biosystems engineering 121 (2014) 118–129

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

Investigation of heating and cooling potential of a modular housing system for fattening pigs with integrated geothermal heat exchanger

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ARTICLE INFO

Article history:
Received 6 August 2013
Received in revised form
18 February 2014
Accepted 20 February 2014
Published online 20 March 2014

Keywords:
Modular housing
Geothermal heat exchanger
Supply air conditioning
Barn climate

Against the backdrop of global reductions in fossil fuel reserves and rising energy prices, there is increasing interest in the use of geothermal heat exchangers (GHEs) in farm animal production. The modular housing concept is a housing system with an integrated GHE area where fresh air is led through a space between slurry pit and soil to condition the supply air.

This modular housing system was investigated for the first time over a one-year experimental period in Warendorf (in western Germany). During this period, the temperature of outdoor, fresh, supply and section air were recorded continuously, along with the relevant air flow volume, electricity and gas consumption. The aim of the study was to quantify the heating and cooling performance of this system under practical conditions over an extended period.

This kind of housing is characterised in particular by the fact that the incoming air into the sections is subject to year-round conditioning depending of the outdoor temperature (pre-heating and pre-cooling of supply air). During the investigation period, the modular housing for 1280 fattening pigs effectively provides a heat quantity of 489,820 kWh at a mean performance of 59.7 kW as well as a cooling quantity of 18,455 kWh at a mean performance of 33.3 kW. This means that there is great potential for saving fossil fuel and energy costs as well as avoiding CO_2 emissions. In contrast, the investment costs are higher than for comparable conventional pig houses.

1. Introduction

In recent decades, energy issues have increased in importance in agriculture not only for economic but also for ecological reasons (see e.g. Barber, Classen, & Thacker, 1989; Corré, Schröder, & Verhagen, 2003; Dahiya & Vasudevan, 1986; Horne, Mortimer, & Elsayed, 2003; Kythreotou, Florides, & Tassou, 2012; Meul, Nevens, Reheul, & Hofmann, 2007). This is due to global reductions in fossil fuel reserves and rising energy prices which are strongly influenced, among other things, by growing demand as a result of economic development of different emerging nations (cf. Corré et al., 2003; Nakomcic-Smaragdakis, Stajic, Cepic, & Djuric, 2012) as well

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http://dx.doi.org/10.1016/j.biosystemseng.2014.02.008

Nomenclature

a	year
BCE	before common era
c_{pl}	specific heat capacity of air with regard to dry air [Wh kg^{-1} K^{-1}] (c_{pl} = 0.28 Wh kg^{-1} K^{-1})
EU	European Union
fp	fattening place
ETHE	earth-tube heat exchanger
GHE	geothermal heat exchanger
h	height [m]
kWh_{el}–kWh_{th}-ratio	ratio of electricity input to energy provided. It describes the amount of thermal energy (kWh_{th}) which is generated by a system having an input of 1 kWh_{el}.
l	length [m]
r	rotation rate [revs min^{-1}]
R^2	coefficient of determination
Q_{eff}	effective energy that has been provided in the entire supply air ducting of the modular housing for heating or cooling of the supply air [kWh]
$\dot{Q}_{eff}$	effective heating/cooling performance of the entire supply air ducting of the modular housing [kW]
$\dot{Q}_{GHE}$	heating/cooling performance of the GHE [kW]
$\dot{V}$	air flow rate [m^3 h^{-1}]
$\dot{V}_{max}$	maximum air flow rate [m^3 h^{-1}]
w	width [m]
$\tilde{x}$	median
ϑ	air temperature [°C]
ϑ_{in}	air temperature entering the supply air ducting [°C]
ϑ_{out}	air temperature leaving the supply air ducting [°C]
ϑ_{T_5}	air temperature at measuring point T_5 [°C]
ρ_{air}	density of air [kg m^{-3}]

as commercial policy activities. Another reason is the climate change brought about by carbon dioxide emissions as a combustion product of fossil fuels (Corré et al., 2003; Horne et al., 2003). Fossil energy can be replaced by renewable energies such as biogas, wind energy and solar power (Corré et al., 2003) as well as geothermal energy.

The use of renewable energies is required by law in the European Union (EU). The EU's ambitious overall target is that at least 20% of the gross final energy consumption in the Community is provided by renewable energy sources in 2020 (EU, 2009; cf. Krozer, 2013). In addition to other factors, this is intended "to reduce greenhouse gas emissions", but also to help the EU become less dependent on energy imports (EU, 2009; cf. Lund, Freeston, & Boyd, 2011).

In many areas of agriculture where there is a high use of energy, especially in livestock farming (Barber et al., 1989; Corré et al., 2003; Kythreotou et al., 2012), measures are being taken to save energy (fossil fuels) and heating costs and to use energy more efficiently. The energy needed by closed ventilated and thermally insulated livestock buildings is made up of the heat produced by the animals and the heat lost through ventilation and structural components (Büscher, 2008; DIN 18910-1, 2004). The heat lost by livestock buildings through ventilation during winter accounts for 70–90% (Lindley & Whitaker, 1996; Spengler & Stombaugh, 1983; Van Caenegem, 2008) and can be reduced e.g. by using a recuperative air-to-air heat exchanger (Rösmann & Büscher, 2010; cf. Allen & Payne, 1987; Lindley & Whitaker, 1996; VDI 2071, 1997). Heat losses through structural components can be diminished by thermal insulation (Büscher, 2008).

Another possibility for saving energy is the use of geothermal energy. The soil has "the potential to be used [...] for winter heating and summer cooling" of the supply air (Barber et al., 1989; cf. Bansal, Mishra, Agarwal, & Mathur, 2012; Florides & Kalogirou, 2007; Van Caenegem, 2008). The idea of using geothermal energy is not a new one. Bahadori (1978) reported on different cooling systems for buildings in Iran by using the "natural environment" (geothermal energy, wind) whereas "Some of these systems [...] were incorporated in buildings as early as 3000 (BCE)". A short summary of the history of earth-tube heat exchangers (ETHEs) and an overview of previous studies has been given by Ozgener (2011).

Nowadays, there is increasing global interest in using geothermal energy (cf. Lund et al., 2011) and this is also shown by the number of international publications on this topic. An overview of the direct uses of geothermal energy worldwide and especially in the USA is given by Lund et al. (2011) and Lund (2003). Florides and Kalogirou (2007) describe different technical systems that use geothermal energy. They categorise the geothermal heat exchanger (GHE) systems into open, closed and miscellaneous systems. GHEs are used, for example, in office buildings (Pfafferott, 2003), residential houses (Badescu, 2007; Bansal et al., 2012; Lee & Strand, 2008; Ozgener, 2011; Thiers & Peuportier, 2008), in industry (Ozgener, 2011), dwellings for zoo animals (Sharan, 2008) as well as agricultural buildings like greenhouses and livestock buildings (Abbaspour-Fard, Gholami, & Khojastehpour, 2011; Barber et al., 1989; Deglin, Van Caenegem, & Dehon, 1999; Goetsch & Muehling, 1983; Hessel, Zurhake, & Van den Weghe, 2011; Lindley & Whitaker, 1996; Ozgener, 2011; Santamouris et al., 1996; Sharan, 2008; Spengler & Stombaugh, 1983; Tiedemann, 1991; Van Caenegem & Deglin, 1998).

In addition to heat pump systems, an ETHE is often used for geothermal energy, especially in agricultural architecture. Fresh air is sucked in through tubes that are laid in the earth. Here, the supply air is conditioned using thermal energy transfer between the supply air and the ground, based on the temperature gradient (cf. Bansal et al., 2012). In some systems, the tubes are arranged in the ground in the area next to the livestock building (e.g. Abbaspour-Fard et al., 2011; Deglin et al., 1999; Goetsch & Muehling, 1983; Pfafferott, 2003; Sharan, 2008; Van Caenegem & Deglin, 1998). In others, they are arranged below the building (Hessel et al., 2011; Santamouris et al., 1996).

According to previous studies, the performance and efficiency of ETHE systems are influenced by different factors such as climatic conditions, the geographical location, geometrical characteristics of the system, soil type, tube properties (material, length, diameter, burial depth, spacing