Energy Analysis Focus Report

A study of Hard to Treat Homes using the English House Condition Survey

Part II: Investigating improvement scenarios for Hard To Treat Homes

Department of Energy and Climate Change
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Executive summary

This is the second of two reports analysing the nature of Hard To Treat (HTT) housing in England. This report builds on the analysis presented in Part I by estimating the carbon dioxide (CO_2) savings which may be achievable through increased energy efficiency in this section of the housing stock. The nature of the solid wall stock in England is also examined in detail, and an attempt is made to estimate the potential for solid wall insulation.

Under an assumed heating regime, the HTT housing stock in England notionally emits ~62 million tonnes of carbon dioxide ($MtCO_2$) for space and water heating. This compares to ~123 $MtCO_2$ from the entire dwelling stock. Dwellings which are solid wall and off gas have particularly high CO_2 emissions. High rise dwellings (which tend to be smaller) have lower mean emissions than other HTT types.

Modelled energy efficiency improvements reveal considerable scope for CO_2 emissions reductions. Installing 'mainstream' insulation and heating upgrades can potentially save ~14 $MtCO_2$, which is a 27% reduction from the base position. When other non-mainstream measures (including solid wall insulation and heat pumps), are also applied, this saving rises to ~34 $MtCO_2$ (a 55% reduction from the base position). If solid wall insulation is excluded from the 'non-mainstream' measures, only ~27 $MtCO_2$ can be saved. The modelling suggests that installing heat pumps in off-gas network dwellings can potentially save as much CO_2 as a stock wide programme of solid wall insulation.

Masonry walls up to nine inches thick are the most common type of solid wall in the English housing stock. Approximately 65% of solid wall dwellings in England are of this type. Masonry pointing is the most common wall finish in the solid wall stock. It is the predominant wall finish in ~55% of the solid wall stock. Approximately 33% of the solid wall stock have a rendered finish.

If we assume that all solid walls without a masonry pointing finish are suitable for solid wall insulation, approximately 46% of the total solid wall area in England can be insulated. If we further assume that all areas in the 'back view' of a dwelling can always be insulated, this potential rises to 69%. Finally, if we assume that all dwellings with floor areas greater than $60m^2$ are suitable for internal insulation, the potential rises to 97%.

Objectives

Part I of this report presented a detailed analysis of the dwelling and household characteristics of the 'Hard to Treat' (HTT) stock in England using data from the English House Condition Survey (EHCS).

In Part II of this report, the carbon dioxide (CO_2) emissions for space and water heating from this section of the stock are examined. The potential for CO_2 emissions reductions is investigated by modelling the installation of a variety of energy efficiency measures. This improvement potential work is carried out by running several scenarios through a SAP-based energy model using the combined three-year 2002+03+04 EHCS data.

Part I of the Hard To Treat analysis recognised that solid wall dwellings make up over two-thirds of all HTT dwellings. Therefore, the scope for installing solid wall insulation as an improvement measure is also discussed at length.

Carbon dioxide emissions from the Hard to Treat stock

Before modelling the effect of any improvement scenarios, it is necessary to calculate the CO_2 emissions of the HTT stock in its current state. This 'base' position for the HTT stock is shown in Tables 1 and 2 below. It is important to recognise that these emissions are *notional* emissions for space and water heating only[1]. They do not include emissions resulting from lighting, the use of appliances or cooking. In addition, they assume a standardised pattern of heating and hot water use and are independent of geographical location.

	Mean annual CO_2 emissions (t CO_2)	Number of dwellings (000s)	Total annual CO_2 emissions ($MtCO_2$)
HTT	6.7	9,206	62.0
Not HTT	4.9	12,343	59.9
All stock	5.7	21,549	122.9

Table 1: Notional CO_2 emissions from the dwelling stock (SAP based)

Hard To Treat Subtype	Mean annual CO_2 emissions (t CO_2)	No. of dwellings (000s)	Total annual CO_2 emissions (Mt CO_2)
Solid Wall	6.2	5,035	31.21
Off gas network	7.0	1,671	11.63
Solid wall & off gas network	11.8	731	8.62
No loft[2]	5.6	644	3.58
Solid wall & no loft[2]	6.8	569	3.88
Off gas & no loft[2]	7.1	122	0.86
Solid wall & off gas & no loft[2]	10.0	109	1.09
High rise	3.5	326	1.13

Table 2: Notional CO_2 emissions for each Hard to Treat subtype

[1] CO_2 emissions for electricity are calculated using an emissions factor of 0.49 $kgCO_2$/kWh. This factor has been used throughout this report for all estimates of emissions and savings (a specific marginal emissions factor for electricity saved has not been used).

[2] As the EHCS cannot collect accurate data on levels of roof insulation in dwellings with no loft space, the thermal performance of the roof is assumed for these subtypes.

In its current state, under the specified SAP heating regime, the HTT stock emits ~62 million tonnes of carbon dioxide ($MtCO_2$) per annum. This compares to total emissions of ~123 $MtCO_2$ from the stock as a whole. The HTT stock is therefore responsible for emitting slightly over half of domestic notional CO_2 emissions, despite representing only 43% of the dwelling stock.

Dwellings which are 'solid wall and off gas' have particularly high mean CO_2 emissions compared to the stock average and the other HTT types. This subtype has higher than average mean space heating requirements and is more likely than the average dwelling to use carbon-rich fuels[3] such as electricity for their main heating system. It can also be seen from Table 2 that high rise flats have the lowest mean CO_2 emissions. This results from their significantly lower space heating requirements, due to their small size and low levels of heat loss.

The box plots shown in Figure 1 enables the comparison of the CO_2 emissions for each of the HTT subtypes. The boxplots show the median (the line across the box), interquartile range (the length of the box which contains 50% of cases), and the spread of the data (the 'whiskers' indicate the position of the last case which is within one-and-a-half times the interquartile range of the median).

It can be seen in Figure 1 that 'solid wall & off gas' and 'solid wall & off gas & no loft' dwellings have a larger spread and interquartile range than the other HTT subtypes. This indicates that these HTT subtypes have a particularly wide range of emissions.

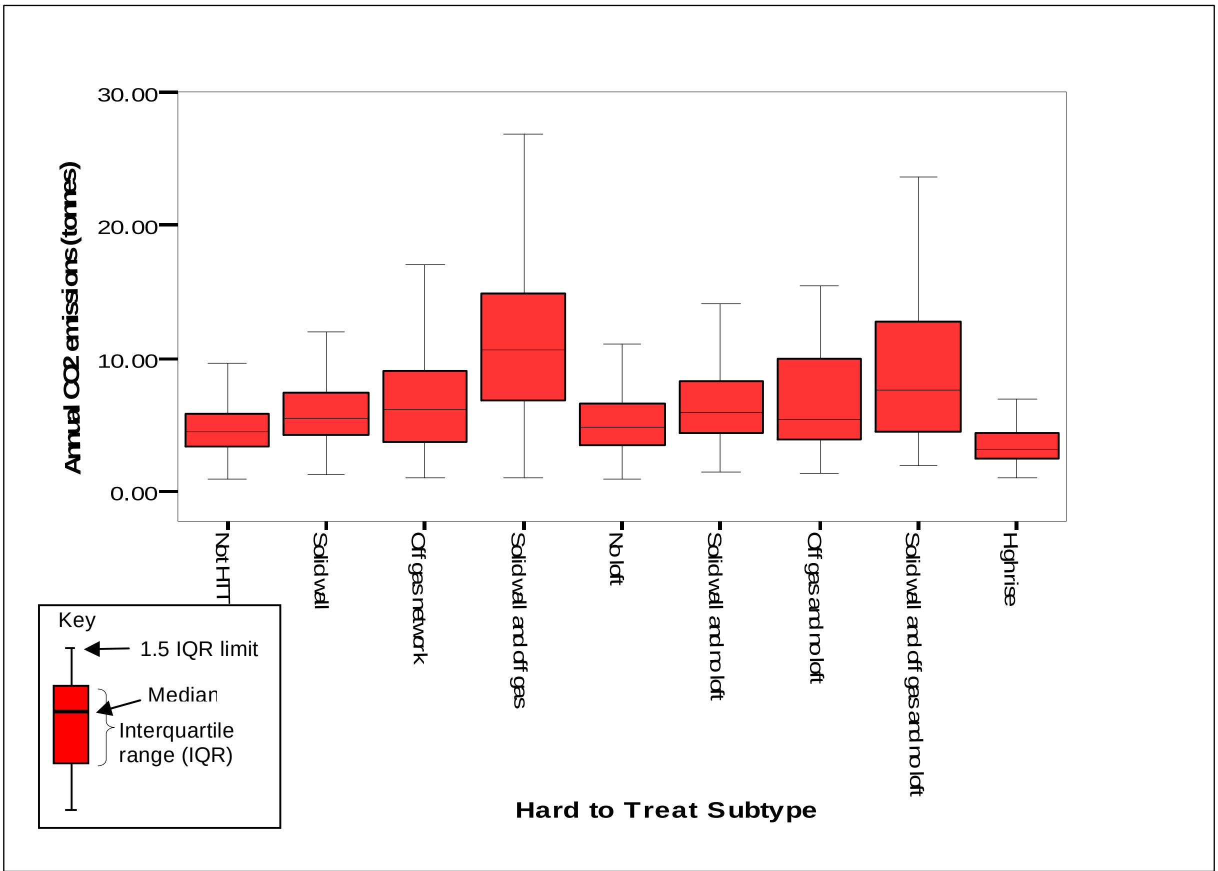

Figure 1: Boxplot of notional CO_2 emissions (tonnes) for each HTT subtype before any improvements

[3] The term 'carbon-rich' is used for fuels which have the greatest carbon dioxide emission factors for delivered energy.

Modelling the improvement potential of the Hard to Treat stock

Having established the base, it is now possible to investigate the scope for energy efficiency to reduce the CO_2 emissions from these dwellings.

This investigation has been carried out in seven stages, split into three main groups. These can be summarised as:

MAINSTREAM MEASURES

- Stage 1: The installation of mainstream insulation measures
- Stage 2: The installation of mainstream heating upgrades

NON-MAINSTREAM INSULATION MEASURES

- Stage 3: The installation of double glazing
- Stage 4: The installation of solid wall insulation

NON-MAINSTREAM HEATING MEASURES (LOW AND ZERO CARBON (LZC) TECHNOLOGIES)

- Stage 5: The installation of solar water heating
- Stage 6: The installation of heat pumps for off gas network dwellings
- Stage 7: The addition of an electrical input from a renewable source for all off gas network dwellings

The first two improvement stages attempt to demonstrate how far the HTT stock can be improved, in terms of a reduction in CO_2 emissions, without the need for the less common (often more costly) measures. Stages 3 to 7 investigate the potential for additional non-mainstream technologies.

It is important to recognise that the individual effect of each of the improvement stages is dependent upon the order in which they are applied. For example, increasing the efficiency of the heating system will be seen to save more energy in absolute terms if it is done before an insulation improvement than after an insulation improvement. Similarly, insulation will be seen to save more energy in absolute terms if it is done before any heating system upgrade.

The results of modelling each of the improvement stages are set out below. Additional work, considering the feasibility of applying solid wall insulation is examined in detail later in this report. As part of this further analysis, the modelling procedure has been repeated to examine the potential for CO_2 reductions *without* this measure (i.e. without stage 4 above).

Improvement stage 1: Cavity wall and loft insulation.

The first improvement stage is the installation of the standard insulation measures: loft insulation and cavity wall insulation.

Loft insulation acts to reduce the heat loss through the loft of a dwelling. It usually consists of a ‘blanket’ of insulating material laid between and over the joists in the loftspace. Cavity wall insulation reduces heat loss through the walls. An insulating material (typically a blown fibre, foam or beads) is injected between the two leaves of a cavity wall. It is worth noting (as outlined in Part I of this analysis) that the majority of HTT dwellings do not have cavity walls, and therefore cannot benefit from this improvement measure.

Loft insulation has been applied to dwellings which currently have 100mm or less of loft insulation. The insulation is brought up to a thickness of at least 270mm. Cavity wall insulation has been applied to all unfilled cavity walls [4], provided that the dwellings are three storeys or less. No account has been taken of cavity walls that cannot be filled for other technical reasons (e.g. narrow cavities, area of flood risk etc.).

Energy savings from the insulation measures have been adjusted following the guidelines set out in the CERT document published by Defra, 2007 [5]. These take into account the ‘comfort factor’ applied to carbon savings resulting from insulation measures. This is a reduction due to part of the saving being taken in improved comfort (such as higher internal temperatures) for the occupant and also a reduction due to other factors such as areas of cavity walls not being filled. The reduction factor is assumed to be 50% for loft insulation and cavity wall insulation upgrades.

The number of measures installed and the effect on the total carbon dioxide emissions from the base are shown in Table 3 and Table 4 below.

	Number of HTT dwellings (000s)	% of HTT stock	% of all dwellings
Loft insulation	4,498	49	21
Cavity wall insulation	1,485	16	7

Table 3: Number and type of installations applied in stage 1

	Total CO_2 emissions from Hard-To-Treat dwellings	CO_2 emissions (Mt CO_2) saved from previous stage	CO_2 emissions (Mt CO_2) saved from base	% reduction in CO_2 emissions from previous stage	% reduction in CO_2 emissions from base
Base	62.0	-	-	-	-
Stage 1: Loft and Cavity Wall Insulation	60.0	2.0	2.0	3%	3%

Table 4: Notional CO_2 emissions after stage 1 improvements

[4] Only predominantly cavity wall dwellings have had cavity wall insulation installed. Dwellings of mixed wall types may have a minor area of cavity wall construction that will remain unfilled.

[5] Defra, 2007. Energy, cost and carbon savings calculations for the CERT 2008-11 Illustrative Mix.

It can be seen that only modest savings (~3% of CO_2 emissions from base) are achieved by the installation of the mainstream insulation measures. This reflects on the 'hard-to-treat' nature of this section of the stock. By definition, many of these dwellings are not eligible for these mainstream insulation measures. However, it is important to recognise that some savings can be achieved by employing these measures. Indeed, any programme of improvement in the HTT stock would be advised to ensure that these measures are in place in the first instance, before attempting any of the more expensive improvements.

Improvement stage 2: Mainstream heating upgrades.

The second stage of improvements is the installation of new heating systems and the upgrade of existing systems.

Gas central heating has been installed in all dwellings which currently have a non-gas and/or a non-central heating system, provided that they are on the gas network [6]. This includes what is known as 'fuel switching', e.g. changing from electric storage heaters to gas central heating where gas is present and upgrading gas room heater systems to a centrally heated system.

Additionally, existing standard, back or combination gas boilers have been upgraded to higher efficiency condensing boilers (either 'standard-condensing' or 'condensing-combination' appliances, depending on the floor area of the dwelling).

Off gas network dwellings have also been improved. Oil boiler systems or modern electric storage radiator systems have been installed depending on the size of the dwelling, and existing oil boilers have been upgraded where feasible.

Finally, hot water cylinder insulation improvements have been made to hot water cylinders that have no insulation or have a 'loose jacket' type of cylinder insulation that is less than 80mm thick.

No comfort factors are applied to the energy savings from heating improvements [7]. The results of this improvement stage are shown in Table 5 and Table 6 below.

	Number of HTT dwellings (000s)	% of HTT stock	% of all dwellings
Gas central heating installed	926	10%	4%
Oil central heating installed	390	4%	2%
Storage radiators installed or upgraded	123	1%	1%
Upgrade gas boiler	5,484	60%	25%
Upgrade oil boiler	695	8%	3%
Water cylinder insulation upgrade	4,673	51%	22%

Table 5: Number and type of installations applied in stage 2.

[6] On gas network dwellings are identified as any dwelling with a current mains gas connection (see Part I of this report for details). All other dwellings are considered to be off gas network.

[7] For this improvement stage it is particularly important to note that the savings are calculated under the standard SAP-based heating regime. It may be the case that households with low efficiency systems are in practice 'under-heating' their homes and not adhering to the SAP heating regime. For example, a household using individual room heaters may not actually heat all rooms in the dwelling, as assumed under SAP. Only when these households have a more efficient system installed (as under this improvement stage), the household may begin to heat the whole of their home. This situation would lead the CO_2 savings shown in Table 6 being too large, although the final value for the emissions would be correct (as the improvement has brought the household in line with the specified heating regime).

	Total CO_2 emissions from Hard-To-Treat dwellings (Mt CO_2)	CO_2 emissions (Mt CO_2) saved from previous stage	CO_2 emissions (Mt CO_2) saved from base	% reduction in CO_2 emissions from previous stage	% reduction in CO_2 emissions from base
Base	62.0	-	-	-	-
Stage 1: Loft and Cavity Wall Insulation	60.0	2.0	2.0	3%	3%
Stage 2: Mainstream Heating Improvements	45.6	14.4	16.4	24%	27%

Table 6: Notional CO_2 emissions after stage 2 improvements.

This improvement stage has a considerable effect on the notional CO_2 emissions from space and water heating, which are reduced by an average of 24% from the previous stage. This reflects the importance of an efficient heating system.

Following the installation of the mainstream insulation measures and these mainstream heating improvements, the CO_2 emissions have been reduced by over 25% from the base position.

Improvement stage 3: Double glazing.

The third stage of the improvement modelling is the installation of double glazing. Double glazing works by trapping air between two panes of glass creating an insulating barrier that reduces heat loss, noise and condensation.

It has been assumed that all areas of single glazing can be upgraded to double glazing. Some dwellings will require all windows to be improved, although many will only require some of the windows to be treated. A reduction factor of 15% has been applied to the savings from this measure, following the CERT guidelines. The number of installations and their effect on the CO_2 emissions are shown in Table 7 and Table 8 below.

	Number of HTT dwellings (000s)	% of HTT stock	% of all dwellings
Double glazing installed	5,242	57%	24%

Table 7: Number and type of installations applied in stage 3

	Total CO_2 emissions from Hard-To-Treat dwellings (Mt CO_2)	CO_2 emissions (Mt CO_2) saved from previous stage	CO_2 emissions (Mt CO_2) saved from base	% reduction in CO_2 emissions from previous stage	% reduction in CO_2 emissions from base
Base	62.0	-	-	-	-
Stage 1: Loft and Cavity Wall Insulation	60.0	2.0	2.0	3%	3%
Stage 2: Mainstream Heating Improvements	45.6	14.4	16.4	24%	27%
Stage 3: Double Glazing	44.1	1.5	17.9	3%	29%

Table 8: Notional CO_2 emissions after stage 3 improvements.

Double glazing has a small but significant effect on the notional CO_2 emissions from this section of the housing stock. CO_2 emissions are reduced by ~3% from the previous improvement stage, and by a total of ~29% from the base after all stages so far. Installation of this measure is not funded by the Government's Warm Front scheme and although some double glazing installations have been funded through the Energy Efficiency Commitment (EEC) program in the past, it is not generally considered a mainstream measure. Although more costly than many other insulation measures, double glazing is often installed as a popular 'home improvement' (particularly by owner occupiers).

Improvement stage 4: Solid wall insulation.

The next improvement stage is solid wall insulation. This measure is applied to dwellings without a cavity (which, therefore, cannot receive cavity wall insulation) to reduce the amount of heat lost through the walls. Solid walls can be insulated either internally or externally. Internal insulation is generally applied on rigid boards which are fixed to the inside of the wall. External insulation is applied to the outside of the walls and usually has a decorative finish.

All solid walls have had their performance improved by adjusting the 'u-value' of wall (which describes the wall's heat loss characteristics). Whether this improvement is due to internal or external insulation is not specified. A reduction factor of 15% has been applied to the savings from this measure, following the CERT guidelines. The number of installations and effect on the CO_2 emissions following this improvement stage are shown in Table 9 and Table 10 below.

	Number of HTT dwellings (000s)	% of HTT stock	% of all dwellings
Solid wall insulation installed	6,741	73%	31%

Table 9: Number and type of installations applied in stage 4

	Total CO_2 emissions from Hard-To-Treat dwellings (Mt CO_2)	CO_2 emissions (Mt CO_2) saved from previous stage	CO_2 emissions (Mt CO_2) saved from base	% reduction in CO_2 emissions from previous stage	% reduction in CO_2 emissions from base
Base	62.0	-	-	-	-
Stage 1: Loft and Cavity Wall Insulation	60.0	2.0	2.0	3%	3%
Stage 2: Mainstream Heating Improvements	45.6	14.4	16.4	24%	27%
Stage 3: Double Glazing	44.1	1.5	17.9	3%	29%
Stage 4: Solid Wall Insulation	36.0	8.1	26.0	18%	42%

Table 10: Notional CO_2 emissions after stage 4 improvements

As can be seen in Table 10, solid wall insulation has great potential to reduce the CO_2 emissions from HTT dwellings. This measure acts to reduce emissions from space and water heating by ~18% compared to the previous improvement stage. Around two-thirds of HTT dwellings have solid walls, and the large effect we observe reflects this. Following this improvement stage, the CO_2 emissions for space and water heating have been reduced by approximately 42% from the base position.

It is recognised that there are a number of potential barriers to installing solid wall insulation in many dwellings. For this reason, the potential savings *without* this particular improvement stage are outlined later in this report. The various issues which may limit the scope for solid wall insulation are also discussed and an attempt is made to quantify the potential for the installation of this measure.

Improvement stage 5: Solar water heating.

The fifth improvement stage is the installation of solar water heating panels. These panels act to heat water directly using heat from the sun. In doing so, they reduce the demand for domestic hot water to be heated by the main boiler or immersion heater.

A $2m^2$ panel has been installed in all homes which do not currently have a panel installed. It is assumed that all dwellings have a suitable location for such a panel. The number of installations and the effect on CO_2 emissions following this improvement stage are shown in Table 11 and Table 12 below.

	Number of HTT dwellings (000s)	% of HTT stock	% of all dwellings
Solar water heating panel	9,182	100%[8]	43%

Table 11: Number and type of installations applied in stage 5

	Total CO_2 emissions from Hard-To-Treat dwellings (Mt CO2)	CO_2 emissions (Mt CO_2) saved from previous stage	CO_2 emissions (Mt CO_2) saved from base	% reduction in CO_2 emissions from previous stage	% reduction in CO_2 emissions from base
Base	62.0	-	-	-	-
Stage 1: Loft and Cavity Wall Insulation	60.0	2.0	2.0	3%	3%
Stage 2: Mainstream Heating Improvements	45.6	14.4	16.4	24%	27%
Stage 3: Double Glazing	44.1	1.5	17.9	3%	29%
Stage 4: Solid Wall Insulation	36.0	8.1	26.0	18%	42%
Stage 5: Solar Water Heating	34.6	1.4	27.4	4%	44%

Table 12: Notional CO_2 emissions after stage 5 improvements

Solar water heating panels reduce the total CO_2 emissions from this section of the stock by around 4% compared to the previous stage. This effect is relatively small. However, a solar water heating panel is one of the more readily installed non-mainstream measures which can act to reduce the emissions from the HTT stock. Following this stage, CO_2 emissions from space and water heating have been reduced by ~ 44% compared to the base position.

[8] Less than 1% of dwellings did not receive this upgrade, due to an existing solar water heating panel being present.

Improvement stage 6: Heat pumps.

The sixth improvement stage installs heat pumps in off gas-network dwellings [9]. Heat pumps extract low temperature heat from the surroundings (in this case the ground or the air) and deposit it at a higher temperature inside the dwelling where it is required.

Under the second stage of the improvement modelling, all dwellings on the gas network had efficient condensing gas central heating systems installed. Very little CO_2 will generally be saved by replacing these systems with heat pumps. However, off gas network dwellings had either storage radiator or oil boiler systems installed or upgraded under Stage 2. Considerable savings can be achieved by further upgrading these dwellings to heat pump systems. Therefore, only off gas network dwellings are improved here.

Two types of heat pumps have been installed in off gas network dwellings: air source heat pumps and ground source heat pumps. Ground source heat pumps generally have a better performance than their air source equivalents. However, they require a sufficient area of ground to install them, and good access to that ground (to allow trenches to be dug or boreholes to be drilled). Air source heat pumps generally offer lower levels of performance, but they have the advantage of being able to install in almost all locations. For these reasons air source heat pumps have been specified for all off gas network dwellings (both houses and flats) in urban areas and all off gas network flats in rural areas. Ground source heat pumps are only specified for all off gas network houses in rural areas.

Air source heat pumps have been installed in combination with a secondary electric heater to supply top-up heating where required, and an immersion heater to supply 100% of the water heating requirement.

All ground source heat pumps have been installed alongside an electric secondary heater, with hot water supplied jointly by the heat pump and an electric immersion heater. The number of installations and the effect on CO_2 emissions following this improvement stage are shown in Table 13 and Table 14 below.

	Number of HTT dwellings (000s)	% of HTT stock	% of all dwellings
Air source heat pump	1,382	15%	6%
Ground source heat pump	1,387	15%	6%

Table 13: Number and type of installations applied in stage 6

[9] Off gas network dwellings are identified as any dwelling without a current mains gas connection (see Part I of this report for details).

	Total CO_2 emissions from Hard-To-Treat dwellings (Mt CO_2)	CO_2 emissions (Mt CO_2) saved from previous stage	CO_2 emissions (Mt CO_2) saved from base	% reduction in CO_2 emissions from previous stage	% reduction in CO_2 emissions from base
Base	62.0	-	-	-	-
Stage 1: Loft and Cavity Wall Insulation	60.0	2.0	2.0	3%	3%
Stage 2: Mainstream Heating Improvements	45.6	14.4	16.4	24%	27%
Stage 3: Double Glazing	44.1	1.5	17.9	3%	29%
Stage 4: Solid Wall Insulation	36.0	8.1	26.0	18%	42%
Stage 5: Solar Water Heating	34.6	1.4	27.4	4%	44%
Stage 6: Heat pumps for off gas	29.1	5.5	32.9	16%	53%

Table 14: Notional CO_2 emissions after stage 6 improvements

As shown in Table 14 above, the installation of heat pumps can have a significant impact on the emissions from space and water heating from the HTT stock. This stage reduces the emissions by 16% compared to the previous stage. Following this improvement stage the total emissions for space and water heating have been reduced by more than 50% from the base position.

Improvement stage 7: Electrical input from a renewable source.

The final stage of the modelling is to supplement the installation of the heat pump in off-gas network dwellings with an electrical input generated from a renewable source. Renewable sources which can directly generate such an input include photovoltaic panels, wind turbines and hydroelectric systems.

An annual 800kWh electrical input is assumed, approximately equivalent to the energy produced by a 10m^2 photovoltaic panel. However, it should be noted that this input could potentially be provided by a number of alternatives to photovoltaic panels, and that smaller panels may be able to provide this input depending on the technology chosen. As heat pump systems are electrically powered, they are particularly suited to this sort of renewable input. The number of installations and the effect on the CO_2 emissions following this improvement stage are shown in Table 15 and Table 16 below.

	Number of HTT dwellings (000s)	% of HTT stock	% of all dwellings
Number of renewable electrical sources installed	2,769	30%	13%

Table 15: Number and type of installations applied in stage 7

	Total CO_2 emissions from Hard-To-Treat dwellings (Mt CO_2)	CO_2 emissions (Mt CO_2) saved from previous stage	CO_2 emissions (Mt CO_2) saved from base	% reduction in CO_2 emissions from previous stage	% reduction in CO_2 emissions from base
Base	62.0	-	-	-	-
Stage 1: Loft and Cavity Wall Insulation	60.0	2.0	2.0	3%	3%
Stage 2: Mainstream Heating Improvements	45.6	14.4	16.4	24%	27%
Stage 3: Double Glazing	44.1	1.5	17.9	3%	29%
Stage 4: Solid Wall Insulation	36.0	8.1	26.0	18%	42%
Stage 5: Solar Water Heating	34.6	1.4	27.4	4%	44%
Stage 6: Heat pumps for off gas	29.1	5.5	32.9	16%	53%
Stage 7: Heat pumps + renewable input	28.0	1.1	34.0	4%	55%

Table 16: Notional CO_2 emissions after stage 7 improvements

This final input provides a small additional reduction in the total CO_2 for space and water heating (~4%). This is the final scenario modelled. Following all improvements the CO_2 emissions have been reduced by ~55%. In order to achieve a reduction of 60% from base, an electrical input of ~3000 kWh is required for these homes. This level of input is likely to require advanced or multiple renewable technologies.

The effect of the improvements on each Hard To Treat subtype.

Figure 2 below shows the effect of each improvement on each of the eight HTT subtypes (as identified in Part I of this analysis). One of the main effects of the improvements is to greatly reduce the wide range of emissions observed between subtypes. Prior to any improvements, the subtypes ranged from an average of ~3 tonnes CO_2 to ~12 tonnes CO_2. Following the improvements, the range has narrowed significantly to between ~2 and ~4 tonnes of CO_2.

It can also be seen where each of the measures has had the greatest effect, and where any particular improvement stage has not affected any of the subtypes at all. Solid wall insulation can be seen to have a large effect on all subtypes with solid walls, and heat pumps have a large effect for all off gas network dwellings. The mainstream heating improvements have a large effect on all subtypes.

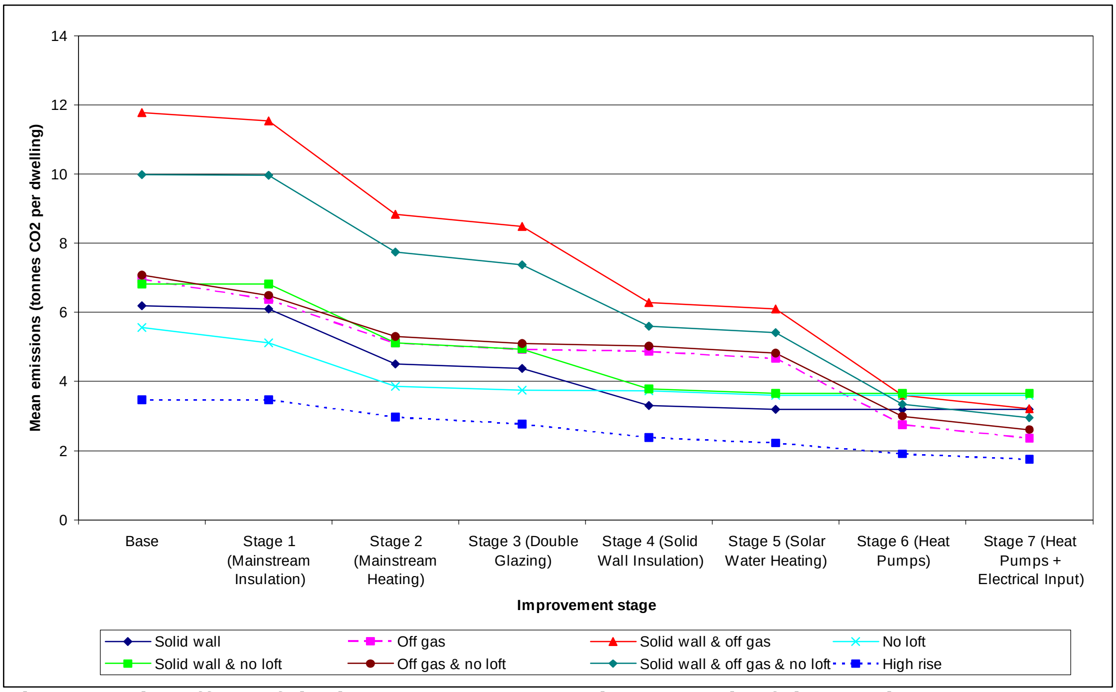

Figure 2: The effect of the improvement scenarios on each of the Hard To Treat subtypes.

Shown in Figure 3 below are boxplots of each of the HTT subtypes after all improvements have been applied. When compared to Figure 1 earlier in this report (the boxplots prior to improvement) it can be seen that, along with the overall levels of emissions being reduced for all subtypes, the spread *within* each of the subtypes has also decreased.

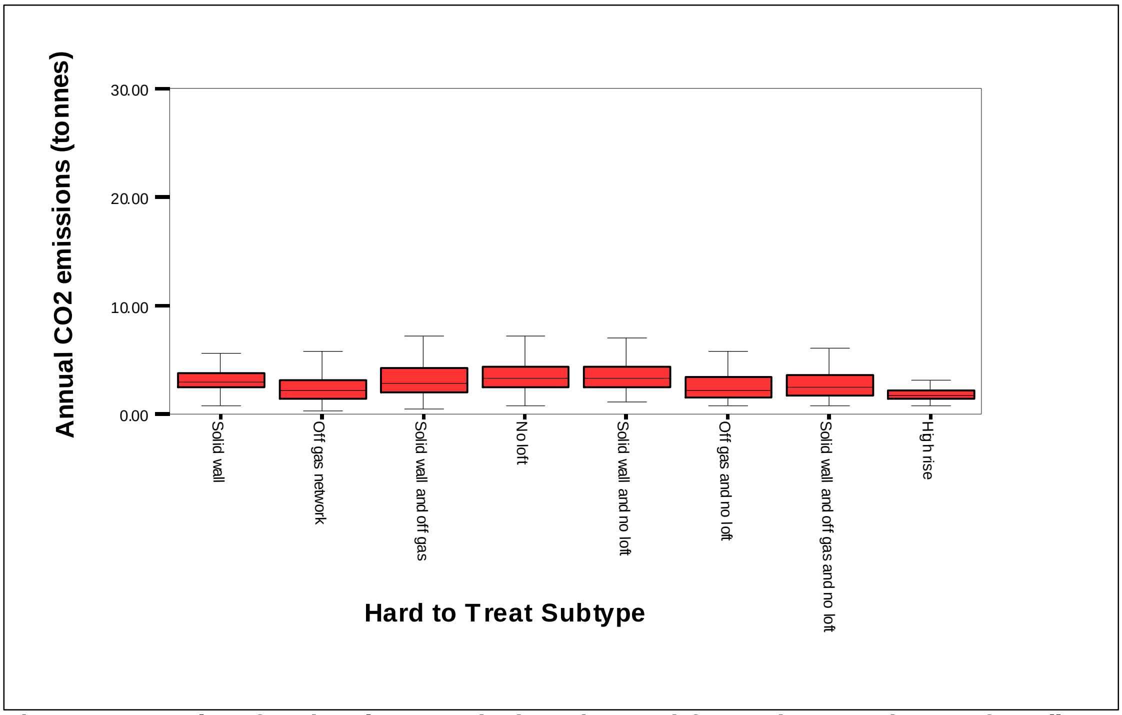

Figure 3: Boxplot of notional CO_2 emissions (tonnes) for each HTT subtype after all improvements

Summary of improvement results

The results of the improvement modelling study show that installing these packages of measures into the HTT stock could potentially save around 34 million tonnes of CO_2 per year. This is a 55% reduction from base levels. Currently, the English housing stock as a whole notionally emits ~123 $MtCO_2$ per year for space and water heating. In order to meet government targets (and assuming that emissions from these uses would need to be reduced in line with the overall targets) it would be necessary to reduce emissions from space and water heating in the domestic sector by 60% by 2050, to ~49 $MtCO_2$ per year (i.e. a saving of ~74 $MtCO_2$). The HTT stock could potentially save almost half of this total requirement if all of the energy efficiency measures as modelled in this work were installed. It should be noted that there are various factors that cannot be accounted for in the modelling, that may reduce the potential numbers of measures installed and the potential for reducing carbon dioxide emissions. For instance, no reduction has been made to account for any current under-heating of homes with inefficient heating systems. It is also assumed that all solid wall homes can be insulated, although we know that there are numerous barriers to this measure. This report continues by considering this issue in detail below.

Assessing the potential for solid wall insulation

As shown above, there is great potential for solid wall insulation to reduce CO_2 emissions from space and water heating in HTT homes. However, it is recognised that there are a number of potential barriers to the installation of this measure. These include: resistance to changes to the external appearance of homes resulting from external wall insulation; loss of floor space from internal insulation; disruption caused by installation process; planning constraints on older properties; occupant conflicts in flats and the high cost of measures.

The scenarios calculated above, including the application of solid wall insulation, suggest that savings of ~34 $MtCO_2$ can be achieved under the specified scenarios and heating regime.

Presented below in Table 17 are the results of the same improvement scenarios, but excluding the solid wall insulation stage. This reduces the total potential savings to around 27 $MtCO_2$.

	Total CO_2 emissions from Hard-To-Treat dwellings (Mt CO_2)	CO_2 emissions (Mt CO_2) saved from previous stage	CO_2 emissions (Mt CO_2) saved from base	% reduction in CO_2 emissions from previous stage	% reduction in CO_2 emissions from base
Base	62.0	-	-	-	-
Stage 1: Loft and Cavity Wall Insulation	60.0	2.0	2.0	3%	3%
Stage 2: Mainstream Heating Improvements	46.6	14.4	16.4	22%	25%
Stage 3: Double Glazing	44.1	1.5	17.9	5%	29%
Stage 4: Solid Wall Insulation	*Not applied*	*Not applied*	*Not applied*	*Not applied*	*Not applied*
Stage 5: Solar Water Heating	42.7	1.4	19.3	3%	31%
Stage 6: Heat pumps for off gas	36.1	6.6	25.9	15%	42%
Stage 7: Heat pumps + renewable input	35.0	1.1	27.0	3%	44%

Table 17: Notional CO_2 emissions after all improvements – excluding solid wall insulation

Under the main scenario analysis (shown in Table 10 earlier in this report), solid wall insulation had a large effect. This measure alone reduced the CO_2 emissions from space and water heating by 18% compared to the previous improvement stage. Together with the previous stages (mainstream heating, mainstream insulation and double glazing) solid wall insulation saves approximately 26 $MtCO_2$ from the base position. As shown in Table 17 above, it is possible to achieve this level of saving (26 $MtCO_2$) *without* solid wall insulation, but advanced heating improvements in the form of heat pumps are required.

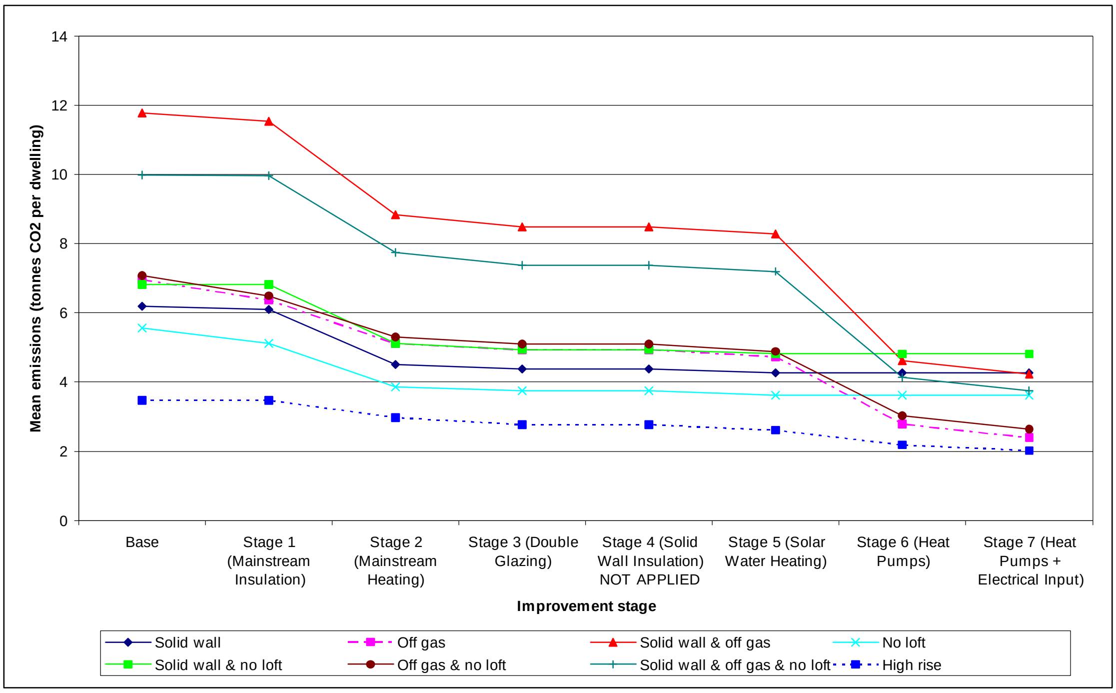

Figure 4: The effect of the improvement scenarios, excluding solid wall insulation, on each of the HTT subtypes.

Figure 4 above shows the effect of this further modelling on all subtypes, and should be compared with Figure 2 earlier in this report. It can be seen that excluding solid wall insulation leads to slightly less clustering of the final position (which now lies between an average of ~ 2 $MtCO_2$ and ~ 4.5 $MtCO_2$). It is also noticeable how some HTT subtypes do not show as much improvement as others. For example, the solid wall & no loft subtype shows a relatively small decrease in CO_2 emissions (from ~ 7 $MtCO_2$ to ~ 5 $MtCO_2$) compared to many of the other groups. This reflects the limited scope to improve this particular subtype without solid wall insulation.

We have now presented the two extreme positions for improvement potential. The potential savings following all measures, including solid wall insulation, is approximately 34 $MtCO_2$. However, without any solid wall insulation this potential is reduced to approximately 27 $MtCO_2$. The true potential is likely to lie between these two figures. The final section of this report attempts to quantify the realistic potential for solid wall insulation by considering the barriers to this measure in detail.

The current rate of installation of solid wall insulation is low. The reasons for this include financial, technical and also social issues. All of these factors affect the true potential for solid wall insulation in the English dwelling stock. The factors which seem likely to be of most importance are:

§ Changes to the external appearance of the dwelling

§ Changes to the internal floor area of the dwelling

§ Occupant conflicts in flats

§ Costs

§ Disruption/ease of installation

In this discussion and analysis, the financial considerations have been largely ignored in the anticipation that a) new grants would cover the costs and b) once uptake rates increased, market forces would drive costs down making the payback periods less of a critical issue.

The nature of the solid wall stock

Before assessing the applicability of solid wall insulation to solid wall dwellings, it is necessary to investigate the detailed nature of the solid wall stock in England.

Solid wall dwellings incorporate several categories of wall structure. These can be summarised as:

- a) masonry
- b) >9" solid
- c) concrete
- d) timber/metal panels
- e) mixed types.

Table 18 shows the numbers of solid wall dwellings with each type of wall structure. This is also represented graphically in Figure 5. It can be seen that the predominant solid wall structure in the English housing stock is masonry construction, making up 65% of the solid wall stock followed by > 9" solid at 20%. The remaining 15% comprises mainly of what are known as 'non-traditional' dwellings; a type of construction (also known as industrialised building) which involves the use of prefabricated components or shuttering. The prefabricated components vary from structural steel, pre-cast concrete panels or timber frame, which may be used with other components or traditional materials.

	Count (000s)	**Column %**
Masonry (single/double leaf)	4,295	65
>9" solid	1,294	20
Concrete (panels/in situ)	387	6
Timber/metal panels	300	5
Mixed types	322	5
Total	6,599	100

Table 18: Predominant wall type of solid wall dwellings

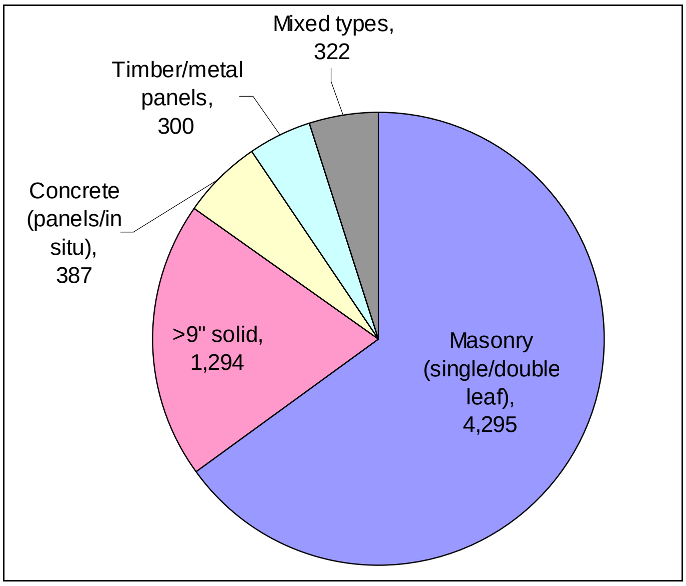

Figure 5: Predominant wall type of solid wall dwellings

For each wall structure there is also an associated wall finish. These are recorded in the EHCS data as either mixed types, masonry pointing, non-masonry natural, rendered, shiplap timber, tile hung, slip/tile faced and plastic/wood/metal panels. The first and latter four categories have been combined into a 'mixed types' variable. Table 19 and Figure 6 show the numbers and percentages of the different wall finishes in the solid wall stock.

Predominant wall finish	Count (000s)	Column %
Masonry pointing	3,642	55
Non masonry natural	149	2
Rendered	2,152	33
Mixed (incl. panels, tile hung)	656	10
Total	6,599	100

Table 19: Predominant wall finish of solid wall dwellings

As would be expected from the proportions of the different wall structures, the predominant wall finish in the solid wall stock is masonry pointing (55%), although it can be seen that a significant proportion of the stock (33%) has been rendered with either a cement render, pebbledash or similar proprietary surface treatment. A further 10% of the stock either has a mixed wall finish (e.g. part masonry pointing, part rendered) or is tile hung or has panelling. A small proportion of the solid wall stock (2%) has a non masonry natural finish. As well as the number of dwellings where any particular wall finish is predominant, we can also examine the relative actual *areas* of each wall finish in the stock. Doing this, we find that approximately 55% of the total area of solid walls in England have a masonry pointing finish.

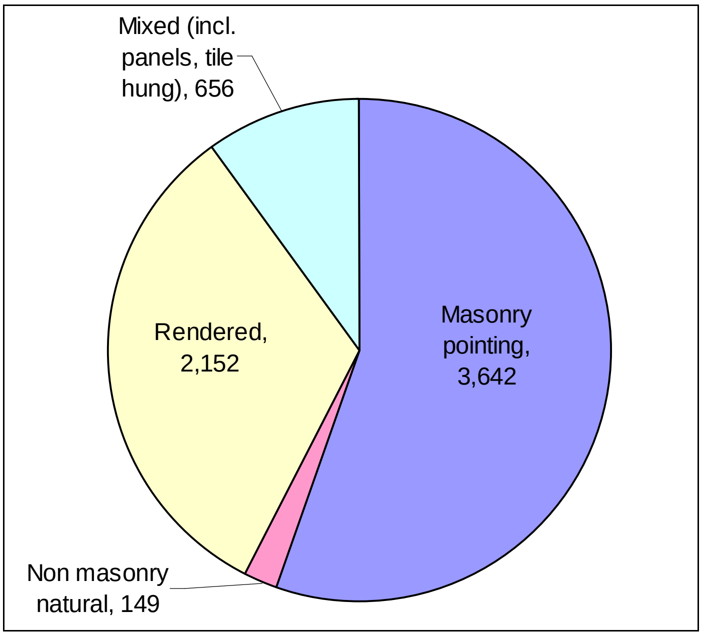

Figure 6: Predominant wall finish of solid wall dwellings

Quantifying the potential for solid wall insulation

Using the above information, we can begin to quantify the scope for solid wall insulation. This needs to be done in the context of the relative merits of internal and external wall insulation.

External wall insulation

External wall insulation systems consist of an insulating layer fixed to the existing wall and a weather protective finish that can either be a wet render system or a dry cladding system. Dry cladding systems can be more aesthetically pleasing than render as different cladding materials can be used. However, they are usually more expensive. External wall insulation can often be installed with minimal disruption to occupants. It can improve the look of aging facades and reduces thermal bridging, therefore minimizing heat loss. However, planning permission may be required and due to the high cost of installing this measure, it can have long payback times.

The following factors are important considerations in estimating the realistic potential for external solid wall insulation:

- In theory, almost all dwellings could be insulated with external wall insulation. Exceptions may include listed dwellings or those in conservation areas, and dwellings in which the walls are structurally unsound.
- Planning permission is usually required as it will change the outside appearance of a dwelling, but facings are available which mimic brick/shipboard etc. Dwellings which are already rendered are unlikely to need additional planning permission.
- The attitudes of homeowners to the application of solid wall insulation to their dwelling is something that cannot be directly investigated using EHCS data. However, it is expected that some homeowners may be averse to changing the external appearance of their dwelling, particularly if it has certain characteristic features that were attractive. Walls with a masonry pointing finish are likely to be most problematic in this regard.
- There is likely to be much less occupant opposition, and fewer problems with planning permission, when applying external wall insulation to the parts of the dwelling as viewed from the rear rather than the front. If we examine the solid wall area at the back of the dwelling, we observe that ~ 43% of the total solid wall area is in the rear 'view' of the dwelling (note that in many cases this will include some areas of wall at the side of the dwelling).
- Installing external insulation on a converted or purpose built flat may be problematic as all owners/leaseholder would have to agree to change the external appearance.
- External wall insulation will generally cause less disruption for the occupant than internal wall insulation.

Internal wall insulation

Internal wall insulation can be either a rigid insulation board or insulation fitted between studwork. Disadvantages of both of these internal systems are that they involve considerable disruption for the occupants and can result in a significant decrease in room size. The advantages of internal insulation over external insulation are that it is cheaper and easier to install and maintains the appearance of the external walls.

The following factors are important considerations in estimating the realistic potential for internal wall insulation:

- In theory all dwellings could have internal insulation.
- Depending on the insulation type, between 80 to 120mm of insulation may be required to achieve significant savings. For small houses this would mean a significant decrease in the internal space available.
- Internal insulation could only realistically be applied on a whole-house level if a major internal refurbishment of the dwelling was planned. Alternatively, it could be applied on a room-by-room basis, perhaps as a DIY installation, when rooms were being redecorated.
- Internal insulation could be a better option than external insulation for households living in converted and purpose built flats as it would not involve the whole block of flats to be insulated. However, these dwelling types (along with bungalows) typically have a small floor area (at least 50% of this type have a floor area < $60m^2$) and adding the required thickness of internal insulation could significantly impinge on the available space. It should also be noted that even internal insulation is unlikely to be installed by all occupiers in a block of flats and from an energy efficiency perspective, installing external wall insulation on the whole block would be the preferable option and possibly even more cost effective if carried out on the whole block level.

In light of these considerations, and our analysis of the nature of the solid wall stock above, it is possible to make some estimates of the scope for external insulation in the English dwelling stock.

General estimates of potential under different constraints

The potential for solid wall insulation can be examined generally by breaking the data down by the most relevant factors. Figure 7 below uses a $60m^2$ threshold to split the dwelling stock by wall finish, tenure and whether the property is a house or a flat.

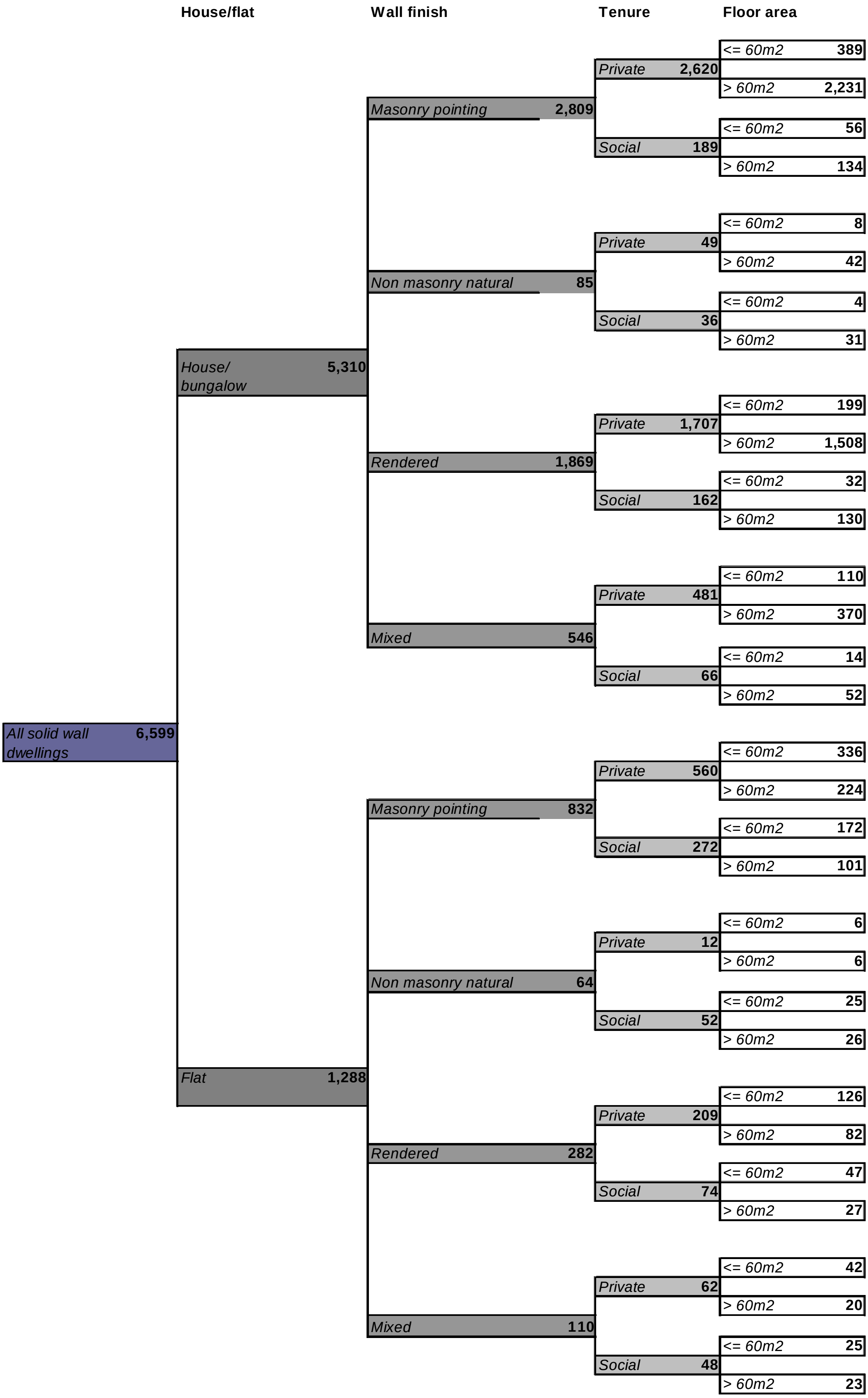

Figure 7: Numbers of solid wall dwellings (000s) split by the criteria of house/flat, wall finish, tenure and floor area.

Figure 7 can be used as a rough guide to assess the scope for solid wall insulation for different types of dwelling, and under differing requirements.

For example, under the broad assumptions that a) all rendered and non masonry natural dwellings could be insulated (externally) b) all masonry pointed dwellings with a floor area greater than 60m^2 could be insulated (internally) and c) 50% of the mixed wall structure types could be insulated; it can be calculated that ~5.3 million dwellings can be treated.

Estimates of the total area of solid wall that can be insulated

Further to the above, we are able to use data in the EHCS on actual wall areas and areas of wall finish to estimate the total areas of solid wall that could be insulated. To do this we need to make various assumptions about which walls could reasonably be treated.

Our first assumption is that all solid walls without a masonry pointing finish can be insulated externally. This would involve replacing any uninsulated render or cladding with an insulating system. Under this assumption, we are able to say that ~ 45% of the total solid wall area (of all dwellings defined here as solid wall HTT) can reasonably be insulated externally. This would require approximately 4.0 million installations. It should be noted that simply because external wall insulation may be possible in these properties, it does not preclude the use of internal insulation as an alternative to insulate these wall areas.

Alternatively, we can assume that the back view of the property can reasonably be insulated externally (no matter what the wall finish). Under this assumption, around 43% of the total solid wall area in England can be insulated. This would require solid wall insulation to be installed in approximately 6.5 million dwellings.

We can achieve a greater potential if we consider a combination of insulating the back view of the property and insulating any areas at the front which have a non-masonry pointing finish. Under these assumptions the potential rises to around 69% of the total solid wall area of the dwelling stock. This would require around 6.6 million installations (all solid wall HTT dwellings).

In theory, the 31% of the total solid wall area that remains uninsulated (walls with a masonry pointing finish at the front of the dwelling) could be insulated internally. However, some dwellings will be too small to be suitable for internal insulation.

If we assume that dwellings with a floor area <= 60m^2 are unsuitable for internal wall insulation due to the loss of floor area, almost all of the uninsulated areas at the front of the house can be treated internally. Only 3% of the total solid wall area of the housing stock remains uninsulated (either externally or internally). This would also require approximately 6.6 million installations. The estimates of potential for insulation under the various assumptions are shown in Table 20 below.

Assumed area that can be insulated	Proportion of total solid wall area in that can be insulated (of all 'solid wall' HTT dwellings)	Number of dwellings treated
All areas of solid wall that are rendered, or other non-masonry pointing finish.	45%	4.0 million
All areas of solid wall that are in the back view of the dwelling.	43%	6.5 million
All areas of solid wall that are rendered, or other non-masonry pointing finish All areas of solid wall that are in the back view of the dwelling.	69%	6.6 million
All areas of solid wall that are rendered, or other non-masonry pointing finish All areas of solid wall that are in the back view of the dwelling. All areas in the front view of the dwelling if dwelling is > $60m^2$	97%	6.6 million

Table 20: Estimates of the proportion of solid walls by area that could be insulated and the number of installations.

Summary

The notional CO_2 emissions and the energy efficiency characteristics of the Hard to Treat (HTT) stock have been examined in detail with a view to assessing the potential remaining in this stock for energy efficiency improvements. It has been shown that the notional CO_2 emissions for space and water heating vary quite significantly between the different HTT types. 'Solid wall' and 'off gas' dwellings have higher mean emissions than the stock average and 'high rise flats' have lower emissions.

Energy efficiency improvements have been applied in 'packages' to the HTT stock. The mainstream measures of loft insulation, cavity wall insulation and heating improvements have been carried out first, followed by the 'non-mainstream' measures of double glazing, solid wall insulation, solar hot water heating, heat pumps and a renewable electricity input.

The results of this improvement modelling have shown that, following all improvements, the notional CO_2 emissions for space and water heating from the HTT stock can be reduced by around 55%. The most significant steps in this reduction are the mainstream heating improvements, the installation of solid wall insulation and the installation of heat pumps.

Further analysis has considered the potential savings that could be achieved without any solid wall insulation. Without this measure, a saving of approximately 44% can be achieved. It has also been demonstrated that installing heat pumps in off gas network dwellings could, in theory, provide approximately the same level of total savings as a stock wide programme of solid wall insulation.

The nature of the solid wall housing stock has also been analysed in detail. Masonry walls less than or equal to nine inches thick are the most common type of solid wall. This wall type comprises around 65% of the solid wall stock. Masonry pointing is the most common wall finish, and is the dominant wall finish in approximately 55% of solid wall dwellings. Around 33% of solid wall dwellings are rendered.

Finally, some estimates of the potential for solid wall insulation have been produced. Under various assumptions, it has been estimated that approximately 69% of the total solid wall area of all dwellings in England could reasonably be insulated. With additional assumptions requiring internal insulation, the potential rises to as high as 97%.

Together with Part I of this analysis, this report provides an in depth examination of the nature of the HTT stock, and the potential for carbon emissions reduction within these dwellings. HTT homes form 43% of the total dwelling stock, and it is clear that there is a need to improve the energy efficiency of this section of the stock (along with the 'non-HTT' dwellings) in order to maximise CO_2 emissions reductions in the domestic sector.