Energy Audit & Feasibility Study

For

Bridge House Farm

Prepared by **Roger Stones, CEM**

November 2022

Contents

Summary

Bridge House Farm (Bridge House) commissioned NFU Energy to conduct an energy audit to identify energy saving measures and examine the feasibility of renewable energy generation.

Bridge House consumes approximately 480,000kWh per year from a 200kVA grid transformer at an average cost of £0.40 per kWh and, self generates approximately 34,000kWh from a solar photo voltaic (PV) array.

Excluding tractors and transport, Bridge House additionally consumes 263,000kWh of propane and 37,000kWh of heating oil.

Heating and motor loads account for most Bridge House's energy consumption.

Energy efficiency

- Installing variable speed drives on a selection of fans can yield savings from 880kWh and £352 to 7,920kWh and £3,168 per annum with simple payback periods of 4.4 to 1.2 years on savings ranging from 20% to 45% respectively.
- With major reengineering of the current ventilation systems and savings ranging from 40 – 60%, heat recovery can save from 74,904kWh and £ 29,962 to 112,356kWh and £ 44,942 per annum respectively.
- With major re-engineering of the heat distribution system, fuel switching to 75% efficient propane, heating oil and red Diesel boilers can reduce the current electricity's heating cost of £74,904 to £15,730, £18,227 and £16,729 per year respectively at historic fuel costs.
- Bore hole water used on the farm can yield 326,799 to 237,672 kWh of thermal potential assuming the water temperature is reduced to 4ºC.
- Because electricty directly heats piglet warming pads and fan heaters, heat pumps present a favourable energy saving solution.
- At a coefficient of performance (CoP) of 2.5 for air source, 3 for ground source and 4 for water source, heat pumps will use respectively 75,000 kWh, 63,000kWh and 48,000kWh, to deliver heat equivalent to the existing direct electric 187,260kWh, thus saving approximately £45,000, £50,000 and £56,000 per year.
- From these savings and assuming heat pumps cost £2,000 per kW, a heat pump of 30 input kW may cost £60,000, thus yielding a simple payback period of 1.3 to 1.1 years respectively.

Renewables

- Not enough micro anaerobic digestion (AD) of pig slurry project data is available to currently recommend or advise against its deployments as an energy source.
- All the modelled PV projects yielded excellent feasibility results in terms of energy yield, cost saving, internal rate of return (IRR) and net present values (NPV).
- The 150kW PV with batteries project performed the worst, the 200kW with batteries performed the best and the 30kW PV only project exported no energy with the best IRR of 38.2%.
- The wind turbine project models also showed good but expensive results compared to PV.
- PV has a capacity factor of 9.9% and wind 23.4%.

NFU Energy, 10th Street, Stoneleigh Park,
Kenilworth, Warwickshire CV8 2LS

Background

Bridge House Farm Ltd, (Bridge House), commissioned NFU Energy to conduct a high-level energy audit and feasibility study to respectively identify energy saving measures and renewable energy generation at their piggery unit, see figure 1 below.

Bridge House consumes approximately 480,000kWh per year from a 200kVA transformer with a load factor of 42.4%. Solar Photo Voltaic (PV) power supplies approximately 34,000kWh yielding a potential saving of £13,600 per year at the current electricity price of £0.40 per kWh.

Excluding tractors and transport, Bridge House additionally consumes approximately 263,000kWh of propane and 37,000kWh of heating oil energy at an historic cost of £0.063 and £0.067 per kWh respectively.

Bridge House uses propane for the incinerator, heating oil for the offices & shower blocks, and electricty for all the other energy demands.

Bridge House produces mainly breeding animals with approximately 7,000 pigs at various stages of growth on site at any given time. The unit consists of multiple building with the highest energy use concentrated in the farrowing rooms, grower units and finisher units.

The slatted floor buildings collect pig slurry into concrete sumps which flush into a holding tank and pump into effluent lagoons.

Bridge House uses approximately 70m^3 of borehole water per day while an automated feed rationing system feeds the pigs.

Figure 1 showing Bridge House Farm piggery unit

Load profile

Table 1 below shows Bridge House's half hourly electricity use statistics for September 2021 to August 2022. Figure 2 below shows a histogram of the kW demand.

For the sample period, Bridge House consumed 445,372kWh at a load factor of 42.4%*. Although demand peaked at 120kW once in October at 00:30, Bridge Farm demand never exceeded 81.1kW for 99.7% of the time. This suggest that the 200kVA transformer has 110 – 120kVA spare capacity for 99.7% of the time.

**Load factor shows the actual energy use compared to what could have been used at peak load over a sample period. For example, how hard a tractor truly works compared to how hard it can work.*

Table 1 showing electricty consumption statistics from September 2021 to August 2022

September 2021 to August 2022			
Sample hours	8,760	Oct	month of max
Load Factor	42.4%	00:30	time of max
kWh sum	445,372		
	kWh	kW	
Maximum	60.0	120.0	
Average	25.4	50.8	
Mode	24.6	49.2	
Mode frequency	173	173	times
Median	24.9	49.8	
Std. deviation	5.0	10.1	
68th percentile	30.5	60.9	
95th percentile	35.5	71.0	
99.7 percentile	40.5	81.1	

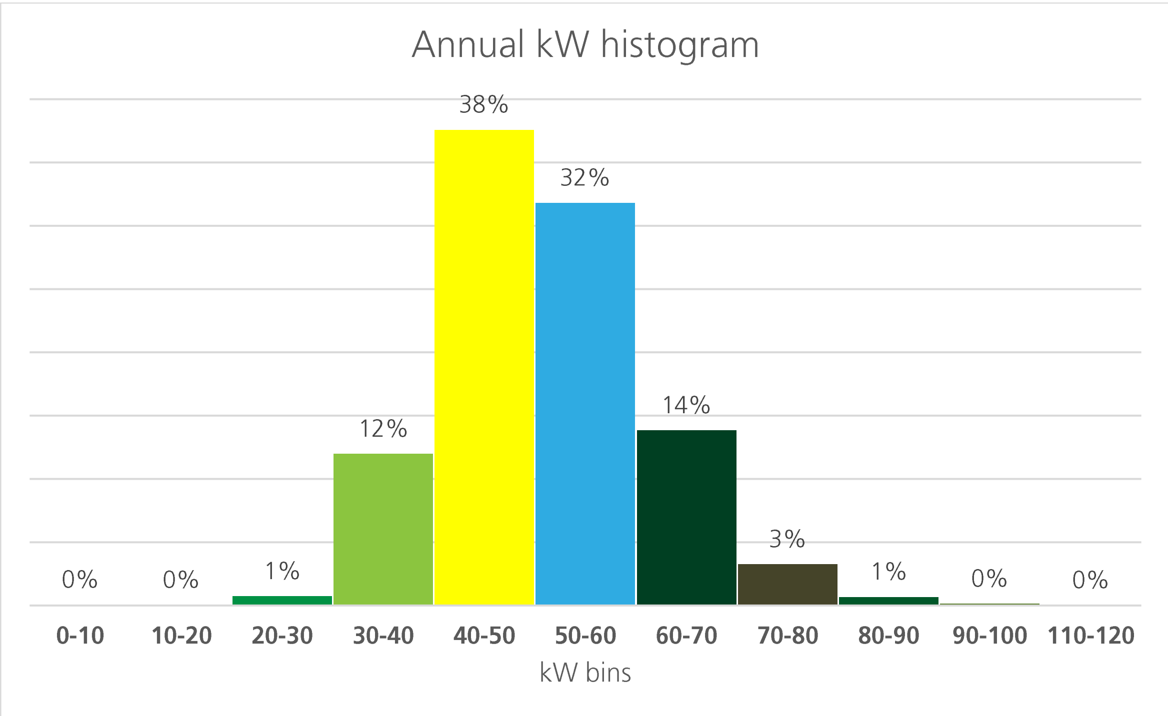

Figure 2 showing a histogram of kW demand

Figure 3 below shows the monthly kWh (energy) demand and figure 4 shows the annual summed kWh for each hour of the day. Figure 3 shows a relatively constant demand with an approximately 10,000kWh per month increase from summer to winter suggesting higher heating loads in winter.

Figure 4 shows increased daytime energy use with a mid-day trough suggesting a) peak demand in the morning and afternoon or b) the offsetting effects of the PV generators.

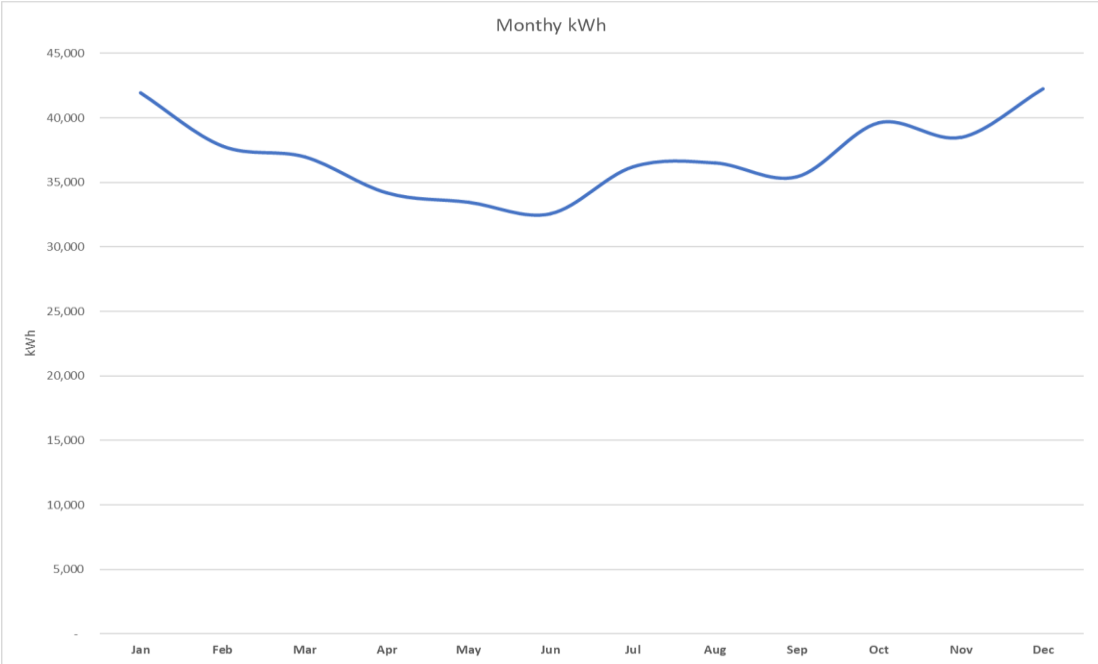

Figure 3 showing monthly kWh demand

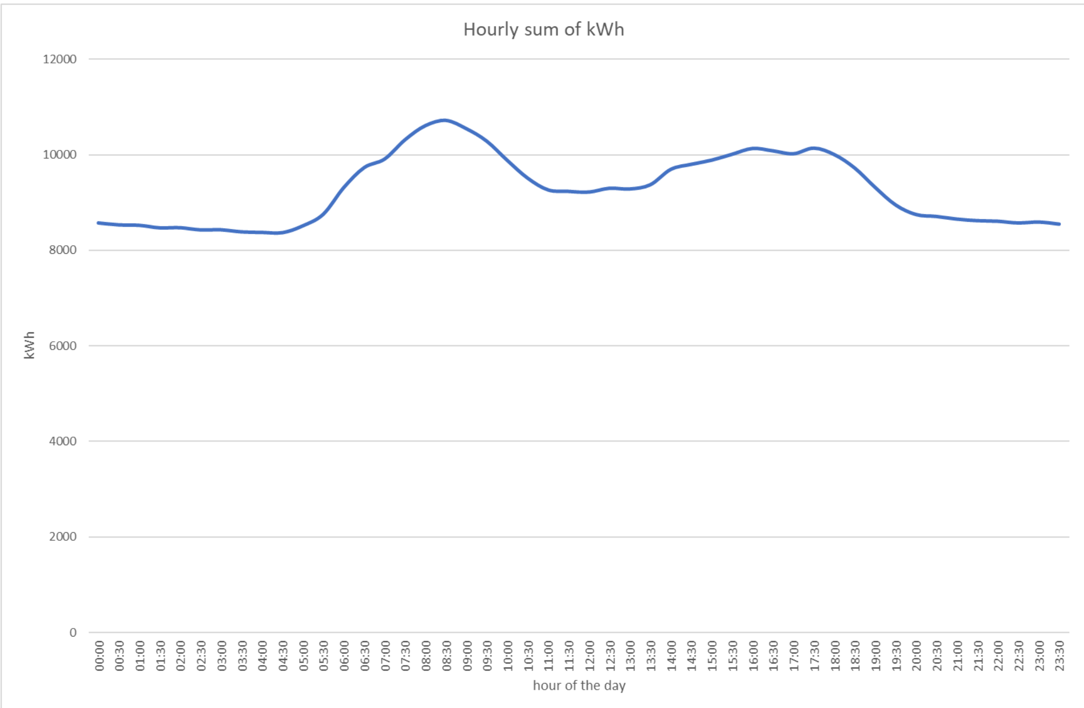

Figure 4 showing annual hourly kWh demand

Energy sources

Excluding solar PV, table 2 and figure 5 below show the relative energy use per fuel type and the associated cost per kWh. Electricty accounts for 55% of the total energy use followed by propane at 33%. This implies that any energy savings associated with these energy types will have the highest impact.

However, the electricty cost accounts for 88.4% of the farm's total energy bill at approximately £178,000 per annum followed by propane, 8.2%, red Diesel, 2.1% and heating oil at 1.2%. This implies that energy saving measures associated with electricty should have the highest overall impact.

Table 2 showing the relative energy use per fuel type

Propane	£ per kWh	Red Diesel	£ per kWh	Heating Oil	£ per kWh	Electricty	£ per kWh
262,725 kWh	£0.063	58,599 kWh	£0.073	37,265 kWh	£0.067	445,372 kWh	£0.400
32.7%		7.3%		4.6%		55.4%	

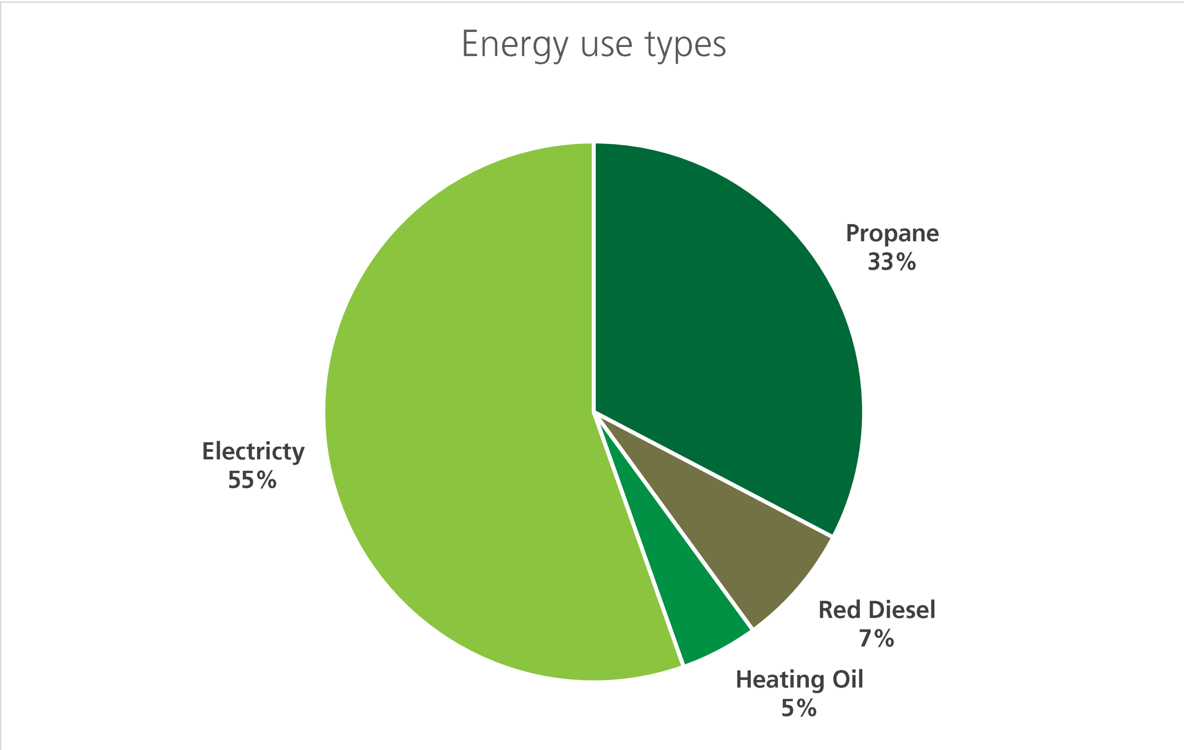

Figure 5 showing the relative energy use per fuel type

Load types

Table 3 below shows a summary of the general electricty use ('electric') and heating fan ('Heating electric') sub-meter data for the growing and finishing unit rooms (RM). The red to orange cells of table 3 indicate higher energy use while the green cells show lower relative demand. The higher heating loads correlate with winter whereas the higher summer 'electric' loads suggest increased ventilated cooling loads.

Table 3 showing sub-metered electricty demand

	Finishing kWh			Growing kWh			
	RM1-2 electric	RM3-4 electric	Heating electric	RM1-2 electric	RM3-4 electric	Electrical Sum	Heat + electric
Dec-21	2,709	2,374	10,388	1,960	2,040	9,082	19,470
Jan-22	2,460	2,403	11,533	2,017	1,681	8,561	20,094
Feb-22	2,356	2,293	10,640	1,637	1,756	8,042	18,682
Mar-22	3,022	2,688	5,459	2,094	1,926	9,730	15,189
Apr-22	2,882	3,016	3,586	2,139	2,083	10,120	13,706
May-22	3,576	3,449	1,852	2,604	2,192	11,822	13,673
Jun-22	3,852	3,834	868	2,517	2,549	12,752	13,620
Jul-22	4,504	4,415	1,869	2,842	2,727	14,487	16,356
Aug-22	4,371	4,426	972	2,983	2,717	14,496	15,468
Sep-22	3,295	3,423	3,946	2,157	2,181	11,055	15,002
Oct-22	3,237	3,133	4,486	2,452	2,068	10,890	15,376
Nov-22	869	815	2,617	564	615	2,863	5,479
Sum	**37,131**	**36,268**	**58,216**	**25,965**	**24,535**	**123,899**	**182,116**

Figure 6 below shows the data in table 3. The figure shows the seasonal changes in heating and ventilation loads.

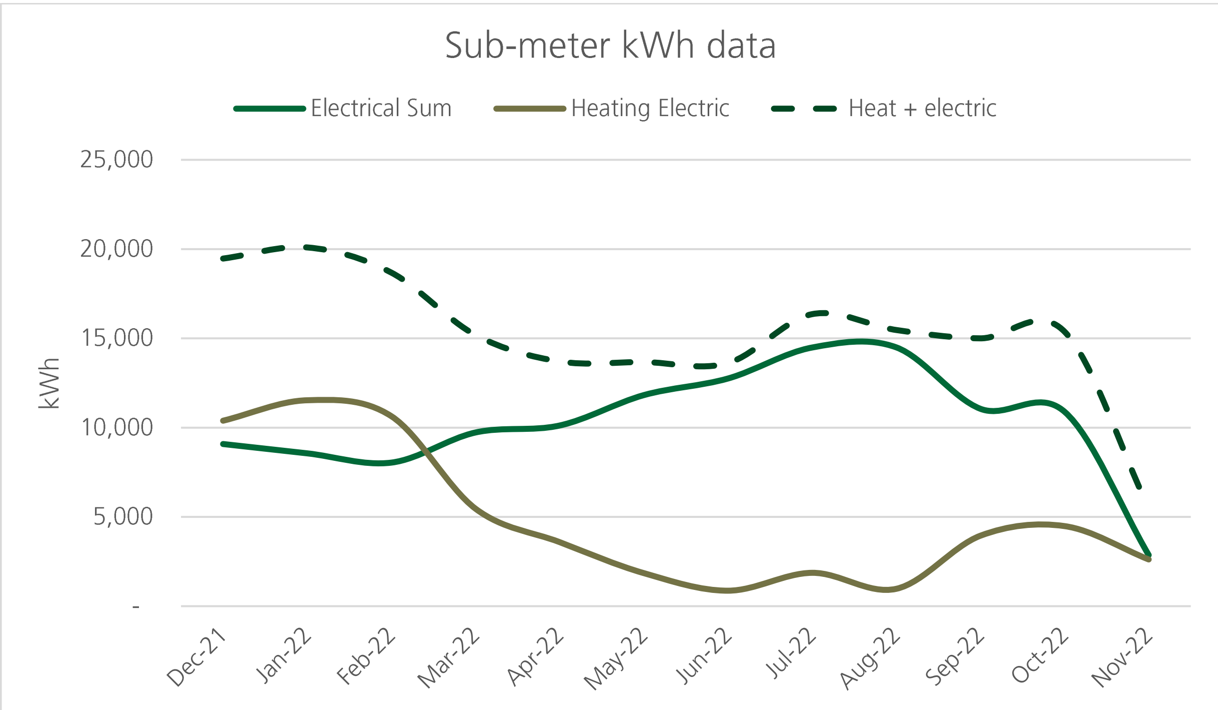

Figure 6 showing the load profiles of the data from table 2

Figure 7 below shows the energy audit's conclusions. In line with the results shown above, heating accounts for approximately 45% of energy use followed by various motor loads 38% and lights.

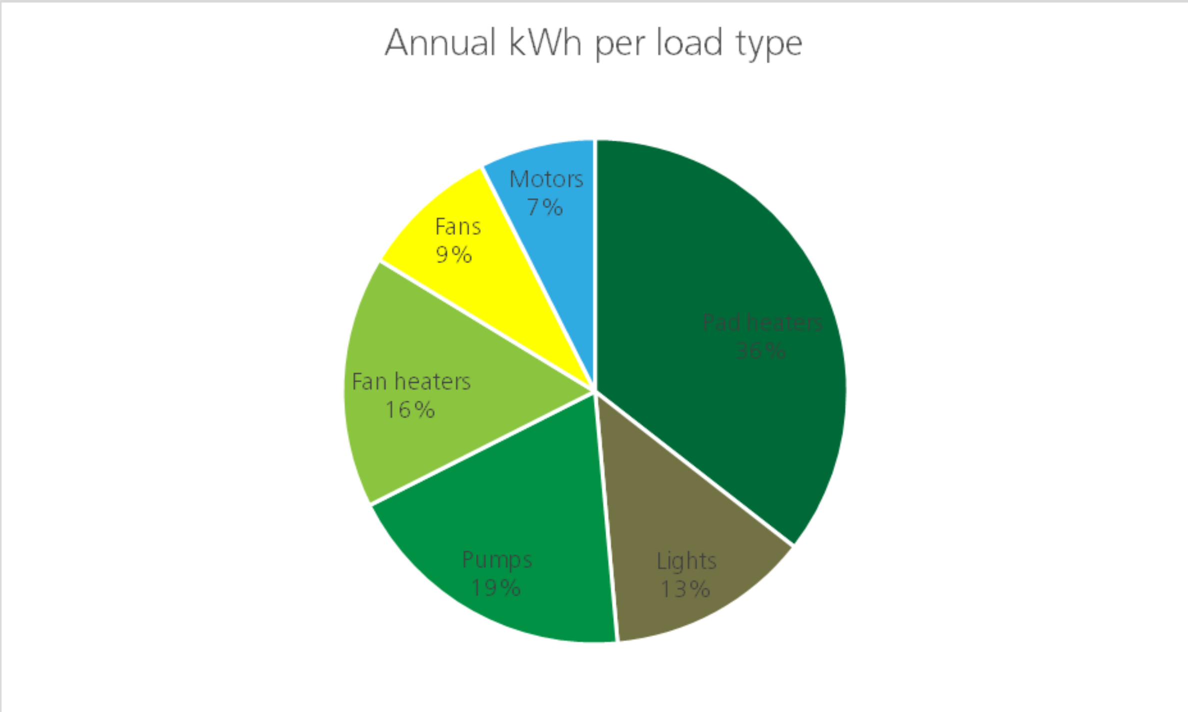

Figure 7 showing total energy use per load type

Energy Saving Measures

The energy and load data above suggest that heating and motor loads offer the best energy saving opportunities. This section examines these opportunities individually.

Variable Speed Drives

Bridge House uses variable speed drives (VSDs) on some of the pumps and feeding system motors. VSDs save energy exponentially as they adjust motor speeds to match variable loads like fans and pumps, see the Appendix for more information on VSDs.

Not all systems benefit from VSDs, we therefore recommend consulting reputable VSD installers for a system specific study like ventilation for instance.

Although not a significant energy cost compared to heating, table 4 below shows a range of possible savings from VSDs on the roof fans. Table 4 assumes 1.1kW per fan and the smallest combination of 4 fans for the 'Low' savings scenario and increasing to all the fan loads at approximately 60kW for the 'Maximum' load.

At £0.40 per kWh, £350 per installed VSD kW and savings of 20% to 45%, the savings range from 880kWh and £352 to 7,920kWh and £3,168 per annum with simple payback periods of 4.4 to 1.2 years respectively.

In addition to the energy savings, VSDs enable precise environmental control, which is very important in pig production. Instead of the on-off effect of direct-on-line starters, VSDs enable uniform climate control by slowing down and speeding up air movement to match the set points.

Also, in the case of extreme temperatures in summer, for limited times, VSDs' can run fans faster than their rated speeds and thus reduce the risk of heat stress.

Table 4 showing a range of savings from VSDs on ventilation fans

Ventilation savings using VSDs, running 1,000 hours pa.	Low	Medium	Maximum
Current kWh sum	4,400	16,600	17,600
Current kW sum	4.4	16.6	17.6
Cost at £0.40 per kWh	£1,760	£6,640	£7,040
Current carbon equivalent kg	851	3,210	3,403
20% savings			
kWh saved	880	3,320	3,520
Average kW saved	0.88	3.32	3.52
Saved at £0.40 per kWh	£352	£1,328	£1,408
Carbon equivalent saved kg	170	642	681
45% savings			
kWh saved	1,980	7,470	7,920
kW saved	1.98	7.47	7.92
Saved at £0.40 per kWh	£792	£2,988	£3,168
Carbon equivalent saved kg	383	1,445	1,532
Project viability			
VSD cost at £350.00 per kW	£1,540	£5,810	£6,160
Simple payback period years, 20.00% saving	4.4	4.4	4.4
Simple payback period years, 45.00% saving	1.9	1.9	1.9

NFU Energy, 10th Street, Stoneleigh Park,
Kenilworth, Warwickshire CV8 2LS

Heating

Table 6 below summarizes the measured electrical heating loads and the connected nameplate kW. The heaters ramp room temperatures down from 26ºC to 18ºC over 14 days as the new-born piglets grow and need less heat.

Four mobile 10kW electrical space heaters consume 58,500kWh and, 185x, 120W pad heaters consume approximately 128,760kWh of electricty per year, see figure 8 below. A number of 'back-up' 150W lamp heaters warm new-born piglets as needed, but do not significantly contribute to the total heating load.

Table 6 shows the heating energy use per year and name-plate load

	kWh	kW
Fan heaters	58,500	45.0
Pad heaters	128,760	22.2
	187,260	67.2

Figure 8 showing a mobile 10kW fan heater left & the red 120W heating pads in the farrowing rooms

System improvement

Saving energy through system improvement ranges from inexpensive changes in process and human behaviour like managing set points and regular maintenance to expensive system upgrades and retrofits.

Heat recovery

The current ceiling fans vent air directly into the atmosphere, see figure 9 below. This is an effective way to ventilate, however, while removing stale air, this system also loses heat. This study only examines heat recovery superficially because it implies expensive and currently unwanted reengineering of the current ventilation system.

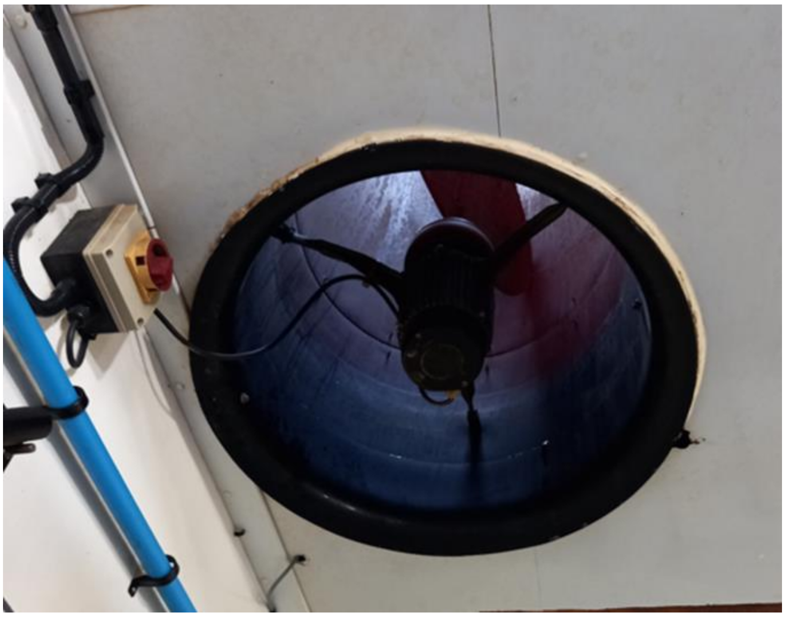

Figure 9 showing ceiling fans venting stale warm air directly to the atmosphere

Many air heat recovery systems exist; however, the cross-flow heat exchanger shown in figure 10 below not only recovers heat, but also enables advanced air filtration, an important sanity consideration with pig production.

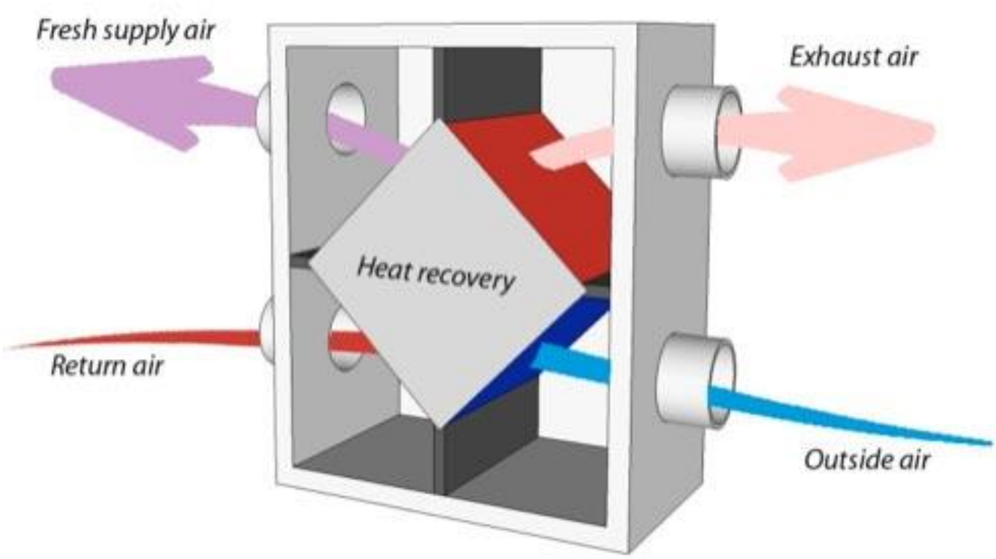

Figure 10 cross flow heat exchanger system

According to Grundfos (1), cross flow heat exchanger efficiency ranges from 40 – 65%. Assuming that such a heat exchanger recovers 40 – 60% of the total 187,260kWh heat load at Bridge House, table 7 below shows savings from 74,904kWh and £ 29,962 to 112,356kWh and £ 44,942 per annum respectively.

However, as mentioned above, heat recovery like this requires significant re-engineering of the ventilation system.

Table 7 showing a range of energy savings potential from a cross flow heat exchanger

Heat recovery system efficiency	40.0% efficiency	50.0% efficiency	60.0% efficiency
Saved per year, from 187,260kWh heat load	74,904 kWh	93,630 kWh	112,356 kWh
	£ 29,962	£ 37,452	£ 44,942

Fuel switching

Installing boilers to meet the farm's heating requirements is very likely to be expensive, however, their associated fuel costs are currently lower than electricty.

In general, biomass is the cheapest energy source at approximately £0.04 - £0.06 per kWh suggesting heating costs of approximately £12,000 to £14,000 per year, thus, using the fuel data in table 2 above, table 8 below compares the costs of electricty with propane, heating oil and red diesel.

Examining the energy only and assuming the 187,260kWh heat load and 75% boiler efficiency, propane, heating oil and red Diesel could cost £15,730, £18,227 and £16,729 per year respectively compared to electricity's £74,904.

Note that, besides boiler and heat distribution installation costs (pipes, valves, pumps), boilers require daily management, regular maintenance and permits above 1.0 megawatt of thermal capacity.

Table 8 comparing the theoretical heat load cost of electricity with propane. heating oil and red Diesel

Heat load fuel comparison	Propane	Heating oil	Red Diesel	Current electricty
Price per kWh	£ 0.063	£ 0.073	£ 0.067	£0.40
Price adjusted for 75% efficiency	£ 0.084	£ 0.097	£ 0.089	187,260 kWh
Cost	£15,730	£18,227	£16,729	£ 74,904

Solar thermal

Solar thermal is a good and often overlooked way to directly heat water. Currently solar thermal systems cost approximately £1,500 per installed kW, maintenance costs are relatively low, and they achieve temperatures of 60 to 80°C, see figure 12 below.

If relevant, install the biggest water vessel possible to store daytime solar thermal gains as this heat is essentially free. To guarantee constant hot water despite weather conditions, ensure that the system has a backup electrical element.

However, because of the night-time heat demand, we do not recommend a solar thermal system for the piggery unless it is carefully engineered. On the other hand, the staff showers and offices may benefit from a solar thermal assisted system.

NFU Energy, 10th Street, Stoneleigh Park,
Kenilworth, Warwickshire CV8 2LS

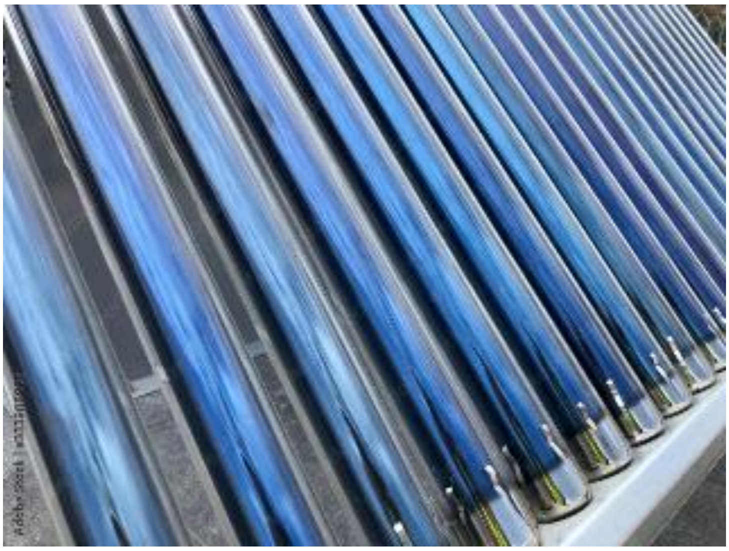

Figure 10 showing solar thermal evacuated tube system

Heat pumps

Heat pumps are nothing new. Air conditioners are heat pumps, however, instead of cooling a space like a room and blowing away the hot air, heat pumps capture the heat into a fluid like water or glycol, see figure 11 below.

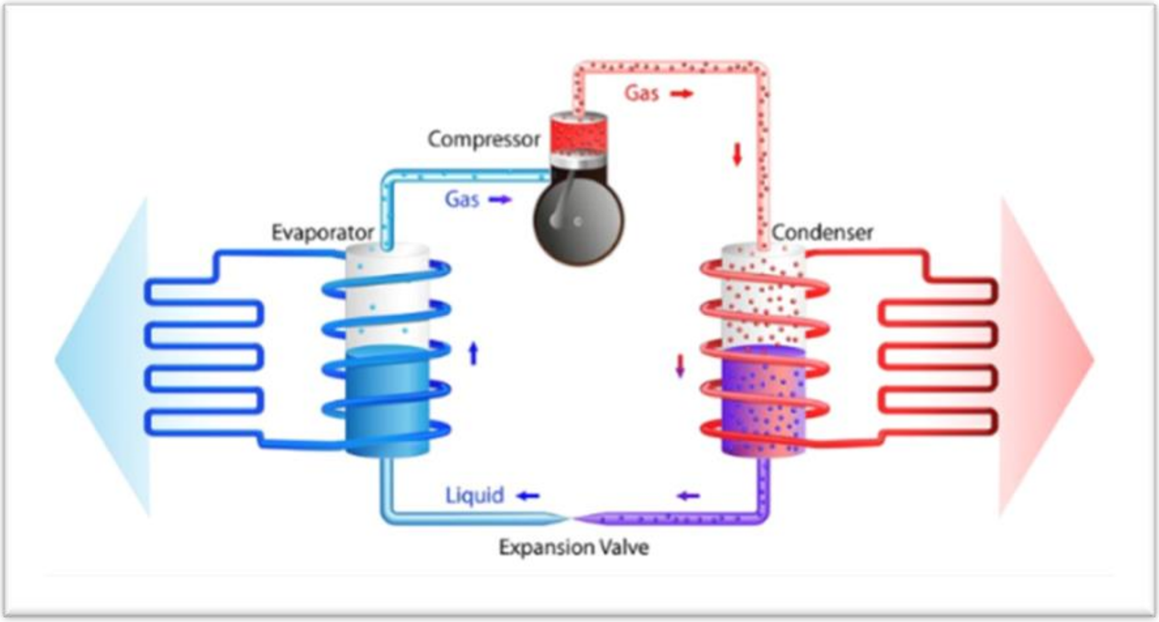

Figure 11 showing a schematic of how heat pumps work

As the name suggests, Heat Pumps absorb energy from an energy source like the air, the ground or from water and pump it to where it is needed. Figure 12 below thus shows how the energy source relates to the Heat Pump type, i.e., air, ground and water source Heat Pumps.

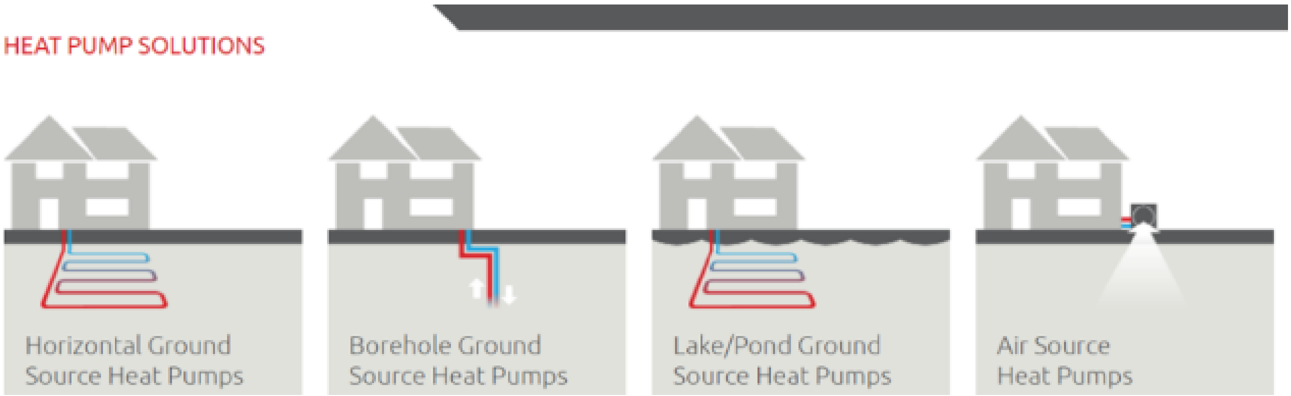

Figure 12 showing various permutations of ground, water and air source Heat Pumps (2)

Coefficient of performance of heat pumps

The co-efficient of performance (CoP) rates the efficacy of a heat pump, a CoP of 2.5 is normal, 3 is good and 4 is excellent. Suppliers claim CoPs of 5, 6 and even higher, however, this study uses 2.5 for air source, 3.0 for ground source and 4.0 for water source heat pumps. If correctly sized, most heat pumps achieve fluid temperatures of approximately 55ºC.

CoP is the ratio of thermal output power divided by the electrical input power. The refrigerant gas does the thermal work while the electrical compressor simply maintains the gas pressure.

Because the compressor needs less power to maintain gas pressure than the thermal work done by the gas, heat pumps use much less electricity than direct electrical heating systems like heating elements or infra-red lamps.

For example, if an air source heat pump produces 2.5kW of thermal work from a 1.0kW electrical compressor, the CoP is 2.5kW / 1.0kW = 2.5.

Borehole water energy resource

Bridge House requested an analysis of the energy potential of the 70,000 litres of borehole water used per day by the pig unit.

According to Bridge House, borehole water temperatures ranges from 12 to 15ºC. Table 8 below shows the thermal potential of this water assuming when reduced to 4ºC.

Assuming a heat pump absorbs this energy and that it is stored or used immediately, the heat pump's cold-water output can cool air through a fan coil, and/or flush pig slurry. It has been shown that low-temperature flush water reduces pig slurry temperature which in turn reduces odours and slurry volatiles.

Table 8 below thus shows that 70m^3 of the above-specified water has from 326,799 to 237,672 kWh of thermal potential.

Table 8 showing the energy potential of 70m³ of water between 15 and 12 degrees C

Thermal capacity from 70m³ water per day

Water temperature 15°C	Water temperature 12°C	
70,000	70,000	kg water per day
25,550,000	25,550,000	kg water per year
4.19	4.19	kJ/kg.K
4.0	4.0	t2 assumed
15.0	12.0	t1 assumed
1,176,475,300	855,618,400	kJ thermal
326,799	237,672	kWh thermal

Heat pump potential

Accepting that unassisted heat pumps produce water at approximately 55°C, table 9 below compares the existing heat load with heat pumps operating at a CoP of 2.5, 3 and 4.

At these CoPs, the current electrical systems use 187,260kWh while an equivalent heat pump will respectively use approximately 75,000 kWh, 63,000kWh and 48,000kWh, saving approximately £45,000, £50,000 and £56,000 per year.

Table 9 shows a range of high-level heat pump project possibilities

Existing per year	kWh	kW	Cost at £0.40 per kWh	Saved	% saved
Fan heaters	58,500	45.0			
Pad heaters	128,760	22.2			
Sum	187,260	67.2	£ 74,904	£-	
Proposed per year					
kWh_e at COP 2.50	74,904	26.9	£ 29,962	£ 44,942	60.0%
kWh_e at COP 3.00	62,420	22.4	£ 24,968	£ 49,936	66.7%
kWh_e at COP 4.00	46,815	16.8	£ 18,726	£ 56,178	75.0%

Assuming heat pumps cost £2,000 per kW, a slightly oversized heat pump of 30 input kW may cost £60,000, thus yielding a simple payback period of 1.3 to 1.1 years.

Heat pump design considerations

Because the borehole water is further utilized on the farm for flushing and drinking, the heat pump's water source must be an open loop. We suggest suitably designed tube-in-shell (see figure 13 below) or plate heat exchangers to achieve this.

Note, these data assume a linear relationship between heat demand and water supply. However, if heat demand and farm water demand do not match, it may be necessary to store supply water, hot water or both to ensure heat on demand.

NFU Energy, 10th Street, Stoneleigh Park,
Kenilworth, Warwickshire CV8 2LS

We also recommend installing a separate heat pump as close to the heat demand as possible. This will enhance:

- flexibility: multiple heat pumps can provide different temperature set points, for example, the farrowing rooms need different temperatures to the growing rooms.
- Redundancy: if correctly designed, multiple heat pumps can provide heat if one of them fails.
- Efficiency: less heat is lost from pipes and valves when the heat source is close to the heat demand and, it's possible to switch individual heat pumps off when their heat is not needed.

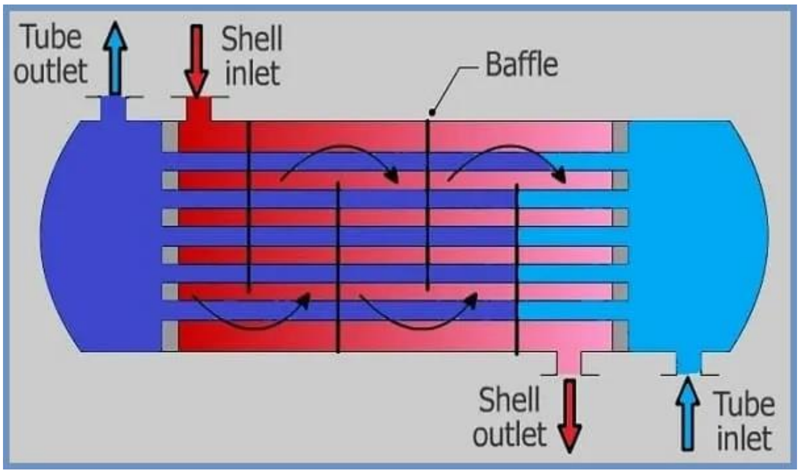

Figure 13 showing a shell in tube heat exchanger, source (3)

Hot water heating pads and fan coils can distribute the heating and cooling as required, see figure 14 below.

Figure 14 showing a typical fan coil system, source (4)

NFU Energy, 10th Street, Stoneleigh Park,
Kenilworth, Warwickshire CV8 2LS

Renewables

We recommend first investing in energy efficiency before installing renewable energy. Installing expensive renewables to drive losses is irrational. For example, by saving 1kW of load through energy efficiency, the farm avoids buying 1kW of renewable energy generation.

Anaerobic digestion

Although anaerobic digestion (AD) of pig slurry produces biogas and the current UK work on micro AD is encouraging, we do not have enough in situ UK data to recommend it with confidence.

However:

- studies show that expanded granular sludge bed (EGSB) reactors and fixed-bed (FB) AD reactors perform well compared to conventionally driven CSTRs, with the EGSB reactor offering a higher methane yield and production rate at a shorter HRT for pig slurry, source (5).
- Adding additional substrates to pig slurry improves biogas yield, however, avoid excessively lignin-based substrates like straw, source (6).
- Ricardo (7), however, states that due to its high moisture content and nitrogen load, pig slurry does not present a good business case for commercial biogas production.
- Table 9 shows that although pig slurry can produce biogas, it is one of the lowest yielding biogas sources (8).

From these extracts, it is clear that micro AD requires further study, which is outside the scope of this report.

Table 9 showing generic biogas yields for a range of wastes

	Cattle manure	**Dairy cattle slurry**	**Beef cattle slurry**	**Pig slurry**	**Poultry/layers**	**Poultry broilers**	**Sugar beet waste**	**Wheat silage**	**Maize silage**	**Grass silage**	**Vegetables**	**C&I^{1} food wastes**	**Household food waste**	**Garden waste**
Dry Matter (%)	25	9	9	5	30	65	18	38	30	21	20	23	23	35
Biogas (m^3/t fresh weight)	45	22	22	26	110	239	81	193	148	111	101	104	104	151

Solar and wind

This study examines solar photovoltaic power (PV) and wind turbine generation. The study modelled these results from proprietary NFU Energy systems, RETScreen Expert (9), PVSOL (10) and PVGIS (11).

Rather than prescribing specific systems, this section presents a range of project possibilities to enable management's decision-making processes.

Please note, before investing further resources into renewable projects, a) where relevant, consult the local council about planning permission, b) ask the district network operator (DNO) for their requirements and c) install a wind mast to measure the site-specific wind resources.

Figure 15 below from RETScreen shows the wind and solar energy resources at Bridge House. Figure 5 shows that a) solar performs well in summer and poorly in winter, b) wind is a consistent energy source and c) combining these energy sources is very likely to significantly contribute to Bridge House's energy needs.

NFU Energy, 10th Street, Stoneleigh Park,
Kenilworth, Warwickshire CV8 2LS

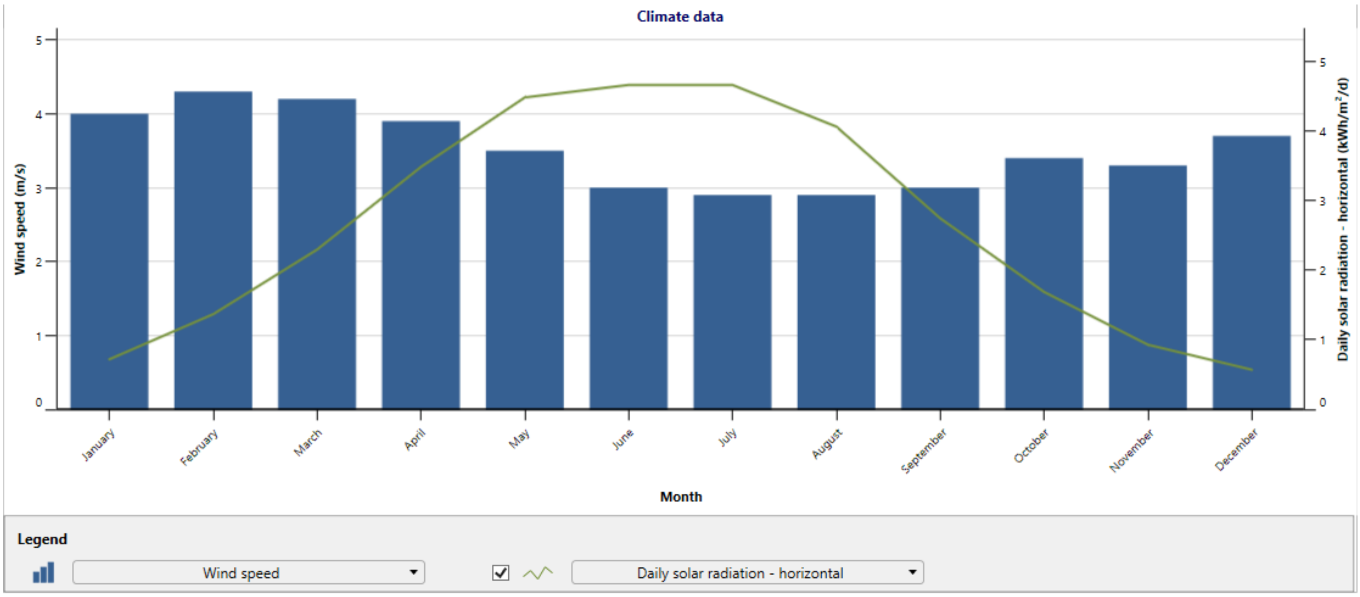

Figure 15 showing solar and wind resources at Bridge House

Project Assumptions

These are the most significant technical and economic project assumptions:

- the PV project's Internal Rate of Return (IRR) is based on a 25-year life cycle, the batteries on 10 years while the wind turbines are based on a 20-year life cycle.
- The discount rate is 9% and inflation is 4%.
- Based on current market norms, PV costs assumed at £1,200 per kW, batteries £850 per kW and wind turbines £4,000 per kW.
- The transformer and current load determine the size range of the proposed generators and batteries.

Photo Voltaic Power

Tables 10 and 11 below show a range of PV project potentials in the geographic area of Bridge House.

Due to Bridge House's "flat" load profile through the year, all the PV projects below show excellent potential. The only limiting factors are budget and space.

Unless a lucrative power purchase agreement incentivises exporting energy, the aim of self-generation projects is to use all the self-generated energy because it avoids importing energy, in this case, at a cost of £0.40 per kWh.

This is achieved by a) sizing the generator to minimize export energy and/or b) storing the energy as electricity or heat/cooling etc., for later use.

- Where investment capital is available, the 200kW with battery project is likely to yield the best long-term solution as it meets many of the criterion mentioned above.
- In terms of export energy, the 30kW PV only project exports almost no energy, it shows the best IRR of 38.32% with a simple payback period of 2.9 years.
- The least attractive prospect is the 150kW PV with battery project as it is more expensive while yielding the same per year cost saving as the 200kW PV only project.

Table 10 showing the potential of a range of PV project sizes

PV systems only						
Grid Feed-in in the first year (incl. module degradation)	1	179	11,636	39,789	76,702	kWh/Year
PV Generator Output	31	50	100	150	200	kWp
Economic Parameters						
Internal Rate of Return (IRR)	38.32	38.23	35.31	31.41	28.27	%
Accrued Cash Flow (Cash Balance)	£452,829	£727,658	£1,309,549	£1,675,646	£1,928,553	£
Amortization Period	2.9	2.9	3.1	3.5	3.9	Years
Electricity Production Costs	0.0506	0.0506	0.0506	0.0506	0.0506	£/kWh
Payment Overview						
Investment Costs	**£37,230**	**£60,006**	**£120,012**	**£180,018**	**£240,024**	**£**
Remuneration and Savings						
Total Payment from Utility in First Year at £0.10 per kWh	£0	£18	£1,164	£3,979	£7,670	£/Year
First year savings at £0.40 per kWh	**£12,899**	**£20,722**	**£36,932**	**£46,464**	**£52,492**	**£/Year**
Savings plus payment from utility	£12,899	£20,740	£38,096	£50,443	£60,163	£/Year

Table 11 showing PV project potential with batteries

PV systems with 180kW, 447kWh battery			
Grid Feed-in in the first year (incl. module degradation)	669	12,495	kWh/Year
PV Generator Output	150	200	kWp
Economic Parameters			
Internal Rate of Return (IRR)	20.35	22.13	%
Accrued Cash Flow (Cash Balance)	£1,762,050	£2,319,106	£
Amortization Period	5.2	4.9	Years
Electricity Production Costs	0.1679	0.1386	£/kWh
Payment Overview			
Investment Costs	**£333,018**	**£393,024**	**£**
PV	£180,018	£240,024	£
Battery 180kW, 447kWh	£153,000	£153,000	£
Remuneration and Savings			
Total Payment from Utility in First Year at £0.10 per kWh	£ 67	£1,249	£/Year
First year savings at £0.40 per kWh	**£ 60,811**	**£ 76,346**	**£/Year**
Savings plus payment from utility	£ 60,877	£ 77,595	£/Year

Wind power

Table 12 below shows the potential of a range of 150kW, 100kW and 50kW wind turbine projects. The turbines in table 12 do not represent all turbines of their just those listed; other turbines are likely to yield different results.

- The 150kW turbine yields the best performance. It will cost approximately £600,000 to install and save approximately £99,600 and 249,153kWh (i.e., 56% of the pig unit's energy use) per annum.
- The 100kW turbine shows the worst results with a negative NPV and poor energy yield compared to the 50kW project, however, this may be a function of the turbine itself and not necessarily other 100kW turbines.

- The wind turbines shown below do not compare well with the PV projects above in terms of cost and annual savings. The turbines however are more reliable as they generate electricty for approximately 23.4% of the time at peak, whereas the PV projects generate electricty for 9.9% of the time at peak capacity.

Table 12 below summarizes a range of wind turbine projects

	Turbine 1	**Turbine 2**	**Turbine 3**
Annual load 445,372 kWh	**Nordex_30m_150kW**	**WindEnSolut_31m_100kW**	**AtlanticOrient_25m_50kW**
Generated	397,933 kWh	100,209 kWh	69,560 kWh
Exported	148,780 kWh	6,701 kWh	838 kWh
Imported	196,219 kWh	351,863 kWh	376,650 kWh
Used/saved	249,153 kWh	93,508 kWh	68,722 kWh
Saved at £0.40 per kWh	£ 99,661	£ 37,403	£ 27,489
Sold at £0.10 per kWh	£ 14,878	£670	£ 84
Cost at £0.40 per kWh	£ 78,488	£140,745	£ 150,660

Net Present Value (NPV)	£ 540,861	-£ 17,486	£ 61,749
Internal rate of Return (IRR)	18.5%	8.5%	12.5%
Simple Payback Period (SPP)	6.41	12.74	9.31
Levelized Cost Of Energy (LCOE)*	£0.17	£ 0.34	£ 0.31

*LCOE is the total lifecycle project costs divided by total lifecycle energy generated, discounted to present value. i.o.w., the flat rate of a kWh for the lifetime of the project.

Turbine placement and size

The government recently relaxed the rules for inland wind turbine planning permission. However, site selection in technical terms is important to project success and is best examined together with reputable installers.

The following rules of thumb can assist you to identify possible sites.

- Install a wind mast to measure the real wind potential.
- Determine the prevailing wind and place turbines upwind of obstacles like buildings and trees.
    - Place the turbine at least 2 x the height of these obstacles.
- Downwind wind turbulence exists within 20 x the height of obstacles, see figure 16 below.
- Depending on turbine height and land slope, site turbines at a distance of at least 6 - 10 times the height of the nearest obstacles, preferably further, see figure 8 below.
- The lowest point of the turbine blade must be at least 10 metres above the height of the nearest obstacle.
- Account for space to install underground or overhead cables to reticulate electricity from the turbine to the load.

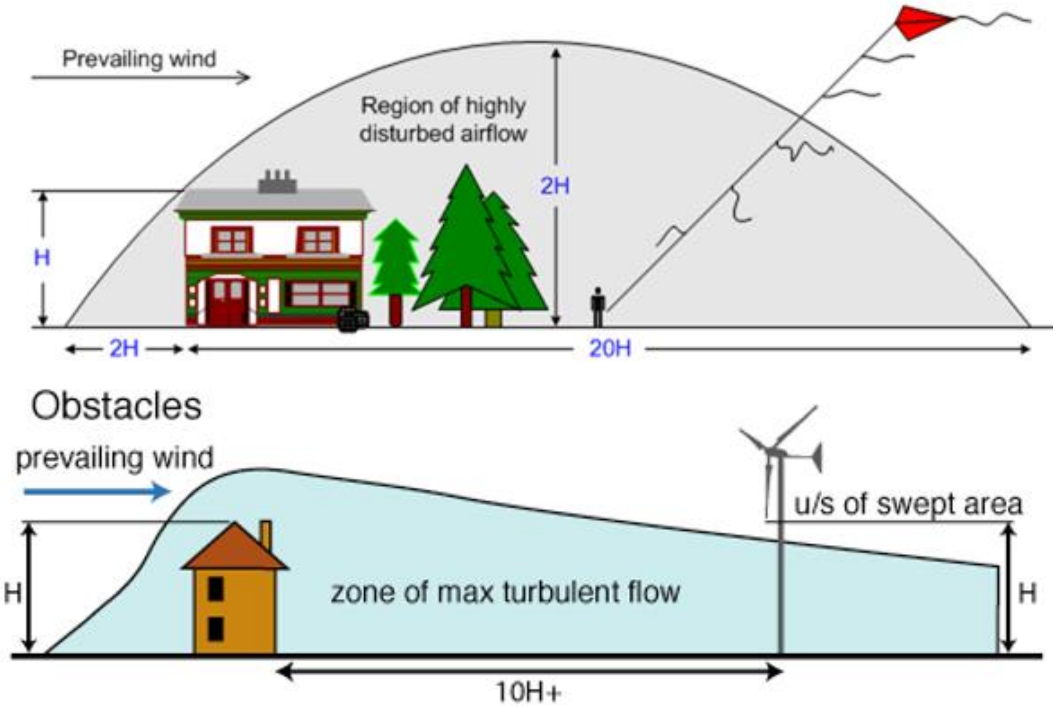

Figure 16 showing how obstacles affect wind turbulence, source (10) (11)

Other Considerations

Wind turbine site selection may need adjusting or may even be refused depending on:

1. Aviation limits like flight paths, radar, and air communications.
2. Designated areas like:
    - Sites of Special Scientific Interest (SSSI)
    - Special Areas of Conservation (SAC)
    - Special Protection Areas (SPA)
    - Radar Site
    - Flood Risk Areas
    - National Character Landscape Features
3. Site Buffers
    - Generally, wind turbines may not be within 1.5x the turbine tip height of electricity pylons, roads, railways, water courses, and site boundaries.

For interest's sake, Figure 17 below shows typical heights of standard wind turbines. For example, a 100kW wind turbine is approximately twice the height of a standard wooden overhead electricity pole.

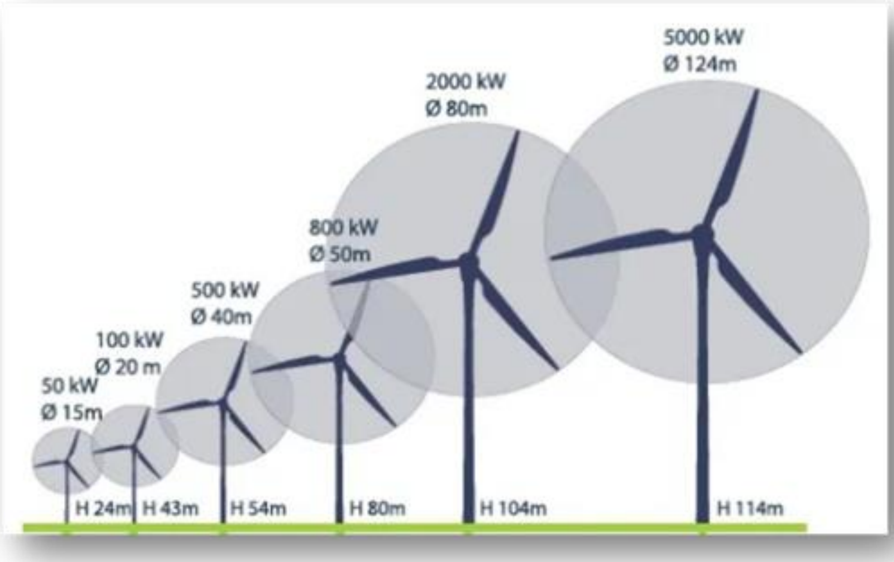

Figure 17 Showing relative height of wind turbines, source (12)

Conclusion

Bridge House consumes approximately 480,000kWh of electricty per year and self generates approximately 34,000kWh of solar energy per year.

- VSDs can save from 880kWh and £352 to 7,920kWh and £3,168 per annum with simple payback periods of 4.4 to 1.2 years.
- With major reengineering, heat recovery can save from 74,904kWh and £ 29,962 to 112,356kWh and £ 44,942 per annum.
- 75% efficient propane, heating oil and red Diesel boilers can reduce the current electricity's heating cost of £74,904 to £15,730, £18,227 and £16,729 per year.
- 70m^3 per day of bore hole water has from 326,799kWh to 237,672 kWh of thermal potential.
- At a coefficient of performance (CoP) of 2.5 for air source, 3 for ground source and 4 for a water source, heat pumps will use respectively 75,000 kWh, 63,000kWh and 48,000kWh, compared to the current 187,260kWh thus saving approximately £45,000, £50,000 and £56,000 per year.
- All the modelled PV projects yield excellent feasibility results.
- The 150kW PV with batteries project performed the worst, the 200kW with batteries performed the best and the 30kW PV only project exported no energy with the best IRR of 38.2%.
- The wind turbine project models also showed good but expensive results compared to PV.

References

1. **https://www.grundfos.com/uk/learn/research-and-insights/cross-flow-heat-exchanger#:~:text=A%20traditional%20cross%2Dflow%20heat, up%20to%2075%2D85%20%25.** [Online]

2. **https://hexenergy.co.uk/.** [Online]

3. **https://civilmint.com/shell-and-tube-heat-exchanger/.** [Online]

4. **https://www.carrier.com/commercial/en/ae/products/marine/fan-coil-units/42d/.** [Online]

5. **https://www.mdpi.com/1996-1073/15/12/4414.** [Online]

6. **https://biotechnologyforbiofuels.biomedcentral.com/articles/10.1186/s13068-017-0922-x.** [Online]

7. **https://www.climatexchange.org.uk/media/2977/farmyard-manure-and-slurry.pdf.** [Online]

8. —. [Online]

9. **https://www.nrcan.gc.ca/maps-tools-and-publications/tools/modelling-tools/retscreen/7465.** [Online]

10. **https://www.solacity.com/small-wind-turbine-site-selection/.** [Online]

11. **https://www.energymyway.co.uk/news/do-small-scale-wind-turbines-work/.** [Online]

12. **https://sustainablebuildingdesign.wordpress.com/2014/12/11/the-power-of-wind/.**

13. **gozuk.com/applications/vfd-for-pumps.html.** [Online]

NFU Energy, 10th Street, Stoneleigh Park,
Kenilworth, Warwickshire CV8 2LS

Appendix

Variable Speed Drives (VSD)

Most farms run pumps, fans and vacuum pumps at constant speed. When valves open and close or clusters detach from cows etc, the affected system's demand or flow rate changes. When the flow decreases, the motor does less work and uses less power. For example, the broken line on figure 18 below shows how power (Y axis) changes as flow changes (X axis) at constant speed, so, if the flow rate dropped to say 50%, the graph shows that the power drops to about 87 – 88% of the full power, thus saving about 12%.

However, by changing the speed of the motor to change the flow rate yields a much better saving, in fact, based on the engineering affinity law: $\frac{P1}{P2} = \left(\frac{N1}{N2}\right)^3$, the saving becomes exponential, (P = power and N = speed).

The solid blue line in figure 18 below shows this exponential saving. Using the same example above, by changing the flow rate to 50% by slowing the motor down, the power drops to about 22 – 25% of full load, thus saving about 75%.

VSDs change motor speed. VSDs are also known as Inverters or Variable Frequency Drives. Note, Soft Starters are not the same as VSDs and do not save energy like VSDs.

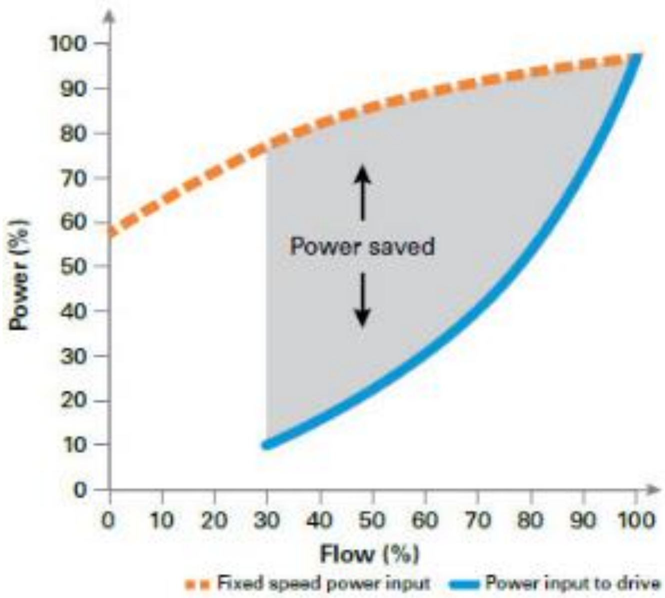

Figure 18 Variable Frequency Drive (VFD) for Pumps Source: (13)

VSDs not only save energy, but they also improve system performance, reduce maintenance costs and enable precise automation. The VSD unit replaces the conventional direct online, star delta and soft starter.

Caveat

VSDs currently cost approximately from £120 - £450 per kW installed, they must be commissioned, they may need transducers to control set points and they generate electrical harmonics that may affect sensitive electronics.

- We therefore advise installing VSDs with built-in harmonic filters and capacitors sourced from reputable suppliers.
- Not all systems benefit from VSDs, and the savings vary per application. We therefore recommend contracting reputable suppliers to analyse the target system before installing VSDs.

NFU ENERGY

www.nfuenergy.co.uk

Phone: **024 7669 6512** | Email: **info@nfuenergy.co.uk**