 2011).

Benefits are different for building owners and tenants – this applies in both domestic and non-domestic sectors. For landlords, marketability is an important benefit – some studies show reduced vacancy rates in more efficient buildings (Cluett & Amann, 2015). A survey of commercial landlords in the USA found that willingness to invest in energy efficiency was linked to belief that tenant retention would improve as a result (Davis, 2019). Tenant satisfaction can also mean fewer complaints, and reduced energy bills can mean more prompt payment of rent (NMR Group, 2011).

In the commercial sector it is easier to monetise benefits such as health improvements, because this leads to fewer sick days and better productivity. Reduced energy use also contributes to environmental targets, for organisations that have them. However, we did not find any practical examples where these benefits had been included. The Berkeley Ordinance did say that opportunities for improving health and comfort should be described, but there is no indication of how to monetise those benefits for calculating paybacks.

Table 4 summarises the main wider benefits of energy-efficiency work in buildings cited in the literature.

Table 4: A summary of wider benefits of energy efficiency improvements for building owners or occupiers

Benefit	Typical use
Thermal comfort	This is widely described but rarely monetised because it is so subjective. A survey of homes in Massachusetts (NMR Group, 2011) found thermal comfort is worth up to $125/year for non-low income groups or $99/year for low income. Thermal comfort is widely recommended for inclusion as a benefit in assessing energy efficiency programmes. However, it is rarely actually included in a regulatory context - except for examples in the UK such as the Green Deal and ECO (DECC, 2012). Here energy savings were reduced by 15% to represent comfort taking and the valuation is based on the cost of the fuel. This is consistent with Green Book guidelines.
Health	A comparison of Energy Efficiency Obligation schemes in Europe and the US (Rosenow & Bayer, 2016) describes this as a benefit for residents. However, the monetisation examples are about savings in the public health care sector, so these are in practice a social benefit.
Increased asset value	The Massachusetts survey estimated house value increases for the residential sector. Also (Rosenow & Bayer, 2014) found evidence for a price premium for energy efficiency in Australia and the Netherlands. However, this benefit is very dependent on context. A case study of an office building in Italy (Aste, 2013) estimated the price premium for energy-efficient retrofit at €4 million. However, this benefit was not actually included in the main analysis.
Marketability	This is potentially a significant benefit in the rented sector, as surveys have shown energy efficiency reduces vacancy rates (Cluett & Amann, 2015). However this is also dependent on context and we did not find any examples where it was actually used in programme evaluations.
Environmental compliance cost	Commercial companies may be subject to environmental taxes or permits related to energy use. These are easily monetised. The Vermont rules for claims for energy efficiency projects require that these costs are included in the simple payback time calculation (Efficiency Vermont,2017)
Employee productivity	This benefit is occasionally recommended to be used in programme evaluation, as in Woolf et al (2014) but is difficult to monetise.

Table 5 below gives examples of participant benefits included or recommended for use in a range of the sources we reviewed. The first three columns on the right apply to all sectors and the last two are mainly for non-domestic participants.

Table 5: Benefits for participants in energy efficiency improvements that are included or recommended to be used in assessing the benefit of energy efficiency improvements.

Key: Regulatory cases in black. Non-regulatory in blue. Y – yes. S – 'Selling point': mentioned, but not incorporated into the analysis.

Example	Thermal comfort	Health	Increased asset value, marketability	Environmental compliance cost	Employee Productivity
(BEIS, 2012) Impact Assessment for the Green Deal and ECO in the UK. Rebound effects are regarded as thermal comfort benefit (and hence the extra energy used is ignored). This is as recommended in the Green Book (BEIS, 2018).	Y				
(Efficiency Vermont, 2017) Calculation of payback period for company energy efficiency schemes, required for cost claims in Vermont.				Y	
(NMR Group, 2011) Proposing assessment methods for residential and low income programs Based on surveys of homes undergoing energy efficiency retrofit: Thermal comfort is worth up to $125/year for non low income groups or $99/year for low income. Health impacts are worth up to $19/year for non-low income groups or $4/year for low income	Y	Y	Y	Y	
(Cluett & Amann, 2015) Reduced vacancy rates reported in surveys from several programs			Y		

Example	Thermal comfort	Health	Increased asset value, marketability	Environmental compliance cost	Employee Productivity
Aste (2013) Case study of benefits of retrofit over repair, in an office building. The increase in value is not actually included in the analysis but remarked on as making a big difference to the result.			S		
(Berkeley Lab, 2016) Thermal comfort and control are the non-energy benefits most highly valued by consumers. They are recommended to be used as a selling point. However, they are not easy to quantify for use in regulations.	S				
(Rosenow & Bayer, 2016) Recommends that thermal comfort is included in program evaluation, using revealed preference techniques (where ranking surveys are used to explore people's priorities) for valuation. Suggests that rebound effects are evidence of thermal comfort. Health is described as a participant benefit but the monetisation examples are about savings in the health care sector, so these are in practice social benefits Gives evidence for a price premium for energy efficiency in Australia and the Netherlands.	Y	Y	Y		
(Woolf et al, 2014) Proposed for evaluating energy efficiency programs	Y	Y			Y
(UKERC, 2016). Evaluation of cost effective energy saving potential for the UK stock. Non-energy benefits are included using Green Book guidelines.	Y				

Hidden costs

There are also hidden costs of energy retrofits (such as maintenance of new equipment, training to use it, replacement costs when components fail, and/or the loss of utility when retrofit work is underway) which by their nature are usually ignored. However, they are important in assessing the likely impact of energy efficiency programs. DECC assessed additional/hidden costs for a range of measures for an impact assessment for the Green Deal. Most were small, but for internal solid wall insulation hassle and hidden costs came to nearly £5,000 (DECC, 2012: Table 29).

Sometimes hidden costs are effectively barriers. Eunomia found from their surveys that companies [and other organisations, such as housing associations] often reject outright projects that impact on day to day operations or have risks in that area (BEIS, 2017).

There is one other cost saving that is easy to monetise but generally ignored: early replacement costs, which the National Standard Practice Manual (NSPM) advised should be factored in (NESP, 2017). This is the avoided cost of replacing the old equipment when it reaches the end of its life. This will be adjusted according to the discount rate. This is only important when the more efficient equipment has comparable costs with the old, as otherwise the installation costs of the new system will dominate, especially after discounting.

Part of the IEA Annex 56 (IEA, 2017a) argued that embodied energy (energy used to make and transport building materials) should also be included in cost effectiveness assessments alongside operational energy (energy used when a building is running, for heating, lighting etc.).

Predicting energy savings

The policy in question is to improve energy efficiency but calculating whether or not this is cost effective requires estimating bill savings and hence energy savings. Unfortunately predicting energy savings is hard, and there are uncertainties.

The risk of actual savings falling short of predicted savings can discourage investment especially for households. In focus groups of tenants discussing the Green Deal many said they would not take it up because the savings were not guaranteed (Quadrangle, 2011). Research by Novikova et al (2011) also showed that uncertainty of savings was the second most common reason for abandoning thermal retrofit decisions, after them being too expensive.

The factors leading to reduced savings include:

- comfort taking (where occupants take part of the saving from energy-efficiency improvements as improved thermal comfort);
- the pre-bound effect (where occupants who are previously under-heating will save less) (Galvin, 2016);
- the performance gap (where as-built performance does not match as-designed).

We found considerable variation as to whether these were taken into account or not. For example the regulations for residential buildings in England (DCLG, 2016) requires that energy use is calculated using SAP 2012 and ignores all of the above. However the Green Deal adjusted for all of them (albeit using broad brush estimates).

Various ways to reduce this uncertainty have been suggested. For the commercial sector Davis et al (2019) proposed trial periods, performance based guarantees, and insurance contracts.

Packages of measures

Where a package of measures is considered, costs and benefits should be assessed for the package as a whole, because measures can interact and the overall effect is not the same as the sum of each individual item. This is particularly true for insulation and heating measures, where savings decline for each successive upgrade – it depends what has already been upgraded. Audits for Energy Performance Certificates and other audits often list upgrades individually, and these should be treated with caution.

There are a number of examples of packages in the literature. When evaluating updates to Building Regulations (DOE, 2017), the building is modelled with both sets of constructions (the specification required to meet previous - and then the proposed - regulations).

Considering individual measures separately may also introduce unintended consequences. The Bonfield report Each Home Counts (Bonfield, 2016) warned about this: 'Standards need to become better integrated, with a holistic or whole building approach incorporated into the process. This approach helps to prevent individual aspects of home retrofit being considered in isolation (e.g. solid wall insulation or boiler replacement) which ultimately can lead to unintended consequences in overall building performance.'

Packages may be optimised in different ways. The IEA Annex 56 (IEA 2017b) advocated packages of measures to maximise carbon savings rather than cost savings so all thermal elements are improved and where appropriate energy efficiency and renewable energy technologies are combined. It noted that combining measures brings opportunities that would otherwise be missed – for example, improving insulation so that more economical renewable heating becomes viable.

A package can be said to be cost effective if there is no net cost (over the chosen time horizon) i.e. NPV is greater than zero. Such a package can include measures that are not cost effective individually because more effective measures offset the extra cost of the less effective measures. To assist in these choices, it can be helpful to list measures sorted by their effectiveness (unless other considerations require particular combinations). Salix energy audits list packages in this way (Salix, 2018). Salix sets a maximum payback period of eight years, but individual measures with a longer payback can be included provided the whole package meets the criteria. Past research for the Scottish Government (CAR, 2008) also examined packages of upgrades for the whole Scottish housing stock – examining trade-offs between costs and carbon savings, including lifetime repair and maintenance costs alongside upfront capital costs and carbon savings.

Maximising carbon savings with no net cost is a higher level of improvement than the cost optimal solution, which maximises NPV. Both these approaches have been used in regulatory contexts: the EU Energy Efficiency Directive (2012) required that energy efficiency measures should be *implemented where they are cost effective*, while the Energy Performance of Buildings Directive (2010) proposed that efficiency measures should be *cost optimal*.

These tests are illustrated by the following diagram (Figure 4) from Skoczkowski et al (2016). Point A is the starting point. Point N maximises energy savings and is cost effective – with no net increase in cost. However, point O, with lower energy savings, is cost optimal – in that it minimises the cost.

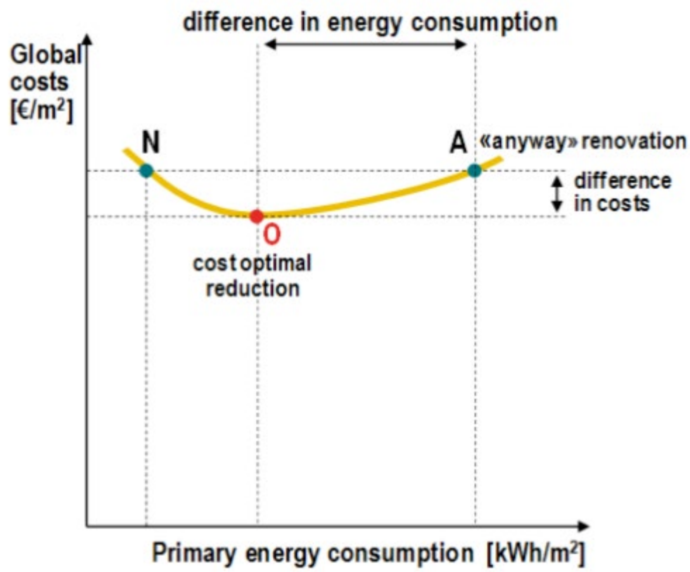

Figure 4: The difference between cost effective and cost optimal (Skoczkowski et al, 2016)

A cost optimal solution may be worse or better than the required regulatory standard. When it is better, then it may be a sensible target, especially when regulatory standards are expected to improve over time. The following table gives some examples from IEA (2017a) of what the different levels can mean in practice.

Table 6: Comparison of cost-effective and Cost-Optimal Packages of Measures (reproduced from Annex 56, IEA, 2017a).

Case study building	Cost effective/ cost optimal	Package	Primary energy and annualised life cycle costs	Annualised life cycle costs
Austrian **Multi-family building**	Cost effective minimum primary energy	Very thick insulation, triple glazed windows with external shading, MVHR, district heating based on renewables	100 kWh/m^2/a	€31/m^2/a
	Cost optimal	Thin insulation, double glazed windows, gas heating	152 kWh/m^2/a	€20/m^2/a
Portuguese **Two-family building (electric heating in the reference case)**	Cost effective minimum primary energy	Thick insulation Heat pump for hot water and space heating	16 kwh/m^2/a	€53/m^2/a
	Cost optimal	Thick insulation Heating using gas	186 kWh/m^2/a	€39/m^2/a

For these case studies the cost calculations were based on life-cycle costs and energy savings only. Co-benefits were discussed but not included.

The IEA Annex 56 (IEA, 2017a) also argued (without offering hard evidence) that the most cost-effective package of measures is often a combination of energy efficiency and renewable energy investments.

Wider benefits – society and energy suppliers

Energy efficiency programmes may be run by the state or by non-government organisations, or by utility companies. For example in the UK, the Energy Company Obligation part of the Green Deal programme is implemented by utility companies. Also in the USA many states have obligated utility companies to implement energy efficiency programmes or have commissioned third party non-profit organisations to do so - such as Efficiency Vermont.

These schemes bring in extra funding which leverage wider benefits. There are cost savings for utilities from reducing demand and public funding often considers benefits to society. These benefits can be used to justify incentives to consumers to upgrade their buildings.

Public benefit

The environmental and social benefits most often included in energy efficiency programmes are: reduced greenhouse gas emissions, improved air quality and improved health (driven by both air quality and also indoor conditions). The UK Green Deal impact assessment (GDA, 2012) included monetised benefits for GHG emissions and air quality; health was also discussed but not monetised, because there was no set methodology for doing so. The Green Deal Assessment also mentioned jobs, reduced fuel imports and reduction in fuel poverty but did not include them in the CBA. The UKERC included benefits for GHG emissions, and air quality in their primary analysis of economic potential for efficiency in the UK as shown in the following diagram (Figure 5). In the secondary analysis they put values on health and GDP (green bar).

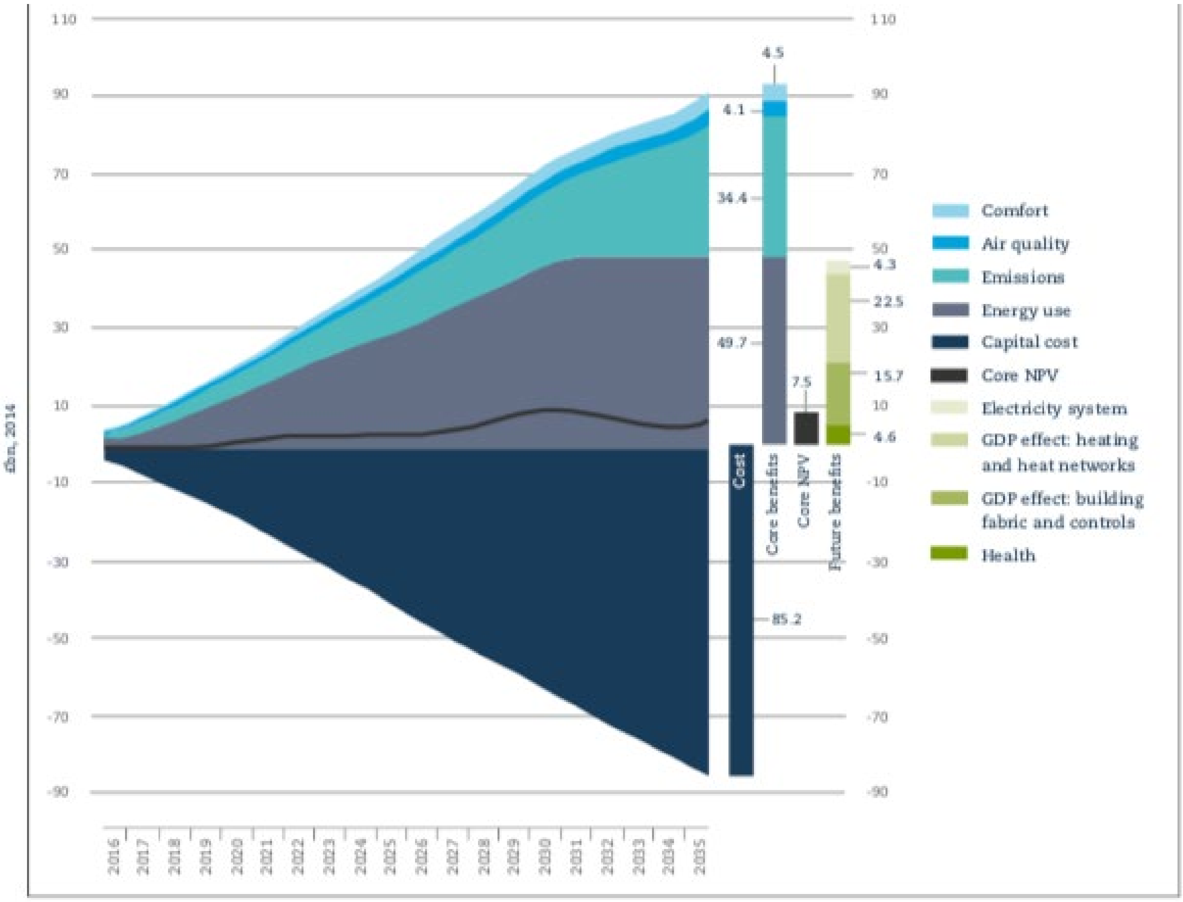

Figure 5: UKERC's policy analysis monetised wider benefits, including comfort and air quality (UKERC, 2017).

Other studies also put values on some of these benefits. For example, a 2013 review of energy efficiency programmes in Europe by the Energy Coalition reports estimated that the KfW (Kreditanstalt für Wiederaufbau, Bank for Reconstruction) renovation programme in Germany gained €3 billion for public budgets, because of the multiplier effect on investment. A more recent report on Energy Efficiency Obligation Schemes in the EU (Rosenow & Bayer, 2016) found benefits to jobs (23 direct jobs per £1 million spent). It also cited a Warm Homes Scheme in Northern Ireland that was found to give €42 cents benefit to the health service for every €1 spend.

Supply-side savings

Definitions of cost-effectiveness are often presented solely from the perspective of energy users. However, energy suppliers often incur cost and benefits too. For utilities, the main cost saving from energy efficiency schemes is from reduced need for generating capacity, transmission and distribution. This is especially important for electricity, where costs are driven by peak demand. For gas, peak demand is smoothed by buffering in the transmission network so this is less critical. In Scotland, the main energy use in buildings is heating (CAR, 2008) and, in the current situation, peak-time electricity is rarely used. However, in the future, if heating systems are converted to use electricity, then insulation will be key to reducing electricity demand. As a result, there will be benefits to utility companies in incentivising it – in essence, negative generation. In some regimes utilities also make savings on environmental compliance schemes, such as renewable energy certificates or emissions licences.

There are other benefits for utilities that are sometimes discussed, though rarely monetised. These are mainly to do with low-income customers who struggle to pay their bills. Reducing bills reduces the need for cut-off notices and general admin, as well as consumer debt.

Sources of funding

There are a number of examples of public and state-sponsored funding in the literature. For Green Deal financing (a loan), the Golden Rule applied, which was based on net annual savings though this was primarily to protect households rather than the public purse. Salix loans for public buildings have two criteria: a maximum payback time and a maximum £/tonne saved. Efficiency Vermont is another example of public funding in the form of loans, this time for commercial projects. The funding provided is limited by net present value and a minimum payback time (to discourage free riders). We found no other examples of cost effectiveness criteria for public funding applied at the building level. Evaluating cost effectiveness for private funding (i.e. self-funded) is at the discretion of those involved. This is very often payback time.

Other cost effectiveness criteria are applied for public funding programs. Many UK government projects have to conform to the Green Book guidelines, which are based on net present value. Other programmes frequently use related criteria such as the cost/benefit ratio. Any criteria applied at the programme level can also be calculated for individual buildings. (As we noted previously, a programme is often a series of individual buildings considered together.)

Government grant provisions for energy efficiency vary across the UK[6]. Aside from these the Energy Company Obligation operates across Great Britain and places requirement on larger energy suppliers to carry out measures that reduce the cost of heating homes where the occupants receive benefits, and so reduce carbon emissions. There is no formal cost-effectiveness test in ECO, and energy suppliers are free to make their own decisions about how to meet their obligations cost effectively.[7]

Practical implementation

There is very little information or evidence in the literature about how to apply definitions of cost effectiveness in practice. Nor did we find any information or evidence about how much complexity can be accommodated by people applying the definitions. By inference, it appears that businesses and government agencies can cope with greater complexity – very likely because they have people with a financial training (accountants, economists), who understand and can interpret discounting and more complicated investment appraisal.

The Green Deal Golden Rule is simply defined in terms of net annual savings – how much money is saved each year, added together and compared against the initial outlay. The complexity is in calculating the energy savings. In the case of the Green Deal there is an adjustment for occupant behaviour, catering for thermostat settings, length of heating period, and similar controls issues. There is also an adjustment for the performance gap. There is no adjustment for comfort taking. However even before these adjustments, the basic audit may be inaccurate. Mystery shopper research related to the Green Deal in 2014 that different assessors (who needed to assess properties before going ahead with the Green Deal) gave different estimates of savings, and even recommended different upgrade measures (DECC, 2014).

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[6] https://www.turn2us.org.uk/Benefit-guides/Grants-for-Energy-Efficiency/Country-schemes

[7] https://www.ofgem.gov.uk/environmental-programmes/eco/about-eco-scheme

Appendix I - Research Method

ClimateXChange and the Scottish Government identified approximately 100 literature sources in advance. Cambridge Energy sorted these, identifying duplication and gaps, and identifying additional research from the UK, the US and a small number from the EU. In total we identified more than 2000 possible sources, and we reviewed titles, abstracts and summaries to pare this down to 200 useful sources. They included government publications, guidance from non-government agencies, journal papers and grey (unpublished) literature.

In each case, we recorded the author(s), year of publication, publisher and place of publication, and a summary of the main points relating to defining ‘cost effective’. These were stored in an Excel spreadsheet. We also summarised worked illustrations that were relevant to the project aims, including outcomes, and real-world evidence. We also scored each entry for its breadth of use (where there was evidence of how widely used a source was).

We looked in particular for advantages and disadvantages of each of the methods proposed in the literature, as well as evidence of their use in policy or regulation, and information about different methods being used in different contexts. We also sought to explore whether and how wider (social) costs were included among the methods presented.

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