Cooling pig slurry to reduce gaseous emissions

Contents

This report introduces the use of slurry cooling and associated heat recovery in the reduction of ammonia emissions from stored pig slurry.

When combined with the heating of pig accommodation on a fully integrated farm, the use of slurry cooling to reduce emissions offers an attractive option for consideration when expanding a unit, meeting compliance targets and reducing energy costs.

Cooling reduces ammonia emissions and energy used for ventilation, while heating with renewables reduces heating costs and attracts the Government's Renewable Heat Incentive (RHI).[1]

The information in this booklet was compiled by Reading Agricultural Consultants.

Background to slurry cooling

As regulation has evolved to reduce risks to the environment and human and animal health, the pressures on the pig industry to reduce emissions of ammonia and odour from slurry have increased.

The most significant source of ammonia in pig production is the breakdown of urea, which is excreted in urine, by the enzyme urease, which is present in faeces, into ammonia and carbon dioxide. The factors that influence this process are the concentration of urea in urine, pH and slurry temperature. Volatilisation of ammonia is influenced by ambient ammonia concentration, air speed and ammonia/dry matter contents of slurry. All these factors can be used to reduce ammonia emissions; slurry cooling reduces emissions at source.

Reductions in ammonia emissions using Best Available Techniques (BAT) can be used, to:

- Increase pig numbers on an existing site
- Obtain an environmental permit
- Support a planning application

Cooling slurry in storage effectively reduces emissions, and the heat extracted can be used to heat livestock housing, so reducing the use of conventional heat sources such as gas and oil. The system uses established heat pump technology to transfer the heat from one site to another, and qualifies under the Government's RHI for quarterly payments over 20 years, based on the amount of heat generated.

The technique has been developed from previous BAT to suppress ammonia emissions that involved cooling the surface of slurry in underfloor stores to 12°C or less, by pumping cold water through a heat exchange system. Cooling together with heat recovery was identified as BAT in the 2017 Reference Document for the Intensive Rearing of Poultry or Pigs,[(2)] having been developed and successfully used in Finland since 2004, and on more than 300 farms in Denmark. Successful installations can also be found in the Netherlands, elsewhere in the Baltic area, North America and China.

Slurry cooling is not classed as BAT when it is not possible to reuse heat. Nor can the system be used in bedded or part-bedded housing systems in which crusts and bottom deposits are likely to reduce system performance.

Cooling is also not effective for large volumes of slurry, so it has to be installed in housing systems where slurry is removed frequently. Retrofitting is only possible in systems where the cooling pipes can be placed above the concrete floor, which may result in a loss of effective storage capacity.

Heat pumps work on the same principle as refrigerators, making use of small temperature differences that transfer a small amount of heat energy from one place to another. Heat pumps are commonly used to heat buildings, but they can be reversed and used for cooling. This technique makes use of both ends of the process, first to cool slurry and then to heat water.

Some European installers anticipate that the cost of an installation can be recouped from savings in energy costs in less than five years. This estimate appears to take into account some subsidies and low-cost loans, but does not take into account RHI payments.

How it works

Heat pump technology

Heat pumps move thermal energy against the thermal gradient using the same principles as the refrigeration cycle. The amount of energy consumed to produce this effect is about 1 kWh of electrical energy for every 2.5–4 kWh of heat recovered. The general rule for application is that any area to be heated is half that of the area from which the heat is harvested.

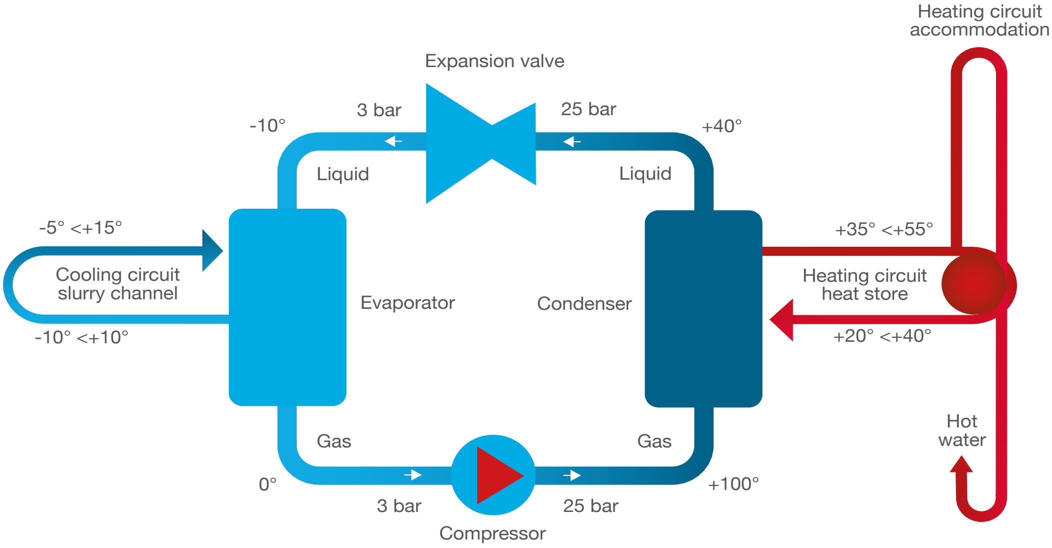

Figure 1. Recovering heat from slurry and generating hot water using a heat pump

Figure 1 shows the principles behind a system designed to cool slurry and heat water using a heat pump. Low temperature water between 10°C and -10°C is pumped around a closed-loop cooling circuit on the left of the diagram, returning to an evaporator at between -5°C and -15°C. Here, about 5°C of heat is used to raise the temperature of a liquid refrigerant (contained at about -10°C and a pressure of about 3 bar) circulating around the heat pump to boiling point (0°), causing it to evaporate. The precise temperatures differ with the type of refrigerant used and the specific applications.

The higher-temperature gas is then compressed, which, with an increase in pressure from 3–25 bar, also increases gas temperature from 0–100°C.

The high-pressure gas is then passed through a condenser, where it is cooled to about 40°C by transferring heat to water moving around the heating circuit; at this point, the refrigerant returns to its liquid state. The pressurised refrigerant is then passed on through an expansion valve, where its pressure and temperature are reduced to about 3 bar and -10°C, respectively, and it is returned to the evaporator.

The heating circuit can either be used directly to heat livestock accommodation or to supply a heat store, which can be used to supply hot water for heating, washing down or domestic use.

Slurry cooling

Cooling slurry reduces the ammonia emissions. Most frequently, the cooling circuit is installed in or on the floor of under-slat or other relatively long-term slurry storage. It can also be installed in the floor of slurry channels where movement is likely to disturb pipes fixed to the floor. Pipes of 18 mm Low Density Polyethylene (LDPE) are cast into or fixed to the floor at 350–400 mm spacing (Figure 2), plumbed in parallel, to reduce differential cooling caused by 'slinky' type (Figure 3) and other systems that operate in series. 'Slinky' networks are commonly used in ground and water source heat installations where accurate cooling is not an issue.

Figure 2. Parallel plumbed pipe network

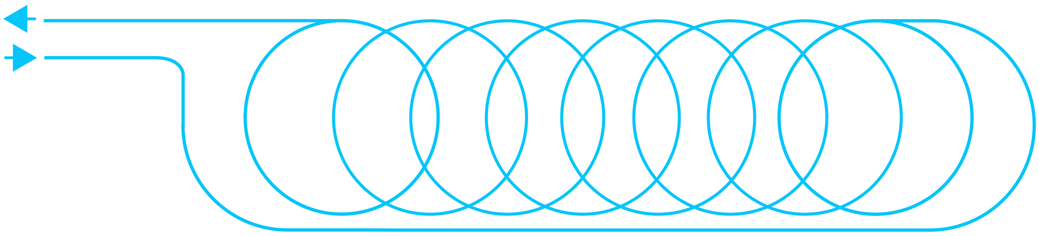

Figure 3. 'Slinky' pipe network

Glycol or other forms of antifreeze can be added to the contents of the closed cooling loop to cool slurry to temperatures approximately or less than 0°C. Extreme cooling has been found to reduce the efficiency of the heat pump, and BAT recommends that systems are designed to cool the slurry to about 5°C.

Cooling water can also be passed through a floating heat exchanger, where arrays of plastic or metal fins are used. The fins are filled with cold water and placed in the pit to float over the slurry. In each manure channel, fins are connected to one another in series, and in parallel between manure channels, for a uniform cooling effect in all cooling elements over the whole slurry surface.

Cooling zones can be plumbed separately and in parallel, and controlled by manual or solenoid valves so cooling can be targeted to areas where it is likely to be most effective. The water in the cooling circuit can be treated with antifreeze so the system can be operated at sub-zero temperatures, although extreme cooling regimes reduce the overall efficiency of the system.

Figure 4. Cooling pipes laid out, wired to reinforcing mesh

Figure 5. Cooling pipes buried under cellar floor

Figure 6. Finished room with under-slat cooling and heated lying areas
Image courtesy of AgriFarm Group

The benefits of the cooling system are:

- Reduced ammonia emissions
- Aids compliance with environmental permit limits
- Reduces energy consumption running cooling fans
- Maintains good air quality in housing

Heat recovery and use

Heat from the condenser element of the heat pump is relatively low-grade, in the form of hot water, normally at between 35–50°C; this is about the temperature of return water to a domestic gas boiler. Moving heat in this form over any distance is expensive, requiring relatively large volumes of water to be moved through insulated pipework to achieve any significant benefit. This means that heat should be used close to the source.

Low-grade heat can be accumulated in heat stores similar to those used in domestic situations. Stored heat can then be used to preheat high temperature water supplies, such as domestic or radiator heating, or used directly in underfloor heating systems. Underfloor systems will mainly be in new-build installations where heating pipes can be cast into floors under farrowing accommodation.

Stored heat gained from cooling slurry during the day can be used to heat farrowing and weaner housing at night in some weather conditions, with the thermal mass of the concrete floor used to minimise temperature variation through the day.

Pipe installations are similar to those seen in Figure 2, which provide more even heating of the floor than a 'slinky' installation, which is best-suited to large area ground source heat applications. Systems can be zoned to limit heating to areas of need, although RHI payments are made only on heat used, not heat harvested.

Figure 7. Heating pipes embedded in solid floor lying area over ventilation duct
Image courtesy of AgriFarm Group

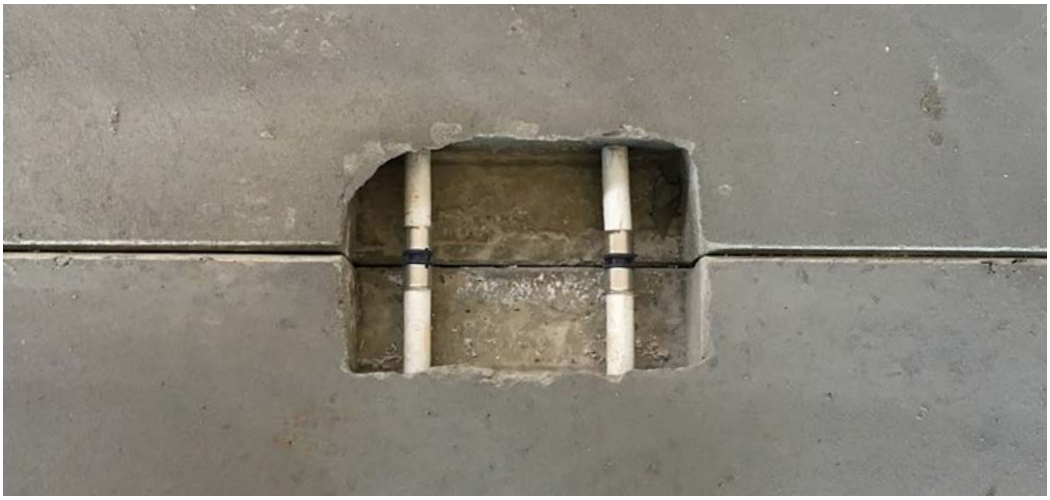

Figure 8. Heating pipes embedded in solid floor; jointing

As bacteria naturally occur in many water systems, where water may be accessed by livestock, care should be taken to manage water temperature in storage to control risk of infection. Most bacteria will not multiply below 20°C, but will thrive between 20–40°C. Generally, bacteria of concern will die at sustained temperatures greater than 60°C.

Cooling benefits

The primary benefit delivered by this element of the system is a reduction in ammonia emissions. Testing on fattening units in Denmark showed that the rate of ammonia emission was reduced by 10% for every 10 W/m^2 cooling achieved.[3] The same researchers recommend a maximum cooling rate of 20 W/m^2 on slatted floor systems to prevent the floor becoming too cold for fattening pigs; greater cooling rates may be appropriate on partially slatted floor systems.

Tables 1 and 2 set out some of the costs and performance calculated from experimental units.

Table 1. Ammonia reductions from cooling and heat produced: fattening pigs

Cooling effect (kWh/m^2)	Power consumption (kWh/t manure ex-animal)	Heat produced (kWh/t manure ex-animal)	NH^3 Reduction (%)	References/comments
10	10.9	32.6	9.6	Hansen et al.[4] Danish EPA BAT Sheet (2011)
20	21.8	65.2	18.4	Hansen et al.[3] Danish EPA BAT Sheet (2011)
24			31	Sows Only – Danish EPA BAT Sheet (2011)
30	32.6	97.9	26.4	Hansen et al.[3] Danish EPA BAT Sheet (2011)
55	60	180	51	Jørgensen et al., (2013)[5]
Not Stated	11.2	33.6	Not Stated	Takala (2013)[6] from Pellon Group Oy, Finland. 1,000-place Fattening Unit. Energy demand is a third of energy produced.

Table 2 shows the significant variation in cost per pig place under slatted housing. The variation is generally related to the floor area of the slurry storage. The cost of cooling relates to the depth and volume of underfloor storage.

Table 2. Cooling power consumption and cooling effect on partly slatted housing systems

Pen design	Cooling area per pig place	kWh/animal place per year		
	m^2	10 W/m^2	20 W/m^2	30 W/m^2
25–49% Solid Floor	0.47	21	42	63
50–75% Solid Floor	0.23	11	21	32

Slurry temperature also plays an important part in odour emission, affecting the concentration and characteristics of odour emissions from slurry. A 10°C reduction in slurry temperature has been shown to reduce odour emissions by as much as 75% (Figure 9).[7]

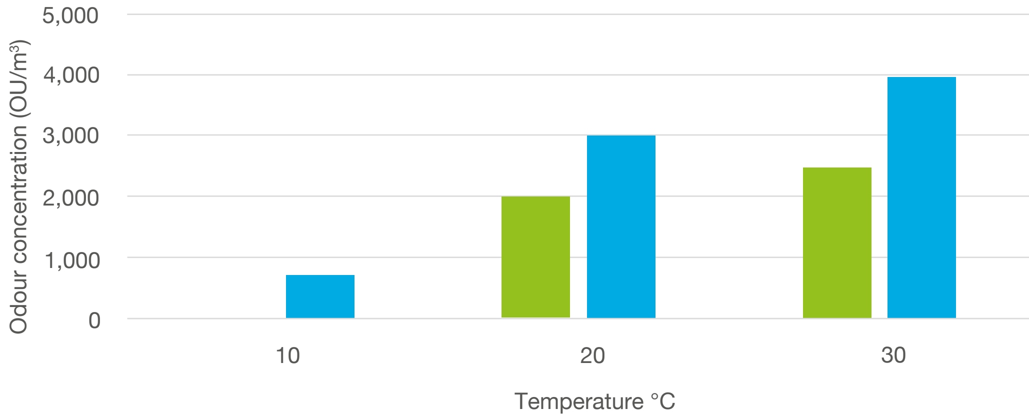

Figure 9. Slurry temperature and odour emission in cow and pig housing

Heating benefits

Compared with the classic heating applied in weaner houses (average consumption of 9 kWh/piglet per year) underfloor heating has significant benefits, both in terms of economy and accurate delivery of heat in the area of need.

The Carbon Trust's energy consumption guide for pig farming[8] estimates that about a third of energy used on pig breeding units is for creep heating. Benchmark energy use for the three main means of creep heating shows the savings that can be made using underfloor heating (Table 3).

Table 3. Benchmark energy use in creep systems

	Open creep electric/gas radiant		Boxed creep electric radiant		Underfloor	
	Typical	Good Practice	Typical	Good Practice	Typical	Good Practice
Average annual energy use (kWh/pig)	8.4	5.0	6.0	4.0	5.0	3.0

Combining the costs saved by underfloor heating in comparison with more traditional heating systems, the advantages associated with the use of heat pump technology reduces uncertainty regarding future energy costs and can provide a secure additional source of income through the design life of the installation.

Reports from established units in Scandinavia suggest that energy savings of between 70–80% can be made using recovered heat, with about 90% of energy used in the pig accommodation coming from slurry cooling. The reported energy consumption in one fattening system was reported to be equivalent to 10 kW/pig place per year.

Storage

Heat can be stored on site for use in higher grade heating systems or used at times when heat demand does not match cooling requirement. Assessing the supply and demand of a proposed system, mismatches can be identified and the heat storage requirement calculated. Heat stores can vary from domestic units, used to preheat domestic hot water, to large-scale stores that can be used to store heat between seasons; this latter system is not currently in demand in the UK.

How it's done

Design

The potential demands of the cooling and heating elements of these systems should be carefully considered when designing whole or part systems, to achieve overall balance.

By calculating heat demand first, the amount of heat necessary can be used to determine the scale of the cooling loop required to supply it. The slurry storage system and power supply can then be designed to ensure that maximum use is made of the energy input, from either a mains or renewable supply. With this approach, payments under RHI can be optimised.

The elements of the system should be located as close to each other as possible, to minimise transmission and insulation costs, and heat losses.

The design of systems is developing and the greatest opportunities for knowledge transfer lie with units that have installed systems and engineered out problems encountered in day-to-day running.

For instance, fin-based cooling systems have encountered problems with crusting and pipe connections under slats, both of which are difficult to fix in a confined space. Systems have also encountered problems with freezing and consequent over-cooling of accommodation. Excessive energy consumption has been a problem in systems where heat differentials have been too great, and renewable sources such as photovoltaic arrays may have to be supplemented with mains electricity where systems have not been designed properly.

It is important to work with knowledgeable contractors with experience of heat transfer systems either in agricultural use of the technology, or of industrial use, where skills can be readily transferred.

Economics

The key to making slurry cooling financially viable is in making use of heat arising from the process, which has the added benefit of attracting payments and tax relief as part of the Government's policy to encourage the use of renewable energy.

Renewable Heat Incentive (RHI)

Heat Pump installations qualify for the Non-Domestic RHI. Full details of the Non-Domestic RHI are available from Ofgem[9] and a more accessible set of frequently asked questions[10] on a separate page.

RHI support comes in the form of quarterly payments made over a number of years rather than as a grant. Payments start three months after the installation is signed off and last for 20 years. The payment level is set out in the RHI regulations and the complexity of factors means that accurate calculations should be made on a site-by-site basis.

Ofgem is responsible for payments to RHI participants, based on the Regulations. Payments will be adjusted in line with the UK Consumer Price Index (CPI) for the previous calendar year, and a table of RHI tariffs is updated and published annually, with the adjusted rates beginning on 1 April and ending on 31 March of the following year.

For budgeting purposes, in April 2018, the maximum payment for metered heat delivered by a ground source heat pump was 9.36p/kWh for the first 1,314 hours spent running at its design capacity, falling to 2.79p/kWh for all subsequent hours.

Enhanced Capital Allowance (ECA) scheme

The ECA scheme gives a first-year allowance against taxable profits of 100% of the cost of an investment in energy-saving plant or machinery in a single tax year. This means that you can write off the cost of the new plant or machinery against the business's taxable profits in the financial year in which the purchase was made.

An ECA is claimed through a business's income or corporation tax return in the same way as any other capital allowance. HM Revenue and Customs is responsible for the tax-related aspects of the ECA scheme. Queries regarding the ECA scheme should be addressed to the Carbon Trust.[10]

New build

To take full advantage of the benefits offered by an integrated cooling and heating system based on heat pump technology, it is best to start on a new unit where buildings can be grouped to minimise heat loss arising from moving low-grade heat around the site. New units also enable heating and cooling loops to be incorporated into the structure of buildings to achieve maximum effect. The green credentials of the system can also be enhanced and operating costs reduced by making use of power from roof-mounted solar arrays.

This system is best implemented in a fully integrated unit, incorporating the full pig production cycle, although it can also provide benefits in a production unit where there is a nearby use for the heat produced.

The low-density polyethylene pipes for the cooling and heating loops are cast in the concrete floors of the relevant accommodation, with a spacing of 35–40 cm between pipes, as shown in Figures 2 and 3.

The cooling loop can be installed onto or cast into the concrete floor of slurry pits, but heating loops should be cast in the concrete of lying areas. Domestic underfloor heating is generally installed on a jig that also provides insulation to retain heat in the upper layers of the floor. It is not necessary to insulate the floor of pig accommodation, and pipes can be wired onto lightweight anti-crack mesh also cast into the floor, the whole having a minimum cover of between 50–75 mm of finished concrete. Figure 1 shows cooling pipes wired onto steel mesh in advance of pouring the cellar floor.

Pipes are connected to a heat-exchanging device (pump or plate) to recover process energy, which might be used for heating other parts of the farm (house for weaners, farrowing pens, private farmhouse or greenhouses, etc.). In the cooling circuit, glycol or other types of antifreeze can be added, to allow the slurry to be cooled to temperatures even below 0°C. However, extreme cooling reduces the heat pump efficiency. Usually, it is recommended that the system is designed to cool down to a temperature of 5°.

Retrofit

The installation of heat recovery pipes in the floors of existing slurry storage is not economical, and the only technique that is considered to be BAT is slurry surface cooling fins. Cooling fins are not BAT for new build housing, but the technique can be used in dry sow, farrowing, weaner and fattening accommodation. However, the technique has encountered significant problems with crust generation, and freezing and technical issues, with connection between fixed and floating elements of the loop.

In this system, the cooling circuit runs through a floating heat exchanger on the surface of slurry in underfloor storage. As the level of slurry fluctuates under the housing, the arrays of plastic or metal fins move up and down on the slurry surface. Fins are connected in series in individual storage areas, with the groups of fins connected in parallel to achieve a uniform cooling effect throughout the housing.

The amount of cooling achieved by this technique has resulted in reductions in ammonia emissions of between 45–75%, according to housing type. In partly slatted sow housing, an ammonia emission reduction of about 50% has been achieved in comparison with fully slatted accommodation with a deep pit.

This performance was achieved with a stocking density of at least 1.0 m^2 per sow place and a minimum 115% ratio of fin cooling surface to manure surface. Corresponding values for group housing are 1.1 m^2 per sow place, and a 135% ratio of fin to manure surface area. This technique also results in a reduction in dust and odour emissions.

Work carried out in the Netherlands estimates energy consumption to be 19 kWh per gestating sow place per year for the partly slatted floor installation.

Cooling pipes can also be fixed to the surface of existing floors in slurry storage and channels using clips. Experience with fixing aeration pipes to the floor of slurry stores suggests that pipes are not disturbed by filling and emptying activities, but that the area between the pipes fills with solid material that effectively reduces the nett storage capacity of the system. The presence of surface-mounted pipes in channels and pits also makes it difficult to thoroughly clean voids in the event of disease outbreaks or unit clean down, particularly in confined areas at greater risk of the adverse effects of gas generation.

Generally, the challenges associated with retrofitting slurry cooling make it unsuitable in existing accommodation.

Installation

It is important to involve an approved heat pump installer when considering using a heat pump for slurry cooling. To obtain RHI, an approved installer must install any heat pump installation with a capacity of less than 45 kWth. For installations with capacities greater than 45 kWth, the design specification and performance of installations must be certificated by the installer. Properly accredited professionals are generally registered with the government's Microgeneration Certification Scheme (MCS).

The installation should be designed to an agreed specification of performance by an experienced technician. Where the underfloor elements of the system are to be installed by the farmer or a third-party contractor, the designer should produce a full specification of the installation and evidence of correct installation, maintained by the installer. The cooling and heating loops should be pressure tested before pouring the overlying floor.

The pipework should be tested to the specification set out in BS EN 805, 1.5 times the maximum design pressure.

Work carried out by the Energy Saving Trust to assess the efficiency of ground source heat pumps found that a proportion of heat pumps tested were incorrectly installed; this meant the heat pumps didn't perform efficiently overall.

Provided the heating and cooling loops are installed to an agreed specification, the plumbing-in of a ground source heat pump, typically, only takes up to three days for a professional installer to complete.

A list of manufacturers and installers is appended to this document, and MCS-approved products can be found at **microgenerationcertification.org/consumers/product-search** A list of MCS-registered contractors can be found at **microgenerationcertification.org/consumers/installer-search**

You will need to apply to Ofgem for support under the RHI. Ofgem has published guidance that sets out all the eligibility criteria and how to apply. This is available on the Ofgem website: **ofgem.gov.uk/environmental-programmes/renewable-heat-incentive-rhi**

Heat pumps have an energy label attached, to provide information about their energy efficiency, with ratings from dark green (most efficient) to red (least efficient). Installers should also be able to produce a similar rating for the system package, based on its component parts.

Appendix

Suppliers and Installers of Ground Source Heat Pumps

If your company offers these services but have not been included on our list please let us know and we will update our list with your information.

Suppliers and installers

Name	Telephone	Website
Alternative Heat Ltd 11 Burrenreagh Road Castlewellan, County Down BT31 9HH Northern Ireland	02843 770700	**www.alternativeheat.co.uk**
Baystar Beechover Court, Forest Road Colgate Horsham RH12 4SY	01293 851459	**www.baystar.co.uk**
Calibrate Energy Ltd West Ditchburn Farm Alnwick Northumberland NE66 2UE	01665 578638	**www.calibrateenergy.co.uk**
Earth Source Energy Unit 6 Silver Birches Business Park Aston Road Bromsgrove Worcestershire B60 3EU	0330 22 33300	**www.earthsourceenergy.co.uk**
Ember Energy 1 Fleming Street Darvel Ayrshire KA17 OED	01563 501582	**www.emberenergy.co.uk**
Finn Geotherm Ltd Wood Farm, Deopham Road Attleborough Norfolk NR17 1AJ	01953 453240	**www.finn-geotherm.co.uk**
JKN Renewables Ltd Office Suite 4 The Gables Business Park Belton Road, Epworth Doncaster DN9 1JL	01427 874308	**www.jknrenewables.co.uk**
Q-Gen Heat Pumps Ltd St Pegs Mill, Thornhills Beck Lane Brighouse West Yorkshire HD6 4AH	01484 475808	**www.q-gen.co.uk**
Yorkshire Renewable Energy Systems Evans Business Centre Monckton Road Wakefield West Yorkshire WF2 7AS	07766 555550	**www.yres.co.uk**

Manufacturers

Name	Telephone	Website
Alto Energy Ltd Hexagon House, Avenue 4 Station Lane, Witney Oxfordshire OX28 4BN	01993 220699	**www.altoenergy.co.uk**
Dimplex UK Ltd Millbrook House, Grange Drive, Hedge End Southampton S030 2DF	0844 8793588	**www.dimplex.co.uk/heat-pumps**
Kensa Heat Pumps Mount Wellington Chacewater Truro TR4 8RJ	01872 862140	**www.kensaheatpumps.com**
Star Renewable Energy Thornliebank Industrial Estate Nitshill Road Glasgow G46 8JW	0141 6387916	**www.neatpumps.com**
Vaillant Group Ltd Nottingham Road Belper DE56 1JT	01733 596109	**www.vaillant.co.uk**
Pellon Group Oy Yrittäjäntie 10 62375 Ylihärmä Finland	+358 6 4837 555	**www.pellon.fi/en**
Klimadan A/S Jylland, Rømersvej 30 7430 Ikas Denmark	+45 96277070	**www.klimadan.dk**

(1) **www.ofgem.gov.uk/environmental-programmes/non-domestic-rhi**

(2) **eippcb.jrc.ec.europa.eu/reference/BREF/IRPP/JRC107189_IRPP_Bref_2017_published.pdf**

(3) Pedersen, P. (1997): Køling af gylle i slagtesvinestalde med fuldspaltegulv. Videncenter for Svineproduktion. Meddelelse nr. 357, pp. 6.

(4) Hansen et. Al. (2012), table 12, page 22 and table 2, page 6

(5) Jørgensen M, A L Riis and P Pedersen (2013): Effekten af gyllekøling i slagtesvinestier med drænet gulv i lejeareal. Erfaring nr. 1312. Videncenter for svineproduktion, den rullende afprøvning. 17. maj 2013.

(6) **www.pellon.fi/en/**

(7) T. Hügle, and H. Andrée. 2001. Odor emission from cattle and swine slurry. Paper No 01-4098, St Joseph, MI: ASAE

(8) **pork.ahdb.org.uk/media/39721/energy_use_in_pig_farms_carbon_trust.pdf**

(9) **www.ofgem.gov.uk/publications-and-updates/non-domestic-rhi-main-guidance**

(10) **www.ofgem.gov.uk/ofgem-publications/102330**

(11) **ECAQuestions@carbontrust.co.uk**

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