Energy and Buildings 139 (2017) 53–62

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Application of dynamic thermal engineering principles to improve the efficiency of resource use in UK pork production chains

Paul Jackson [a,*], Jonathan Guy [a], Sandra A. Edwards [a], Barbara Sturm [a,b], Steve Bull [c]

[a] School of Agriculture, Food and Rural Development, Newcastle University, Newcastle upon Tyne, UK
[b] Postharvest Technologies and Processing Group, Department of Agricultural and Biosystems Engineering, University of Kassel, Witzenhausen, Germany
[c] School of Chemical Engineering and Advanced Materials, Newcastle University, Newcastle upon Tyne, UK

ARTICLE INFO

Article history:
Received 26 June 2016
Accepted 30 December 2016
Available online 5 January 2017

Keywords:
Pig building
Ventilation
Thermal conductivity
Sustainable
Modelling

ABSTRACT

This paper investigates the potential for incorporation of human commercial building design modelling into the pig production industry. During the last decades pig building design has relied heavily on building manufacturers compared to human commercial buildings that regulate standards to improve the sustainability of the building. Thus, the aim of this paper was to gain a greater understanding of the design requirements for sustainable forms of pig housing, which could potentially improve the welfare of the pig and promote greater resource use efficiency. Part of an existing mechanically ventilated UK pig production building, which represents three adjacent fully-slatted units each capable of holding approximately 292 pigs and measuring approximately 18 m x 14m, was used as a basis to create a dynamic thermal model of the building. The model takes into account the possibility of future rises in environmental temperature and the effect of this climate change on building performance and pig growth, feed efficiency and welfare. The results of the model showed that as the finishing pigs increased in size they have the potential to be subject to increasingly poor indoor air quality, during the winter months. The model also shows that improving the thermal properties of the building not only helps with reducing the amount of time that the pigs could potentially spend at extreme low temperatures, by approximately 1115 h (46 days), but can also help with reducing the number of hours the pigs spend above 26 °C during the summer months, by approximately 8 h.

1. Introduction

Pork is the most consumed meat in the world, with animal feed accounting for 62% of the cost of pig production [5]. For UK producers, feed costs reached a record high in 2013, amounting to £1.06/kg carcass produced, although this decreased by 19% to £0.85 p/kg in 2014 [1]. To be efficient, producers must provide an environment which allows pigs to exhibit their genetic potential to convert feed into muscle growth. Animals need to be kept comfortably within their thermo-neutral zone, thus avoiding energy waste in maintaining body temperature [8], and in highly hygienic conditions, thereby avoiding inefficient protein utilisation from immune system activation [24].

Direct energy usage in agriculture is relatively small, representing approximately 1% of the UK's energy use [9]. However, much of the energy used in pig production is not represented in energy statistics since it is inherent in the food consumed by the pigs. It has been estimated that feed inefficiency can be as much as 30% of feed intake as a result of suboptimal building design [7], as illustrated by Lopez et al. [16] who reported that pigs kept at cold temperatures were 43% less efficient than those kept at an optional temperature. These potentially inappropriate living conditions for the pigs can lead to increased production costs through reduced feed efficiency and increased veterinary charges. Production costs can escalate across the different stages of growth, since pigs require very different environments for adult sows during pregnancy and lactation, and for their progeny through suckling, weaning, and finishing for meat production.

During the last decades, pig building design has relied heavily on the experience of building manufacturers rather than regulated standards. This contrasts with the design of commercial buildings for humans, where substantial advances have been made in improving standards in terms of ventilation, heating and cooling systems for sustainable buildings.

* Corresponding author.
E-mail address: p.jackson4@newcastle.ac.uk (P. Jackson).

http://dx.doi.org/10.1016/j.enbuild.2016.12.090

1.1. Limitations of current UK pig building design

For buildings in the UK, on the few occasions when the external temperature is higher than the internal setpoint temperature (i.e. the intended internal temperature of a space as specified on the control system), approximately 3% of the year, no amount of internal air changes will be able to reduce the internal temperature to the intended setpoint. Thus the thermal conditions inside the building will always be too hot, showing a degree of lift above the prevailing external temperature. At the other end of the scale, in the winter months when temperatures in the UK fall below 0 °C and ventilation rates are reduced to the minimum fan speed limit, this can result in the building being prone to conditions which are too cold and of an inappropriate indoor air quality (IAQ). Both these scenarios will have a detrimental effect on feed efficiency and the well-being of the pig and affect the energy efficiency of the overall pig production programme.

In these circumstances two options are available to reduce the internal extreme high and low temperatures in a mechanically ventilated building. One option is to introduce mechanical air conditioning to control the internal setpoint, which potentially would have a detrimental effect on the overall energy consumption and sustainability of pig production. The second option would be to introduce a passive design into the building structure to reduce heat loss in winter and external heat gains in summer. This can be achieved by increasing the thermal insulation and thermal mass of the building. The introduction of more thermal mass into the building fabric could potentially benefit the internal environment in the summer as it will slow the penetration of direct solar energy gain through the surfaces and potentially help stabilize and reduce the internal extreme high temperatures. This slowing down of solar gain through the building, as a 'time lag', can help with internal temperature control simply by storing the solar energy in the thermal mass of the building fabric, rather than releasing the solar energy into the internal space straight away. The energy stored can then be released into the external environment when the external temperature decreases later in the day, therefore restricting any unwanted solar heat gains into the internal space. Introducing a high amount of thermal insulation will also reduce the amount of internal heat gains that escape from the internal space to the external environment in the cooler winter months; this will potentially keep the internal temperature higher, which could also help in providing more fresh air into the space during winter, thereby reducing levels of ammonia and CO_2 produced by the pigs.

If these passive designs are to be explored, the key factor is infiltration. The building has to be relatively air tight or the passive design fails, due to the external environment simply by-passing the passive infrastructure by leaking into the internal environment. While the thickness of the insulation also needs to be considered in terms of capital cost of the building, as there will be a point where the cost of the insulation will exceed any potential energy savings [3].

Thus, the aim of this paper was to incorporate human commercial building design modelling into the pig production industry in order to gain a greater understanding of the design requirements for sustainable forms of pig housing so as to improve the welfare of the pig and promote greater resource use efficiency.

2. Materials and methods

Figs. 1 and 2 represent a section of a finishing pig building at an existing pig production site in Staffordshire (UK), a dynamic thermal model of which was created using DesignBuilder software (V4.2.0.054, EnergyPlus 8.1, DesignBuilder Software Ltd, Stroud, UK). The scaffolding lines around the finishing building in Fig. 1 represent the annual path of the sun for that specific location. The dynamic model takes into account thermal radiation, conduction and convection between all the building elements in conjunction with internal and external environment conditions, as well as occupancy density, air flow and solar gains into the building. The model also takes into account the possibility of future rises in environmental temperature and the effect of this climate change on building performance and pig growth, feed efficiency and welfare in the years 2030, 2050 and 2080. These future weather files, which are location-specific and are available for 2030, 2050 & 2080, were used as the basis for the research of Du, Underwood & Edge (2012) into future air-conditioning loads for commercial buildings.

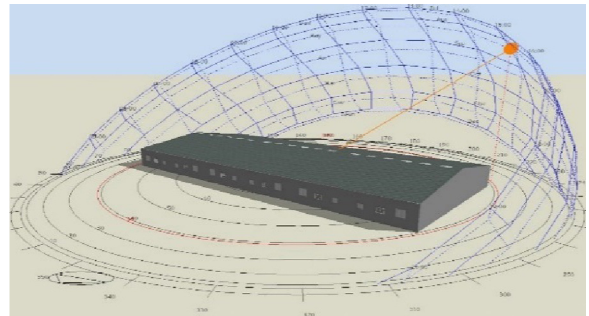

Fig. 1. Dynamic thermal model created in DesignBuilder to represent three adjacent units within a finishing pig building (each unit is capable of housing approximately 292 finishing pigs).

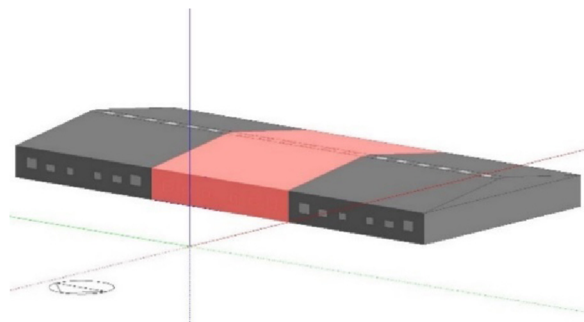

Fig. 2. The central unit (shown in red) of the finishing pig building which was selected since it takes into account all other surrounding internal areas. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

All results reported and discussed in this paper relate to one central unit of the pig finishing building highlighted in Fig. 2. The model represents three part-slatted rooms, capable of holding approximately 292 pigs. Each room is approximately 18 m x 14 m with a service corridor running outside the rooms along the length of the building. The central unit was chosen to model since it takes account of all other adjoining internal environmental influences. The room is ventilated by four in-wall panel extract fans (Multifan, Vostermans Ventilation BV, Venlo, Netherlands), comprising two fans of diameter 915 mm and two fans of diameter 574 mm, with a respective volume flow rate at 50 Pa of 16800 and 9400 m^3/h per fan. The fans are located in the side wall opposite to the service corridor, operated with a step controller, with air entry through a controlled ridge opening to maintain a 5 m/s inlet jet along the ridge of the ceiling.

Amongst other requirements of the building design such as appropriate feed, floor structure and space requirements, equilibrium of heat is required between the pig and its environment to improve the welfare of the animal and promote greater resource