

BSmART Housing Development Options Appraisal

Phase 3 Report

For Tomintoul and Glenlivet
Development Trust



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Executive summary

The Phase 3 report for the BSmART Housing Development Options Appraisal was initially produced for the Tomintoul and Glenlivet Development Trust by Locogen in May 2020, following Phases 1 and 2 of the project earlier in the year. The aim of Phase 3 was to analyse the domestic energy system technologies that had been shortlisted as a result of the earlier phases, in order to determine the most suitable systems for the development of 12 affordable homes in Tomintoul, on a financial and environmental basis.

Within this report, three Air Source Heat Pump (ASHP) options for primary heating and hot water systems were contrasted. Secondary systems of wood burning stoves also considered, as were mechanical ventilation options, including mechanical ventilation with heat recovery. Solar PV for electricity generation and batteries for energy storage were also considered, along with two options for domestic electric vehicle charging. For all of these systems, an outline system design has been proposed, and the practical and cost considerations of installation, operation and maintenance discussed. The financial and carbon impacts of each technology were considered, as are the potential social benefits in each case. A similar exercise was also undertaken for a central system of EV chargers a centralised PV-battery system to benefit the whole development.

As per the project brief, Locogen also investigated impacts of the recommended electricity systems on grid connection costs; benchmarked the homes' anticipated energy demands against the Firm Foundations and Passivhaus standards; and explored the potential for wider learning opportunities through in-situ monitoring of the home energy systems.

The Phase 3 report concludes that although they were more expensive than Air-to-Air heat pumps to install, Air-to-Water systems would provide the most energy-efficient heating and hot water system to the homes, making them the most cost-effective option for occupants and also the least carbon-intensive one. Heat from an Air-to-Water system could be delivered via underfloor heating or radiators, with the latter being lightly recommended over the former as they are cheaper to install and more familiar to future occupants. Wood burning stoves were also demonstrated to be a low-cost, ultra-low carbon back-up system. Mechanical ventilation with heat recovery was noted to have a limited impact on running costs at large capital expense. The report also highlighted that maximising the solar PV capacity on each property would see reductions in the grid reliance, costs and emissions and will contribute to wider decarbonisation strategies. Conversely, batteries were noted to have diminishing returns as capacity increased, so smaller systems were recommended to enhance the benefits of the PV systems. Lastly, consultation with SSEN confirmed that slow EV chargers could be installed at each property with no additional grid connection costs, hence these were recommended for the development over fast chargers.

Following the appointment of a design and build team for the development, including an architect who produced finalised layouts for the development, Phase 3b was conducted. The Phase 3b analysis was added to this document in 2021 and demonstrated the positive financial and carbon impacts of the energy systems chosen by the Client. The energy demand basis of each unit type was also recalculated in line with the proposals from the project's Architect. Based on the conclusions of the Phase 3 report, and the Clients budget, the impacts of Air-to-Water heating systems, solar PV and Sunamp heat batteries are presented and compared to one that passes building regulations at a minimum cost. Through this comparison, the case for funding the chosen energy systems is made clear.

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1. Introduction

1.1. Project background

The Tomintoul and Glenlivet Development Trust (TGDT or 'the Client') have appointed Locogen as their energy consultant to perform a three-phase options appraisal for their BS^mART housing development project. This report is the key deliverable of the third stage of the project, which is supported by CARES and Community Housing Scotland.

TGDT have identified a need for affordable housing in Tomintoul, Moray, and plan to deliver 12 affordable community homes on the site of the village's former high school. The development, which includes nine social rent and three private-tenure properties, is currently in pre-planning stages, and an indicative site layout has been developed as a design basis. A copy of this layout is contained in Appendix B of this report.

Initial consultations and inquiries have been conducted with the local authority, Cairngorms National Park, and with Scottish and Southern Electricity Networks (SSEN), amongst other relevant bodies. In order to better understand the impact of the development's generation and energy loads on grid connection costs and opportunities, Locogen have consulted further with SSEN and arranged a second budget estimate grid connection, which has been shared with the client.

During Phase 1 of the project, the properties' energy demands were estimated, with heating demands presented for three illustrative building fabric efficiency (U values) scenarios, which are detailed in Appendix A. Based on these energy demand estimates, the key portion of Phase 1 involved investigating the development site's key opportunities and constraints, in order to develop a longlist of energy system technologies for assessment in Phase 2. For this assessment, a traffic light matrix was produced to evaluate the energy technologies on a cost, risk, complexity, environmental and social impact basis. The outcome of Phase 2 was the following shortlist of technologies to take forward to Phase 3 for detailed consideration:

- Air Source Heat Pumps (ASHP);
- Log burning stoves (as a secondary heating source);
- Mechanical ventilation with heat recovery;
- Solar PV installations;
- Electric batteries and Sunamp heat batteries;
- Domestic Electric Vehicle (EV) chargers; and
- A central energy system with PV, battery storage and EV chargers.

1.2. Aims and objectives

The aim of Phase 3 is to summarise the viability of the above energy system technologies in sufficient detail, and with sufficient background information, to provide recommendations for one or more preferred options to be taken forward. These recommendations should be based on consideration of technical, operational and financial viability, as well as net carbon savings, environmental impacts and social benefits. The intended outcome of this phase is to facilitate the project to move forward towards development of a suitable energy system for the properties.

1.3. Report structure

The report will review stage by stage the technologies identified in Phase 2 to compare their integrated benefits and limitations to provide a systems-level approach to their viability for the properties planned. These will be applied to the current layouts and specifications as provided by the client, and will use the 'good' insulation standard identified in Phase 1 as the base thermal case for the properties.

The following sections have been structured to analyse the key technologies considered to deliver heat, hot water, ventilation and power to the properties.

- Space heating and Domestic Hot Water (DHW)
- Ventilation
- Solar Photovoltaics (PV)
- Energy Storage (ES)
- Electric Vehicles (EVs)

A further section considers the development site's communal area and the potential for a shared PV installation with battery and EV charging points (EVCs). Following this, the report will consider the developments' integrated system costs and emissions, and discuss the implications for grid connections and for wider learning opportunities. Additionally, the properties' energy performance has been benchmarked against the Firm Foundations guidelines and the Passivhaus standard. Lastly, the findings of the report are summarised and presented alongside recommendations for moving the development forward.

2. Primary heating and hot water systems

2.1. Overview

Phase 3 will review the comparison of different ASHP solutions for each of the property types along with their relative merits and considerations. This will consider both the ability for the system to deliver space heating and domestic hot water (DHW). Other solutions, such as Ground Source Heat Pumps, biomass and integrated District Heating solutions were compared and discounted as part of Phase 2. Each of the variants will be evaluated for their technical, operational, financial and social impacts.

2.1.1. Space heating

With regards to ASHP systems, two variants are considered here:

Air-to-Water (A2W) systems – These are ASHP systems where the refrigerant within the heat pump is used to heat system water, which is then circulated around pipes to either appropriately sized radiators or Underfloor Heating (UFH) to heat the building. These systems can also be used to heat Domestic Hot Water cylinders. These ASHPs are the standard type installed most regularly for heating systems, with around 44,000 domestic units installed and accredited in the UK under the domestic RHI scheme¹.

Air-to-Air (A2A) systems – These are ASHP systems where the refrigerant within the heat pump is circulated directly to one (or several) air heating units. These units directly heat the air within the space. Due to the lack of an intermediate step between the ASHP and the air to be heated, the efficiency of the units is higher. However, the A2A units are not able to provide DHW, so a further system is required to provide this.

These A2A units have been installed throughout the world but more traditionally as air conditioning units. As such they have not been installed regularly in the UK as heating sources, partly due to the lack of UK acceptance of blown air heating, but also due to their non-eligibility to the domestic RHI scheme.

Secondary heating system options have been considered in section 3.

2.1.2. Domestic Hot Water

In terms of the provision of DHW, where an A2W unit has been considered, this system will be connected to a domestic hot water cylinder. An electric immersion coil can be installed to act as a dump load in the situation of excess solar PV energy, or in future when price/cost signals determine the system to be most cost effective.

Where A2A systems have been considered, the use of phase change thermal storage batteries has been assumed. These allow the use of electricity (either from the onsite generation or imported from the grid) to charge the unit and store heat for use. Sunamp batteries are currently the only commercial battery of this kind known to Locogen and are available in four sizes between 3.5-13.5kWh. For these properties, a Sunamp storage capacity of 7kWh is recommended, as this value is best matched to be anticipated the daily hot water demands of the properties. However, as the cost of Sunamp batteries is essentially equivalent to the option of a cylinder with a dump load for excess PV, the options are effectively interchangeable. If space is an important constraint, the Sunamp batteries may win out as they are more compact.

¹ As of 21st Jan 2020 - <https://www.ofgem.gov.uk/environmental-programmes/domestic-rhi/contacts-guidance-and-resources/public-reports-and-data-domestic-rhi>

2.2. Design

2.2.1. Space heating

Each of the ASHP units will comprise of a series of key components:

- An evaporator unit will be installed either internally or externally. If externally a unit will be mounted on a suitable solid base with clear air flow. Internally this will require additional plant space and wall mounted intake/extract louvres.
- Internally space will be required for a thermal store (for DHW production – cylinder or phase change system)
- Additionally, an internal controller will be mounted in a communal space to control the unit. This will be tied to an external air temperature sensor.

Where the A2W unit is installed, additional internal requirements would be:

- Buffer vessel
- Distribution pump and ancillary pipework (expansion vessel and PR valve)
- Heat emitters installed throughout the building

Where the A2A unit is installed, additional internal requirements would be:

- Air heater unit(s)
- Refrigerant pipework

Where A2A units are installed, traditionally they were connected to a single heater unit. However, a version of the system known as a split A2A system (in air conditioning systems these are known as VRF or VRV systems) allows for the connection of multiple air heater units to a single external unit. These allow for the differential heating (and cooling) of multiple rooms within a building. However, these are typically limited to around five internal units, so the location of these, along with the internal design of the space may need to be considered carefully. The use of supplementary direct electric heating in certain spaces (such as bathrooms or potentially even bedrooms) would need to be considered at the detailed design stage.

The location for the installation of the ASHP plant has yet to be determined and should be established as part of the evolving design process. However, it should be assumed that a utility cupboard/plant space of approximately 2x1m minimum floor area will be required within any design. This will be increased if the ASHP evaporator is located indoors, and based on the selection of ventilation plant. Any ASHP system should be designed in coordination with the Microgeneration Certification Scheme (MCS) standard MIS 3005 V5.0 and all ancillary documents associated with the MCS standard.

At this stage specific installers have not been specified, however data from a number of different manufactures has been reviewed to ensure modelled data is comparable with commercially available system topologies. Therefore, the selection of manufacturers should be limited to the detailed design and value engineering stage following the conclusions of Phase 3. Any system installed in compliance with MCS should meet a minimum Seasonal Performance Factor (SPF) of 2.5. Current consultation on the RHI replacement scheme is proposing an increased SPF minimum target of 2.8. It is suggested that 2.8 be taken as the minimum acceptable design standard for any installation, and values slightly higher than this have been assumed in the design calculations, based on reviews of the better performing installed ASHP data gathered

from UK ASHP installations^{2,3}, on the basis that best practice installation guidance will be implemented and lessons learned to ensure high performing systems are delivered.

One key point raised from the analysis of the data from installed ASHP installations relates to the prevalence for short cycling and the effect on system efficiency. This should be carefully considered at the detailed design stage, including control mechanism, the provision of sufficient system volume and balancing of the distribution infrastructure.

Secondly, due to the low external air temperatures encountered at the design location, it has been proposed that if the ASHP evaporator unit is internally located, then exhaust air from the MVHR unit can be used to supplement the incoming air to the ASHP system, raising the temperature (and resultant COP) during winter. The value of this would need to be established during detailed design and value engineering stage as the additional complexity may outweigh the operational benefit.

Another option to enhance the performance of the ASHP systems is integration of heating and mechanical ventilation. This is considered in section 4.1.

2.2.2. DHW

The operational size of the DHW storage has been estimated based on a typical UK water consumption of 45l/p/d. This assumption can be reviewed during the detailed design stage on the basis of installed water saving features (such as low flow taps and aerating shower heads).

For both units, the technical complexity relates to the output temperature of the A2W ASHP units and their ability to sufficiently heat the DHW. The space heating distribution temperatures for the system have been assumed at 45°C flow. The water stored within the cylinder will need to be heated to 60°C for legionella protection. This can either be achieved with high temperature heat pumps for the DHW cycle, or through the timed use of the electric immersion heater to pasteurise the cylinder (the preferred approach recommended here). Within the Phase Change storage system, the system will need to receive water at 65°C in order to facilitate the phase change of the storage medium. These systems do not need to be pasteurised or comply with the G3 regulations. However, due to the complexity of achieving the required flow temperature, only the direct electric phase change storage systems have been considered here at this stage, and will be applied in coordination with the A2A units.

Where A2W units have been considered the selection for the DHW storage has been anticipated to be an unvented DHW cylinder in compliance with G3 regulations. These cylinders are provided with energy ratings under the European Energy-related Products Directive (ErP) and products should be selected that conform to the higher A standard as a minimum. This should be considered in light of any changes coming forward in the proposed section 6 update to the Scottish building regulations. Cylinders should be specified with special consideration to the lower flow temperatures from the heat pump, which will necessitate a larger coil surface area.

The cylinder systems should be installed with a backup electric immersion heater. This can potentially be connected to a solar PV diverter switch to spill excess electricity into the DHW storage should other stores be full. Units must be selected that can integrate with the electrical storage systems, and therefore are more limited in supplier. Key examples of systems that are

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https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/606829/DECC_RHPP_160428_On_performance_variations_v20.pdf

³ <https://energysavingtrust.org.uk/sites/default/files/reports/TheHeatisOnweb%281%29.pdf>

thought to be suitable would be Eddi⁴ or ImmerSun⁵, although further discussions would be required at the detailed design stage to ensure suitable cross functional integration with the other systems controllers.

Phase change systems integrate with the solar PV in a similar way, but also requires direct electricity to provide the rest of the DHW provision.

All of these units are easily available and require little specific equipment or training for a competent installer. Therefore, no significant technical hurdles are perceived outwith the need to ensure that the controls infrastructure is correctly commissioned to facilitate the careful cascade of the energy through the generation and storage systems.

2.3. Installation

The installation of either system is not outwith the scope of correctly trained and certified installers, and these are prevalent. Ones with experience of integration of multiple renewable energy systems would be advocated due to the complexity of controls integrations. The installation of A2A systems will require F-Gas certified installers, and both systems should be undertaken by MCS accredited ASHP installers.

If correctly planned, the installation should not see significant complexities as part of the build process, although it is strongly recommended that the building designs are developed in coordination with the heating contractor to ensure sufficient allowance is made for ducts and penetrations at the foundation stage. This will minimise the need for additional penetrations by heating and electrical contractors which will further compromise the air tightness of the structure.

The installation phase for either of the A2A or A2W systems (with their respective DHW systems) is likely to take place over three-four phases and will need to be coordinated into the build programme.

The main technical risks relate to the integration of controls at the commissioning stages. Additional time and resource should be allowed to ensure that the systems are effectively commissioned and handed over.

2.4. Operation and maintenance

The operation of ASHP units is relatively simple. They require an annual service and for the filters to be cleaned on any air ductwork and intakes. This annual service should also consider the DHW systems and a check on the controls functionality. Where A2A wall heaters are installed, the filter units within these should also be cleaned or replaced annually (or as per manufacturers recommendations). The service and maintenance of these units is more specialist than comparable oil and gas systems, but still sufficiently common for there to be a number within the local area. None are listed on the MCS database for Tomintoul, but the closest ten registered engineers are located in Aboyne, Kingussie, Forres, Elgin and Inverness.

In terms of reliability, these units are typically reliable with limited moving parts (heat pumps only contain a scroll compressor and a fan). Once operational and if serviced regularly they are anticipated to be reliable systems for providing heat and hot water. Most operational issues stem from incorrect use of controls infrastructure or overly complex requirements which are short-cut by the operator (but at reduced functionality). It is advised that this is carefully

⁴ <https://myenergi.com/product/eddi/>

⁵ <https://www.immersun.co.uk/>

considered and, where possible, operations made as simple and as fool-proof as possible. Training should be provided to all tenants/homeowners and best practice would be to provide follow-up engagement after 3-6 months of operation to resolve any issues that will have arisen after a period of use.

The life expectancy of an ASHP unit is typically anticipated to be 10-15 years for the evaporator unit. This can be considerably less in coastal environments, however at this location it is not perceived to be a significant risk. The life expectancy for the wider system components could be upwards of 20-30 years. Water quality is a degrading factor in DHW and other pipework and should be tested and considered to ensure system components are appropriately selected at the design stage.

It is advised that heat and electricity metering be installed as per MCS recommendations to allow for ongoing performance monitoring, and that a provision be put into each purchase/lease contract that anonymised data can be used for ongoing research into the performance of the systems.

2.5. Regulations and other requirements

The systems outlined here would need to be considered within the planning process in terms of their noise effects on their neighbouring properties. The MCS process includes an initial assessment of noise impact in locating external ASHP units and this should be considered when providing the initial planning layouts. All components will need to be defined for building warrant and heat pumps will need to be specified for the formal grid application.

All of the plant items identified here are at TRL 9 and are widely installed. The integration of these systems along with the coordination of the different controls infrastructures could be classed at TRL 7-8.

2.6. Costs

2.6.1. Space heating

The cost of each heating system component for the properties are shown in Table 1. Because the peak heating demands are so small, the cost of the ASHP units are not likely to vary between properties as they as minimal capacity units would meet the demand of all properties. For A2W systems, two scenarios for heat distribution have been presented; firstly, with underfloor heating, and secondly with conventional radiators. It should be noted that a combined system, such as with underfloor heating on ground floors with radiators upstairs would also be feasible and would provide a more cost effective balanced solution. In Table 2, the total system costs are presented for each property.

Component	A2A	A2W + UFH	A2W + rads
Outdoor unit	£1,500	£2,000	£2,000
Indoor unit	n/a	£1,500	£1,500
HW system	£1,500	£1,500	£1,500
Heat emitters	£250 per unit	£35/m ²	£150 per unit
Installation	£2,000	£3,000	£3,000

Table 1: Heating and DHW system Capex breakdown

Property	A	B	C	D	E
A2A system capex	£5,750	£6,000	£6,000	£5,750	£6,000
Emitters required	3	4	4	3	4
A2W + UFH capex	£10,625	£12,725	£13,075	£10,450	£11,080
A2A + rads capex	£9,050	£9,800	£9,650	£8,900	£9,050
Emitters required	7	12	11	6	7

Table 2: Heating and DHW system total Capex comparison

It is clear from Table 2 that the A2A systems represent the lowest cost system to install, and also vary the least from property to property. However, the running costs of each of the systems should also be considered when determining which represents the best investment.

2.6.2. DHW

The supplied cost for each unvented DHW cylinder (suitable for heat pumps) is anticipated to be in the region of £1,200-1,700 each, plus the cost for installation and ancillary connections. The supplied cost of a Sunamp phase change storage unit is comparable, at around £1,200-£1,700 for the range of sizes considered here. In order to make the best use of the cascade energy storage systems, a solar immersion switch has been considered with both scenarios. These cost in the region of £300-500 each, plus installation.

Where the use of either the phase change storage system or the immersion system with solar switch is considered, once the electricity diverted to the battery has been accounted for, it is anticipated that these systems will benefit from between £30 and £75 worth of useful solar energy per year (compared to the value of exporting under the SEG scheme). Therefore, these measures will see a positive benefit over their life, but would be more applicable where the properties have larger PV arrays.

2.6.3. Operational costs

The estimated cost for an annual service of each property is estimated at £120-180. The fuel costs will vary depending on end-user preference in terms of heating routines and indoor temperature, and in depending on how much of the electricity consumption is offset by direct or stored solar PV generation. The annual operation costs presented in Table 3 are based on calculated annual demands for the good insulation scenario without MVHR. They are inclusive of maintenance costs (at £180) and based on a fixed electricity tariff of 14p/kWh. Savings versus oil boiler systems are also shown in the table, as a comparison between a nominal off-grid system.

Property	A	A (L/W)	B	C	D	E
A2A (no PV)	£695	£745	£930	£925	£655	£795
With 30% PV	£545	£580	£705	£705	£515	£615
Min savings vs oil	-£45	-£45	£10	£5	-£70	-£100
A2W + UFH (no PV)	£545	£580	£745	£740	£500	£585
With 30% PV	£440	£460	£580	£575	£405	£465
Min savings vs oil	£105	£120	£195	£190	£85	£110
Max savings vs A2A	£150	£165	£185	£185	£155	£210
A2W + rads (no PV)	£570	£610	£790	£785	£520	£610
With 30% PV	£455	£485	£610	£605	£420	£485
Min savings vs oil	£80	£90	£150	£145	£65	£85
Max savings vs A2A	£125	£135	£140	£140	£135	£185

Table 3: Heating and DHW system operational cost comparison

Table 3 demonstrates that despite being the cheapest option to install, A2A systems are the most expensive to run. This is because despite having a higher COP for space heating, they do not benefit from any COP for DHW provision, unlike the A2W systems. A2W systems with underfloor heating are slightly cheaper to run than with radiators, due to their higher SCOP. The 'With 30% PV' cases represent an illustrative scenario in which 30% of the annual heating demand is met by direct or stored PV generation. They show that as more of the heating demand is met on site, the cost of heating is lowered, and that gap between operating costs of A2A and A2W systems begins to close.

2.6.4. Revenue

The provision of the heating and hot water systems directly to the buildings and without an interconnected district heating network makes it challenging to operate as a revenue stream for the community group. The installations will not be eligible for the domestic RHI under Assignment of Rights (as the properties are new build but not self-build), nor eligible for the non-domestic RHI as they are not a communal shared loop installation. It is therefore not possible for an incentive revenue to be obtained from the properties.

A heat service revenue could be leveraged, if the community group decided to own and operate the individual heat pumps and sell heat to the individual buildings (at a metered rate). However, this would make the community group the heat service provider and liable for all call-outs and repairs on all properties. Also, it would necessitate adding additional cost to the p/kWh heat rate for each property. If 1p/kWh were added to hear unit of heat used within the buildings (which would increase the cost of delivered energy by 20-25%) this would only generate ~£1,000 per year for the community group. The cost of administering the scheme would exceed this, therefore this not anticipated to be any viable way of administering a scheme like this.

2.7. Social and environmental aspects

The ASHP systems specified will be able to mitigate the likelihood of fuel poverty compared to carbon intensive oil heating (except possibly for A2A systems). The likelihood of fuel poverty will be further reduced by the benefits of solar PV and energy storage (as discussed subsequently in this report). Energy storage will also be able to provide the heating systems with some resilience to power cuts, but given the location's cold climate, a secondary, non-electric, heating system is advised as a back-up.

3. Secondary heating systems

3.1. Overview

The client has noted interest in wood burning stoves, given their relative simplicity and cost effectiveness compared to other heating systems. CHS also noted that they are known to be highly favoured by social housing tenants. In the Phase 1 report, Locogen raised the issue that the process of adding wood fuel to the stoves is manual and can only be reliably performed by willing and competent adults. As such, elderly, infirm, or injured occupants cannot be expected to safely charge these, and they are therefore not recommended as a primary heating system, especially in the rental properties. However, wood burning stoves are a wise consideration for a secondary or back-up heating system to provide resilience against winter power cuts and provide an alternative source of fuel. Log stoves also provide a focal point within the living space and are anecdotally cited as providing improved perceived quality of living for occupants.

3.2. Design

The best location for a wood burning stove would be in the living area of the properties. Positioning the stove against an internal wall would mitigate heat losses, although would potentially add cost and complexity to the stove's flue system. The size of the stove itself depends its heat capacity, which would need to be 2-4kW, depending on the peak demand of each property. This range is approaching the minimum size of stoves available in the UK. Additionally, although not required under building regulations for stoves under 5kW, it is advised that a dedicated primary air supply be installed. There would also be a space requirement for log fuel, which has an energy density of around 1600 kWh/m³. This means that to meet a quarter of the annual space heating demand, 1-1.5m³ of logs would be required annually.

In terms of energy efficiency, a quoted value of around 70-80%⁶ would be considered good. However, the energy efficiency of wood burning stoves varies greatly in practise, as it depends on the type, size and quality of the wood fuel used, as well as how much air is supplied to the stove, which is manually controlled.

In order to minimise emissions and maximise efficiency, it is recommended that a stove be selected from the Ecodesign compliant list⁷ to ensure the stoves are designed to meet the most stringent emissions standards. This would futureproof the installation against proposed future legislative changes.

3.3. Installation

The process for installing a log burning stove is relatively simple. Firstly, a structural hearth should be included in the design for most installations (although a subset of manufacturers issue guidance that theirs can be installed without – to be determined during any detailed design exercise). The flue arrangement must be installed and ensured that it maintains sufficient distance from any combustible building materials. Stove data plate should be installed not the installation. All of these issues are covered within the Building Regulations and would be addressed by any suitably qualified HETAS stove installer if coordinated into the design process early enough. As referred to above, due to the low air change rate of the proposed construction it would be advisable to consider an external air supply for the stove. There are few technical

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https://www.researchgate.net/publication/269131508_Field_Study_of_Energy_Performance_of_Wood-Burning_Stoves

⁷ <https://www.hetas.co.uk/ecodesign-compliant-stoves/>

risks associated with this system as long as suitably qualified installers are included in the design process.

3.4. Operation and maintenance

Wood burning stoves are a long-established, reliable technology, likely to last for around 30 years. In terms of maintenance, they require an annual flue cleaning service, which should cost around £100. This would need to be undertaken and arranged by the homeowner/tenant. The operational requirements involve adding and igniting wood fuel to the stove and adjusting its air intake. Both of these tasks can be difficult to get right – for example, if too much air is allowed into the stove, the logs will burn out quickly. The stoves must also be periodically cleared of ash, which, once cooled, can be disposed of or used as compost.

3.5. Regulations and other requirements

Wood burning stoves systems are classed as permitted developments so long as their flues are not located on the front elevation of the building and do not extend more than a metre above the highest part of the roof. They must also comply with building regulations, although this can easily be ensured by using an installer who is certified with HETAS, the UK organisation for quality and safety in biomass heating systems. HETAS should also be used to identify competent local services engineers, to locate quality fuel supplies and for reference information regarding safe practise for using stoves.

The client may also wish to consider the option of arranging a bulk fuel delivery system for the rental properties. This is likely to benefit from a bulk discount, but is also likely to encounter issues in terms of timing of supply, as the usage patterns of each properties depend on resident preference. The danger of this is the potential oversupply of wood, which may take up significant space and/or be wasted or if not used in good time.

3.6. Costs

The capital cost of installing a woodburning stove is likely to be around £1,500 for each property. The operational costs will obviously vary greatly depending on the properties, the weather and user preference between the stove and the main heating system. The calculations in Table 4 and Table 5 are based the logs providing on 15% and 30% of the annual heat demand. The calculations are based on a wood fuel cost of 8p/kWh and the space heating cost of the primary heating system options without any savings from PV generation.

Property	A	A (L/W)	B	C	D	E
Stove use (kWh/ year)	815	897	1370	1349	658	798
Annual fuel cost	£65	£72	£110	£108	£53	£64
Additional annual cost vs primary heating	£27-37	£30-40	£45-62	£45-61	£22-30	£26-36

Table 4: Wood fuel costs (15% annual heat demand)

Property	A	A (L/W)	B	C	D	E
Stove use (kWh/ year)	1,631	1,794	2,739	2,697	1,316	1,595
Annual fuel cost	£130	£144	£219	£216	£105	£128
Additional annual cost vs primary heating	£54-73	£59-81	£90-123	£89-121	£43-59	£53-72

Table 5: Wood fuel costs (30% annual heat demand)

Although the above costs above only represent two generalised scenarios, they indicate that, at the assumed fuel cost rate, wood burning stoves represent a low-cost means of supplementing or backing up the properties' primary space heating system – albeit they are more expensive than the ASHP options themselves. However, this is made less significant by the fact that the stoves would serve a crucial purpose as a back-up heating system.

3.7. Social and environmental aspects

Whilst being relatively low cost to procure and operate, wood burning stoves are considered by some to be luxury appliance and highly valuable in terms of comfort and enjoyment. As such, they are likely to be appreciated by residents and may also offer a small improvement on the sale value and desirability of the properties. Being somewhat cheaper to run (based on the modelling assumptions in this report) they have the potential to reduce the likelihood of fuel poverty, although this effect is likely to be minimal and difficult to guarantee. Additionally, the local authority is generally supportive of biomass heating generally and the use of the stoves would support the local wood industry.

Wood fuel also offers a very low carbon heat source, with an emissions intensity of less than 0.01 kgCO₂/kWh of useful heat. This value is at least seven times lower than the emissions intensity of air source heat pumps, based on the 2020 grid carbon factor, and remains two times lower based on the current estimates for 2040. However, there have been a number of national discussions related to the emissions created by domestic stoves, including the 2019 Clean Air Strategy⁸ which attributed 38% of local particulate emissions to the use of stoves. This has been disputed by HETAS⁹, but still makes clear that poor use of wood burning appliances can create a potential local air quality issue. It is therefore suggested that the stoves be selected Ecodesign certification, and that homeowners be provided with guidance such as the 'Ready to Burn'¹⁰ guidance on the best way to operate a stove.

⁸ <https://www.hetas.co.uk/clean-air-strategy-2019/>

⁹ <https://www.hetas.co.uk/understanding-the-impact-of-domestic-wood-burning/>

¹⁰ https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1901291307_Ready_to_Burn_Web.pdf

4. Ventilation options

4.1. Overview

The ventilation requirements of new homes are closely linked to the methods and materials used in their construction. Under Scottish building regulations, the required type of ventilation is linked to the designed airtightness of the property, which is essentially a measure of the 'leakiness' of the building envelope. Typically, residential buildings have always been naturally ventilated, but improved construction techniques have increased airtightness to the extent that they can run into comfort and fabric issues without assisted ventilation.

Below an airtightness level of $5\text{m}^3/\text{h}/\text{m}^2$ @n50 – meaning a tested result at a pressure of 50 Pascals – mechanical ventilation of some form is required. This can be centralised (i.e. whole house) or decentralised (just in kitchens and wet rooms). Below $3\text{m}^3/\text{h}/\text{m}^2$ @n50, Mechanical Ventilation with Heat Recovery (MVHR) or centralised Mechanical Extract Ventilation (MEV) becomes mandatory. To achieve a Passivhaus certification, 0.6 air changes per hour @n50 – equivalent to around $1.5\text{m}^3/\text{h}/\text{m}^2$ – would be required. MVHR is often chosen for Passivhaus homes, as it allows the incoming air supply to be heated by the extracted air, which leads to a reduction in heat demand and associated fuel cost savings.

For MVHR systems, the value of integrating any of the ASHP options with the MVHR system was considered. The advice from industry was that this gets complicated very quickly – ventilation times and heating times are often different and integrating the heating and ventilation means that if one system breaks down, both do. Another issue with this option is that the integrated systems are only offered by a few manufacturers and therefore going down this route would potentially tie the project to a single supplier, which carries significant financial risks. The best option for these systems is to tie the ASHP into a post-MVHR heat exchanger from the ASHP buffer, however, this has not been taken further as at this stage due to this risk and as it would be a more appropriate consideration for detailed design.

4.2. Design

In terms of sizing, mechanical ventilation systems must be sized to meet the extraction flowrates prescribed by building regulations, based on the total number of 'wet rooms' (i.e. kitchens, utility, bathrooms, etc). Ventilation systems require space for both installed plant, ductwork and access. It is typical for the main ventilation plant to be installed in the loft space of new builds, but a cupboard or plant room would also be suitable, and would likely make periodic access for maintenance easier. The ventilation settings are usually controlled via an interface on the main unit, although some models are also available with remote, wall mounted controls and control and monitoring apps.

4.3. Installation

Ventilation fan systems work at low power and are susceptible to poor installation practice. Squashed ductwork, sagging connections and sharp angles should be avoided at all points. Duct installation needs to be installed during the first fix internal construction phase, before walls and ceilings are completed. Grill connections can then be installed after surfaces have been installed, and finally covers placed after decoration. Any locations for access points should be marked to allow these to be cut and fitted after surfaces have been installed, if in locations that cannot be accessed (such as lofts).

All duct systems should be commissioned by the installer and balanced to ensure appropriate air flow in each room. It is advised that noise checks be undertaken to ensure that no system noise leakage is present before the installer leaves site. If suitable ventilation contractors, or preferably domestic MVHR specialists are used, then risks and complexities should be minimised. As with other aspects of the system infrastructure, early coordination with the ventilation contractor can ensure that any routing and timing issues can be mitigated. Unlike most building services, ventilation is harder to re-route around other services without having significant effects

on its performance. Therefore, it is imperative that the layout for the ductwork be considered early in the system design and be installed as one of the earliest first-fix service installs to ensure the system performs to its anticipated potential.

4.4. Operation and maintenance

Centralised ventilation systems (both MHVR and MEV) have relatively few moving parts and are anticipated to not require any major component replacements within 10 years. At this time, the main fan unit may need to be replaced, but the ductwork should be serviceable for 20-30 years with minor repairs to grilles and checks for leaks. Localised wall fans typically are less reliable and have a life expectancy of 3-5 years. These are usually controlled by 'on/off/boost' switches, whereas centralised systems tend to have additional modes including summer bypass to avoid overheating.

Any extract located in a bathroom or kitchen will need to be cleaned regularly to remove dust, fluff and grease. MVHR and MEV systems will often have a grease trap fitted to the kitchen extract grille that will need to be removed and cleaned regularly (annually advisable).

MVHR systems include centralised filter unit(s) that will need to be replaced. Manufacturers differ on the period between filter changes, with advice ranging between 3-12 months, with 6 months as a typical maximum inspection length. A filter set can be anticipated to cost between £20-40. It is recommended that filters should be changed after construction, and again shortly (2-3 months) after first occupying the property to deal with increased dust levels caused by the construction and moving/decorating processes.

All ducted systems should be cleaned every few years, although limited service providers are available to offer this. We are advised that it can be done manually with flexible brushes and a long vacuum cleaner hose.

4.5. Regulations and other requirements

As mentioned above, local or centralised mechanical ventilation is required by Scottish building regulations below certain airtightness levels. The chosen airtightness standard and ventilation method also have a small effect on the energy efficiency ratings of the buildings, as shown in section 10. In summary, MVHR facilitates the highest SAP scores, followed by natural ventilation (with a higher airtightness value) then mechanical ventilation without heat recovery.

4.6. Costs

For properties of this size, capital costs for MVHR systems are in the range of £4,000 to £6,000 including installation. MEV tends to be cheaper, at around £2,000 to £3,000 for centralised MEV. Extractor fans will cost £50-£100 each and will not require installation by a ventilation specialist. The operational cost of a mechanical ventilation system is small, roughly £20-£50 annually, due to the electrical demand of their fans.

Table 6 and Table 7 show the maximum annual savings arising from MVHR compared to natural ventilation and MEV respectively, based on MVHR providing a 30% reduction in annual space heating demand. The savings presented are based on central estimates of the capex stated above (i.e. an additional expenditure of £5000 vs natural ventilation and £2,500 vs MEV) and an annual electricity consumption equivalent to £25 for both mechanical ventilation systems. Savings from PV generation are excluded in order to represent maximum savings potential.

Property	A	A (L/W)	B	C	D	E
Heat saved (kWh/ year)	1,631	1,794	2,739	2,697	1,316	1,595
Annual cost savings	£41	£48	£87	£85	£29	£40
Max 20-year savings minus additional Capex	-£4,170	-£4,035	-£3,265	-£3,300	-£4,425	-£4,195
Max 20-year savings per £1 additional Capex	£0.17	£0.19	£0.35	£0.34	£0.11	£0.16

Table 6: MVHR cost savings vs natural ventilation

Property	A	A (L/W)	B	C	D	E
Heat saved (kWh/ year)	1,631	1,794	2,739	2,697	1,316	1,595
Annual cost savings	£67	£74	£113	£112	£54	£66
Max 20-year savings minus additional Capex	-£1,160	-£1,020	-£240	-£260	-£1,420	-£1,180
Max 20-year savings per £1 additional Capex	£0.54	£0.59	£0.90	£0.90	£0.43	£0.53

Table 7: MVHR cost savings vs MEV

These tables indicate that compared to natural ventilation, MVHR offers a small reduction in annual energy bills, as the heating savings are offset by the additional cost of running the ventilation system. Compared to MEV, which would have a similar self-consumption cost, MVHR offers greater savings on heating costs. As such, the (indirect) returns of investing in MVHR are shown to be more favourable against MEV compared to natural ventilation. Of course, there are further consideration that affect these decisions, in terms of the costs and implications of building to different airtightness standards, which are beyond the scope of this report as they required specialist construction knowledge.

4.7. Social and environmental aspects

The social key benefit of mechanical ventilation is that it helps facilitate the Passivhaus standard, which may be desirable to the client and to potential buyers to the high levels of design quality and comfort associated. MVHR also allows small savings in heating emissions and costs, so has a small impact in mitigating fuel poverty, whilst offering an increase in comfort compared to MEV (as it supplies partially warmed air). Lastly, the design and commissioning of centralised mechanical ventilation must be carefully considered to minimise noise impacts. If the noise from the ventilation is perceived to be a nuisance to occupants, there is a risk that they will turn off the system and create a 'stuffy' environment.

5. Domestic Solar PV options

5.1. Overview

Solar PV has been identified as the key opportunity for the development to generate its own electricity, in order to significantly reduce energy costs and to provide an income stream to residents to further reduce import bills. For each property, a rooftop PV array has been assumed to be the base case, and solar carports have been considered as a 'nice to have' addition. For rooftop arrays, roof-mounted and roof-integrated PV modules have been considered.

A further alternative is solar tiles, which would cover the majority of a rooftop to mimic the appearance of roof slates. At present, these are only available from one manufacturer in the UK and cost at least 3 times more than roof-mounted PV per kW installed. They also operate at reduced efficiencies, so offer lower energy savings per unit area. As such, Locogen would only recommend consideration of solar tiles in the unlikely case that local authority do not grant planning permission for the development for other types of PV.

5.2. Design

Rooftop PV

For new build housing, roof-integrated systems are becoming increasingly popular, as they offer better aesthetics and their higher costs are partially offset by avoiding the requirement to tile the area underneath them. An example installation is shown in Figure 1 below.



Figure 1: Roof-integrated Viridian solar PV arrays¹¹

For roof-mounted and roof-integrated PV, the available area for an array has been determined assuming each property's roof pitch to be 40°, as this was found to maximise annual PV yields in Phase 1. It was also noted in Phase 1 that pitches within 5° of this would provide similar outputs. The peak PV capacity has been based on filling roof area with 1x1.7m modules of 300Wp capacity (as this represents a high specification for both roof-mounted and roof-integrated systems). In order to provide a conservative estimate, given that the buildings have not been designed in detail, two panels have been subtracted from the maximum capacity of each building to account for any roof lights that may be necessary or desired.

¹¹<https://www.viridiansolar.co.uk/gallery-of-solar-installations.html#>

A half-hourly energy flow model of the properties' annual demands has been used to confirm that the reduction in electricity costs arising from PV generation scales more or less directly with installed capacity, before any additional savings from battery storage are considered. Figure 2 exemplifies this trend for property C (with A2A heating and one EV). Installing the maximum capacity of rooftop PV is also likely to have better aesthetics and to benefit from economies of scale.

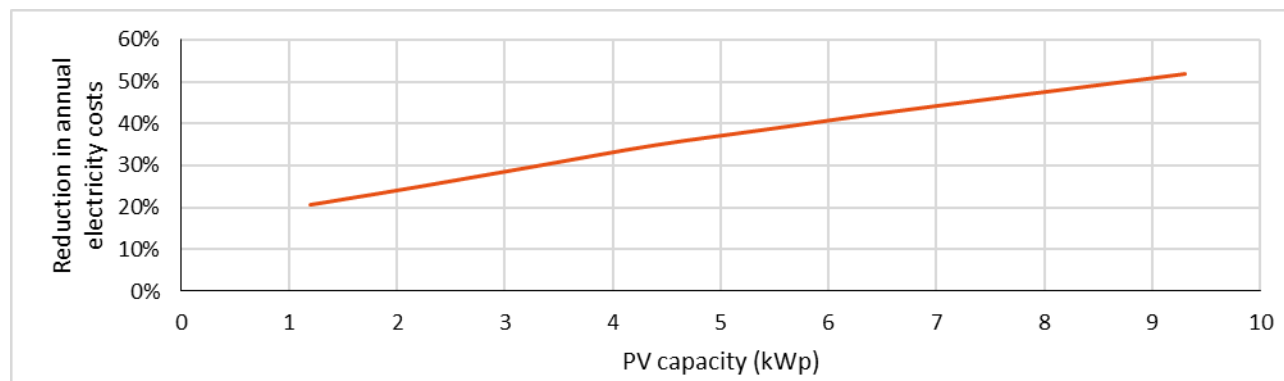


Figure 2: PV capacity vs electricity savings for property C

The resultant maximum rooftop PV capacities are presented in Table 8 along with annual yields, calculated using PVSol software. The table highlights that, as a single storey building, property A will benefit the most from a maximised PV installation as greater percentage of its annual demand will be generated¹².

Property	A	A (L/W)	B	C	D	E
Roof Orientation	SW	SW	SW	SW	SE	SE
Max PV capacity (kWp)	5.4	5.4	5.4	6.6	3	3.9
Annual yield (kWh)	3,860	3,860	3,860	4,715	2,145	2,785
Annual generation vs annual demand	70%	55%	47%	58%	42%	38%

Table 8: Development rooftop PV capacities

Carparks

The trend in Figure 2 also suggests that solar carports are a worthwhile consideration for the development. There is presently a limited range domestic-scale options, as not all installers operate across the whole of the UK, although those that do although usually provide as turnkey options from design to installation. From an industry contact, Locogen received a quotation of £10,000 per carport installed. Locogen considered the development layout and determined that plots 1-4 and 8-12 were either too shaded or too small to accommodate a 3x5m carport. On this basis, and due to their high costs, domestic carports have therefore not recommended for further consideration.

Ancillaries

The main pieces of ancillary equipment required for PV are an inverter to convert the DC electricity generated to AC for domestic use, and a controller to divert PV generation to a hot

¹² Note that Table 8 displays generation divided by annual electricity demand, and does not indicate the percentage of PV generation that is utilised onsite to meet demand.

water cylinder/Sunamp or electric battery. These diverters are usually small wall-mounted appliances that should be easily accessible. They can be programmed to prioritise different loads at different times of the day, to make best use of the generated electricity.

5.3. Installation

Installation of rooftop PV should be performed by an installation firm with MCS accreditation. There are several MCS certified installers operating from Inverness and Aberdeen and a handful more locally to Tomintoul¹³. Rooftop arrays of this size are likely to take 1-2 days to install and will require scaffolding. Therefore, it would be prudent to arrange roof-mounted PV installations at the same time as the installation of roof tiles/slates. Once the roof is battened out the solar PV panels can be installed and the roof tiles then installed around the perimeter of the panels to overlap the flashings.

5.4. Operation and maintenance

Most solar PV modules now come with a warranty of around 25 years, and a minimal performance degradation of $\sim 0.7\%$ per year. Roof-integrated PV is more susceptible to overheating, as there is no airgap between them and the building. This can lead to a slight drop in performance compared to an equivalent roof-mounted system of about 3%.¹⁴ Conversely, roof-mounted PV has a disadvantage in the respect that if there is an issue with the roof covering (such as loose tiles underneath the array) the whole PV system would have to be decommissioned and reinstalled once the issue is resolved.

There are no regular operational or maintenance requirements for PV, as arrays at pitches of at least 10° are considered to be self-cleaning. However, it is recommended that the systems are visually inspected each year, any filters on the inverters should be cleaned, and the modules checked for dust or leaf build-up. In areas with dust, nesting birds or other contaminants the modules may require periodic cleaning, but this can be gauged during the initial operational period. This can be typically be done by a window cleaning service from the ground.

5.5. Regulations and other requirements

The rooftop solar arrays will have to be included in the main planning application of the development. The PV may be subject to scrutiny in terms of its impact on local visual amenity, therefore it is advised that the client discusses this with their planning officer prior to finalising the PV specification. All components will need to be defined for building warrant and the PV capacity and inverter specification will need to be specified for the formal grid application.

As demonstrated in section 10, adding PV to the properties energy systems has a very beneficial impact on their SAP ratings. This indicates that PV may be of key strategic importance to the development in securing SAP energy efficiency ratings of at least 80, as required by the Firm Foundations guidance.

5.6. Costs

Based on Locogen's extensive experience of solar PV installs, the cost installation cost of roof-mounted PV will be around £800/kW for this development. For roof integrated PV, costs are higher at around £1,500/kW due to the technology's relative novelty. Crucially though, the cost of roof-integrated PV is offset by the avoided cost of installing roof slates or tiles. This saving is

¹³ <https://mcs-certified.com/find-an-installer/>

¹⁴ https://www.viridiansolar.co.uk/assets/files/briefings/08_In-roof_Performance_of_PV.pdf

likely to be in the region of £1,000 per property, although this has not been included in the cost analysis as it would need to be confirmed by a specialist at a later stage in the design process.

Table 9 provides an overview of the expected cost the various PV options for each property, including diverter costs. The table makes clear the additional investment required for roof-integrated systems to achieve the same generation capacity as roof-mounted systems.

Property	A	B	C	D	E
Max PV capacity (kWp)	5.4	5.4	6.6	3	3.9
Roof-mounted PV cost	£4,320	£4,320	£5,280	£2,400	£3,120
Roof-integrated PV cost	£8,100	£8,100	£9,900	£4,500	£5,850

Table 9: Development PV installation costs

The significant maintenance cost for PV is the replacement of the inverter which is likely to be required after 10-15 years, at a cost of around £700 per dwelling. Solar diverters cost in the region of £400 and would likely need replaced at least once over the PV installation's lifetime.

The operational savings for each PV option are demonstrated in detail in section 9, although Figure 2 indicates that these can be expected to be in the region of 30-40%, prior to any savings from battery storage. These savings are based the properties obtaining under the Smart Export Guarantee (SEG). The SEG is the national mechanism for rewarding the export of decentralised electricity generation to the grid, and is paid out by electricity supply companies. Therefore, it is an opt-in mechanism and income will depend on the chosen energy company's rates. Based on the current offers¹⁵, a rate of 5p/kWh has been applied to the financial analysis.

5.7. Social and environmental aspects

In reducing reliance on grid-imported electricity, solar PV will directly reduce the emissions and energy bills of each property. It will therefore safeguard the development against power cuts and fuel poverty, although to a lesser extent during the winter months. Through the SEG, the client can benefit from generation over periods where the properties are not rented. This of course would not a predictable or particularly large source of income. An additional, wider benefit of integrating PV to the development is that it will provide decentralised zero-carbon electricity to the grid, making a modest contribution to local and national decarbonisation targets.

¹⁵<https://www.solar-trade.org.uk/resource-centre/advice-tips-for-households/smart-export-guarantee/>

6. Domestic energy storage options

6.1. Overview

Battery storage is a relatively new technology, but as installation costs continue to decrease, the domestic electrical battery market is growing as the technology becomes more viable option for storing onsite generation to reduce grid reliance and save on electricity costs. An emerging capability of battery storage, if linked to an appropriate smart control system, is response to variable grid tariffs, to allow further operational costs by charging at the cheapest times of the day. As the proposed heating systems of the properties are electric, the benefits of battery storage are likely to be particularly significant.

6.2. Design

Most domestic scale batteries are able to be wall mounted and require less than 1m² of wall area. Depth will vary from model to model but single units will tend to take up around 0.2-0.5m plus access space. A well ventilated cupboard or utility room would be a suitable location for a battery, and although some models (such as the Tesla Powerwall) can be installed outdoors, this is not recommended due to the potential of the development's local climate to affect performance.

The key performance aspects of batteries that vary between manufacturers are:

- Storage capacity – how much energy the battery can store
- Charging capacity – maximum power input from grid or renewables
- Discharging capacity – maximum power output to grid or building loads
- Round trip efficiency – energy losses between energy generation and usage

The goal in selecting an appropriate battery is to balance these with PV capacity, electricity demand and capital costs. For this development, the chosen option must also be compatible with solar PV diverters.

6.3. Installation

Batteries should be installed by MCS certified electricians in accordance with the new Battery Storage Standard (MIS 3012). Installation is likely to take a few hours and should be performed in conjunction with, otherwise after, installation of the solar PV array. The installation process and system configuration will depend on whether the batteries can be coupled to the PV array via an AC or DC connection. Some models (such as the Tesla Powerwall) have built-in AC coupling, whilst others (such as the Solax models) are DC coupled. Where batteries do not have built-in coupling, DC tends to be more common for newbuilds and will allow a higher round-trip storage efficiency.

6.4. Operation and maintenance

Warranties for high quality domestic scale batteries now extend up to 10 years, indicating that their lifetimes are likely extend a few years beyond this period. As they have no moving parts, there are no maintenance requirements for batteries, and provided that the battery is interfaced with an appropriate PV diverters, no regular operational requirements either. However, depending on the balance between generation and demand over the winter, batteries may be required to be manually switched to 'winter mode' to avoid safeguard their performance if they are not likely to be used for longer periods. This function would not be required if the battery was programmed (by the home PV controlled) to store off-peak electricity from a variable tariff.

6.5. Regulations and other requirements

Domestic use of batteries is a relatively new process, as exemplified by the introduction of the MCS Battery Storage Standard only earlier this year. As such, they are present a slightly higher investment risk as their long-term performance is not as tried and tested as PV or heat pumps. Similarly, batteries are not yet compatible with SAP modelling in Scotland. As with the PV, heat pumps and EV chargers, the specification and size any batteries chosen will be required to submit a formal grid application. Locogen has been advised that for this development, the inclusion of batteries of any size is not likely to influence the costs of the grid connection, for the reasons discussed in section 9.3.

6.6. Costs

The capital costs of electrical batteries vary widely between manufactures, currently from around £400/kWh to £1,100/kWh capacity. The number of options available to this development are more limited as they must be compatible with solar diverters such as the Eddi and ImmerSun units. There are no maintenance or operational costs associated with batteries, although they may need be replaced within the lifetime of the PV installation.

The batteries that have been incorporated into the energy flow model for this development are Solax Triple Power models, up to three of which are can be installed in series, and Tesla Powerwalls. Although at smaller capacities, Solax offers considerably better value for money, both these models are considered to be reliable.

The cost of installing these batteries is shown in Table 10, along with savings based on the A2W systems in property C. The savings are based on the annual cost of the property's gross electrical demand of £1,117 (with EV demand and before savings from PV generation). In the table, 'Savings per £1' represents the electricity cost saved over 10 years (the minimum battery lifetime) divided by the capex of each battery. The 'Savings per additional £1' is the electricity cost saved over 10 years *on top of the savings from the smallest battery*, divided by the cost difference between each other battery compared to the smallest one.

Battery model	Capacity	Capex	Cost/kWh	Savings per £1	Savings per additional £1
Solax Triple Power x1	5.8kWh	£2,500	£431	£0.47	£0.00
Solax Triple Power x2	11.6kWh	£4,200	£362	£0.42	£0.35
Tesla Powerwall x1	13.5kWh	£8,300	£615	£0.23	£0.12
Solax Triple Power x3	17.4kWh	£6,000	£345	£0.33	£0.24
Tesla Powerwall x2	27kWh	£14,600	£541	£0.15	£0.08

Table 10: Selected battery system sizes and costs

A half-hourly energy flow model of the properties' annual demands has been used assess the impact of battery capacity on electricity costs, on top of reductions from PV installations. Figure 3 demonstrates, for the example of property C that the benefit of adding battery capacity begins to flatten out at around 15kWh. Savings for the A2W system shown in Figure 3 have been used to demonstrate electricity savings per £1 of battery investment, as well as the marginal benefit of adding additional capacity.

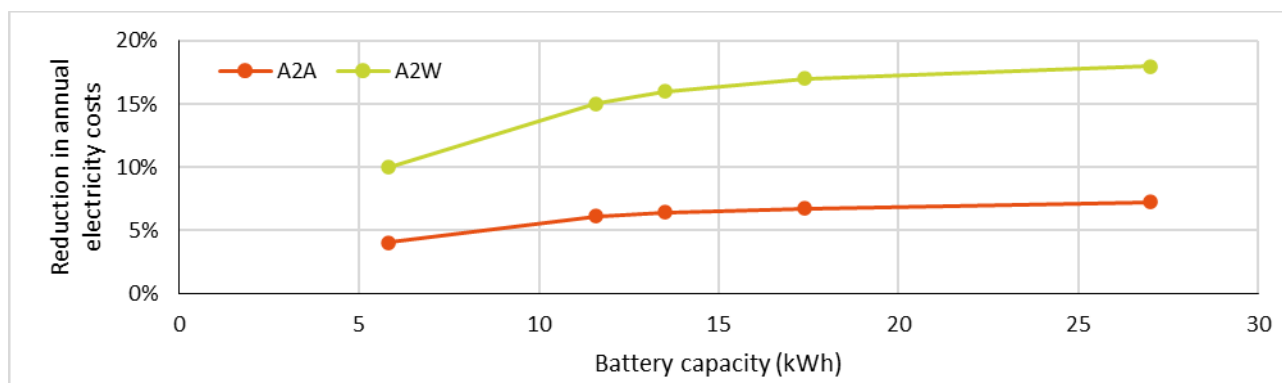


Figure 3: Battery capacity vs additional electricity savings for property C

Based on this analysis, Locogen have used a system of 2 Solax batteries as the baseline for each of the homes, as this represents a good balance between investment and benefit to the occupants.

The above analysis is based on a fixed electricity tariff and does not include any further savings that batteries would facilitate through importing off-peak electricity for use at peak times. Currently, the Economy 7 tariff offers a reduced rate at during the night, and Octopus and Social Energy both offer flexible tariffs that change every half hour depending on the output of the national grid. Essentially, these flexible tariffs are incentives to provide demand-side response services and indirect grid services. Such tariffs could allow a further reduction in electricity costs for each property by around 15%, but these should not be relied upon to bring savings to the end users as, in Locogen's experience, consumers can be sceptical of and reluctant to reduce their options for energy supplier. Ultimately the choice rests with each consumer, so although there may be practical benefits to selecting alternative or more innovative electricity tariff arrangements, it cannot be guaranteed or assumed, so we have used standard tariffs as the baseline for all calculations

6.7. Social and environmental aspects

As with solar PV, batteries are an energy efficiency technology by design and will therefore offer considerable operational savings to occupants to protect them against fuel poverty. They also have a capacity to build resilience to power cuts, although expectations should be managed in this regard as this will depend on the starting level of the battery at the time. Flexible tariffs and certain models also provide an opportunity for the development to provide demand side response to the electricity grid in order to keep the UK's energy supply balanced. Therefore, the development can play a very small role in assisting in the grid to cope with the decarbonisation and decentralisation of electricity generation.

Batteries do not have operating emissions but in allowing more of the generated PV electricity to be used onsite, they will assist in reducing the operational carbon footprint of each property, as demonstrated in section 9.

7. Domestic EV charging options

7.1. Overview

In order to futureproof the development, the client is considering the installation of domestic EV chargers. Although not currently a requirement for new-build housing, they soon to be made mandatory in England, so Scotland can be expected to adopt the same requirement in time. As provision for EV chargers was expected to have a key impact on the grid connection costs, the client was interested in exploring several options, including providing fast or slow chargers to the whole development, or just to the three properties that are to be sold.

An additional consideration for EVs is Vehicle to Grid (V2G) technology, which allow electric cars to be used as batteries and exchange electricity with the grid to help balance supply and demand and provide income to car-owners. Whilst the future electric vehicle uptake will create a huge energy storage resource, V2G has been slow to take off due to apprehension from consumers and car manufacturers. As such, only a few EV models are compatible with V2G chargepoints and therefore V2G is not recommended for this development.

7.2. Design

Domestic EV chargers can be wall mounted or standalone, with the former being more advantageous as they are smaller, making them cheaper and lowering their visual impact, and because they do not require underground electrical wiring from the property. They also are more likely to be located in close enough proximity to the home to allow a Wi-Fi connection to the charger. In order to cater for all types of plug-in electric cars, the chargers should have a universal socket – that is, one that is compatible with cars that need ‘type 1’ and ‘type 2’ plugs. This would require that users provided their own charging cable, which is considered very reasonable given that these come as standard with EVs. A Pod Point charger is shown in Figure 4 as an example of a suitable universal model.



Figure 4: Wall-mounted universal EV charger¹⁶

In terms of power output, there are two types of domestic chargers:

- Slow (3-7kW) – able to charge a typical EV in 8-10 hours
- Fast (22kW) – able to charge a typical EV in 2-4 hours

Despite the additional convenience associated with fast domestic chargers, it appears (from discussion with SSEN) that slow chargers remain the most popular option for residential

¹⁶ <https://www.propel-ev.co.uk/product/pod-point-solo/>

charging. This is very likely due to the cost of the additional grid electricity supply capacity required for fast charging, as discussed in section 7.6.

7.3. Installation

Installation of domestic chargers should be a relatively simple, low risk process and should take a few hours per property. The chargers must be installed following the electricity supply, and should be installed by an electrician registered with OLEV, the UK Government's Office for Low Emission Vehicles. Locogen have noted that there are accredited installers operating from Aberdeen and Inverness. That said, not all of these installers will be able to lay cabling in the ground if this is required for a standalone (versus a wall-mounted) charger, so this option would add cost and complexity to the installation.

7.4. Operation and maintenance

Basic EV chargers need only be connected to an EV in order to work. Many of the available domestic chargers in the UK are also wi-fi enabled, so that charging can be monitored and controlled by an app. Some models allow the EV charger to be interfaced with home electricity management platforms, such that the speed of charging can be modulated depending on PV generation and the demand from other electrical loads. The drawback of installing one of these in the properties is that the chargers are not universal so would only charge vehicles with one of 'type 1' or 'type 2' connections.

Domestic chargepoints tend to come with a warranty of 2-3 years. Given that they are simply an outlet for electricity with no moving parts, they should remain reliable throughout their lifetime and any performance issues will be self-revealing. However, given that EV chargers are relatively new technology, it is difficult to be certain on an expected operational lifetime, although the UK government currently work with an estimate of 15-30 years¹⁷. The maintenance burden is not fully established, especially over the longer term, but annual inspections and ad-hoc repairs could be performed by local OLEV accredited electricians.

7.5. Regulations and other requirements

The domestic EV charging market is still in its infancy, although it is expanding rapidly in alignment with the UK Government's planned phase-out of new combustion engine vehicles by 2035. Planning permission or inclusion in building warrants is not a requirement for EV chargers, and they are not currently included in SAP models.

The key external consideration for chargepoint provision is the cost of the grid supply. Through discussions with SSEN, Locogen have confirmed that installing one slow charger per property would have no effect on the grid connection costs for the development. In order to install one fast charger per property, SSEN would need to install a new substation on the development site to cope with the demand of the chargers, and this would cost an additional £55,000 compared to the baseline connection estimate of circa £25,000. Clearly, there is a considerable investment associated with the provision of fast chargers. As such, fast chargers are not recommended on the basis that slow chargers represent suitable provision for domestic EVs.

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https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/818810/electric-vehicle-charging-in-residential-and-non-residential-buildings.pdf

7.6. Costs

Whilst the cost of slow domestic chargers can vary depending on the model, manufacturer and installer and capabilities, an upper estimate for supply and installation would be in the range of £1,000 to £1,500 each. Fast chargers are likely to cost up to £500 more to install, plus the additional grid connection cost, which equates to approximately £4,600 per property.

Currently, OLEV are offering grants of £350 to residential EV owners, with an additional £300 available through the Energy Saving Trust in Scotland. Although not available directly to the client, the grants can be given to renters if their landlord provides permission. Therefore, it may be possible to wait to install EV chargers in the rental properties once there are tenants who own an EV, to save the majority of the cost of the charger installation. TGDT would be able to reimburse tenants the remaining portion of the cost. That said, there is no guarantee that these will continue to be available in the future.

The operational costs of EV charging depends on the frequency of use of a given vehicle and the source of the electricity that is used to charge it. Based on a central estimate of 1,500kWh (around 12,500 miles) annually and a grid import cost of 14p/kWh, it would cost £210 annually to charge an EV. Broadly, this is less than a quarter of the fuel cost of a petrol car, and the cost would of course be reduced if a portion of the required energy for charging was met by domestic PV.

7.7. Social and environmental aspects

The key benefit of installing domestic chargepoints is that they will make the impending transition to EVs more simple and convenient for the development's residents. In line with this, use of the chargepoints will also contribute to the reduction of CO₂ emissions associated with transport, especially if the electricity is produced from direct or stored solar PV.

8. Centralised energy & transport system

8.1. Overview

As an addition or an alternative to installing individual charging points at each property, the client also wished to consider that the four car parking spaces in the centre of the development have EV charge points installed, potentially with a solar carport and battery to offset the electrical demand of charging from the grid. This could be utilised by residents, locals and tourists and would perhaps cater towards a more gradual transition towards electric vehicle ownership for the residents of the development.

The charge points installed could be used by any electric vehicle owner in the area and, if a pay-for-charge system was implemented, this could bring income to TGDT. Any export from the PV generation would also provide income to TGDT under the SEG, however this is likely to be quite small. Another option would be to make some or all of the spaces for car club vehicles. The car club vehicles would be shared EVs which are available for use by anyone who purchases a membership to the car club. This would include residents of the development and the wider community, and it would be possible to work with a car club service to offer discounted memberships to social tenants. Previously, there has been grant funding available from Transport Scotland for procuring a zero-emission car club service, however the fund is currently closed. If similar funding was found, then this may make it more feasible to install fast chargers.

The charge points installed could either be slow or fast chargers, but the optimum choice depends on the pattern of use, which is very hard to predict, and the costs associated with the installation, which are analysed in this section. The cost of the grid upgrades required to accommodate EV charge points in the central area does not increase with 4 fast chargers compared to what it would be for 4 slow chargers, which is why this has been considered as the maximum installation capacity.

8.2. Design

There are many options when it comes to solar carport design, however the Figure 5 below shows an example of a structure covering two spaces. A similar design could be installed over the four parking spaces in the centre of the development. Locogen recommend that the chargers should have universal sockets for the same reasons described in section 7.2.



Figure 5: Example solar carport design

If batteries were to be integrated as well, they could be contained within an integrated battery-charge point structure or in a standalone weatherproof container. There are also several manufacturers offering carport structures that can accommodate battery storage or has the battery storage built in. This would need to be investigated at the detailed design stage.

After analysing the space available over the four parking spaces, Locogen have estimated that up to 8.4kWp capacity of solar panels which could be installed as a carport, at a pitch of 15°. This may vary depending on the structure/manufacturer selected, however this value has been used for the subsequent cost benefit analysis in Section 8.6.

8.3. Installation

Installing a solar carport is more complex than just installing the domestic electric charge points with rooftop solar as this would involve a standalone structure which may require foundations depending on the manufacturer. Foundations can increase the complexity and cost of an installation considerably, however some manufacturers such as Solarsense offer carports which do not require foundations by using reinforced concrete support bases instead. Snow and wind loading will not be an issue provided that the carport structure is designed to conform with BS-EN 1991 – Eurocode: Actions on Structures. It is anticipated that the construction of a solar carport would cause minimal disruption as the additional car parking spaces are not essential and the construction would not take long (1-2 weeks).

8.4. Operation and maintenance

From discussions with contacts within the solar carport industry, Locogen expects the lifetime of a solar carport to be approximately 40 years, however the solar panels may need replacing after approximately 25 years. Additionally, the inverter would need to be replaced after 10-15 years, at a one-off cost of around £1,500.

There is minimal maintenance required other than annual service checks and ad-hoc cleaning of the solar panels, however it is a good idea to set aside money each year to account for any unexpected repairs/replacement parts that may be required. For these reasons Locogen suggests that £200/year would be an appropriate value for maintenance costs for the solar carport and charge points combined. If only charge points were installed, then £100/year should be sufficient. As mentioned in Section 7.4 this maintenance and any ad-hoc repairs could be carried out by local OLEV certified electricians.

Metering

As mentioned previously, it will be possible for TGDT to profit from the EV charge points if they are metered. The EV chargepoint market in the UK is new and evolving, and as such there are a variety of metering system available. Contactless and app-based payment are likely to be the frontrunning systems for commercial charging going forward and are available from suppliers including Chargemaster and Elmtronics. As an analogue option, a token-based approach may also be suitable for the communal parking spaces, such as that offered by the 'AutoCharge EV Token Mech PAYG Superfast' model by Rolec.

8.5. Regulations and other requirements

As mentioned before, the uptake of electric vehicles in the UK is rapidly increasing but is still in the early stages. For these reasons, a centralised solar carport with EV chargers may be a good intermediate point as it accommodates a small number of EVs in the local area, with the option of installing domestic charging points in the future as the number of local EVs increases. If the level of EV uptake is anticipated to be high around the development, then it would also be possible to install domestic chargers at each property in addition to the four communal chargers which could serve the wider community. The grid connection fee would allow this combination of 12 domestic slow chargers and 4 fast chargers without the £55,000 increase mentioned previously that would be required to enable fast chargers in all the properties.

Planning permission will be required for the installation of a solar carport, so if this option is appealing then the local authority should be contacted discuss this at an early stage. The planning department will be able to advise on whether there would be any issues in obtaining

planning permission for the carport, although the likelihood of this is considered to be low, as residential developments often carry a planning obligation to improve local transport facilities.

8.6. Costs

To understand the financial benefits of the various technology options and their combinations some financial modelling was undertaken. Three main technology combinations were identified:

- EV charging points (utilising electricity from the grid only)
- EV charging points with a solar carport
- EV charging points with a solar carport and battery storage

The solar capacity of the carport was taken as 8.4kWp as this was Locogen's estimate of the maximum capacity that could be installed over the four car parking spaces. This is costed at £15,000 in this analysis, although this value would need to be refined following detailed design. An investigation into the financial benefits of varying the battery capacity modelled was also carried out which will be discussed later in this section.

Within each combination there is the capacity for up to 4 charging points, however these could either be fast chargers or slow chargers depending on the client's preferences. To illustrate how different combinations of these charger types would impact the project financially, three combinations were chosen to investigate:

- 4x slow chargers (3.7kW)
- 2x slow chargers (3.7kW) and 2x fast chargers (22kW)
- 4x fast chargers (22kW)

The financial benefit of these EV chargers is very dependent on the selling price of electricity which would be chosen by TGDT. For the purposes of the modelling, this has been set at 20p/kWh, however this could be increased if desired, so long as the cost of charging remained competitive with any other local options. The benefits are also very dependent on the behaviour of the users and the types of EVs they own.

In Table 11 to Table 14, the returns from the above charger combinations are presented for cases with and without carports and battery storage. The PV and battery savings in the tables represent the net income from avoiding imports and from exporting surplus energy to the grid under the SEG tariff.

Characteristic	4 x slow chargers	2 x slow 2 x fast	4 x fast
CAPEX	£6,000	£7,000	£8,000
Annual PV savings	£-	£-	£-
Annual Battery savings	£-	£-	£-
Annual EV charging income	£916	£916	£916
Total gross annual income	£866	£866	£866
20 year IRR	16%	13%	11%
ROI (years)	6.9	8.1	9.2

Table 11: Financial modelling of centralised EV chargers

Characteristic	4 x slow chargers	2 x slow 2 x fast	4 x fast
CAPEX	£21,000	£22,000	£23,000
Annual PV savings	£253	£239	£216
Annual Battery savings	£-	£-	£-
Annual EV charging income	£916	£916	£916
Total gross annual income	£1,069	£1,055	£1,033
20 year IRR	2%	1%	1%
ROI (years)	19.6	20.8	22.3

Table 12: Financial modelling of centralised EV chargers with solar carport

Characteristic	4 x slow chargers	2 x slow 2 x fast	4 x fast
CAPEX	£37,000	£38,000	£39,000
Annual PV savings	£157	£137	£105
Annual Battery savings	£289	£306	£332
Annual EV charging income	£916	£916	£916
Total gross annual income	£1,263	£1,260	£1,255
20 year IRR	-1%	-2%	-2%
ROI (years)	29.3	30.1	31.1

Table 13: Financial modelling of centralised EV chargers with solar carport and 10kWh battery

After analysing the addition of battery storage at different capacities, the following table of results was obtained for the base case of 4 x slow chargers.

Characteristic	10kWh	20kWh	30kWh	40kWh	50kWh
CAPEX	£37,000	£48,000	£59,000	£70,000	£81,000
Annual PV savings	£157	£134	£133	£133	£133
Annual Battery savings	£289	£355	£360	£360	£360
Annual EV charging income	£916	£916	£916	£916	£916
Total gross annual income	£1,263	£1,308	£1,311	£1,312	£1,313
20 year IRR	-1%	-1%	-5%	-6%	-6%
ROI (years)	29.3	28.3	45.0	53.3	53.3

Table 14: Financial modelling of battery storage capacities combined with EV chargers and solar carport

Table 14 makes it quite clear that increasing the battery capacity of the system results in a large increase in CAPEX which is not represented well in the returns on the project. The optimum battery capacity appears to be 20kWh from the table however this slight improvement in IRR

comes at an additional cost of £11,000. From a financial perspective Locogen does not recommend installing higher battery capacities which is why these have not been modelled for the various charger options.

8.7. Social and environmental aspects

Installing communal EV chargers will not only benefit the residents of the development but also the wider community. If fast chargers are installed then EV owners nearby may travel to the communal chargers to use these in cases where they need to travel urgently and cannot wait for their slow domestic charger. The chargers will also encourage the local community to transition towards EVs in the coming years, as access to charging facilities is often a factor which discourages people from buying an EV.

9. Domestic energy system considerations

9.1. Energy flow modelling

Figure 6 demonstrates the changes in monthly energy flows for two example scenarios for property C with an A2A heating system. Scenario A represents the domestic energy system with maximum rooftop PV and two Solax batteries, whilst Scenario B includes demand from an electric vehicle.

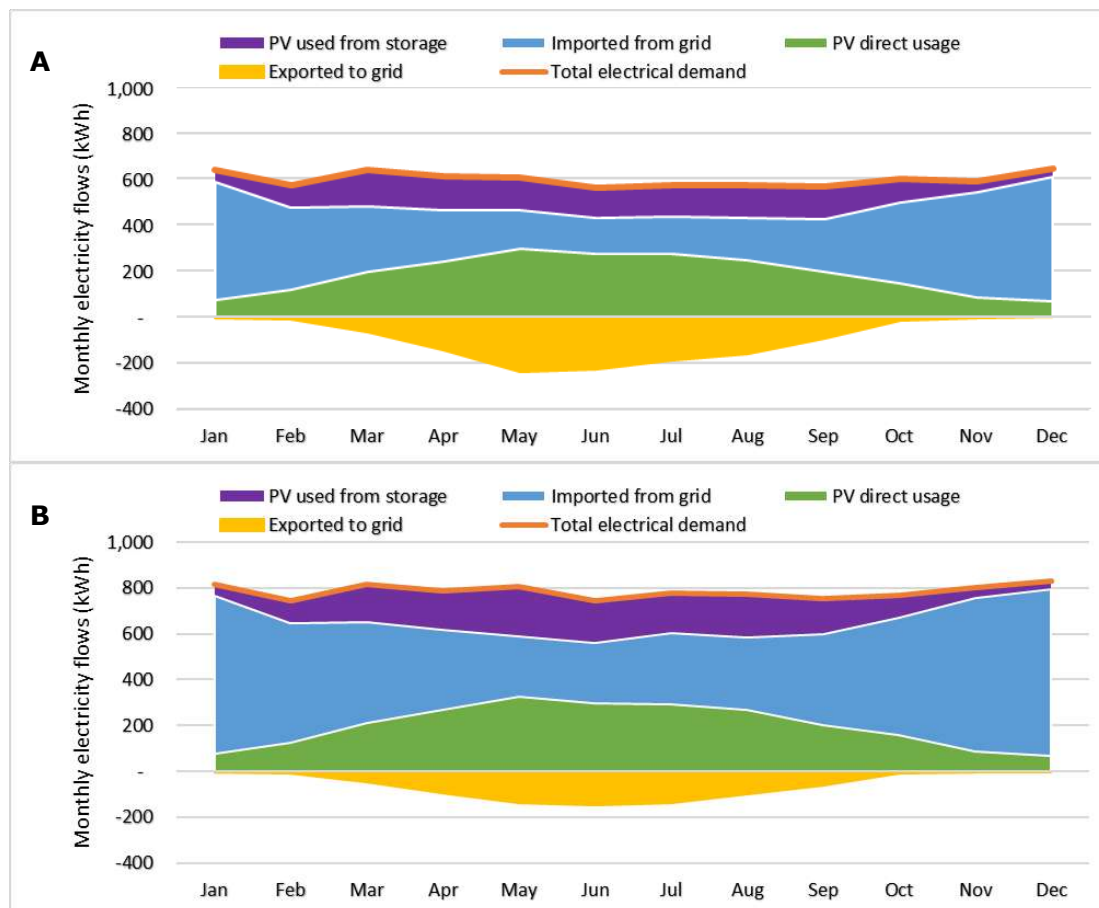


Figure 6: Example energy flow scenarios (property C with A2A heating)

As expected, the figure demonstrates in each case an increased grid reliance in the winter, when energy demand is greatest. Additionally, energy storage is utilised most in the summer due to excess PV generation, which is also when most PV is exported to the grid.

The effect of the seasonality of solar generation on the portion of electricity imported is shown in Figure 7, based on Scenario A. Although the values are only representative of this particular case, this figure highlights how the carbon emissions and energy costs of the properties will vary significantly over the year.

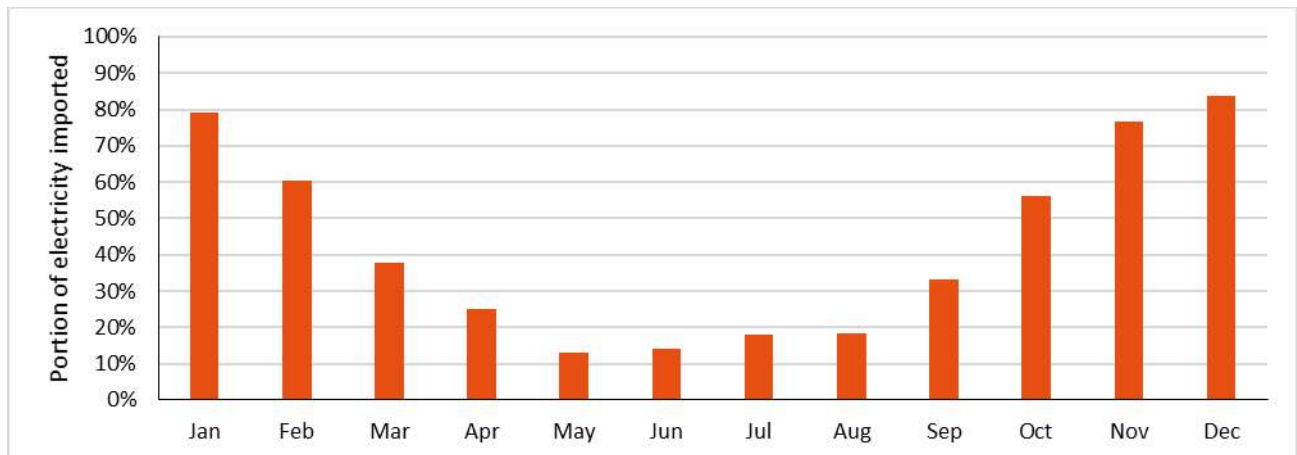


Figure 7: Seasonal changes in electricity imports (property C with A2A heating)

9.2. Financial and carbon modelling

9.2.1. Financial returns

With regards to the building integrated renewables (thermal, generation and storage systems) it is not possible to evaluate these in terms of an IRR basis, as the investment by the developer is not being repaid by the savings encountered by the domestic customer.

It is possible to evaluate the investment cost of the ASHP systems against the oil counterfactual to show the operational and savings that are obtained for the chosen investment strategy. In Table 15, the operational savings of each system compared to oil boilers is shown, along with the (indirect) returns of each system over 20 years. These values are exclusive of any savings arising from utilised PV generation in order to represent minimum (i.e. worst case) savings.

Property	A	A (L/W)	B	C	D	E
A2A annual savings	 -£41	 -£42	 £13	 £7	 -£69	 -£99
System Capex	£ 5,750	£ 5,750	£ 6,000	£ 6,000	£ 5,750	£ 6,000
20-year savings minus Capex	-£6,570	-£6,590	-£5,745	-£5,850	-£7,135	-£7,980
20-year savings per £1 Capex	-£0.14	-£0.15	£0.04	£0.02	-£0.24	-£0.33
A2W + UFH annual savings	 £108	 £122	 £198	 £194	 £87	 £113
System Capex	£10,625	£10,625	£12,725	£13,075	£10,450	£11,080
20-year savings minus Capex	-£8,460	-£8,185	-£8,760	-£9,190	-£8,705	-£8,810
20-year savings per £1 Capex	£0.20	£0.23	£0.31	£0.30	£0.17	£0.20
A2W + rads annual savings	 £81	 £92	 £153	 £149	 £65	 £87
System Capex	£ 9,050	£ 9,050	£ 9,800	£ 9,650	£ 8,900	£ 9,050
20-year savings minus Capex	-£7,430	-£7,210	-£6,745	-£6,665	-£7,595	-£7,310
20-year savings per £1 Capex	£0.18	£ 0.20	£0.31	£0.31	£0.15	£0.19

Table 15: ASHP heating system investment comparison vs oil

Table 15 demonstrates that the A2W systems with underfloor heating present the best operational savings compared to oil. Therefore, they present the best long-term savings per pound invested, closely followed by the A2W systems with radiators. However, A2A systems are significantly cheaper to install (by ~£3,000 vs A2W with radiators and by ~£6,000 vs A2A with underfloor heating). Therefore, it is difficult to objectively conclude that any of the options constitute a better investment, although Locogen would suggest that A2W systems with radiators strike the best balance between investment and long-term savings.

Based on this recommendation, the annual running cost (electricity bills) and savings from PV and batteries are presented in Table 16. These costs are presented exclusive of EV charging costs, which would be in the range of £200-300 based on modelled EV use.

Property	A	A (L/W)	B	C	D	E
Annual cost before savings	551	710	832	804	495	718
PV and battery savings	-£412	-£435	-£469	-£532	-£272	-£360
Net annual cost	£139	£275	£363	£272	£223	£358
Percentage saved	75%	61%	56%	66%	55%	50%
Percentage imported	37%	43%	48%	43%	48%	52%
Net annual cost per bed	£70	£138	£121	£91	£112	£119

Table 16: Development annual running costs and savings

Table 16 shows that the PV and battery systems generate significant energy savings and are essential to ensuring that the properties are affordable to operate. The table also reveals a discrepancy between the running costs of the properties on an occupancy basis. Properties D and E are shown to be more costly to run than the other non-live work properties (A and C). This due to their comparatively small roof areas, especially compared to that of property A, which is a single storey and therefore has the best ratio of PV capacity to demand.

In Table 17, the discrete operational savings from PV and batteries are shown, along with the (indirect) returns of each of these system over 20 years. For the batteries, the capex has been doubled to account for the likelihood that they will need to be replaced within in the 20-year horizon considered.

Property	A	A (L/W)	B	C	D	E
PV only annual savings	£306	£336	£347	£397	£201	£274
Roof-mounted: 20-year savings minus Capex	£1,400	£1,968	£2,178	£2,942	-£408	£843
Roof-mounted: 20-year savings per £1 Capex	£1.32	£1.46	£1.50	£1.56	£0.83	£1.27
Roof-integrated: 20-year savings minus Capex	-£2,380	-£1,812	-£1,602	-£1,678	-£2,508	-£1,887
Roof-integrated: 20-year savings per £1 Capex	£0.71	£0.78	£0.80	£0.83	£0.44	£0.68
Battery annual savings	£106	£99	£122	£135	£71	£86
20-year savings minus Capex	-£5,250	-£5,458	-£4,774	-£4,388	-£6,290	-£5,844
20-year savings per £1 Capex	£0.38	£0.35	£0.43	£0.48	£0.25	£0.30

Table 17: PV and battery investment comparison

Table 17 indicates that on a purely financial basis, roof-mounted PV is a much more rewarding investment in the long term. However, as stated in section 5, roof-integrated PV has several advantages that mean it should still be considered as an option for the development. The recommended battery systems are shown to have a much smaller impact on energy savings than PV, but their impact is still significant.

9.2.1. Financial Sensitivities

The calculations include a number of key assumptions and sensitivities. There are four key sensitivities which have been identified in the evaluation of these modelling exercises:

- 1) Electricity demand
- 2) Solar Generation
- 3) Electricity Price
- 4) SEG rate

The effect of these on the annual running cost of property C with A2W heating with radiators is shown in in Table 18. With all the below base values applied, the annual running cost of the property is £272.

Sensitivity	PV Generation	Electricity demand	Electricity price	SEG rate
Base value	4,715kWh	5,740kWh	14p/kWh	5p/kWh
Annual costs at 110%	£237	£337	£306	£264
Effect	-13%	24%	13%	-3%
Annual costs at 90%	£307	£208	£237	£279
Effect	13%	-24%	-13%	3%

Table 18: Impact of sensitivities annual costs

Clearly, the findings of this report are very sensitive to modelled assumptions, and this should be taken into account when using the information presented to make investment decisions.

9.2.2. Environmental aspects

The maximum carbon CO₂ emissions of the ASHP heating systems as well as the annual savings compared to a counterfactual oil boiler system are shown in Table 19. Year 1 emissions are based on the current UK grid intensity of 0.22kg/kWh, and Year 20 emissions are based on the BEIS prediction of 0.074kg/kWh for 2040.

Property	A	A (L/W)	B	C	D	E
A2A Y1 emissions (kg)	825	910	1,205	1,200	765	990
Y20 emissions (kg)	275	300	400	395	255	330
Y1 carbon savings (kg)	1,780	695	900	895	590	750
Y20 carbon savings (kg)	2,330	2,565	3,705	3,660	2,000	2,495
A2W + UFH Y1 emissions (kg)	530	585	835	825	460	575
Y20 emissions (kg)	175	195	275	275	155	190
Y1 carbon savings (kg)	425	465	640	635	380	460
Y20 carbon savings (kg)	2,430	2,670	3,830	3,785	2,100	2,630
A2W + rads Y1 emissions (kg)	585	640	920	910	505	630
Y20 emissions (kg)	195	215	305	300	170	210
Y1 carbon savings (kg)	465	505	700	695	410	495
Y20 carbon savings (kg)	2,410	2,650	3,800	3,755	2,085	2,610

Table 19: ASHP heating and DHW system emissions comparison vs oil

Table 19 shows that as with operational costs, A2A systems have the highest operating emissions of the three systems under the scenario with no PV generation. Again, as with costs, the A2W systems have the lowest operating emissions.

These carbon savings are demonstrated graphically in Figure 8 and Figure 9, for space heating only, against oil, direct electric heating and wood burning stoves. The figures show that, owing to its high space heating COP, the A2A systems operate at a slightly lower emissions intensity than the other two ASHPs. The decarbonisation of the grid in the coming decades will lead to a tail-off in the cumulative emissions of all of the ASHP systems, meaning that the differences in emissions intensity become less significant over time. Figure 9 also demonstrates the huge

carbon savings compared to oil and even direct electric heating systems over time. It also shows the cumulative emissions of wood burning stoves to be significantly smaller than those of the ASHPs, indicating that they represent an ultra-low carbon option for back-up heating.

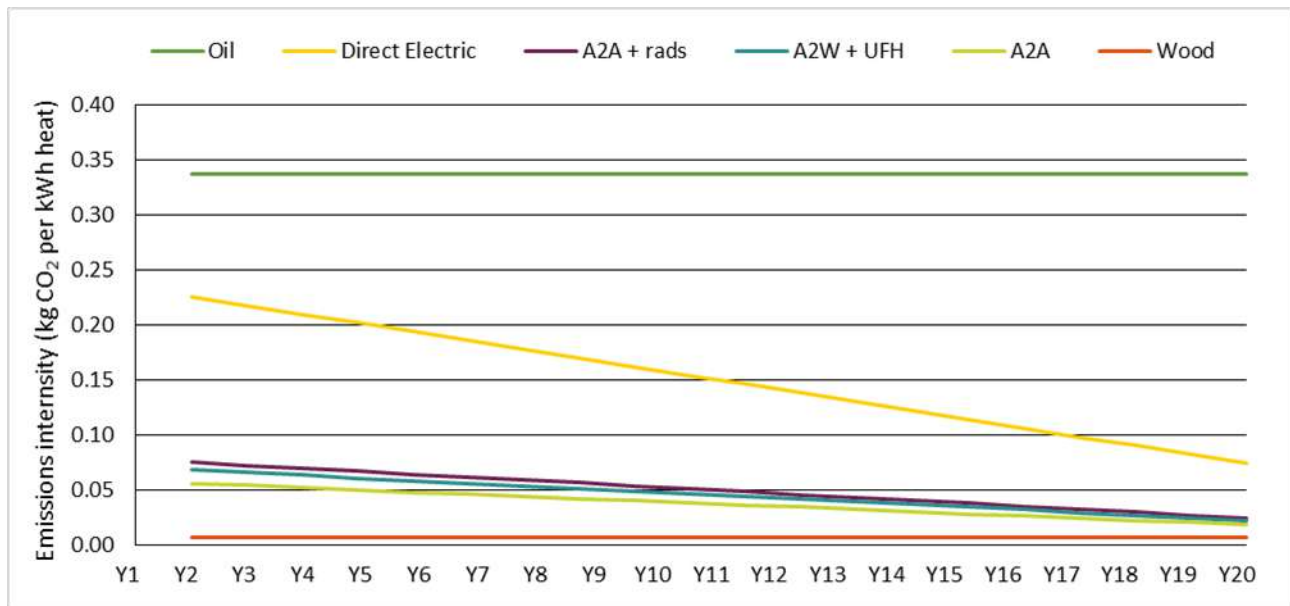


Figure 8: Emissions intensity of heating systems

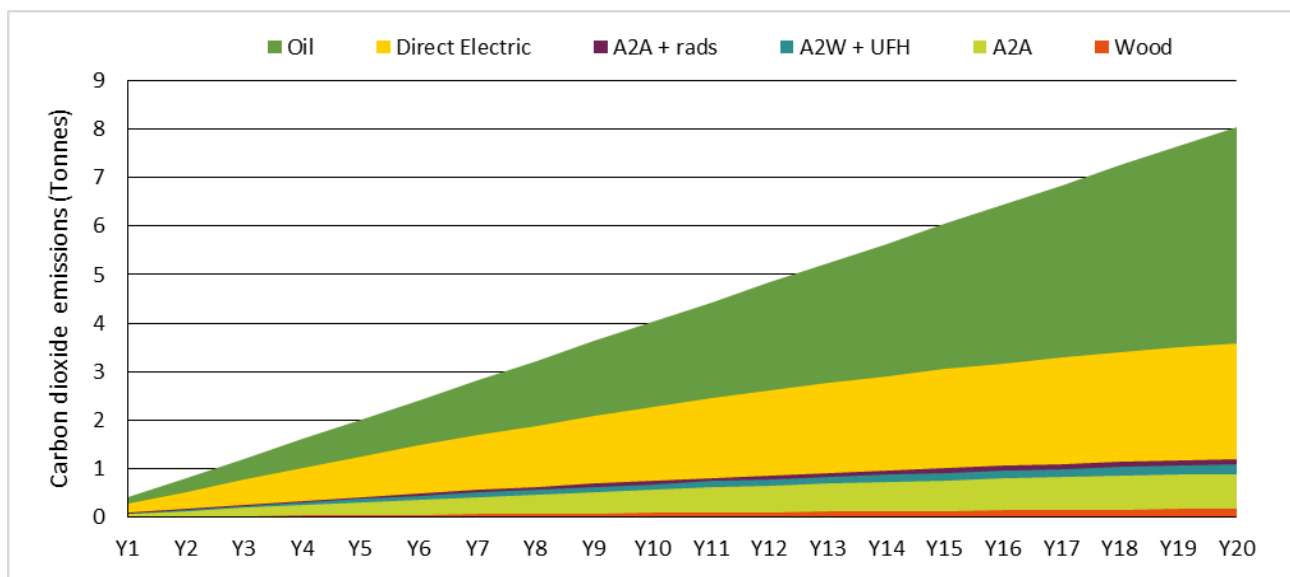


Figure 9: Cumulative emissions of heating systems (for Property C demand)

The actual emissions of heating and the rest of the properties' energy demand, as well any EV charging demand, will depend on the portion of demand met by imported electricity. The more PV generation that is used directly or indirectly, the lower the annual carbon footprint of each property will be. The annual emissions and emissions avoided due to PV and energy storage for the recommended energy system are shown in Figure 10.

Property	A	A (L/W)	B	C	D	E
Year 1 emissions (kg)	330	495	650	560	390	605
Year 20 emissions (kg)	110	165	215	185	130	200
Year 1 emissions avoided (kg)	560	655	695	740	415	560
Year 20 emissions avoided (kg)	185	220	230	245	140	185
Year 1 emissions per bed (kg)	165	250	220	190	195	205

Figure 10: Development annual emissions

9.3. Grid connections

Prior to the beginning of this project, SSEN had provided a budget estimate for the 12 new electricity connections that will be necessary for the development. This estimate was based on each property having ASHPs (which could be accommodated on regular single-phase domestic supplies) and was costed at £24,200-26,620. The key works required to provide these connections involve replacing the existing transformer at the substation near Tomintoul square in order to boost its capacity from 300kVa to 500kVa. This upgrade is required to increase the capacity of the local Low Voltage network and will be necessary regardless of the properties' heating systems or generation capacity of the development.

Upon discussion of this budget estimate with Locogen, SSEN's connections designer advised that the new domestic connections would be each be able to accommodate slow EV chargers, and that the associated upgrade to the local transformer would allow the site to accommodate up to 4 fast (22kW) chargers in the centre of the development, with no significant impact on the cost of connection. SSEN then provided a second budget estimate, to demonstrate the effect of each property having a fast EV charger, along with four central fast chargers. This was costed at £78,000-85,800, with the large increase in cost attributed to the requirement of a dedicated 500kVa substation on the development site.

The connections designer also cautioned that budget costs are high level estimates that will be subject to change and refinement over the formal connection application process – although in this case the requirement for upgrades is particularly clear cut. It was also noted that the effect of storage and generation technologies would be considered in the formal application (as detailed in an associated G98 or G99 aggregate capacity connection form), but that these technologies are not likely to offer savings against the connection cost as SSEN have to provide infrastructure to cope with their worst case scenario modelling. With regard to the possibility of implementing a flexible connection, Locogen were advised that the formal application process is iterative and that various options will be discussed with the client or their agent, and that flexible connections are usually considered above a connection costs threshold of £50,000. A final point to note from discussions with the connections designer is that is that a connection offer fee of £1,765 is likely to be incurred, due to the extent of scenario modelling that is likely to be required.

In terms of added value to the project delivery team, ongoing discussions with SSEN during the ensuing formal application process are likely to enable better understanding of the connections process for further community housing developments where similar constraints are encountered.

9.4. Wider learning opportunities

This project provides significant opportunities for future learning about the use of domestic energy and the impacts on the affordability of operating environmentally designed community housing. It is strongly advised that monitoring systems be put in place to capture data related to actual integrated system performance. The benefits would be on several aspects:

- Understanding of the actual usage compared to predictions in low energy housing
- Quantitative comparison of the benefits of high levels of onsite generation, storage and consumption in meeting affordability and fuel poverty targets in new build properties
- Understanding the future opportunities for community housing projects to retain ownership/value from embedded renewables and storage infrastructure.

- Qualitative understanding of the user experience of integrated renewable energy systems and how to futureproof other installations in terms of successful soft landings and operation.

In the future, this form of community installation could be suitable for operation as a community energy platform, however the legislative and market conditions at the present do not allow for this, and no clarity is available as to the ways that this could be implemented (hence it has not been discussed in detail in report). Locogen are involved in an ongoing development project in Huntly, Aberdeenshire, looking at implementing a system to be ready for these changes, but it is still at a relatively low TRL level. Collecting data would enable the community group to be in a position to better evaluate such an opportunity going forward, and if correctly drafted, have legal agreements in place to facilitate the benefit of this for both householder(s) and community group.

Given that this will require significant support through the design and implementation phases, we would suggest that this could be the subject of a further grant application. We would stress that without further grant funding, it is the experience of the authors that all monitoring and evaluation process will unfortunately end up being removed during the value engineering stages of the project to focus resource on the core elements that will deliver immediate savings to end-users or match regulatory compliance. Ring fencing the monitoring, support and evaluation funding within a separate grant fund application would ensure that this can be provided throughout the project planning and delivery phases. This would also allow for the delivery of any legal agreements that would be required, preparation and delivery of any qualitative research questions over time and the analysis and writeup of the data.

As a next step, Locogen would be happy to discuss possible joint applications to a number of potential innovation grant schemes that could fund this next stage of research works.

10. Energy benchmarking

The properties energy systems have been benchmarked against the Firm Foundations Guidelines, via the Standard Assessment Procedure (SAP) method, and the PassivHaus standard below. The properties have not been evaluated against the BREEAM Home Quality Mark because energy only forms a small portion of this holistic assessment method.

10.1. Firm Foundations

As established in the Phase 1 report, the Firm Foundations Design Brief is a set of guidelines for high quality affordable housing, based on design quality, placemaking, liveability and sustainability. As well as mandating zoned heating controls, solar gain utilisation and high building fabric efficiency, the properties are required to achieve a SAP energy efficiency score of at least 80, which is equivalent to an A or B energy efficiency rating. To benchmark the properties against this score, SAP calculations were modified to simulate the following sensitivities:

- Variation in building fabric between 'regulation', 'good' and 'very good' U values;
- Variation between ventilation technologies (natural ventilation, MVHR and MEV); and
- Variations due to installation of PV on rooftops.

Table 20, Table 21 and Table 22 below illustrate the impact of each of the above analyses respectively on the property's energy efficiency rating (SAP result) and an environmental impact Rating (EI rating). A red icon indicates a C rated SAP; an orange icon indicates a B rated SAP, and a green icon indicates an A rated SAP. The SAP results will correlate to the EPC score of the properties once built.

Given that the properties have not yet been designed in detail, these scores are subject to a number of assumptions as detailed in Appendix A. For additional clarification, the 'base case' represents a model with the 'good' U value scenario, natural ventilation, and no PV. Also note that SAP does not have a 'live/work' option and so only one set of results for property type A is presented.

Property	regulation		good		very good	
	SAP result	EI rating	SAP result	EI rating	SAP result	EI rating
A	 77	 79	 78	 80	 80	 82
B	 76	 79	 79	 81	 81	 83
C	 80	 82	 82	 84	 84	 85
D	 80	 82	 81	 83	 82	 84
E	 81	 83	 82	 84	 83	 85

Table 20: SAP sensitivity to changing U values

Property	BASE CASE		MVHR		MEV	
	SAP result	EI rating	SAP result	EI rating	SAP result	EI rating
A	 78	 80	 79	 81	 76	 78
B	 79	 81	 80	 82	 76	 78
C	 82	 84	 83	 85	 79	 81
D	 81	 83	 82	 84	 79	 81
E	 82	 84	 83	 85	 79	 82

Table 21: SAP sensitivity to changing ventilation systems

The tables above illustrate several factors, including the fact that the scores for the two storey buildings are higher than those of property A (single storey) and property B (1.75 storey), which is due to their favourable volume to area ratios. Additionally, the benefits of better the fabric efficiency and airtightness are shown to be minimal in terms of improving the SAP ratings for all of the properties.

Table 22 shows the impact on the base case of adding 3.9kWp of rooftop PV capacity (where this is lower than the maximum) and of adding the maximum capacity as stated in section 5. Note that PV installations for new homes are often capped at around 3.9kW due to grid connection impacts which would not apply to this development. Therefore, it represents a standard size of domestic rooftop array. This table clearly illustrates that with a reasonable area of rooftop PV, the properties are likely to greatly surpass the SAP result required by the Firm Foundations guidelines.

Property	BASE CASE		3.9kWp		Max rooftop PV	
	SAP result	El rating	SAP result	El rating	SAP result	El rating
A	 78	 80	 94	 95	 101	 101
B	 79	 81	 89	 90	 93	 94
C	 82	 84	 92	 93	 99	 99
D	 81	 83	n/a	n/a	 94	 95
E	 82	 84	 97	 97	 97	 97

Table 22: SAP sensitivity to varying PV sizes

10.2. Passivhaus

The Passivhaus standard was presented as a further aspiration of the development. In Table 23 below, the properties are compared to the Passivhaus targets based on their annual energy demands (excluding that of EV charging). There are further requirements of Passivhaus standards regarding cooling loads, and for a tested airtightness measurement of 0.6 ACH @n50. These are not tabulated below as, due to the local climate, the buildings will have no cooling requirement, and because the airtightness is a construction decision rather than a system performance measurement. Achieving this low airtightness level would require a centralised mechanical ventilation system, as discussed in section 4.

Component	Annual primary energy demand (kWh/m ²)	Annual space heating demand (kWh/m ²)
Passivhaus Target	≤ 120	≤ 15
Property A	89	35
Property A (L/W)	108	38
Property B (L/W)	77	33
Property C	68	27
Property D	86	28
Property E	94	26

Table 23: Development performance versus PassivHaus targets (very good U values)

Table 23 demonstrates that although the anticipated primary energy demands of the properties would meet the Passivhaus standard, the space heating demands are too high to qualify, even with the very good U values adopted. This should not be too surprising, due the fact that, as noted in Phase 1, most Passivhaus developments in the UK are in England (i.e. in warmer locations) and almost all of these are flats or terraced houses, with minimised areas of exposed building envelope. It is possible that the development could overcome its locational disadvantage and achieve the Passivhaus standard, although this would likely require consideration of even lower U value materials, as well as a complete reworking of the site's layout, potentially leading to compromises on the wider design ethos of the development.

11. Conclusions and recommendations

This report marks the completion of a 3-Phase options appraisal undertaken by Locogen on behalf of the Tomintoul and Glenlivet Development Trust for their social housing development. In order to specify and assess the energy systems of the proposed development, the demand and generation modelling undertaken during Phase 1 of the project was advanced and supplemented with an energy flow modelling exercise. This modelling has been used to provide insight into the expected performance of the domestic energy systems and to evaluate the annual costs and carbon emissions of the properties. The modelling highlighted that achieving affordable energy bills for the properties – a key aim of the project – is very much possible with the right mix of technologies. None of the technologies considered present any notable technical risks, although the combination and integration of these in domestic buildings can be considered innovative.

Additional energy modelling against two particular benchmarks has highlighted that the properties are very likely to surpass the SAP scores required by the Firm Foundations guidelines but that, due to a locational disadvantage and the proposed layout of the development, they are unlikely to achieve Passivhaus standard.

Given that the development proposes to provide low carbon heating, electricity and transport in an affordable housing context, there are widespread and important lessons to be learned from understanding the practical performance of the domestic energy systems. Therefore, Locogen strongly advises that monitoring systems be put in place to capture data related to actual integrated system performance. We would suggest that this exercise is funded separately from the rest of the project costs in order to make it the focus of a dedicated scope of works.

Conclusions and recommendations specific to each of the systems considered are highlighted below:

Heating and Hot Water

Three air source heat pump systems were considered for the development:

- Air to air systems with a heat battery for hot water provision
- Air to water systems with radiators
- Air to water systems with underfloor heating

These three options are similar in terms of complexity and operation, although A2W with radiators has a slight advantage in being operationally familiar to occupants. Locogen has compared the estimated costs and emissions of these systems compared with each other and against an oil counterfactual. All of these systems offer considerable emissions reduction compared to oil, that will further improve over time as the electricity grid decarbonises. A2W with underfloor is the most energy efficient of these options, and therefore the least cost- and carbon-intensive to operate. However, they are significantly more expensive than A2W with radiators, which are only marginally less energy efficient. Therefore, as radiators are significantly cheaper to install these systems would be Locogen's main recommendation as the best balance between investment and operational savings. That said, the A2A are the cheapest systems to install so the client should consider how they wish to balance the affordability of construction against that of operation, given that they will not see the returns from any of these systems directly.

Secondary heating stoves

Wood burning stoves are recommended as a secondary heating system to provide protection against power cuts and unexpected issues with the primary heating system. They have been shown to offer a low-tech, ultra-low emissions back up heating system and are the cheapest of all the considered technologies to install. Additionally, they will give provide a degree of freedom which is likely to be appreciated by residents.

Ventilation

Mechanical ventilation with heat recovery may be required depending on the chosen airtightness of the properties' construction. Whilst offering savings against heating costs of up to 30% per annum, the self-consumption of these systems partially offsets its benefits, particularly as the properties already have such low heat demands. As such, MVHR will have a net positive impact on energy bills but at a considerable investment. The client should consider if this additional cost is justified against a simpler natural ventilation strategy. The design and build contract team will be best placed to make recommendations as to what air tightness standard the properties should be built to, which will influence the ventilation strategy.

Solar PV

The report has demonstrated that a maximised rooftop PV array will maximise energy savings to the occupants. The electricity produced from PV will directly reduce the grid reliance, costs and emissions of the properties and will contribute to wider decarbonisation strategies. In order to ensure that the benefit of PV is maximised across the domestic home energy systems, a solar diverter unit is strongly recommended.

Locogen recommends that the client considers roof-integrated and roof-mounted PV arrays, instead of solar carports and solar tiles as the cost of these technologies, along with other constraints, makes them difficult to justify. Between the roof PV options, roof-mounted modules offer the best value for money, although roof-integrated systems have other advantages, particularly in terms of aesthetics and maintenance. Therefore, roof-integrated systems are recommended if the project's budget is able to accommodate their addition cost.

Energy storage

By further reducing grid reliance and providing additional resilience to power cuts, battery storage will be a very beneficial addition to the properties. As there are diminishing returns associated with scaling up the energy storage capacity of the battery systems, Locogen has recommended a particular model to ensure value for money. It is also important to consider that batteries come with the shortest warranty of all the technologies considered, so would need to be replaced within the lifetime of the home energy systems. Although not quantified in this report, an additional benefit of batteries is their ability to respond to variable electricity tariffs to further reduce the operational costs of the properties and offer balancing services to the grid.

Electric vehicle chargers

Consultation with SSEN has confirmed that slow EV chargers can be installed at each property with no additional grid connection costs. The capital cost of installing these chargers is low, and Locogen would therefore recommend that these be provided in order to assist the residents' transition to low emissions transportation. The chargepoints should be wall-mounted with universal sockets.

Central energy and system

Lastly, Locogen considered a range of options for the central area of the development, including four chargepoints, a solar carport and electric batteries. Under the assumed charging behaviour, the chargepoints offer reasonable returns, unlike the domestic technologies, which would be direct to the client. The carport and battery options do not currently represent good investments, although these may become more favourable in time as their respective installation costs reduce. A benefit of installing fast chargers here is that they will offer an alternative if residents cannot wait for slow charging. Additionally, the central chargers will also assist the wider community to adapt to EVs too. These are therefore recommended due to their various benefits to residents, locals and the client.

12. Phase 3b

12.1. Introduction

Following issue of the Phase 3 report, the Tomintoul and Glenlivet Development Trust appointed Alpha Contracts to design and build the homes. Alpha's architects have since produced finalised layouts and elevations for each house type and have specified the U-values of the homes. These have been selected to allow the development to achieve the 'Silver' Standard for Sustainability under Scottish Building Regulations, the energy demand requirements for which are broadly equivalent to those of the 'Good' standard under the Firm Foundations guidelines. The Architect's scheme layout drawing is attached in Appendix C.

Following the conclusions presented in the Phase 3 report, the client has also now decided which home energy technologies to pursue for the development. Air-to-water heat pumps have been chosen for the heating systems, as they provide a more energy-efficient system for heating and hot water than Air-to-Air heating with direct electric hot water generation. Sunamp heat batteries have been chosen to complement these, as they have lower standing losses than conventional domestic hot water tanks as well as several other benefits, including reduced maintenance burdens. It has also been decided to install the maximum extent of solar PV possible on each unit type, although batteries are not being taken forward due to the limited availability of grant funding for this technology. Additionally, the homes will have slow EV chargers, as well as smart controls and home energy monitoring systems as per the recommendations of the Phase 3 report.

In order to assist with capital funding applications for these elements, Locogen has conducted an additional work package to demonstrate the impact of the specified energy systems on the capital cost, operational cost and emissions of the properties. Phase 3b represents the period of project support from June 2020 to January 2021, including liaison with industry, as well as the findings of this additional section within the Phase 3 report.

12.2. Methodology

Following receipt of the architect's proposed drawings of the development, as well as the target building fabric information, Locogen have revised the heat demand calculations of each property type. Although property type C has been removed in favour of an additional type B in plot 11, the small differences between the live/work and standard type A and type B properties mean that 6 property types have been evaluated. Given that the two type B1 properties have different aspects, an additional variant has been considered whilst assessing the impacts of solar PV.

In order to demonstrate the impacts of the heat pumps, solar PV and heat batteries, the electricity demand of each property has been revised compared to the findings of Phase 3. This revised demand forms a basis for a cost and emissions evaluation which aims to demonstrate the beneficial impacts of each of these technologies on the operation of each home. Further systems, namely EV chargers, energy monitoring systems and smart controls have also been discussed, although not on a numerical basis, as have opportunities to 'bridge the gap' between the design as it stands and one that achieves Net Zero emissions.

Locogen also discussed the project with industry experts including heat battery and ASHP manufacturers and an airtightness specialist. As mentioned in section 4.1, airtightness is a measure of the 'leakiness' of the building envelope. The specialist advised against specifying an airtightness value that would require centralised mechanical ventilation or MVHR. The key reason for this was that it would add significantly to the cost of building fabric and commissioning the homes. In addition, centralised mechanical extract ventilation would do so whilst adding to the electricity demand of the homes, without reducing their heating demands. MVHR would reduce the heating demand significantly, but the specialist advised that these are expensive systems which are often compromised due to poor installation methods. Moreover, they add to the complexity of operating the home for tenants, who are known to switch off the systems, which

can lead to issues such as poor air quality and dampness. Therefore, LocoGen do not advise that the contractor specifies a higher airtightness value than what is proposed.

12.3. Baseline energy demand

12.3.1. Heat demand

Each property type's heat demands have been recalculated based on the new building layouts and the architect's target U-values, as per Table 24 below. Given the increased level of detail compared to previous phases, the new peak and annual demands were determined using the MCS-certified room-by-room method, making them much more thorough representations of the buildings' likely heat demands. The same local climate information (degree days) and external design temperature (-10°C) were used as in Phases 1-3.

Fabric Element	Building Regs	Design Values
External wall ($\text{W/m}^2\text{K}$)	0.22	0.20
Party wall ($\text{W/m}^2\text{K}$)	0.20	0.20 (assumed)
Floor ($\text{W/m}^2\text{K}$)	0.18	0.15
Roof ($\text{W/m}^2\text{K}$)	0.15	0.10
Glazing ($\text{W/m}^2\text{K}$)	1.60	1.40

Table 24: Design versus regulation U-values

The revised peak and annual heat demands of each property are presented in Table 25 below. Note that the annual values presented in the table are for space heating only and do not include hot water demands, which have not been revised.

Property	Annual heat demand (kWh)			Peak heat demand (kW)		
	Regs	Design	Reduction	Regs	Design	Reduction
A1 (L/W)	6,427	5,749	-11%	2.54	2.29	-10%
A2	6,021	5,388	-11%	2.37	2.14	-10%
B1 (L/W)	9,367	8,711	-7%	4.21	3.87	-8%
B2	8,563	7,998	-7%	3.89	3.58	-8%
D	8,158	7,613	-7%	3.51	3.25	-7%
E	8,886	8,315	-6%	3.86	3.58	-7%

Table 25: Design versus regulation heat demands

The above table indicates that the design U-values offer varying reductions in peak and annual demand versus what would be the case if the homes were built to the maximum permitted under Scottish building standards. These reductions are not as significant as what is modelled under the 'good' scenarios assumed in Phase 1-3, and additionally, the irregular (i.e. non-rectangular) layouts of types B1, D and E increase their demand relative to what was previously modelled. Both factors result in a larger starting basis for electricity demand than in the previous phases.

12.3.2. Electricity demand

The above demands for heating, along with confirmation that air to water heat pumps are to be used in the development, allowed for the development's electricity demands to be recalculated. These are broken down as follows and underpin the ensuing cost and carbon analysis. Note that the totals presented do not include potential demand from EV charging.

Property	Annual electricity demand (kWh)			
	Heating	Hot water	Power	Total
A1 (L/W)	2,395	955	1,800	5,150
A2	2,245	955	1,800	5,000
B1 (L/W)	3,630	1,274	2,900	7,803
B2	3,333	1,274	2,900	7,506
D	3,172	955	1,800	5,927
E	3,465	1,274	2,900	7,638

Table 26: Electricity demands for the development as designed

12.4. Impact of building fabric

The annual impact on emissions and running costs of the specified u-values for the development compared to the Building Regs values are demonstrated in Table 27 below. Annual cost and carbon savings are both modest, and fairly evenly split across the development.

Property	A1	A2	B1	B2	D	E
Annual heat & hot water opex (design u-values)	£402	£385	£585	£552	£489	£566
Annual opex – heat only (design u-values)	£268	£251	£407	£373	£355	£388
Annual opex – heat only (building regs u-values)	£300	£281	£437	£400	£381	£415
Annual opex savings	£32	£30	£31	£26	£25	£27
Y1 carbon emissions (kg)	432	405	655	601	572	625
Y1 savings vs building regs (kg)	51	48	49	42	41	43
Y20 carbon emissions (kg)	143	134	216	198	189	206
Y20 savings vs building regs (kg)	17	16	16	14	14	14
20-year emissions (Tonnes)	5.7	5.4	8.7	8	7.6	8.3
20-year savings vs building regs (Tonnes)	0.7	0.6	0.7	0.6	0.5	0.6

Table 27: Costs and emissions with specified building fabric vs building regs u-values

12.5. Impact of heating system

Despite the increased peak demand of the properties compared to previous phases, the impact on the capital cost of each A2W-radiator heating system is not significant, with the key difference being the additional cost of further radiators to allow the peak demand to be delivered. The impact (in terms of capital costs, operating costs and emissions) of the chosen A2W heating system, compared to the lowest cost energy system that would meet minimum building standards is presented in Table 28 below. Although direct electric heating systems would be cheaper than A2A systems, these would require solar PV to meet building standards (i.e., to pass SAP) and therefore A2A systems represent the cheapest energy system overall as they would not require PV to pass SAP.

Note that the capital costs (capex) in Table 27 are Locogen's estimates, which differ from those of the contractor. Despite this, the cost difference between A2A and A2W systems calculated by Locogen and the contractor are very similar, indicating that the returns calculated by Locogen are highly relevant. (Locogen's calculated additional capex for A2W systems are ~90% of the values presented by the contractor.) These values do not account for the cost or impact of heat batteries, as these are assessed subsequently, following consideration of the impacts of solar PV. The operational costs have been shown with and without maintenance (approximately £150 p.a.) as it is possible that this could be paid for by the occupants or by TDGT, depending on if the homes are sold or let.

Property	A1	A2	B1	B2	D	E
Annual opex	£402	£385	£585	£552	£489	£566
Annual opex inc. maintenance	£552	£535	£735	£702	£639	£716
Saving vs A2A	£120	£124	£148	£156	£98	£153
Annual opex per bed	£134	£128	£146	£138	£163	£142
Saving vs A2A per bed	£40	£41	£37	£39	£33	£38
System Capex	£9,050	£9,050	£9,800	£9,650	£9,500	£9,650
Additional capex vs A2A systems	£4,200	£4,200	£4,700	£4,550	£4,650	£4,550
20-year savings vs A2A minus additional capex	-£1,798	-£1,714	-£1,739	-£1,423	-£2,683	-£1,497
20-year savings vs A2A per £1 additional capex	£0.57	£0.59	£0.63	£0.69	£0.42	£0.67
Y1 carbon emissions (kg)	648	621	942	889	788	913
Y1 savings vs A2A (kg)	193	200	239	252	158	246
Y20 carbon emissions (kg)	214	205	311	293	260	301
Y20 savings vs A2A (kg)	64	66	79	83	52	81
20-year emissions (Tonnes)	8.6	8.3	12.5	11.8	10.5	12.1
20-year savings vs A2A (Tonnes)	2.6	2.7	3.2	3.4	2.1	3.3

Table 28: A2W heating system costs and emissions vs A2A systems

It is clear from Table 27 that A2W systems are more energy efficient than A2A systems, as they are cheaper to run and produce less emissions in doing so. This is due to the fact that, although they have a higher space heating sCOP, unlike A2W heat pumps, A2A heat pumps cannot produce hot water, and so this must be done at a 1:1 efficiency by a direct electric hot water system. Because the hot water demand represents a relatively large portion of each unit's total heating demand, the A2A systems require more energy to run overall. The impact of this on the development's long term emissions is significant, with the A2W systems allowing 33.5 Tonnes of carbon dioxide to be abated over 20 years. This benefit (and the operational benefits to the occupants) comes at a capex premium, therefore grant funding to match this premium would facilitate these important impacts .

Relative to occupancy, the operational cost heating each home is shown to be fairly consistent throughout each property type, which would likely be perceived as a positive. Properties B1 and D have the highest relative costs due to their irregular shapes (having single-storey elements). As the heat pumps (here without PV or energy storage) take all their electricity demand from the national grid, the emissions of each property type are shown to decrease significantly over time.

12.6. Impact of solar PV

As the sole energy generation technology across the development, rooftop solar PV is key to ensuring the buildings operate with as low costs and emissions as possible. Therefore, maximising the PV capacity on each building will allow the net energy costs to be minimised, due to direct utilisation of onsite generation, income from surplus exports, and also from energy stored via the heat batteries.

The following table demonstrates the PV capacity indicated on the layouts, versus the maximum capacity relative to the current designs and the assumptions made up to Phase 3. Previous estimates had not accounted for the presence of dormer windows, which detract from the available roof space. The Client has decided to maximise the capacity of PV on each building, without utilising the dormer roofs, as this carries additional complexity through the requirement for dedicated invertors.

Property B1 has been included twice in Table 29 as plot 5 and plot 11 have different aspects and therefore different areas of south-facing roof suitable for a PV installation. Additionally, since completing the Phase 3 report earlier this year, Locogen now work with a standard PV module capacity of 330Wp, rather than 300Wp. This allows for a 10% increase in generation capacity over the same area.

Property	PV capacity (kWp)				
	Aspect	As drawn	Maximum	Increase	Phase 3
A1	SW	1.98	6.6	233%	5.4
A2	SW	1.98	5.94	200%	5.4
B1 (plot 5)	SW	1.32	4.95	275%	5.4
B1 (plot 11)	SW	1.32	2.64	100%	5.4
B2	SW	1.32	2.64	100%	5.4
D	SE	2.64	3.3	25%	3.0
E	SE	1.32	2.31	75%	3.9

Table 29: Rooftop PV capacity options

Based on A2W heating systems, each property type's electricity usage, and their associated running costs and emissions before considering solar PV are presented in Table 30, as follows. As with heating costs, the electricity costs modelled at this stage are fairly stable across the development, relative to occupancy.

Property	A1	A2	B1	B2	D	E
Annual cost	£612	£598	£911	£880	£638	£864
Annual cost per bed	£204	£199	£228	£228	£220	£213
Y1 emissions (kg)	986	964	1,468	1,418	1,028	1,392
Y20 emissions (kg)	325	318	484	468	339	459

Table 30: Electricity costs and emissions before PV

The impact of solar PV on operation of each property type (including the two PV-variants of B1) is indicated below – for the extent of PV as drawn by the architect in Table 31 and for the maximum extent in Table 32, based on Locogen's interpretation of the elevations. For the capital costs of each system, roof-mounted PV systems have been assumed. The cost savings presented are inclusive of income from exporting surplus electricity to the grid under a Sustainable Export Guarantee (SEG) contract.

Property	A1	A2	B1-p5	B1-p11	B2	D	E
Generation (kWh)	1,414	1,414	943	943	943	1,886	943
Cost saving	-£171	-£170	-£131	-£131	-£131	-£213	-£130
Demand imported	75%	74%	86%	86%	85%	72%	85%
Percentage saved	28%	28%	14%	14%	15%	33%	15%
Net annual cost	£441	£428	£780	£780	£749	£425	£734
Net annual cost per bed	£147	£143	£195	£195	£187	£142	£184
Capex	£1,984	£1,984	£1,456	£1,456	£1,456	£2,512	£1,456
20-year savings minus Capex	£1,436	£1,416	£1,164	£1,164	£1,164	£1,748	£1,144
20-year savings per £1 Capex	£1.72	£1.71	£1.80	£1.80	£1.80	£1.70	£1.79
Y1 emissions savings (kg)	319	319	213	213	213	425	213
Y20 emissions savings (kg)	105	105	70	70	70	140	70
20-year emissions savings (Tonnes)	4.2	4.2	2.8	2.8	2.8	5.7	2.8

Table 31: Electricity cost and carbon savings – PV as drawn vs no PV

Table 31 illustrates that installing PV systems to match what has been drawn by the contractor would provide annual cost savings to each property, reaching a third of annual energy costs in the case of property D. This relates to a meaningful reduction in emissions, compared to a scenario with no PV, with long term (20 year) emissions abatement across the development reaching 48 Tonnes. However, the vast majority of each property's electricity demand would still be drawn from the national grid.

Property	A1	A2	B1-p5	B1-p11	B2	D	E
Generation (kWh)	4,715	4,245	3,540	1,890	1,890	2,360	1,650
Cost saving	-£401	-£369	-£369	-£235	-£233	-£249	-£209
Demand imported	62%	63%	68%	76%	76%	69%	77%
Percentage saved	66%	62%	41%	26%	26%	39%	24%
Net annual cost	£211	£229	£542	£676	£647	£389	£655
Net annual cost per bed	£70	£76	£136	£169	£162	£130	£164
Capex	£5,680	£5,152	£4,360	£2,512	£2,512	£3,040	£2,248
20-year savings minus Capex	£2,340	£2,228	£3,020	£2,188	£2,148	£1,940	£1,932
20-year savings per £1 Capex	£1.41	£1.43	£1.69	£1.87	£1.86	£1.64	£1.86
Y1 emissions savings (kg)	1,064	957	798	425	425	532	372
Y20 emissions savings (kg)	351	316	263	140	140	175	123
20-year emissions savings (Tonnes)	14.1	12.7	10.6	5.7	5.7	7.1	5.0

Table 32: Electricity cost and carbon savings – maximum PV vs no PV

Table 32 illustrates that maximising the extent of PV on each building compounds the benefits seen in Table 31. Clearly, the more PV that is installed, the more the occupants benefit financially and the more emissions are avoided. As such, the long term (20 year) emissions abatement across the development almost doubles, reaching 93 Tonnes. The percentage of each property's energy demand imported from the nation grid also decreases, although not evenly so given the varying geometries of each unit's south-facing roof areas. Most notably, being single storey units, types A1 and A2 have a much larger roof area to floor area ratio than the other units and therefore can benefit the most from PV.

12.7. Impact of heat batteries

Lastly, the impact of heat batteries on the operation of the properties has been examined. As these heat batteries replace hot water cylinders, they do not carry a significant net capital cost increase to the heating and hot water systems. At £1,900, the cost of an appropriately-sized Sunamp heat battery is £400 greater than that of a cylinder.

In terms of energy, a key benefit of heat batteries versus conventional DHW cylinders is in their energy storage efficiency. New, high specification cylinders tend to have a standing loss of around 1.6kWh/day, whereas this value is 0.74kWh for Sunamps. This means that with a Sunamp, each property would save approximately 314kWh per year, which translates to a £44 annual saving and a year-1 emissions saving of 30kg to each property. As well as this benefit, Sunamps are very compact and no maintenance requirements.

Another impact of the heat battery (although also true of a DHW cylinder if connected to the PV systems via the heat pump) is that it allows surplus PV generation to be stored, by utilising this to run the heat pump and then to store the heat generated until it is required for space heating

or hot water. This process would be controlled by a PV diverter unit. This benefit is quantified in for the proposed maximum extents of solar PV in Table 33.

Property	A1	A2	B1-p5	B1-p11	B2	D	E
PV energy stored (kWh)	314	324	15	15	18	534	20
Battery cost saving	-£93	-£88	-£82	-£29	-£30	-£61	-£22
Total cost saving	-£483	-£447	-£438	-£259	-£259	-£300	-£228
Additional % saved	15%	15%	9%	3%	3%	10%	3%
Demand imported	39%	40%	55%	72%	71%	55%	74%
Net annual cost	£129	£151	£473	£652	£621	£338	£636
Net annual cost per bed	£43	£50	£118	£163	£155	£113	£159
Y1 emissions savings (kg)	247	233	218	76	81	162	58
Y20 emissions savings (kg)	82	77	72	25	27	54	19
20-year emissions savings (Tonnes)	3.3	3.1	2.9	1.0	1.1	2.2	0.8

Table 33: Heat storage cost and emissions savings – maximum PV

Table 33 indicates that heat batteries (or indeed DHW cylinders) do offer significant savings where there is sufficient PV generation. In this case, the addition of the heat batteries allows the percentage of imported electricity to fall further, making the properties even more affordable to operate. Although, as with PV, this impact is not shared equally between the homes. In particular, units B1 (plot 11), B2 and E do not benefit to as great an extent because they have more demand relative to maximum PV capacity and so utilise more of their PV directly.

It is important to note that although not captured in this analysis, heat batteries can offer further financial benefits. Namely, if the occupants signed up to a variable electricity tariff, such as a half-hourly one or one with cheaper overnight pricing, the home energy system could be programmed so that the heat pump could run on cheaper electricity rates (usually occurring at night) and send heat to the battery for use during the daytime.

12.8. Further recommendations

Smart controls

Integration of each heat pump, PV and heat battery system via their respective control units is key for effective operation across the development. The specifics of the controls systems must be reviewed and assessed before installation, to ensure that integration can be achieved. All controllers should be Zigbee compatible – it is unclear what capability this may mean as the UK smart control market is still evolving and is not yet standardised.

Once the manufacturer of the heat pumps is confirmed, their manufacturer-specific control options should be reviewed for their ability to provide smart control and integrate with other smart systems. Alternatively, a third party control system (Such as Nest, Hive, Honeywell Smarthome, etc) should be investigated – these systems would be in the order of £300 to supply. The PV diverter systems should be able to interact with both the heat pump and heat battery controls. Options include the immersun and myenergi models, which are roughly £500 to supply.

It is important that these systems are commissioned properly, although this is a specialist activity and it may be difficult to find an appropriately trained contractor locally. The last aspect that is key to successfully integrating the control systems and realising the long term operational benefits of this is sufficient training/education for the homes' occupants.

Home energy monitoring

Each of the houses will be fitted with smart meters and will have a heating interface. Both of these will provide user feedback on current energy and long term trends, typically in visual format which will be sufficient for the needs of the occupants. However, they typically do not allow the long term storage and download of data – in the case of smart meters, this data is owned by the electricity supplier and is not shared with the consumer.

Therefore, as outlined in section 9.4, the Client may be interested in setting up a monitoring system. This would include installation of a CAD device in each home to capture the data, as well as the set-up of the database to capture the information collected. Additionally, data agreements would need to be put in place with each occupant, and someone would need to be appointed to review and compile data on regular basis. The cost for these elements has been estimated at £1,000 per property. The energy usage information and real-world running costs from the development would be very useful to organisations developing similar projects.

EV chargers

As stipulated in section 7, wall-mounted slow EV chargers are recommended for each property in order to futureproof the development and de-risk the uptake occupants. These are not yet a requirement for domestic new-builds but are likely to be in the near future. The likely cost for an EV charger that be able to integrate with a home energy monitoring system would be in the range of £1,200, including fitting by an OLEV-approved installer.

Bridging the gap to 'Net Zero'

Table 33 demonstrates that although several renewable and energy-saving technologies proposed for the development, each property is estimated to draw 40-75% of their energy demand from the national grid. Therefore, the development, as proposed and modelled, cannot be classed as 'Net Zero.' The most effective way to bridge this gap would be to employ higher efficiency building fabric in order to lower the gross heating demand of each property. As demonstrated in the Phase 3 report, MVHR would have a further impact on reducing heat demand but this would be offset by the systems' self-consumption. Additionally, installing hot water heat recovery and wood burning stoves would reduce the demand on the primary heating system, provided the fuel source could be guaranteed to be renewable. Batteries would also reduce the net electricity demand of each unit, but these have already been noted to be out of budget for the project. Lastly, the rooftop PV capacity could be further maximised by utilising the dormers or by specifying top of the range PV modules (up to now 400Wp being possible). All these measures would of course carry significant capital expense.

More drastic measures, such as altering the shape and orientation of the units, would also have an impact, but these would likely contravene several amenity and place-making measures that are important for integrating the development in the village sympathetically. In addition, the local climate makes reaching Net Zero more challenging (and therefore expensive) in this location compared to most others in the UK. However, being all-electric, the homes will decarbonise over the next few decades in line with the decarbonisation of the grid. In this way, they will eventually reach Net Zero emissions.

12.9. Conclusions

In line with the detailed drawings and target U-values produced by the housing development's architect, each unique property type's peak and annual heating demands have been revised. These are noted to offer a small reduction in demand compared the Scottish building regulations maximum standards, but an increase in demand versus what has modelled across Phases 1-3.

Based on the conclusions of the Phase 3 report, the Client has decided on Air-to-Water heat pumps for the homes. The Phase 3b energy modelling has demonstrated that, although more expensive than Air-to-Air systems with direct electric hot water production, these are the cheapest systems to operate, making them the most beneficial ASHP heating system for the future occupants of the Tomintoul homes. The A2W systems will also operate with the lowest emissions and will abate 33.5 Tonnes over 20 years compared to A2A systems. Both of these systems are cheaper and less carbon-intensive to run than oil or direct electric heating systems, making them a very good choice in financial and environmental terms.

Solar PV is to be the sole renewable electricity generation technology for the development. The Phase 3b analysis clearly demonstrates that maximising the PV capacity across the development by increasing the extent over and above what the project's Contractor has proposed will significantly benefit the occupants of the homes. The additional PV allows the running costs of each unit type to be lowered (although not evenly, due to the different geometries and gross energy demands of the various units), which reduces the environmental impact of running each home proportionately. Further to this, the analysis has shown that maximising PV allows for a net reduction in hot water demand by allowing more PV energy to be stored in the heat batteries instead of being exported. Although this effect could be achieved with hot water storage cylinders too, heat batteries have lower standing losses which result in a small financial saving to occupants, among other benefits.

Lastly, the benefits and practicalities of recommended electric vehicle chargers as well as control and monitoring systems have been presented. These offer further value to the occupants whilst allowing for data capture for the potential benefit of similar housing developments in the future. The factors that keep the project from achieving Net Zero emissions have been discussed, although it is noted that over time, the homes' energy demand – being fully electric – will decarbonise over time with the national grid.

13. Phase 3b - Summary tables

House Type and tenure		Property A1 (Live & work)						
Estimated energy demand		peak heat: 2.29 kw heat: 5,749 kWh/an hot water 2292 kWh/an electricity: 1800 kWh/an						
Technology Type	Capital cost	Maintenance cost	Replacement costs	Annual running cost	Operational difficulty	Annual CO ₂ emissions	Approx. Lifetime	Notes
A2W + rads	£9,050	£120-180	HP: £2,000	£402	Medium	648kg	20-30y	
PV + diverter	£5,680	-	Diverter: £400, Inverter: £700	-£401	Easy	-1064kg	25+ y	Possible planning advantage w/ int.
Heat battery	£1,900	-	-	-£44	Easy	-30kg	25+ y	-
EV charger	£1,000	-	-	£200-£300	Easy	< 340kg	15-30y	Slow chargers w/ universal sockets
Responsibility	TGDT	TGDT / Owner-occupier	TGDT / Owner-occupier	Owner-occupier / Tenant	-	-	-	-

House Type and tenure		Property A2						
Estimated energy demand		peak heat: 2.14 kw heat: 5,388 kWh/an hot water 2292 kWh/an electricity: 1800 kWh/an						
Technology Type	Capital cost	Maintenance cost	Replacement costs	Annual running cost	Operational difficulty	Annual CO ₂ emissions	Approx. Lifetime	Notes
A2W + rads	£9,050	£120-180	HP: £2,000	£385	Medium	621kg	20-30y	
PV + diverter	£5,152	-	Diverter: £400, Inverter: £701	-£369	Easy	-957kg	25+ y	Possible planning advantage w/ int.
Heat battery	£1,900	-	-	-£44	Easy	-30kg	25+ y	-
EV charger	£1,000	-	-	£200-£300	Easy	< 340kg	15-30y	Slow chargers w/ universal sockets
Responsibility	TGDT	TGDT / Owner-occupier	TGDT / Owner-occupier	Owner-occupier / Tenant	-	-	-	-

House Type and tenure		Property B1 (Live & work)						
Estimated energy demand		peak heat: 3.87 kw heat: 8,711 kWh/an hot water 2292 kWh/an electricity: 1800 kWh/an						
Technology Type	Capital cost	Maintenance cost	Replacement costs	Annual running cost	Operational difficulty	Annual CO ₂ emissions	Approx. Lifetime	Notes
A2W + rads	£9,800	£120-180	HP: £2,000	£585	Medium	942kg	20-30y	
PV + diverter	£4,360	-	Diverter: £400, Inverter: £702	-£369	Easy	-798kg	25+ y	Possible planning advantage w/ int.
Heat battery	£1,900	-	-	-£44	Easy	-30kg	25+ y	-
EV charger	£1,000	-	-	£200-£300	Easy	< 340kg	15-30y	Slow chargers w/ universal sockets
Responsibility	TGDT	TGDT / Owner-occupier	TGDT / Owner-occupier	Owner-occupier / Tenant	-	-	-	-

House Type and tenure		Property B2						
Estimated energy demand		peak heat: 3.58 kw heat: 7,998 kWh/an hot water 2292 kWh/an electricity: 1800 kWh/an						
Technology Type	Capital cost	Maintenance cost	Replacement costs	Annual running cost	Operational difficulty	Annual CO ₂ emissions	Approx. Lifetime	Notes
A2W + rads	£9,650	£120-180	HP: £2,000	£552	Medium	889kg	20-30y	
PV + diverter	£2,512	-	Diverter: £400, Inverter: £703	-£235	Easy	-425kg	25+ y	Possible planning advantage w/ int.
Heat battery	£1,900	-	-	-£44	Easy	-30kg	25+ y	-
EV charger	£1,000	-	-	£200-£300	Easy	< 340kg	15-30y	Slow chargers w/ universal sockets
Responsibility	TGDT	TGDT / Owner-occupier	TGDT / Owner-occupier	Owner-occupier / Tenant	-	-	-	-

House Type and tenure		Property D						
Estimated energy demand		peak heat: 3.25 kw heat: 7,613 kWh/an hot water 2292 kWh/an electricity: 1800 kWh/an						
Technology Type	Capital cost	Maintenance cost	Replacement costs	Annual running cost	Operational difficulty	Annual CO ₂ emissions	Approx. Lifetime	Notes
A2W + UFH	£9,500	£120-180	HP: £2,000	£489	Medium	788kg	20-30y	
PV + diverter	£3,040	-	Diverter: £400, Inverter: £704	-£249	Easy	-532kg	25+ y	Possible planning advantage w/ int.
Heat battery	£1,900	-	-	-£44	Easy	-30kg	25+ y	-
EV charger	£1,000	-	-	£200-£300	Easy	< 340kg	15-30y	Slow chargers w/ universal sockets
Responsibility	TGDT	TGDT / Owner-occupier	TGDT / Owner-occupier	Owner-occupier / Tenant	-	-	-	-

House Type and tenure		Property E						
Estimated energy demand		peak heat: 3.58 kw heat: 8,315 kWh/an hot water 2292 kWh/an electricity: 1800 kWh/an						
Technology Type	Capital cost	Maintenance cost	Replacement costs	Annual running cost	Operational difficulty	Annual CO ₂ emissions	Approx. Lifetime	Notes
A2W + rads	£9,650	£120-180	HP: £2,000	£566	Medium	913kg	20-30y	
PV + diverter	£2,248	-	Diverter: £400, Inverter: £705	-£209	Easy	-372kg	25+ y	Possible planning advantage w/ int.
Heat battery	£1,900	-	-	-£44	Easy	-30kg	25+ y	-
EV charger	£1,000	-	-	£200-£300	Easy	< 340kg	15-30y	Slow chargers w/ universal sockets
Responsibility	TGDT	TGDT / Owner-occupier	TGDT / Owner-occupier	Owner-occupier / Tenant	-	-	-	-

14. Phase 3 - Summary tables

House Type and tenure		Property A						
Estimated energy demand		peak heat: 2.32 kw heat: 5436 kWh/an hot water 2292 kWh/an electricity: 1800 kWh/an						
Technology Type	Capital cost	Maintenance cost	Replacement costs	Annual running cost	Operational difficulty	Annual CO ₂ emissions	Approx. Lifetime	Notes
Oil	£9,000	~£150	-	£500	Easy	2,600kg	20y	For comparison only
A2A*	£5,750	£120-180	HP: £1,500	£515	Medium	825kg	20-30y	Primary system options. Heat pump unit replacement after 10-15y
A2W + UFH*	£10,625	£120-180	HP: £2,000	£365	Medium	530kg	20-30y	
A2W + rads*	£9,050	£120-180	HP: £2,000	£390	Medium	585kg	20-30y	
Wood Stove	£1,500	£100	-	£65-130	Medium	4.9-9.8kg	30y	Secondary system 15-30% heat demand
Natural ventilation	£200	-	-	-	Easy	-	3-5y	Cost for extract vents in wet rooms
Centralised mech-vent	£2,500	Filters: ~£30/an	Fan: £200	£25	Medium	40kg	20-30y	Required for high airtightness in construction
MVHR	£5,000	Filters: ~£30/an	Fan: £200	Net vs nat vent: -£41	Medium	-68kg	20-30y	
PV + diverter	Mount: £4,720 Int: £8,500	-	Diverter: £400, Inverter: £700	-£176 w/ SEG: -£306	Easy	-870kg	25+ y	Possible planning advantage w/ int.
Heat battery*	£1,500	Factored into heating & HW	-	Factored into heating & HW	Easy	Factored into heating & HW	20+ y	Sunamp or cylinder with PV dump load
Electricity battery	£4,200	-	-	-£106	Easy	-	10-15y	-
EV charger	£1,000	-	-	£200-£300	Easy	< 340kg	15-30y	Slow chargers w/ universal sockets
Responsibility	TGDT	TGDT / Owner-occupier	TGDT / Owner-occupier	Owner-occupier / Tenant	-	-	-	-

* Operating costs are shown for heating and HW. The capital costs of the heating systems includes the stated cost for a heat battery. This could be a Sunamp or a HW tank with a PV dump load, which are cost comparable. Because of this, a form of heat battery is considered as standard in the energy and modelling.

House Type and tenure		Property A (live and work)						
Estimated energy demand		peak heat: 2.32 kw heat: 5979 kWh/an hot water 2522 kWh/an electricity: 2900 kWh/an						
Technology Type	Capital cost	Maintenance cost	Replacement costs	Annual running cost	Operational difficulty	Annual CO ₂ emissions	Approx. Lifetime	Notes
Oil	£9,000	~£150	-	£550	Easy	2,860kg	20y	For comparison only
A2A*	£5,750	£120-180	HP: £1,500	£565	Medium	910kg	20-30y	Primary system options. Heat pump unit replacement after 10-15y
A2W + UFH*	£10,625	£120-180	HP: £2,000	£400	Medium	585kg	20-30y	
A2W + rads*	£9,050	£120-180	HP: £2,000	£430	Medium	640kg	20-30y	
Wood Stove	£1,500	£100	-	£72-144	Medium	5.4-10.8kg	30y	Secondary system 15-30% heat demand
Natural ventilation	£200	-	-	-	Easy	-	3-5y	Cost for extract vents in wet rooms
Centralised mech-vent	£2,500	Filters: ~£30/an	Fan: £200	£25	Medium	40kg	20-30y	Required for high airtightness in construction
MVHR	£5,000	Filters: ~£30/an	Fan: £200	Net vs nat vent: -£48	Medium	-78kg	20-30y	
PV + diverter	Mount: £4,720 Int: £8,500	-	Diverter: £400, Inverter: £700	-£223 w/ SEG: -£336	Easy	-870kg	25+ y	Possible planning advantage w/ int.
Heat battery*	£1,500	Factored into heating & HW	-	Factored into heating & HW	Easy	Factored into heating & HW	20+ y	Sunamp or cylinder with PV dump load
Electricity battery	£4,200	-	-	-£99	Easy	-	10-15y	-
EV charger	£1,000	-	-	£200-£300	Easy	< 340kg (Y1)	15-30y	Slow chargers w/ universal sockets
Responsibility	TGDT	TGDT / Owner-occupier	TGDT / Owner-occupier	Owner-occupier / Tenant	-	-	-	-

House Type and tenure		Property B (live and work)						
Estimated energy demand		peak heat: 3.78 kw heat: 9131 kWh/an hot water 3057 kWh/an electricity: 2900 kWh/an						
Technology Type	Capital cost	Maintenance cost	Replacement costs	Annual running cost	Operational difficulty	Annual CO ₂ emissions	Approx. Lifetime	Notes
Oil	£9,000	~£150	-	£790	Easy	4,100kg	20y	For comparison only
A2A*	£6,000	£120-180	HP: £1,500	£750	Medium	1,205kg	20-30y	Primary system options. Heat pump unit replacement after 10-15y
A2W + UFH*	£12,725	£120-180	HP: £2,000	£565	Medium	835kg	20-30y	
A2W + rads*	£9,800	£120-180	HP: £2,000	£610	Medium	920kg	20-30y	
Wood Stove	£1,500	£100	-	£110-219	Medium	8.2-16.4kg	30y	Secondary system 15-30% heat demand
Natural ventilation	£200	-	-	-	Easy	-	3-5y	Cost for extract vents in wet rooms
Centralised mech-vent	£2,500	Filters: ~£30/an	Fan: £200	£25	Medium	40kg	20-30y	Required for high airtightness in construction
MVHR	£5,000	Filters: ~£30/an	Fan: £200	Net vs nat vent: -£87	Medium	-140kg	20-30y	
PV + diverter	Mount: £4,720 Int: £8,500	-	Diverter: £400, Inverter: £700	-£240 w/ SEG: -£347	Easy	-870kg	25+ y	Possible planning advantage w/ int.
Heat battery*	£1,500	Factored into heating & HW	-	Factored into heating & HW	Easy	Factored into heating & HW	20+ y	Sunamp or cylinder with PV dump load
Electricity battery	£4,200	-	-	-£122	Easy	-	10-15y	-
EV charger	£1,000	-	-	£200-£300	Easy	< 340kg (Y1)	15-30y	Slow chargers w/ universal sockets
Responsibility	TGDT	TGDT / Owner-occupier	TGDT / Owner-occupier	Owner-occupier / Tenant	-	-	-	-

House Type and tenure		Property C						
Estimated energy demand		peak heat: 3.67 kw heat: 8990 kWh/an hot water 3057 kWh/an electricity: 2900 kWh/an						
Technology Type	Capital cost	Maintenance cost	Replacement costs	Annual running cost	Operational difficulty	Annual CO ₂ emissions	Lifetime	Notes
Oil	£9,000	~£150	-	£780	Easy	4053kg	20y	For comparison only
A2A*	£6,000	£120-180	HP: £1,500	£745	Medium	1,200kg	20-30y	Primary system options. Heat pump unit replacement after 10-15y
A2W + UFH*	£13,075	£120-180	HP: £2,000	£560	Medium	825kg	20-30y	
A2W + rads*	£9,650	£120-180	HP: £2,000	£605	Medium	910kg	20-30y	
Wood Stove	£1,500	£100	-	£108-216	Medium	8.1-16.2kg	30y	Secondary system 15-30% heat demand
Natural ventilation	£200	-	-	-	Easy	-	3-5y	Cost for extract vents in wet rooms
Centralised mech-vent	£2,500	Filters: ~£30/an	Fan: £200	£25	Medium	40kg	20-30y	Required for high airtightness in construction
MVHR	£5,000	Filters: ~£30/an	Fan: £200	Net vs nat vent: -£85	Medium	-138kg	20-30y	
PV + diverter	Mount: £5,620 Int: £10,300	-	Diverter: £400, Inverter: £700	-£251 w/ SEG: -£397	Easy	-1064kg	25+ y	Possible planning advantage w/ int.
Heat battery*	£1,500	Factored into heating & HW	-	Factored into heating & HW	Easy	Factored into heating & HW	20+ y	Sunamp or cylinder with PV dump load
Electricity battery	£4,200	-	-	-£135	Easy	-	10-15y	-
EV charger	£1,000	-	-	£200-£300	Easy	< 340kg (Y1)	15-30y	Slow chargers w/ universal sockets
Responsibility	TGDT	TGDT / Owner-occupier	TGDT / Owner-occupier	Owner-occupier / Tenant	-	-	-	-

House Type and tenure		Property D						
Estimated energy demand		peak heat: 1.79 kw heat: 4387 kWh/an hot water 2292 kWh/an electricity: 1800 kWh/an						
Technology Type	Capital cost	Maintenance cost	Replacement costs	Annual running cost	Operational difficulty	Annual CO ₂ emissions	Lifetime	Notes
Oil	£9,000	~£150	-	£435	Easy	2247kg	20y	For comparison only
A2A*	£5,750	£120-180	HP: £1,500	£475	Medium	765kg	20-30y	Primary system options. Heat pump unit replacement after 10-15y
A2W + UFH*	£10,450	£120-180	HP: £2,000	£320	Medium	460kg	20-30y	
A2W + rads*	£8,900	£120-180	HP: £2,000	£340	Medium	505kg	20-30y	
Wood Stove	£1,500	£100	-	£53-105	Medium	3.9-7.8kg	30y	Secondary system 15-30% heat demand
Natural ventilation	£200	-	-	-	Easy	-	3-5y	Cost for extract vents in wet rooms
Centralised mech-vent	£2,500	Filters: ~£30/an	Fan: £200	£25	Medium	40kg	20-30y	Required for high airtightness in construction
MVHR	£5,000	Filters: ~£30/an	Fan: £200	Net vs nat vent: -£29	Medium	-47kg	20-30y	
PV + diverter	Mount: £2,800 Int: £4,900	-	Diverter: £400, Inverter: £700	-£146 w/ SEG: -£201	Easy	-483kg	25+ y	Possible planning advantage w/ int.
Heat battery*	£1,500	Factored into heating & HW	-	Factored into heating & HW	Easy	Factored into heating & HW	20+ y	Sunamp or cylinder with PV dump load
Electricity battery	£4,200	-	-	-£71	Easy	-	10-15y	-
EV charger	£1,000	-	-	£200-£300	Easy	< 340kg (Y1)	15-30y	Slow chargers w/ universal sockets
Responsibility	TGDT	TGDT / Owner-occupier	TGDT / Owner-occupier	Owner-occupier / Tenant	-	-	-	-

House Type and tenure		Property E						
Estimated energy demand		peak heat: 2.18 kw heat: 5317 kWh/an hot water 3057 kWh/an electricity: 2900 kWh/an						
Technology Type	Capital cost	Maintenance cost	Replacement costs	Annual running cost	Operational difficulty	Annual CO ₂ emissions	Lifetime	Notes
Oil	£9,000	~£150	-	£545	Easy	2817kg	20y	For comparison only
A2A*	£6,000	£120-180	HP: £1,500	£615	Medium	990kg	20-30y	Primary system options. Heat pump unit replacement after 10-15y
A2W + UFH*	£11,080	£120-180	HP: £2,000	£405	Medium	575kg	20-30y	
A2W + rads*	£9,050	£120-180	HP: £2,000	£430	Medium	630kg	20-30y	
Wood Stove	£1,500	£100	-	£64-128	Medium	4.8-9.6kg	30y	Secondary system 15-30% heat demand
Natural ventilation	£200	-	-	-	Easy	-	3-5y	Cost for extract vents in wet rooms
Centralised mech-vent	£2,500	Filters: ~£30/an	Fan: £200	£25	Medium	40kg	20-30y	Required for high airtightness in construction
MVHR	£5,000	Filters: ~£30/an	Fan: £200	Net vs nat vent: -£40	Medium	-65kg	20-30y	
PV + diverter	Mount: £3,520 Int: £6,250	-	Diverter: £400, Inverter: £700	-£1 w/ SEG: -£274	Easy	-629kg	25+ y	Possible planning advantage w/ int.
Heat battery*	£1,500	Factored into heating & HW	-	Factored into heating & HW	Easy	Factored into heating & HW	20+ y	Sunamp or cylinder with PV dump load
Electricity battery	£4,200	-	-	-£86	Easy	-	10-15y	-
EV charger	£1,000	-	-	£200-£300	Easy	< 340kg (Y1)	15-30y	Slow chargers w/ universal sockets
Responsibility	TGDT	TGDT / Owner-occupier	TGDT / Owner-occupier	Owner-occupier / Tenant	-	-	-	-

House Type and tenure		Property A						
Estimated energy demand		peak heat: 2.32 kw heat: 5436 kWh/an hot water 2292 kWh/an electricity: 1800 kWh/an						
Technology Type	Capital cost	Maintenance cost	Replacement costs	Annual running cost	Operational difficulty	Annual CO ₂ emissions	Approx. Lifetime	Notes
Oil	£9,000	~£150	-	£500	Easy	2,600kg	20y	For comparison only
A2A*	£5,750	£120-180	HP: £1,500	£515	Medium	825kg	20-30y	Primary system options. Heat pump unit replacement after 10-15y
A2W + UFH*	£10,625	£120-180	HP: £2,000	£365	Medium	530kg	20-30y	
A2W + rads*	£9,050	£120-180	HP: £2,000	£390	Medium	585kg	20-30y	
Wood Stove	£1,500	£100	-	£65-130	Medium	4.9-9.8kg	30y	Secondary system 15-30% heat demand
Natural ventilation	£200	-	-	-	Easy	-	3-5y	Cost for extract vents in wet rooms
Centralised mech-vent	£2,500	Filters: ~£30/an	Fan: £200	£25	Medium	40kg	20-30y	Required for high airtightness in construction
MVHR	£5,000	Filters: ~£30/an	Fan: £200	Net vs nat vent: -£41	Medium	-68kg	20-30y	
PV + diverter	Mount: £4,720 Int: £8,500	-	Diverter: £400, Inverter: £700	-£176 w/ SEG: -£306	Easy	-870kg	25+ y	Possible planning advantage w/ int.
Heat battery*	£1,500	Factored into heating & HW	-	Factored into heating & HW	Easy	Factored into heating & HW	20+ y	Sunamp or cylinder with PV dump load
Electricity battery	£4,200	-	-	-£106	Easy	-	10-15y	-
EV charger	£1,000	-	-	£200-£300	Easy	< 340kg	15-30y	Slow chargers w/ universal sockets
Responsibility	TGDT	TGDT / Owner-occupier	TGDT / Owner-occupier	Owner-occupier / Tenant	-	-	-	-

* Operating costs are shown for heating and HW. The capital costs of the heating systems includes the stated cost for a heat battery. This could be a Sunamp or a HW tank with a PV dump load, which are cost comparable. Because of this, a form of heat battery is considered as standard in the energy and modelling.

House Type and tenure		Property A (live and work)						
Estimated energy demand		peak heat: 2.32 kw heat: 5979 kWh/an hot water 2522 kWh/an electricity: 2900 kWh/an						
Technology Type	Capital cost	Maintenance cost	Replacement costs	Annual running cost	Operational difficulty	Annual CO ₂ emissions	Approx. Lifetime	Notes
Oil	£9,000	~£150	-	£550	Easy	2,860kg	20y	For comparison only
A2A*	£5,750	£120-180	HP: £1,500	£565	Medium	910kg	20-30y	Primary system options. Heat pump unit replacement after 10-15y
A2W + UFH*	£10,625	£120-180	HP: £2,000	£400	Medium	585kg	20-30y	
A2W + rads*	£9,050	£120-180	HP: £2,000	£430	Medium	640kg	20-30y	
Wood Stove	£1,500	£100	-	£72-144	Medium	5.4-10.8kg	30y	Secondary system 15-30% heat demand
Natural ventilation	£200	-	-	-	Easy	-	3-5y	Cost for extract vents in wet rooms
Centralised mech-vent	£2,500	Filters: ~£30/an	Fan: £200	£25	Medium	40kg	20-30y	Required for high airtightness in construction
MVHR	£5,000	Filters: ~£30/an	Fan: £200	Net vs nat vent: -£48	Medium	-78kg	20-30y	
PV + diverter	Mount: £4,720 Int: £8,500	-	Diverter: £400, Inverter: £700	-£223 w/ SEG: -£336	Easy	-870kg	25+ y	Possible planning advantage w/ int.
Heat battery*	£1,500	Factored into heating & HW	-	Factored into heating & HW	Easy	Factored into heating & HW	20+ y	Sunamp or cylinder with PV dump load
Electricity battery	£4,200	-	-	-£99	Easy	-	10-15y	-
EV charger	£1,000	-	-	£200-£300	Easy	< 340kg (Y1)	15-30y	Slow chargers w/ universal sockets
Responsibility	TGDT	TGDT / Owner-occupier	TGDT / Owner-occupier	Owner-occupier / Tenant	-	-	-	-

House Type and tenure		Property B (live and work)						
Estimated energy demand		peak heat: 3.78 kw heat: 9131 kWh/an hot water 3057 kWh/an electricity: 2900 kWh/an						
Technology Type	Capital cost	Maintenance cost	Replacement costs	Annual running cost	Operational difficulty	Annual CO ₂ emissions	Approx. Lifetime	Notes
Oil	£9,000	~£150	-	£790	Easy	4,100kg	20y	For comparison only
A2A*	£6,000	£120-180	HP: £1,500	£750	Medium	1,205kg	20-30y	Primary system options. Heat pump unit replacement after 10-15y
A2W + UFH*	£12,725	£120-180	HP: £2,000	£565	Medium	835kg	20-30y	
A2W + rads*	£9,800	£120-180	HP: £2,000	£610	Medium	920kg	20-30y	
Wood Stove	£1,500	£100	-	£110-219	Medium	8.2-16.4kg	30y	Secondary system 15-30% heat demand
Natural ventilation	£200	-	-	-	Easy	-	3-5y	Cost for extract vents in wet rooms
Centralised mech-vent	£2,500	Filters: ~£30/an	Fan: £200	£25	Medium	40kg	20-30y	Required for high airtightness in construction
MVHR	£5,000	Filters: ~£30/an	Fan: £200	Net vs nat vent: -£87	Medium	-140kg	20-30y	
PV + diverter	Mount: £4,720 Int: £8,500	-	Diverter: £400, Inverter: £700	-£240 w/ SEG: -£347	Easy	-870kg	25+ y	Possible planning advantage w/ int.
Heat battery*	£1,500	Factored into heating & HW	-	Factored into heating & HW	Easy	Factored into heating & HW	20+ y	Sunamp or cylinder with PV dump load
Electricity battery	£4,200	-	-	-£122	Easy	-	10-15y	-
EV charger	£1,000	-	-	£200-£300	Easy	< 340kg (Y1)	15-30y	Slow chargers w/ universal sockets
Responsibility	TGDT	TGDT / Owner-occupier	TGDT / Owner-occupier	Owner-occupier / Tenant	-	-	-	-

House Type and tenure		Property C						
Estimated energy demand		peak heat: 3.67 kw heat: 8990 kWh/an hot water 3057 kWh/an electricity: 2900 kWh/an						
Technology Type	Capital cost	Maintenance cost	Replacement costs	Annual running cost	Operational difficulty	Annual CO ₂ emissions	Lifetime	Notes
Oil	£9,000	~£150	-	£780	Easy	4053kg	20y	For comparison only
A2A*	£6,000	£120-180	HP: £1,500	£745	Medium	1,200kg	20-30y	Primary system options. Heat pump unit replacement after 10-15y
A2W + UFH*	£13,075	£120-180	HP: £2,000	£560	Medium	825kg	20-30y	
A2W + rads*	£9,650	£120-180	HP: £2,000	£605	Medium	910kg	20-30y	
Wood Stove	£1,500	£100	-	£108-216	Medium	8.1-16.2kg	30y	Secondary system 15-30% heat demand
Natural ventilation	£200	-	-	-	Easy	-	3-5y	Cost for extract vents in wet rooms
Centralised mech-vent	£2,500	Filters: ~£30/an	Fan: £200	£25	Medium	40kg	20-30y	Required for high airtightness in construction
MVHR	£5,000	Filters: ~£30/an	Fan: £200	Net vs nat vent: -£85	Medium	-138kg	20-30y	
PV + diverter	Mount: £5,620 Int: £10,300	-	Diverter: £400, Inverter: £700	-£251 w/ SEG: -£397	Easy	-1064kg	25+ y	Possible planning advantage w/ int.
Heat battery*	£1,500	Factored into heating & HW	-	Factored into heating & HW	Easy	Factored into heating & HW	20+ y	Sunamp or cylinder with PV dump load
Electricity battery	£4,200	-	-	-£135	Easy	-	10-15y	-
EV charger	£1,000	-	-	£200-£300	Easy	< 340kg (Y1)	15-30y	Slow chargers w/ universal sockets
Responsibility	TGDT	TGDT / Owner-occupier	TGDT / Owner-occupier	Owner-occupier / Tenant	-	-	-	-

House Type and tenure		Property D						
Estimated energy demand		peak heat: 1.79 kw heat: 4387 kWh/an hot water 2292 kWh/an electricity: 1800 kWh/an						
Technology Type	Capital cost	Maintenance cost	Replacement costs	Annual running cost	Operational difficulty	Annual CO ₂ emissions	Lifetime	Notes
Oil	£9,000	~£150	-	£435	Easy	2247kg	20y	For comparison only
A2A*	£5,750	£120-180	HP: £1,500	£475	Medium	765kg	20-30y	Primary system options. Heat pump unit replacement after 10-15y
A2W + UFH*	£10,450	£120-180	HP: £2,000	£320	Medium	460kg	20-30y	
A2W + rads*	£8,900	£120-180	HP: £2,000	£340	Medium	505kg	20-30y	
Wood Stove	£1,500	£100	-	£53-105	Medium	3.9-7.8kg	30y	Secondary system 15-30% heat demand
Natural ventilation	£200	-	-	-	Easy	-	3-5y	Cost for extract vents in wet rooms
Centralised mech-vent	£2,500	Filters: ~£30/an	Fan: £200	£25	Medium	40kg	20-30y	Required for high airtightness in construction
MVHR	£5,000	Filters: ~£30/an	Fan: £200	Net vs nat vent: -£29	Medium	-47kg	20-30y	
PV + diverter	Mount: £2,800 Int: £4,900	-	Diverter: £400, Inverter: £700	-£146 w/ SEG: -£201	Easy	-483kg	25+ y	Possible planning advantage w/ int.
Heat battery*	£1,500	Factored into heating & HW	-	Factored into heating & HW	Easy	Factored into heating & HW	20+ y	Sunamp or cylinder with PV dump load
Electricity battery	£4,200	-	-	-£71	Easy	-	10-15y	-
EV charger	£1,000	-	-	£200-£300	Easy	< 340kg (Y1)	15-30y	Slow chargers w/ universal sockets
Responsibility	TGDT	TGDT / Owner-occupier	TGDT / Owner-occupier	Owner-occupier / Tenant	-	-	-	-

House Type and tenure		Property E						
Estimated energy demand		peak heat: 2.18 kw heat: 5317 kWh/an hot water 3057 kWh/an electricity: 2900 kWh/an						
Technology Type	Capital cost	Maintenance cost	Replacement costs	Annual running cost	Operational difficulty	Annual CO ₂ emissions	Lifetime	Notes
Oil	£9,000	~£150	-	£545	Easy	2817kg	20y	For comparison only
A2A*	£6,000	£120-180	HP: £1,500	£615	Medium	990kg	20-30y	Primary system options. Heat pump unit replacement after 10-15y
A2W + UFH*	£11,080	£120-180	HP: £2,000	£405	Medium	575kg	20-30y	
A2W + rads*	£9,050	£120-180	HP: £2,000	£430	Medium	630kg	20-30y	
Wood Stove	£1,500	£100	-	£64-128	Medium	4.8-9.6kg	30y	Secondary system 15-30% heat demand
Natural ventilation	£200	-	-	-	Easy	-	3-5y	Cost for extract vents in wet rooms
Centralised mech-vent	£2,500	Filters: ~£30/an	Fan: £200	£25	Medium	40kg	20-30y	Required for high airtightness in construction
MVHR	£5,000	Filters: ~£30/an	Fan: £200	Net vs nat vent: -£40	Medium	-65kg	20-30y	
PV + diverter	Mount: £3,520 Int: £6,250	-	Diverter: £400, Inverter: £700	-£1 w/ SEG: -£274	Easy	-629kg	25+ y	Possible planning advantage w/ int.
Heat battery*	£1,500	Factored into heating & HW	-	Factored into heating & HW	Easy	Factored into heating & HW	20+ y	Sunamp or cylinder with PV dump load
Electricity battery	£4,200	-	-	-£86	Easy	-	10-15y	-
EV charger	£1,000	-	-	£200-£300	Easy	< 340kg (Y1)	15-30y	Slow chargers w/ universal sockets
Responsibility	TGDT	TGDT / Owner-occupier	TGDT / Owner-occupier	Owner-occupier / Tenant	-	-	-	-

Appendix A. Assumptions

Technical assumptions

U values for fabric performance scenarios:

Fabric Element	Building Regs	Good	Very good
External wall (W/m ² K)	0.22	0.17	0.12
Party wall (W/m ² K)	0.2	0.16	0.12
Floor (W/m ² K)	0.18	0.14	0.10
Roof (W/m ² K)	0.15	0.13	0.10
Glazing (W/m ² K)	1.6	1.2	0.7

Development energy demands:

Property	A	A (L/W)	B	C	D	E
Electrical appliance demand (kWh)	1800	2900	2900	2900	1800	2900
Hot water demand (kWh)	2292	2522	3057	3057	2292	3057
Heat demand (kWh)	5436	5979	9131	8990	4387	5317
Peak heat demand (kW)	2.32	2.32	3.78	3.67	1.79	2.18

Coefficients of performance for heating options:

System	A2A	A2W + UFH	A2W + Rads
Heating SCOP	4	3.3	3
Hot water COP	n/a	2.4	2.4

Emissions intensity rate assumption:

- 2020 grid carbon intensity: 0.2256 kg/kwh
- 2040 grid carbon intensity: 0.07445 kg/kwh

Oil boiler counterfactual assumptions:

- capex: £9,000
- annual maintenance: £150
- boiler efficiency: 85%
- carbon intensity: 0.286 kg/kWh
- fuel costs: 5.5 p/kWh

Financial assumptions

Values used in energy flow modelling:

- Annual tariff inflation :2.0%
- SEG income: £0.05/kWh
- Electricity price: £14.00/kWh
- Economy 7 Night £0.09/kWh
- Economy 7 Day £0.16/kWh

SAP assumptions

In all simulations, the following assumptions were applied:

- Only one U value was applied to walls, floors and roofs, with no variation regarding, for example, heated/unheated attic spaces or unheated voids in roof rooms. This therefore represents worst-case scenario.
- The living area fraction of the properties is not yet known, so was assumed to be 20% of the total floor area. Thermal bridging values are also unknown, so a default ψ value of 0.15 was specified for each property.
- Orientation for all properties was unspecified, including window orientation. PV was assumed to be southwest facing for property types A, B and C, and southeast facing for property types D and E.
- Unless otherwise stated, natural ventilation was prescribed as the base case, including 2x extractor fans (kitchen and bathroom) for all properties. An air permeability of $6\text{m}^3/\text{h}/\text{m}^2$ was therefore applied. For options where MVHR or MEV were utilised, and air permeability of $2\text{m}^3/\text{h}/\text{m}^2$ was assumed. In all situations, it was assumed that windows were openable half the time.
- For consistency in simulation, a nominal heat pump was used. This was simplified to be a 6kW A2W heat pump in properties A, D and E, and a 9kW A2W heat pump in properties B and C. In all cases, this provided energy to a 300L cylinder with a standing loss of 1.9kWh/day.

Property Types

Type A:
Single Storey detached timber
framed; 2 bedroom.
With/ without porch
75m² floor area

Type B:
1.75 Storey timber frame
3 bedrooms With / without
porch. 135m² floor area

Type C:
2 Storey timber frame
3 bedrooms - 145m²
floor area

Type D:
Semi detached 2 Storey -
2 bedrooms - 70m² floor
area

Type E:
Semi detached 2 storey
3 bedrooms - 88m² floor area

Legend

- All abilities parking
- Parking
- Cycle storage
- Bin storage
- District Heating plant
- Planting
- Shared surface (pedestrian / cycle priority)
- Site Boundary
- Scottish Water - Supply
- Scottish Water - Drainage
- SSE power supply
- BT Openreach

Design Intent

The objective is to redevelop the site of the old secondary school to create affordable, attractive and energy efficient properties in the heart of Tomintoul - that are sympathetic to the vernacular style within the village while providing modern comforts. This design has 12, 2 & 3 bed properties.

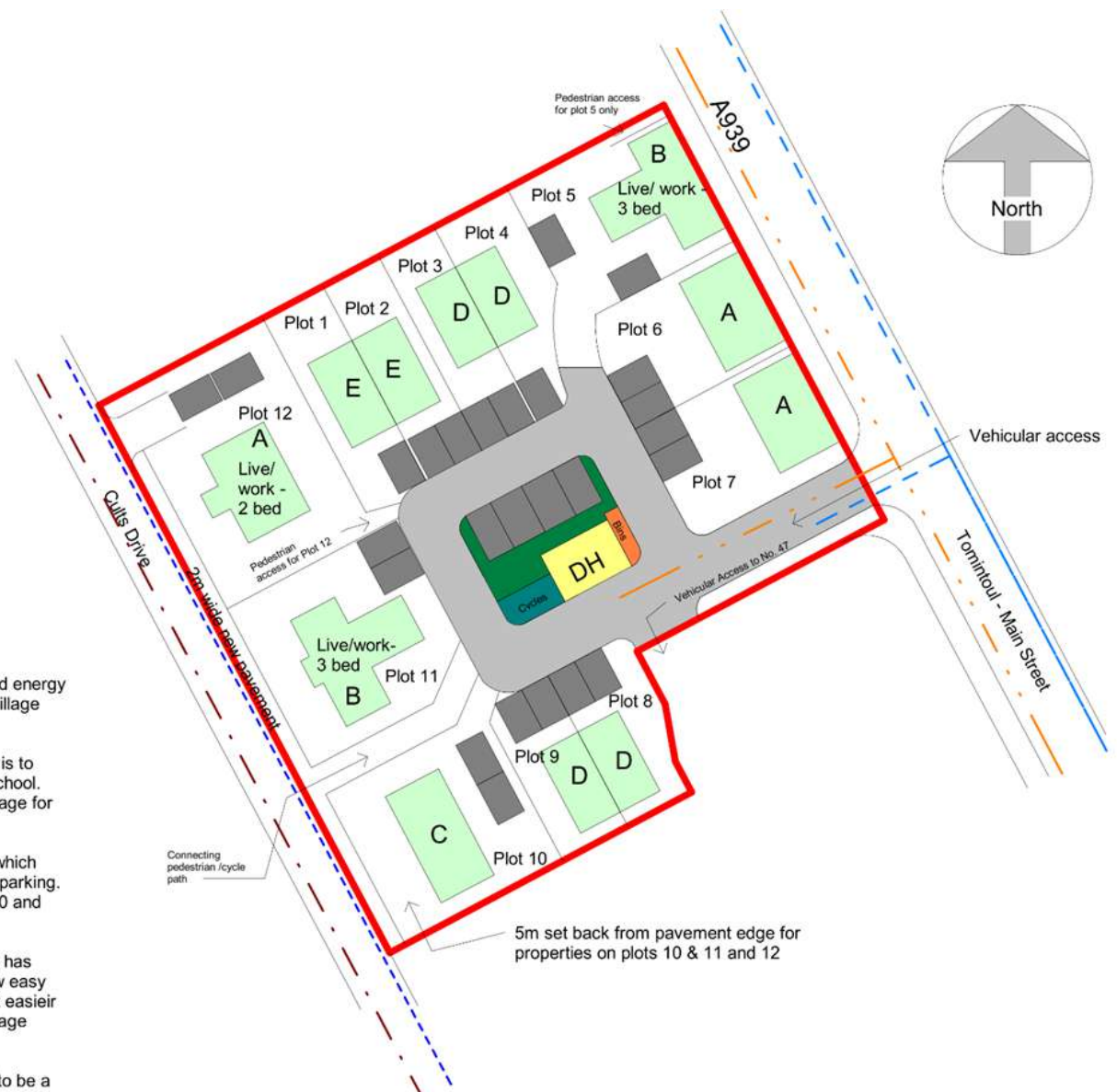
The only vehicular access to all plots, except plot 12, is from the main street within the village. This is to encourage cycling and walking for journeys within the village and to minimise traffic in front of the school. With no through road for cars, there will be no temptation to use it as a short cut. Access to the garage for No 47 is to be maintained.

The shared surface in the centre will prioritise walkers & cyclists while providing additional parking which could be utilised by primary school staff who currently park on the site in the absence of alternative parking. Easy access to the school is available through a connecting pedestrian/ cycle path, between plots 10 and 11.

A district heating system is a possibility and provision has been made for a plant room for this. This has been located centrally to all properties to minimise pipework required; maximise efficiency and allow easy access for delivery of fuel. The central space could also house a communal bin store, making uplift easier and also cycle parking, if desired. Other uses could include soft landscaping/ planting/ SUDS drainage area.

Plot 5 opens on to the pavement as do many of the properties on the High street. This is designed to be a work/ live unit incorporating the space for a business. Pedestrian access to the rear of this property is provided to the north of the property creating separation from the immediate neighbour. Other live/ work units are at plots 11 & 12. Plots 6 & 7 are single storey and set back from the pavement edge, to assist with visibility for vehicles leaving the site.

Plot 12 has vehicular access from Culds Drive and pedestrian access to the centre area, if required.



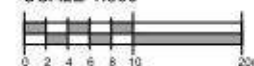
1

Draft Site Layout- 12 houses

1 : 500

1. Protected by Copyright, no reproduction without express permission of Community Housing Scotland
2. Contractor is responsible for checking all dimensions prior to construction.
3. Discrepancies to be referred to Architect for decision.
4. Must be read with reference to written specification and engineers/ sub contractors construction information.

SCALE 1:500



Property Types

Type A:
Single Storey
Detached House
4 Person - 2 bedroom
(A.1 Live-Work)

Type B:
1.75 Storey
Semi-Detached House
5 Person - 3 bedroom
(B.1 Live-Work)

Type C:
Two Storey
Detached House
5 Person - 3 bedroom

Type D:
Two Storey
Semi-detached House
4 Person - 2 bedroom

Type E:
Two Storey
Semi-detached House
5 Person - 3 bedroom



1 **Scheme Layout**
1:500 @ A3

Rev B 25.09.20 House Type B revised



Client: Alpha Projects

DWG. NO. SK - 200 B

Project:
Housing Development
Main Street
Tomintoul

Title:
Scheme Layout

1:500 @ A3

Job No: 760

Date: April 2020

Purpose: Design

Drawn by: HG

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