European Union
European Regional Development Fund

MIDLANDS ENGINE

European Regional Development Fund
2014-2020 Programme

Intervention Report

Guidance notes for completion

This Report Form is to be completed by Advisors as authorised by the **EnTRESS 2** project.

After completion, the fully signed **ORIGINAL** should be sent to the **EnTRESS 2**project office for retention as EU evidence.

EnTRESS
University of Wolverhampton
ML024 City Campus Molineux
Wolverhampton
WV1 1LY

Reference Number	**EnTRESS2/**	**029**	**Name of Beneficiary**	Solution by Jigsaw Ltd
			Report Date	01/11/2021

Section 1: Agreed Scope of Support to be provided

Solution by Jigsaw Ltd is developing a whole service approach for decarbonisation of heating. Their process includes the installation of solar, battery, insulation, infrared heaters, smart hot water, and smart control systems. The basis of their infrared system, manufactured in the Black Country, uses aluminium/glass panels and a smart control system that can be controlled by air temperature and/or motion in the room.

EnTRESS 2 agreed to support the company with developing a simulation model of a newly-built, typical social home where their selected infrared heating panels, either their aluminium or glass range was in use. The Building performance simulation results were calculated using Design Builder software tool, a widely used energy modelling tool within the built environment sector. Simulation outputs help to investigate the product performance in comparison with the traditional heating method (gas boiler) and with selected electric heating technology (heat pump). A report will be generated which sets out the findings, includes detailed information, and the simulation model will be provided to the company for future development. The application PV and/or coupled with battery systems to reduce grid import will also be developed.

The project will be carried out in a timely manner with an expected duration of between two and three days of support. All work & report generation should be completed within two months of the project initiation date unless unforeseen circumstances occur.

Section 2: Actual Support provided

In 2025, gas boilers will be replaced by renewable heating systems in all new-build homes. This is part of a government effort to achieve net-zero CO2 emissions by 2050.

EnTRESS 2 undertake the following activities:

- Developing the building simulation of a newly built two-bedroom house. Occupancy: 2 working adults and 1 child that means the dwelling is not occupied during 7:30 – 17:30 during weekdays.
- HVAC: gas central heating as the base case (1), Solution by Jigsaw infrared heating pannels for all rooms in the building to provide heating demand (2), and smart hot water also simulated to provide energy data for both space and water heating for comparison between various scenarios.
- HVAC: Modelling air to water heat pump heating system (3) as an alternative solution to gas central heating.
- Comparing energy and cost efficiency amongst the three aforementioned heating systems.
- Further investigating the energy performance of the infrared heaters for integrated PV-battery system in dwelling working towards decarbonisation of domestic sector.

Section 3: Findings/Recommendations

1. Background context

The built environment accounts for nearly 40% of UK greenhouse gas emissions, of which around 14% emissions coming from the 28 million homes (Climate Change Committee, 2021). In order to bring these levels down, the Future Homes Standard, coming into effect from 2025, ensure homes produce 75-80% less carbon emissions compared with current levels and become net zero as the electricity grid continues to decarbonise rather than requiring fitting additional measures/ technologies. 95% of UK homes utilise central heating using fossil fuels, either gas or oil boilers, which are responsible for 58.5 million tons of carbon emissions per annum. It is seen as the biggest challenge to decarbonise heat to meet the net zero target. As part of the Future Homes Standards, no new homes will be connected to gas network from 2025. Instead, they will be built with high level of energy efficient insulation coupled with low carbon heating sources. An interim uplift in building standards, expected to be published by end of 2021, requires new homes to produce 31% less carbon dioxide emissions compared to current levels.

U-Values measure how effective a home's fabric is at preventing heat from transmitting between the inside and outside of the home. The lower the U-value the better, as this means heat is less able to quickly transmit through your home. The proposed new levels of thermal performance published in the government's response to the Future Homes Standard consultation are:

Table 1: Minimum requirement of thermal performance for building components

Thermal Element	Minimum Standard U-Value – W/m^2K
Wall	0.18
Roof	0.13
Floor	0.13
Windows	1.4
Doors	1.0
Air Permeability	5.0 $m^3/(h.m^2)$

1.1. Infrared heating technology

The real innovation in infrared heating technology lies in the energy-efficient way in which it heats a room. The radiation is the substantial mechanism in the heat transferred from the warm surface of the floor to humans/objects within the space and the other surfaces of the building enclosure using an infrared heating system. In contrast to convective heating that warms the air first and heats also lost through draughts, infrared heating provides a pleasant environment with constant humidity and minimal convection currents. Another bonus to infrared heating is how quickly the room is heated up. Gas central heating can often take around 30 minutes before occupants can start to feel the warmth as it heats the air within the space. Infrared heating heats objects, not the air, meaning that the warmth can be felt much quicker, normally less than 10 minutes. Such a feature works well in the application for lightweight construction using the Modern Method of Construction, such as SIPs, ICF, CLT systems. This means that the heating will be on for less time than the gas central heating. On another hand, air source heat pumps also have a lower output than the gas boiler and IR floor heating. This means they cannot deliver heat as quickly as the infrared heating system. Instead, they're best used to heat the house slowly over a longer period.

1.2. Product information

Solution by Jigsaw is a family owned business, offering the full service from the design, manufacturing, and installing infrared heating technologies in domestic and commercial properties.

IR heaters are frameless, with simple, elegant lines enhancing the quality. Their aluminium range uses robust aluminium to create a substantial heater which retains a light weight. These can be either ceiling or wall mounted using the company's simple and elegant mounting system. Certified in the UK to the following standards: EN 60335-1:2012 / EN60335-2-30 (Safety of Electrical Appliances), EN55014 1 + 2 / EN61003-2 / EN61003-3 (EMC), EN62233-2008 (EMF), EN60529-1992 + A2 (IP44 rating), 2011/66/EU RoHS, and CE Certified.

a) JIGSAW ECO Aluminium Heater

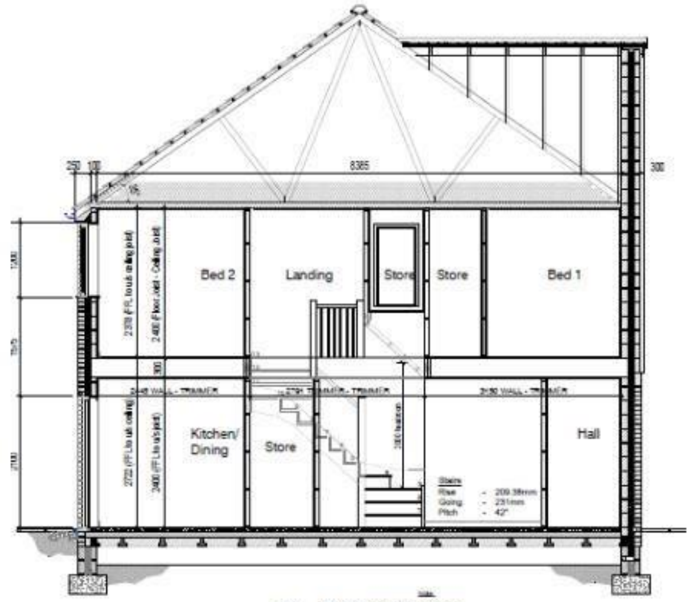
b) Glass and Mirror Heater

c) Wired / Wireless thermostat control hub with control app

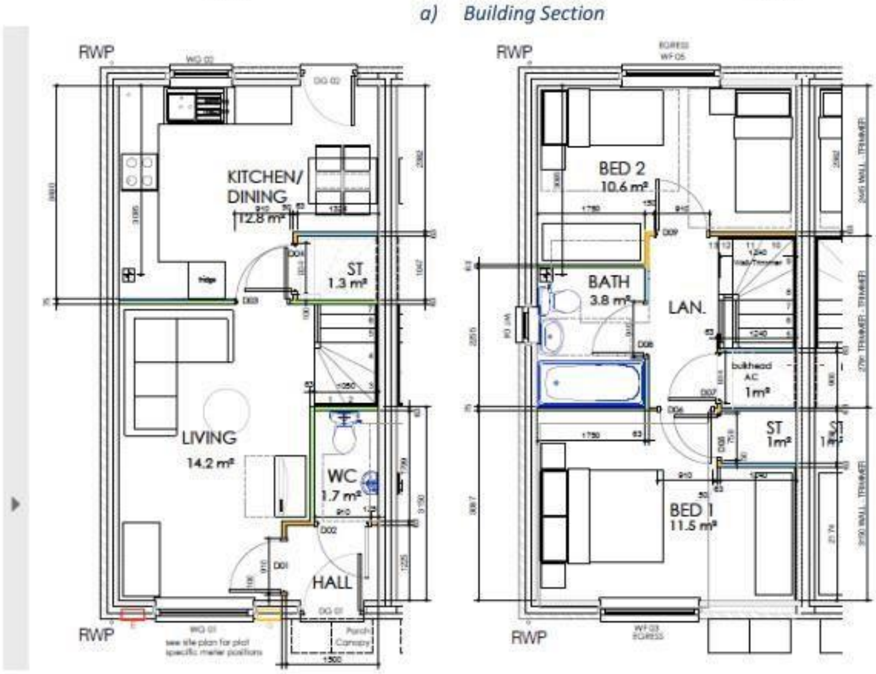
Figure 1: Infrared heating panel products by Solution by Jigsaw Ltd

2. Building information and simulated model development

A two bedroom semi-detached house was selected and used for the simulation. The building was recently built and managed by a local housing association for council tenants. Figure 2 includes the front section and floor plan of the dwelling.



a) Building Section



b) Floor plan

Figure 2: Building section and plan

2.1. Building information

The table below includes the thermal properties of building components used in the building simulation. Detailed building materials and thermal properties of building components can be found in the report. U-value of selected dwelling meets the minimum U-value standards for Future Home Standards as discussed in Section 1.

Table 2: Thermal properties and areas of building elements of the simulated dwelling

U-values of opaque elements:

BR 2006/2010 Pitched Roof	0.096 W/m^{2}K
BR 2006/2010 Ground Floor	0.145 W/m^{2}K
BR 2006/2010 Cavity Wall	0.225 W/m^{2}K
Internal Timber Floor	0.847 W/m^{2}K
Internal Solid Wall	0.250 W/m^{2}K
Door	0.810 W/m^{2}K

Properties of glazing elements:

U-value	1.25 W/m^{2}K
Solar transmittance	0.76
Light transmittance	0.80

Areas of building elements (Total) as below:

Floor area	69.82 m^2
Envelope area	372 m^2
Window (Glazing)	6.8 m^2
External doors	3.6 m^2

<u>Air tightness test result:</u>

The building had undergone several airtightness tests, the air permeability results averaged at 4.16 m^3/m^{2}h at 50 Pascal test conditions. Taking into account the building's overall dimensions, it is equivalent to 4.56 air changes per hour at 50 Pa.

In order to produce an Energy Performance Certificate (EPC) of a sale/ rental residential building, Standard Assessment Procedure (SAP) calculation is used to show energy efficiency compliance for new-build dwellings and is required as part of Part L Building Regulations. The building's EPC information is shown in Figure 3, at level B energy efficient rating.

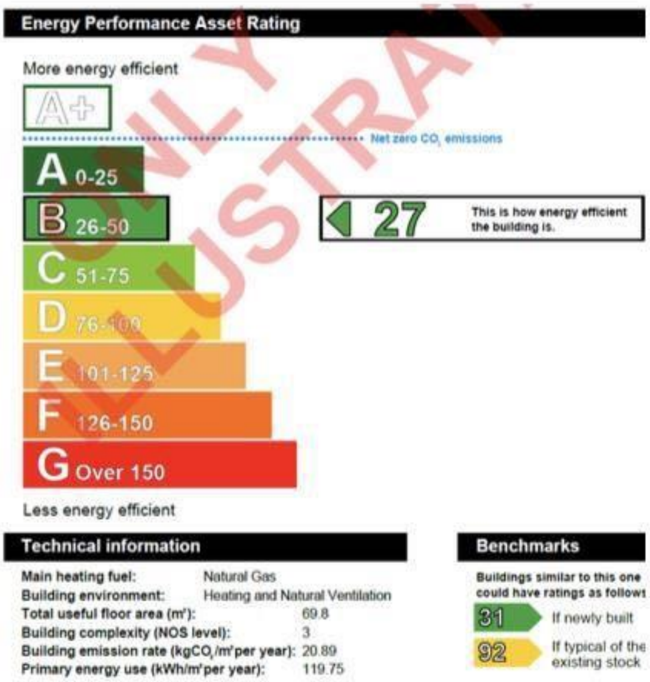


Figure 3: Modelled building's SAP information

2.2. Selected IR panel for simulation

Aluminium infrared heater panels were used for the modelling.

<u>In-situ performance of IR heating panel:</u>

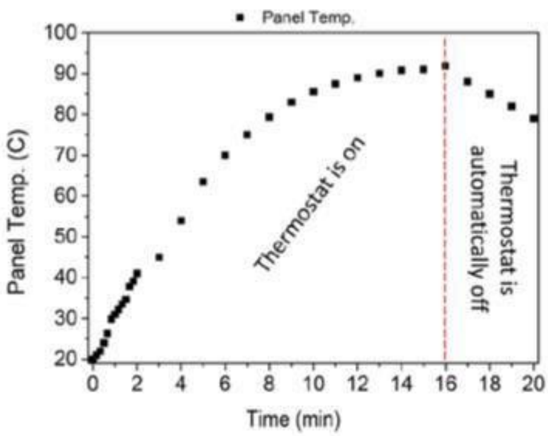
Intervention Report

Solution by Jigsaw Ltd also worked with the ETICC project at Aston University on a field experimental study of in-situ measurement of the IR heating panels in an 8m^2 room in comparison with two heating systems (2kW Kingfisher and Dimplex storage and convection heaters).

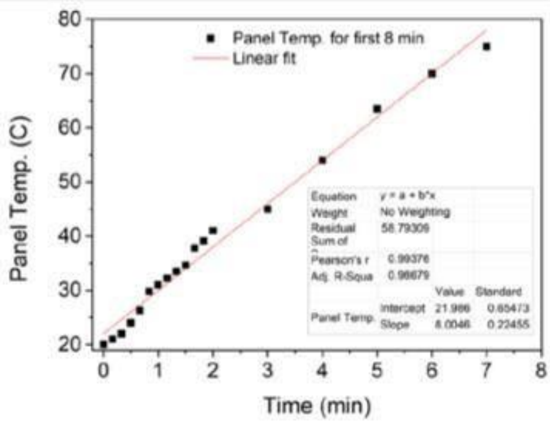
a) Aluminium infrared heating panel

Voltage: 230 Volt, 50 Hz
Wattage: 400W, 800W, 1200W
Protection: IP 44
Installation: Ceiling or wall mounting.
Connection: 1.8m of 3 core flex
Wattage (W) Weight Size (mm) Amps
400W range 4.3 kg 595 x 595 x 10* 1.7
800W range: 8.3 kg 595 x 1195 x 10* 3.48
1200W range: 10.5 kg 595 x 1595 x 10 * 5.2

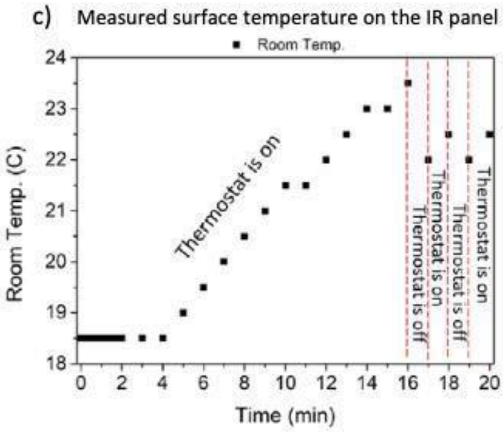
b) Product information



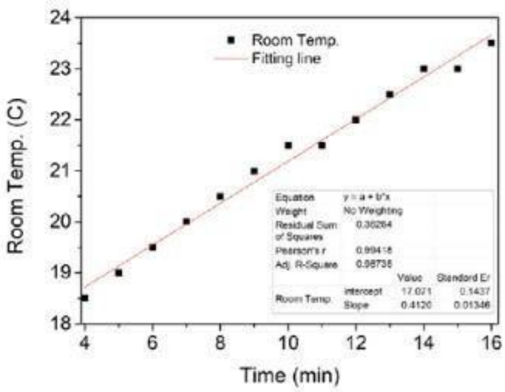
c) Measured surface temperature on the IR panel



d) Slope efficiency calculation (first 8 minutes)



e) Measured test room temperature



f) Slope efficiency calculation (first 8 minutes)

Figure 4: Aluminium infrared heating panel – Solution by Jigsaw Ltd

2.3. Simulation model development

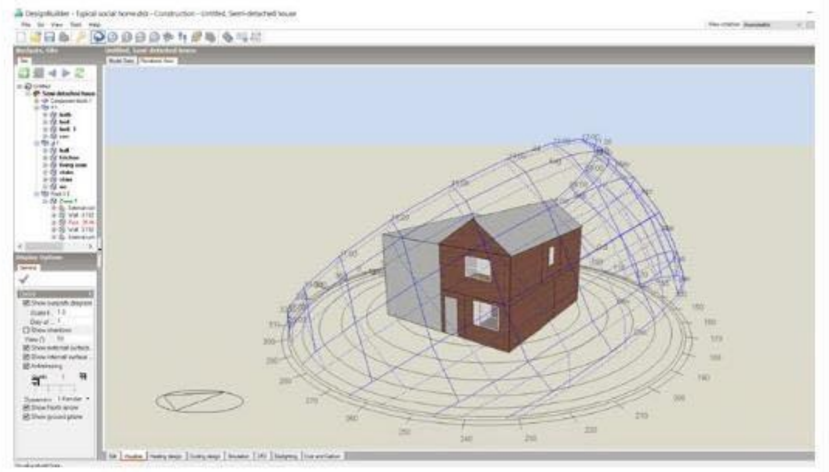


Figure 5: The 2 bedroom semi-detached simulation developed in Design Builder platform.

The Design Builder building simulation tool was selected for its wide application within the built environment sector. The scope of the project is to assess the energy consumption for heating, therefore it is assumed that all windows remained closed (no natural ventilation during the warm period) and there was infiltration occurring.

Occupancy profile: NCM Residential spaces (dwelling) profiles were selected per zone accordingly.

Weather file: The Birmingham weather file and site was used in the simulation.

Infiltration

The air infiltration rate for rooms in this dwelling on normally exposed sites in winter is calculated using an empirical value of air change rate divisor for the two-storey building (Table 4.24 CIBSE guide A, 2020). The 1/17 value was selected as the air change rate divisor for this dwelling. The building's airtightness level under test condition of 50 Pascal pressure difference was 4.56 ac/h. The infiltration rate of the dwelling was simulated on the continuous mode: 1/17*4.56 = 0.27 ac/h.

Mechanical Ventilation:

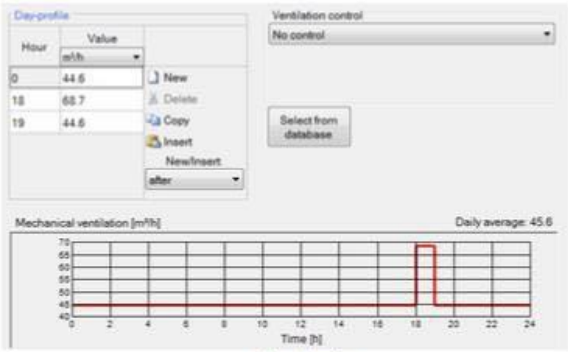
The Building Regulations (Document F) are designed to remove steam and smells at source before they can migrate causing damage to colder parts of the dwelling.

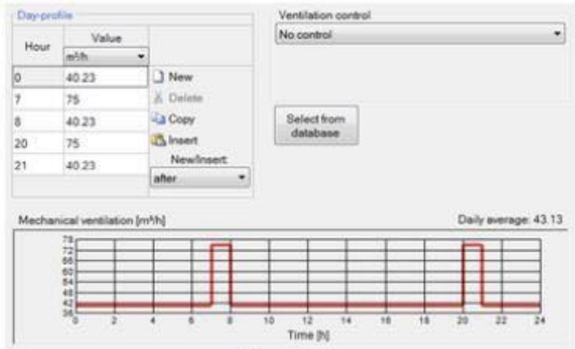
There are two extractor fans in the dwelling. One is located in the kitchen on the ground floor and one is located in the bathroom on the first floor. The mechanical ventilation system is in use in continuous mode and boost mode when being occupied.

Table 3: Mechanical ventilation rate for wet rooms

Room	Flow rate (m^3/h)	Flow rate with boost (m^3/h)
Kitchen	44.6	68.7
Bathroom	40.23	75

Such information was inputted into the mechanical ventilation profiles for the model:

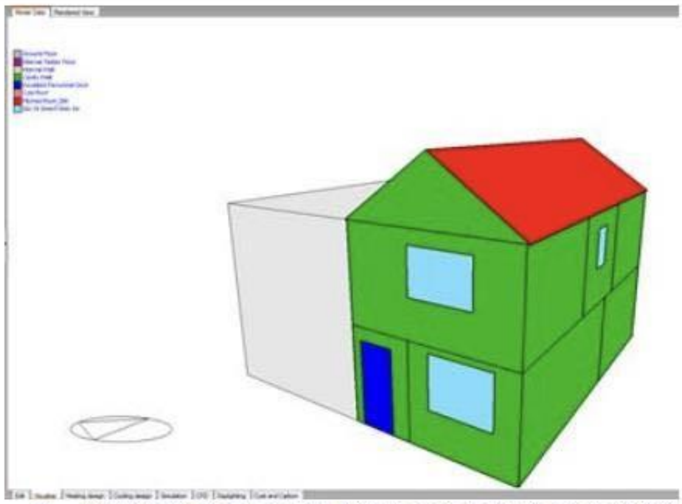




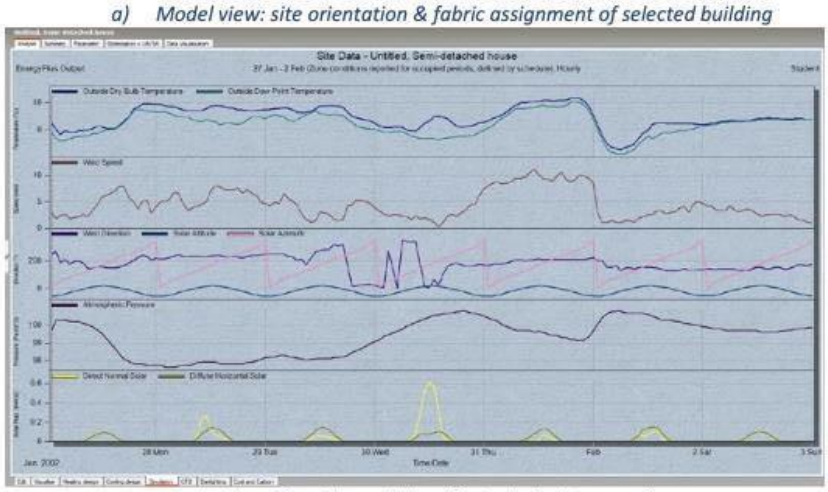
a) Kitchen *b) Bathroom*

Figure 6: The occupancy profile developed for the kitchen and bathroom

Figure 6 illustrates fabric assignment on the model and building orientation.



a) Model view: site orientation & fabric assignment of selected building



c) Climatic condition of a typical winter week.

Figure 7: Simulation inputs

Domestic Hot Water (DHW): Hot water consumption is normally a significant proportion of domestic energy consumption. The average hot water energy consumption of UK homes is approximately 4 kWh per day (based on 2.4 occupants; approx. 80 litres of hot water at 55°C)[1]. This average is based on field trial data obtained by the Energy Saving Trust but varies significantly between homes.

2.4. Simulation scenarios:

2.4.1 Scenario 1: Natural gas boiler central heating:

The building uses a modern condensing boiler (i.e. Worcester 30i model, to heat water, which is then pumped around the property through pipes and radiators to heat the space, and either pumped directly to taps and showers. The system is very energy efficient for its range.

Heating, ventilation, and air conditioning systems	
Name	Worcester Greenstar 30i ErP
Type	Central heating using water: radiators
Heat source	LTHW boiler
Heating fuel type	Natural Gas
Heating seasonal efficiency	0.896
Uses CHP	NO
Variable speed pumping type	-
Generator radiant efficiency	-
Cooling generator type	-
Cooling fuel type	-
Cooling seasonal energy efficiency ratio	-
Cooling nominal energy efficiency ratio	-
Mixed-mode cooling operation	-
Heat recovery system	-
Heat recovery seasonal efficiency	-
Variable heat recovery efficiency	-
Specific fan power [W/(l/s)]	-
Submetering and M&T for this system	NO
Heating - Central time control	YES
Heating - Optimum stop/start control	NO
Heating - Local time control	NO
Heating - Local temperature control	YES
Heating - Weather compensation control	NO

Figure 8: Simulation inputs for gas boiler

2.4.2 Scenario 2: Jigsaw's infrared heating panels

Steady-state heating load calculation was conducted to provide the zone sensible heating. For the heating calculation, the outdoor air temperature was set at -5°C, with set air temperature for the ground floor living area

[1] https://www.bre.co.uk/filelibrary/SAP/2012/STP09-DHW01_Analysis_of_EST_DHW_data.pdf

at 21°C and First Floor with 2 bedrooms, hall, and bathroom at 18°C. The aluminium range for infrared heating panels' available capacities are of 400w, 800w, 1200w. (Note: Ground floor: GF vs First Floor: FF).

Table 4: Thermal zoning and infrared heating panels

Room Height: 2.4 metres	Floor area, m^2	Volume, m^3	Estimated heating load, W	Select infrared heating panel by Solution by Jigsaw Ltd
Entrance hall (GF)	2.05	4.92	185	1 panel 400W
WC (GF)	1.97	4.728	82	1 panel 400W
Living room (GF)	14.39	34.54	788	1 panel 800W
Kitchen (GF)	13.13	31.52	708	1 panel 800 W
Stair + under stair cupboard	3.41	8.18	74+52 = 126	1 panel 400W
Main bedroom (FF)	13.17	31.61	566	1 panel 800W
Bedroom 2 (FF)	10.93	26.23	501	1 panel 800 W
Bath (FF)	3.84	9.22	125	1 panel 400W
Hallway (FF)	7.01	16.82	171	1 panel 400W

Based on heating demand per thermal zone, only one panel is required per thermal zone. For the simulation, the infrared heating panels were modelled to be at the centre of the ceiling level.

DHW: A standalone water tank connected to an electric boiler was simulated. Mixergy water tank is a stainless steel cylinder designed to optimise energy consumption by only heating the water when needed, and enabling control over water usage using smart apps. It might be useful to note that the Mixergy tank can be connected with a range of energy sources: Gas boiler, electric, solar PV, solar thermal, or even heat pumps.

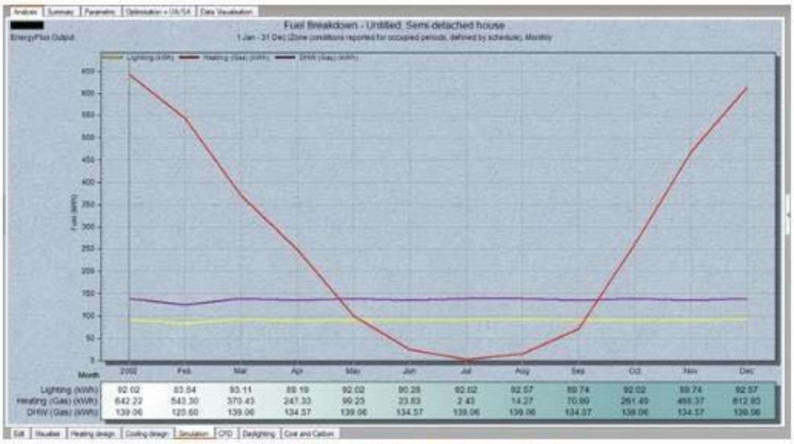
2.4.3 Scenario 3: Heat Pump

Heat pumps are an effective and energy efficient way to create hot water to heat your home. They work by absorbing heat from a source and transferring it to a liquid, which is compressed to increase the temperature further. The heat is transferred from the liquid into water which is used to provide heating for a property, either through wall radiators or underfloor heating. Unlike a traditional electric radiator that turns that 1kWh into one unit of useful heat, a heat pump can theoretically convert 1kWh into 3.5kW or more units of useful heat, therefore it can be an efficient way to heat the home from the energy perspective (energy efficiency ratio is 3.5 in this case)

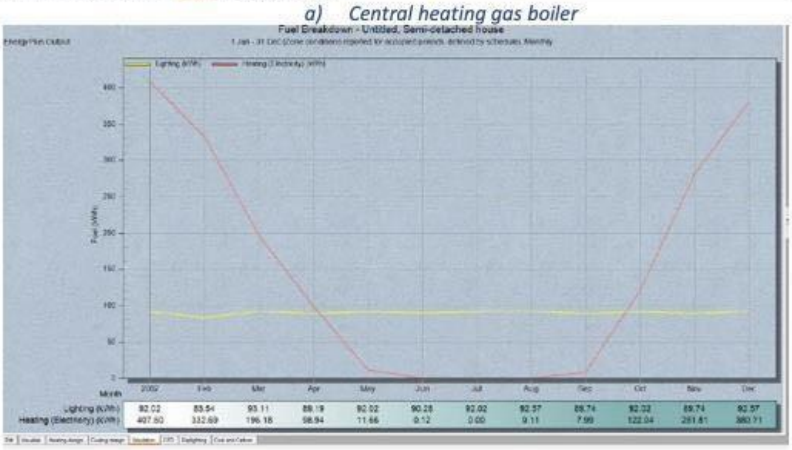
Air Source Heat Pump (ASHP) was used for the simulation as part of the comparison. The air-to-water heat pumps where heat from the air generates heat for water, which is then pushed around traditional heating systems like radiators and/or underfloor heating. There have been several studies suggesting that the seasonal energy efficiency ratio of ASHP, in moderate to cold climate is measured at the averaged 2 across the year which means 1kWh of electricity power can generate 2kWh of useful heat. As the heating demand of the selected building is not great, only wall radiators were simulated for overall system cost efficiency.

3. Simulation results

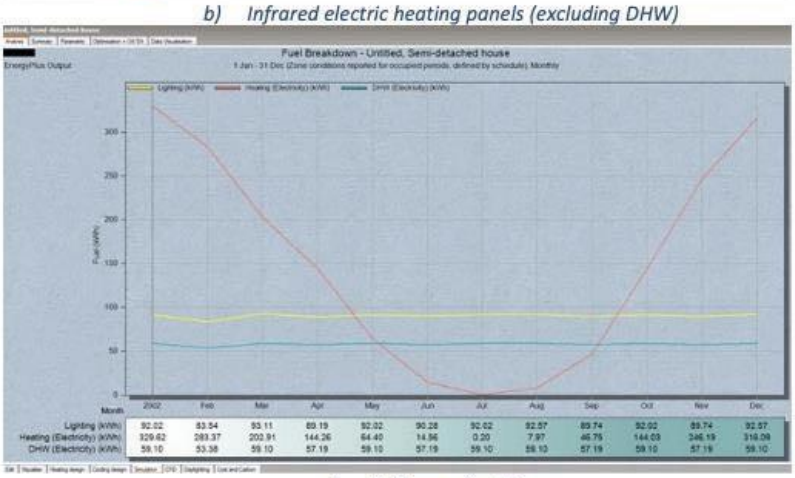
3.1. Comparison of energy demand



a) Central heating gas boiler



b) Infrared electric heating panels (excluding DHW)



c) Air Source Heat Pump

Figure 9: Comparing monthly energy usage amongst three systems on the simulation outputs

Lighting energy figures remained the same in 3 scenarios as the simulation results only compare 3 heating technologies hence space heating and water heating data might differ.

For a standalone electric DHW (emersion heater) used for IR heating panels as the solution of electrifying heating in domestic buildings, it requires 1,546 kWh for water heating.

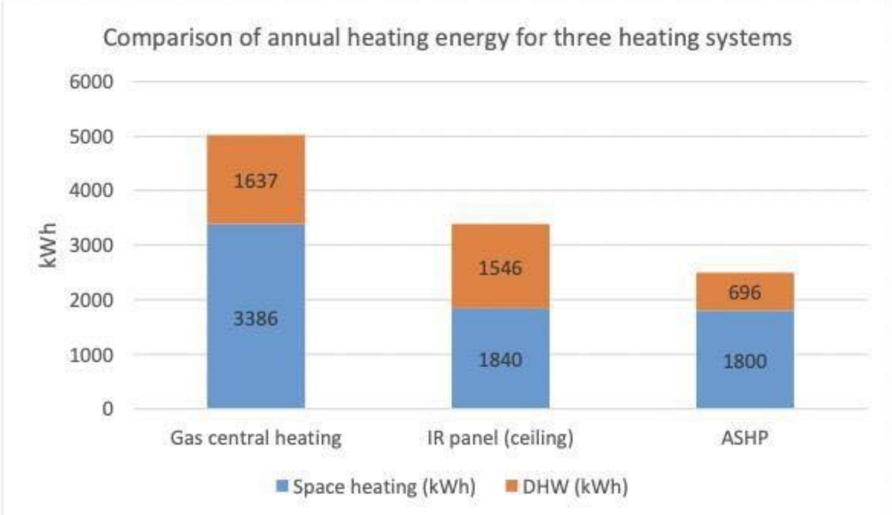


Figure 10: Comparing annual heating energy use for the two-bedroom social house in three scenarios: Gas central heating, infrared panels installed on ceiling, and air-to-water heat pump.

To give context, an average UK home requires 10,000 kWh for heating demand. The Passive House (Passivhaus) standard, which limits energy used for heating to just 15 kWh/m^2. If this home is thermally improved to the highest energy efficiency level that meets the Passivhaus standards, its space heating energy would be 1,047 kWh.

The selected home was designed to obtain EPC level B with an existing gas heating system, £5,023 kWh heating energy per annum. In terms of space heating efficiency, IR heating systems offer 45% improvement compared to the existing gas central heating system, which is comparable to air source heat pump systems. However, as the whole solution for space and water heating, this comes second in terms of energy efficiency amongst the three systems.

3.2. Comparison of the running cost

Fuel pricing data using Energy Saving Trust sources, which was last updated in June 2021, based on average fuel costs over the previous 12 months.

Table 5: Fuel pricing and their standing charges

Energy type	Class of consumption	Running cost
Natural Gas	Standard rate[2] (SR)	4.17p/ kWh (or 0.0417 £/kWh) £93.39 (standing charge)
Electricity from Grid	Standard rate[2] (SR)	16.36p/kWh (or 0.1636 £/kWh £87.48 (standing charge)
Natural Gas	Green energy supplier (GR)	2.93 p/kWh (or 0.0293 £/kWh) £91.83 (standing charge)
Electricity from Grid	Green energy supplier (GR)	15.77 p/kWh (or 0.1577 £/kWh) £75.65 (standing charge)

[2] Fuel prices last updated in June 2021, based on average fuel costs over the previous 12 months https://energysavingtrust.org.uk/about-us/our-data/

The running cost of heat pump technology can be further reduced when a homeowner takes part in the Government's Renewable Heat Incentives Scheme that the payment made for 7 years and based on the amount of renewable heat produced[3].

Table 6: Operating cost of three heating systems per annum

Heating system	Annual energy consumption (kWh)	Annual operating cost (GBP)
Central gas heating	Space heating = 3,386 kWh	= 0.0417 (£/kWh) x (3,386 + 1,637) kWh + £93.39 = £302.85 (SR)
	DHW = 1,637 kWh	= 0.0293 (£/kWh) x (3,386 + 1,637) kWh + £91.83 =239 (GR)
Infrared heating panel	Space =1,840 kWh	= 0.1636 (£/kWh) x (1,840 + 1,546) kWh + £87.48 = £641.43 (SR)
	DHW = 1,546 kWh	= 0.1577 (£/kWh) x (1,840 + 1,546) kWh + £75.65 = £609.62 (GR)
ASHP	Space =1,800 kWh	= 0.1636 (£/kWh) x (1,800 + 696) kWh + £87.48 = £495.83(SR)
	DHW = 696 kWh	= 0.1577 (£/kWh) x (1,800 +696) kWh + £75.65 = £ 469.27(GR)

Figure 11 compares annual operating cost amongst the three heating systems for space heating and hot water on standard rate (A similar trend can be observed with green supplier as from Table 6, though the associated carbon emissions would be nil if using green energy suppliers).

Payment tariff worked out around 10.92 pence/kWh for installation and claiming by December 2021. Based on current modelling outputs, a £220 per annum would be paid as part of RHI over 7 years.

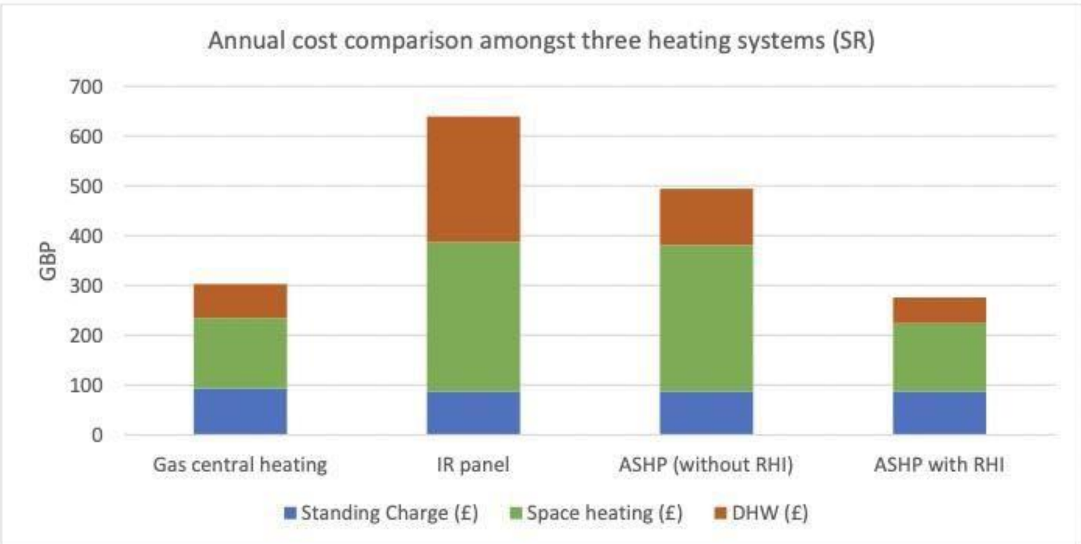


Figure 11: Annual operating cost comparison on standard tariff between gas central heating, IR panels and ASHP systems. And when taking into account of RHI grant (for the first 7 years).

[3] https://www.gov.uk/renewable-heat-incentive-calculator

3.3. Comparison of the total cost over a building's lifetime

The below costing table is for illustrative purpose only, assuming the fuel price remained at the same rate as at the current reporting, whereas fuel price inflates every year. When gas heating is phased out, it will have a knocked-on effect on the fuel market and renewable electricity and technology will be more affordable.

Central gas heating for combi boiler

For a two bedroom house requiring a gas central heating installation, the job will take about three days (£250 per day for gas safe engineer) and will cost around £3,000. The breakdown of the different components for illustrative study as below:

Gas boiler:
Boiler supply and installation – £1,100-1,700.
Radiators parts and labour – £830.
Pipework supply and installation -£230.
Extra parts and labour – £230.

IR heating panels: 400w = £395; 800w = £595; 1200w = £795
According to Table 4: 9 IR panels are required: 5 x 400W and 4 x 800W.
Cost of IR panels: 5x£395 + 4x£595 = £1,975 + £2,380 = £4,355
Room thermostat (One for each room) = £89. Cost of room thermostats: 9x £89= £801
Motion Control Sensor (One per room - If required for study) = £45. Not required.
Control Hub (One per property) = £129

Total unit and parts cost for IR heating panels: £4,355+£801+£129= £5,285.

IR panel installation is estimated to be maximum 1 day work for electrician including materials, which would be £500 for a second fix. The first fix completed by the builder would take a couple of hours per property for the heaters. Estimated £200 total. Total installation cost including materials = £700

ASHP: The cost of air to water heat pump (5kw to 17kw) ranges from £4,000 to £8,000.

Installation for a small semi-detached/terrace house ranges from £5,000 to £10,000[4], averaged at £7,500.

Table 7: Costing of three heating systems over a building's lifespan

	Gas-fired boiler – central heating	Infrared heating panels	ASHP (air to water heating)
The unit and parts	Boiler: £1,000[5] Radiators with associated fittings: £1,000	£5,285 (IR)	£4,000

[4] https://www.checkatrade.com/blog/cost-guides/air-source-heat-pump-cost/
[5] https://www.greenmatch.co.uk/blog/gas-boiler-prices#combi-prices

Installation costs (inc. materials)	£1,000[6]	£700	£7,500
Annual running cost (Figure 11)	£302.85	£639.40	£494.33 (without RHI) £274.33 (RHI for 7 years)*
Cost related to servicing, repair & replacement (as part of running cost).	£100 (gas safe, annual)	0	£150 - £200 (every 2 years) Or £100 per annum
During a building lifetime of 50 years, Replacement cost (Assuming a new system is fitted every 10 years for ASHP & gas boiler); 17-20 years for IR system.	£3000 x 4 = £12,000	£5,985 x 2 = £11,970	[(£4,000+£7,500-£5,000) x4= £26,000 (Incentive for new installation: £5000)
Total over building lifetime – 50 years (Illustrative figure only)	£3,000 + (£100 + £302.85)x50 + £12,000 = £35,142.50	= £5,985 + 639.40x50 + £11,970 = £49,925	£11,500+100x5+£26,000 + [(£274.33x7+£494.33x3) + 494.33*40] = £65,676.40.

*Air Source Heat Pump RHI benefit per year: **£220** – Payable quarterly for **7 years;** RHI scheme extended for a new installation to March 2022. Installation from April 2022, Clean Heat Grant will offer £5,000 upfront.

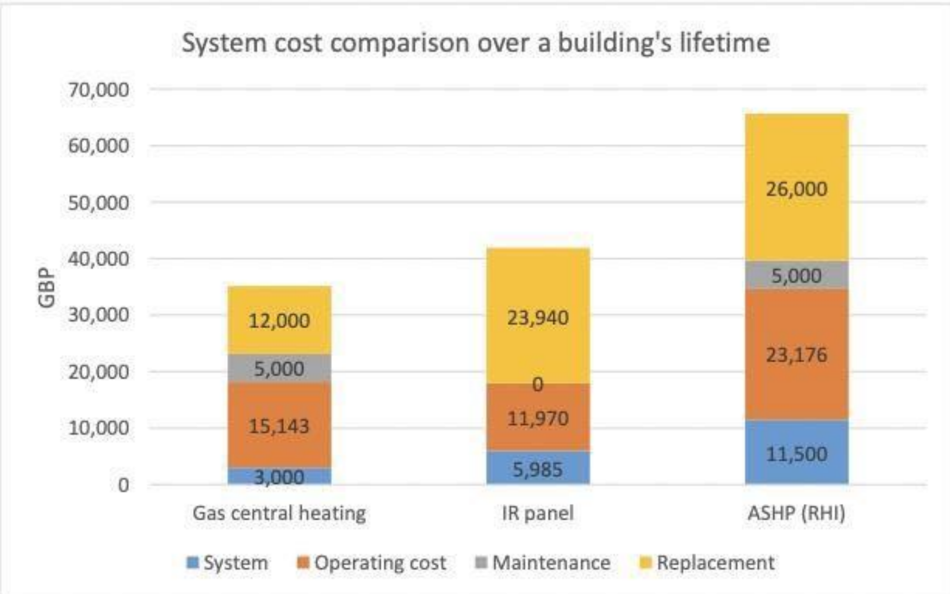


Figure 12: Comparison of overall system cost over a building's lifetime between the three heating systems

[6] https://www.theheatinghub.co.uk/guide-to-boiler-installation-costs

3.4. Comparison of the associated carbon emissions

Energy	Emission factor ($kg\ CO_2e/kWh$)	Associated CO_{2e} emissions, ($kg\ CO_{2e}$)	
		Space heating	DHW
Natural gas (central heating)	0.208	=0.208x3,386 = 704 ($kg\ CO_{2e}$)	=0.208 x1,637=340
Electricity from Grid	0.277	=0.277x1,840 = 510 ($kg\ CO_{2e}$) for IR panels =0.277x1,800=499 ($kg\ CO_{2e}$) for ASHP	=0.277x1,546 = 428 ($kg\ CO_{2e}$) for an electric emersion heater = 0.277x696=193 ($kg\ CO_{2e}$) for ASHP
Electricity from a renewable source (e.g. Green energy supply, integration with PV, etc.)	0	0	0

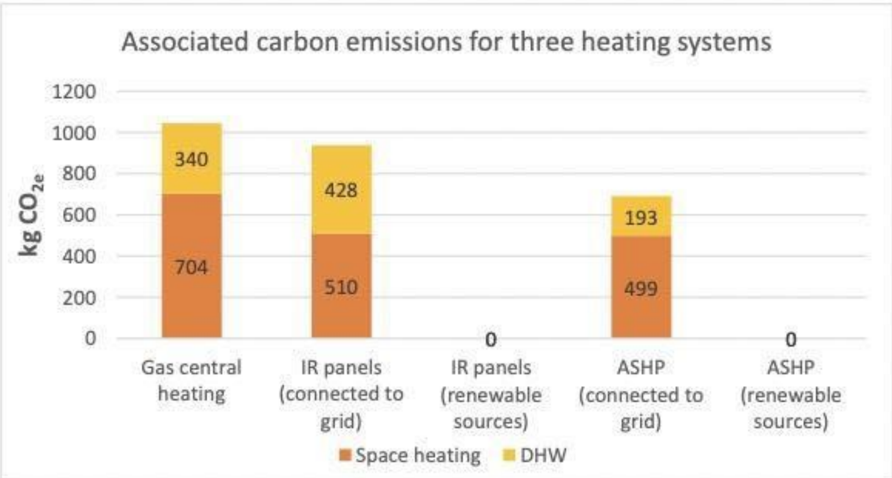


Figure 13: Comparison of associated carbon emission for three heating systems per annum

3.5. Zone control and operation

IR panels offer flexibility in zone heating and control. In fact, it can be more energy and cost-efficient to only heat a room in use rather than the whole house (like gas central heating). For example: when an occupant work from home so only the office room is heated, or when a family spends time in the living room. Figure 14 depicts heating during 8 hours usage to maintain indoor temperature around 21°C whilst outdoor air temp ranged from -0.98 to 1.6 °C. The total energy usage for an 800W panel operating during 8 hrs would be around:

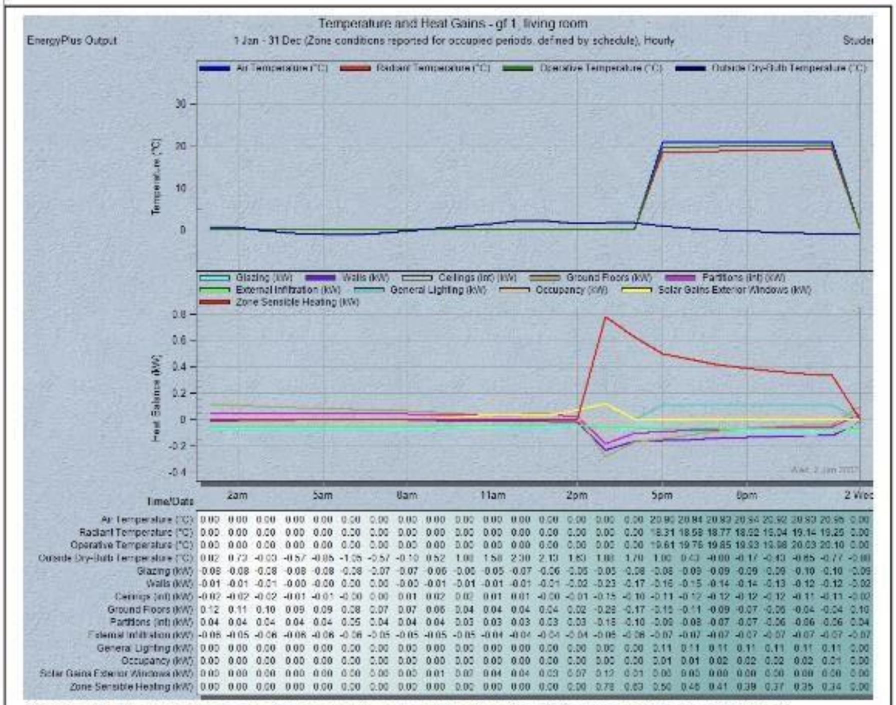


Figure 14: Heat Balance and Temperature profiles for the Living room (Design Builder)

4.3kWh. Average electricity price from the grid is 16.36p/kWh. The total cost of running IR heating for this zone: 4.3 kWhx 16.36 (p/kWh)= 70.35 pence.

In case of heating the whole house by gas central heating, the energy would be 2.5kW x 8hrs = 20kWh. And the price will be: 20 kWh x 4.17 (p/kWh) = 83.4 pence.

© 2020 The World Bank, Source: Global Solar Atlas 2.0, Solar resource data: Solargis.

3.6. Integrating with solar PV or PV- battery system

Solar is clean, renewable energy and will help homeowner/ businesses to greatly reduce carbon footprint. Solar panels capture the sun's energy via photovoltaic cells and turn it into electricity. They can be fitted onto the building roof and produce the electricity required for household needs. **Photovoltaic Power Potential (PVOUT)** map provides a summary of estimated solar photovoltaic (PV) power generation potential. It represents long-term average of yearly/daily potential electricity production from a 1 kW-peak grid-connected solar photovoltaic (PV) power plant.

<u>+ Integrating with solar PV:</u>

The area of the roof's slope facing south is 21.92 m^2. Due to limited available roof area suitable for PV installation, 3kWp PV systems was selected (10 PV panels of 300W, size of each panel is 0.9m x 1.6m). Figure 14 depicts solar PV generation over a 1 year period, assuming there are no shadow affecting panels' performance.

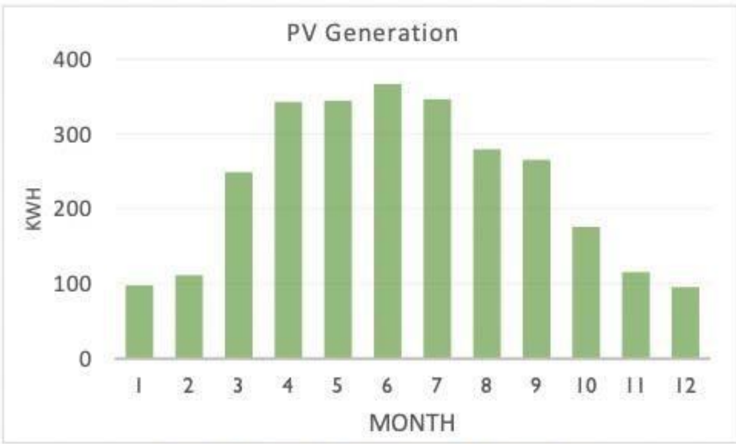


Figure 15: Monthly PV generation for Birmingham

Annual PV generation: 2,787 kWh.

Photovoltaic (PV) Solar Panel Energy Generation data used for the prediction was downloaded from a project run by UK Power Networks. The dataset collected field measurement data of 20 substations and 10 domestic premises for nearly 1.5 years[7] (Figure 15).

Based on measured solar PV generation data, it is suggested that PV integrated with IR panels during daytime can sufficiently work on heating a single zone with minimal grid import.

+ Integrating PV-battery system

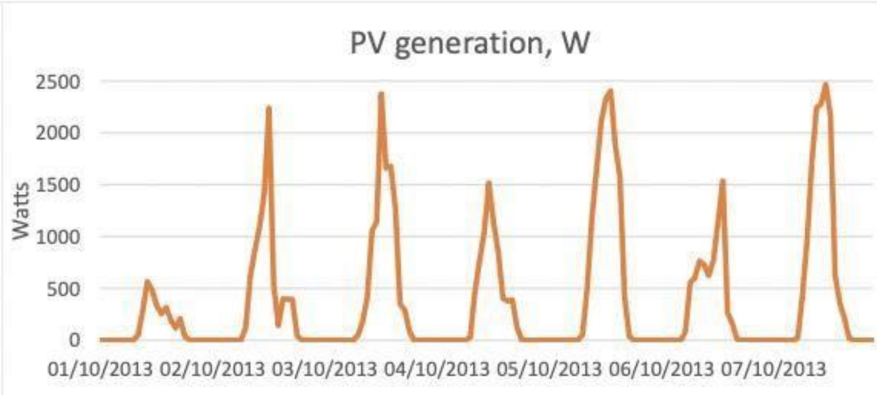


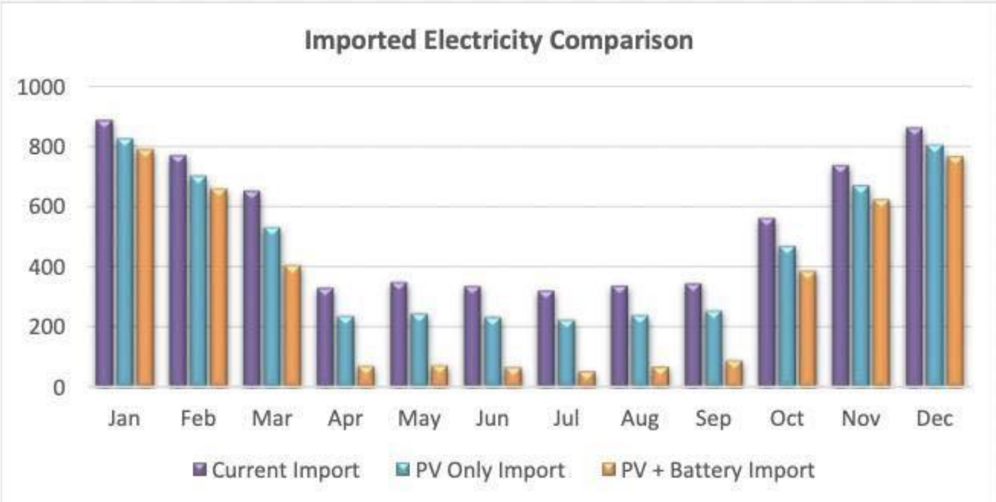
Figure 16: Measured 1 week PV generation data for domestic building (3kWp PV panel)

Due to the mismatch between solar availability (hence the electricity generation) and the occupied time when the heating is required (e.g. evening time from 5 pm onwards), a hybrid battery system for Solar PV is considered. In order to create a self-sufficient home, integrating solar PV - battery to run the infrared heating can help reduce electricity need, reducing the running cost to make it more affordable.

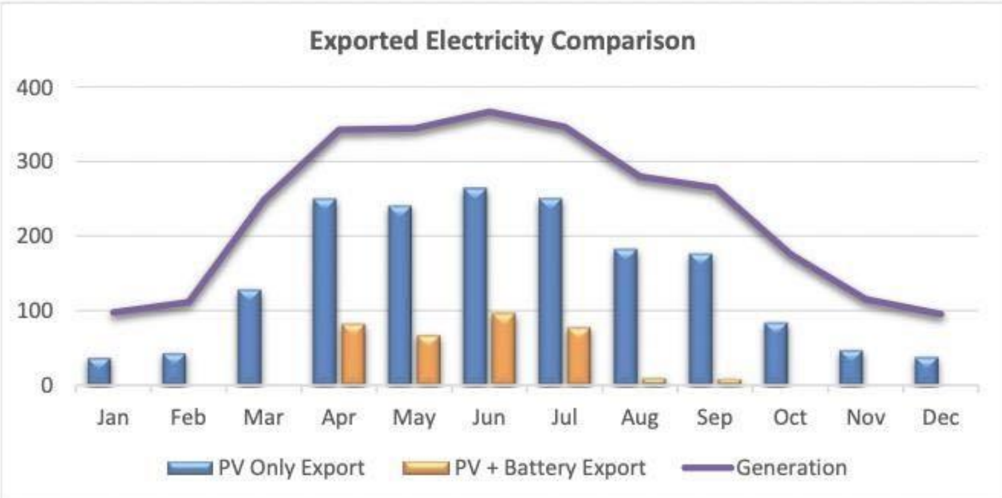
It is important to note that the electricity for household appliances can vary largely. According to the Department for Business, Energy & Industrial Strategy (BEIS), the average household uses 3,731 kWh per

[7] https://data.london.gov.uk/dataset/photovoltaic--pv--solar-panel-energy-generation-data

year[8]. The electricity used for household appliances in this scenario is 2,663 kWh per annum (a small household with energy-efficient appliances). The total electricity consumption is 6,049 kWh per annum. Figure 16 depicts the comparison of imported electricity required for the household in three scenarios: without renewable resources versus with PV and with PV-battery system. In addition to electric heating and boiler, household appliances account for the majority of electricity consumption. A 5 kWh hybrid battery storage was used for the calculation.



a) Comparison of imported electricity in three scenarios: no PV, PV only, and PV-battery system



b) Comparison of exported electricity between a PV-battery system and PV only.

Figure 17: Comparison of imported electricity without and with PV system

[8] https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

Electric consumption directly from PV totalled at 1,041 kWh per annum against 2,787 kWh total generation. By integrating PV and battery system to maximise consumption, self-consumption increased to 2,444 kWh (against 2,787 kWh PV generation, or 88%. The system reduces the grid reliance for the building owner by 62.41%.

The prediction shows that an annual savings of £487.47 when using PV-battery system against £1,151.51 electricity bill at the current cost (14.36p/kWh for electricity). The cost for PV-battery system: 650 x 3 = £1,950 (PV) and £3,800 for the battery. Without taking into account changes in fuel price and technology cost, it will take 14 years payback. If the fuel price increases by 5%, it can reduce to 11 years payback.

Using current carbon conversion factor, the amount of CO_2 emissions saved over 50 years will be 2,444(kWh) x 0.277 ($kgCO_{2e}$/kWh) x 50 = 33.8 Tonnes. As the UK Government is decarbonising the grid, to be neutral by 2050, the carbon emission saved would be lower.

4. Discussions

The UK pledged to prevent global warming from spiraling out of control by signing the 2015 Paris Agreement. And it is legally bound by its law to achieve net-zero emissions by 2050. As a result, it is required that natural gas boilers and all other forms of fossil fuel heating will officially not be permitted in new homes from 2025.

4.1. Legislation

An infrared electric heating system as the alternative solution to natural gas, can be an ideal solution for heating homes for both new build and retrofitting sectors. IR panels can operate from renewable sources (PV, PV-battery, micro wind turbine), or connect to the central grid. The UK government has confirmed plans to decarbonise the country's electricity grid by 2035 therefore electrifying heating to reduce reliance on fossil fuels is a must.

4.2. Energy & cost efficiency:

Amongst the three systems, ASHP uses the least energy, followed by Infrared heating then the gas boiler. However, due to the current fuel price market, gas is significantly cheaper than electricity, making gas boilers the most affordable system in terms of annual running cost. This may change as a result of the UK Government's ban on gas heating from 2025. In the context of a new build home that is thermally efficient (low heating demand), an infrared heating system might be more suitable than an ASHP as it has a lower upfront cost and as well as over costing over the building's lifetime. The infrared system also benefits the homeowner with lower running costs and no ongoing maintenance and service costs.

The real innovation in infrared heating technology lies in the energy-efficient way in which it heats a room. The radiation is the substantial mechanism in the heat transferred from the warm surface of the floor to humans/objects within the space and the other surfaces of the building enclosure using an infrared heating system. In contrast to convective heating that warms the air first and heats also lost through draughts, infrared heating provides a pleasant environment with constant humidity and minimal convection currents. Another bonus to infrared heating is how quickly the room is heated up. Gas central heating can often take around 30 minutes before occupants can start to feel the warmth as it heats the air within the space. Infrared heating heats sufficient with little grid import to boost up when the sun is not available. In order to create a self-efficient home, integrating solar PV - battery to run the electrical appliances including IR panels due to the mismatch between solar availability and the occupancy period. A hybrid battery with PV helps reduce electricity demand, reducing the running cost to make it affordable.

The IR heating panel application coupled with PV panels suits well in office/retailer context as the consumption during the daytime occupancy (8am-5pm) can draw directly from PV generation, without the need of battery system and reduce grid reliance.

4.5. Other indoor comfort issues (IAQ, noise)

The uptake of ASHP is slow due to a lack of workforce skill (MCS accredited installers) as well as home occupants being skeptical on the noise issue. In the past, many air source heat pumps were irritatingly noisy though it is getting better. However, the noise can be problematic when operating at a higher temperature (e.g. when heating the hot water cylinder), stopping and starting rather than steadily continuous running. Gas central heating warms the room by convection currents that circulate dust particles continuously around the home. The infrared system heats matter not air by radiation, no air circulation means no dust or bacteria in circulation. They also do not dry out the air like the gas central heating system. Therefore, infrared heating systems are an ideal solution for people who suffer from asthma or other respiratory problems.

Section 4: Further Actions

1. Technical development and review

Electric heating systems apart from electric boilers fall into Lot 20 (which came into force on 1 January 2018) must now include all of the following features: Electronic room thermostat, 24/7 programmable timing control, Labelling specifying the power consumption for heating and auxiliary systems (i.e. fans and controls). In addition, the system also includes distance control to allow remote system interaction (e.g. via an app) and motion detectors for the product to shut down if no one is present in the room.

EnTRESS 2 recommends the company investigate the system performance using black-bulb sensors, which measure thermal comfort temperature as the temperature control to improve the energy efficiency of the system and reduce wasted heat. EnTRESS 2 will introduce the company to another project (Built Environmental and Climate Change Innovation) for a field study on measuring thermal comfort in a highly thermal-performing building with its infrared heaters.

EnTRESS 2 is in discussion with supporting the Green Square Accord housing developer in a research and innovation project on electrifying new-build flats. The field experimental data is expected to start in Autumn 2022 that test the PV-battery and infrared heaters in twelve new-build flats. The company will also take part as a solution provider and be part of the research consortium to improve the design and inform product development.