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An investigation into the cost optimality of the Passive House retrofit standard for Irish dwellings using Life Cycle Cost Analysis



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Abstract

The Passive House standard represents perhaps the current state-of-the-art in low-energy building design. It is often hailed by its advocates as a cost-optimal standard to be applied to both new and existing dwellings in order to achieve Ireland's energy and CO₂ reduction targets. However, meeting the rigorous standards of Passive House in existing buildings is demanding and generally requires significantly higher initial capital investments. This paper summarises a research study involving an investment appraisal of an individual dwelling retrofit constructed to the Passive House standard. The research aim was to determine if the Passive House standard could become a cost-optimal model for the deep-retrofit of Irish dwellings. The problem was investigated using energy analysis (DEAP v3.2) and Life Cycle Cost Analysis tools (BLCC5), applied to a real-life case study Passive House dwelling retrofit project. Total life cycle costs for the baseline (pre-retrofit) dwelling, the Passive House retrofitted dwelling, and a range of alternative retrofit scenarios were computed. An economic appraisal using Life Cycle Cost Analysis, together with sensitivity analysis, demonstrates that the deep retrofitting of an existing dwelling to the Passive House standard can become cost optimal, if longer investment periods (≥ 43 years), lower discount rates ($\leq 2.6\%$), or higher fuel inflation ($\geq 7\%$) are considered.

Keywords:

Low-energy Retrofit, Passive House, Cost-Optimal, Life Cycle Cost Analysis.

1. Introduction

The economics of energy retrofitting are based on the premise of spending-to-save – meaning additional initial capital invested today in energy-efficient refurbishment measures should be balanced by energy cost savings in the future.

The aim of this research was to investigate whether it is more cost-effective for an individual private home-owner in Ireland to carry out energy efficient refurbishment measures to an existing dwelling in an intensive way (i.e. to Passive House standard); or to adopt a less intensive retrofit strategy, with higher operational energy demand, but requiring lower initial capital costs.

This research question was investigated by carrying out an economic evaluation, using Life Cycle Cost Analysis (LCCA), of a case study relating to an Irish dwelling retrofitted to the Passive House standard.

2. Background

The existing Irish housing stock has been described as one of the worst-performing in terms of energy efficiency in Europe, with the average Irish dwelling consuming over 25,000 kWh of primary energy (Brophy *et al.*). CO₂ emissions for Irish dwellings have been stated as being 47% higher than the average dwelling in the UK and 104% higher than the EU-27 average (Ahern *et al.*).

Current and future EU energy performance policy and directives are placing a new impetus on all member states to develop *cost-optimal*, advanced energy-efficiency standards for both new and existing buildings, in order to deliver on energy and emissions reduction commitments. The Energy Performance of Buildings Directive (recast) outlines long-term objectives for all EU member states of decreasing the CO₂ emission levels for the building sector by 80% in 2050, compared to 1990 levels (EPBD, 2010; EC, 2102).

Retrofitting the existing building stock to the required standards will clearly require significant financial investments by both governments and private individuals. It is recognised within EU policy that to realise the full potential of these energy and emissions savings, the whole life cycle costs of a building over its entire life-span must be taken into account, as opposed to just focusing on initial capital investment costs (BPIE, 2013).

The energy used for space heating in existing Irish dwellings on average accounts for over 67% of household delivered energy (SEAI, 2013). Given this fact, significant reductions in both energy demand and carbon emissions can be achieved with the deep-retrofit of existing dwellings in order to minimise heat losses occurring through the building fabric.

The Passive House standard represents perhaps the current ultimate in such "fabric-first" low-energy building design, and is hailed by its advocates as a cost-optimal standard to be applied to both new and existing dwellings, in order to achieve the necessary energy and CO₂ reductions (Passipedia, 2015).

Passive House dwellings are typified by high levels of thermal insulation (very low U-values), triple-glazed high-performance windows, minimised thermal bridging (continuity of insulation layer), structural

air-tightness, and the use of Mechanical Ventilation Heat Recovery systems (MVHR) to recover residual heat otherwise lost in ventilation. Meeting the Passive House (Classic) standard requires achieving an ultra-low space heating and cooling demand of no more than 15 kWh/m² per year, or a peak heat load of 10 W/m², as calculated using the Passive House Planning Package (PHPP). A very high level of air-tightness must also be provided in order to achieve an air-leakage rate no greater than 0.6 times the house volume per hour under a pressurisation of 50 Pascals (PHI, 2015a).

A marginally-relaxed variation of the Passive House standard introduced for existing buildings – EnerPHit – stipulates a maximum space heating demand of 25 kWh/m² per year, and an air-tightness target of 1.0 ac/h (PHI, 2015b).

However, achieving the rigorous and comprehensive standards of either full Passive House or EnerPHit in existing dwellings generally requires significant intervention, and optimised fabric and component standards, and hence higher capital investment. This poses the question – do the financial savings accrued from ongoing reduced operational energy use over the whole life-span of a Passive House retrofit justify the higher initial capital investment costs?

An attempt to answer this question requires economic analysis, using appropriate investment appraisal techniques. This means examining and properly quantifying all relevant capital and operational costs, occurring at different points in time, and over the whole life cycle of a building. Simple payback calculations (the amount of time it will take to recover the initial investment in energy savings) are insufficient.

Simple payback ignores the future costs and benefits occurring over the complete lifetime of a building, residual values, fuel escalation, as well as the time value of money (the impact of inflation and interest rates). Life Cycle Cost Analysis is a technique that can be used to properly evaluate the total economic performance of buildings, or energy-efficiency measures over their entire life cycle (SCSI, 2012; WBDG, 2014).

3. Literature review

There is debate as to whether it is more cost-effective to refurbish existing dwellings in an intensive way in order to minimise operational energy use, or whether it is better to adopt a less intensive retrofit strategy with lower initial capital costs (Versele *et al*).

Previous studies have used LCCA to examine the total life cycle costs of different energy-retrofit standards, in order to ask the question — is the retrofit standard with the lowest operational energy costs the most cost-optimal standard?

Neroutsou (2014) used LCCA to determine the most cost-effective way to refurbish the thermal envelope of a case study end-of-terrace Victorian house in London by comparing the life cycle costs of the original pre-refurbishment building, the actual as-built “regulations-compliant” retrofit standard, and a higher Passive House (EnerPHit) standard.

Total life cycle costs of the Passive House retrofit were shown to be 30% higher than the regulations-compliant standard. Neroutsou concluded, however, that Passive House could become the

economically-optimal retrofit option, but only with rising energy prices, lower discount rates (< 3.5%), and longer investment lifespans (more than 33 years).

An earlier Belgian study (Versele, Vanmaele, Breesch, Kein & Wauman, 2009) conducted a similar cost benefit analysis of energy retrofitting a 1950s single-family dwelling. Four different energy performance levels for retrofitting the dwelling were considered, including Passive House. Energy costs were calculated using both PHPP and the Flemish national energy-rating tool, EPB. The study found a 92% reduction in total end-use energy could be achieved with the Passive House standard, compared with 81% from a less intensive “low-energy” standard. The cost-optimal standard varied according to the predicted rate of fuel inflation, and the investment timescale. With a low fuel inflation forecast (2%), the Passive House retrofit failed to pay for itself, even after 40 years. Passive House was shown to be cost optimal only with a (perhaps improbable) 10% energy price increase every year, and over a 30-year investment horizon. This study correlates with the findings of Audenart, De Cleyn and Vankerckhove (2008).

As in Neroutsou (2014), these studies all highlight the need for treating the conclusions of LCCA with care – the calculations are based on multiple assumptions of retrofit construction costs, estimated energy savings, variable interest rates, inflation and energy price escalation which are all difficult to predict with certainty.

Famuyibo (2012) applied a similar LCCA methodology, but on a larger scale in order to provide more generalised findings and policy guidance on the economic viability of applying the Passive House standard to retrofitting the entire Irish housing stock. Famuyibo used statistical sampling, stock modelling methods, and the development of a range of representative dwelling “archetypes”. This was then combined with LCA tools to try to determine the extent of national reductions in energy, life cycle costs and carbon emissions that could be achieved in retrofitting the Irish housing stock to differing standards, meeting (then-current) Building Regulation standards, as well as to a more ambitious Passive House standard. This study concluded that retrofitting the building stock to Passive House standard could reduce national life cycle primary energy-related emissions (from dwellings) by over 84%, but that both retrofitting to Current Regulations and to a higher Passive House standard have significantly higher life cycle costs than a “do-nothing” base-case scenario. These findings would seem to be at variance with Neroutsou (2014) and Versele *et al* (2009).

4. Research methodology

4.1 Life Cycle Cost Analysis – key concepts and standards

Life Cycle Cost Analysis (LCCA) is a technique for evaluating the total economic performance of a building asset or element over its projected lifespan, or defined period of analysis. It can be described as the overall cost of constructing, operating, maintaining, repairing, renewing and disposing of an asset over its entire service life (ISO 2008a). LCCA enables comparative financial appraisals to be made, of two or more project alternatives, in order to select the one that has the lowest life cycle costs and hence is the most cost-effective over the anticipated lifespan (SCSI, 2012; WBDG, 2014).

In the context of building design and retrofitting, LCCA is a powerful economic analysis tool that can be used by architects, engineers, surveyors and other construction professionals to better inform energy-related investment decisions. LCCA allows the assessment of two key investment decisions: (1) are the increased initial investment costs incurred today justified by lower operating costs in the future? and, (2) out of two or more potential investment alternatives, which is the most economical in the long run? The alternative with the lowest overall life cycle costs will be the most cost-effective choice, assuming that it satisfies all other relevant performance requirements (Fuller & Petersen, 1995).

The methodology of this study is as per the international standard (ISO 15686:Part 5), and the draft EU CEN methodology: "Cost optimal building performance requirements" (ISO 2008a, ECEEE 2011).

4.2 Life Cycle Cost formula

Life Cycle Costs (LCC) are in essence the sum of all capital and operational costs, occurring at various times over the life of a building or asset.

The basic formula for the summation of all life cycle costs is as follows:

$$LCC = I + OM\&R + Repl - Res + E$$

Where

LCC – Total life cycle costs;

I – Initial capital investment (construction) costs;

OM&R – Present-value operating, maintenance + repair costs;

Repl – Present-value capital replacement costs;

Res – Present-value residual value, less disposal costs;

E – Present-value energy costs.

4.2.1 Initial Capital Costs

Initial investment costs include all direct and indirect project and construction costs associated with achieving the energy retrofit performance standard. The study involved assessing all relevant retrofit and refurbishment costs and then separating costs into "energy-efficiency costs" (retrofit or renewal works attributable to improving energy performance), and "incidental refurbishment costs" (general refurbishment, upgrade, or reconfiguration works required to the dwelling independent of any energy performance improvements).

4.2.2 Maintenance, repair and replacement costs

Maintenance, repair and replacement costs are an integral part of overall life cycle costs (ISO 2008a). Annually recurring maintenance and repair costs for a dwelling will typically include boiler or heating system servicing, changing of MVHR filters, cleaning of ductwork and maintenance of air-tight seals to windows.

Depending on the chosen study period and the expected life-span of the dwelling, LCCA calculations are generally required to include any future replacement costs for building elements, equipment, and systems. This requires an estimation of the service life of such components in order to anticipate maintenance and replacement cycles. ISO 15686 gives detailed guidance on service-life planning and

estimation of life expectancy for building materials and components (ISO, 2008b). Replacement costs are assumed to be in line with current capital costs, (with costs escalated to their future value).

4.2.3 Operational energy costs (DEAP)

Annual operational (fuel) energy costs for all project alternatives were calculated using the DEAP (Dwelling Energy Assessment Procedure) energy analysis software. Although the case study retrofit dwelling was designed to meet the Passive House performance criteria using the Passive House Planning Package software (PHPP), DEAP was adopted to estimate the operational energy demand for the various alternatives. DEAP is currently the only recognised energy performance calculation tool that can be used to provide an energy performance rating and demonstrate compliance with Part L (Conservation of Fuel & Energy) of the Irish Building Regulations, in accordance with the EU Performance of Building's Directive (EPBD Recast Directive 2010/31/EU Article 3). For the retrofitted case-study dwelling a high correlation was observed between the (DEAP) predicted operational energy use, and the actual (post-occupancy) monitored energy use (Coyle, 2015).

Operational fuel costs for the LCCA analysis were then obtained by multiplying the calculated annual Delivered Energy (kWh by fuel type) given in the DEAP results page, by the relevant fuel price kWh unit costs (including VAT). These unit costs were based on the current SEAI average national fuel price database (Table 1.) (SEAI, 2015).

Table 1. Average current domestic fuel costs – 1/1/2015 (Source: SEAI 2015b).

Natural gas unit price €/kWh	Oil unit price €/kWh	Electricity unit price €/kWh	Solid fuel (coal/peat) €/kWh
0.0681	0.0755	0.2107	0.0687

4.3 Present value analysis – calculating NPV of retrofit alternatives

Fundamental to LCCA is the concept of Net Present Values (all future costs converted to their present value at the start of the project, taking into account the effects of interest rates and inflation).

LCCA involves looking at cash flows and costs occurring at different time periods of the life cycle of a building. In order to be able to add and compare these costs, LCCA calculations must convert all amounts to present values (the value of anticipated future-occurring costs in "today's money"), by applying a discount rate that reflects the "opportunity cost of money over time". For all future-occurring costs the LCCA methodology first escalates the base year costs to their anticipated future time of occurrence, based on an escalation or inflation rate, and then discounts all costs to give Net Present Value costs (SCSI, 2012).

The Net Present Value (NPV) of a particular investment scenario is thus calculated using a formula combining the escalation rate (inflation), discount rate (interest), and the study period (investment period):

$$NPV = \sum_{t=1}^T \frac{C_t}{(1+r)^t}$$

Where

NPV – Net present value;

C_t – is the cost in year *t*;

r – is the expected real discount rate per annum;

t – is the no. of years at the occurrence of the costs;

T – is the period of analysis (investment term).

4.4 Software tools to calculate NPV

Using the above basic mathematical formula a simple LCCA calculation tool can be developed using an Excel spreadsheet. Alternatively, a range of LCCA software programmes are available. One such programme is the BLCC5 software (Building Life Cycle Cost Program, version 5), developed by the US National Institute of Standards & Technology (NIST), and provided freely by the US Department of Energy.

The BLCC5 software requires user input of all life cycle cost data (initial capital investment costs and operational costs) as well as defining the economic boundary conditions (discount rate, escalation rate, investment period, service life and residual value factor). The software will then compute (in present-value currency) total life cycle costs for each project alternative, based on the entered cost data and economic assumptions.

4.5 Financial assumptions used for LCCA

For the initial LCCA calculations the study adopted the following key financial assumptions:

Discount Rate:	4%
General Price Inflation Rate:	2%
Energy Price Escalation Rate:	4%
Study Period (Investment Term):	30 Years
Lifespan (of retrofit measures):	50 Years
Residual value	40%

A calculation of the Net Present Value (NPV) for project alternatives was then performed using the above assumptions. Sensitivity analysis was also used to assess input data uncertainty and the effect of changing the key assumptions and economic parameters underpinning the calculations.

The initial financial assumptions used were in line with ISO 15686, as well as the LCCA methodology described in the EU comparative methodology framework, the Cost-optimal Regulations [Commission Regulation (EU) 244/2012], and expanded upon in the associated Cost-optimal Guidelines [Guidelines accompanying (EU) 244/2012] (EC, 2012).

A discount rate of 4% was found to be an appropriate initial assumption based on Irish Central Bank historical data for average (real) interest rates for household mortgages over the last 15 years

(Central Bank of Ireland, 2015). For general inflation, the historical annual inflation rate for Ireland, averaged over the last 20 years, of approximately 2% was used (CSO, 2015).

With respect to the energy price escalation rate, a somewhat conservative rate of 4% was initially selected for the calculations [the actual annual escalation rate for household heating oil, for example, has been shown to average at around 6% for the period 2005-2012] (SEAI, 2013). The calculations were then repeated with a range of both higher and lower fuel escalation rates.

A 50-year design life for the retrofit measures was deemed as a reasonable assessment of the minimum design life of the installed energy retrofit measures. The 30-year study period was based on an assumed maximum investment term for a fixed rate residential mortgage. Residual values (40%) were then calculated using a straight-line depreciation method in accordance with both the NIST and EU cost-optimal methodology, (WBDG, 2014; EC, 2012).

5. Case study dwelling

The subject of this LCCA study is a Passive House deep-retrofit of a domestic building located in Galway City, Ireland. Designed by Simon McGuinness Architect, and completed in April 2014, the house is one of only three (at the time of writing) certified Passive House retrofit projects in Ireland (PHI, 2015c). Passive House calculation, design and construction standards were adopted to produce a retrofitted dwelling with a predicted 90% reduction in operational fuel costs, primary energy demand and CO₂ emissions.



Figure 1. Case-study building — the existing dwelling prior to, and after PH retrofitting works (McGuinness, 2014).

5.1 Existing construction and energy performance

The original (1960s) dwelling was constructed of 300 mm thick externally-rendered and internally-plastered cavity walls (uninsulated), and a timber-trussed roof with concrete tiles. The house had an (uninsulated) solid concrete floor and timber-joisted intermediate floor, with plasterboard ceilings. Windows and doors were single-glazed and aluminium-framed. The dwelling had an outdated and inefficient heating system resulting in a very poor energy performance. The calculated Building Energy Rating (BER) for the existing original building was an *F* rating, with a Primary Energy Use of 388 kWh/m²/yr (Table 2).

5.2 Passive House retrofit measures

The retrofit design strategy follows the Passive House design principals of a super-insulated thermal envelope (insulation continuity to avoid thermal bridging), triple-glazed Passive House certified windows, and an exceptionally-high level of structural airtightness combined with an efficient whole house mechanical ventilation system with heat recovery. The retrofit fabric and systems upgrades resulted in a retrofitted dwelling with an A2 BER rating, with a calculated total primary energy demand of 43 kWh/m²/yr. (Table 2).

Table 2. Key Energy Performance Characteristics

	Base (Existing)	B3 'Shallow Retrofit'	Passive House
U-Values (W/m ² K)			
Walls	1.78	0.21	0.12
Roof	2.30	0.16	0.11
Floor	0.84	0.84	0.17
Windows	5.80	1.6	0.96
Doors	3.0	2.0	0.90
Thermal Bridging factor) (y-value, W/m ² K)	0.15	0.30	0.08
Fabric air-tightness m ³ /m ² .hr @ 50 Pa	14	7	0.4
Ventilation system	natural	natural	MVHR
Heating system	oil boiler	condensing boiler	Air-Water HP
Heating system efficiency %	75	92	292
Heating Energy Demand (kWh/m ² .yr)	270	94	0
DHW Energy Demand (kWh/m ² .yr)	46	18	8
Primary Energy (kWh/m ² .yr)	388	136	43
BER Rating	F	B3	A2

Table 3. Total initial capital investment costs (four alternatives)

	1. Base 'Do Nothing'	2. Systems Upgrade	3. B3 'Shallow Retrofit'	4. Passive House
Capital Costs	€0	€12,500	€57,441	€110,510

Table 4. Energy demand (Delivered Energy) -- kWh/yr

	1. Base 'Do Nothing'	2. Systems Upgrade	3. B3 'Shallow Retrofit'	4. Passive House
Heating – primary	31,768	25,053	11,170	0
Heating – secondary	8,420	8,573	1,622	–
DHW – primary	5,354	4,115	2,450	1,173
DHW – secondary	1,471	–	–	–
Auxiliary electrical	230	230	335	671
Electrical lighting	1,326	626	634	634
Total	48,568	38,598	16,211	2,478
BER	F	E1	B3	A2

5.3 Capital investment costs of Passive House retrofit

Initial capital investment costs for the case study retrofit project were compiled and assessed in accordance with the methodology described in Section 4.2.1. The total initial capital costs were calculated in the amount of €169,580, including VAT, professional fees and ancillary costs. Separating out the costs of the Passive House (energy-saving) measures from the general refurbishment and alteration works gives costs in the order of €110,510 (€778 per m²), representing 65% of the total project costs (Table 3).

5.4 Retrofit alternatives

In order to assess the Passive House life cycle costs in comparison with other less intensive (and less costly) interventions, two alternative notional retrofit scenarios were additionally examined: (1) The existing pre-retrofit dwelling with only systems upgrades (space heating and DHW) – estimated total cost €12,500, and (2) a “shallow retrofit” involving systems upgrades as well as more conservative fabric upgrades (new double-glazed windows, external wall and roof insulation, no floor replacement or insulation), and the provision of a solar hot water system (roof mounted solar panel). This alternative is calculated to have a B3 BER rating (136 kWh/m²/yr) with initial capital costs of €57,441 (€410 per m²) – approximately half the cost of the actual realised Passive House retrofit (Tables 2,3,4).

6. Results and analysis

6.1 Operation energy, fuel costs and CO₂

Delivered energy, CO₂ emissions and operational energy costs for each of the four retrofit scenarios were calculated and compared. The results indicate an estimated 95% reduction in total delivered energy and a 90% reduction in both CO₂ emissions and operational energy costs achieved in the Passive House retrofit over the original base-line (pre-retrofit) dwelling.

6.2 Total life cycle costs

Total life cycle cost calculations were carried out for the Passive House retrofit as well as the three other retrofit scenarios. The LCCA computes total (present value) life cycle costs for the Passive House retrofit to be €112,924. This includes an NPV deduction of €24,689 in respect of the remaining residual value for the retrofit works.

A comparative analysis between the Passive House and the original “do-nothing” base case dwelling shows that the Passive House measures are cost-effective, with predicted Net Savings (NS) in the amount of €34,626, a Savings-to-Investment Ratio (SIR) of 1.4, and an Adjusted Internal Rate of Return (AIRR) of 5.18%. Simple Payback occurs in year 18, and Discounted Payback after 28 years.

Table 5. Results of LCCA calculations for project alternatives

	Initial Capital Costs	Total LCC (PV)	Net Savings (PV)	Payback Period (Discounted)
1. Base – ‘do nothing’	€0	€147,550	–	–
2. Upgrade Systems	€12,500	€131,210	€16,341	15 yrs
3. ‘Shallow Retrofit’ B3	€57,441	€101,241	€46,309	19 yrs
4. Passive House	€110,510	€112,924	€34,626	28 yrs

From the comparative LCCA results (Table 5), it is evident that all of the retrofit measures have lower total life cycle costs than the “do-nothing” base dwelling, meaning they are all cost-effective, or “profitable” over the 30-year study period. On a total Life Cycle Cost basis, doing nothing is actually the most expensive option.

On a purely financial basis, the LCCA suggests that the B3 “shallow retrofit” scenario is the most cost-optimal of all the alternatives considered. The LCCA calculates it to have the lowest overall life cycle costs, generating the highest net savings (€46,309). This is followed in second place by the Passive House retrofit with net savings of €34,626.

The fact that the retrofit alternative involving only an upgrade of the heating system produces the lowest net savings (€16,341), despite having much lower initial capital costs and the fastest payback period (15 years), illustrates the point that payback is a poor indicator of overall cost-effectiveness, and moreover the principle in deep-retrofit economics of “spending more to save more”.

6.3 Sensitivity analysis

It is apparent that LCCA is affected by a number of unpredictable economic variables fluctuating over time and hence contains an inherent degree of uncertainty (ECEEE, 2011, BPIE, 2013). Changing any one of the key assumptions or parameters in a LCCA calculation can impact dramatically on the results of any investment appraisal. LCCA therefore must also involve a series of “sensitivity analyses” in order to assess the impact of changing individually, and in combinations, all of the key economic variables such as:

- Discount rate (real rate of annual interest);
- Fuel inflation (escalation rate);
- Investment time span (study period);
- Residual values;
- Variations in actual capital construction costs;
- Fluctuations in actual operational energy savings.

The discount rate selected is perhaps the most critical factor in LCCA calculations, and hence the cost-effectiveness of the energy retrofitting measures assessed. Low discount rates produce higher net savings, encouraging higher initial investment costs, whereas an increasing discount rate leads to decreasing present-value future savings.

With a discount rate at or below 2.7%, the Passive House retrofit becomes more cost-effective (greater total net savings) than the cheaper B3 “shallow retrofit” alternative. The net savings (profits) generated by the Passive House retrofit increase to over €200,000 with a 0% discount rate, while at a discount rate above 5.6% the Passive House retrofit measures become no longer cost-effective (negative Net Present Values), (Figure 3 – top).

An increasing fuel escalation rate on the other hand leads to increasing net savings from the Passive House retrofit measures. Net savings increase exponentially with increasing fuel inflation. The initial LCC calculation used a fairly conservative 4% fuel inflation rate. Although perhaps an unlikely long-term scenario, with static or falling fuel prices ($\leq 2\%$ inflation rate), the Passive House retrofit becomes no longer economic (Figure 3 — middle).

At a fuel escalation rate of around 7%, the Passive House retrofit overtakes the cheaper B3 “shallow-retrofit” alternative in terms of cost-effectiveness. Assuming a future fuel inflation rate of 10% (unlikely perhaps but possible), the profits generated by the Passive House retrofit increase nearly eight-fold to over €250,000.

The longer the investment period considered, the greater the net savings generated by energy retrofitting. With a study period less than 19 years, the Passive House becomes no longer economic – operational energy savings accrued are not enough to offset the initial higher capital investment. With with a study period of over 43 years the Passive House retrofit overtakes the cheaper B3 “shallow-retrofit” alternative (Figure 3 – bottom).

Assuming a 100-year investment period, the net savings (profits) generated by the investment in the Passive House retrofit increase to over €300,000.

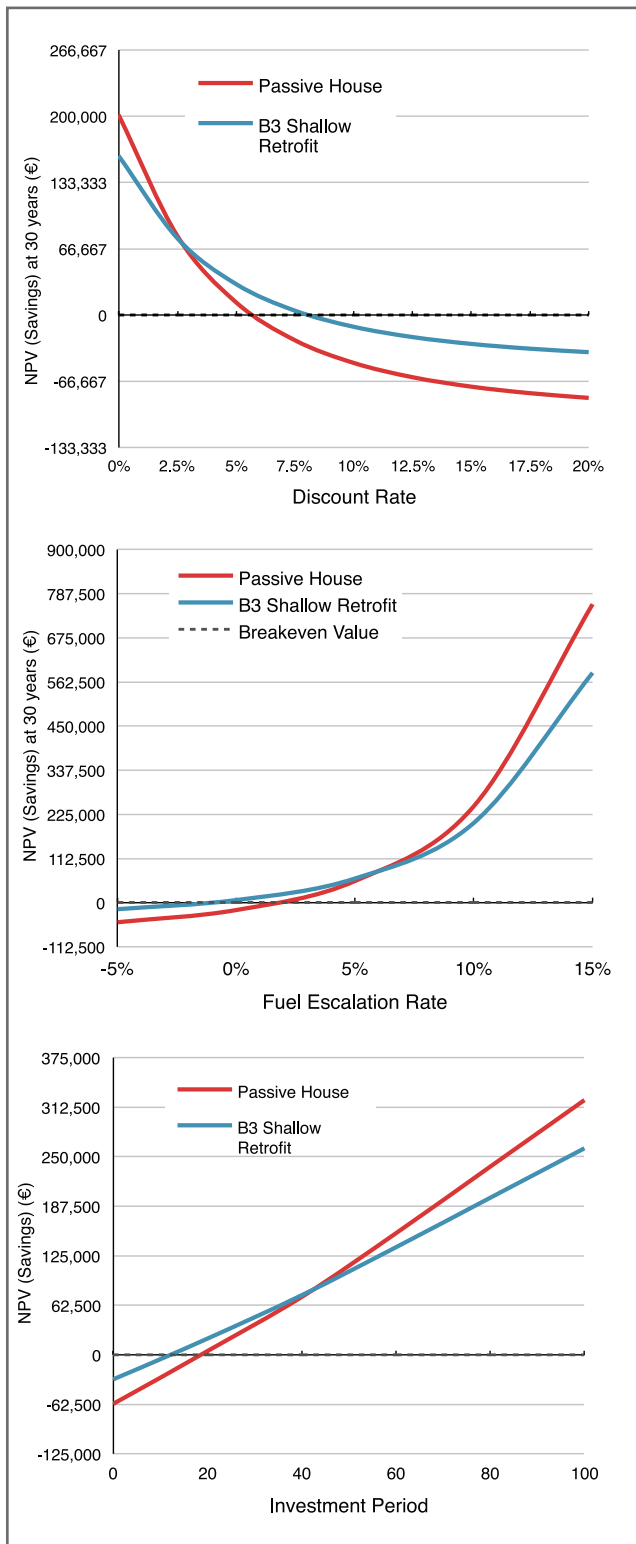


Figure 3. Sensitivity analysis: effect of varying discount rate, fuel inflation rate and investment period on NPV (cost savings).

7. Conclusions

The primary aim of this research was to conduct an economic appraisal of the Passive House retrofit standard using Life Cycle Cost Analysis, in order to determine if Passive House could become a cost-optimal standard for the deep-retrofit of Irish dwellings.

The case study project analysed in this study demonstrates how a state-of-the-art, deep-retrofit of an existing dwelling can achieve advanced levels of energy performance. Energy analysis of the case study dwelling showed that reductions of over 90% in energy and CO₂ emissions can be delivered in a typical “pre-regulations” Irish dwelling by deep retrofitting to the Passive House standard. Applied on a much wider scale, this offers the potential to realistically meet, and even exceed, the building-related emissions reduction targets Ireland has committed itself to delivering by 2050.

The economic appraisal carried out using Life Cycle Cost Analysis suggests that the deep retrofitting of existing Irish dwellings to the Passive House standard can be cost-effective for a private homeowner, with the right combination of interest rates ($\leq 4\%$), fuel inflation ($\geq 4\%$), long-term investment periods (≥ 30 years), and the inclusion of residual values.

With these initial economic parameters, the LCCA calculation showed the Passive House was a cost-effective, and even profitable, investment option, generating a positive investment return over the 30-year investment time period. That said, from a purely private, micro-economic perspective, a less intensive “shallow retrofit” is likely to be more profitable, generating greater net savings over the assumed investment term.

However, with lower interest rates, longer investment timescales or higher fuel inflation, Passive House can become the cost-optimal standard. The study further demonstrated that increasing the life-span of the investment (>43 years), reducing interest rates ($<2.6\%$), or assuming a higher rate of fuel price escalation ($>7\%$), all increase the cost-effectiveness of the Passive House and can justify (economically) the higher capital investment.

This research study was limited in scope to an analysis of the life cycle costs for an individual private house owner. Monetisation of wider societal or environmental costs and benefits was therefore deliberately avoided. The societal perspective (such as the environmental and economic cost of greenhouse gas emissions) was not considered. Furthermore, co-benefits such as improved indoor air quality, longevity of building construction achieved by elimination of interstitial condensation risks and potential mold growth, and also resulting improvements in user’s comfort, health and amenity were excluded (even though it is recognised that there are likely to be consequential economic benefits as a result of these).

This research also focused on an economic assessment of a specific dwelling retrofit. Although the limitations of a study based on an individual case study need to be recognised, the methodology and approach taken by this research could be applied on a broader scale to investigate the life cycle cost impacts of applying the Passive House retrofit standard more widely to the existing Irish housing stock.

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List of abbreviations

ach	Air changes per hour
AIRR	Adjusted Internal Rate of Return
BER	Building Energy Rating
BLCC5	Building Life Cycle Cost Program
CEN	European Committee for Standardisation
CO2	Carbon dioxide chemical formula
DEAP	Dwelling Energy Assessment Procedure
DHW	Domestic hot water
EN	European Standard
EPBD	EnergyPerformance of Buildings Directive
EU	European Union
EU-27	Total EU member countries
EWI	External wall insulation
ISO	International Organisation for Standardisation
LCC	Life Cycle Costs
LCCA	Life Cycle Cost Analysis
MVHR	Mechanical ventilation with heat recovery
NPV	Net Present Value
NS	Net Savings
OM&R	Operation, Maintenance and Repair
Pa	Pascals (pressurisation units)
PHI	Passive House Institute
PHPP	Passive House Planning Package
PV	Present Value
SEAI	Sustainable Energy Authority of Ireland
SCSI	Society of Chartered Surveyors Ireland
SHW	Solar hot water