Research into Heat for Non-Domestic Buildings

Final Report

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Executive summary

- The Scottish non-domestic building stock comprises over 220,000 buildings, but there is currently a lack of publicly available data to reliably characterise these, particularly with respect to heating systems.

- To explore issues around developing and operating Zero Direct Emissions Heating (ZDEH) systems, stakeholders in non-domestic Scottish buildings with successful ZDEH installations were interviewed and 20 case studies produced.

- Through the process of identifying the case studies, a longlist of over 140 existing or proposed buildings with ZDEH were identified (with thousands more listed in EPC registers), across a broad range of scales, organisations and locations in Scotland.

- Capital costs, site constraints, and soft factors were the main barriers impacting ZDEH across the case studies. However, given the inherent bias to the case studies being successful examples of ZDEH installations, other barriers to ZDEH adoption are likely.

- Most case studies cited grant funding and/or incentives as drivers to enable the ZDEH installation. National, local and internal policy, specifically regarding the climate crisis, and desires for positive end-user impacts were other strong drivers.

- Stakeholder experiences of drivers and barriers for adopting ZDEH in their buildings, varied across different types of buildings, tenure, organisations, and locations.

- Snagging was a common issue, although very few experienced major and unexpected maintenance requirements. Dissatisfaction with heat control was noted by sites with manually operated direct electric heating systems, but most case studies did not report issues with running costs.

- There was a lack of real running cost data available from case studies due to a lack of submetering and limited timescales of this research. This resulted in limited numerical evidence to support the qualitative findings regarding ZDEH running costs.

List of abbreviations

ASHP	Air Source Heat Pump
BMS	Building Management System
BREEAM	Building Research Establishment's Environmental Assessment Method
CARES	Community and Renewable Energy Scheme
CHP	Combined Heat and Power
COP	Coefficient of Performance
DHN	District Heat Network
DNO	Distribution Network Operator
EPC	Energy Performance Certificate
GSHP	Ground Source Heat Pump
LEED	Leadership in Energy and Environmental Design
LCITP	Low Carbon Infrastructure Transition Programme
MVHR	Mechanical Ventilation with Heat Recovery
NBHS	New Build Heat Standard
RHI	Renewable Heating Incentive
SEEP	Scottish Energy Efficiency Program
SBEM	Simplified Building Energy Model
SME	Small and Medium Enterprise
VRF	Variable Refrigerant Flow
WSHP	Water Source Heat Pump
ZDEH	Zero Direct Emission Heating
ZWS	Zero Waste Scotland

Table of contents

Executive summary 4
List of abbreviations 5
Table of contents 6
1. Background 7
a. Policy context 7
b. Research aims 7
2. Project Scope 9
a. Methodology 9
b. Technology Scope 10
c. Case study characterisation 10
d. Limitations of this research 11
3. Heat in the Scottish building stock 12
a. Overview 12
b. EPC register 12
c. RHI data 13
4. Experiences of adopting zero emissions heating 14
a. Techno-economic factors 15
b. External factors 18
c. Soft Factors 19
d. Overarching differential experiences 20
5. Impacts of installing zero emissions heating 23
5.1 Overview 23
b. Impacts on operation 23
6. Conclusions 27
Appendix A. Case Studies 30
Appendix B. Data Collection 33
Appendix C. Confidential - Case Study Contacts**Error! Bookmark not defined.**
Appendix D. Longlist of Scottish buildings with Zero Emissions Heating 38
Appendix E. Historical operational costs for ZDEH and fossil fuel alternatives 48

1. Background

a. Policy context

A major challenge that must be addressed in order to meet Scotland's target of net zero greenhouse gas emissions by 2045 is the decarbonisation of heat in buildings. Until its closure in 2021, the main incentive for heat decarbonisation across the UK was the Renewable Heat Incentive (RHI), which provided payments for renewable heat generation in buildings. In Scotland, renewable heat has also been incentivised by the Zero Waste Scotland (ZWS) SME Loan Scheme, with further initiatives available for domestic properties.

As set out in the Scottish Government's Heat in Building Strategy[1], the incoming New Build Heat Standard (NBHS) will mandate the use of Zero Direct Emissions Heat (ZDEH) technologies in all new buildings applying for a building warrant from 2024. The policy definition of ZDEH is understood to include any technology which provides heat (or cooling) with zero direct emissions (within the curtilage of the building) under normal operation. Technologies included in this scope are direct electric systems, heat pumps, heat network connections, and potentially hydrogen. Biomass combustion is not classed as ZDEH, but it is an established source of renewable heat in Scotland. Due to concerns around the air quality impacts of biomass combustion and priorities over the use of our biomass resource, the Scottish Government is currently deciding under what circumstances, if any, biomass combustion will be allowable under NBHS and other regulations.

In the Strategy the Scottish Government has also committed to regulations to decarbonise heat in existing non-domestic buildings from 2025. Aside from new builds (and domestic buildings, which are not within the scope of this research), the approximately 220,000 existing non-domestic buildings in Scotland must be decarbonised. Although a complete dataset of this stock is not currently available, the Scottish Government estimates that approximately half of these buildings are already heated by traditional direct electric (which until recently has not been considered as a ZDEH technology) or to a lesser extent other ZDEH technologies. The majority of these buildings use electrical heating, either in the form of direct electric, reversible air conditioning or Variable Refrigerant Flow (VRF) systems. Only a very small proportion currently use heat pumps and heat network heating systems that potentially offer the lowest operational cost for ZDEH systems. Therefore, it is anticipated that insight can be obtained from early-movers of new ZDEH systems as to how the rest of Scotland's buildings can successfully implement ZDEH by the Government's 2045 target.

b. Research aims

Locogen were appointed by the Scottish Government to undertake a research project investigating best-practise installations of ZDEH systems in non-domestic buildings to inform the regulatory approach for the non-domestic buildings. The three goals of the research are:

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[1] Scottish Government, Heat in Buildings Strategy, 2021

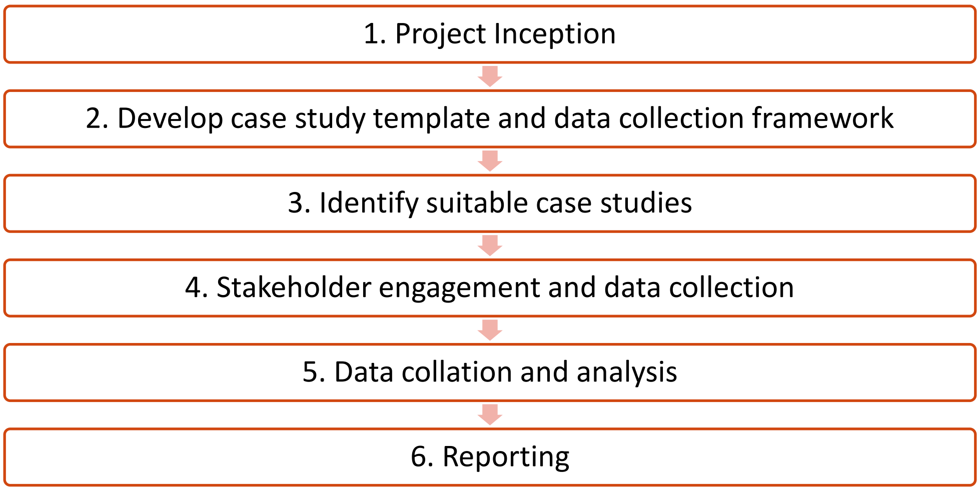
- To produce at least 14 case studies for new-build, non-domestic buildings with best-practice ZDEH technology installations.
- To produce at least 6 case studies for existing non-domestic buildings with best practice ZDEH technology installations.
- To identify any barriers to installation (including reasons why ZDEH are not being installed in certain classes of new builds, if found to be true),
- To understand the impact that switching to ZDEH technologies will have on the operation of existing non-domestic buildings.

This report provides a summary of the findings from the case studies, namely the barriers and drivers to installation and the impact of retrofitting ZDEH technologies.

2. Project Scope

a. Methodology

To meet the aims of this research (as outlined Section 1) the following methodology was used:



i. Project inception

At the initiation of the project in January 2022, Locogen and the Scottish Government project teams met virtually to agree the aims, definitions and scope of the research.

ii. Develop case study template and data collection framework

We carried out secondary research to find examples of 'best practice' case study dissemination templates. From this critique, we created a template, based on the objectives of this research, for presenting the case studies and this was agreed upfront with the Scottish Government. We also created a data collection template that would be sent to stakeholders to collect real world data on ZDEH systems. These templates were used as a foundation for collecting qualitative and quantitative information through the course of the project.

iii. Identify suitable case studies

We created a long list of potential case studies from primary research, utilising our network of contacts across the Scottish building industry, as well as secondary research to expand the search as far as possible. We categorised the long list of buildings identified and created a shortlist of buildings to showcase as case studies, based on a set of criteria developed in collaboration with the Scottish Government. The shortlist of buildings was agreed with the Scottish Government prior to data collection.

iv. Stakeholder engagement and data collection

A contact log, discussion guide and data collection templates were created ahead of stakeholder engagement to facilitate the interviews. For each case study, interviews with developers, owners and/or occupants were held to obtain as full an understanding as possible of the drivers and barriers of selecting ZDEH, the installation process and the technology's performance. For each case study, a project information questionnaire was issued to collect numerical data (included in Appendix B).

v. Data collation and analysis

Following the stakeholder engagement, the themes and trends were identified from the qualitative and quantitative information gathered, to provide insights regarding the installation of ZDEH technologies.

vi. Reporting

We created 20 case studies to showcase ZDEH in non-domestic buildings. The insights gathered across the case studies on the barriers, drivers and impacts of adopting ZDEH have been presented in this report and in the accompanying excel document which collates the quantitative data from case studies.

b. Technology Scope

i. Considered technologies

At the inception meeting, the following technologies were deemed in scope for this research:

- Heat pumps (excluding gas or hybrid versions)
- Direct electric heating
- District heat networks (DHNs)
- Biomass boilers

Importantly, biomass boilers are not a ZDEH, but they been included in the scope of this work, where examples of other technologies were not available to create case studies, since they are commonly used.

ii. Other technologies

After discussions with the Scottish Government, the following technologies were deemed out of scope for this research. This was due to the technologies not providing a full heating solution, not being of interest to the new building standards, or too innovative to consider in this research:

- Solar Thermal
- Waste heat (other than in DHNs)
- Variable Refrigerant flow (VRF) systems
- Hydrogen boilers

c. Case study characterisation

A range of buildings were selected to profile in the case studies as examples of ZDEH in non-domestic buildings. Theses selected to demonstrate a range of technologies, across different organisations, building types and tenure, locations and based on availability of building owners and operators that we could talk to within the limited time available to complete the study. The tables in Appendix A provide a summary of the 20 case studies selected.

d. Limitations of this research

There are a number of limitations of this research that need to be taken into account. As outlined in Section 1 and Section 3, there are approximately 220,000 existing non-domestic buildings in Scotland and there are no robust datasets to characterise heat in the non-domestic building sector. As only 20 case studies have been researched (from a long list of 137 buildings identified, Appendix A), it is not possible to determine the extent to which the case studies are representative of the Scottish non-domestic building stock.

The insights gathered include qualitative and anecdotal evidence from a range of building stakeholders, including project managers, owners, occupants, engineers and consultants, with a range of experience, expertise and understanding of the heating system. Additionally, it is evident that not all buildings fit neatly into a newbuild or retrofit category, or into a single planning class. Additionally, one of the aims of this research was to consider the barriers to adopting ZDEH.

However, there is an inherent bias in the data collected, in that the buildings identified all successfully installed ZDEH and therefore did not encounter any barriers that were significant enough to block the adoption of ZDEH altogether.

This research was conducted over a short timeframe. Whilst every effort was made to select case studies across all non-domestic planning categories and a range of technologies, locations, and building sizes, the selection process prioritised stakeholders who were willing to engage within the timeframe. Difficulties were encountered in this process as various stakeholders from fast food and large retail chains declined to participate in the study. Ultimately, it was not possible to source a case study for a fast-food restaurant. Furthermore, some stakeholders did not want to participate due to negative experiences with, or lack of knowledge of, their heating systems. As such, lessons learned from case studies that experienced significant challenges have been missed. Conversely, some participating case studies provided fewer learnings, and/or quantitative data than requested and anticipated. This is due to a various factors including, the implementation process being externally managed, because the ZDEH system operated very well and there was limited feedback to provide, due to stakeholders not being able to provide the data and insight within the short timescales.

3. Heat in the Scottish building stock

a. Overview

There are several publicly available data sources that provide insight on the mix of heating systems adopted in the existing non-domestic building stock. These are the Scottish EPC register and statistics from BEIS regarding RHI accreditations to date, although neither can be relied on to fully represent the current situation. These sources were examined for this project during the process of identifying case studies. Although neither proved valuable to this process, a high-level assessment of the information that they contain provides an understanding of why it is difficult to characterise heat in the Scottish building stock based on publicly available information.

b. EPC register

The Scottish EPC register contains data from the EPC certificates of 50,835 non-domestic buildings from 2013 until the end of the most recent quarter. The register only represents approximately a quarter of the non-domestic building stock, meaning the available data is not wholly representative of the total building stock. Unfortunately, EPC data does not indicate whether the heating technology was originally in place or if it was retrofitted.

Figure 1 below details the mix of technologies among the 49,358 buildings which are noted to have a main heating fuel (as opposed to being ‘unconditioned’). It indicates that over half of buildings on the register are already operating with zero direct emissions from their main heating fuel, as they are heated either by heat pumps, electricity, district heating schemes or waste heat.

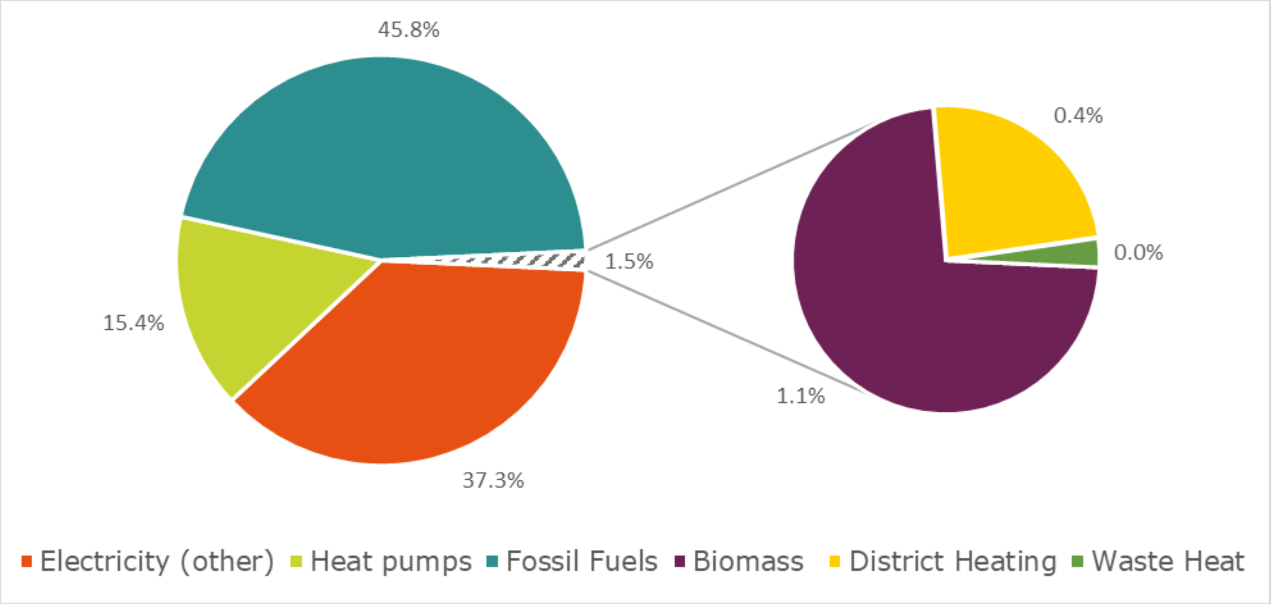


Figure 1: Technology mix of main heating fuel for 49,358 buildings’ EPCs. Alt = Pie chart break down; 45.8% Fossil fuels, 37.3% Electricity, 15.4% Heat pumps, 1.5% other including Biomass, District Heating and Waste Heat.

c. RHI data

The non-domestic RHI statistics from 2011-2021 indicate that there have been 4,123 accredited RHI applications in Scotland. Figure 2 below indicates that nearly 90% of these applications, approximately 3,700, have been for biomass boiler systems. This is 7 times more than is registered in the EPC database (because the installation of a new heating system would not necessarily necessitate a revised EPC). Conversely, approximately 360 applications were logged for heat pumps, which is only 5% of the number in the EPC register. Together, these values exemplify the risk of relying on either dataset to characterise Scottish building stock.

The prevalence of biomass boilers among the RHI applications can be explained by two factors. Firstly, historical RHI payment rates favoured biomass boilers over other technologies. Additionally, biomass boilers are, in most cases (and as discussed subsequently) the easiest renewable heating technology to retrofit into existing buildings with incumbent fossil fuel boilers.

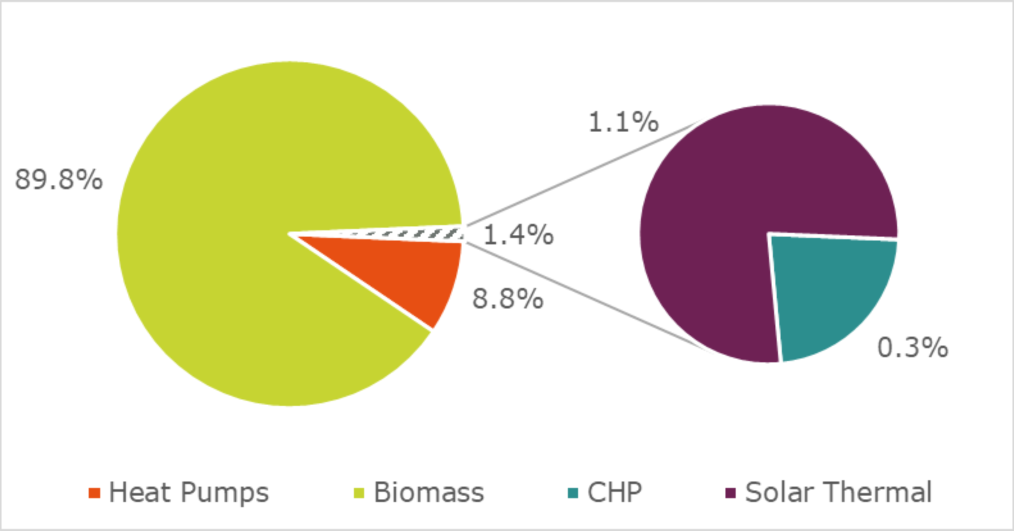


Figure 2: Technology mix of 4,123 accredited Scottish RHI applications since 2011. Alt = Pie chart break down; 89.9% Biomass, 8.8% Heat Pumps, 1.1% Solar Thermal and 0.3% CHP.

Unlike the EPC register, the RHI data breaks down the heat pump category by heat source. The accredited applications made for heat pumps since 2011 are split as follows:

- Air source: 30%
- Ground source: 64%
- Water source: 6%

Whilst these values clearly show that the majority of accredited applications were made for ground source heat pumps, it is not possible to ascertain if this split is representative of the spread of heat pump installations in Scotland.

4. Experiences of adopting zero emissions heating

The stakeholder experiences of adopting ZDEH across the 20 case studies varied. Whilst the scope of our research was to identify barriers to adopting zero-emissions heating, it was clear from the stakeholder interviews, that most barriers could also act as drivers for ZDEH. Given that all case studies showcased 'successful' implementation of ZDEH, this is not surprising. However, it is important to note that this creates an inherent bias to the following analysis, in that no barriers were insurmountable, since all ZDEH systems were installed.

We identified multiple factors which impact adopting ZDEH systems in non-domestic buildings, via the stakeholder interviews, which can be grouped into the eight categories below. The table below provides a brief description of the drivers and barriers and an overall score across all 20 case studies. The low, medium, high score is qualitative and represents the strength of the barrier or driver based on a count of explicit or implicit statements relating to the driver or barrier.

Table 1: Summary of the drivers and barriers to adopting zero direct emissions heating in non-domestic buildings across 20 case studies. The 'overall rating' is based on the count of stated issues across case studies (low occurring in 0-5 case studies, medium 6-10, high 11+).

Factors	Description	Barrier Rating	Driver Rating
Capital costs	The upfront cost of ZDEH compared to alternatives, which can impact the financially unfeasible project.	🟥🟥🟥 High	🟥▨▨ Low
Financial Incentives	The availability of financial grants or ongoing incentives that enable a ZDEH to be installed.	🟥▨▨ Low	🟥🟥🟥 High
Operational costs	The ongoing running costs and maintenance requirements of ZDEH compared to alternatives.	🟥▨▨ Low	🟥🟥🟥 High
Site constraints	The location, conditions, surroundings and business requirements of a site impact its ability to accommodate different ZDEH technologies.	🟥🟥▨ Medium	🟥🟥▨ Medium
Grid connection	The availability, ability, timing, requirements, complexity and costs of connecting to the grid.	🟥▨▨ Low	▨▨▨ Low

Policy & regulation	National and local policy and regulations that could impact a ZDEH.	🟥▨▨ Low	🟥🟥🟥 High
Supply chain	Availability of the right products, people and expertise in the right place and at the right time.	🟥🟥▨ Medium	▨▨▨ Low
Soft factors	A range of end user factors can impact a project, including internal politics, internal policy, confidence and/or experience of a new technology, project planning, timing and considering the impact to end users.	🟥🟥🟥 High	🟥🟥🟥 Medium

a. Techno-economic factors

i. Capital costs

There was evidence of capital costs acting as a barrier to installing ZDEH systems in half of the case studies. For three community buildings, grant funding was necessary to facilitate installations of ASHPs. Four large-scale projects were also made possible through LCITP funding. Where grant funding was not required, this was most commonly because payback was anticipated through RHI payments. Conversely, there were six examples of subsidy-free or grant-free installations, although two of these were direct electric heating systems (significantly lower capital cost compared to e.g., AHSPs). For these two case studies, the low upfront cost of direct electric panel and space heaters (as well as other business drivers) resulted in these being selected over other, more expensive, options. Stakeholders from both organisations however commented on rising electricity costs and the need to retrofit to reduce their energy bills.

ii. Financial Incentives

The availability of a financial incentives was a driver for 14 of the 20 case studies, with stakeholders from two community and two public organisations voicing that these incentives made retrofitting ZDEH possible. The most common grant funding accessed was the LCITP and/or CARES and across all retrofit case studies except for two. Six case studies benefited from RHI payments. Despite not being an explicitly stated driver, it could be inferred that the two case studies that installed biomass boilers were motivated to do so due to very favourable RHI tariffs compared to those for other technologies (amongst other drivers mainly due to ease of integrations with existing systems). A further two case studies planned to receive RHI payments, however, in one case the conditions of the scheme changed during the refurbishment and its GSHP system was no longer eligible. Another case study was not able to complete an RHI application before the scheme closed due to lack of internal resource.

Three stakeholders indicated that grant funding spend deadlines added significant pressure to project timelines, as budgets had to be spent within certain periods (most commonly one financial year). This was noted as a barrier to community groups, who, due to low resources, do not tend to have 'shovel ready' projects that can be started up as soon as funding becomes available. This also caused issues for end users in finding contractors that could action the works within the specified time, limiting their tendering process to one response in two cases. One community case study which faced this barrier, was only able to overcome this as it had been previously supported to produce a Local Energy Plan, which highlighted viable energy-saving projects that could be actioned as soon as funding became available.

iii. Operational costs

Most case studies only considered running costs after installation. This included the two case studies with direct electric heating systems, which both highlighted high operating costs given the recent increase in electricity prices. Both are considering options to reduce electricity costs, including replacing direct electric with heat recovery to make use of the available 'free waste heat' from the building operations; and potentially adding a combination of solar PV, battery, and replacing direct electric with ASHPs.

Anticipated lower operational costs were noted as a driver to select certain technologies over others. For the biomass boiler retrofits the similar cost of biomass fuel compared to gas encouraged the selection and use of biomass boiler in the two case studies. The ASHP retrofits replacing direct electric systems at three case studies were driven by a desire to reduce the operational cost of the heating system. Similarly, the anticipated lower cost of operating a GSHP and WSHP compared to an ASHP factored into two further case studies.

Five stakeholders referenced that onsite renewable electricity generation helped to justify the operational costs of ZDEH. For example, in one case study direct electric boilers were originally specified, as it was cheaper to install than ASHP, and it was anticipated that generation from an onsite wind turbine would offset operational costs. However, the turbine was removed after a few years, and as operational costs were higher than expected, the electric boilers were replaced with ASHPs (and a payback has since been facilitated from this outlay). A grant-funded micro-hydro scheme was also installed at another case study to reduce the running costs of the GSHP system, ahead of the GSHP installation itself.

As noted in section 5.1b.iv, due to the limited data made available, it has not been possible to confirm any cost savings in practice, except for at one case study, where total electricity demand fell by a quarter following the ASHP installation.

iv. Site constraints

Site constraints were noted to be a barrier in seven case studies. This impacted the choice of ZDEH due to factors such as a lack of external or internal space, the location of the site, the proximity to other buildings, and business operations.

Two case studies specified ASHPs over DHNs due to site constraints. One case study found that the buildings onsite were too distant from each other to justify the costs of installing a new DHN. Another project had a preference to connect to a DHN but given the lack of an existing DHN in the vicinity of the site, the project also opted for an ASHP instead. Having a low temperature distribution network was thought to futureproof the site to enable connection to any future DHN in the area that might arise.

Internal and external space was noted as a barrier to choosing certain ZDEH. In one case study, a lack of external space was a barrier to installing GSHP, with ASHPs being chosen. Conversely, a GSHP was chosen over an ASHP in two further case studies, due to the GSHP system having no external parts. In one of the GSHP case studies this was important given the coastal climate and in another this was concerning the visual impact. Although not a direct barrier to installing the chosen technology, the two case studies that did retrofit biomass boilers had limited onsite space and required compact, containerised solutions. In both cases, this constraint significantly reduced the number of contractors who could provide suitable systems. Two further case studies selected heat pumps over biomass boilers due to the requirement of fuel sourcing and associated transportation and storage logistics (one case study being located on an island).

Site characteristics also relate to business operations that may prevent certain technologies physically fitting in the buildings. For the two direct electric case studies, electric panel heaters and VRFs were opted for due to the sensitivities of the process environment and critical business processes. Both demonstrate how business critical processes are prioritised over heating system considerations. The availability of a waste heat resource arising from refrigeration was another site characteristic that led to a bespoke heat pump system being selected and could lead to future changes for another case study.

The condition of an existing building’s fabric was not noted as a constraint to retrofitting ZDEH. This can be partially explained by the specificity of the case study projects, as in two cases, buildings installing ASHPs were already of a high fabric efficiency standard (one being PassivHaus) and in another, a DHN connection was made to a building that was previously derelict so was undergoing fabric upgrades anyway.

v. Grid connections

Grid connection costs impacted three case studies. The six-figure cost of grid connection and reinforcement works would have been a barrier to one case study, but SSE provided grant funding to cover these costs. However, the specification of heat pumps did not impact the grid connection costs explicitly. Additionally, the development of the data centre required a new substation for a seven-figure cost. This was not seen as a barrier, given the nature of the business, overall site power requirements, and financial backing from the parent company. In this case the main driver for grid capacity was power rather than heat. The third case study was located close to the gas grid but deemed the gas connection to be expensive and unjustifiably disruptive to the surrounding area and opted for a heat pump instead.

Across the other case studies, no issues with grid connections or costs were experienced, even where heat pumps were replacing direct electric heat, or where a new building was developed on a site with an existing correction.

b. External factors

i. National Policy

National policy, specifically the Net Zero target, was referenced by six stakeholders as a driver to installing ZDEH over alternatives. These stakeholders all represented public bodies or educational institutions. Five of these also cited their own climate agendas as motivations to install ZDEH systems. Whilst this may seem low, this can be partially explained by the high portion (45%) of case study projects which are located off the gas grid, where electrically driven heating is the preferred option for reasons other than policy (i.e., availability of options, security of supply and operational costs). This is also likely to be the case because half were completed before the NBHS or the Net Zero legislation were announced.

ii. Local policy

Local authority policy was only noted to act as a barrier to one case study. In this case the Council wanted to connect the new building to a gas DHN, however the building owner wanted to pursue a ZDEH solution, as the Council's proposal was deemed to be incompatible with their ambitions for the building to be net zero. To address this, a heat pump DHN was successfully proposed this to the Council as an alternative.

Planning permission was not a barrier for any of the case studies. However, two stakeholders mentioned that they had to retrospectively seek planning permission (for biomass boiler and ASHP retrofits) due to impending grant funding spend deadlines. A further biomass boiler case study appointed consultants to model the impact of the proposed installation in order to satisfy planners. Both representatives of biomass boiler case studies indicated that they would not expect planning permission to be as easy to acquire now or in the future, given increasing concerns around the impact of emissions.

iii. Regulation

Regulation was cited as a driver for one case study, as low carbon technologies were required for the project to meet building standards. It was not cited as a barrier for any of the case studies.

iv. Design brief

Being able to meet design briefs was an issue for two case studies due to the cost and required criteria. In one case study the high cost of designing to PassivHaus standard was a barrier to specifying ASHP initially, as the extra cost of an ASHP compared to electric boilers was deemed an unjustifiable expense. However, it was later deemed to be a more suitable choice for the building on an operational cost basis and subsequently retrofitted. The second case study targeted a BREEM 'Excellent' rating for its swimming pool, which was achieved.

However, it did not achieve an 'A' EPC rating as intended, due to having a higher hot water load than a leisure centre without a pool would have.

v. Supply chain

Supply chain issues were cited as a barrier for rural locations, and sites with constraints or special requirements. Project managers from three case studies in the Highlands, and two Island case studies, indicated having limited options for contractors and installers in these rural and remote locations. No stakeholders from urban developments cited this issue. Contractor limitations were also found to be an issue affecting maintenance, as discussed in section d.

Aside from locational issues, the choice of suppliers was limited by specialist requirements that arose due to site constraints. Two biomass boiler retrofit case studies received only one and two tenders respectively, which in one case led to higher capital costs than budgeted for. An ASHP case study had requirements for the retrofit to be conducted over evenings and weekends, which made it more difficult to find contractors willing to meet this constraint. There was also an issue with obtaining electrical components, including compressors and fans, for the custom WSHP due to limited availability of parts.

c. Soft Factors

Across the case studies there were a wide range of soft factors that impacted the selection of ZDEH systems in most case studies, including internal sustainability ambitions, stakeholder confidence, internal expertise, ZDEH perceptions, potential end user impacts and project timing.

i. Building owner/operator concerns

There were perceived concerns in two case studies that certain ZDEH would not be suitable for buildings with high heat demands or to provide the required flow temperatures (~100^{o}C) for the existing heat distribution system, hence biomass boilers were selected.

Stakeholder confidence with certain technologies and/or internal expertise were soft drivers for five case studies. Having prior experience with specific technologies and expert knowledge on hand to help steer decisions helped two case studies. In both cases, external feasibility studies were conducted to validate the ZDEH technology choice too, further boosting confidence. A further three case studies had existing internal expertise which helped to deliver the systems, identify grant opportunities, and drive the process.

Ambitions to minimise emissions and showcase sustainability drove internal decision making towards ZDEH technologies in all eleven case studies located on the gas grid, and in two off-gas grid case studies. One of these case studies had to work hard across multiple departments and personnel to update their internal policy to specify 'no gas' when developing new buildings, which was achieved. This required a lot of time and a significant cultural shift to enable all-electric heating and provide enough confidence that moving away from gas heating and gas back-up systems was viable.

ii. End-user impacts

Anticipated end user impacts guided four of the case studies. For hospital and care centre case studies this was important given the occupancy profile. This limited the technology choice for the hospital since the heat supply could not be interrupted, meaning that technologies that couldn’t provide the same temperature as the existing gas system were automatically ruled out. End user considerations restricted the location and construction period for a biomass boiler in another case study, due to building users requiring high security onsite. This required a containerised system to be built offsite, which significantly constrained the number of viable solutions and contractors. A fourth case study also considered the impact of the heating system on the end users and undertook significant building simulation modelling to model and validate the heating and ventilation system size and requirements against various occupancy levels anticipated in the new building.

iii. Timing

As mentioned in a.i, the requirement to spend grant funding by the end of a financial year added significant pressure to four case studies, tenured by community and public organisations. For two of these case studies, the impact of this pressure was that planning permission had to be sought retrospectively. This issue was noted to be exacerbated by the limited resource of the community group who led the project. Limited resources also impacted a case study that could not apply for the RHI in time before the scheme closed in 2021.

Timing played a role in the selection of ZDEH technology for three case studies, tenured by private organisations. For example, installing heating to meet current needs rather than proactive planning due to uncertain company growth, and developing the building ahead of potential DHN infrastructure.

d. Overarching differential experiences

Through conducting the case study interviews, differences were noted in the extent to which issues are experienced. Below, the impacts on the type of technology, organisation and building are discussed, as well as those relating to location. These differential experiences are based on 20 case studies and should not be taken as a representative sample of Scotland’s non-domestic built environment.

i. Type of technology

The principal barriers to installing each of the technologies in scope have been identified as follows from the case studies:

- **Direct electric heating**: Higher operational costs versus heat pumps.
- **WSHP and GSHP**: Site constraints.
- **ASHP:** Visible external parts, concerns regarding operation in costal locations, and higher capital costs versus direct electric systems.
- **DHNs**: Requirements for heat demand density, an anchor load, for a long-term strategy and the need to negotiate across disparate parties.

ii. Type of organisation

Public organisations, such as the NHS and Local Authorities, are usually governed by central objectives, particularly regarding financial and environmental policy. For example, several Local Authorities in Scotland have declared a climate emergency. In this respect, there is a degree of pressure on these organisations to lead by example – as evidenced by the high portion of public buildings found during the case study longlisting process. Of the seven case studies of public buildings, climate policy was cited as a driver for six of these, although in some cases, under alternative names including 'sustainability' and 'carbon management'.

Additionally, the public organisations interviewed had energy and facilities staff who focus on designing, project managing the implementation of, and managing energy systems. It was also evident that public bodies are also more likely to procure external work via frameworks, and to develop or retrofit multiple buildings under one programme, leading to economies of scale.

Large private organisations are also likely to have a centralised energy and environmental strategy. The three large commercial organisations represented among the case studies, all cited sustainability as one of their main drivers to install ZDEH. It can be inferred that branding was also a motivator for these organisations, as a result of climate change concerns among the public forcing sustainability and environmental impacts of operations higher up the business agenda in recent years.

Smaller private organisations with small or single-building estates are the least likely to have either internal teams with specialisms in energy, or established procurement strategies. This increases the 'unknown' element of adopting ZDEH and reduces the likelihood of benefits from economies of scale. However, community organisations are most likely to fall into this category, and they tend to have the most opportunities for external funding of both consultancy on and implementation of ZDEH. All four of the community group projects within the case studies (along with one for a small charity) received grant funding and free advice from consultants via CARES or Zero Waste Scotland. Conversely, the remaining five private organisations who delivered ZDEH projects independently received no grant funding.

iii. Type of tenure

There was only case study which has a tenant organisation, rather than having staff from same the organisation as the owner (or a subsidiary). In this case, issues arose due to the handover process between the owner and tenant organisation. Although it is not possible to suggest whether this issue is representative of other leased buildings, it is clearly important to ensure that ZDEH systems and their controls are thoroughly explained to new tenants in order to ensure correct operation and a positive user experience.

iv. Type of building

Depending on the building's usage, the required temperature or pattern of heat delivery may impact the suitability of certain technologies. For example, a biomass boiler was selected for a hospital as it was deemed to be the only solution that could meet the existing heating system's temperatures, which was required to avoid overhaul to the internal heat distribution system, as this would have disrupted operations within the hospital.

Planning class (i.e., building usage) and ZDEH technology choice had no impact on each other for most of the case studies. This means that in most cases, the decision to install a particular ZDEH system was not linked to the use of the building. Aside from the hospital referenced above, the supermarket was the other exception to this, as the waste heat available from its refrigeration system provided a heat source for space heating.

The type of building also impacts whether backup heating systems are required, with ten case studies in total incorporating backup systems. Six case studies (including two newbuilds) have gas or oil backup systems. Three further buildings have direct electric back-up systems. All of these buildings provide services to the public (in the form of education, events, leisure, health or retail) meaning that building operations and/or income are linked to user comfort, in that users may chose not to attend or may be put at risk if the building is not adequately heated. Lastly, a data centre with direct electric heating had a diesel generator to provide resilience to power cuts, although that was notably to ensure continuing power supply (and therefore business activities) rather than heat supply specifically.

v. Locational differences

Of the ten case studies in urban locations, all of these installed ZDEHs (or biomass boilers) in order to reduce emissions compared to existing or potential gas heating systems. Six of these utilised external funding (including RHI) in order to do so.

In rural locations that are not served by the gas grid, ZDEHs are more common, and building owners and end-users are less likely to consider these to be novel technologies – this was clear from discussions with rural stakeholders. Similarly, the high costs of oil and LPG heating lead to an enhanced financial case for implementing ZDEH instead of (or to replace) these fuels. The increased prevalence of ZDEH rurally is exemplified by the high number of case studies (9 of 20) that represent off gas grid locations.

However, stakeholders in remote rural locations have expressed that they pay a premium for installation and maintenance of ZDEH systems, due to lack of competition between contractors. This is because there are often few or no local options, and those who are willing to attend from further away will pass their travel and accommodation costs onto the customer. Three case studies were affected by this.

5. Impacts of installing zero emissions heating

5.1 Overview

The following impacts of installing or retrofitting ZDEH technologies into new and existing buildings have been identified via our stakeholder interviews for the ZDEH case studies. The table below provides a brief description of these impacts and an overall rating based on scoring across the 16 case studies that are occupied buildings (4 being under construction). Notably, all of these impacts are negative, except for end-users, which were found to be both positive and negative.

Table 2: ZDEH installation and operation issues identified. The 'overall rating' is based on the count of issues across case studies (low occurring in 0-5 case studies, medium 6-10, high 11+).

Impact	Description	Overall Rating
Snagging	Unexpected problems occurring shortly following commissioning	🟥 🟥 ▨ Medium
Control	Manual or automatic control regime implemented to ensure the system runs correctly	🟥 ▨ ▨ Low
Maintenance	Any scheduled or unexpected maintenance required	🟥 ▨ ▨ Low
Running costs	The cost of operating a ZDEH system, including fuel and maintenance	🟥 ▨ ▨ Low
End-user impacts	The experience of end-users, including control requirements and comfort	🟥 🟥 ▨ Medium
Additional impacts	Unexpected issues on other physical systems and activities within the building, e.g., delivery of heat.	🟥 ▨ ▨ Low

b. Impacts on operation

i. Snagging

Four case studies experienced some form of snagging issue on commissioning. Only one case study cited system balancing issues and this was due to internal heating zones needing to be rebalanced to provide enough heat at the entrance vestibule. In one of the biomass boiler case studies, snagging occurred due to the system being located outside, meaning that the internal Building Management System was not able to communicate with the biomass boiler plant. This took approximately a year to fix, and the building's energy manager felt this issue could have been mitigated through enhanced communication with the building's IT team prior to the retrofit taking place.

ii. Control

Stakeholder experiences with heating controls varied depending on heating system, size of organisation and control type / set up. The heat pump and biomass boiler systems among the case study projects are all programmed to run automatically. However, one of the biomass boiler case studies noted that its control programme had to be adjusted iteratively to get the right heat output from the biomass boiler. The direct electric systems (panel and space heaters) require manual control, and this had an impact on end user comfort, both suggesting better, and more automated controls would be advantageous.

As well as impacting comfort and heating system operation, controls were also noted to impact costs too. In one case study the building's sensors had a standing electrical load that was higher than anticipated and the building operator suggested that the control systems had a non-negligible impact on energy costs given this.

iii. Maintenance

Aside from scheduled services (annual for heat pumps and quarterly for biomass boilers), most case studies have not had faults that required unscheduled maintenance. However, specific instances were identified in four case studies. The most extensive maintenance has been required for both of the biomass boiler case studies, including replacement of fuel delivery system parts, but these issues have all been addressed under the boilers' maintenance contracts. In the leisure centre case study, the placement of the heat pump units in the same plant room as the pool's water treatment system led to corrosion of the units' casing and ancillary pipework, due to the corrosive atmosphere created by the chemicals in the treatment system. Additionally, one of the DHN case studies experienced unscheduled maintenance. This should have run smoothly, given the DHN maintenance company is required to provide plug-in electric heaters for unscheduled maintenance, however, staff were not made aware of this initially.

Anticipation of unexpected maintenance was factored into design and decision making, with most case studies having some form of back-up power or resilience designed in, to ensure building operations were not interrupted. For example, the two biomass boiler case studies retained their original gas systems, oil boilers were retained to back-up one off-gas grid heat pump, a backup electric boiler and an oversized heat pump were used in another case study, and diesel generators are used as back-up in one case study.

Another example of designing for maintenance includes the positioning of the system components. One case study mentioned that the underground manifold for the heat pump was designed and positioned to minimise maintenance requirements and provide easy access, if required.

iv. Running costs

Only two of the retrofit case studies provided annual running costs. Total electricity demand fell by a quarter following the replacement of electric boilers with an ASHP in one case study, whereas the gas to biomass boiler retrofit case study saw a 10% increase in fuel costs following the retrofit. Given that we were only able to collect two data sources, it is not possible to quantify or estimate the impacts of installing ZDEH on running costs for other case studies or indeed other buildings. However, anecdotal evidence from stakeholder interviews has been collected, as provided below.

Five case studies reported concerns with operating costs. Three of these have direct electric heating systems and their building owners have considered retrofitting a range of technologies to replace direct electric heating and reduce costs, including gas generators, Solar PV, battery and ASHP. An ASHP was retrofitted in place of direct electric heating in one of the three mentioned previously several years later as electricity costs had been higher than anticipated.

The other two case studies reporting high operating costs (anecdotally) had AHSPs. One was considering undertaking further analysis (if grant funding can be secured) into installing a battery to store the existing excess solar PV to divert into the ASHP, which would allow for reduced electricity costs. The second found through investigation that the kitchen appliances had high electrical loads which were the cause of the high costs and not the ASHP.

v. End user impacts

Various negative end-user experiences were noted in six case studies, including lack of comfort in certain spaces, lack of confidence with controls post-handover and low satisfaction with direct electric systems. For example, the staff at a school found the building to be stuffy, due to ventilation actuators being broken, and remaining so for a long time due to the difficulties in sourcing replacement parts and in getting contractors to the rural location. Another case study mentioned that staff thought they did not receive sufficient education at handover. Two buildings experienced colder temperature and drafts, so plug in electric heaters were installed to raise user comfort in two of these.

Two case studies highlighted positive end-user experiences. Firstly, the building’s elderly occupants of a care centre built relations with the heating contractors during the ASHP retrofit install through taking an interest in the process. This led to a positive learning experience and increased awareness of sustainability among the end users. It also fostered goodwill with the contractor, which led to a thorough handover process and generous post-completion support for staff. Another case study building owner was very involved in the installation of the building’s GSHP, even assisting with construction. They also expressed a desire to learn more about the system so that they could perform future maintenance as necessary.

vi. Additional impacts

For three buildings, the heating system was noted to impact business or building operations. One building was noted to sometimes be too hot in summer, which posed a risk to perishable goods in the building. At the second, the biomass plant and fuel store are in a secure compound and the police require advanced notice of fuel deliveries, so that any impact on access to the compound can be mitigated. At the third, it was discovered during the first year of occupation that extractor fans in the kitchen impacted heating by removing heat from the building. This was easily addressed by ensuring that staff did not leave fans running overnight.

6. Conclusions

In order to investigate the impacts of installing ZDEH we have interviewed stakeholders from 20 non-domestic buildings in Scotland which have installed ZDEH and created case studies. The case studies cover the processes of choosing, installing and operating ZDEH systems, and represent a range of planning classes, newbuild and retrofit, as well as a wide range of technologies, organisations and locations.

Given that this researched focussed on finding examples of ZDEH in buildings, none of the case studies experienced insurmountable barriers to adopting ZDEH. Therefore, the findings inherently miss some of the known barriers that can stop ZDEH from being installed. Additionally, it is not possible to confirm that the 20 case studies within this report form a representative sample of Scotland's non-domestic buildings. Therefore, the findings outlined throughout this report are specific to this research.

Learnings from identifying case studies

Through the process of identifying potential case studies, we identified over 140 examples of buildings with heat pumps, direct electric heating systems, biomass boilers, and connections to heat networks at a broad range of scales across Scotland. The EPC register, although limited in value to this project, demonstrates that there are thousands more such ZDEH installations throughout the country, on top of the VRF systems that have been commonplace for decades. This indicates that ZDEH installations and compliance with the incoming New Build Heat Standard are both already realised at scale in Scotland.

Through the case studies, there was a conscious aim to represent a range of locations (including rural and urban settlements, on and off the gas network), building tenures, as well as types and sizes of organisations. Over 50 organisations were approached to request case studies. however, many stakeholders were not willing or able to participate within the required timeframes. Additionally, two stakeholders declined to participate due to ongoing maintenance concerns with their GSHP systems, after suppliers in both cases went into administration. Similarly, a restaurant owner who had recently moved into a building with an ASHP had very limited understanding of the system and did not feel able to contribute to the research. Conversely, public organisations and universities were particularly forthcoming in showcasing their buildings. This was expected given that many such organisations have declared climate emergencies and are enthusiastic to be seen as leading the way towards net zero. Seeking case studies from private organisations, such as hotels, businesses and shops was particularly challenging. Secondary research was utilised more for these planning classes, which may have led to a disproportionally high number of buildings which received grant funding being profiled. Although the EPC register was used to identify a shop and a hotel, both had received grant funding. Although conclusions cannot be drawn from this, it is likely that the availability of incentives and grants have been a stimulus and/or enabler for the uptake of ZDEH, due to the cost differential compared to the counterfactual options.

An issue raised during longlisting that was not evident from the case studies was around regulatory compliance. Penalties associated with overestimating emissions during compliance modelling was cited by a city planning officer as a reason that several recent newbuilds were deterred from specifying heat pumps and opted for gas with solar PV instead. However, following the introduction of the NBHS, this will no longer be a barrier to ZDEH uptake.

Experiences of adopting zero direct emissions heating

When planning and installing ZDEH systems, various barriers are experienced, in the form of techno-economic and external constraints (i.e., policy, regulatory and supply chain). Additionally, soft factors such as owner and end-user concerns, and project timing can also make ZDEH deployment challenging. Among the case studies, capital costs, physical site constraints, timing and end-user impacts were most frequently encountered as barriers. It was also found that different technologies, buildings, tenure arrangements, organisations and locations experienced barriers to different degrees. For example, public organisations benefited from inhouse expertise and rural locations experienced more challenges associated with supply chains.

Given the inherent biases of the buildings profiled, in that all successfully installed ZDEH, it was also evident that a similar set of factors posed as drivers for ZDEH. Almost all case studies cited grant funding and/or additional incentives as important drivers to enable their preferred technologies. National, local and internal policy, specifically regarding the climate crisis were other prevalent drivers, along with desires for positive end-user impacts. This highlights that although ZDEH may currently cost a premium to install and operate (as per Appendix D), awareness of the climate crisis has driven the uptake of ZDEH ahead of this being mandated, albeit with external financial support.

Despite the lack of evidence of grid connections affecting ZDEH development from the case studies selected in this project, we would, based on our extensive project development experience, caution against drawing a conclusion that electric heating systems do not impact grid connections. It is evident from industry forums, associations, and contacts that DNOs are concerned and actively working on the impact of electrifying heat on the grid.

Impacts of installing zero direct emissions heating

Through the case study interviews, the impacts of various aspects of operation were explored, including snagging, control and maintenance as well as non-technical factors including running costs and the impacts to end-users. Snagging was a common issue, experienced by half of the case studies, although only four experienced unexpected maintenance requirements. Ongoing dissatisfaction with heat control was noted only for the two case studies with direct electric heating systems. Although most case studies did not report issues or dissatisfaction with running costs, the fact that electrically driven heat demand is not metered in all case studies is likely to have fed into this outcome. This also resulted in a lack of real data being made available to evidence the running costs of these systems.

Impacts to end-users were noted by less than half of case studies, but these were split evenly between positive and negative outcomes. In terms of end-user impacts, is evident from the case studies that considerations and experience of heat within a building are often combined with the end-users' experience of other building services, and their positive or negative associations with one may affect their experience of all. In addition, users, aside from building and/or energy managers, do not tend to think about heating systems unless they are faulty.

The low volume of maintenance and unresolved end-user issues, although drawn from only a small number of buildings, does bode well for the future rollout of ZDEH systems, provided that these are designed, installed and handed over effectively.

Appendix A. Case Studies

20 case studies on the buildings listed in Table 3 and Table 4**Error! Reference source not found.Error! Reference source not found.** have been provided separately, in the document named '7496-TA-REP-0005-Case Studies of Zero Direct Emissions Heat'.

Table 3: Summary of newbuild sites profiled in case studies

Case Study Site	Planning class	Building type	Organisation	ZDEH type	Location	On gas grid?
Armadale Stores	Shops	Newbuild	Private	ASHP	Rural	Off
Arbikie Distillery Visitors Centre	Food and Drink	Newbuild	Private	ASHP	Rural	Off
Saughton Park Café	Food and Drink	Newbuild	Public	GSHP	Urban	On
National Manufacturing Institute Scotland	Business	Newbuild (in development)	Private	WSHP DHN	Urban	On
DataVita	Storage or distribution	Newbuild	Private	Direct electric	Urban	On
Kilbride Hostel	Hotels and Hostels	Newbuild	Private	GSHP	Rural	Off
Dundreggan Rewilding Centre Accommodation	Residential institution	Newbuild (in development)	Private	ASHP	Rural	Off
Arachale Primary School	Non-residential institution	Newbuild	Public	ASHP	Rural	Off

Usher Institute	Non-residential institution	Newbuild (in development)	Private	ASHP	Urban	On
V&A Dundee	Non-residential institution	Newbuild	Public-private	GSHP	Urban	On
Regional Performance Centre for Sport (RPC) Dundee	Assembly and Leisure	Newbuild	Public	GSHP	Urban	On
Lochore Meadows Visitors Centre	Assembly and Leisure	Newbuild	Public	WSHP	Rural	On
Pickaquoy Leisure Centre	Assembly and Leisure	Newbuild	Public	GSHP	Rural	Off

Table 4: Summary of retrofitted buildings profiled in case studies

Case Study Site	Planning class	Building type	Organisation	ZDEH type	Location	On gas grid?
Waitrose Comley Bank	Shops	Retrofit (in development)	Private	WSHP, ASHP	Urban	On
West Lothian Civic Centre	Services	Retrofit	Public	Biomass Boiler	Urban	On
Loch Ness Hub	Services	Retrofit	Private	ASHP	Rural	Off
Ayr Hospital	Residential institution	Retrofit	Public	Biomass Boiler	Urban	On
Glenurquhart Care Centre	Non-residential institution	Retrofit	Private	ASHP	Rural	Off
Barracks Conference Centre	Non-residential institution	Retrofit	Private	WSHP DHN	Urban	On
Dunnet Bay Distillery	General industrial	Retrofit and Newbuild	Private	Direct electric	Rural	Off

Appendix B. Data Collection

Data Collection Framework

The data collected for the 20 case studies has been provided separately, in the document named '7496-TA-REG-0001-Data collection framework'.

Data Collection Forms

Supplementary to the data collection process via stakeholder interviews, the following tables were used to collect information on the case studies' heating systems. These were issued as word documents.

For **newbuilds**, the following were issued (with instruction to ignore requested for actual data where buildings were still in development.

General information	
Information	Response
Address	
Internal floor area (m^2)	
Usage description	
EPC rating	
EPC reference number	
Completion Certificate Date	
Occupation Date	

Heating system - technical	
Information	Response
Heating technology	
Heating fuel	
Heating tech make and model	
Heating peak capacity	
System efficiency or Coefficient of Performance	
Target room temperature	
Internal heat distribution method	
Wet heating flow/return temperatures	
Alternative technology considered, if so	

Heating system – energy consumption and costs	
Information	Response
Estimated capital costs	
Actual capital costs	
Source of capital funds	
Estimated annual maintenance cost	
Actual annual maintenance cost	[please include year]
Estimated annual heat demand (kWh)	
Actual annual heat demand (kWh)	[please include year]
Estimated annual fuel cost	
Actual annual fuel cost	[please include year]
Electricity tariff rate	
Estimated annual emissions, if any	
Actual annual emissions, if any	[please include year]

Additional information	
Information	Provided?
1x image of the building's exterior	
1x image of the building's heating system	
End user feedback on heating system (e.g., surveys, if conducted)	
Heat demand profile from metering (e.g., spreadsheet with half-hourly demand/fuel consumption, if available)	

For **retrofits**, the following information was requested:

General information	
Information	Response
Address	
Original internal floor area (m^2)	
New internal floor area, if changed (m^2)	
Old EPC rating (prior to heating system retrofit)	

New EPC rating	
EPC reference number	
Completion Certificate Date (building)	
Occupation Date	
Date heating system retrofit completed	
Building usage – brief description	
External building fabric description	
Heating system prior to retrofit	
Information	Response
Prior heating technology	
Prior heating fuel	
Prior heating peak capacity	
Prior system efficiency or Coefficient of Performance	
Prior target room temperature	
Prior wet heating flow/return temperatures	
Prior annual fuel quantity (kWh)	[please include year]
Prior annual heat demand (kWh)	[please include year]
Prior fuel tariff	[please include year]
Prior annual fuel cost	[please include year]
Prior annual maintenance cost	[please include year]
Prior annual emissions	[please include year]

Energy efficiency measures (where relevant)	
Information	Response
Energy efficiency measures installed alongside/following heating system retrofit (e.g., insultation, reglazing, etc)	
Reduction in peak heat demand, if quantified (kW)	
Reduction in annual heat demand, if quantified (kWh)	

New heating system - technical	
Information	Response

Heating technology	
Heating fuel	
Heating technology make and model	
Heating peak capacity	
System efficiency or Coefficient of Performance	
Target room temperature	
Wet heating flow/return temperatures	
Alternative technology considered, if so	

New heating system – energy consumption and costs	
Information	Response
Estimated capital costs	
Actual capital costs	
Capital costs for alternative technology, if considered	
Source of capital funds	
Estimated annual maintenance cost	
Actual annual maintenance cost	[please include year]
Estimated annual fuel quantity (e.g. kWh elec / kg biomass)	
Actual annual fuel quantity (e.g. kWh elec / kg biomass)	[please include year]
Estimated annual heat demand (kWh)	
Actual annual heat demand (kWh)	[please include year]
Estimated fuel cost	
Actual fuel cost	[please include year]
Actual fuel tariff	
Estimated annual emissions, if any	
Actual annual emissions, if any	[please include year]

Additional information	
Information	Provided?

1x image of the building’s exterior	
1x image of the building’s heating system	
End user feedback on heating system (e.g., surveys, if conducted)	
Heat demand profile from metering pre- and post-retrofit (e.g., spreadsheet with half-hourly demand/fuel consumption, if available)	

Appendix C. Longlist of Scottish buildings with Zero Emissions Heating

The following tables provide the longlist of non-domestic buildings with ZDEH (and biomass) systems that were identified as part of our primary and secondary research. A map of the buildings on the longlist is provided after the tables.

It is stressed that these tables are by no means exhaustive, and they are not representative of Scotland or the individual planning classes. More research with the building owners would be required to confirm the technology options. Given that the scope of the project was to focus on the technologies outlined in Section 2.1b, VRF, MVHR were not a focus for secondary research.

Table 5: Newbuilds with Zero Emissions Heating

Planning category	Building	Location	Technology
Shop	Asda (Queens Quay Clydebank)	East Dunbartonshire	WSHP DHN
	Oak Mall Shopping Centre	Inverclyde	Electric
	Farmfoods	Glasgow	ASHP
	Intu Braehead Shopping Centre	Renfrewshire	ASHP
	Glasgow Fort Shopping Centre	Glasgow	ASHP
	Coop supermarkets	Various	ASHP
	Lidl supermarkets	Various	ASHP
	The Heron Farm Shop	South Lanarkshire	ASHP
	Armadale Stores	Highland	ASHP
Services	Aberdeen Health Village	Aberdeen	Gas DHN
	John G Course Funeral Home	Orkney	ASHP
Food and drink	Saughton Park Café	Edinburgh	GSHP
	McDonald’s	Glasgow	ASHP
	McDonald’s	Various other	ASHP
	KFC	Various	ASHP
	Starbucks	Various	ASHP
	Arbikie Distillery Visitor Centre	Angus	ASHP

Planning category	Building	Location	Technology
	Matzaluna Pizza, Queens Quay	East Dunbartonshire	WSHP DHN
	Nando's Clydebank, Queens Quay Clydebank	East Dunbartonshire	WSHP DHN
	Larid’s Table Restaurant	East Ayrshire	WSHP
	Whitelee Visitors Centre Café	Glasgow	Direct electric
Business	Scottish Centre for Regenerative Medicine	Edinburgh	GSHP
	Scottish Crime Campus	Glasgow	GSHP
	NMIS	Renfrewshire	WSHP DHN
	177 Bothwell St	Glasgow	ASHP
	Barclays Bank	Glasgow	WSHP
General Industry	Dunnet Bay distillery	Highland	Direct electric
	Scania GB	North Lanarkshire	ASHP
	Breichen Dairy	Angus	GSHP
	North Fish	Shetland	Direct electric
	Technip RSU	Aberdeen	ASHP
	Scottish Water Wastewater Treatment Plants	Various	Direct electric
	Macro Micro Studio	Dundee	Direct electric
Storage or distribution	DataVita, Fortis	North Lanarkshire	ASHP
	Kirkton Farm	Dundee	Direct electric
	Clarebrand Industrial Estate	Dumfries & Galloway	Direct electric
	Mid Hill Wind Farm Stores Building	Aberdeenshire	Direct electric
	Kilbride Hostel	Eilean Siar	GSHP

Planning category	Building	Location	Technology
Hotels and hostels	Kings House Hotel	Highland	Biomass Boiler
Residential institutions	Kalisgarth Care Home	Orkney	GSHP
	Smiddybrae Care Home	Orkney	GSHP
	Papdale Halls of Residence	Orkney	GSHP
	Dundreggan Rewilding Centre Accommodation	Highland	ASHP
	Orkney Hospital	Orkney	ASHP
	Ripple Retreat	Stirling	ASHP
Non-residential institutions	Acharacle Primary	Highland	ASHP
	Stromness Primary	Orkney	ASHP
	Forth Valley College	Fife	GSHP
	Ayrshire College	Ayrshire	Biomass Boiler
	Kirkwall Grammar School	Orkney	GSHP
	RGU Garthdee Campus	Aberdeenshire	GSHP
	Port Glasgow Community Campus	Inverclyde	Biomass Boiler
	Borders College	Scottish Borders	WSHP
	Barony Campus	East Ayrshire	Biomass Boiler
	Glasgow School of Art Reid Building	Glasgow	Biomass Boiler DHN
	South Lanarkshire College	South Lanarkshire	GSHP
	Press and Journal Live	Aberdeen	CHP DHN
	Blackridge nursery	West Lothian	ASHP

Planning category	Building	Location	Technology
	V&A Dundee	Dundee	ASHP
	Edinburgh Botanic Biomes	Edinburgh	GSHP
	Lochore Meadows Visitors Centre	Fife	WSHP
	Glencorse Centre	Midlothian	ASHP
	Royal Botanic Gardens Visitors Centre	Edinburgh	Biomass Boiler
	Culloden Centre	Highland	Biomass Boiler
	The Aboyne and Mid-Deeside Community Shed	Aberdeenshire	ASHP
	GALE Centre	Highland	Direct Electric
	Rocking Horse Nursery	Aberdeen	ASHP
Assembly and leisure	Campbeltown Aqualibrium	Argyll & Bute	WSHP
	Making Waves	South Lanarkshire	ASHP
	Aberdeen Aquatic Centre	Aberdeen	CHP DHN
	RPC Dundee	Dundee	GSHP, CHP DHN
	Aberdeen Sports Village	Aberdeen	DHN CHP
	Fort William Cinema	Highland	ASHP
	Armadale Village Hall	Highland	ASHP
	Ormiston Sports Pavilion	East Lothian	ASHP
	Linwood Community Sports Hub	Renfrewshire	ASHP
	Michael Woods Sports & Leisure Centre Indoor Football Arena	Fife	ASHP

Planning category	Building	Location	Technology
	Cromarty Cinema	Highland	ASHP
	Kirkton Equestrian Centre	Glasgow	ASHP
Multiple Categories	Queens Quay district heat network	East Dunbartonshire	WSHP DHN

Table 6: Buildings retrofitted with Zero Emissions Heating

Planning category	Building	Location	Technology
Shops	Waitrose Comely Bank	Edinburgh	WSHP, ASHP
	Day-Today Local Myre Store	Dumbarton	ASHP
	East Kilbride Sainsburys	South Lanarkshire	GSHP
	Merryhatton Garden Centre	East Lothian	ASHP
	Aviemore Aldi	Highland	ASHP
	Loch ness hub	Highland	ASHP
Services	West Lothian Civic Centre	West Lothian	Biomass
Food and drink	Inver	Argyll & Bute	ASHP
Business	Aberdeen City Council Office	Aberdeen	CHP DHN
	Hydrogen Office	Fife	GSHP
	Warehouse Buildings	Orkney	WSHP
	Fife Council office	Fife	Biomass DHN
	Taylor Wimpey Office	Fife	ASHP
	Bandeath Industrial Estate Energy Project	Stirling	WSHP
	H Williamson & Sons (Scalloway) Ltd	Shetland	ASHP
	Otter Ferry Seafish	Argyll & Bute	WSHP
	SW Enviro	West Lothian	ASHP
	Edinburgh Centre for Carbon Innovation	Edinburgh	ASHP & CHP DHN
	Zero Waste Scotland	Stirling	WSHP DHN
	The Capitol offices	Aberdeen	ASHP

Planning category	Building	Location	Technology
	Barracks Conference Centre	Stirling	WSHP DHN
Hotels and hostels	New Lanark Mills	South Lanarkshire	WSHP
	The Islay Hotel	Argyll & Bute	GSHP
	Glen Mor Hotel	Inverness	WSHP
	Fingask Castle	Perth & Kinross	GSHP
	Manderston Stables	Scottish Borders	GSHP
	Ardeonaig Hotel	Stirling	ASHP
	Glenmoriston Arms Hotel	Highland	Biomass
	Gleneagles Hotel	Perth & Kinross	Biomass
Residential institutions	Raigmore Hospital	Highland	Biomass
	Ayr Hospital	South Ayrshire	Biomass
	Fetes School	Edinburgh	GSHP
	Glenfuir Court Care Home	Falkirk	ASHP
	Glenurquhart Care Centre	Highland	ASHP
Non-residential institutions	Stewarton Academy	Shetland	Biomass
	Bressay Primary School	Shetland	ASHP
	Clyde Campus	Glasgow	GSHP
	Gullane Village Hall	West Lothian	ASHP
	Guildtown Community Hall	Perth & Kinross	GSHP
	Woodhall Community Centre	Glasgow	GSHP
	Kilmelford Church	Argyll & Bute	ASHP
	Jubilee Hall	Aberdeenshire	ASHP

Planning category	**Building**	**Location**	**Technology**
	Scout Hall (Northeast Scotland Scouts)	Aberdeen	ASHP
	Iona Abbey	Argyll & Bute	ASHP
	Queen Margret University	Edinburgh	Biomass
	University of St Andrews	Fife	Biomass DHN
	Telford College	Edinburgh	WSHP
	Dalkeith Corn Exchange	Midlothian	GSHP
	Aberdeen Science Museum	Aberdeen	CHP DHN
	Kelvingrove Art Gallery	Glasgow	WSHP
	Grampian transport Museum	Aberdeenshire	ASHP
Assembly and Leisure	Pickaquoy Leisure Centre	Orkney	GSHP
	Aberdeen Ice Rink	Aberdeen	CHP DHN
	Cumnock Outdoor Swimming Pool	East Ayrshire	GSHP
Multiple Categories	Lerwick district heat network	Shetland	WSHP DHN

The figure below indicates the geographical spread of the newbuild (yellow pins) and retrofitted (red pins) buildings listed in the two tables above.

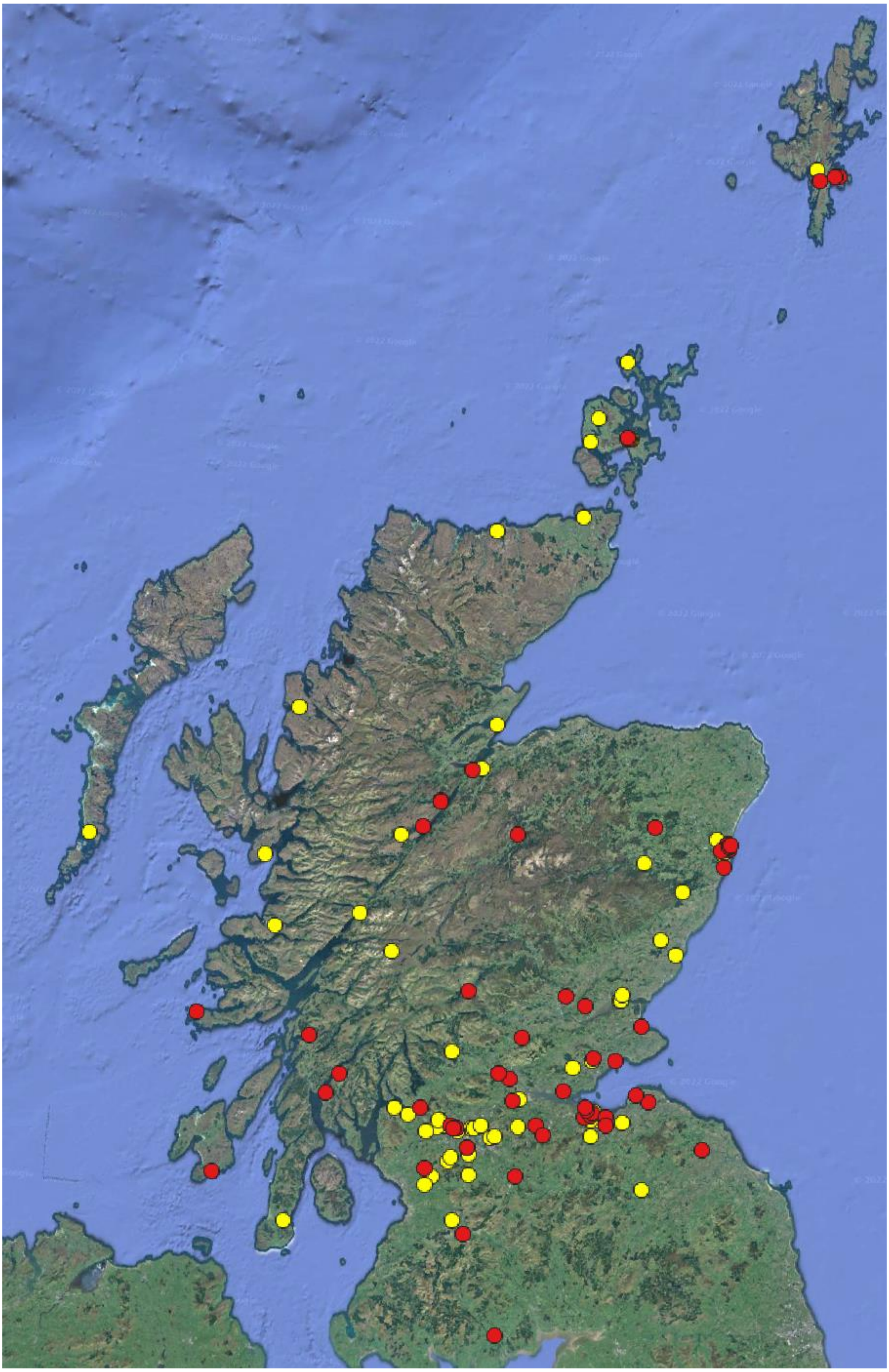


Figure 3: Geographical spread of longlisted buildings (with yellow pins representing newbuilds and red pins representing retrofits). Alt =

Relatively equal spread of new builds and retrofits across Scotland, most densely populated in the central belt.

Appendix D. Historical operational costs for ZDEH and fossil fuel alternatives

The table below shows the delivered heat cost per unit (kWh) for different fuels over the past five years. These costs exclude the Climate Change Levy, standing charges and VAT.

Table 7: Operational cost of common heating systems

Fuel	Gas	GSHP	ASHP	Biomass	Oil	LPG
2018	£ 0.039	£ 0.038	£ 0.045	£ 0.047	£ 0.073	£ 0.087
2019	£ 0.031	£ 0.043	£ 0.051	£ 0.049	£ 0.070	£ 0.093
2020	£ 0.028	£ 0.042	£ 0.050	£ 0.051	£ 0.061	£ 0.095
2021	£ 0.025	£ 0.042	£ 0.050	£ 0.052	£ 0.067	£ 0.095
2022	£ 0.059	£ 0.063	£ 0.074	£ 0.055	£ 0.117	£ 0.108

The table was produced using a combination of price sources (identified below). Where possible, average values for the year have been taken. Where data offers a range of likely values based on consumption volumes, those for small commercial organisations have been selected.

For 2022, the values represent current average prices based on available data. These values do not represent the full year average, but likely costs for either commodity prices or short term contract renewal. Some fuel sources (oil, LPG) provide spot values throughout the year, and these values have been taken at a comparable time period to the price cap date in each year.

For each system, the following seasonal efficiency values have been taken based on industry average values for the relative system types.

Table 8: Efficiencies of common heating systems

Fuel	Notes
Gas	Assumes seasonal boiler efficiency 92%
GSHP	Assumes seasonal performance factor 3.2
ASHP	Assumes seasonal performance factor 2.7
Biomass (Pellets)	Assumes seasonal boiler efficiency 85%
Oil	Assumes seasonal boiler efficiency 88%
LPG	Assumes seasonal boiler efficiency 92%

Data sources for fuel prices:

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1043434/Quarterly_Energy_Prices_December_2021.pdf

https://www.gov.uk/government/statistical-data-sets/prices-of-fuels-purchased-by-manufacturing-industry

https://www.boilerjuice.com/red-diesel-prices/

https://www.mylpg.eu/stations/united-kingdom/prices/#chart

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Any enquiries regarding this publication should be sent to us at

The Scottish Government
St Andrew's House
Edinburgh
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