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Economic Analysis of Energy Savings & Cost Effectiveness of Deep Energy Retrofits of Residential Buildings in England

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Abstract

Buildings are known to consume a large proportion of the final energy demand (approximately 37%) in the United Kingdom. Fragmenting this further, about 60% of the supply of a building is expended in space and water heating. Modern building stock are constructed with thermal insulation and are fitted with energy efficient appliances and fixtures. For this reason, focus has to switch to the older building stock in England in order to identify more techniques to reduce energy consumption therefore reducing the carbon footprint of these buildings, to this end, several building energy upgrade methods such as double-glazed windows, attic insulation, green spaces etc. have been proposed and are commercially available; However, house owners and building stakeholders are often misinformed in making retrofit decisions, and often do so based on the strong marketing techniques of manufacturers. This paper generates a smart decision making matrix for stakeholders to select and invest in the optimal energy saving measures which would suit their building type.

Keywords: Energy Savings; Energy Retrofits; Old Building stock; Insulation

1.0. INTRODUCTION

Climate change has been widely accepted as a threat to the earth as well as all living things and immediate action is required from all sectors to mitigate its impending effects (Pachauri et al., 2014). Approximately 30% of anthropogenic CO_2 emissions are directly attributable to the high-end energy consumption in the building sector. The International Energy Agency (IEA) has labelled buildings as energy intensive. This has consequently drawn the efforts of energy policy and carbon emission reduction efforts from around the world. Urban built up areas in developed countries are often involved in leading the way in climate action (Rosenzweig et al, 2010). An example is New York which aims to reduce its carbon footprint by 80% by 2050. (Wright et al, 2014) The UK has a similar act in place committing the UK to reducing its greenhouse gas emissions by at least 80% from 1990 levels by 2050 as published in the Great Britain Climate Change Act (2008). This is hoped to be achieved by putting an explicit or implicit price on energy use or carbon emissions or by encouraging investment in energy efficient or low-carbon technologies (Ang et al., 2016). Other similar strategies in place to achieve this include establishment of economic incentives for building renovations and a requirement for energy performance certificates for buildings when they are built, sold or rented (Dodoo et al., 2017). The cruxes of these climate action plans mainly focus on the building sector as the origin for improved energy efficiency and reduced emissions – this is expected to be largely driven by the high return on investment (ROI) rates for energy efficiency retrofits in buildings. Energy demand for heating normally increases during the colder periods of the year (winter) and reduce during the warmer periods of the year; these periods of high consumption could be seen from a different perspective as the target times for energy use reduction through investment in end use efficiency retrofits which has been identified as researchers to be one of the lowest cost means of meeting energy demand and reducing greenhouse gas emissions (Jafari and Valentin, 2018). While older buildings have been identified as being the main origin of high energy consumption in the residential or building sector, the rate of replacement of older buildings with newer, more efficient ones is only at an average of 1% - 3% per year (Cooper et al.,2012). At this rate, improving the energy efficiency of existing through retrofits is a priority task that needs more focus in order to stem the environmental impacts of the high carbon footprint buildings. In the European Union (EU) as a whole, approximately 35% of the buildings are well over 50 years old (European Commission, 2016). This undoubtedly presents an urgent need for widescale adoption of renovations to these buildings to improve their energy efficiency. Sweden already employs a “million homes” programme which ensures that buildings constructed before energy efficiency legislation was implemented in the Swedish building code. A number of studies conducted to investigate the energy saving potential and economic implications of different energy efficiency measures for buildings. Harvey (2009, 2013) conducted a review of the currently existing energy retrofit techniques and reported that heat savings of up to 50-90% has been achieved after renovating a number of buildings at reasonable cost. Rødsjø et al. (2010) reported that some energy retrofit projects conducted in the past have been able to achieve up to 80 – 95% final energy savings, though at high cost. A number of ways exist to mitigate the problem of building thermal inefficiency in temperate regions such as the UK.

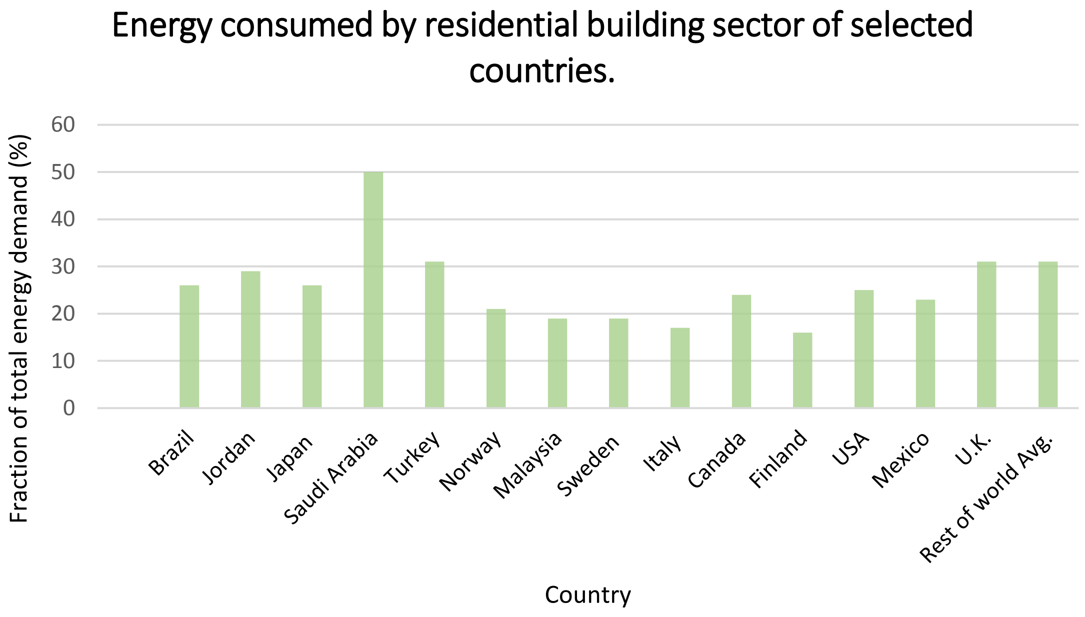


Figure: Worldwide)

1.1. Building Energy Distribution

Palmer and Cooper, working in alliance with the Department of Energy and Climate Change (2013), estimates based on modelled energy consumption for households, that approximately 68% of total energy is used for space and water heating; 28% is used in lighting and appliances, while 5% is used in cooking. While this is an averaged value, the actual heating costs are variable and depend on the building type, individuals in the property, and the type of fuel used in space heating (i.e. either electricity, natural gas or coal), and the quality of thermal insulation used. In the figure below, it can be observed that electricity and gas have been the major sources of building energy for over 30 years, and have almost completely displaced other sources such as coal used for home heating.

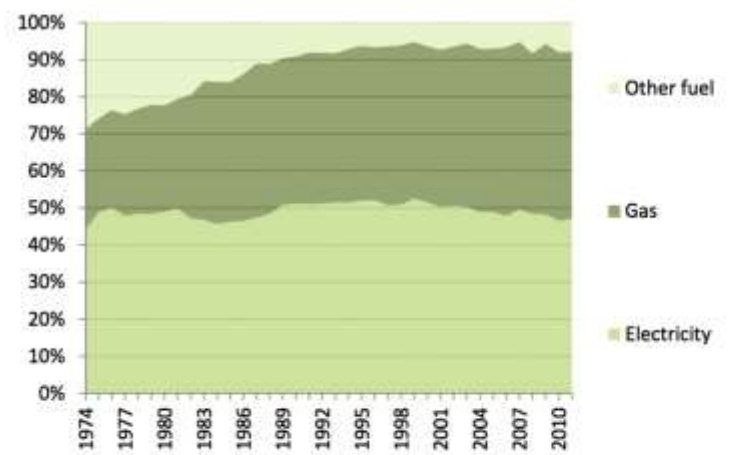


Figure: *Adapted from*

Currently, the objectives of the energy efficiency policy in the building sector are to maintain security of UK energy supply, reducing greenhouse gas emissions and addressing the drivers of fuel poverty. As stated by Andrews and Jelley (2013), “The building sector provides the largest potential for emissions reduction, estimated by the Intergovernmental Panel on Climate Change to be 6 Gt of CO2 per year”. The most effective methods to improve energy efficiency arise from heat-saving techniques; this is supported by the fact that heating is the single largest source of consumption, a figure put at 65% by Palmer and Cooper (2012). From a broad perspective, the methods to improve building energy efficiency include Loft Insulation, Boiler upgrade, double, triple and vacuum glazing, cavity wall insulation and occupant behavioural changes. With loft insulation, the rate of heat flow out through the roof of a building is minimised. Cavity wall insulation is applied within the walls of a building to reduce heat losses. Energy Saving Trust (2014) state that most buildings over 10 years old lack cavity insulation but can be retrofitted to include it.

The main purpose of loft insulation is to reduce the rate of heat flow out of the building through the roof. There exists a wide range of loft insulation types, made out of different materials with similar thermal properties. Blanket insulation is made in form of rolls of a mineral fibre, and is known to be the most common type of insulation, Loose-fill loft insulation is made up of a selection of lightweight materials, e.g. mineral wool or cork; new greener options for loose fill loft insulation make use of recycled paper. Other loft insulation types are sheet loft insulation which work well with sloping roofs, and lastly, blown-fibre loft insulation, which is made using bits of recycled paper or wool. Blanket insulation is relatively cheaper; depending on building type, the prices can range from £375 - £400 for a four-bedroom detached house, and is able to offer payback within 2 years (The Renewable Energy Hub, 2018).

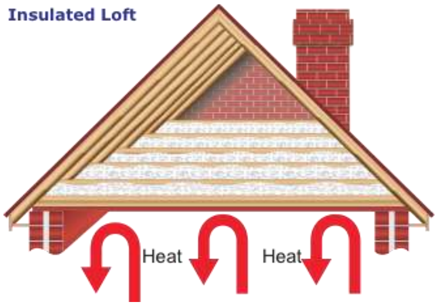


Figure 3: An insulated loft, with the insulation material shown between ceiling joists.

Another well-known method to improving the efficiency of building energy is by undertaking boiler upgrade. The more efficient a boiler is, the more energy is conserved; modern boilers are able to recover more energy from the fuel by extracting latent heat of condensation with a heat exchanger (Che et al, 2004). The EU directives 2010/30/EU and 2002/91/EC serve to boost the recognition and adoption of more energy efficient appliances (Paepe et al, 2013).

Cavity wall insulation is applied within the walls of a building to reduce the rate of heat loss from the heated parts of the building. The Energy Saving Trust (2014) states that most buildings more than 10 years old are devoid of cavity insulation, but are still suitable for receiving it, and can be easily installed by a building services engineer. Typical insulation materials used for cavity wall insulation among others include mineral wool, polystyrene beads or foam. Cost and complexity of installation are usually dependent on the size of the building.

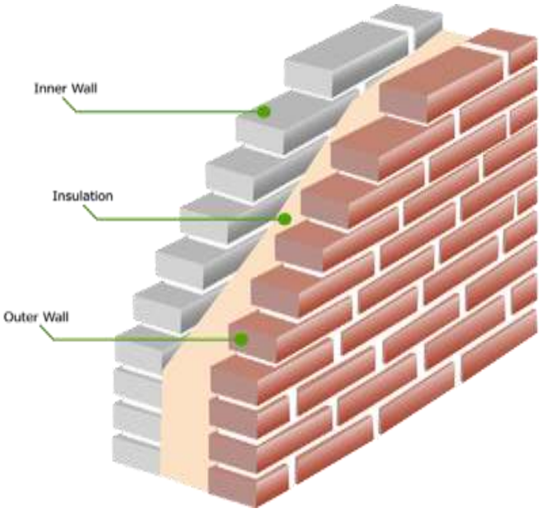
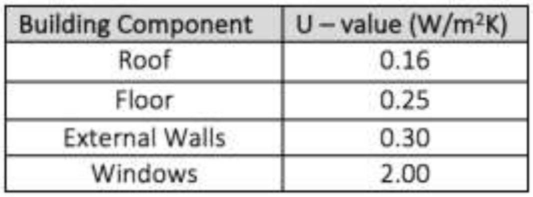


Figure 4: An insulated wall cavity, with the insulation material within the inner and outer wall.

Insulated glazing is another energy saving measure adopted in the colder climates of the world. Cuce and Riffat (2015) affirm that the greatest fractions of energy are lost through the building envelope, consequently as a result of poor insulation and poor thermal performance of building elements. Windows are responsible for a great proportion of energy losses in buildings as they are made of materials with notably higher U-values than other components. Typical U-values for building components are given in table 2.1.

Table 1: Typical U- values of building components. Reproduced from Cuce et. al., (2015)



Building Component	U – value (W/m^{2}K)
Roof	0.16
Floor	0.25
External Walls	0.30
Windows	2.00

According to Jochem et.al, (2000), over 60% of energy is lost in the process of conversion of primary energy into secondary forms. With an average conversion efficiency of 37%. Energy end-use efficiency offers a great potential for energy saving. Over 60% of energy is lost in the conversion of primary energy into secondary forms; on average, the current global efficiency of is estimated to be 37 percent (Jochem, et. al, 2000). Thus, increasing the efficiency of the end use of secondary energy (e.g. electricity) through occupant behavioural changes, would reduce the demand for conversion of more primary energy (e.g. coal). In most cases, the responsibility for efficient energy use lies in the hands of the end users, of which a great percentage lies in the residential sector.

The United Kingdom government, in conjunction with the Cabinet office and the Department of Energy and Climate change (DECC) carried out an assessment on ways by which individuals can be encouraged to be less profligate with energy by becoming more energy efficient. In their findings, they noted that individuals and households are not willing to take steps to improve energy efficiency (i.e. spend money) because the benefits of doing so are far fetched.

Therefore, it was found that people can be persuaded to invest in home energy improvement retrofits by offering them immediate rewards, rather than long term savings in energy costs. The Green Deal is a measure through which the United Kingdom government hopes to combat this issue. This defers the costs of home retrofitting, also adding benefits such as a one-month exemption from council tax in some cases, and free product vouchers in some other places. (Cabinet Office, 2011). These strategies hope to increase the inertia of people's commitment to improve the end use efficiency of energy. Other techniques adopted by the UK government to boost the energy consciousness of individuals is by enabling collective purchasing, encouraging efficient energy use through social media (e.g. websites, social networks), removing the building disruption associated with home retrofits as they are a major psychological barrier to households committing to home improvements. A potentially highly effective way of inducing behavioural change in individuals is also by motivating them through community rewards; by doing this, individuals within a local community may strongly encourage others within the local area to engage in energy efficiency improvements in their homes; this common interest induced will supplement the the original motivation to save money from energy bills (Cabinet Office, 2011). Around 25% of total heat loss is through the roof of a building (Jenkins, 2012), therefore insulation of the roof - known as loft insulation is a fairly common and effective technique for reducing improving building energy efficiency. Loft insulation approaches were highlighted in 1.4.1 above. Older buildings usually have sloping roofs. A suitable insulation technique for insulating sloping roofs is Rafter insulation which involves installing insulation between the rafters in the roof This is often done when it is impossible to insulate between the joists in a loft. According to (Jenkins, 2012), most rafters are of sufficient depth (210mm) to accommodate insulation.

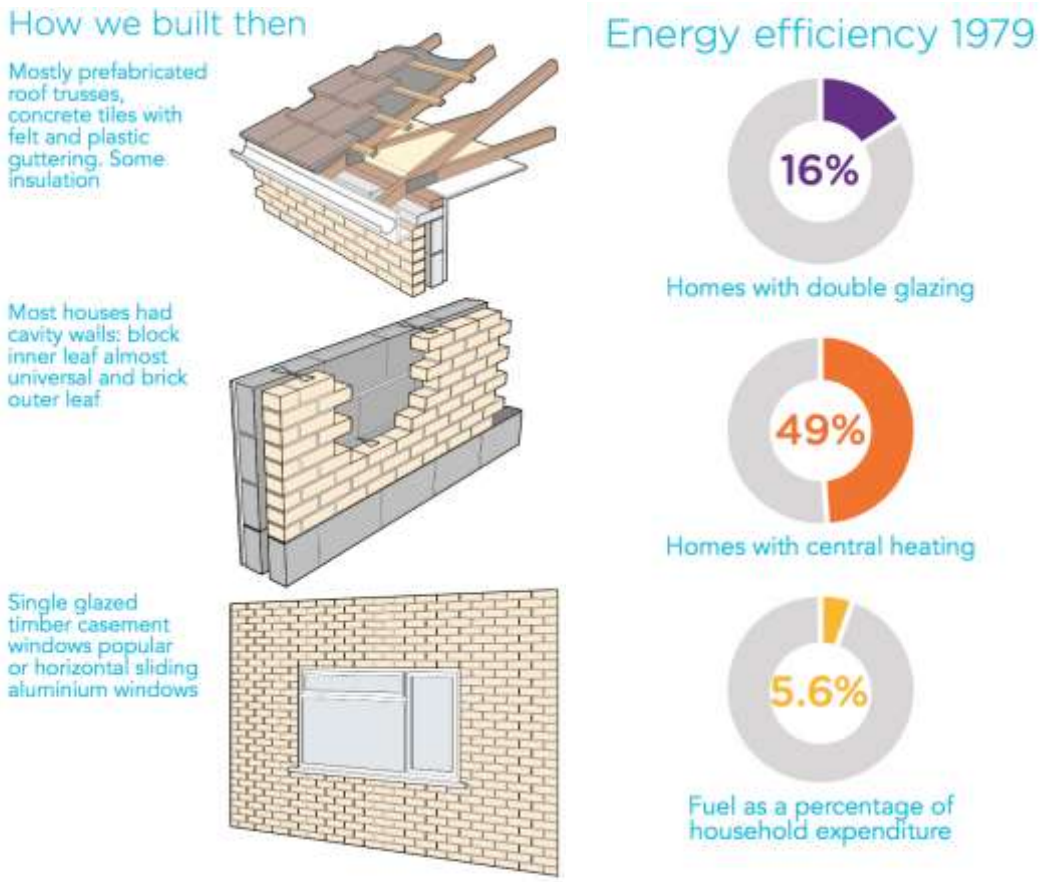


Fig 5 (a & b): Typical construction attributes of buildings in the 1970's, statistical data on efficiency measures. Adapted from NHBC (2015)

2.0. METHODOLOGY

Bottom-up economic approach is used to explore the viability and feasibility of installing cost effective measures and packages using dynamic energy balance through energy modelling in medium-sized (4 bedroom) residential buildings in England. The total and marginal investment cost of energy efficiency measures are compared against the NPV (Net Present Value) of total and marginal savings of the installed measures. The theory behind this study is: for a cost effective individual energy savings measure or energy savings package, the NPV offered by the savings must at least equal the investment cost for the measure.

2.1. Overview of engineering and economic approaches

A typical sample medium-sized 4-bedroomed building in the UK will be identified for the purpose of carrying out experimental software modelling. Different energy retrofit measures such as double glazing, loft insulation, green roof installation, cavity wall insulation, efficient doors, advanced surface materials etc. will be modelled individually in EnergyPlus to obtain the possible energy savings with each measure. Based on these individual savings, a number of packages are developed comprising of 3 or 4 individual measures; the cost implication of this is determined and compared with the NPV of total savings. The vital factors in this analysis include the investment costs for the energy retrofits, energy cost savings over an assumed rest-of-life service period of 50 years. For the purpose of simplicity of this project, it is assumed the potential change of the energy prices increases annually within 1% of the nominal price for 2018 in England. Renovations to the building envelope such as double-glazed windows are assumed to last through the remaining service life of the building. Mechanical ventilation and air duct units are assumed to last at least 25 years from installation.

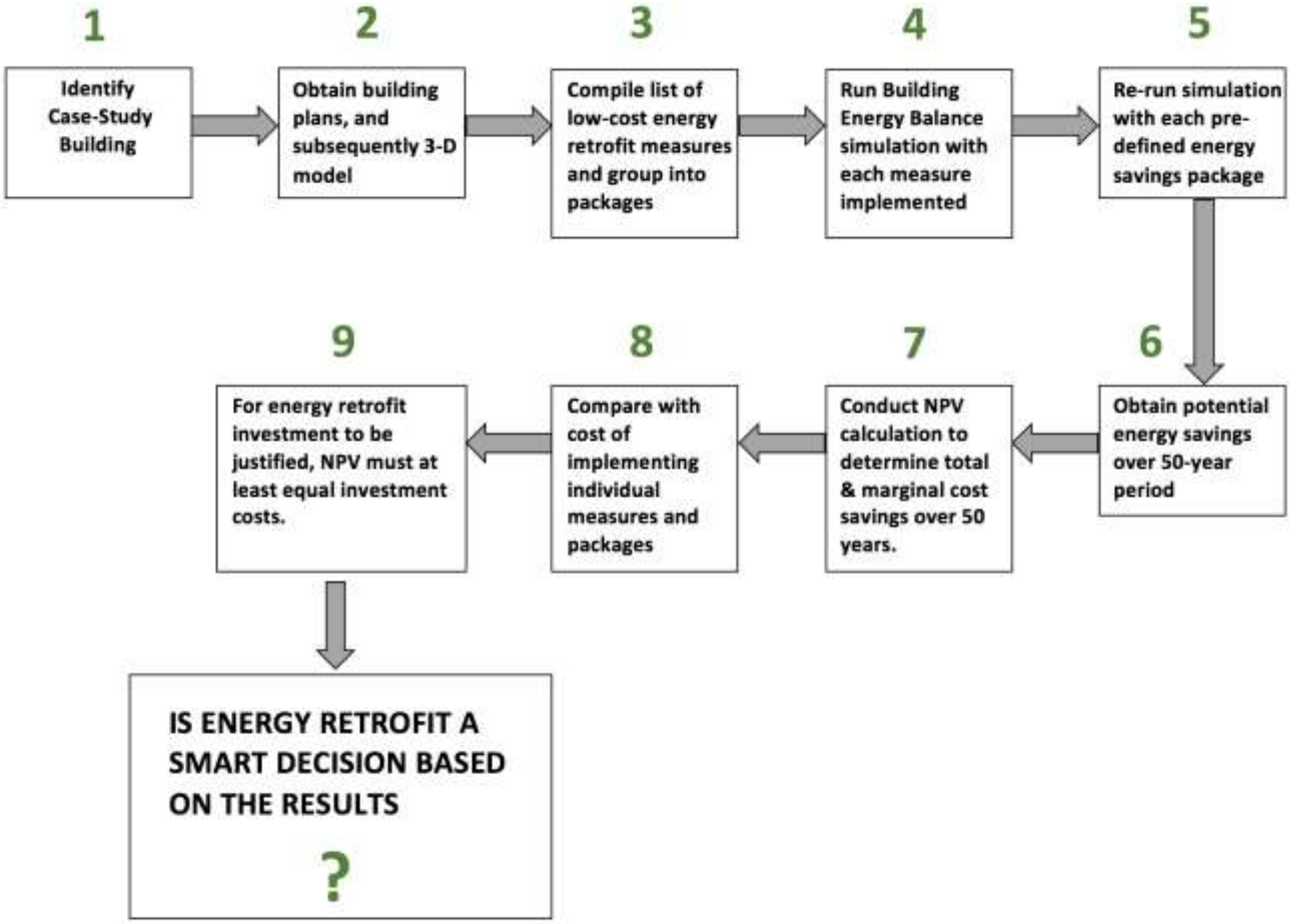


Figure -chart

2.2. Case-study building

The case-study building is 1 unit of medium-sized 4-bedroom British house from 1965 in Derby, England. It consists of 4 bedrooms, 1 kitchen, two bathrooms and one lounge/living area. Windows are single glazed and there is no loft/cavity insulation. The building plan is roughly based on a rectangular plan and has a total length of 9.7m and a width of 6.8m; the total floor area of the building is 130m^2 distributed over two floors; construction and thermal characteristics of the building without any energy retrofits is presented in table 2. Space heating energy is supplied in form of Gas via underground lines. Gas and electricity are supplied by utility retailer Scottish Power (assumed for purpose of uniformity). This building was chosen because it represents a good example of old UK building stock.

Figur(e : -study lding

2.3. Energy savings analysis in EnergyPlus

The intricate interaction of various factors is vital to the accurate modelling of the interaction between buildings energy use and the energy savings impact of various renovation measures. The software used for design, modelling and analysis is EnergyPlus within Autodesk Revit 2018 (Version 8.90) developed by the United States Department of Energy for calculating the final energy use and energy savings in various types of buildings around the world. EnergyPlus allows a while building energy simulation, enabling engineers, architects and researchers to model both energy consumption – for heating, cooling, ventilation, lighting and plug loads as well as water use within a building (US Department of Energy, 2018). The energy savings of renovation measures may vary depending on the input data; data specific to the particular building site in England are used for the software calculations. The weather data in EnergyPlus software is arranged by the World Meteorological Organisation (US Department of Energy, 2017).

For the region of Derby, UK in 2016, the average temperature, wind speed and relative humidity and air pressure were 5°C, 14km/h, 85% and 1003hPa respectively (The Met Office, 2017).

Building occupancy information is also integrated into the energy model – being a residential building, it is assumed that average internal heat gain is decreased during the day as occupants are not home. The reverse is the case for evening periods where the occupants are assumed to have returned. Energy demand is also assumed to be higher at this time. An average distribution of indoor appliances is also implemented into the building model.

2.4. Economic Analysis

The NPV of total and marginal energy savings are calculated for the different scenarios using the 2018 district heating and gas/electricity tariffs for the UK. The selected electricity tariff for the simulation is that offered by British Gas which comprises of an annual standing charge of £114.28 and an actual energy charge of 12.376 pence per kilowatt hour (£0.124/kWh) for a typical home in the Derby area. NPV is typically calculated with the following formula according to Zore et al. (2018):

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

n = service life of retrofit measure (in years); t = a particular year; C_t = annual energy cost for year "t"; r = real discount rate.

It should be noted that the investment costs used in the economic analysis for this research include the material costs, installation costs, as well as the all ancillaries and planning costs. This analysis also assumes the building to be renovated is in a generally good condition and no repairs or maintenance is undertaken prior to installation of the energy measures. The calculated costs are expressed in British Pound Sterling (£). The UK building renovation reduced VAT tariffs for 2017/2018 is used, as well as standard off-the-shelf prices from local retailers. The marginal cost of investment in a particular measure is determined as the change in investment cost relative to the retrofit measure applied.

2.5. Energy retrofit measures to be applied to building

Figure -study .

2.5.1. Enhanced roof insulation

From a general perspective, the fabric or façade of the case-study building is in a good physical condition. Structurally, it consists of a cavity wall which has a cinder block inner structure and a brick outer leaf; the brick inner leaf is covered with wooden panels. The foundation is of a concrete strip type and descends approx. 1.5m into the ground. The roof consists of pre-fabricated roof trusses covered with concrete tiles and felt and plastic guttering with 2cm of mineral wool insulation. The windows are of single-glazed type, encased in a timber frame with a vertical sliding aluminium window; the U-value of the windows was measured to be 5.1W/m^{2}k which can be considered to be high. It is assumed that the performance of the mineral wool insulation originally installed in the building's roof would have deteriorated over the 53 years of its existence. The building roof is of a low cross-hipped type and only has an additional space allowance of 15cm for extra insulation. In this situation, only compact high-performance insulation systems may work. The single-glazed uncoated windows are replaced with double-glazed (argon air gap) coated windows.

2.5.2. Enhanced doors and glazing

High performance state-of-the-art doors will replace the older low efficiency external doors of the building. Experimental and case studies on the effects of double glazing by Gil-Lopez and Gimenez-Molina, (2013), as well as several other authors have proven that substantial energy savings is possible when existing fenestration is replaced with double or triple glazed alternatives by reducing thermal transmittance and draught. In this analysis, the possible energy savings realisable from the case-study building after retrofitting with high performance insulation, windows and doors is explored. Replacement windows with U-values of 1.5 W/m^{2}k, 1.3 W/m^{2}k, 1.1 W/m^{2}k, 0.9 W/m^{2}k, and 0.7 W/m^{2}k are used to determine the possible energy savings.

2.5.3. Upgraded fabric insulation

Addition of insulation to a fabric of a building has the potential of increasing the thermal resistance of the building subsequently the thermal comfort of the rooms within the building. According to Marshall et al. (2016), the typical calculated U-value for an uninsulated wall is 2.1W/m^{2}K. However further research has proven that the – value for uninsulated walls is considerably less than this. Energy Savings Trust has put the average U-value for uninsulated walls at 0.44W/m^{2}K; therefore, this would be used as a pre-retrofit value for the case-study.

2.5.4. Efficient appliances and lighting systems

The possibilities of energy savings with the implementation of energy efficient lighting and appliances within the building is also explored. This subject area ties in strongly with the energy savings behaviour of the building occupants as it is possible for a building to have highly efficient appliances and lighting in place but still remain inefficient due to the energy profligacy of its occupants. A bottom-up modelling analysis of the final energy savings as well as cost-effectiveness is performed.

3.0. RESULTS

The 3D model of the building with varying input factors is run through EnergyPlus to evaluate the effects of introducing a number of retrofit measures into the building. The output of the simulations gives the potential energy savings which is subsequently used to determine cost savings based of the average unit cost of electricity in England.

3.1. Energy demand and cost savings of individual retrofits

Table 2.0 depicts the individual energy retrofits for the case-study building including their estimated service life for the purpose of simulation. Table 3.0 presents the improved U-values, final energy savings and investment costs from replacing the windows of the building with new and improved windows. Table 4.0 presents the improved total U-value, energy savings and investment cost for installing additional 150mm of high performance insulation beneath the roof. Table 5.0 presents the improved. Table 6 consists of the improved total U-value, energy savings and investment cost for installing efficient doors, Table 7 provides information on the U-value, energy savings and investment cost for embarking on a roof replacement project – replacing the traditional black roof with a cool roof which reduces the cooling load of the building during summer.

Table *-study*

Energy retrofit measure	Description	Service Life of measure
Additional attic insulation	100 – 150mm mineral wool insulation	45 – 50 years
Double glazed windows (argon filled)	1.9w/m^{2}K U-value glazing	50 – 60 years
Energy efficient appliances	Varies	20 years
Cool roof	Increased solar reflectance roof	50 years
Green roof	Increased thermal insulation	50 years
Efficient doors	1.4w/m^{2}K U-value doors	50 years
Exterior wall insulation	200mm mineral wool insulation	50 years

Table r windows.

New windows	R-value of glazing	Space heating use (MWh/year)	Final heat savings (MWh/year)	Investment Cost (000 £) (Total)
Reference (In-situ)	0.74	209.3	65.2	-
1.5 W/m²k	1.44	164.7	68.0	1.86
1.3 W/m²k	2.44	156.2	72.8	1.39
1.1 W/m²k	2.90	148.3	74.7	1.35
0.9 W/m²k	3.14	143.8	76.2	1.12
0.7 W/m²k	3.54	138.9	79.2	1.93

Table draft door types.

New door(s)	Thermal resistance (W/m²k)	Space heating use (MWh/year)	Final heat savings (MWh/year)	Investment Cost (000£) (Total)
Reference (In-situ)	0.65	230.8	63.5	-
1.5 W/m²k	1.44	164.7	67.0	1.086
1.3 W/m²k	2.44	158.4	68.6	1.139
1.1 W/m²k	2.90	155.3	69.8	1.435
0.9 W/m²k	3.14	149.8	72.3	1.612
0.7 W/m²k	3.54	147.4	73.0	1.943

Table d

thicknesses.

Additional Mineral fibre Insulation	Thermal resistance (W/m²k)	Space heating use (MWh/year)	Final heat savings (MWh/year)	Investment Cost (Total)
Reference (In-situ)	0.75	220	-	-
50mm	2.22	205	16.2	342.50
100mm	3.57	194	17.6	404.16
150mm	5.00	180	18.0	473.40

Table types.

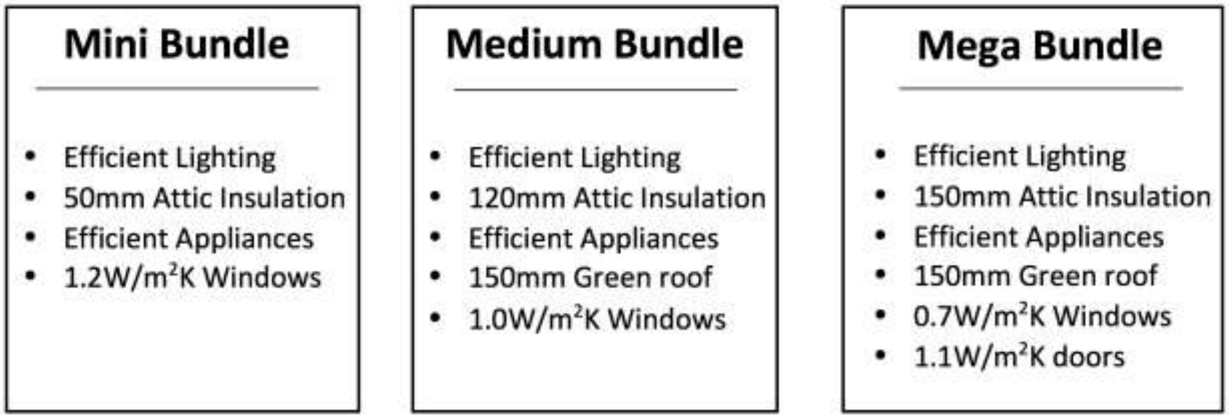
Green roof substrate thickness	Thermal resistance (W/m²k)	Space heating use (MWh/year)	Final heat savings (MWh/year)	Investment Cost (000£) (Total)
Reference (In-situ)				
50mm intensive	3.7	152.5	13.2	5.41
150mm	6.25	138.4	16.5	5.83
300mm	12.5	112.2	20.4	6.31

Table

External insulation	Household electricity use (MWh/year)	Electricity savings (MWh/year)	Increase space heat use (MWh/year)	Total investment cost (x 1000£)
Reference value:	88.7			
Major				
Refrigerator	57.9	8.0	0.9	0.68
Washer	58.5	1.4	0.2	0.45
Dishwasher	58.3	1.8	0.8	0.38
Oven/Hob	58.2	1.8	0.2	0.30
Lights	59.1	0.6	0.03	0.24

3.2. Energy retrofit bundles

The energy bundles comprising of individual retrofit measures such as Double-glazed windows, attic insulation, cavity wall insulation, efficient lighting, efficient doors, green roofs, cool roof, green spaces, basement insulation are grouped into three different packages named "Mini", "Medium" and "Mega" in this analysis based on the number and intensity of individual measures within the bundle and therefore capital cost implication.



Mini Bundle

- Efficient Lighting
- 50mm Attic Insulation
- Efficient Appliances
- 1.2W/m²K Windows

Medium Bundle

- Efficient Lighting
- 120mm Attic Insulation
- Efficient Appliances
- 150mm Green roof
- 1.0W/m²K Windows

Mega Bundle

- Efficient Lighting
- 150mm Attic Insulation
- Efficient Appliances
- 150mm Green roof
- 0.7W/m²K Windows
- 1.1W/m²K doors

Figure *-sizeddential*

3.3. Energy & Cost savings of energy retrofit bundles/ identification of most cost effective bundle

According to the results of the energy analysis on the case-study building, the most cost-effective package is the "Mini" bundle which includes energy efficient lighting and major appliances such as the oven, fridge, freezer coupled with 50mm attic/loft insulation and new windows with 1.2W/m^{2}K U-value; this combination led to total heat savings of 38.8kWh/m^2 and electricity savings of 14.0kWh/m^2. For the "Medium" package, the retrofit measures included are efficient home appliances and lighting, 120mm attic/loft insulation, new windows of 1.0W/m^{2}K U-value, green roof of 150mm substrate thickness. The total electricity savings for this scenario is 14.0kWh/m^2, while the heat demand reduction is 61.8kWh/m^2. For the final "Mega" bundle, the retrofit measures implemented include efficient appliances and lighting, 150mm attic insulation, new windows with overall thermal transmittance of 0.7W/m^{2}K and new draught proof doors of U-value 1.1 W/m^{2}K. The use of all these resulted in a total reduction in heat demand of 86.9kWh/m^2. Total electricity savings of 14.0kWh/m^2 is also recorded when this package is simulated. Use of 150mm mineral wool Insulative cladding leads to additional 16.4kWh/m^2 of heat savings but was found to be economically un-justifiable, costing up to £22,000 for a detached building. (Energy Saving Trust, 2017).

Table gs,

Bundle Name	**Bundle Contents**	**Heat Savings (kWh/m^2/year)**	**Electricity Savings (kWh/m^2/year)**	**Total Investment cost (000 £/m^2)**	**NPV of savings (£/m^2)**	**NPV/ investment cost.**
Mini	Efficient Lighting	-	3.5	1.95	20.4	10.5
	50mm Attic Insulation	6.0	-	0.50	13.2	26.4
	Efficient Appliances	-	10.5	2.1	16.8	8.00
	1.2W/m^{2}K Windows	32.8	-	7.8	58.3	7.47
	Total:	38.8	14.0	12.3	108.7	8.84
Medium	Efficient Lighting	-	3.5	1.95	17.4	8.9
	120mm Attic Insulation	7.8	-	0.70	18.3	26.1
	Efficient Appliances	-	10.5	2.1	43.8	20.8
	150mm Green roof	13.6	-	0.25	45.6	182.4
	1.0W/m^{2}K Windows	40.4	-	9.3	143.4	15.4
	Total:	61.8	14.0	14.3	268.5	18.77

Bundle Name	Bundle Contents	Heat Savings (kWh/m^2/year)	Electricity Savings (kWh/m^2/year)	Total Investment cost (000 £/m^2)	NPV of savings (£/m^2)	NPV/ investment cost.
Mega	Efficient Lighting	-	3.5	1.95	23.5	12.1
	150mm Attic Insulation	9.7	-	1.3	28.6	22.0
	Efficient Appliances	-	10.5	2.1	48.3	23.0
	150mm Green roof	13.6	-	0.25	56.6	226.4
	0.7W/m^{2}K Windows	48.2	-	12.3	161.4	13.1
	1.1W/m^{2}K doors	15.4	-	1.1	49.1	44.6
	Total:	86.9	14.0	19.0	367.5	19.3

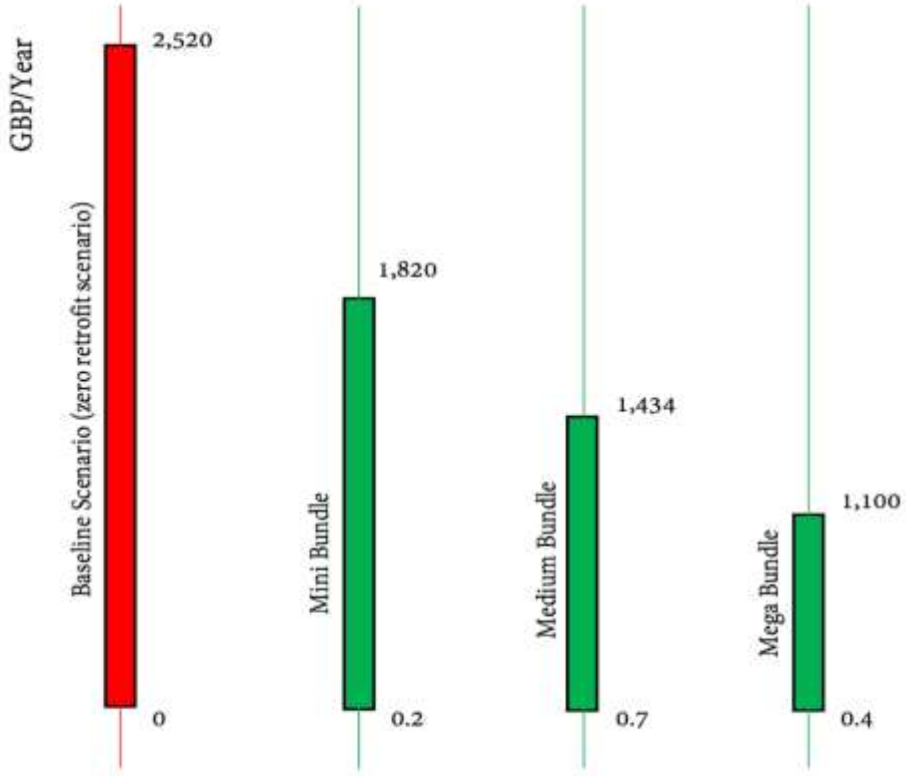


Figure: Energy Simulation Annual energy
retrofit

4.0. DISCUSSION

Based on the methodology developed by Dodoo et al., (2017), this study depicts the total as well as marginal modelling of cost effective building energy retrofit measures for a typical 4-bedroom detached residential building in England from the 1935 -1960 era. It is believed that this building presents an accurate representation of an example of the older building stock in the United Kingdom. The approach involves the simultaneous use of energy modelling in EnergyPlus as well as bottom-up economic calculations taking into account investment costs of the various energy retrofits with NPV calculation method. In a publication by the European Commission (2012); the suggested time period for the most accurate results for residential building is 30 years, however it is argued that most of the retrofits to the building fabric such as attic insulation, double glazing, etc. have the potential of lasting well beyond the remaining service life of the building. This investigation however considers the energy savings over the remaining service lifetime of the case-study building which is projected to be at least 50 years. The energy analysis in EnergyPlus show that there is greater heat demand reduction when the current single-glazed windows are replaced with high efficiency double glazing than when 50mm additional insulation is added to the attic floor. It is also observed that an upgrade of the low performance appliances and lighting within the building lead to significant amounts of final energy savings within the building – they also contribute to efficient space heating demand while at the same time consuming less electricity. Amongst all the building fabric upgrades, the addition of 150mm mineral insulation to the roof, double glazing with 0.7W/m^{2}K windows proved to be the most cost-effective ways to reduce consumption; these are followed by replacement of both doors of the building which although is not quite as expensive, leads to only a fractional amount of energy savings. Being a small building, the use of mechanical ventilation is impossible. The use of external insulation cladding is also not economically feasible due to the associated high capital cost. The green deal programme by the United Kingdom government (2012) has made the energy upgrade process significantly easier by providing homeowners and stakeholders access to finance for energy retrofits – most of the common upgrades such as insulation, new heaters, draught proofing, double glazing are permissible under the green deal.

The energy cost savings period for the homeowner or stakeholder is quickest under the “mega” energy retrofit bundle which consists of installation of efficient lighting, 150mm of attic insulation, efficient appliances, 150mm thick green roof, 0.7W/m^{2}K double glazed windows and 1.1W/m^{2}K doors which all have high initial cost but offer the advantage of reduced bills but over a longer payback period. The intermediate retrofit bundle is the “medium” energy bundle which offers payback period of approximately 30 years, leaving 20 years of energy savings without financial implication, and offers the stakeholder a better balance between reduced bills and short payback period. The least-expensive retrofit package is the “mini” package consisting of only four retrofit measures of which two have been proven to be highly effective in reducing losses. The NPV of total savings range from approximately £108 - £370 while the the total investment costs range from £3,900 - £14,000. The increase in energy prices (assumed to be 5%) over the years also has an impact on the energy and therefore cost savings achievable with timely energy retrofit measures. The framework developed in this study presents a somewhat complex however informed way of helping stakeholders or building owners make energy retrofit decisions by grouping the available retrofits into packages or bundles which would be suitable for their building type. This will then be analysed using energy simulation software such as EnergyPlus – which would determine a near-accurate value of projected energy and cost savings over the service life of the measures. The advantage of such a framework over conventional energy estimators is the added functionality of the possible increase in energy prices being taken into account.

5.0. CONCLUSION

During this investigation, a typical English building from the 1935-1965 era is used to model the cost-effectiveness of a number of energy retrofit measures both individually and in groups or bundles. The building is a four-bedroom residential dwelling completed in 1965; with generally good condition of most of its original fittings, it represents an ideal example of the UK's old building stock which must now be retrofitted to meet the higher energy efficiency standards of today whilst saving money on energy bills. Individual energy savings measures are grouped into three bundles based on their total initial cost and payback period and yearly energy savings – this potentially allows homeowners take better informed decisions for building energy renovation. Current manufacturers of building components tend to sell their products to un-informed consumers which may not lead to optimal savings in their particular building type. This investigation however shows that before energy retrofit projects are embarked upon, several factors need to be taken into account which include the building age, building type and functionality, occupancy information, existing thermal insulation information, orientation, sunlight infiltration information, etc. Future work has to be done in incorporating more dependent factors to ensure that the accuracy of results is increased; a more efficient software-based calculator can also be developed from this algorithm which takes the building age, retrofit budget, estimated remaining building lifetime etc. as the input and yielding/ranking the most effective energy retrofit measures as an output. On a city-level, this can aid faster reduction of building carbon footprint if adopted on large scale.

6.0. BIBLIOGRAPHY

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