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Cost and Carbon Effectiveness Analysis of Energy Renewable Option for Delivering Net Zero Housing in the UK †

Jamal Mohamed Alabid [1,*] and Husein Ali Adarawe [2]

[1] School of Architecture, Built environment & Creative Industries, University of Bradford, UK
[2] Department of Architecture and Urban Planning, University of Almergib, Libya; hadarwe@elmergin.edu.ly
* Correspondence: j.alabid@bradford.ac.uk
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Abstract: The UK government has legal binding objectives under the "climate change act 2008" to accomplish net zero carbon emissions by the year 2050. The government has implemented a variety of measures across many different sectors of the UK economy that are accountable for the emissions. The aim of this research is to evaluate and compare some existing renewable energy technologies. It discusses the advantages and disadvantages of installing these technologies into homes across the UK and the impact it has on contributing to the "net zero housing" scheme. A series of results produced using SAP rating deploying an existing dwelling case study in Bradford-UK fitted with a gas boiler, compared to an air source heat pump ASHP and a heat recovery mechanical ventilation system MVHR. The tree systems were analysed in terms of cost effectiveness, carbon footprint and energy savings. The study found that gas boiler costs less than any other system to install whilst ASHP involves high upfront costs. However, the later showed higher energy savings with an efficiency of 4.0 compared to 0.75 and 0.95 for gas boiler and MVHR respectively. SAP rating showed that ASHP has a carbon footprint of 2396.3 kg/year for the studied flat of 65.72m2, whilst 3406.92 CO2 kg/year for gas boiler and 7143.45 kg/yea for MVHR. The study concluded that ASHP works better for most of existing UK housing unless a whole building fabric improvement is considered, so some other renewable options could be a choice.

Keywords: renewable heating systems; carbon cost effectiveness; net zero carbon; UK housing

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1. Background

The UK government set a target that all new homes will be built to net zero standards by 2025, and for all existing homes to reach net zero by 2050. (Potton & Hinson, 2020). Currently, heating, and conditioning buildings counts for almost 40% of the UK's total energy consumption, whilst new regulation states that new homes emissions must be lower than 30% current rates to help the country move towards net zero carbon. UK government has introduced policies and initiatives to promote the delivery of net zero housing, this includes Green Home Grants (GHG) in 2020, the Energy Company Obligation (ECO) and Future Homes Standards FHS). The GHG launched in 2020 provides homeowners grants to upgrade their homes energy efficiency under eligibility terms and conditions. The ECO government funding programme, latest is ECO 4 scheme are incentives to help lowering energy bills and support the fuel poverty act (UK Energy Support,2023). These schemes are just a few of the practises to achieve net zero housing within the UK.

1.1. Air Source Heat Pump ASHP:

What is an air source heat pump, and how does it operate? EDF energy (2023) defined ASHP as a type of low-carbon heating technology uses the principles of thermodynamics to transfer heat energy from outside air into heat energy for conditioning a building even when outdoor temperatures are below freezing levels. ASHPs system utilises the building ambient air to extract thermal energy which can be used for both space and hot water heating. The thermal energy is gathered from outside to be absorbed into a loop through a refrigerant fluid (GreenMatch, 2023).

The system consists of three main components; the evaporator (outdoor unit), the refrigerant (a substance used to carry heat from one source and remove it to another), and the condenser (the indoor unit). The refrigerant shifts the heat as it flows between the outdoor and the indoor unit. The outdoor unit of an air source heat pump contains a fan, a compressor, a heat exchanger, and a refrigerant. The fan spins to draw air in from outside; this air contains thermal energy, so even at low temperatures the system will still be able to provide heat energy in the winter. The heat exchanger then takes the heat energy and transfers it to the refrigerant. The refrigerant is in a liquid form but once it is in contact with heat, it turns into a low-pressure gaseous state. The compressor compresses the refrigerant which in turn raises its temperature even further (DaikinEurope, 2023).

The Indoor unit contains a second heat exchanger; this exchanger takes the heated refrigerant from the outdoor unit and passes it over pipes surrounded by cooler water. The water is heated by this process and is then circulated through a network of pipes around the property to provide hot water and heating to rooms. It can also provide heat to under floor heating. The expansion valve opens and lowers the pressure of the refrigerant turning it into a liquid form and the cycle can begin all over again (Ltd & Robinson, 2023).

This system can extract thermal energy as low as -15 degrees Celsius providing heat and hot water all year round (Jackman, 2023). The only non-renewable energy the system uses is electricity. It is used to power and run the compressor, fan, and the circulating pump. However, this can be powered by a renewable energy source such as solar panels. In addition to providing heat, some air source heat pumps can also be used to cool down houses in the summer. This is done by reversing the flow of the refrigerant, in this case, the air source heat pump removes thermal energy from inside of the property and releases it outside. Ground source heat pumps are out of this research scope as retrofitting scheme funds are mostly supporting ASHP which considered to be suitable for most UK housing. However, according to Match-Green and other sources there two common types of ASHP found in the UK context and the main distinction between them is the way heat being distributed either via air or water.

1.1.1. Efficiency:

It has been reported by Josh Jackman at 'theecoexpets' that the "air source heat pump has an efficiency rate of 300%, there are more reports of higher ratings for the more expensive high-end pumps." The above statement shows that generally, for every unit of electric energy used by an air source heat pump, three units of energy are produced by the pump. To put this into an energy perspective, an average UK home uses just over 12,000 kWh per annum for heating, with an air source heat pump installed it can provide the same amount of heat for around the figure of 4,000 kWh. (Jackman, 2023). As a rough example, if electricity is priced at £0.14* per unit, the total yearly costs will be an estimate of £560.

1.1.2. Cost

As it stands there are around half a dozen major brands who are currently manufacturing air source heat pumps, for example, Samsung, Panasonic, Vaillant and Mitsubishi Electric. The prices vary from around £2,500 – £20,000 depending on the brand, size and model that is purchased. There are cheaper systems however they supply heat to only under-floor heating or the systems are completely different in being an air-to-air heat pump. However, this report is looking at heat pumps to replace existing boilers so the air source heat pump will heat radiators and supply heated water. (The heat pump warehouse, 2021).

The government officials are now offering grants of up to £5,000 to property owners who replace their gas central heating and hot water system with a heat pump. This research investigated two major companies who sell and install air source heat pumps and pricing will be used from both companies to create an average for a comparison against the heat recovery system. We have supplied information of the property that will be used in our case study to get an accurate pricing for these systems.

One of the company's is Daikin Airconditioning UK LTD, they provide indoor climate management solutions for industrial, commercial, and residential customers. They are a subsidiary company of Daikin Europe NV. The Daikin heat pump calculator has estimated a price for the specific property, We will be using during this report, to be a total of £10,970.00. this is for the Diakin Altherma 3 H HT High-Capacity Heat Pump (14-18 Class) Integrated Indoor (R32) This includes setting up the system, which is given at a cost of £1,950.00 plus material cost at £576.00. This system is powered by single phase electricity. This selected solution comes with an indoor standing unit and an outdoor unit.

This system will produce a heating capacity of 10.18 kW, this figure should compensate the property's heat loss to guarantee comfort in the worst weather conditions. This air source heat pump will generate 5674kWh/y, which has an annual heating energy demand of 100097.23 kWh and a SCOP (seasonal coefficient of performance) rating of 4.51.

By only using the heat pump, the outdoor unit delivers a leaving water temperature of 70 degrees Celsius at -15 degrees Celsius temperature. By -15 degrees Celsius, this outdoor unit limits heating capacity loss. It can also extract thermal energy at -28 degrees Celsius though. The standard operation mode produces a sound pressure of 38dBA at 3m distance away and on ultra-low sound mode produces 35 dBA at the same distance away. Also, this model is equipped with the R-32 refrigerant. This specific product reduces environmental footprint by 68% compared to the R-410A refrigerant. Using the R-32 directly leads to lower energy consumption due to its high energy efficiency and has a 30% lower refrigerant charge.

In addition, the Daikin Altherma 3 Heat pump's indoor unit comes with a built-in domestic hot water tank which can store up to 180L of water which is sufficient for hot water usage, showers and other domestic use including appliances. The indoor unit comes with all hydraulic components built in, meaning no third-party components are required. A benefit of using this system is that it does not require the homeowner to buy new radiators, the Diakin Altherma just connects to the radiators inlet and outlet pipes and works the same way a boiler would. Gas connection is not required for installing this system as mentioned it will produce heat using renewable energy and will use electricity to generate power required to the fan and pump (Daikin-Europe, 2023).

The outdoor unit is a smaller sized machine which is positioned on the outside of the dwelling, it can be either placed on the ground away from the building, on the ground against the wall or placed on the roof. The homeowner would have to take into consideration the material needed when fixating the outdoor unit outside. A pipe is installed between the two units and so the length of the pipe adds to the material cost.

The system also comes with a thermostat and the buyer has an option of choosing between the single room thermostat and a multi room thermostat. The single room thermostat is a master controller which manages the levels of the whole house from one of the rooms. The multi room thermostat is an optional extra and comes with a multi zone control, changing the climate zones of each room individually.

1.2. Heat Recovery System

1.2.1. What is a MV with Heat Recovery System and How does it work?

Mechanical ventilation heat recovery systems also known as heat recovery system, is a whole house ventilation system, it is designed to recover generated by various processes in a property.

The system consists of a heat recovery unit, a network of ducting which is placed in each room, supply air diffusers and an extract air grille. The heat recovery unit is typically positioned in an insulated loft or a utility room. Different rooms in the house create different amounts of heat, for example the kitchen and the bathroom are hotter rooms as they generate additional heat from cooking and showers. This is where the extractor ducts would be placed as well as a few other rooms.

The system works by continuously extracting the warm stale air through these extractor ducts and at the same time, through a separate duct, fresh air supply is drawn in and filtered from the outside air. The fan that draws fresh air from outside, filters it to clean the pollutant air and airborne allergens. The stale air is then expelled from the property. The heat is captured from the stale air and is passed over a heat exchange matrix, the matrix sits inside the heat recovery unit. The heat is then transferred to the incoming fresh air from the intake ducts. The warm, fresh air is then pumped through the ducting outlets around the house.

The transfer of heat is used to either pre-heat or pre-cool the drawn in air, depending on the season, this lowers the energy needed to condition the air to a comfortable warmth or coolness. This portrays that less energy is necessary to heat or chill the building, which can result in significant energy savings over time.

Heat recovery systems have become significantly popular over the last few years amongst new build houses. Airtightness is a key aspect in achieving thermally efficient houses. Airtightness stops cold from entering the home (in the form of draughts) and stops heat escaping from the house. Building regulations have been updated to improve airtightness and heat conservation within homes. The improved airtightness within newer homes, leads to homeowners opting to buy a heat recovery system as these newer homes lead to stuffy rooms and the heat recovery system can prevent this by pumping fresh filtered air into them. To install such a system the house needs to be airtight, as mentioned above, any poor insulation or leaks in the house will result in heat loss. (BPC ventilation: Heat Recovery Systems: Home ventilation system 2022).

1.2.2. Cost

The price for a heat recovery system varies on the property size, the size of the unit required, the amount of ducting required, installation and the commissioning costs. On average, a basic heat recovery system can cost around £3,000 to £5,000 for a small residential property. However, larger properties or those with more complex layouts may require more advanced systems that can cost upwards of £10,000. Rega Ventilation, a company manufacturing heat recovery system for 40 years, has two variations of the heat recovery systems main unit. The heat recovery unit comes as either being a wall mounted unit or a loft mounted unit. Depending on the size of dwellings and space available the homeowners can choose between the two. Both wall mounts have an airflow capacity up to 130 litres per second, with a single unit able to service 350m2 floor area and come with various fan powers as low as w/l/s. the heat recovery unit comes with two types of duct systems: branched and radial as well as three types of vents supplied from Rega Ventilation a roof terminal, wall mounted grilles and internal vents (Rega, 2018).

The typical cost based on the Mitsubishi range of units in the UK ranges from £2690.17 - £4,823.60. An average home of floor area size 150m2 including, a kitchen, bathroom, utility, W.C. and ensuite, 3-bedroom, living room and dining room will cost around £3,092.45 excluding installation cost and any home improvements that are needed to install the system.

2. Research Rational

The originality of this research is the application and data collected represents real case study. All SAP input data has been carefully selected and accurately inserted so that simulation reports reflect reliable outcomes which are compared to actual data. Heating systems are all selected and sized based on the actual building details to obtain realistic estimation as systems' providers are all based in the UK. The essence of this study is to provide homeowners with important details and information when it comes to renewable heating systems choices in the UK. Moreover, it makes homeowners aware of other parameters like carbon cost effectiveness of systems rather than solely comparing pricing as community became an important element in achieving Net Zero Carbon.

3. Research Methodology

This article discusses the viability of some options of energy heating systems considered by ECO 4 scheme as renewable systems in terms of its carbon cost effectiveness compared to conventional gas heating system. A detached bungalow house in 24 Abbey Lea Allerton Bradford city owned by a friend. However, the house has recently converted into two-storey detached house with all plans and details provided later in this article. The main method used to study the carbon cost effectiveness of this property is the use of SAP (standard assessment procedure) to generate a series of reports comparing the three scenarios (gas boiler, air source heat pump and MVHR system). In addition, SAP outputs will be compared with current EPC of the house and actual energy bills.

4. The Building Model and Simulation

4.1. The case study

The property chosen for this study is a detached two-storey house which was originally detached bungalow house located in Allerton, Bradford. The property is a bricked house with a cavity wall of 100mm gap, filled with polystyrene beads (Thermabead insulation) and has an ACC block (Autoclaved Aerated Concrete) on the inner side of the wall. The roof is a pitched roof and has 270mm of insulation sat in the loft. All internal walls are insulated with sound insulation and layered with plywood, which is sat on the timber frame, with a plasterboard and a coat of plaster on top of this. All works are compliant with the specific building regulations.

The main heating source is a combi boiler controlled with a programmer, a room thermostat and TRVs. The hot water is supplied through the main heating source and the floor is suspended with 220mm earth wool insulation placed in between the joists. All windows are double glazed with a 12mm air gap between the glass.

Error! Reference source not found. below shows the makeup of the house:

Table 1. shows the construction details of 24 Abbey Lea.

Element	Material	Construction makeup	Insulation	Area in m^2
Walls	Brick. Cavity wall-100mm. ACC Block.	Brickwork outer leaf (102.5m). Cavity wall filled with Polystyrene beads (100mm). Concrete ACC block (100mm). Plasterboard dot on dab. Plaster.	Thermabead insulation in cavity wall.	2 x 45.4526 2 x 30.848
Roof	Pitched – plaster board insulated at flat ceiling level.	concrete tiles. wooden hardwood timber joists. Roof space. Insulation roll. Timber frame. Softwood/plywood chipboard.	300mm insulation roll (earth wool).	65.72

		Plasterboard. Plaster.		
Floor	Suspended timber floor on both ground floor & first floor.	Unheated space/void Hardwood timber joists Insulation between joists Softwood chipboard carpet	Insulation rolls of 220mm.	65.72.
Window s	PVC-U doubled glazed.	Window fixings Expanding foam Window sealant (outside) PVC trim	12mm air gap.	Combined window area is 14.0922.

4.2. SAP modelling; Findings and Discussion

Error! Reference source not found., shows the new plans for the converted two storey house in 24 Abbey Lea as a full new floor extension added on top. The calculated energy requirements of a dwelling are converted into a primary energy demand figures by the SAP application using primary energy factors. This will contribute to the final SAP rating and all emissions produced in the SAP Worksheet. The SAP report has given a figure of the total fabric heat loss for this property to be 154.81 W/K.

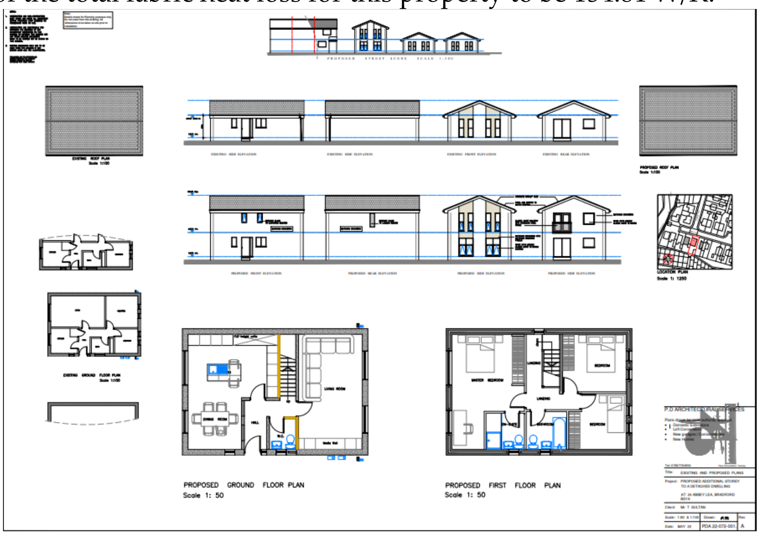

Figure 1. Previous and new design drawing plans for 24 Abbey Lea.

Three different set of scenarios were created by inputting data into SAP of the two-storey house. The first scenario is simulating the house as it is with a standard condensing combi boiler as the primary heat source. The measurements of the house as well as any construction and structural elements are maintained the same for all scenarios. Therefore, first scenario data is used as a datum for the other two. Air source heat pump ASHP has replaced the combi boiler for the second report, whilst Heat Recovery System MVHR unit was selected for the third scenario.

All non-renewable sources of energy are becoming more finite. Consequently, this has an impact on the energy prices and is currently putting the UK in an energy crisis. This might have an impact on the SAP ratings as well. The SAP report has by default set the efficiency of the three individual main heating system at an average rate. It estimates that a standard condensing combi boiler system with radiators to be 89.0% efficient, whilst the ASHP system with radiators to be 170% efficient, and the heat recovery ventilation system at 100% efficient.

4.2.1. Mains gas heating source report

It can be understood from the SAP worksheet for the mains gas heating source, it is shown to produce a total of 3406.92 CO_2 kg/year is generated which is a CO_2 emission of 28.23 per m^2. The contributing factors are: (these factors are all included in SAP worksheet reports)

- Space heating (main system and secondary)
- Water heating
- Electricity for lighting
- Electricity for pumps, fans, and electric keep hot.

The report has given this particular dwelling a SAP rating of 73.56 for this individual heating system. The dwelling with this heating source has a predicted EPC of 74, which is a low C. This is an accurate rating as the dwelling has been constructed to achieve this band.

4.2.2. Air source heating pump report

The SAP rating given for the ASHP is 78.47, this rating is calculated by the CO_2 emissions produced by the system. The total CO_2 emissions produced is 2396.3 kg/year and the CO_2 emissions per m^2 is 19.85. This shows approximately 30% reduction in operating carbon emissions compared to the mains gas boiler system. However, this doesn't mean the whole system is more cost-carbon effective without understanding all carbon emissions associated over the lifespan of the system including production and maintenance.

The air source heating pumps simulation has shown to be very efficient as most results are calculated to have a higher CO_2 emission. This shows that the dwelling chosen, has been built to a high standard. However, the air source heat pump is widely accepted to be an efficient in providing thermal energy for space heating. The predicted EPC has come back with a score of 78, this is a band C on the scale. It shows that the air source heat pump despite running on electricity only, is a good choice in its thermal efficiency.

4.2.4. Heat recovery ventilation system report

The SAP worksheet report has calculated and given a figure of the total CO_2 emissions to be 7143.45 kg/year and the total CO_2 emissions per m^2 to be 59.18. The SAP rating for this system is 36.79, this is relatively low compared to the other two heating systems. Although this system is deemed to be very efficient and uses renewable energy, the SAP programme considers the electricity that will be used to run this renewable source.

The carbon footprint that will be calculated, will be reviewed as electricity rather than gas, which is much worse than gas, leading to a lower rating and an alleged higher carbon footprint if the system is not fed by solar panels PV.

The SAP programme has calculated these figures and has considered that the electric is more expensive than gas. The factor to also consider is the loss of electricity from where it travels, and the primary energy calculation done to work out the CO_2 emissions. To put into perspective the primary energy factor is 1.22 for gas and is 3.07 for electric, this more than 2x bigger, hence the lower rating for this system. Depending on where the electricity is supplied from the SAP calculation estimates how the electricity is produced and the conversion process it has undertaken to be created into electric energy.

SAP processes all these factors and creates a rating based on this, hence a low rating. The EPC for the dwelling with a heat recovery system installed is 38 a low E/high F. This was predictable as the system relies on electric energy. The hot water system is powered by an electric immersion heater, this will also contribute towards a lower rating.

5. Conclusion

In conclusion, both energy technologies (air source heat pump and heat recovery system) are efficient systems in producing heat generated by renewable sources. However, the air source heat pump is a better option to help with delivering to the net zero housing scheme. The air source heat pump has a higher efficiency output as wellbeing simple to install, the existing boilers of dwellings around the UK can easily be replaced with this system and unlike the heat recovery system, it can provide both heating to the property as well as hot water around the house. It can also be installed into properties that don't have any mains gas. The heat supplied from this system can be transferred to radiators and underfloor heating. The air source heat pump can be paired with PV panels to create a net zero carbon home, this is the most effective way to reach the target set by the UK government in reaching the net zero target by 2050. The £5000 government incentive is a good reason to opt for this system and will spur homeowners to install it, as well as cutting back on energy bills. Since we are in an energy crisis, it will motivate homeowners into installing these systems.

The study believes the heat recovery systems will be more efficient to install into commercial buildings, as it can be installed during the construction phase and is a better alternative to commercial boilers, as well as reducing the CO_2 emissions for the infrastructure. The heat recovery system can be made to run off PV panels which would create a carbon neutral heating system; however, the downfall of the heat recovery system is installing it into an existing dwelling, the dwelling would need to have all partitions exposed to install the ducting for the system and would result in the homeowner paying extra money towards the overall cost of the heat recovery ventilation system.

We would propose to the UK government to target all existing dwellings to be installed with an air source heat pump and all new builds to be fitted in with a heat recovery system. In doing so the target to reach net zero housing will be achieved at a quicker rate.

Both systems have their downfalls but for reducing bills and creating lower carbon emissions, they do the job. It depends on the property type and the amount of money; the homeowner is willing to spend and their energy improvement targets. In general, the air source heat pump will be the best solution for delivering the net zero housing in the UK. The study has limitation on including more energy heating systems due to time and budget, and it recommends comparing simulation results to actual performance of each system with longer monitoring period. Further study on Ground source Heat Pumps and Combined Heat and Power systems might be useful to draw a wider conclusion and recommendations.

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