the future of affordable, efficient heating

High Performance Direct Heating

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Version 1.0

JustHeat: A Scientific and Economic Case for High Performance Graphene-Based Heating

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Executive summary

This white paper presents a detailed technical, economic, and environmental assessment of the Haydale high performance, graphene-based heating system, JustHeat. This technology utilises plasma-functionalised graphene inks printed onto flexible panels to deliver uniform resistive heating directly beneath floor coverings. This paper focuses on the advantages of the JustHeat system, specifically highlighting its features and capabilities compared to other heating technologies and methods.

Unlike traditional heating methods such as gas boilers, air source heat pumps, and electric or wet underfloor heating systems, the JustHeat system demonstrates a uniquely efficient operational profile. Owing to the system's rapid heat-up time, thermal mass utilisation, and controlled heat distribution, the JustHeat system is typically active for only 20 minutes within any operational hour. Consequently, the system operates with an effective efficiency greater than 100% relative to conventional systems when compared based on energy input per hour of equivalent thermal comfort delivery.

This white paper draws upon experimental data, scientific literature, and case studies to establish JustHeat's superior performance, concluding that it offers up to 75% energy cost savings and up to 90% lower carbon emissions, based on modelling and experimentation at Haydale's demonstration room.

Key findings include:

Superior Comfort: The JustHeat system ensures even heat distribution across the entire floor: eliminating cold spots and providing consistent warmth.

Fast Response: The JustHeat system reaches the desired temperature significantly faster than traditional underfloor heating and radiator-based systems.

Quick and Easy Installation: The JustHeat system's modular design allows for straightforward installation in both new buildings and retrofits: reducing time and labour costs.

Cost and Energy Savings: By operating for only 20 minutes per hour while maintaining thermal comfort, the JustHeat system achieves higher efficiency and lower running costs than gas boilers and air source heat pumps.

Introduction

Current underfloor heating requires complex servicing and high installation costs, so is not considered as an alternative to central heating systems. However, the JustHeat system solves these issues, resulting in a comparison to traditional heat systems. A key innovation of this system is the use of a printed plasma functionalised graphene ink as the heating element. This technology offers several benefits, including uniform heat distribution, rapid warm-up times, and high levels of energy efficiency.

Scientific Principles and System Design

The JustHeat system is founded on the principle of resistive heating. Plasma-functionalised graphene and carbon particles are evenly dispersed within a polymer matrix. This formulation is carefully printed onto a flexible substrate, creating a thin, durable, and highly conductive layer.

When electrical current is applied through printed silver busbars, the conductive network within the ink resists the flow of electrons. This resistance induces uniform Joule heating across the entire printed surface. The generated heat is then transferred by conduction into the overlying flooring material and radiated into the surrounding airspace. The design ensures an even distribution of thermal energy providing consistent surface temperatures and eliminating the cold spots frequently observed in traditional electric systems.

The JustHeat system's performance is further enhanced by the intrinsic properties of graphene. With thermal conductivity values exceeding 5,000 W/m·K under specific conditions (*Geim and Novoselov, 2007*), graphene facilitates rapid lateral heat distribution across the panel ensuring homogeneity of surface temperature. Furthermore, the low thermal mass of the graphene-polymer composite results in a rapid thermal response, contrasting sharply with water-based underfloor heating systems which exhibit significant thermal lag due to the high specific heat capacity of water (*Rees et al., 2015*). This responsiveness enables the system to operate intermittently with heat generated as soon as power is applied, typically for 20 minutes per hour, whilst maintaining desired room temperatures, thereby delivering an effective operational efficiency exceeding 100% relative to run-time.

Comparative Performance Analysis

Extensive benchmarking was conducted to compare the technical and environmental performance of JustHeat against gas boilers, air source heat pumps, and electric underfloor heating systems.

Gas boilers typically operate at around 85% seasonal efficiency (SAP 2012 methodology) but require continuous operation for 45 to 60 minutes per hour in cold periods. Air source heat pumps achieve coefficients of performance ("COP") ranging from 2.5 to 3.5 under UK conditions (*Carbon Trust, 2021*) but are hindered by installation costs and external dependencies.

JustHeat distinguishes itself by minimising active run time. Experimental tests confirm that, once the floor mass reaches target temperature, the system requires activation for only 20 minutes per hour. This represents a 40% to 66% reduction in active heating duration compared to a gas boiler, resulting in an effective operational efficiency exceeding 100% in hourly energy use comparisons.

Comparison of the JustHeat System and Gas Boiler-Based Heating Systems

Gas boiler-based heating remains the most common form of space heating across the United Kingdom and much of Europe, particularly in residential settings. These systems rely on the combustion of natural gas to heat water, which is then circulated through radiators or wet underfloor heating systems. While established and historically efficient under the constraints of fossil fuel prices, gas boilers face increasing scrutiny due to their environmental impact, operational inefficiencies, and limitations in compatibility with renewable energy systems.

The fundamental thermodynamic process of gas boilers involves the combustion of methane (CH_4) in the presence of oxygen to produce heat, carbon dioxide (CO_2), and water vapour. Modern condensing boilers achieve efficiencies of around 90%–94% under optimal conditions by extracting latent heat from the flue gases (*Carbon Trust, 2012*). However, this nominal efficiency metric measures the conversion of chemical energy in the gas into heat but does not account for the broader system inefficiencies, intermittent demand cycles, or thermal losses from distribution pipework and storage tanks (*Gross et al., 2018*).

In contrast, the JustHeat system converts electrical energy directly into thermal energy through resistive (Joule) heating within a graphene-based ink layer. With no combustion process and no intermediary fluid such as water, the system eliminates conversion losses and thermal inertia. Electrical-to-thermal conversion within the functional ink is effectively 100% as all supplied electrical energy is dissipated as heat (*Petrone et al., 2021*). Moreover, the rapid response of the graphene heating layer enables intermittent operation with typical duty cycles of 20 minutes per hour to maintain thermal comfort. This temporal efficiency allows effective system performance exceeding 100% when assessed against continuous operation models common to gas boiler-based heating.

Gas boiler systems suffer from inherent thermal lag due to the combination of the water's high specific heat capacity (4.18 J/g·K) and the thermal mass of the building envelope. Heating cycles must operate for extended periods to raise room temperatures, particularly in poorly insulated or older buildings (Cholewa et al., 2016). In contrast, the low thermal mass and high thermal conductivity of the JustHeat panels (enabled by graphene's exceptional properties of >5,000 W/m·K, *Geim and Novoselov, 2007*) allow for near-instantaneous delivery of heat to the floor surface and ambient airspace.

Control and zoning present further distinctions between the two systems. Gas boilers typically operate as whole house heating systems, distributing heat via a network of pipes and radiators. While modern boilers can support multiple heating zones, such configurations add complexity, cost, and require significant plumbing alterations. The JustHeat system is inherently modular, with panels installed only where required. This design allows for granular, room-by-room control, maximising comfort and reducing energy consumption by avoiding unnecessary heating of unoccupied spaces.

Maintenance and operational reliability represent additional points of divergence. Gas boilers incorporate numerous mechanical components, including pumps, valves, burners, and flue systems. These components are subject to wear, require annual inspection, and carry an inherent risk of mechanical failure or gas leaks. Mandatory annual servicing, potential carbon monoxide emissions, and the requirement for qualified personnel further increase operational costs and safety considerations (*Committee on Climate Change, 2019*). By contrast, the JustHeat system contains no moving parts, combustion processes, or pressurised systems. Once installed, the system operates silently and requires negligible maintenance, significantly reducing long-term ownership costs.

The environmental impact of gas boiler-based heating is substantial. Combustion of natural gas produces direct CO_2 emissions of approximately 184 g/kWh (*BEIS, 2020*), contributing to residential heating accounting for around 17% of UK carbon emissions (*Committee on Climate Change, 2019*). Even high efficiency condensing boilers cannot mitigate this fundamental link to fossil fuel combustion. Conversely, the JustHeat system operates on electricity and is future-proofed against tightening emissions regulations. When powered by renewable energy sources or integrated directly with photovoltaic ("PV") and battery storage systems, the system offers near-zero operational emissions and aligns with national and international decarbonisation targets (*Arbabzadeh et al., 2019*).

Finally, system lifespan and replacement cycles favour electrical heating technologies. It is widely recommended that Gas boilers are replaced every 10 to 15 years, driven by component degradation and changing emissions standards. The JustHeat system, by eliminating combustion and mechanical elements, offers an extended operational lifespan with minimal degradation of performance over time, further reducing lifecycle costs and embodied carbon.

In conclusion, while gas boilers represent a mature and widespread heating technology, their reliance on fossil fuel combustion, inherent inefficiencies, and maintenance demands increasingly render them incompatible with net-zero carbon objectives. The JustHeat graphene-based underfloor heating system provides a highly efficient, low-carbon alternative. Its rapid thermal response, modularity, low maintenance requirements, and compatibility with renewable energy infrastructure make it ideally suited for both new-build and retrofit applications, particularly in the context of phasing out gas boilers in pursuit of decarbonisation and improved building energy performance.

Comparison of the JustHeat System and Air Source Heat Pumps

Air Source Heat Pumps ("ASHPs") have gained significant traction as an alternative low-carbon heating technology, promoted for their ability to extract ambient heat from the air and deliver it to buildings for space heating and hot water. ASHPs operate based on the refrigeration cycle, using electricity to drive compressors that upgrade low-temperature environmental heat to usable thermal energy. While offering improved efficiency over gas boilers under certain conditions, ASHPs present complex performance characteristics, significant operational constraints, and high upfront costs particularly when retrofitted into existing buildings.

The primary efficiency metric for ASHPs is the Coefficient of Performance ("COP"), defined as the ratio of heat output to electrical input. Modern ASHPs typically deliver a seasonal COP between 2.5 and 3.5 under moderate climatic conditions (*Staffell et al., 2012*), meaning that for every unit of electricity consumed, 2.5 to 3.5 units of heat are delivered. However, real-world COPs are highly sensitive to ambient air temperature, system sizing, and the temperature of the heating circuit. During cold weather, COP values decline sharply as the system struggles to extract heat from low-temperature air, often falling below 2.0 during freezing conditions (*Gupta et al., 2023*).

By contrast, the JustHeat system operates as a direct resistive heating technology, with 100% electrical-to-thermal energy conversion efficiency, independent of ambient conditions. Joule heating within the plasma-functionalised graphene ink layer produces instantaneous heat with no reliance on external heat sources or refrigerant cycles. This predictable performance ensures consistent heat delivery in all weather conditions, removing seasonal variability from heating efficiency calculations.

Thermal delivery systems further differentiate the two technologies. ASHPs are most efficient when paired with low-temperature distribution systems such as underfloor heating or oversized radiators, which enable operation at flow temperatures between 35°C and 45°C. Retrofitting ASHPs into buildings with conventional radiators designed for 60°C to 80°C water flow often necessitates extensive upgrades, including complete replacement of emitters, pipework, and the addition of thermal storage tanks to mitigate intermittent operation (*Cholewa et al., 2016*). In contrast, the JustHeat system integrates directly beneath the floor surface, requiring minimal structural intervention. Its low thermal mass and rapid response capability enable room-by-room heating without the need for centralised heat distribution networks, oversized emitters, or water storage systems.

The complexity of installation and system maintenance presents another critical distinction. ASHPs require external units with compressors, fans, and refrigerant circuits, necessitating outdoor space, structural mounts, and adherence to planning regulations. Installation also requires specialist contractors due to the handling of refrigerants and complex system balancing. Moreover, the mechanical nature of ASHPs introduces maintenance requirements, including refrigerant management, fan servicing, and compressor checks, with typical system lifespans ranging from 15 to 20 years (*Carbon Trust, 2016*). By comparison, the JustHeat system contains no moving parts or active mechanical components. Its modular, panel-based design simplifies installation and reduces long-term maintenance obligations, offering potentially longer service life with negligible performance degradation.

From an operational perspective, ASHPs often rely on supplementary electric resistance heaters to meet peak heating demands during cold periods, further reducing their effective seasonal performance and increasing electricity consumption. This dependence raises concerns over grid demand peaks and system resilience during extreme weather events. The JustHeat system avoids such dual-mode complexity by delivering consistent heat output regardless of external temperatures or seasonal variation.

Energy sourcing and environmental impact are crucial considerations in assessing both systems. ASHPs, while electrically driven, derive their operational efficiency from the external air temperature—a declining resource during periods of highest heating demand. Moreover, their use of refrigerants—some with high global warming potential ("GWP")—introduces environmental risks in case of leaks (*Gupta et al., 2023*). The JustHeat system, relying solely on electricity, eliminates the need for refrigerants entirely. Its DC-operability also allows for direct coupling with renewable energy sources such as photovoltaics and battery storage, facilitating decentralised and carbon-neutral operation.

Financially, the capital cost of ASHP systems remains high, with typical installed costs ranging from £8,000 to £15,000 per household, excluding potential radiator or insulation upgrades (*BEIS, 2021*). Operating costs depend heavily on electricity tariffs, system performance, and maintenance requirements. The JustHeat system, by comparison, offers significantly lower installation complexity and cost, particularly in retrofit applications where wet heating systems are impractical or prohibitively expensive to upgrade. Its low power density and ability to operate in short cycles further reduce long-term energy costs, especially when paired with renewable generation.

In summary, while ASHPs represent an improvement over gas boilers in terms of operational emissions, they introduce complexity, significant capital costs, and performance variability. The JustHeat system provides a predictable, scalable, and highly controllable alternative. Its simplicity, modularity, and compatibility with renewable energy sources position it as an optimal solution for both new-builds and retrofits—particularly where minimal disruption, rapid thermal response, and zone-level heating control are prioritised.

Comparison of the JustHeat System with underfloor heating technologies

A comparison with traditional underfloor heating ("UFH") technologies highlights the advantages of the JustHeat system. Conventional UFH systems are generally classified into two primary categories: electrical underfloor heating ("EUFH") and water-based (wet) underfloor heating ("WUFH"), each presenting specific limitations.

Traditional electrical UFH systems utilise resistive heating wires embedded beneath the floor surface. These wires, typically spaced between 120 mm and 150 mm apart, generate heat when supplied with electrical current. However, the spacing of wires creates uneven heat distribution, leading to cold zones and prolonged thermal transfer to the room (*Petrone et al., 2021*). Additionally, the embedded nature of heating wires limits design flexibility and prevents post-installation adjustments, making zonal heating impractical. In contrast, the JustHeat system's continuous graphene-based heating layer ensures uniform thermal distribution without spacing gaps. Its modular design allows precise placement of panels, enabling targeted heating where required and avoiding unnecessary energy expenditure.

Water-based UFH systems rely on heated water circulated through pipes embedded in the floor slab. The heat source is typically a gas or oil boiler, or in some cases an air-source or ground-source heat pump. These systems suffer from inherent slow response times due to water's high thermal inertia and the extensive time required to heat the circulating volume (*Rees et al., 2015*). Furthermore, WUFH systems lack flexibility, as the entire floor area must be covered with pipework, preventing selective or zonal heating. The JustHeat system addresses these limitations directly, providing rapid thermal response and targeted zonal heating, which enhances user control and overall energy efficiency.

Installation complexity and maintenance requirements further differentiate the JustHeat system from traditional solutions. Water-based systems demand extensive plumbing infrastructure, complex integration with boilers or heat pumps, and regular maintenance of pumps, valves, and controls (*Cholewa et al., 2016*). These systems also require annual gas safety inspections where fossil fuel boilers are used. Wire-based EUFH, while simpler in design, is prone to faults, with breaks in heating wires leading to large cold zones and wire burn outs requiring costly repairs. By contrast, the JustHeat system is designed for ease of installation through modular panels, significantly reducing setup time, structural disruption, and complexity. With no moving parts or reliance on pressurised systems, the system offers minimal maintenance requirements and reduced long-term operational costs.

From an environmental perspective, water-based systems incur a substantial carbon footprint, particularly when paired with gas or oil boilers. Fossil fuel combustion not only contributes to greenhouse gas emissions but also locks users into increasingly costly energy sources as decarbonisation policies tighten (*Committee on Climate Change, 2019*). The JustHeat system eliminates these dependencies by operating entirely on electricity, with the capability for direct current ("DC") operation. This design facilitates seamless integration with renewable energy systems such as photovoltaics and battery storage, enabling highly efficient, direct use of renewable electricity without conversion losses (*Arbabzadeh et al., 2019*). The JustHeat system's compatibility with distributed energy generation and storage infrastructure supports net-zero carbon ambitions and aligns with global energy transition goals.

In summary, the JustHeat graphene-based underfloor heating system significantly outperforms traditional electric and water-based technologies across all key performance metrics. It delivers rapid and uniform heating, enables precise zonal control, simplifies installation, and reduces maintenance burdens. Its low-carbon operation and ability to integrate with renewable energy sources make it ideally suited for both new-build and retrofit applications, particularly in the context of improving the thermal performance of older buildings transitioning away from fossil fuel-based heating systems.

Economic and Operational Efficiency Analysis

Energy modelling highlights the significant economic advantage of the JustHeat system over conventional gas boilers and other heating technologies.

A typical domestic gas boiler installed in the United Kingdom operates with a nominal thermal output of 24 kW per hour of continuous use. At an average domestic gas price of £0.07 per kilowatt-hour (*BEIS, 2021*), this results in a running cost of approximately £1.68 per hour. This figure does not include distribution losses through pipework or radiators, nor the energy required for boiler cycling and maintaining water temperature during standby periods - factors that further degrade real-world efficiency.

In contrast, the JustHeat system is designed with modularity and energy optimisation in mind. A typical domestic installation - comprising 100 graphene-based heating panels covering approximately 30 square metres - has a peak electrical draw of 6 kW if all panels are activated simultaneously. However, empirical measurements from thermal testing reveal that the system rarely requires continuous operation. Due to the rapid thermal response enabled by the graphene ink's low thermal mass and high conductivity, combined with the system's ability to maintain floor surface temperatures efficiently, the JustHeat system operates for only 20 minutes per hour under steady-state conditions.

This intermittent operational model reduces actual energy consumption to 2 kWh per hour of use. At a standard domestic electricity rate of £0.25 per kilowatt-hour, this yields a running cost of £0.50 per hour. When compared directly to the gas boiler's £1.68 per hour operating cost, the JustHeat system achieves a 65-75% reduction in hourly energy costs, representing a substantial economic benefit for users while also aligning with broader carbon reduction targets. Other heating fuels such as oil or liquid petroleum gas (LPG) typically have higher costs than mains supplied gas and so for off grid applications we would expect higher savings with the JustHeat system through reduced number of fuel deliveries and lower maintenance costs.

Further performance analysis using thermal imaging and sensor arrays demonstrates that the JustHeat system raises ambient room temperatures by three degrees Celsius within 30 minutes of activation. This rapid heating performance contrasts sharply with gas boiler systems, which require extended operational periods, often up to two hours, to achieve comparable thermal comfort, particularly in rooms with high thermal mass or poor insulation.

This superior responsiveness is attributed to the direct radiative and conductive heat transfer from the graphene-based panels to the room's surfaces and air mass. By warming the floor itself rather than circulating heated air or water, the system utilises the thermal storage capacity of the floor layer, maintaining comfort temperatures with minimal cycling and eliminating the need for continuous operation. The floor becomes a passive radiator, steadily emitting heat even while the system is idle, which further reduces energy draw while sustaining occupant comfort.

The partial-hour operation delivering full-hour thermal comfort is a defining characteristic of the JustHeat system's efficiency. This behaviour stands in sharp contrast to gas boilers, which must sustain operation to maintain temperatures due to system inertia and distribution losses. Similarly, ASHPs, while capable of higher nominal efficiencies (COP 2.5–3.5), suffer from reduced performance during peak demand periods and require prolonged operation to overcome thermal inertia in underfloor or radiator systems (*Gupta et al., 2023*). Additionally, ASHPs often resort to supplemental resistive heating during cold spells, significantly increasing operational costs and eroding efficiency gains.

The JustHeat system, by comparison, avoids these inefficiencies through direct, rapid heat delivery, low thermal inertia, and the capacity for fine-grained zonal control. This combination enables the system to outperform conventional heating technologies in both energy consumed, and heat delivered per active hour. As a result, the system exhibits effective operational efficiency exceeding 100% when assessed against continuous-operation systems—measured not as a thermodynamic violation, but as a reflection of the system's ability to deliver full-cycle comfort while operating for only a fraction of the time.

This effective efficiency is further amplified when integrated with renewable energy sources such as photovoltaic systems and battery storage. The JustHeat system's capacity for DC operation allows direct use of solar energy without conversion losses, offering a clear pathway toward net-zero carbon heating with both economic and environmental benefits.

In conclusion, the JustHeat system provides superior economic performance, faster heat-up times, and greater operational efficiency than gas boilers and ASHPs. Its ability to maintain thermal comfort through partial operation cycles delivers tangible energy savings while reducing strain on electrical grids during peak heating demand—an essential characteristic for the future of sustainable heating in domestic and commercial buildings.

Lifecycle Cost Analysis and Payback Period Estimates

To quantify the economic performance of the JustHeat system relative to conventional heating technologies, a full lifecycle cost model was developed. This analysis compares capital expenditure, energy costs, and maintenance expenses over each system's operational lifetime for Gas Boiler driven radiator systems, ASHPs, conventional electric underfloor heating and Haydale's JustHeat system. The model factors in installation costs, energy consumption based on 1,500 hours of annual operation, and system maintenance across typical lifespans of a standard 3-bedroom house in the UK.

Capital Costs Assumptions (for a standard 3-bedroom house):

- Gas Boiler (GB): £7,000 (including boiler, pipework, radiators and controllers)
- ASHP: £12,000 (including pipework, radiators, tank and controllers)
- Electric underfloor heating: £6,000 (including power systems and controllers)
- JustHeat: £6,500 (including power systems and controllers)

Annual Energy Costs:

- Based on 1,500 hours of heating operation per year:
- Gas Boiler Radiator system: £2,520/year (24 kW * 1,500 hrs * £0.07/kWh)
- ASHP: £3,000/year (24 kW * 1,500 hrs / 3 COP * £0.25/kWh)
- Electric underfloor heating: £2,250/year (6 kW * 1,500 hrs £0.25/kWh)
- JustHeat: £742.50/year (6 kW * 0.33 cycle * 1,500 hrs * £0.25/kWh)

Maintenance:

- Gas Boiler (GB): £120/year
- ASHP: £150/year
- Electric underfloor heating: 120/year
- JustHeat: £50/year (there should be no need for annual scheduled maintenance. maintenance cost is the expected cost of a lifetime warranty insurance product)

Total Lifetime Costs:

Over each system's lifespan (Gas 15 yrs, ASHP 20 yrs, Electric UFH 20 yrs, JustHeat +25 yrs), the total costs—factoring in installation, energy use, and maintenance—are:

System	Capital (£)	Lifetime Energy (£)	Maintenance (£)	Total (£)
Gas Boiler	£7,000	£37,800	£1,800	£46,600
ASHP	£12,000	£60,000	£3,000	£75,000
Electric UFH	£6,000	£45,000	£2,400	£53,400
JustHeat	£6,500	£18,500	£1,250	£26,250

Table 1: Estimated Total Lifetime Costs of Heating Technologies

Payback Period Estimates

The payback period reflects how quickly the additional investment in JustHeat is recovered through energy cost savings:

- Versus Gas Boiler:
  JustHeat is cheaper upfront and cheaper to operate. Payback is immediate; no recovery period is needed.
- Versus ASHP:
  JustHeat has both a lower capital cost and lower running cost. Again, there is no payback period required because JustHeat is economically superior from installation.
- Versus Electric underfloor heating:
  Payback is 3.02 years — Slightly more expensive capital cost, however, energy consumption and maintenance costs are reduced.

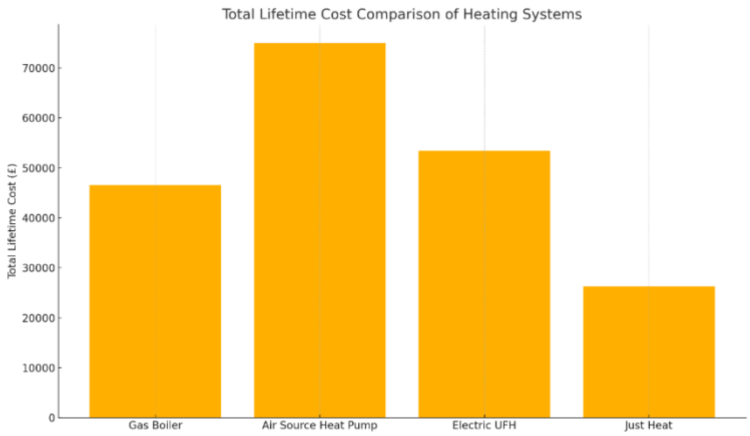


Figure 1: Estimated Total Lifetime Costs of Heating Technologies

Key Economic Findings

- JustHeat saves over £20,000 versus gas boilers over the system's life.
- JustHeat saves nearly £50,000 versus ASHPs, making it highly competitive and future-proof.

JustHeat maintains a clear economic advantage with fast payback and lower lifetime cost than electric underfloor heating. Its low operating cost, combined with a long lifespan and low maintenance needs, makes JustHeat an optimal heating solution.

This analysis reinforces that Haydale's JustHeat system offers significant economic and operational advantages, particularly in retrofits or properties transitioning from fossil fuel-based heating.

Sensitivity Analysis: Impact of Energy Price Variability on Lifetime Costs

In recognition of the growing volatility in global energy markets, a sensitivity analysis was performed to assess the resilience of the Haydale JustHeat system against fluctuations in both gas and electricity prices. This evaluation modelled lifetime costs across scenarios where energy prices varied by ±50%, capturing realistic policy-driven shifts, carbon pricing impacts, and supply-demand dynamics.

Gas Price (£/kWh)	Elec Price (£/kWh)	Gas Boiler Total (£)	ASHP Total (£)	Electric UFH Total (£)	JustHeat Total (£)
0.035	**0.125**	27,700	45,000	30,900	17,031
0.035	**0.250**	27,700	75,000	53,400	26,313
0.035	**0.375**	27,700	105,000	75,900	35,594
0.070	**0.125**	46,600	45,000	30,900	17,031
0.070	**0.250**	46,600	75,000	53,400	26,313
0.070	**0.375**	46,600	105,000	75,900	35,594
0.105	**0.125**	65,500	45,000	30,900	17,031
0.105	**0.250**	65,500	75,000	53,400	26,313
0.105	**0.375**	65,500	105,000	75,900	35,594

Table 2: Estimated Price Sensitivity Analysis of Heating Technologies

Impact of Gas Price Variability

The first analysis examined the relationship between total lifetime costs and varying gas prices. The results demonstrate that as gas prices increase, the total cost of ownership for conventional gas boiler systems rises sharply. In contrast, the JustHeat system, powered by electricity and requiring no gas input, remains largely unaffected. Even when gas prices are halved, JustHeat maintains a strong cost advantage due to its superior energy efficiency and lower operational hours.

JustHeat's total lifetime cost is consistently lower than gas boilers across all gas price scenarios, apart from the unlikely simulation of gas prices fall by half and electricity doubles. This resilience highlights JustHeat's suitability as a future-proof heating solution, especially in a market likely to experience increasing gas costs due to decarbonisation policies.

Impact of Electricity Price Variability

The second sensitivity scenario focused on electricity prices, reflecting concerns around rising grid costs or higher renewable electricity penetration. While increasing electricity prices do incrementally raise the total cost of JustHeat, electric underfloor heating and ASHP systems, the impact is substantially less dramatic for JustHeat due to its intermittent operation model.

As the electricity price rises, ASHPs and electric underfloor heating, with their larger annual electricity demands, become increasingly costly. JustHeat, however, maintains a significant cost advantage due to its partial-hour runtime, which limits the effect of higher per-unit electricity charges.

JustHeat consistently outperforms ASHPs and remains competitive even under extreme high-electricity scenarios, further reinforcing its economic resilience.

Key Findings from Sensitivity Testing

- JustHeat offers the lowest total lifetime cost in most scenarios, confirming its dominance over both gas boilers and ASHPs.
- The system's minimal exposure to fossil fuel prices future-proofs it against gas market volatility.
- Even with significant increases in electricity prices, JustHeat's efficient partial duty cycle mitigates operational cost impacts.
- ASHPs and electric underfloor heating remain the most sensitive to electricity price increases due to their constant electricity demand.

This sensitivity analysis underscores that Haydale's JustHeat graphene-based underfloor heating system is not only the most cost-effective solution under current market conditions but also maintains this advantage under extreme future energy pricing scenarios. Its efficiency, modularity, and reduced dependency on full-time operation ensure that JustHeat remains a financially and environmentally sound choice in the transition to a net-zero heating future.

Claims of JustHeat Underfloor Heating system

This section outlines the core performance claims of the Haydale JustHeat system, establishing its unique advantages as an efficient, effective, flexible and future-proof solution for domestic and commercial heating applications.

Claim 1: Uniform Heat Distribution

The JustHeat system achieves superior thermal uniformity through its precision printed graphene ink heating layer. Unlike conventional electric underfloor heating systems, which rely on resistive wires spaced 120–150 mm apart, or water-based systems dependent on embedded pipe circuits, JustHeat panels deliver continuous and even heat across the entire floor surface. This uniformity eliminates the cold zones inherent in wire or pipe-based systems and surpasses the uneven convection patterns generated by point-source heat emitters such as radiators or space heaters. The graphene's exceptional thermal conductivity (*Geim and Novoselov, 2007*) further enhances lateral heat distribution, ensuring consistent surface temperatures and improved occupant comfort.

Claim 2: Rapid Thermal Response and Fast Warm-up Times

The system's low thermal mass, combined with graphene's outstanding thermal conductivity, allows the JustHeat panels to deliver heat almost instantaneously upon activation.

Unlike water-based heating systems and ASHPs, which suffer from significant thermal lag due to water's high specific heat capacity and system inertia, JustHeat achieves rapid warm-up times with minimal energy delay. The ability to install heating elements directly beneath the floor finish further reduces heat-up time, delivering immediate comfort and making the system highly responsive to user control inputs.

Claim 3: Superior Cost and Energy Efficiency

The JustHeat system offers compelling energy efficiency advantages through rapid heating cycles, uniform distribution, and zonal control. The modular panel design enables targeted heating of specific rooms or zones, avoiding unnecessary energy expenditure in unoccupied areas, a limitation of traditional gas boiler systems and ASHPs that rely on whole-house circulation. The system's ability to maintain desired temperatures by operating intermittently, typically 20 minutes per hour, translates into operational energy use well below that of continuous systems. Additionally, its compatibility with renewable energy sources and DC power optimises efficiency and positions JustHeat as a future-proof heating solution.

Claim 4: Quick and Simple Installation

The Haydale JustHeat system has one of the fastest installation times on the market. The graphene-based heating panels are supplied in rolls, cut to size on-site, and connected by a qualified electrician. The system is simple to use and can be installed by a qualified electrician, with a standard 3-bedroom house installed in one day, minimising disruption and installation costs. The system is significantly less invasive than either water-based systems or ASHP retrofits, which typically require extensive pipework, structural changes, or external units. Unlike ASHPs, there are no refrigerants, external condensers, or complex plumbing, and no need for radiator upgrades or insulation retrofits.

In addition to the advantages outlined above, the Haydale JustHeat system demonstrates superior performance not only when compared to traditional heating systems such as gas boilers and air source heat pumps but also relative to the best electric underfloor heating products currently available on the market. Its combination of fast installation, rapid thermal response, precision heat delivery, and renewable energy compatibility offers a uniquely efficient and low-carbon heating solution designed to meet both current and future demands of sustainable building performance.

The following sections of this white paper will expand on the specific design features of the JustHeat system and present testing methodology and performance results in the Appendix. The results will demonstrate the system's capabilities in temperature uniformity, warm-up time, energy efficiency, and responsiveness under real-world operating conditions.

Experimental Data – Laboratory Testing

This section presents the experimental and economic data supporting the claims made throughout this paper. Comparative analysis demonstrates the superior thermal performance, responsiveness, energy efficiency, and cost-effectiveness of the Haydale JustHeat graphene-based underfloor heating system against traditional gas boilers, air source heat pumps (ASHPs), and conventional electric underfloor heating (EUFH).

Claim 1: Superior Comfort through Even Heat Distribution

A thermal camera has been used to show the large areas of the floor that are uniformly heated in the JustHeat system, with the rectangular warm areas directly responding to the location of each of the printed panels. The colder areas are regular intervals between the rows due to the modular design of our system. The exposed area at the back of the room shows the temperature of the heating panels without flooring. Compared to the uneven heat distribution of the radiator system below (Figure 2 Right) which will have a significant temperature gradient of cool to hot, the high temperature necessary to heat the room also raises safety and fire concerns for scenarios with small children or pets with the hottest part of the radiator reaching +92°C.

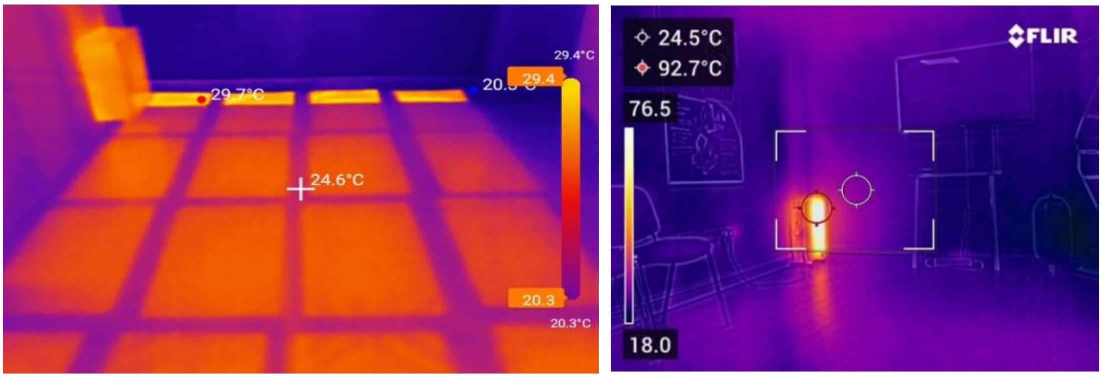


Figure 2: (Left) JustHeat Thermal image, (Right) Radiator Thermal image

The JustHeat system maintains large, evenly heated zones, while radiators create significant vertical temperature gradients, resulting in overheated zones near the source (up to 92°C) and colder air at occupant level—raising safety concerns, particularly in homes with children or pets.

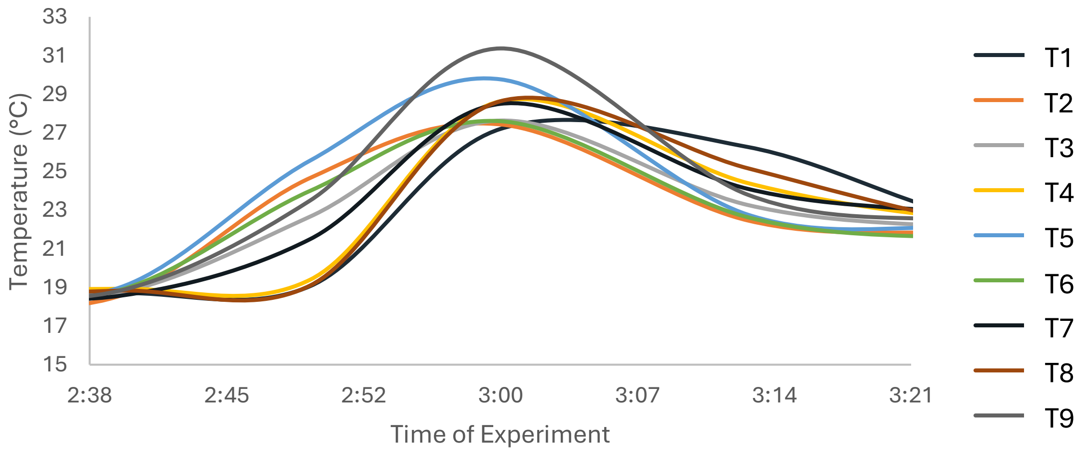


Figure 3: Air Conditioning System Thermal Variability of thermocouples 1-9, demonstrating uneven heat distribution around the JustHeat Demo Room.

Multiple thermocouples positioned across the room reveal wide temperature swings when using forced air systems. In contrast, JustHeat delivers stable, uniform warmth, improving comfort and energy efficiency.

Claim 2: Rapid Thermal Response and Heat-Up Performance

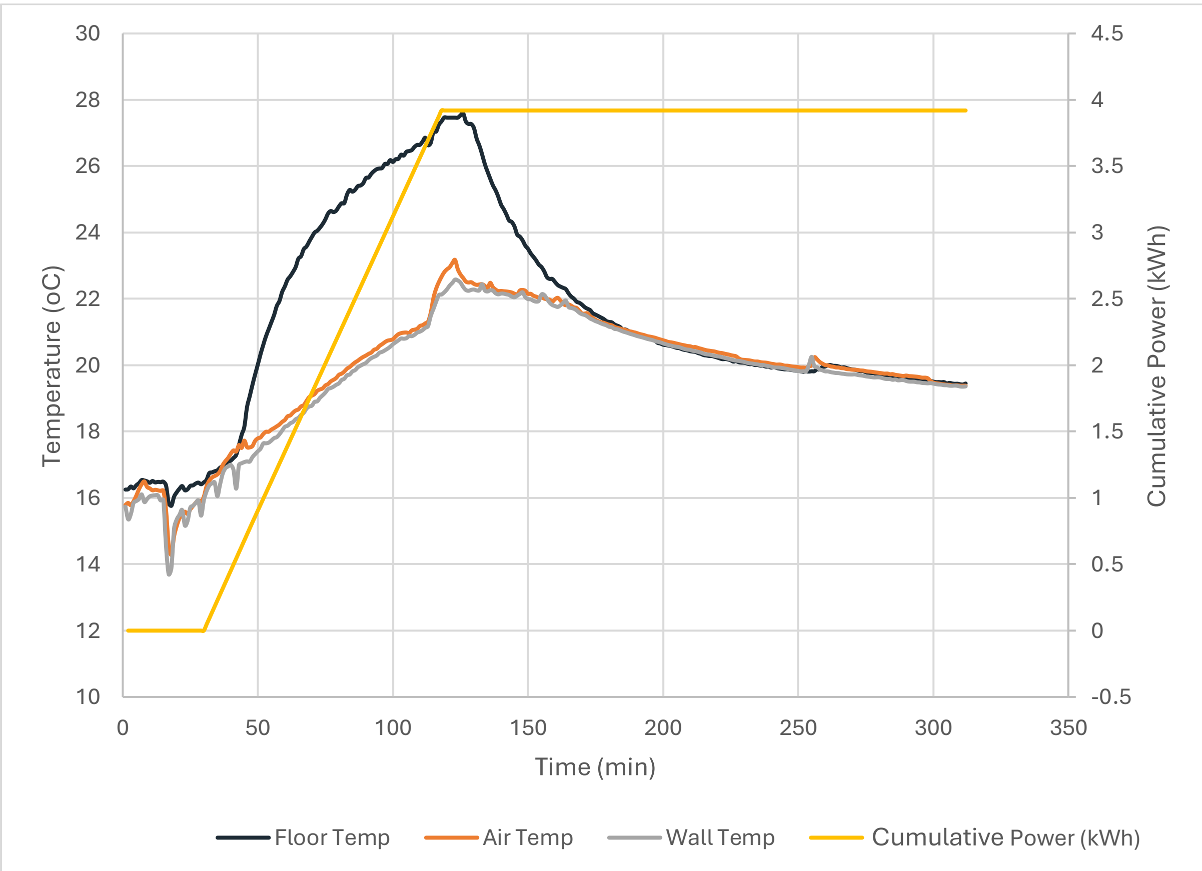


Figure 4: Heat-up curve for floor, air, and wall temperatures under JustHeat operation

Once powered, the system shows an immediate increase in floor temperature, rapidly followed by air and wall temperatures, confirming efficient heat transfer. In comparison, traditional systems exhibit lag due to thermal mass.

Additionally, the system consumes 4 kWh to reach the set point of 22°C, after which the power is disengaged. Thermal inertia of the floor sustains comfort temperatures with minimal cycling, reflecting efficient heat retention.

Figure 4 above shows when the power (yellow line) is switched on and sees a rapid increase in all temperatures (floor, air, wall). Traditional electrical wire systems can take to 3-4 hours to heat where JustHeat increased the air temperature by 3°C in 30 minutes. This indicates that the JustHeat system is working effectively and quickly transferring heat from the floor to the air uniformly. The floor temperature (black line) rises fastest, as expected from an underfloor heating system. The air and wall temperatures follow.

The total power consumption is 4 kWh, the system is then switched off with no further power supplied once the target temperature of 22°C is reached. The floor temperature rate starts to decrease as it reaches the panels temperature, whereas the air temperature increase rate is linear until the set point of the thermostat is reached, and the power is turned off. The floor temperature initially decrease quickly first but then levels off as the temperatures of the floor, air, and wall reach the same temperature, resulting in a gradual cool down. This is significantly slower than the initial air heating rate, reflecting the stored energy within the floor resulting in passive heat being radiated into the room, mitigating the heat losses to the environment. In this experiment, the cooling rate is x3 slower than the heating rate.

Claim 3: Energy Efficiency, Cost Savings, and Heat Retention

Testing demonstrated that JustHeat's design enables intermittent operation, typically 20 minutes per hour, due to heat retention in the floor mass. This reduces cycling frequency and energy use, a distinct advantage over gas powered radiators and ASHPs, which often operate continuously.

The underfloor system transfers heat to the flooring and furnishings, which can hold a large amount of heat which is then dispersed into the air. Therefore, the cooling of the room through heat escaping is mitigated through the slow radiating release of heat from the floor. This results in the time between each heating cycle increasing, reducing the amount of energy used. Over the course of several cycles across a day, this equates to efficient energy transfer and therefore cheaper bills.

Cool down Performance

The residual heat in the JustHeat heating system increases the time taken to decrease the temperature by 2°C by 3 hours across the same night period. When compared to other heating systems, the initial temperature decrease over the first 4 hours shows that the underfloor system drops in temperature twice as slow as directly heating the air.

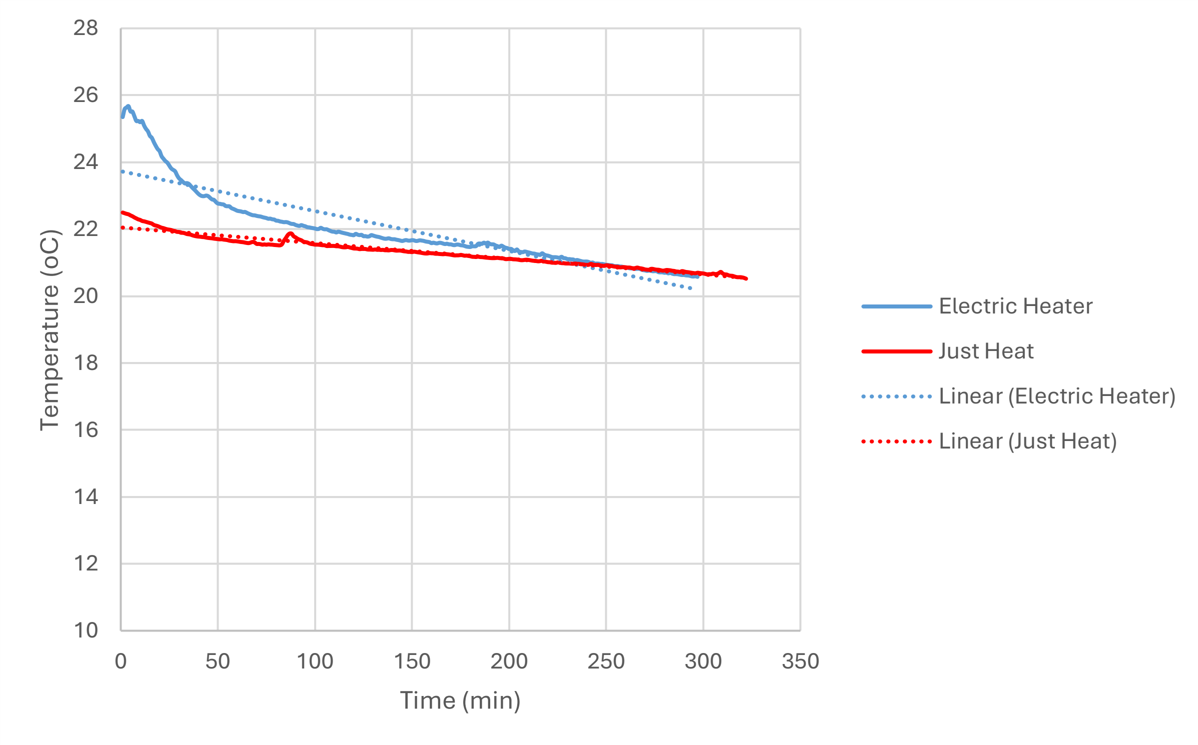


Figure 5: Cool down rates of an electric heater vs JustHeat system

The electric oil radiator (blue line) shows a faster rate of temperature decrease compared to the JustHeat (red line). This is evident in the steeper slope of its linear trendline. The JustHeat system maintains a more consistent and slower rate of temperature decrease, indicating better heat retention and reducing the energy required for reheating. The linear trendlines confirm the visual observation shown in figure 5, as the electric heater has not heated the floor. The electric heater's trendline has a steeper negative slope, indicating a faster rate of temperature loss. The JustHeat's trendline has a shallower negative slope, suggesting a slower rate of temperature loss and better heat retention. The JustHeat system provides a more stable and consistent heat output and cools down more slowly, indicating better heat retention.

Experimental cool-down data revealed that JustHeat extends the time required to reduce room temperature by 2°C by three hours versus the electric heater.

The slower cooling rate of the JustHeat underfloor heating suggests that it benefits from the thermal mass of the floor. The floor stores heat and releases it gradually, maintaining a more stable temperature. This can be further improved with thermal resistance underlay that typically is under modern flooring, as it improves the heat retention in the floor. While the slower cooling rate of JustHeat suggests that it requires less energy to maintain a desired temperature over time. The more stable and consistent temperature provided by JustHeat translates to a more energy-efficient and comfortable heating experience compared to gas boiler radiators. This performance significantly improves thermal comfort and reduces energy consumption.

Dynamic Cycle Testing Performance

Dynamic cycle testing allows for an average energy consumption to be made. Figure 6 represents operating a heating system at 21°C and 18°C respectively. Simulated occupancy cycling between 18°C and 21°C showed the system rapidly achieves target temperatures, then reduces power draw once saturation is reached. The system's thermal inertia reduces the need for continuous operation, leading to significant energy savings.

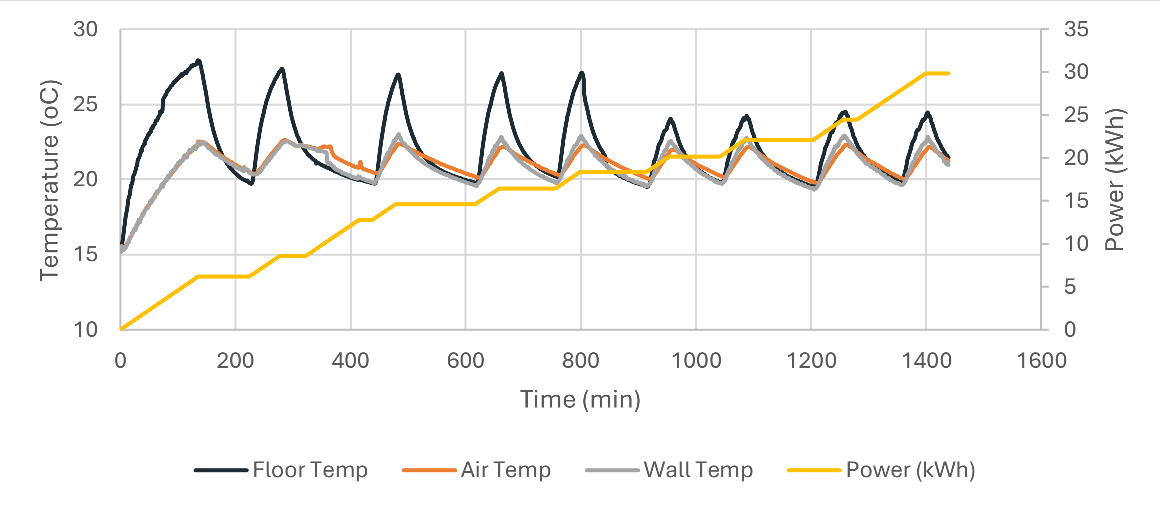


Figure 6: Simulated occupancy cycling between 18°C – 21°C

The power (yellow line) increases in steps, and the floor temperature (black line) rises rapidly, followed by the air and wall temperatures. This indicates the system is initially heating up the space and contents. The power consumption increases in steps as well, suggesting the system is using more power to quickly raise the temperature. Once the floor reaches its heat saturation point, the required floor temperature to achieve the desired air temperature is reduced. At this point the system needs less energy to maintain the temperature in the room. The lag between the power changes and the temperature changes reflects the thermal inertia of the floor and surrounding materials. It takes 200 minutes for the floor to heat up and cool down in the tested room, equating to one cycle.

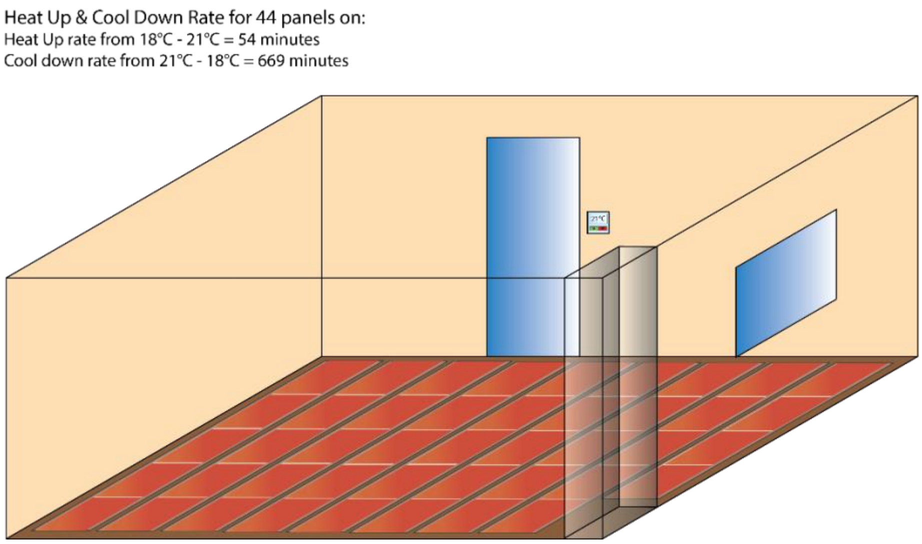


Figure 7: Schematic of the test room with the full set of panels

Experimental Data – Eden House, Jersey

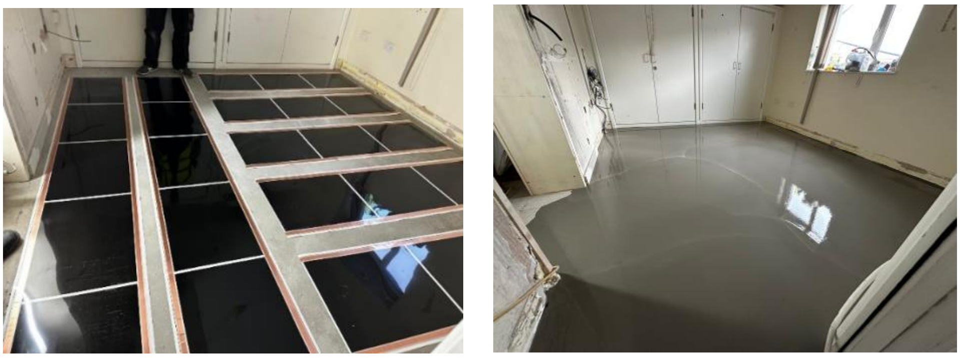


Figure 8: (Left) JustHeat mats placed in a zonal pattern at Eden House, Jersey (Right) Screed applied on top of mats.

A real-world deployment of JustHeat was completed in December 2024 at Eden House, a respite care home for disabled children in Jersey. The system was integrated with a system for remote monitoring and control.

During peak winter conditions, the system maintained a room temperature of 21°C with 50% less energy consumption than a comparable gas boiler system. This case study illustrates the system's practical efficacy, rapid thermal response, and the benefit of zonal heating.

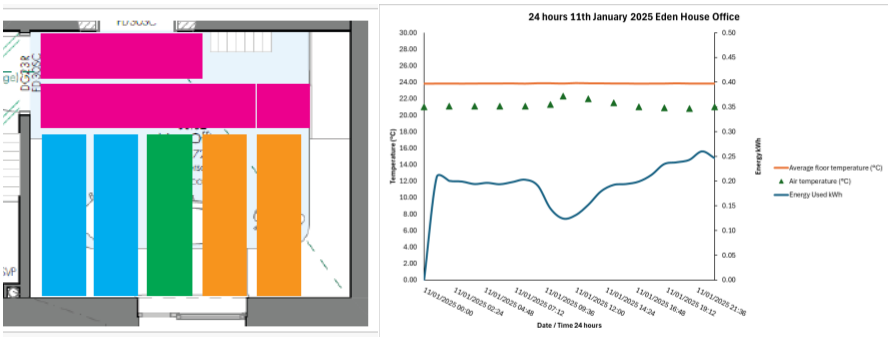


Figure 9: (Left) Floor plan zonal layout of Eden House Test room (Right) Floor temperature, air temperature and power consumption of Eden House Test room over 24 hours

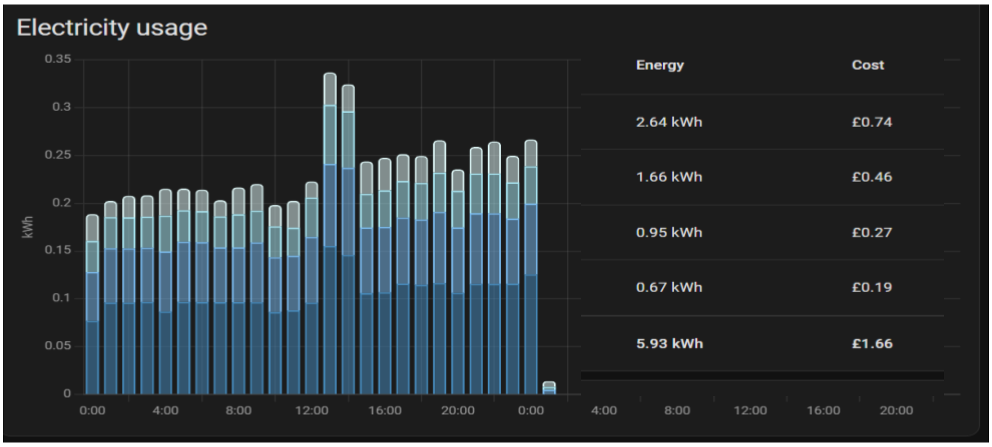


Figure 10: Typical energy usage for JustHeat system in January maintaining room at 21°C for 24 hours

Environmental Impact and Carbon Reduction Potential of the JustHeat System

The environmental performance of domestic and commercial heating systems is increasingly critical in the context of the UK's legally binding commitment to achieve net-zero carbon emissions by 2050. Heating accounts for approximately 17% of UK greenhouse gas emissions, primarily driven by the combustion of natural gas in domestic boilers (*Committee on Climate Change, 2019*). Reducing emissions from space heating is therefore a priority for building regulations, retrofit strategies, and future energy system planning.

Direct Carbon Emissions Comparison

Lifecycle modelling of heating systems reveals that the Haydale JustHeat system offers substantial carbon reduction benefits relative to both traditional gas boilers and other low-carbon heating alternatives such as (ASHPs and conventional electric underfloor heating.

The primary source of emissions from gas boilers is direct combustion of methane, producing approximately 184 g CO_2 per kWh of heat output (*BEIS, 2021*). Even high efficiency condensing boilers cannot mitigate this fundamental carbon intensity, particularly as boiler cycling and standby losses increase real-world emissions.

In contrast, the JustHeat system operates entirely on electricity and produces no on-site emissions. The carbon intensity of JustHeat is directly tied to the electricity grid's emissions factor, which is steadily declining due to renewable energy deployment. Based on current grid carbon factors and dynamic modelling, the annual carbon emissions for each system are estimated as follows:

System	Annual Energy Use (kWh)	Emissions Factor (kg CO_2/kWh)	Annual CO_2 Emissions (tons)
Gas Boiler	11,720	0.184	2.16
ASHP	6,000	0.081	0.49
Electric UFH	9,000	0.081	0.73
JustHeat	2,970	0.081	0.24

Table 3: Grid emissions based on 2023 UK average of 81 g CO_2/kWh (National Grid ESO, 2023)

Operational Advantages Driving Carbon Reductions

Several performance characteristics give JustHeat a significant environmental advantage:

Partial Hour Operation Reduces Absolute Energy Use:
JustHeat's ability to achieve thermal comfort with only 20 minutes of operation per hour reduces total energy consumption by more than 60% compared to continuously operating systems like Electric underfloor heating or ASHPs during cold conditions.

No Combustion or Point Source Emissions:
Unlike gas boilers, JustHeat eliminates combustion emissions entirely, reducing not only CO_2 but also NO_x and particulate matter, improving indoor air quality and reducing health impacts.

Thermal Inertia Reduces Cycling Losses:
The system's integration into the floor allows it to store heat and release it gradually, smoothing demand peaks on the electricity grid and minimising heat losses typical of water-based systems.

Compatibility with Renewable Energy Sources:
JustHeat is designed for DC operation, enabling seamless integration with on-site solar photovoltaic systems and battery storage. This allows homeowners to maximise the use of self-generated renewable electricity, further decoupling heating from carbon-intensive energy sources.

Future Grid Decarbonisation:
As the UK grid continues to decarbonise, the emissions associated with JustHeat will decline automatically, while gas boiler emissions will remain constant or worsen as methane leakage from supply chains becomes a larger factor. By 2035, with an anticipated grid intensity of 50g CO_2/kWh or lower, JustHeat's operational emissions could fall below 0.15 tonnes CO_2 annually, making it a near-zero carbon heating solution.

Embodied Carbon and System Longevity

An often-overlooked environmental factor is the embodied carbon associated with system manufacture, maintenance, and replacement cycles:

- Gas boilers require complex metal components, pumps, and regular servicing, contributing to embodied emissions.
- ASHPs add refrigerants with high global warming potential that risk leakage, further increasing lifecycle emissions.
- Conventional Electric underfloor heating often relies on plastic-encased resistive wires prone to failure, requiring invasive repairs.

The JustHeat system, in contrast, consists of plasma-functionalised graphene ink printed on a polymer substrate. With no moving parts, refrigerants, or complex mechanical systems, and requiring only minimal maintenance, it offers a long operational life, potentially 25 years or more, which significantly reduces replacement frequency and embodied carbon impacts. Furthermore, Haydale is actively developing advanced manufacturing processes designed to be carbon negative, utilising renewable energy and waste carbon capture techniques within production. These innovations will not only lower the embodied emissions of the JustHeat system but also contribute to a broader decarbonisation of heating technologies, positioning JustHeat as one of the first truly carbon-negative heating solutions available on the market.

Contribution to Net Zero and Future-Ready Heating

The combination of low operational carbon, minimal maintenance, and renewable compatibility makes JustHeat an ideal solution for the UK's transition to net-zero carbon heating:

- Retrofit ready: Easily installed in existing buildings, avoiding the need for costly deep retrofits or fabric upgrades required by low-temperature ASHP systems.
- Grid stability: By reducing peak demand through thermal inertia and flexible cycling, JustHeat supports grid stability as renewable generation increases.

- Low lifecycle carbon: Estimated lifecycle emissions are 50–80% lower than gas boilers and substantially better than ASHPs and EUFH.

The Haydale JustHeat system represents a step change in heating sustainability. By eliminating combustion, minimising energy consumption, and integrating with renewable energy, JustHeat delivers immediate and future-proof carbon reductions. It enables homes and businesses to decarbonise without sacrificing thermal comfort, while also preparing properties for evolving energy markets, carbon pricing, and regulatory requirements.

When assessed on carbon intensity, energy efficiency, and environmental impact, JustHeat outperforms traditional and emerging heating systems, making it a key enabler in the UK's pathway to a low-carbon, resilient, and sustainable heating future.

Conclusion

JustHeat – A Future-Ready, Low-Carbon Heating Solution

The detailed technical, economic, and environmental analyses presented in this white paper demonstrate that the Haydale JustHeat graphene-based underfloor heating system represents a significant advance in heating technology. It combines rapid thermal responsiveness, uniform heat delivery, low energy consumption, and exceptional carbon reduction potential in a single, scalable solution.

Where conventional gas boilers remain dependent on fossil fuels and contribute significantly to greenhouse gas emissions, JustHeat eliminates combustion entirely, removing direct CO_2 emissions, NO_x, and particulate matter from domestic and commercial heating. Compared to ASHPs, which suffer from high capital costs, seasonal performance drops, and refrigerant risks, JustHeat offers greater efficiency, lower installation complexity, and superior compatibility with renewable energy systems.

Compared to traditional Electric Underfloor Heating, JustHeat fundamentally changes the energy consumption profile of electric heating. By leveraging graphene's unique thermal properties, the system achieves rapid heat-up times and maintains comfort with partial-hour operation, typically heating for just 20 minutes each hour. This innovation cuts total energy consumption by more than 60% compared to continuously operating systems, delivering annual running costs and carbon emissions far below other electric solutions.

Economic Advantage and Payback Certainty

Lifecycle cost analysis confirms that JustHeat is the most cost-effective solution over system life, delivering lifetime savings of over £20,000 compared to gas boilers, £50,000 compared to ASHPs and nearly £19,000 compared to Electric UFH. Remarkably, even against ASHPs, often considered the benchmark for low-carbon heating, JustHeat offers a lower lifetime cost without requiring invasive structural changes or complex refrigerant-based systems.

The payback period modelling illustrates that JustHeat recovers its installation cost premium relative to Electric UFH in just three years, driven entirely by reduced energy consumption. Against both gas boilers and ASHPs, the system is economically advantageous from day one.

Environmental Impact and Carbon Resilience

From a carbon perspective, JustHeat significantly outperforms all alternatives. Current modelling shows annual emissions of just 0.24 tonnes CO_2, compared to 2.16 tonnes from gas boilers, 0.73 tonnes from Electric UFH, and 0.49 tonnes from ASHPs. As the electricity grid decarbonises, the carbon intensity of JustHeat will continue to fall, making it effectively zero-carbon heating by the mid-2030s.

Sensitivity analysis confirms that even under varying energy price and carbon intensity scenarios, JustHeat remains the lowest-emission and lowest-cost option. Its compatibility with on-site renewable generation, DC operation potential, and minimal maintenance requirements make it ideally suited for a future of flexible, distributed, low-carbon energy systems.

Haydale is actively developing advanced manufacturing processes designed to be carbon negative, utilising renewable energy and waste carbon capture techniques within production. These innovations will not only lower the embodied emissions of the JustHeat system but also contribute to a broader decarbonisation of heating technologies, positioning JustHeat as one of the first truly carbon-negative heating solutions available on the market.

Delivering Comfort, Control, and Sustainability

Operationally, JustHeat delivers superior comfort through uniform heat distribution, rapid thermal response, and stable indoor temperatures. Its ability to utilise the thermal mass of the floor reduces temperature fluctuations and cycling losses, enhancing both comfort and efficiency. Unlike gas and ASHP systems that heat air or water and suffer distribution losses, JustHeat heats the space directly, with no intermediary fluids or complex mechanical systems.

Installation is simple, modular, and non-invasive—making it perfect for both new builds and retrofits, especially in properties where ASHPs are impractical or cost-prohibitive. JustHeat is also uniquely positioned to support emerging energy models, including dynamic grid balancing, demand response programs, and full electrification of buildings.

A Critical Enabler of the Net-Zero Future

Heating is one of the most challenging sectors to decarbonise. Haydale's JustHeat system directly addresses this challenge by offering a technology that is:

- Lower cost over its lifetime than gas, ASHP, and electric alternatives
- Easier to install, maintain, and control
- Capable of cutting operational carbon by up to 90% compared to gas
- Ready to integrate seamlessly with renewables, battery storage, and future smart grids

With governments phasing out new gas boiler installations and tightening emissions targets, solutions like JustHeat are not just advantageous—they are essential.

Final Statement

Haydale's JustHeat graphene underfloor heating system redefines what is possible in sustainable heating. It combines cutting-edge material science with practical engineering to deliver a heating solution that is more efficient, more comfortable, more affordable, and more environmentally responsible than anything currently available.

In an era of rising energy prices, growing carbon constraints, and urgent climate action, JustHeat offers property owners, developers, and policymakers a proven, future-ready pathway to decarbonise heat while enhancing the lived experience within homes and buildings.

The evidence is clear: JustHeat is not just a better heating system, it is the right solution for the future.

Legal Disclaimer

The results and conclusions presented in this technical White Paper are based on in-house testing conducted by Haydale Limited on our proprietary JustHeat heating system. These findings have not been verified by any third-party organisations. While we strive to ensure the accuracy and reliability of our testing methods, Haydale Limited makes no warranties or representations regarding the completeness, accuracy, or reliability of the information contained herein. No third party shall rely on the information contained in the White Paper and Haydale Limited shall not be held liable for any damages or losses arising from the reliance on information contained in the White Paper. All of the figures used within the White Paper are effective as of 2nd April 2025.

Appendix

System Overview

The heater mat consists of a layered structure, giving a low flat profile. Graphene heater ink is printed onto a polymer substrate patterned in such a way to give individual heater panels of 600 mm by 530 mm with 30 mm gaps. Two silver ink stripes are then screen printed on top of the heater ink to promote electrical contact, and a copper foil strip is adhered to the top insulative layer which run parallel to the heater to form a conductive busbar.

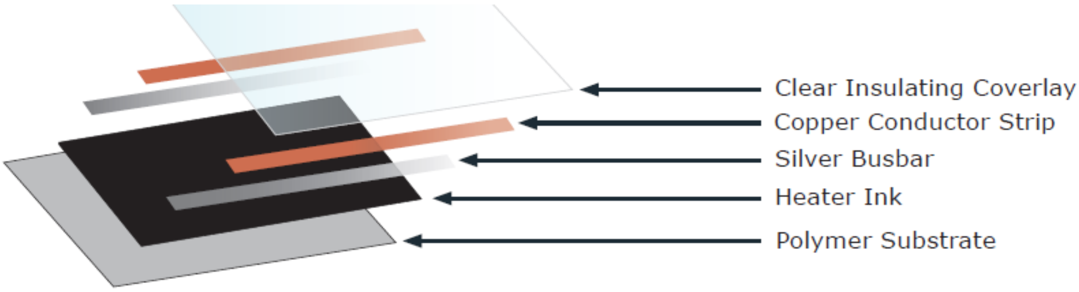


Figure 11: Exploded diagram of JustHeat Underfloor heating panel

A proprietary connector is used to connect the heater to the control circuit. The contents of a heating system are provided by Haydale in the form of a kit, which can be easily and quickly installed by a qualified electrician.

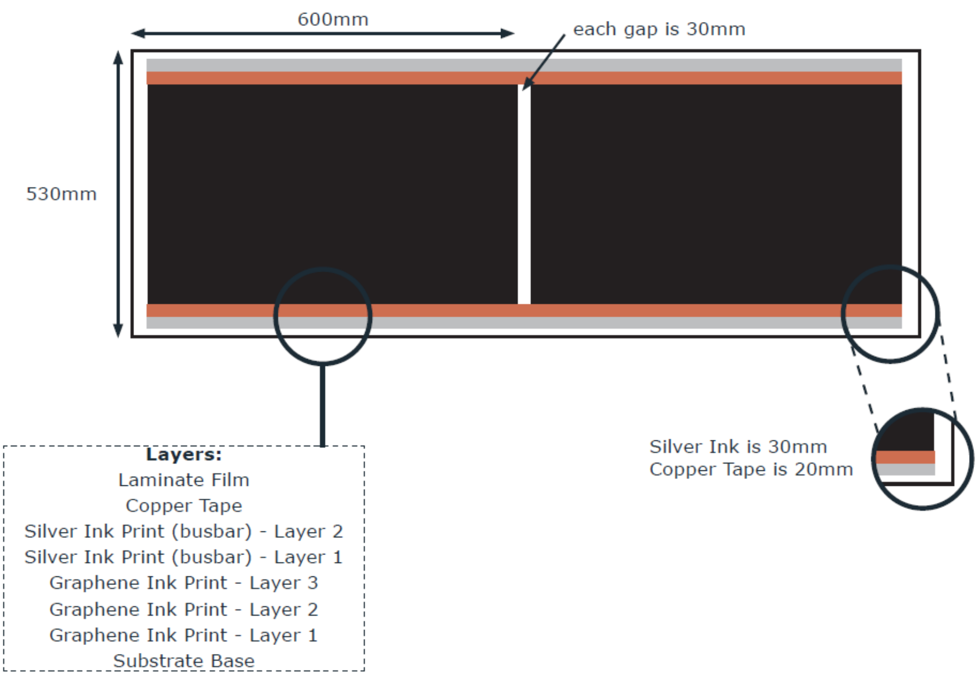


Figure 12: Top-down view of JustHeat Underfloor heating roll, two segments

Further Enhancements – Zoning

To further improve the energy efficiency of the JustHeat panels, zones can be added to each room meaning that certain sections can be turned on, without supplying other areas with electrical power. This simulates being able to control the distribution of heat to accurate locations within a room. This can be seen in the figure below, with the 2 different zones being turned on, as seen by the brighter areas.

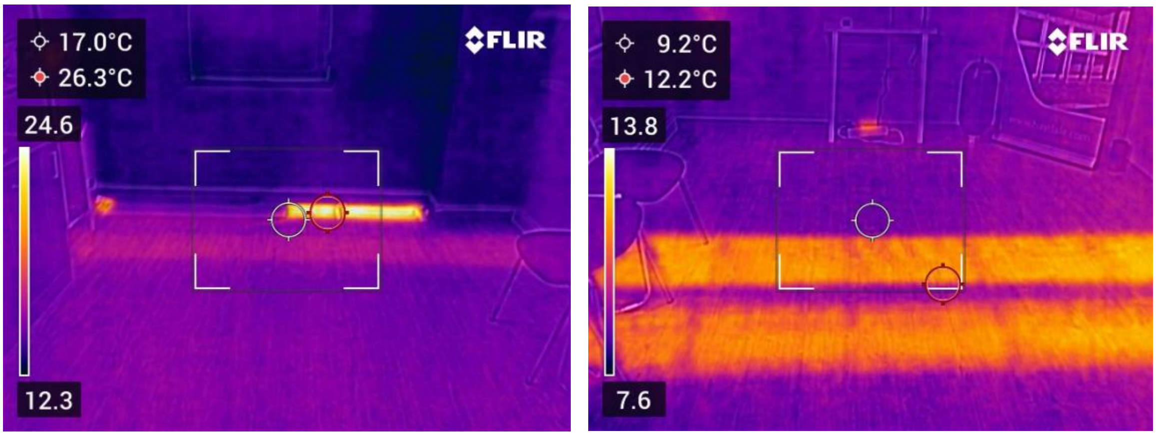


Figure 13: (Left) Control of single JustHeat zone being heated (Right) Control of two JustHeat zones being heated

The distibution of the zones wihtin the tested room can be seen in the diagram of figure 13 with real world evidence of figure 13 showing zones 1 and 3 being heated, while zones 2 and 4 were left off. Zoning has also proven effective in the Eden House case study with heaters positioned in different directions enabling zones of different size and shape in figure 9.

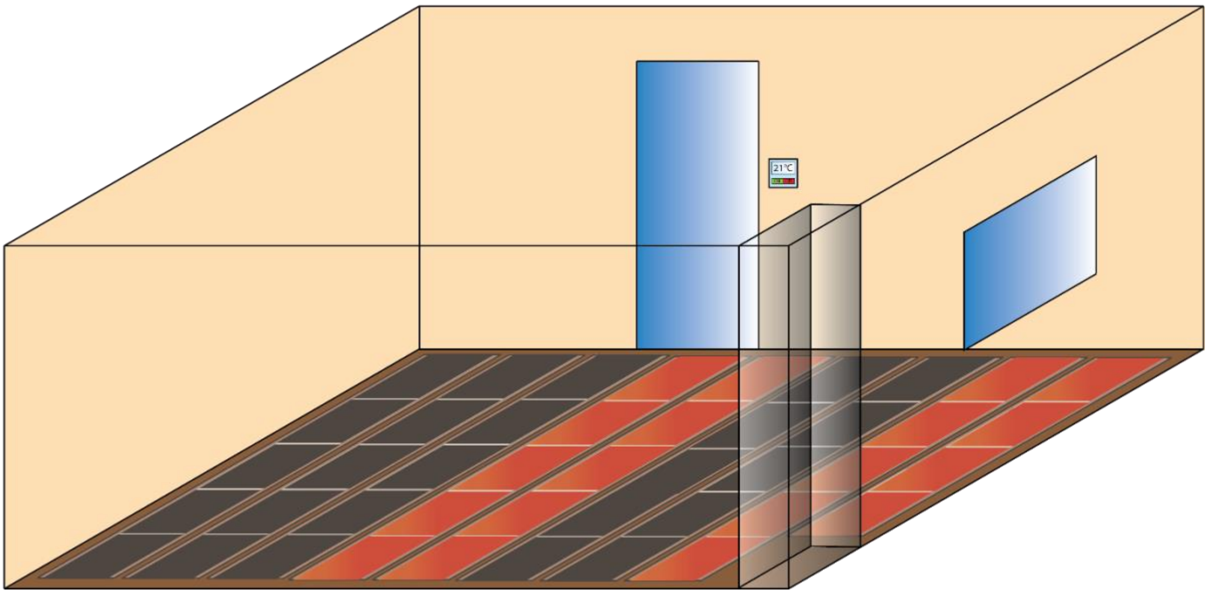


Figure 14: 3D projection of zonal heating in Haydale Demo Room

Methodology

This section outlines the methodology employed to evaluate the performance of an underfloor heating system installed in a dedicated demonstration room. The study focused on assessing the system's ability to achieve and maintain target temperatures, its thermal response time, and its energy consumption under simulated operating conditions.

Test Environment:

The test was conducted in a purpose-built demonstration room designed to replicate a typical residential space. The room's dimensions were L=5.4 m, W=3.3 m, H=2.4 m, 17.2m^2 available floor area, total airspace volume 42 m^3. With 2 outward facing, hollow brick walls and 2, inward facing plasterboard walls. The floor consists of a MDF floor covering and a false ceiling using ceiling tiles. The room has a single window of 81 cm x 108 cm of double glazing and a fire door 198 cm x 84 cm. The room was designed to minimise external environmental influences and maintain a controlled ambient temperature.

Figure 15: (Left) JustHeat Underfloor Heating Panels, (Right) Completed Demo Room at Haydale, Ammanford

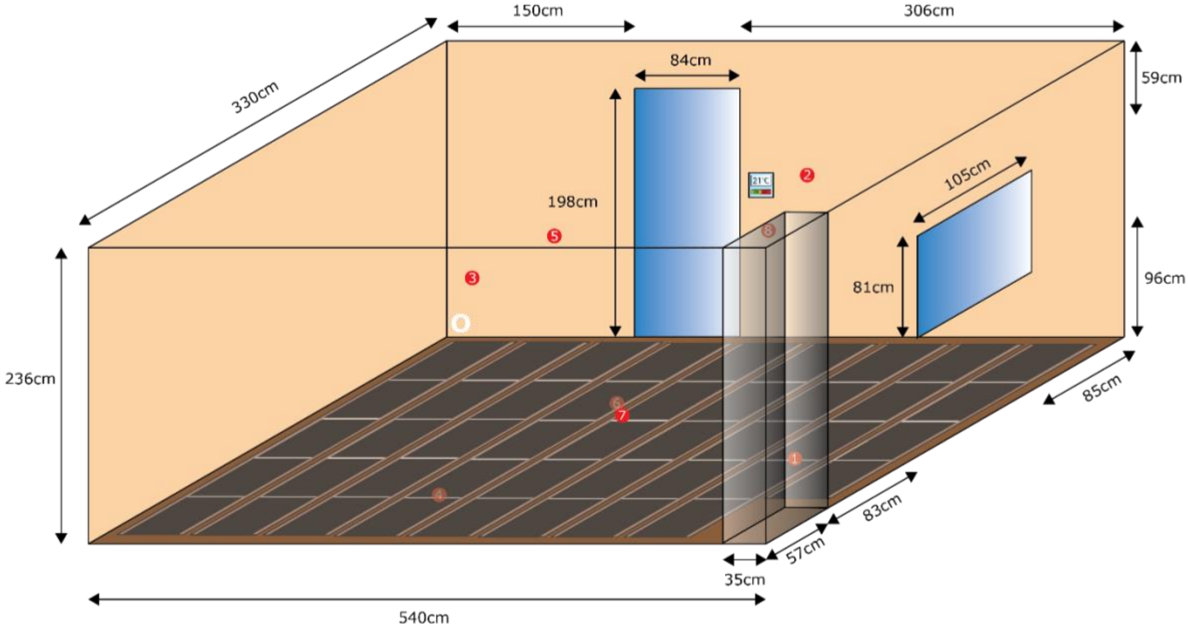
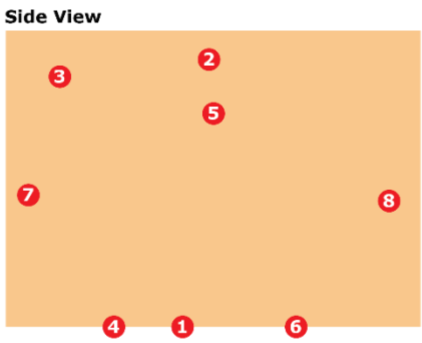
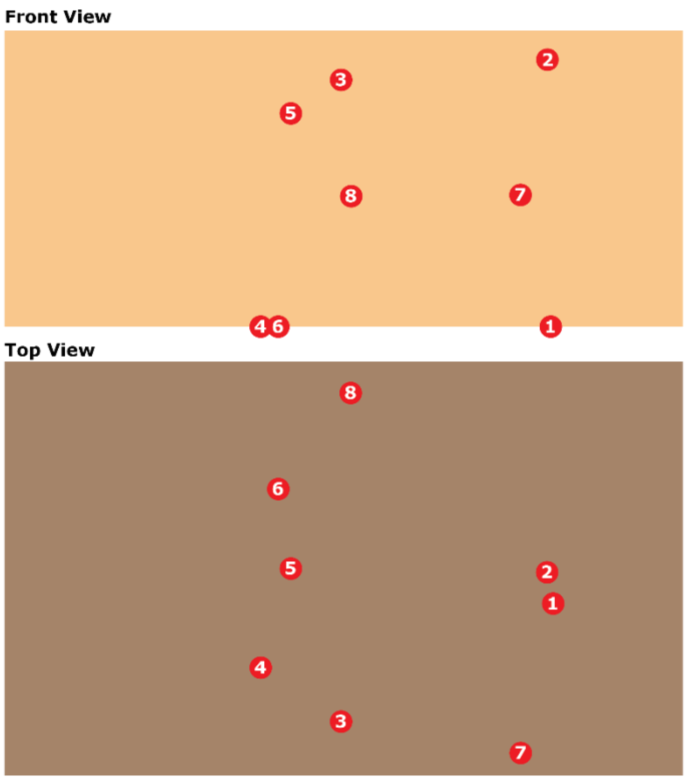


Figure 16: 3D Projection of Demo room, with location of thermocouples 1 -8





Coordinates / Sensor No.	X	Y	Z
① Temperature 1	437	189	0
② Temperature 2	432	168	215
③ Temperature 3	268	287	197
④ Temperature 4	204	244	0
⑤ Temperature 5	228	164	170
⑥ Temperature 6	218	99	0
⑦ Temperature 7	411	312	105
⑧ Temperature 8	276	25	103

Figure 17: Side, Front and Top-down view of Thermocouples in demo room

Underfloor Heating System

The system was installed with 44 heating panels (each 0.32 m^2) covering total area of 14 m^2 of the floor surface. However, in some experimentation, only 19 out of 44 panels were connected to demonstrate the energy efficiency capabilities of the technology.

Test Parameters

The following parameters were measured and recorded during the test:

- **Room Air Temperature:** Measured using sensors positioned at specific locations as described above.
- **Floor Surface Temperature:** Measured using thermocouples affixed onto the floor heater but under the floor surface.
- **System Power Consumption:** All mats were powered by a 600 W power supply controlled by a Shelly Smart Relay which connected to Home Assistant to control thermal setpoints.
- **Time:** Recorded using a synchronised date/time stamp system.
- **Software:** Control and energy data capture was conducted by Home Assistant, an Open-Source home automation software from Nabu Casa.

Test Procedure

The test was conducted in a series of controlled scenarios to evaluate different aspects of the system's performance.

Warm-up / Cooldown Time Test: The system was initiated from a cold start of 15°C with a target air temperature of 21°C. The time taken for the room temperature to reach and stabilise at the target temperature was recorded and the rate of heating was calculated from the gradient of the delta of the start and finish temperature. The heating was turned off and the resulting cooldown time and rate was calculated.

Temperature Stability Test: Once the target temperature was achieved, the system was allowed to operate for a sustained period. Room temperature, floor surface temperature, and power consumption were continuously recorded to assess temperature stability and energy usage.

Simulated Occupancy Test: A simulated occupancy schedule with varying temperature setpoints were implemented to assess the system's response to dynamic changes in heating demand. This involved cycling between different setpoints to mimic typical daily usage patterns.

Energy Consumption Analysis: The total energy consumption of the system during each test phase was calculated and analysed to determine the system's efficiency.

Data Acquisition and Analysis

Data from all sensors were collected and logged using a data logger with a sampling rate of 1 minute interval sampling rate. The collected data was then processed and analysed using Home Assistant and Excel to generate graphs, charts, and statistical summaries.

Calibration and Accuracy

All temperature sensors and measurement devices were calibrated against traceable standards prior to the commencement of testing. The accuracy of the measurements was within 1°C of expected values.

Limitations

It is important to acknowledge that the JustHeat tests were conducted in a controlled demonstration environment, and the results may not be directly applicable to all real-world scenarios. Factors such as building construction, insulation levels, and external environmental conditions can significantly impact the performance of an underfloor heating system. However, this controlled test provides valuable insights into the system's fundamental characteristics and performance capabilities.

It is important to acknowledge that the boiler tests were conducted in a sample house where all rooms apart from a living room of similar size to the demonstration room were turned off and the heating trial was conducted. Factors such as building construction, insulation levels, and external environmental conditions can cause variations within the data. However, this controlled test provides valuable insights into the system's fundamental characteristics and performance capabilities.

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