Technical options for retrofitting the building stock. A case study from the United Kingdom

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Abstract:

This paper presents a qualitative exploration of technical options for reducing the energy demand in buildings and a quantitative exercise on three specific neighbourhoods in Newcastle upon Tyne, UK. The aim is to arrive at an evaluation of the potential for energy reduction, taking into account the interactions between the dwelling stock and the energy supply systems. We first conceptualize the importance of planning and place, and then the Newcastle sustainability vision and the appropriate legislation and master plans that make it possible. One of the key components for this vision is the renewables and the micro-generation strategies. First, we propose energy refurbishing measures in building fabric, the cost-effectiveness and market penetration of each measure and finally the most appropriate measures for Newcastle; then measures for improving the air-tightness and ventilation, and a reengineering of heat supply systems. Finally, a complementary strategy for low-income households, those are not able to meet the UK Green Deal Policy requirements of eligibility.

Keywords:

Airtightness, Energy consumption, Ground source heat pumps, Heating systems, Refurbish, Solar collection, Thermal efficiency, Uptake measures, Urban energy modelling.

1. Introduction

This paper presents a qualitative exploration of technical options for reducing the energy demand in buildings and a quantitative exercise on three specific proto-blocks in the case study areas. The aim is to arrive at an evaluation of the potential for energy reduction, taking into account the interactions between the dwelling stock and the energy supply systems.

Section one first conceptualizes the importance of planning and place, and then introduces the Newcastle sustainability vision and the appropriate legislation and master plans that make it possible. One of the key components for this vision is the renewables and the micro-generation strategies; Section two shows this research approach to reduce the energy demand in dwellings; Section three proposes energy refurbishing measures in building fabric, the cost-effectiveness and market penetration of each measure and finally the most appropriate measures for Newcastle; Section four proposes the air-tightness and ventilation, and the reengineering of heat supply systems; Section five compile the measures in a framework for consideration in the Green Deal Policy.

The paper continues in Section six with an estimation of the annual energy consumption intensity (AECI) of buildings in three districts: Castle, South Heaton, and Westgate. AECI is calculated by dividing the total energy consumed by the building in one year (measured in kWh) by its total footprint area (measured in square meters). Footprint area is defined as the area of the orthographic projection of the whole building in the two-dimensional map of the city.

Energy consumption intensity is more appealing for energy efficiency measures as declines in energy intensity are a proxy for efficiency improvements, provided (i) energy intensity is represented at an appropriate level of disaggregation to provide meaningful interpretation, and (ii) other explanatory factors are isolated and accounted for. For example, as people get older, they will use more energy to heat their home during the winter. While the efficiency of heating equipment in the building has not changed, the energy intensity of the house has increased to maintain a suitable living environment (conditioned space).

Finally, Section seven apply these measures to three specific neighborhoods and Section eight summaries the paper and proposes a complementary strategy for low-income households who are not able to meet the Green Deal Policy requirements of eligibility.

2. Approaches for reducing the energy consumption

Graham and Healey [1] conceptualize and explore the relationships between planning action and practice to the dynamic of place; they emphasize the importance of four interrelated points. First planning must consider relations and processes rather than objects and forms; second, must stress the multiple meanings of space and time; third, needs to represent places as multiple layers of relational assets and resources; and four, should recognize how are the relations within and between the layers of the power geometrics of place. Davoudi [2] asserts that planning practice should follow the evolution of spatial thinking, re-orienting planning towards space and place.

In order to regain such integrated capacity, many commentators believe that there is a need for a new vision, one which can reach out to society as a whole, addressing its wants, needs, and insecurities; such a vision can now emerge from what has come to be called sustainability [3]. Equally, the evolving UK Climate Change Programme placed emphasis on the role of spatial planning[1] in delivering emissions reductions through such means [4].

Shifting the balance of energy supply away from fossil fuels towards other sources of energy is a critical aspect of mitigating climate change. The Energy White Paper [5] sets out proposals for facilitating renewables deployment to 2020, and the Micro-generation strategy, which sets out the actions to overcome a range of non-financial barriers that could prevent the microgeneration sector from realising its full potential.

The Renewable Energy Directive [6] sets a target to achieve fifteen percent of its energy consumption from renewable energy sources by 2020. At least ten percent of the energy used by transport is also required to come from renewables by 2020.

Under the Planning practice guidance for renewable and low carbon energy [7], "*the Local planning authorities are responsible for renewable and low carbon energy development of 50 megawatts or less installed capacity. Renewable and low carbon development over 50 megawatts capacity will be considered by the Secretary of State for Energy, under the Planning Act 2008, and the local planning authority will be a statutory consultee. Micro-generation is often permitted development and may not require an application for planning permission*".

In Newcastle upon Tyne, the city vision is transforming by 2021 into a sustainable city with excellent air quality, low waste levels, low carbon emissions, and high recycling rates. To achieve

[1] The new vision established the Royal Town Planning Institute follows the principles for spatial planning: spatial, sustainable, integrative, inclusive, value driven and action oriented.

this vision, the city of Newcastle has set up the Citywide Climate Change Strategy & Action Plan 2010 – 2020 [8]. The major elements of the energy strategy [9] are (i) a commitment to reducing energy demand; (ii) improving energy efficiency; (iii) exploring opportunities to generate requirements from renewable sources. These objectives are explored in a detail master plan set in context with European, national and local policy drivers and targets. The Newcastle master plan [10] then focuses on the key aspects identified in achieving these strategies.

The approach is to identify which developments (measures) and combinations of developments (building fabric and in the energy supply) are capable of making a significant contribution and which are marginal in a range of UK policies and technologies.

Figure 1 presents the contributions of various building fabric elements to the heat loss of the average British dwelling [11]. Shorrock and Utley estimate the overall the heat loss of the average dwelling reduced approximately by 31% between 1970 and 2001.

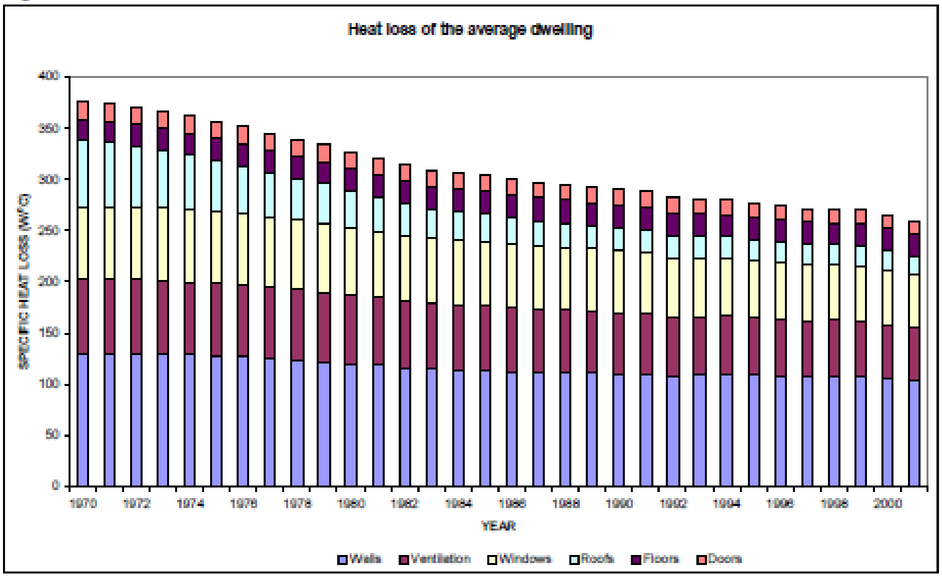

Figure 1. Heat loss of the average dwelling

Figure 1 shows that the mean heat loss has fallen approximately by 115 W/K in the average house, and approximately 40% reduction is in insulation of roofs. Also in Figure 1, there is a small reduction in walls, windows and ventilation (mainly air leaking) by 2001 presumably to the fact that most walls (solid or cavity) remain uninsulated and there is a significant housing stock with single glazing in windows.

Furthermore, on the energy supply side, in 1970 only 31% of homes had central heating, by 2001 this had risen to 90%. Most of this growth has been accounted for by gas central heating, see Figure 2.

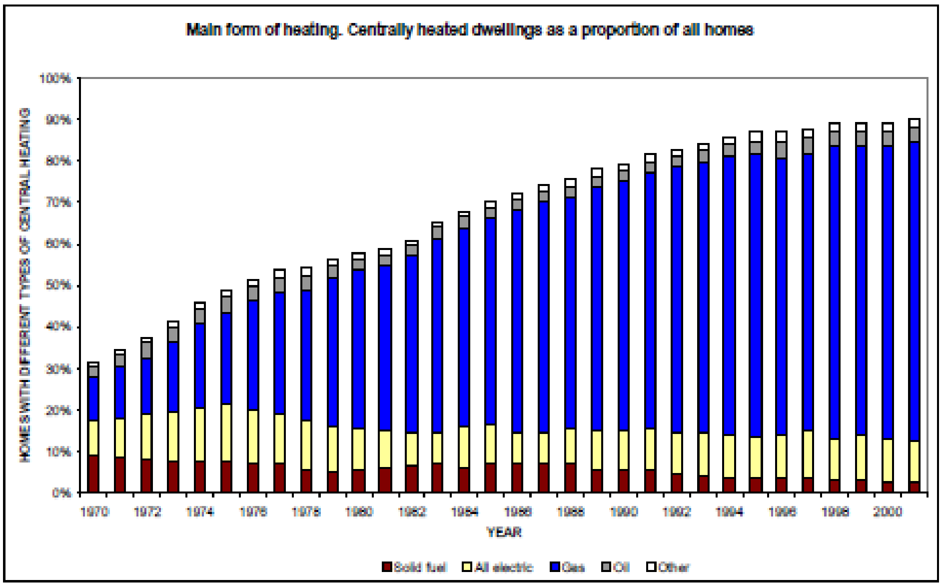

Figure 2 Main form of heating

From Figure 2, in 1970 solid fuels accounted by almost half of delivered energy. By 2000, there is a change and 90% of delivered energy use was by natural gas and electricity. Parallel to this shift in energy supply, there are an increasing number of dwellings with energy efficient technologies for space and water heating in the form of heat pumps and combined heat and power (CHP) among others recent technologies.

Section 3 explores energy refurbished in dwellings: in Section 3.1 boilers efficiency and in Section 3.2 the elements of the building fabric: windows, walls and roof insulation technologies; both as key elements for reducing the intensity of energy delivered in the form of heat and electricity. This section also initiates the discussion of the durability of those elements and the building regulations that encourage a potential improvement.

3. Energy refurbishment in dwellings

One important factor determining the energy refurbishment in dwellings is the durability of the subsystems. The least durable subsystem tends to be the heating system, expected to last 15 years[2]. Loft insulation is effective for at least 40 years[3], windows frames should last decades but sealed glazing units may last 20 years[4], masonry external walls can last for centuries[5].

3.1 Replacement of a primary heating system

The main driver for the replacement of a primary heating system is the building regulations. As an example, the building regulation 2013 part L [12] encourages replacing an existing heating system by a significantly less carbon efficient one; the seasonal efficiency of the new equipment should have a 2 percentage points lower than the seasonal efficiency of the controlled service being replaced. In the **UK** is measured as the **S**easonal **E**fficiency of **D**omestic **B**oiler (SEDBUK) rating

Following an amendment to the Building regulations in 2005 [13], almost all new boilers should be condensing. The general guidelines for condensing regular boilers are in Table 1, for Building regulation 2013 in terms of the SEDBUK[6] rating.

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[2] British Gas has a guarantee of up to five years for a new heating system

[3] Energy Saving Trust states that in an uninsulated home a quarter of your heat is lost through the roof.

[4] Poorly- installed windows can fail much sooner – sometimes within a year.

[5] Although it is like to require significant maintenance – re-rendering or re-pouring- at intervals of 50 – 100 years.

[6] SEDBUK was developed under the Government's Energy Efficiency Best Practice Programme with the co-operation of boiler manufacturers, and provides a basis for fair comparison of the energy performance of different boilers.

Table 1. Recommended minimum energy efficiency standards

Gas-fired wet central heating	SEDBUK 2009[7]	SEDBUK 2005[8]
Condensing boilers	88%	90%

3.2 Improvements in the thermal efficiencies in the building fabric

The thermal efficiency of the UK building stock is governed through the Building Regulations standards. The UK's first mandatory Building Regulations were enforced in response to public health issues: Scotland in 1964, England and Wales in 1966 and Northern Ireland in 1967 [14]. Following 1976, these standards were produced on the need to improve the energy efficiency of dwellings providing minimum U-value standards[9] to limit the heat losses through the walls, roof and floors in new dwellings. Table 2 lists historic minimum U-values and air permeability targets for compliance with Building Regulations for England and Wales from 1976 - 2006[10].

Table 2. Minimum U-values and air permeability targets for compliance with Building Regulations

Building[11] Regulation	Exposed walls[12] ($W/m^2 K$)	Roof ($W/m^2 K$)	Floor ($W/m^2 K$)	Windows[13] ($W/m^2 K$)	Air permeability (m^3/m^2h @ 50Pa)
1976	1.0	0.6	Not specified	Not specified	Not specified
1982	0.6	0.35	Not specified	Not specified	Not specified
1990	0.45	0.25	0.45	3.3	10
1995	0.45	0.25	0.35	3.3	10
2000	0.35	0.25	0.25	2.2	10
2006	0.35	0.16	0.25	2.0	10

From Table 2, continual revisions to Building Regulations have caused minimum U-value targets for all new buildings have decreased meaning enforcement of high level of insulation. The next section summarizes for the Cost-effectiveness analysis of the uptake measures in the building refurbished.

3.3 Cost-effectiveness analysis of the uptake measures

Shorrock et al. [15] published figures for the capital cost of different refurbish measures against the estimated energy savings obtained from reduced heating. Data is shown in Table 3. Shorrock et al. methodology assume: (i) all costs quoted represent the value for a typical 3 bedroom semi-detached house; (ii) capital cost mainly represent the typical purchase price of the measure assuming no grants was made available; (iii) 30% of savings from heating-related measures would be taken in improved comfort instead of energy savings; (iv) a discount rate of 3.5% was assumed for all calculations in this study; (v) energy savings for insulation and heating measures were calculated using BREDEM to model BRE's standard semi-detached dwelling; (vi) Payback[14] calculations assume annual fuel price raises and discount interest rates are at equal percentages, resulting in a simple return on investment (ROC) calculation.

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[7] This is the version of SEDBUK used in SAP 2009, replacing SEDBUK(2005)

[8] This is the version of SEDBUK used in SAP 2005.

[9] A U value is a measure of heat loss in a building element, and measures how well parts of a building transfer heat. The higher the U value the worse the thermal performance of the building envelope, the lower U-value usually indicates high levels of insulation.

[10] numeric data from Killip (2005)

[11] Additional measures such as eliminating thermal bridges and limiting air permeability to reduce heat losses through infiltration also occurred as part of the 1990 Building Regulations.

[12] U-value requirements for exposed walls only imply the presence of full cavity wall insulation in new buildings registered after 1995

[13] minimum U values for windows were only raised beyond single glazing standards by 1990

[14] The payback period is calculated by counting the number of years it will take to recover the investment in a measure

Table 3. Cost-effectiveness analysis of the uptake measures

Retrofit measure	Capital cost (£)	Annual saving (£/yr)	Measure lifespan (yrs)	Lifetime saving (£)	Simple R.O.I. (£)	Payback period (yrs)
Solid wall insulation	3,272	145.6	30	4,376	1,104	22.4
300mm loft insulation (currently 0mm)	273	86.2	30	2,587	2,314	3.2
300mm loft insulation (currently 50mm)	254	38.2	30	1,146	892	6.6
300mm loft insulation (currently 100mm)	211	11.3	30	338	127	18.7
300mm loft insulation (currently 150mm)	199	5.4	30	162	37	36.9
300mm loft insulation (currently 200mm)	170	2.7	30	81	89	63
Cavity wall insulation (pre 1976 construction)	325	80.1	40	3,205	2,880	4.1
Cavity wall insulation (post 1976 construction)	325	47.1	40	1,884	1,559	6.9
From single to low e double glazing	4,000	40.8	20	816	3,184	98
75mm DHW tank insulation (currently 0mm)	20	28.8	15	431	411	0.7
75mm DHW tank insulation (currently 25mm)	20	12	15	180	160	1.7
75mm DHW tank insulation (currently 50mm)	20	3	15	45	25	6.7
Raised timber floor insulation	1,000	32.8	30	983	18	30.5
Draught proofing	110	5.7	10	57	53	19.4
New gas condensing boiler	300	45.4	12	546	246	6.6
Improved heating controls	250	57.4	12	689	439	4.4
Energy efficient light bulb	85	21.2	6	127	42	4

Table 3 suggests:

- draught proofing, floor insulation, and loft insulation (with 150mm and 200 mm of insulation already in place) are marginally uneconomic i.e. payback period exceeds the measure lifespan;
- double glazing shows an extremely poor financial return on investment since the payback period far exceeds the predicted product lifespan and the energy savings alone do not justify the capital investment;
- insulating a loft which previously had no insulation appears to provide the shortest payback at just over 3 years, far shorter than double glazing at 98 years.

In summary, many of the measures for improving the fabric efficiency of existing dwellings involving replacing existing subsystems are characterized by high fixed and low marginal cost Energy efficiency uptake trends

3.4 Market penetration of uptake measures

Another analysis from Shorrock et al. [15] relates to the current uptake of conventional refurbished measures and future forecasts. For double glazing and gas condensing boilers, these figures are based on “all that is economically and technically possible”. Here it can be seen that certain retrofitting measures have more scope for installation than others. Note that projections for solid wall insulation were not available in [15]. However, a similar forecast based on the industry’s current capacity of 15,000 to 20,000 installations per year has been added. This data, generated from both sources is shown in Figure 3.

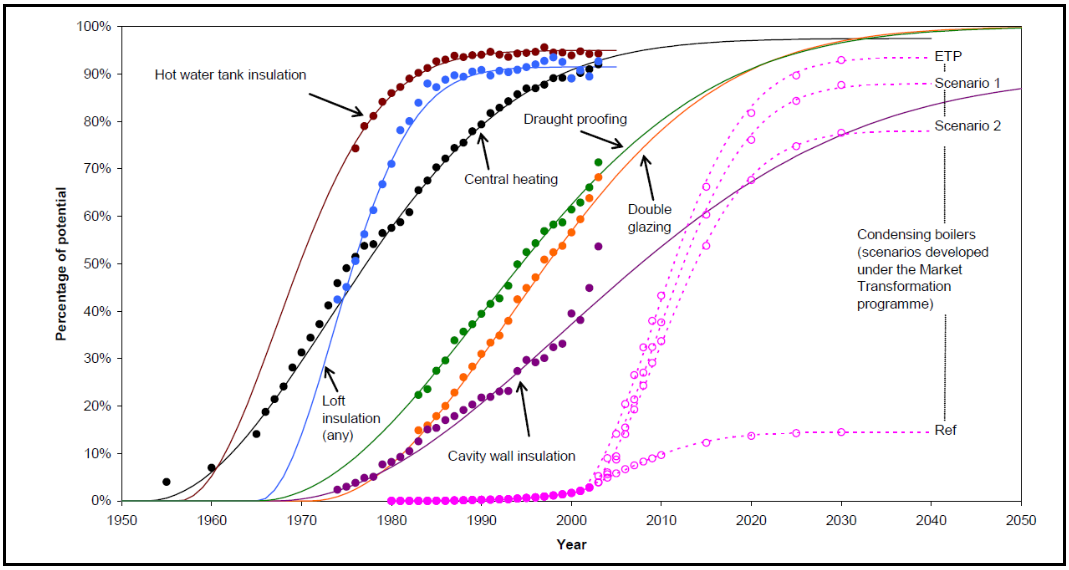

Figure 3. Market penetration of conventional energy efficiency measures [15]

From Figure 3

- Cavity wall insulation has good potential as a measure; Newcastle reports 82% of cavity properties and uninsulated properties in excess of 50%.
- Newcastle reports 66% of properties have double glazing, despite the high capital costs, levels are expected to reach saturation over the coming decades. An interesting characteristic of the Your Home Newcastle (YHN) housing is that through the decent home programs all YHN have double glazing.
- There is an enormous potential for super glazing, as Newcastle reports 5.8% of mix glazing (a mix of single and first generation double glazing). The potential for installing a triple glazing option with U-values of 1 W/m^2K, except for listed building status.
- Ideally there is potential for uptakes of loft insulation to ensure that all lofts have above 100mm of insulation, however, 74.2% of Newcastle does not have information on the floor level.

Newcastle reports 14% of walls are solid wall. Most of the solid wall properties are in LLSOA 8362 (South Heaton), which in recent years become a very popular student residence, this reflects on the high number of House in Multiple Occupation, in lower 3-4 story mid-terraced flats and detached and linked houses, corresponding to the Late Victorian / Edwardian (1870 -1914) buildings. Shorrock [15] argues that for solid walls uptakes seem unlikely to reach saturation over the next few decades due to high capital costs.

However, Lowe [16], Dowson [17], Roberts [18], and Strube [19] suggest for solid wall properties a refurbishment similar to that used in BREEAM (Building Research Establishment Environmental Assessment Method) EcoHomes, i.e. to requirements for modern energy standards.

Finally, Ravetz [20] argues that since 1996 there has been a substantial reduction across all Tenures in the proportion of homes failing the decent homes standard. This implies that many homes are first generation retrofits in need of renewal.

In summary, applying conventional retrofitting measures in Newcastle upon Tyne do show positive returns of investment, with the largest benefit occurring from filling cavity walls within pre-1976 stock.

3.5 Approaches to the fabric

The strategy which stands out most is Passivhaus. This is not because it is necessarily the most appropriate strategy for large-scale retrofit in the UK, but because of its tight performance specification and the organisational and scientific backing that its proponents receive from the Passivhaus Institut, its UK affiliate the Passivhaus Trust, and the international Passivhaus community. Deep and shallow retrofits are qualitatively different. While shallow retrofit can be achieved by insulation, deep retrofit characteristic requires replacement of existing heating and ventilating systems, and the installation of renewables.

Assuming that the retrofitted house continues to use gas for space and water heating, up to half the gas can be saved by insulating the fabric and hot water system. Perhaps a third of the electricity can be saved by changing the lights and appliances. Achieving CO_2 savings much above 50% requires either systems such as photovoltaics to offset the emissions from the gas and electricity or a switch to low carbon heat, for example from combined heat and power

Passivhaus strategy, involving the reduction of wall U values to around 0.14, and roof U values to around 0.08 W/m^{2}K. The aim was to reduce air permeability to below 1 m^3/m^2/h @ 50 Pa, by the addition of a continuous air barrier around the whole dwelling. Which is remarkably low compared with the average for existing dwellings in the UK, 12 ac/h @ 50 Pa. Moreover, they are low enough for the chosen ventilation strategy – whole house mechanical ventilation with heat recovery (MVHR) – to provide significant CO_2 savings.

External insulation has the following advantages: minimises impacts on occupants, enables thick and therefore relatively cheap insulants to be used, while achieving low U values, minimises risks to existing walls from interstitial condensation, requires careful coordination at junctions with the roof and with drainage, should be done at the same time as the replacement of windows and external doors, in order to minimise thermal bridging. An interesting approach is hybrid insulation strategy for mid-terraced – typically external at the rear and internal on facades that would be visible from the front.

3.6 Approaches to ventilation

The role of heating and ventilation systems is second only to that of the fabric in retrofit performance. Successful retrofits require an understanding of the ways in which these systems interact with the building fabric, control systems, and occupants.

There is likely to be little to choose between continuous mechanical extract systems and MVHR at air permeability around 5 ac/h, but that once this threshold is crossed, well-designed, installed and commissioned MVHRs allow steadily increasing energy benefits from airtightness.

4. Airtightness in buildings

In retrofitting older terraced houses with solid outer walls usually, the insulation measures can be on the inside with plasterboard or on the outside with a proprietary finish designed for weather protection and attractive visual appearance. The choice and viability of either internal or external insulation is determined by cost, appearance, room dimensions and the physical practicalities and details of fitting the insulation, particularly at openings. However, if a house is externally insulated then the wall is on the inside of the insulation, protected from the external climate and exposed to the interior. The effective 'thermal storage capacity' will be increased and the house should take on more of the characteristics of a well-insulated heavyweight house.

Terraced houses tend to be leaky, lack insulation, and their energy efficiency is low compared with newly built housing. Achieving airtightness can significantly improve energy efficiency, occupant comfort and reduce carbon dioxide emissions. The physical property used to measure airtightness of the building fabric is the air permeability (AP). AP is defined as "*air leakage rate per hour per square meter of envelope area at a test reference pressure differential across the building envelope of 50 Pascal (50N/m^2·)* [21]. The envelope area of a building is total area of all floors, walls and ceilings ordering the internal volume subject to the test; in the case of a terraced house includes the party walls and for individual dwellings includes the floor, walls and ceilings which are shared with adjacent dwellings.

The limiting air permeability (LAP) is the worst allowable air permeability. The LAP is established in the documents L1A and L2A is the air permeability should be less than 10m^3/h.m^2 at 50 Pa., the actual value of air permeability (AAP). Additionally to have a building airtight is to have it well ventilated to significant better air quality; this is explained in the approved document F.

4.1 Compliance with building regulation

To comply with regulations 17C the Dwelling Emission Rate (DER) or Building Emission Rate (BER) must be no worse than the target Emission Rate (TER). The final BER (or DER) must be based on the building ‘as constructed’.

Recent revision to the approved document of Building Regulations Part L in 2010 (ADL1A) [21] have resulted in even tougher targets (25% improvement on 2006 ADL1A), and future revision are predicted to require even tougher targets. Achieving an airtight building is ever more important to achieve compliance with Building Regulations.

The limiting parameter is established in the documents L1A and L2A is the air permeability should be less than $10m^3/h.m^2$ at 50 Pa.

5. Reengineering the heat supply

This section makes the case study for heat pumps and in particular the ground source heat pump (GSHP) for the heat supply. The case study is in local small areas of Newcastle with electricity heat supply with a selected tariff (E7).

Writing about heat pump overall efficiencies of GSHP, EST (adapted) writes:

> *overall efficiencies ground source heat pump (GSHP) are inherently higher than for air source heat pumps (ASHP), because (i) ground temperatures are higher than the mean air temperature in winter and lower in summer, (ii) the ground temperature also remains relatively stable, allowing the heat pump to operate close to its optimal design point, whereas air temperatures vary both during the day and the season, and might be low at times of the peak heat demand, and (iii) air has a lower specific heat capacity (the specific heat capacity, or specific heat, is the heat capacity per unit mass of a material) than water, so to supply the same energy more air must be supplied to the heat pump, which in turn requires more energy.* [22]

This research proposes ground source heat pumps.

5.1 Ground source heat pump elements

A GSHP system consists of three elements: (i) a ground heat exchanger, which collects heat from the ground, (ii) a water-to-water or water-to-air heat pump, which raises the heat collected to a useful temperature and transfers it to the house, (iii) a heat distribution system, which provides the heat to the house (e.g. under-floor heating).

The ground heat exchanger can be open-loop or closed-loop. An open-loop GSHP system uses groundwater as the heat source whereas the closed-loop uses the ground as a heat source and a circulating antifreeze formulation (e.g. water with Ethylene glycol) in a system well of buried pipes.

Open-loop GSHP system is preferred when there is an availability of groundwater; however, there are three disadvantages of this system: water availability (a well with a flow of in the range of 30 – 50 litters/min), water quality and the environmental regulations covering the use of groundwater are increasingly restrictive [23]. Another anticipated problem is the disposal of cold water after the process is completed.

By contrast, the use of closed-loop systems where their natural ground is the heat source is more efficient. The ground has three advantages: the temperature is stable at depths of three to four meters; also, the ground has high heat capacity[15] and low thermal conductivity[16]. Something to

[15] Heat capacity (or thermal capacity) is the ratio of the heat added to (or subtracted from) an object to the resulting temperature change

consider however is the fact that the pipes are made of high-density polyethylene (HDPE) plastic (plastic have a low thermal conductivity); therefore there is a significant drop in temperature between the ground and the circulating antifreeze formulation.

The ground heat exchanger wells come in two designs: vertical and horizontal. Vertical is more efficient than horizontal because (i) ground temperature is steadier in vertical wells than horizontal wells and (ii) require less space. However, closed-loop with vertical wells tends to be more expensive than a horizontal trench [24].

The heat pump itself consists of an evaporator, a compressor, a condenser, and an expansion valve. Together these components take the heat from the antifreeze formulation and transfer it to the domestic heating system increasing the temperature in the process. A ground source heat pump increases the temperature from the ground in the range of one and a half to four times – so if the ground temperature is 12°C, the output would be between 18 and 48°C). The domestic heating systems are water-to-water (wet systems) or water-to-air systems.

Water-to-water systems are used in radiators, hot water or under-floor heating systems whereas water-to-air units are designed to be used with new (or existing) oil or gas forced air furnace systems. Forced air uses air as its heat transfer medium. Unlike a conventional system, a ground source heat pump provides low-temperature heat and this needs to be delivered via larger heating surfaces, the most common domestic heating system is the under-floor heating (UFH). This research uses UFH.

UHF warms the floor structure by convection; this causes the surface to radiate heat into space. It is important that the under-floor system is designed correctly. Hot water is distributed in plastic (or plastic/metal) composite pipes to manifolds[17]. Each manifold comprises a flow and a return header from which loops are taken to serve the building. In a typical two storey building the first floor is served by a first manifold and the second by a second manifold. A single loop serves a small room and multiple loops are in place for large rooms. Each loop is a continuous pipe, leaving the flow header and returning return heater (without any fitting). In the case of solid floors, UHF pipes are fixed to the floor insulation and further on the top a concrete screed is laid.

Depending on its size relative to the heat loss of the property, a heat pump may need to run for longer periods than a traditional boiler. It is essential that any building using GSHP technology be well insulated and draught-proofed. This means it is well-suited to new buildings which need to be built to high levels of insulation and also buildings which have undergone a significant retrofit to reduce heat losses.

5.2 Modelling GSHP

The ground heat exchanger models are analytical or numerical. Analytical models are Kelvin's line source model and the cylinder source model. Numerical models use polar or cylindrical grids; in addition, numerical models can be inconvenient to incorporate directly into a whole-building energy analysis program [25].

The line source model the ground is assumed as an infinite medium with uniform and constant initial temperature. Therefore, the heat conduction process in the ground is simplified as a one-dimensional one. This approach has been widely utilized in analytical design methods.

5.3 Cost-effectiveness analysis of GSHP

Developing and installing Ground Source Heat pumps can be expensive. Apart from identifying your own funds, there are other funding options available to invest in renewable technology including Ground Source Heat Pumps (GSHP). There are two possible options: (i) government

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[16] Thermal conductivity is the property of a material to conduct heat. Heat transfer occurs at a higher rate across materials of high thermal conductivity

[17] A pipe or chamber branching into several openings

Incentives and Initiatives: Renewable Heat Incentive (RHI), Green Deal and (ii) private finance: Prudential Borrowing, Energy Services Companies, and Energy Performance Contracting.

Renewable Heat Incentive. There are three aspects which are considered when assessing the eligibility for receiving the RHI: the size of the installation, the type of heat use (i.e. space, water or process heating and the installation of heat meters (for non-domestic, i.e. >45kW) systems).

The tariff for domestic buildings is 18.8 pence/kilowatt-hour renewable heat. For non-domestic buildings see Table 4.

Table 4 Cost effectiveness of GSHP

Generation Technology	Size	Tariff rate pence/KWh	Tariff duration (years)
Small ground source	Less than 100 KWth	4.3	20
Large ground source	Above 100 KWth	3	20

Payments are based on the following formulae: yearly payment = (incentive rate/kWh heat consumed) x metered heat; total payment = (incentive rate/kWh heat consumed) x metered heat x total number of years.

"Operating heat pumps overnight on the off-peak electricity tariff is the most cost-effective way of providing space heating from a heat pump".[26] It is possible to supply domestic hot water with a ground source heat pump. The water from the heat pump will be used for pre-heating and then an immersion heater to bring the temperature up. For better results, the building must be well insulated for you to gain the most benefit. The cost of a GSHP system is directly related to the heat losses, which will generally be higher in older buildings

Finally, a ground source heat pump can be expected to last over 20 years – longer than a combustion boiler – and the ground heat exchanger should have a life of over 50 years. The ASHP system has a life expectancy of only 10 to 20 years.

5.4 Policy context, planning permission and building regulations

Several government policies affect the uptake of heat pumps, particularly financial incentives but also planning policy and building regulations. Heat pumps can be financially attractive in certain circumstances but are more expensive than conventional options such as gas-fired boilers. The government's main policy for low-carbon heating is currently a financial incentive, the Renewable Heat Incentive (RHI). This provides payment for each unit of heat produced, with "tariff levels varying depending on the type of heat pump and its size".[27] The RHI is similar to the Feed-in-Tariff scheme, which is available for small electricity-generating technologies.

Social Housing landlords are unique in the RHI because they are eligible to claim under either the domestic or the non-domestic scheme: a renewable heating installation which serves a single private residential home qualifies for the domestic tariff and a renewable heating installation which serves multiple residential homes, qualifies for the non-domestic tariff

The installation of a ground source heat pump or a water source heat pump on domestic premises is usually considered to be permitted development, not needing an application for planning permission [28].

6. Guidelines for energy efficient neighborhoods

This section will propose guidelines for reducing energy consumptions in households using the Green Deal mechanism. "Green Deal is a framework to enable private firms to offer households energy efficiency improvements to their homes at no upfront cost, and recoup payments through a charge in instalments on the energy bill".[29]

The Energy Act 2011 included provisions for the Green Deal. An Energy Company Obligation (ECO) integrated with the Green Deal, allows subsidy and Green Deal Finance to come together into one seamless offer. In this way, the Green Deal and the ECO will work in combination to drive the installation of energy efficiency improvements[18], often referred to as measures[19] .

The Energy Act 2011 also made clear that the Green Deal may cover measures which generate renewable energy in a cost-effective way. For example, micro generation will use renewable sources of energy (such as the air, sun and ground heat) to generate energy and this ultimately results in fuel bill savings. Under the Green Deal households are always protected by the Golden Rule[20] .

There are 45 measures or areas of a home approved to receive funding under the Green Deal. This research groups those measures in seven functional categories, for modelling purposes, covering improvements in (i) the building fabric; (ii) space heating; (iii) electric; (iv) water heating; (v) community heating- CHP; (vi) heat from the earth, the air and newly dead biological matter burn in a boiler, and (vii) microgeneration, and also included a change in the proportion in user behaviour and electric lightning in time as measures.

As a summary, certainly, if the Government makes sure the Green Deal work properly, then it could have a sizeable role to play in improving the energy efficiency of some of the UK's households. But the Green Deal has fundamental limitations as a mechanism, even when work properly it will not be attractive to:

- Households that can afford the repayments on the loans – those who are not in fuel poverty.
- People who would need to honor a previous loan – those with spare cash who have invested in energy efficiency already are unlikely to want a new loan.
- People in relatively easy-to-improve homes

Green Deal is at best a partial solution. For the bigger picture, a real strategy is needed which delivers whole-building, street-by-street retrofits to eliminate fuel poverty properly, this research will contribute to this aim by proposing a methodology to find those households in fuel poverty in the first place. In those households, Green Deal is not a strategy, but well it could form part of one.

Another important issue in constructing a strategy for the fuel poor is a study from Cambridge Econometrics and Verco shows that investing in improving the energy efficiency of fuel poor homes has additional benefits. The analysis shows that energy efficiency investment has the following advantages: (i) economic benefits by investing the money in improving the homes of fuel poor households has a better outcome on growth and employment; (ii) social benefits, because between 75% and 87% of the households that would have otherwise been in fuel poverty are removed from fuel poverty, improving the quality of millions of lives of some of the most vulnerable members of society and reducing health care costs; and (iii) environmental benefits as UK CO_2 emissions fall by more than 5% compared to baseline by 2027, contributing to the UK's legal commitment to reduce GHG emissions by 2050. Appropriate energy measures for selected areas.

6.1 Castle solar collection

The first case study is located in Castle in the Kingston metro area, this study argues that a low-density urban form can reduce the energy demand by better use of solar access and daylight conditions trough adequate photovoltaic panels. In the following paragraphs, we will describe the low-density area of the case study, the underpinning policy, the rationale, and the research questions.

A major aim of the Newcastle One Core Strategy [30] is to direct new developments to sustainable locations in order to reduce the need to travel, especially by private car. In the strategy, the majority

[18] The term used in the Green Deal legal framework to describe the installation of a measure in a property.

[19] Generic energy efficiency improvements which can be made to a property, for example, loft insulation, cavity wall insulation or a replacement boiler.

[20] The Golden Rule means the charge attached to the energy meter in a property cannot be higher than the estimated savings for the package of measures in that property

of new housing development will be located in areas close to existing facilities and shops and to transport hubs and bus routes. The housing density criteria is that a cluster of high density houses and apartments around a hub of key services not only provides a critical mass of core demand to support quality services but also affords high levels of accessibility to services for households with more limited mobility. Meanwhile, the density of surrounding housing declines with distance from the centre, with low-density family homes located towards the periphery of the neighbourhood [31]. With this in mind one of the Green Belt sites identified by the Newcastle City Council is the Kingston Park / Kenton Bank Foot areas as part of the North Great Park (NGP) project [32].

Regarding energy-efficient housing, the Supplementary Planning Document (SPD) policy NGP16 promotes energy-efficient standards above that required by the Building Regulations. Policy NGP17 requires the developers to "bring forward as part of each Housing Development Cell Strategy Statement proposals for an energy project". The resulting projects promoting sustainable construction methods and efficient energy use are a welcome feature of the development. [33]

The Urban Task Force [34] argues that towns and cities should be well designed, be more compact and connected, support a range of diverse uses within a sustainable environment which is well integrated with public transport and adaptable to change, for dwellings, the energy implications of compact densification are balanced between the benefits from reduced heat losses and the non-benefits of reduced solar and daylight availability [35]. Cheng [36], however suggest that medium to low density housing may in some cases enable a greater saving in CO_2 emissions than higher density development because of the greater amount of space for collection of renewable energy.

One of the low-density housing in Castle is over the south of Kingston Metro, the 8294 LLSOA with around 50% of standard semi-detached houses and semi-detached type house in multiples of 4, 6, 8, etc. Those houses correspond to the 1964 – 1979 period (see Figure 4). This paper propose a solar collection of renewable energy for this area.

Figure 4 Castle solar collection

6.2 Refurbish South Heaton HMOs

The South Case study is on Simonside Terrace (see Figure 5), an area where a correlation between incidents of historical flooding, and properties at risk from large areas of surface water flooding, provide a good indication as to the location of vulnerable areas to surface water flooding. These are known as Critical Flood Areas (CFAs)[21]. According to the Newcastle Strategic Flood risk

[21] CDAs tend to be defined by areas of low lying ground where the capacity of the sewer system is likely to be exceeded.

assessment [37], Heaton is a CFA. Additionally is an area for Article 4 Direction - Area of Housing Mix is enforced and finally, some parts are on Smoke Control [22]

The following paragraphs setups the case study, the underpinning policy, and the research question.

England has one of the oldest housing stocks in Europe and in 2009, 38% (8.8 million) of all dwellings[23] had been built before 1945; over half of these (4.8 million) were built before 1919 [38] i.e. the Edwardian and Victorian period. This study (phase 1) uses the Cambridge Housing Model (CHM). CHM [39] reads in the EHS dwelling (i.e. self-contained units) for each case and performs building physics calculations to determine energy consumption and associated CO_2 emissions, by use and by fuel type.

To date, Newcastle is a principal centre for education and has experienced significant growth in recent years. It continues to be the case that student numbers have been steadily increasing over recent years and it is forecast that this growth will continue this continual growth has resulted in a corresponding increase in the demand for accommodation. Much of this demand has been met by the private rented sector. However, the provision of purpose-built student accommodation has fallen behind the rising demand [40]. Alongside encouraging the development of purpose-built student accommodation, the Council [41] is improving the management and repair of private homes in Newcastle to meet the government's Decent Homes Standard, to implement the licensing of Houses in Multiples Occupations (HMO) and review standards in student and private landlord accreditation schemes.

A HMO [42] is a building or part of a building (i.e. a flat) in which more than one household shares an amenity such as a bathroom, toilet or cooking facilities or a converted building that does not entirely comprise self-contained[24] flats and where the standard of conversion does not meet the minimum that is required by the 1991 Building Regulations, and more than one third of the flats are occupied under short tenancies.

Is it possible [16], [17], [18], [19] to assess a refurbishment of a traditionally built block of houses dating from the period 1870 - 1914 similar to that used in BREEAM Building Research Establishment Environmental Assessment Method) EcoHomes, i.e. to requirements for modern energy standards.

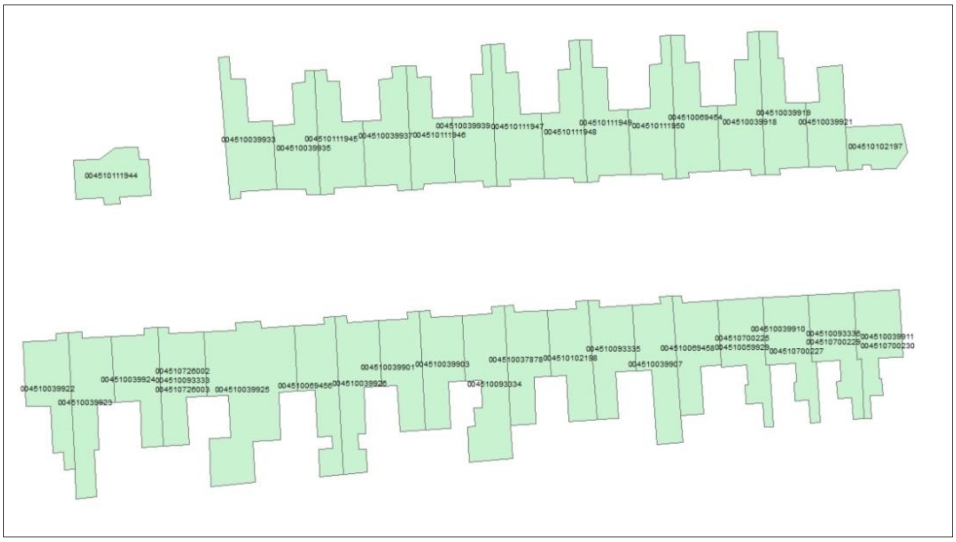

Figure 5. Refurbishment of South Heaton buildings

[22] Under Part III of the Clean Air Act 1993, many parts of the city have been designated as 'smoke control areas'. This means that, in general, smoke must not be emitted from chimneys within these areas and that specific controls upon the types of fuels which may be used apply.

[23] A dwelling is a self-contained unit of accommodation (normally a house or flat) where all the rooms and amenities (i.e. kitchen, bath/shower room and WC) are for the exclusive use of the household(s) occupying them.

[24] A self-contained unit is defined as a building or part of a building which has been constructed or adapted for use as separate living accommodation.

The refurbishment energy target is: (i) SAP - minimum of 80; CO_2 ≤35 kg/m^2/yr; Air permeability 7 m^3/hour/m^2 at 50 pascals or below (current best practice is 5 m^3/hour/m^2 at 50 Pascals or below); Energy saving - greater than 60%; Energy production (conventional) - high efficiency gas condensing boiler with zone controls; energy production (renewables) - at least 10% of energy demand.

A simpler option would be to use a solid, externally insulated wall which can be more easily constructed, allowing greater attention to detail on site. Techniques from Europe may also be helpful in achieving airtightness. Glued panellised brickwork sections, such as those used in the Hanson House 2 at BRE's Innovation Park are highly airtight, meaning that attention on site can be focussed on ensuring the joints between panels are made airtight.

Table 5 Summary of fabric and ventilation strategies

Summary of fabric and ventilation strategies	EWI, AC, CHS, low leakage, whole house MVHR	HPCF, PIV	EWI, low leakage	HWI EV+HPHR, inter-mediate leakage	HWI	EWI, AC, low leakage, whole house MVHR	EWI, AC, low leakage, whole house MVHR	HWI, inter-mediate leakage, HV (natural + individual MVHR)

Where AC = airtight construction BME = black and minority ethnic CHS = communal heating system EV+ HPHR = exhaust ventilation with heat pump heat recovery EWI = external wall insulation HA = housing association HPCF = high performance cavity fill HV = hybrid ventilation HWI = hybrid wall insulation – e.g. external at the back, internal at the front LA = local authority MVHR = mechanical ventilation heat recovery PIV = positive input ventilation.

External wall insulation can impact on poorly constructed extensions, eliminating some thermal bridges http://www.cewales.org.uk/files/3014/7671/0110/Post_Installation_Performance_of_Cavity_Wall__External_Wall_Insulation.pdf . Handling such issues demands a clearly thought through retrofit strategy, sufficient funding within the project budget. Internal insulation is a difficult option, especially in limited spaces. It is, however, an option in particular situations where properties are located in conservation areas. Solid floors are often not insulated due to the disruption involved. While various products currently exist on the market today, all involve the complete removal of the floor covering.

Based on demonstration projects, external wall insulation is regarded as an adequate solution to "hard-to-treat" properties insulation, as it is considered to be a viable option than internal insulation when undertaking the retrofit of a group of houses as it also minimises thermal bridging.[43]

For external insulation, the following details must be adequately planned for:

- Eaves: in the case of external insulation, eaves must be extended to accommodate the extended facade. For future retrofits attached eaves extension solutions could enable this to take place more easily.
- Windows: positioning of windows needs to be considered to maintain facade appearance and light levels within the internal space. It is important that high-quality and sufficiently informative detailing is provided to ensure that the window–wall–insulation interfaces are correctly handled.
- Where there are stringent planning constraints, more acceptable external insulation solutions should be developed to allow increased applicability. These should ideally aim to more closely replicate existing finishes, therefore, decreasing the thickness of current external insulation materials. A defective floor makes insulation considerably easier, using straightforward approaches and materials.

Thermal bridging is where heat loss occurs through the junction of building elements such as walls and floors where the continuity of the insulation is interrupted. Linear thermal transmittance ψ(Psi)-

values are used for thermal bridging. Thermal bridging heat losses may be significant, but can be reduced by adopting Accredited Construction Details (ACDs) [44]. A y-value is calculated as the sum of (L × ψ) for all junctions divided by the total area of external elements (which includes exposed elements but not party wall).

The ACD document produced by the DCLG and the Enhanced Construction Details (ECD) from the Energy Saving Trust document [45] focuses on insulation continuity and airtightness and gives guidance on how to demonstrate that provision has been made to eliminate thermal bridges in the insulation layers. The use of ACDs means that ψ-values from Appendix K of SAP 2009 [46] can be used; giving an equivalent y-value of 0.08 instead of the default y-value of 0.15 that would otherwise be used, i.e. the default y-value of 0.15 does not include Accredited or Enhanced Construction Details. Thus the thermal bridging using the default of y = 0.15 W/mK, and airtightness of 10 $m^3/m^2/h$ @ 50 Pa represents the worst case in terms of thermal bridging and airtightness that will comply with ADL1A. When applying the ECDs philosophy to a default ADL1A design, it is possible readily to achieve the energy requirements of Code level 2, which requires an 18% reduction of the DER below the TER [47].

For ventilation and airtightness, there is a complex range of choices in ventilation systems and strategies that can be used when retrofitting properties. The key technologies and strategies that were used in the sample projects were mechanical ventilation with heat recovery (MVHR), continuous mechanical extract ventilation (MEV), positive input ventilation (PIV) and passive stack ventilation (PSV).

MVHR can significantly reduce energy consumption; however, it requires a high level of airtight construction A high-quality MVHR installation needs sized ducts and heat exchangers and for sound attenuation, and to allow for maintenance. At intermediate levels of airtightness, strategies such as continuous MEV or PIV may deliver lower CO_2 emissions at lower cost than MVHR. PIV, in principle, delivers lower energy use than MEV by recovering heat from attic spaces and using it to heat the home. Both MVHR and PIV filter the air supply; but PIV may be less effective at controlling internal sources of air pollution than MVHR or MEV unless used with local extractor fans. PSV has the advantages of being silently operable and not requiring electricity http://www.carltd.com/sites/carwebsite/files/Insulation%20and%20thermal%20storage%20materials%20pre-publication%20draft_1.pdf.

Figure 6 shows there is a wide range of modelled energy consumption within a single property type and that these are closely linked to specific characteristics of the properties. The semi-detached sample shown in Figure 6 presents uninsulated properties using a standard boiler with high energy consumption. It is possible, therefore, to decrease the energy consumption by 40% by changing the boiler type a condensing one and insulating the walls.

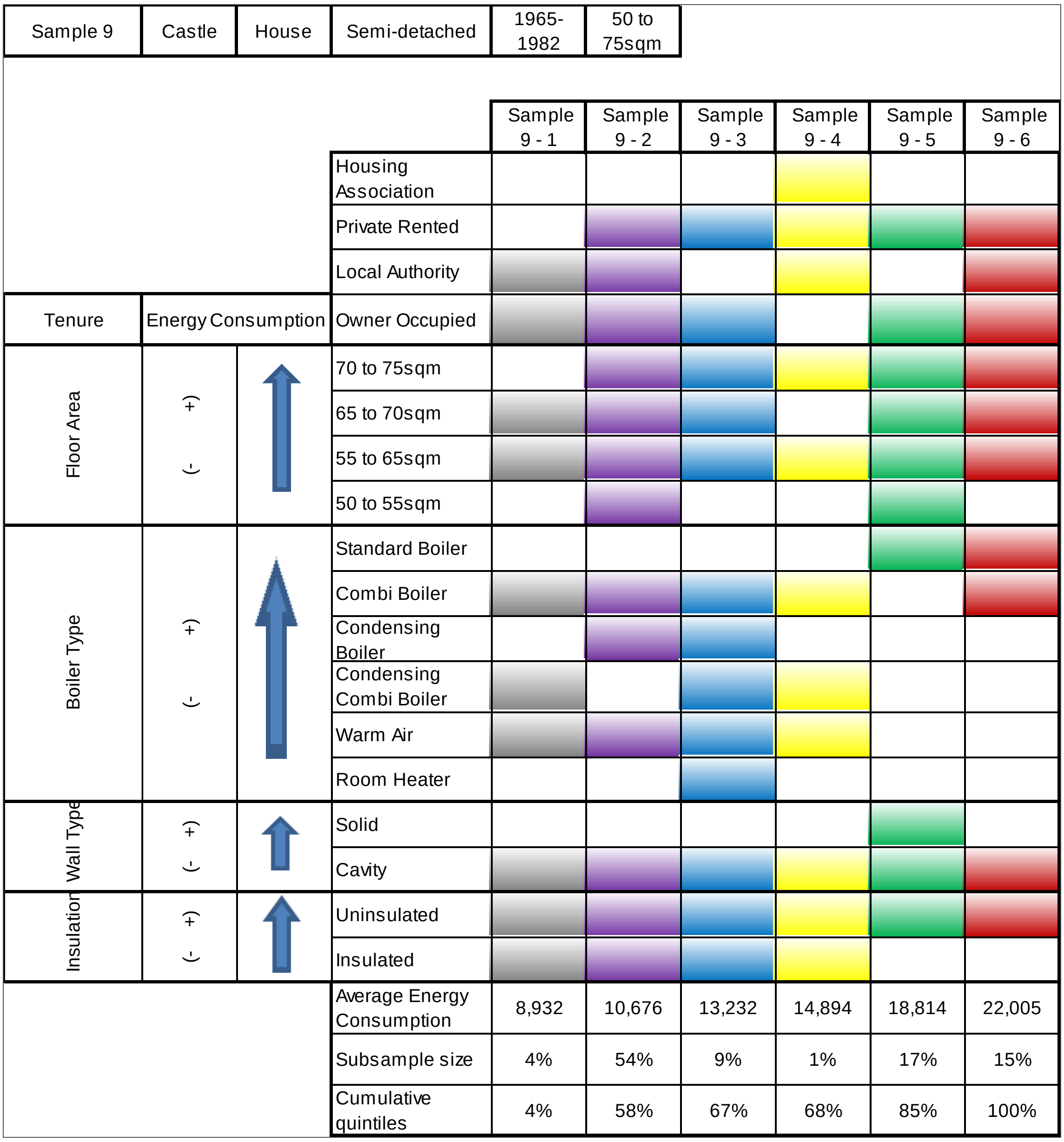

Figure 6 Retrofitting in South Heaton semi-detached houses

6.3 Westgate reengineering the heat supply

The third case study is in Westgate, DECC reports in 2009 that the 8440 LLSOA [48] an annual economy seven (E7) electricity consumption of 6,557,803 KWh, by far the biggest E7 consumption in the city, also the biggest LLSOA in the mix-uses building. The following paragraphs frame the method for a proposed match of the heat demand/supply in city nodes.

In this study the load profiles are simulated for each individual dwelling of mix uses building, with load disaggregated by end use, season, and time of day and all information linked to a GIS database. The model is used to analyse the technical potential for distributed cogeneration. Potential reductions in primary energy demand and CO_2 emissions are estimated assuming that cogeneration is implemented in all technically feasible locations, where locations might include individual dwellings, groups of co-located dwellings, or blocks, depending on the scenario. This study argues that distributed cogeneration with small (~1 MW) gas turbines could reduce building-sector primary energy demand. Residential neighbourhoods with multi-family buildings are good sites for supply nodes because they tend to have thermal energy load that is several times larger than electric load. Overall, this study proposes a new approach to local energy planning, in which supply nodes emerge from the fabric of demand, and this can contribute to alternative energy development in cities.

In centralized energy systems, buildings are demand nodes; in distributed generation[25] (DG) systems, buildings can also be supply nodes. To understand whether DG can play a larger role in urban energy systems and what impacts DG might have on system design and efficiency, this model matches building load profiles with distributed supply options. Such models can be used to scan a neighbourhood to determine opportunities for DG, whether DG can increase energy efficiency and reduce greenhouse gas (GHG) emissions, what types of generators are suitable, and what unique urban factors influence the viability of DG.

Cogeneration is a commercially mature technology that can supply district energy systems or, at smaller scales, be integrated into individual buildings and cover all major building loads. Advantages of distributed cogeneration may include the ability to use waste heat, improving the thermal efficiency of generation; reduction in transmission and distribution losses; ability to optimize local systems to match local demand profile; reduction in GHG emissions if cogeneration is less carbon-intensive than the existing fuel mix; and long-term cost savings. Disadvantages of cogeneration may include high capital cost; local impacts including noise and/or air pollution; complexities and costs of interconnecting with the main distribution grid; and reliability and performance of generators and distribution networks.

Availability and adequacy of gas supply is another major concern. These issues are beyond the scope of this analysis and are not addressed as part of this research.

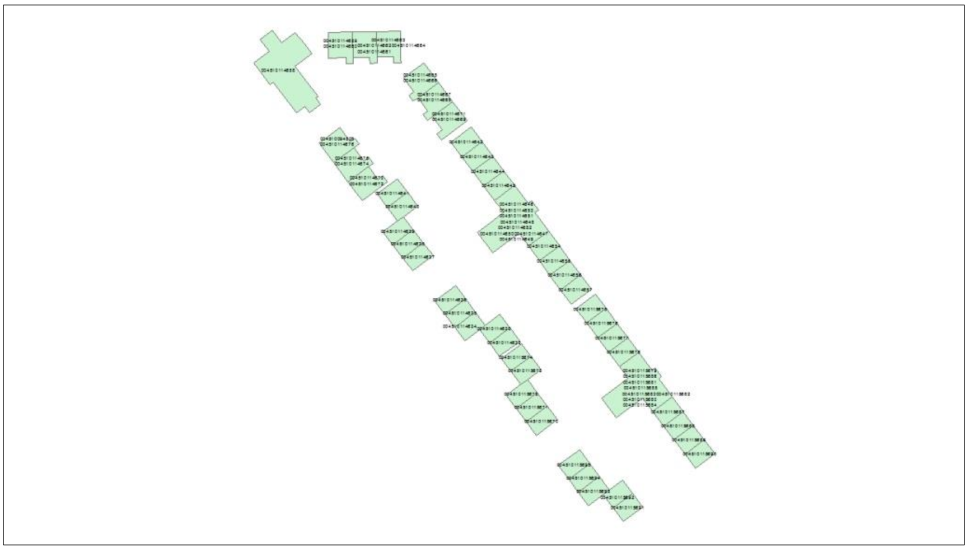

Figure 7. Retrofitting Westgate

The system is shown in Figure 7. A heat transfer fluid is pumped through a series of vertical boreholes, where heat is collected with a corresponding fluid temperature increase. Borehole depth is project dependent. The coefficient of performance (COP) and capacity of heat pumps depend on several parameters such as fluid flow rate and temperatures on the source and load sides https://moodle.polymtl.ca/file.php/309/H_2009/MEC4250_TD_H09/28668sustainability_bernier.pdf .

7. Summary and further research

For a sizeable proportion of low-income households and the fuel poor, it is imperative that substantial grant aid for energy efficiency measures were in place. Two potential sources of funds for future grants for low-income households could be (i) grant aids directly from the government.

[25] In this study, the focus is on cogeneration (combined heat and power, or CHP), a DG technology that can reduce primary energy demand by recovering waste heat that is normally lost during electricity production, and using this energy to supply buildings with hot water and space heating.

Some of the proceeds of auctioning EU emissions trading scheme permits, or from a UK carbon floor price, could be utilised to fund such grants; (ii) In recognition of the regressive nature of funding for supplier obligations, the Government should develop a model to ensure that savings are focused on disadvantaged households who are least likely to be able to benefit from pay- as-you-save type programmes, such as the Green Deal.

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