Unlocking the potential - Low-Energy Dwelling & Heat Pump.

Investigating their multiple benefits, and how to increase adoption rates

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ABSTRACT: This paper is novel in that it is a first attempt to analyse the direct and indirect costs and benefits of constructing a 3-bed social house dwelling to low-energy standards in Northern Ireland. It uses data on direct construction and energy costs and augments this with estimates for some of the indirect benefits for three potential low energy upgrade for the real scheme of new dwellings. While estimation of Indirect Benefits is by it's nature imprecise, the analysis provides fresh insights and indicates that a financial argument exists for constructing to low-energy standards at both societal and individual levels. However the analysis also demonstrates that the decision-maker is dis-incentivised, leading to poor adoption rates for the low energy, carbon efficient dwellings. This has potential policy implications for UK social housing given the conflict with the UK's stated decarbonising objectives.
KEYWORDS: Passive House, Low Energy Dwelling, Social House, Financial Analysis, Multiple Benefits

1. INTRODUCTION

The benefits of energy efficient housing are multiple and varied, and appear to be an obvious solution for the provision of current and future sustainable buildings. However, despite possessing a multitude of benefits, low-energy, for example houses built to the Passive House (PH) standard, have not been universally deployed. This paper inquires as to why this is so, by carrying out a holistic cost and benefit analysis by including estimated economic value for a range of indirect benefits. By looking beyond energy cost savings, it aims to inform discussion and identify the means of unlocking the potential of low-energy home provision.

The paper quantifies the energetic and financial benefits of low-energy and PH in combination with low temperature Heat Pumps (HP), by optimising the design for a real case study building in the UK. Three potential energy upgrade options for the new-build three bedroomed 94m^2 social house are presented. A detailed energy, cost and direct benefits analysis is carried out based on the UK's SAP energy rating software and the Passive House Planning Package (PHPP), for the three options including that of a PH with HP. The paper applies the 'Multiple Benefits' (MB) framework [1] to enable comparison of the indirect financial benefits for current and future building regulations. It then uses the Multi-Beneficiary Analysis (MBA) to determine the costs and benefits for the involved stakeholders, based on a number of seminal studies identified in the literature. It should be noted however that there is a paucity of published analysis of certain benefits.

The analysis indicates that in order to realise the considerable potential of low energy social housing, tailored government support is required (and justified) to address the "split incentives" dilemma which the analysis has unveiled and quantified.

2. METHOD

2.1 Overview

The analysis was carried out on a scheme of 12 x 95 m² properties as described in [2] which are planned to be constructed to the optional social housing low-energy Energy Efficiency Multiplier (EEM) standard in Northern Ireland (NI). This is a voluntary standard for which Housing Associations (HA) receive a multiplier of 1.03 on the agreed costs of delivering the standard dwelling (equivalent to approximately 50% of the cost differential of achieving the higher energy efficiency standard).

The EEM Standard is equivalent to the current English building regulations [3] while the PH [4] standard is similar to the Change Committee's (CCC) recommended standard for the UK. For the PH dwelling, two different heating systems (Gas and electric HP) are considered.

The four energy efficiency standards were analysed and compared, with all but the base case qualifying for the EEM incentives for the Housing Association (HA):

1. Base Case of current NI minimum building regulations – assessed with SAP 2009 – "Base SAP 2009".
2. The English Building Regulations standard equivalent to the base EEM standard (assessed with SAP2012 and referred to as "EEM" below.
3. The PH standard using gas fired central heating- "PH (Gas)".
4. The PH standard heated with a HP integrated into the Heat Recovery and Ventilation system

"PH (Heat Pump)" is a design which is novel in NI but has proven successful elsewhere [5].

2.2 Energy Consumption

All four variants are presented in Table 1 with the predicted space heating demand calculated using both the SAP rating system and the PHPP software. Table 1 shows that in the case of the EEM and PH dwellings, the building fabric is considerably more energy efficient than the dwelling complying with the minimum building regulations (see PHPP output in the bottom line). While the standard house requires 77.6 kWh/m^2/a for space heating and the EEM requires 44.6 kWh/m^2/a while the 2 PH variants only require 18.2 and 18.9 kWh/m^2/a.

Item	Base SAP 2009	EEM	PH (Gas)	PH (Heat Pump)
Floor {W/m^2K}	0.2	0.12	0.1	0.1
Walls {W/m^2K}	0.21	0.17	0.18	0.18
Roof {W/m^2K}	0.14	0.09	0.08	0.08
Windows {W/m^2K}	1.4	1	0.75	0.75
Doors {W/m^2K}	1.6	1	0.75	0.75
Average U Value	0.71	0.476	0.372	0.372
Ventilation	Trickle Vents, Mech extract	Ventaxia MVHR	Nilan MVHR	Nilan MVHR
Air Permeability	5 $m^3m^{-2}hr^{-1}$	3.5 $m^3m^{-2}hr^{-1}$	0.35 ach^{-1}	0.35 ach^{-1}
Air Permeability	5	3.5	0.35	0.35
Heating	Condensing Gas Boiler	Condensing Gas Boiler	Condensing Gas Boiler	MVHR & integrated HP
Renewables	none	2kW PV Panels	1.5 kW PV Panels	900W PV panels
SAP Space Htg {kWh/m^2a},	36	26	10.6	12.85
EPC	B83	A92	A92	A93
PHPP {kWh/m^2a}	77.6	44.6	18.2	18.9

Table 1 Energy Specific Parameters for Social House dwelling

2.3 Costs

The costs for each of the upgrade options considered comprise the year one costs (the cost of upgrading to the EEM standard & PH standard in year one).

2.4 Quantification of Benefits

The MB and Multiple Beneficiary Analysis (MBA) captures the overall benefits and assigns them to the three beneficiaries – tenant, HA and government/common purse. This enables an analysis of not only the financial benefits for the four variants of the case study dwelling, but also to whom they accrue.

Direct benefits (reduced energy costs and associated carbon taxes) and indirect benefits accrue [1] (increased capital and rental value, benefits to the local economy and the financial benefits associated with improved health). While the quantification of the indirect benefits (increased capital & rental value and benefits to the local economy) is difficult and imprecise, their exclusion from analysis would lead to an underreporting of the full economic benefit for policy makers.

3. RESULTS

3.1 Extra construction costs

Table 2 gives the breakdown of the base costs and additional costs for each of the higher energy performance variants [2]. All benefit from the EEM financial incentive of 3% of the construction costs and so the HA will benefit from a 3% contribution based on the assumed construction cost of £110,000 (i.e. £3,300).

Item	Base SAP 2009	EEM (Gas)	PH (Gas)	PH (Heat Pump)
Floor	5,030	368	892	892
Walls	20,019	441	263	263
Roof	7,000	112	260	260
Windows & Doors	4,155	435	3,149	3,149
Mech & Electrical (excl renewables)	11,900		-	1,800
Renewables		3,020	2,020	1,270
Ventilation	-	2,980	2,980	2,980
Airtightness	940	-	784	534
Construction cost differential		7,356	10,348	11,148
Preliminaries	-	-	-	- 2,523
PH - Optional extras - Certification			1,100	1,100
Total Extra Cost incl Certification	-	7,356	11,898	10,175
Total Extra Cost excl certification	-	7,356	10,798	9,075

Table 2 Cost differential for energy influencing elements per three bed social house variants

The extra cost of upgrading to the EEM standard (in year one) is calculated at £7.4k.

The government contributes £3.3k via the EEM incentive, and the HA contributes the remaining £4.1k. It is assumed that the HA will have to meet the full cost of upgrading in year 20 in order to meet the net carbon commitments. The extra costs of constructing the dwelling to the PH standard are:

1. Integrated HP/HRV system (£9.1k).
2. Traditional gas central heating (£10.8k)

3.2. Benefits – EEM / English Building Regulations

Heating Energy savings. Due to the upgrade in the building standard from the Base Case (BC) to the EEM specification, the space heating energy consumption reduces by 28% from 36 to 26 kWh/m^2/a (based on the SAP rating), or from 77.6 to 44.6 kWh/m^2/a (47%) based on the Passive House Planning Package (PHPP) predictions - Table 3. The two software packages (PHPP and SAP) provide different predictions due to their different assumptions. The savings associated with the improved EEM standard range from £1,463 to £4,829, (depending on the space heating energy consumption prediction software employed) accrue to the tenant (Table 5).

Calculation Methodology	Spec energy consn {kWh/m2/a}		Extra Consumption(BC Vs EEM)		Spc Htg Cost	Min/Max
	Min Bldg Regs	EEM	{kWh/m2/a}	{kWh/a}	(Gas) {£/a}	Cost Savings {£}
SAP	36	26	10	950	73.18	1463.51
PHPP	77.6	44.6	33	3135	241.48	4829.58

Table 3 EEM Minimum and Maximum Energy Consumption Cost Savings

Given that the cost differential for upgrading to the EEM standard is £7,356, the simple payback period is approximately 100 years (based on the SAP annual space heating cost reduction of £73.18), or 30 years (based on the PHPP annual space heating cost reduction of £241

.48). However, this payback does not recognise the extra indirect multiple benefits which accrue:

Carbon emissions savings

Table 4 shows that carbon emissions for the base case total 17.26 tonnes for the gas heating system, and 4.79 tonnes in the case of the same dwelling built to the EEM standard, representing a saving of 12.47 tonnes (equivalent to £947 at a potential cost of £76 per tonne[6]) over the 20-year period). Based on the PHPP predictions for the energy consumption, the savings amount to £1,625 over the same period. Table 5 shows that the benefits accrue to both the tenant (through reduced carbon taxes) and the Government (through reduced emissions penalties).

Calc Method	Min Bldg Regs {kWh}	Min Bldg CO2 {tons}	EEM (kWh}	EEM CO2 {Tons}	CO2 Saved (Ton	£ Saved
SAP	83786.19	17.26	23273.94	4.79	12.47	947.38
PHPP	180605.79	37.20	76804.01	15.82	21.38	1625.12

Table 4 carbon emissions savings

Value of building

Many studies have estimated the effect of improved energy efficiency on property values. While a review of the associated literature is beyond the scope of this paper, based on the analysis by Fuerst et al [7] an assumption of a 2% increase in the value of the property is viewed as reasonable. This would lead to an increase in value by £2,656 due to the increase in energy efficiency.

In another study Cajias et al [8] propose that the value of the property will increase by 0.45% per 1% decrease in energy costs, leading to an increase in the value of the property by as much as £5,738. This is calculated as follows: based on the SAP predictions the total primary energy consumption of the dwelling is 7,927 kWh/a, of which 2,740 kWh/a is used for space heating. The space heating element will be reduced from 36 to 26 kWh/m^2/a (72%) leading to a reduction in space heating from 2,740 to 1,979 kWh/a. This is equivalent to a reduction of 761 kWh/a, representing a 9.6% reduction in the overall energy consumption of the dwelling, leading to a 4.3% increase in the value of the property for the HA.

It is noted that the lower values for the property increase are less than the cost required to upgrade the property to the higher energy efficiency standard, and the upper value approximates the upgrade cost.

Increase in rent

In NI, social housing tenancies that commenced prior to September 1992 have a controlled rent, while all other properties have a decontrolled rent, with rents set by individual HAs [9], who can charge a premium for newer units. HA's can assess each scheme individually, with rent set to reflect the cost of building (including finance) and maintenance.

Assuming that 50% of the estimated energy savings costs are paid by the tenant, the extra rental payment will range between £0.7k and £2.4k over the 20-year period. This equates to between £0.67 and £2.30 per week. Given that the average HA weekly rent for a 3 bed *general needs* accommodation is £93.97 [9], this equates to an increase of no more than 2.4% for the HA, paid by the tenant (Table 5).

Benefits to the local economy

The GDP of NI [10] is estimated at €53.3bn (£47.97bn), equating to £68,207 per household per annum, if the total is simply divided by the number of households (703,300 households). In a study from Scotland [11] it was proposed that a 5% decrease in energy consumption would lead to a 0.1% improvement in GDP, equivalent to a contribution to the economy of NI of £1,364 per household over the 20-year period. Based on this increase in GDP for every 5% decrease in expenditure on energy costs [11], the increased benefit to the common purse per household is between £2,620 (SAP) and £4,010 (PHPP).

Health benefits

Parameter	Benefit {£ '000}		Beneficiary {£ '000}		
	Range	{£k/dwelling}	HA	Tenant	State
Extra Cost for EEM Vs Base (Yr 1)	**n/a**	**-7.4**	**-4.1**	**0.0**	**-3.3**
Heating energy saving	Lower	1.5	0.0	1.5	0.0
	Upper	4.8	0.0	4.8	0.0
CO2 Saving	Lower	0.4	0.0	0.4	0.4
	Upper	1.2	0.0	1.2	1.2
Value of building increase	Lower	2.7	2.7	0.0	0.0
	Upper	8.8	8.8	0.0	0.0
Increase in rent	Lower	0.7	0.7	-0.7	0.0
	Upper	2.4	2.4	-2.4	0.0
Economy Benefits	Lower	2.6	0.0	0.0	2.6
	Upper	4.0	0.0	0.0	4.0
Health benefits	Lower	1.5	0.0	0.0	1.5
	Upper	2.0	0.0	0.0	2.0
Total Benefit	Lower	9.1	3.4	1.1	5.0
	Upper	20.3	11.2	3.6	6.7

Table 5 MBA for social house built to the EEM standard (Gas Heating)

Estimation of the economic value of energy efficiency on home occupant health is based on the Kirklee project benefits analysis [12]. The estimated for the health benefits associated with the energy upgrade is 20% of the upgrade cost, equivalent to £1,471, while the Chief Medical Officers [13] estimate of 42% of expenditure saving on health costs is equivalent to up to £2,028, based on a heating cost saving of £4,830 over the period.

Who Benefits and who pays?

The 'Extra Cost …' row in Table 5 indicates a total cost of £7.4k (from Table 2), split between government (£3.3k(the EEM incentive)) and the HA (£4.1k (=£7.4-3.1k)). Total benefits are calculated to range from £9.1k to £20.3k over the 20-year period, split between HA (£3.4k to £11.2k), tenant (£1.1k to £3.6k) and government (£5k to £6.7k).

The (year 1) extra cost for upgrading to the EEM standard (rather than the prevailing minimum building regulations) is £7.4k, comprises mainly of additional costs associated with the building. It is seen that for a cost of £7.4k, benefits of between £9.1k and £20.3k represent paybacks of between 124% and 276%.

In terms of the Multi-Beneficiary Analysis, the figures show that the tenant benefits significantly, and the government accrues a significant portion of the benefits, based on the year one investment of £3.3k and the £4.1k by the HA. The stakeholder charged with providing the higher standard accommodation may not recover the investment (if only the lower estimated £3.4k benefit is realised), although the HA may realises a substantial benefit of £11.2k, the largest potential benefit. This benefit is achieved primarily as a result of the increased capital value of the property (a metric on which the HA is not assessed).

3.3 Passive House Standard

3.3.1 Overview

The MB and MBA analysis was also carried out using the same methodology for the dwelling constructed to the PH standard for the two heating systems.

Extra cost is incurred in upgrading the building fabric to the PH standard (to achieve the 15kWh/m^2/a which the CCC proposes). However, the benefit is that air can be used as the heat transport mechanism, eliminating the need for a Gas Fired Central Heating (GFCH) system. While it is recognised that HAs may have a preference for GFCH as it is well established (and maintenance is standardised and understood), significant extra cost would be incurred in installing a gas central heating system and replacing it in 20-year's time to meet the CCC recommendations.

The PHs have been designed to comply with the EEM standard and therefore also avail of the 1.03 multiplier, equivalent to a £3,300 contribution from the government towards the upgrade costs in year one.

3.3.2 PH with integrated HP/HRV system

Table 6 shows that the additional year one cost of constructing the electrically heated PH compared with the base case is £9.1k. These costs are split between the HA (£5.8k) and the government (£3.3).

The cost of £9.1k yields benefits of between £15.2k and £29.1k over the 20-year period, representing a payback of between 167% and 321% (see table 8).

The largest beneficiary is the Government, with between £8.5k and £13k accrued over the 20 years (for the investment of £3.3k), and the HA is the next largest beneficiary at between £4.7k and £11.4k (due primarily to increased property value). The tenant is seen to benefit by between £2.6 and £6.6k.

Table 7 shows that the extra cost of constructing the dwelling to the PH standard with GFCH is £10.8k. The benefits which accrue due to the year one cost of £10.8k range from £16.1k to £28.4k over the 20-year period.

Parameter	Benefit {£ '000}		Beneficiary {£ '000}		
	Range	{£ k/dwelling}	HA	Tenant	State
Extra Cost for EEM Vs Base	**n/a**	**-9.1**	**-5.8**	**0.0**	**-3.3**
Heating energy saving	Lower	4.0	0.0	4.0	0.0
	Upper	9.5	0.0	9.5	0.0
CO2 Saving	Lower	0.6	0.0	0.6	0.6
	Upper	1.8	0.0	1.8	1.8
Value of building increase	Lower	2.7	2.7	0.0	0.0
	Upper	6.6	6.6	0.0	0.0
Increase in rent	Lower	2.0	2.0	-2.0	0.0
	Upper	4.8	4.8	-4.8	0.0
Economy Benefits	Lower	6.1	0.0	0.0	6.1
	Upper	7.1	0.0	0.0	7.1
Health benefits	Lower	1.8	0.0	0.0	1.8
	Upper	4.0	0.0	0.0	4.0
Total Benefit	**Lower**	**15.2**	**4.7**	**2.6**	**8.5**
	Upper	**29.1**	**11.4**	**6.6**	**13.0**

Table 6 MBA for social house: PH with Heat Pump

3.3.3 PH with traditional gas central heating

Parameter	Benefit {£ '000}		Beneficiary {£ '000}		
	Range	{£ k/dwelling	HA	Tenant	State
Extra Cost for EEM Vs Base (Year 1)	**n/a**	**-10.8**	**-7.5**	**0.0**	**-3.3**
Heating energy saving	Lower	3.7	0.0	3.7	0.0
	Upper	8.7	0.0	8.7	0.0
CO2 Saving	Lower	0.9	0.0	0.9	0.9
	Upper	2.2	0.0	2.2	2.2
Value of building increase	Lower	2.7	2.7	0.0	0.0
	Upper	6.6	6.6	0.0	0.0
Increase in rent	Lower	1.9	1.9	-1.9	0.0
	Upper	4.3	4.3	-4.3	0.0
Economy Benefits	Lower	6.7	0.0	0.0	6.7
	Upper	7.2	0.0	0.0	7.2
Health benefits	Lower	2.2	0.0	0.0	2.2
	Upper	3.7	0.0	0.0	3.7
Total Benefit	**Lower**	**16.1**	**4.5**	**2.8**	**9.7**
	Upper	**28.4**	**11.0**	**6.5**	**13.0**

Table 7 MBA for social house: PH with gas heating

Given that the PH complies with the EEM standard, the HA will benefit from the government payment of £3.3k in relation to the additional construction costs in year one. Therefore the HA would have to pay the remaining £7.5k in the case of gas-fired central heating.

The largest beneficiary is the Government with between £9.7k and £13k benefits accrued over the 20 years, for an outlay of £3.3k. The tenant also benefits significantly (by £2.8k to £6.5k), and does not have to make any investment. The HA benefits by between £4.5k and £11k, again primarily as a result of the increase in the capital value of the dwelling due to the investment of £7.6k.

4 DISCUSSION

4.1. Overall Returns

Table 8 gives an overview of the benefits which accrue over a 20 year period, (without considering the extra 20 year upgrade costs to meet the CCC recommended energy efficiency standard). The payback for the PH (HP) is 19 years, with the worst-case (EEM) resulting in 30.5 years to recoup the extra initial cost.

Overall returns for the respective investments were estimated at between 124% to 276% (EEM), 148% to 263% (PH with GFCH) and 167% to 321% (PH with HP). Therefore, it is seen that the overall business case for energy upgrades is positive.

Item	EEM	PH (Heat Pump)	PH (Gas)
Extra initial cost {£}	7356	9075	10798
Heating Energy Saving (PHPP) {£ pa}	241	477	435
Payback (Operational Energy) {Yrs}	30.5	19.0	24.8
Overall Benefits (MBA) - Worst case {£}	9132	15197	16112
Overall Benefits (MBA) - Best case {£}	20298	29145	28367
Return (MBA) Worst case {%}	124%	167%	149%
Return (MBA) Best Case {%}	276%	321%	263%

Table 8 Summary of 20-year Benefits for the three Social House Variants

There is however an additional significant benefit which accrues to the HA - that of avoided future energy upgrade costs required to meet UK net zero carbon commitments. Based on the CCC's recommendation that new dwellings are built to meet 15 kWh/m^2/a (equivalent to that the PH standard) [14], dwellings constructed to lesser standards will need to be upgraded in the future. It costs significantly more to build dwellings to current minimum building regulations and subsequently upgrade (£26,300) compared with incorporating the extra insulation and airtightness etc at the initial design and build stage (£4,800) [14].

4.2 Future Upgrade Costs

When the future upgrade costs are added to the initial costs estimated as part of this study, a more holistic perspective is obtained. See Fig 1. On the left (in orange) are the costs associated with carrying out the energy-efficient upgrade at the build stage and (in red) the additional costs associated with the future upgrade costs to meet a space heating requirement of 15 kWh/m^2/a, and the installation of a HP (all assumed take place in year 20).

For the EEM, it is seen that at the end of the 20-year period, a significant extra cost of £26. 3k will be incurred to upgrade the building fabric to the required standard, and install a heating system based on a low-temperature HP. This is a significant future liability.

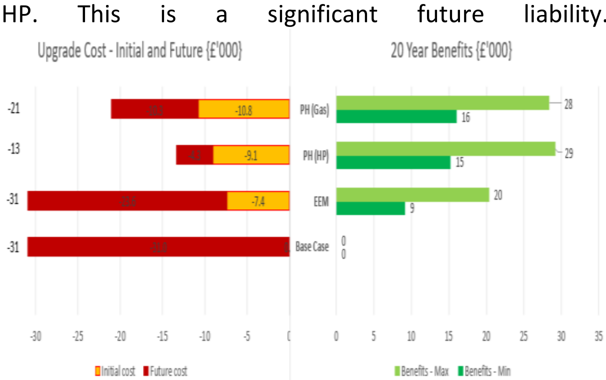

Fig 1 Costs and 20-year Multiple Benefits of 3 Bed Low-Energy social house Dwelling

For the PH, the building fabric would meet the CCC proposed standard, and in the case of the PH heated with HP, replacing the installed HP in year 20 costs £4.3k. For the PH with GFCH, the cost of upgrading from a gas fired heating system in Year 20 to an electric HP is estimated at £11,250 [5].

4.3 Returns per beneficiary

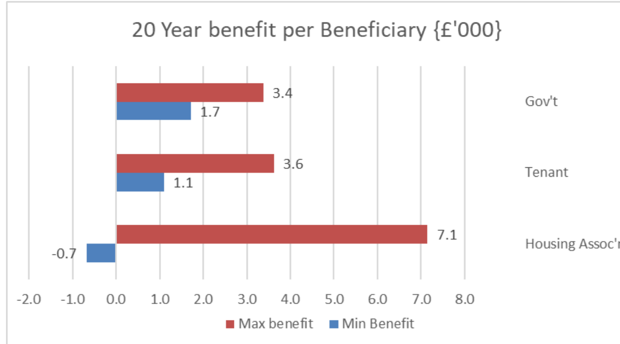

Figure 2 Summary of Benefits per beneficiary (EEM)

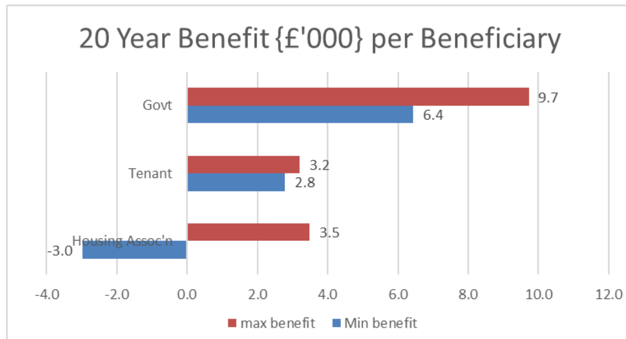

Figure 3 Summary of Benefits per beneficiary (PH, Gas)

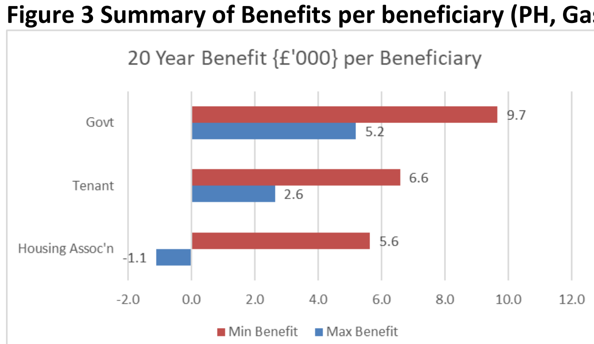

Figure 4 Summary of Benefits per beneficiary (PH Dwelling with HP)

Figures 2, 3 and 4 show the 20 year benefit per beneficiary for each of the upgrade scenarios considered.

In each case the summary of the 20-year benefits per beneficiary shows that the public purse (government) is a net beneficiary, and in two cases enjoys higher benefits than any other stakeholder. The tenant also accrues significant benefits.

The government benefits, not only through the avoidance of health costs and carbon emissions penalties, but also from the substantial economic benefits which accrue as a direct result of reduced social housing energy consumption.

The tenant accrues significant benefits through avoided heating costs and associated carbon dioxide levies (which will likely be levied on fuel in the future).

However, while the tenant and government benefit significantly, the stakeholder charged with deciding on the extra investment, the Housing Association is seen to have to bear significant increased capital costs of between £4.1k (Table 5) and £7.6k (Table 7). The benefits which accrue to the HA are in all cases potentially insufficient to cover the costs and any potential net benefits are based on property values, a metric which is not of interest to the HA.

5. CONCLUSION

This analysis has the limitations of being based on predicted energy consumption rather than recorded data. Further, assumptions have had to be made to provide estimates for a number of the often intangible indirect benefits. It also doesn't consider possible rebound, or comfort taking phenomena that has been reported in the socio-technical literature.

However, a number of insights are emerging from the Multiple Benefits and stakeholder analysis.

1. Overall, upgrading to improved energy efficiency standards is seen to be financially beneficial, with the PH standard heated with an electric HP being most advantageous (Table 8).
2. When the future upgrade cost to the CCC recommended standard is included in the analysis, lowest overall cost (£13.4k) and the highest overall benefits (£29k) are achieved with the PH heated with HP (Fig 1).
3. The future liabilities (should the HA defer the decision to meet the CCC standard) are seen to be significant (£26.3k), compared with building to the standard now (£13.4k).
4. Substantial individual & societal benefits accrue over the 20 year period by adopting improved energy efficiency standards now (fig 1).
5. The HA must fund an extra £4.1k (Table 5) to £7.6k (Table 7) and, irrespective of the energy-efficient upgrade path chosen, the HA is dis-incentivised from making the upgrade decision now (figures 2, 3 and 4).
6. It is noted that the Government ultimately is responsible for providing social housing at least cost and greatest value, and enjoys significant benefits over the 20 year period (in two cases being the principal beneficiary).

Given the significant benefits which accrue, and the often life changing impact on typically disadvantaged social housing tenants, the paper indicates that potential exists for strategic investment by government (via HA's) to unlock the significant multiple benefits of low energy dwellings. Further, investment would make a significant contribution to achieving much needed carbon savings.

ACKNOWLEDGEMENTS

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