CFD prediction of the effective temperature in the laying area of pig pens with partly solid floor

Bjerg, Bjarne Schmidt

Publication date:
2016

Document version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Bjerg, B. S. (2016). *CFD prediction of the effective temperature in the laying area of pig pens with partly solid floor*. Paper presented at CIGR - AgEng conference, Aarhus, Denmark.

CFD prediction of the effective temperature in the laying area of pig pens with partly solid floor

Bjarne Bjerg

Department of Large animal Science, University of Copenhagen, DK1870 Frederiksberg C, Denmark

*Email: bsb@sund.ku.dk

Abstract

Use of solid floor as an alternative to drained or slatted floor in the laying area of pig pens includes significant advantages in relation to animal welfare, low odour and ammonia emission, low energy consumption and reduced building costs, however solid floor is most often deselected by the pig producers due to the risk that fouling in the laying area and the consequent risks of increased working load, poor animal welfare and poor indoor climate. The risk of fouling of the laying area increases at increased indoor temperature and it is recommended that the temperature should be held around 13 °C in the last part of the growing period if diffuse air intake is used. The result is undesired high temperature in around 40 % of the yearly hours even at the relatively cold Danish climate (average outdoor temperature of around 8 °C).

This study aims to investigate the potentials of using a ceiling inlet to control the air velocity and the chilling of the pigs in the laying area of a pen for finishers. CFD methods were applied to predict relevant parameters to calculate the effective temperature in the laying area. A traditional diffuse air inlet through the ceiling was assumed to deliver the entire air change as long the outdoor temperature were below 10 °C. At higher outdoor temperature a ceiling jet inlet above each pen was assumed to opened gradely and create a wall jet along the ceiling continuing along the wall down into lying area. The investigations showed that the ceiling jet inlet, at the same total ventilation rate, could be adjusted to decrease the effective temperature in the laying area with up to approximately 6 °C. At Danish climate conditions this will decrease the number of yearly hours where it becomes undesired warm by around two third. A free jet were developed if the assumed inlet were 30 % or more open and the results showed that the largest reduction of effective temperature was obtained when the inlet where less open and generated a wall jet.

1. Introduction

Use of solid floor as an alternative to drained or slatted floor in the laying area of pig pens includes significant advantages in relation to animal welfare, low odour and ammonia emission, low energy consumption and reduced building costs, however solid floor is most often deselected by the pig producers due to the risk that fouling in the laying area and the consequent risks of increased working load, poor animal welfare and poor indoor climate. The risk of fouling of the laying area increases at increased indoor temperature and it is recommended that the temperature should be held around 13 °C in the last part of the growing period if diffuse air intake is used. The result is undesired high temperature in approximately 40 % of the yearly hours even at the relatively cold Danish climate (average outdoor temperature of around 8 °C).

This study aims to investigate the potentials of using a ceiling inlet to control the air velocity and the chilling of the pigs in the laying area of a pen for finishers.

2. Materials and Methods

CFD methods were applied to predict relevant parameters to calculate the effective temperature in the laying area. A traditional diffuse air inlet through the ceiling was assumed to deliver the entire air change as long the outdoor temperature were below 10 °C. At higher outdoor temperature a ceiling jet inlet above each pen was assumed to opened gradely and create a wall jet along the ceiling continuing along the wall down into lying area.

The study was based on an assumed 11.4 m wide building including 5.2 m long and 2 m wide pens on both sides of a 1 m wide longitudinal aisle. The ceiling height was 2.6 m and the thermal insulation of building corresponded to normal Danish practice. The building was equipped with air intake through the attic and a porous ceiling that allowed diffuse inlet to the animal room. In addition an adjustable jet inlet - with dimension as DA 1800 Ceiling Inlet from Skov (www.skov.com) – was centred in the ceiling above each pen. At small openings the inlet directed the jet against the wall, where it deflected and continued down the wall and reached the animal occupied zone were the air velocity aided to cool the animals. At larger openings the inlet directed the jet directly in to the animal occupied zone.

Each pen included 15 pigs and the animals were assumed to weigh 90 kg which was anticipated to be representative for the period from 80 to 100 kg where the recommended temperature was the lowest. Assumed total heat production originated from CIGR (2002) where the pig specific curve were used for total heat production and the general curve were used for calculating the division between sensible and latent heat production. Finally the calculated sensitive heat production was reduced by 5 % to account for the increased latent heat production that often is found under practical conditions.

The commercial CFD (Computational fluid Dynamic) code Ansys Fluent 15 and the Standard k-ε turbulence model (Launder & Spalding, 1974) were used to calculated the air flow, the temperature distribution and humidity distribution in one half pen section of the room including the attic above. The chosen section was divided into 257565 hexahedral cells, and the grid on surfaces and the used boundary conditions (BC) are shown in Fig. 1 and 2.

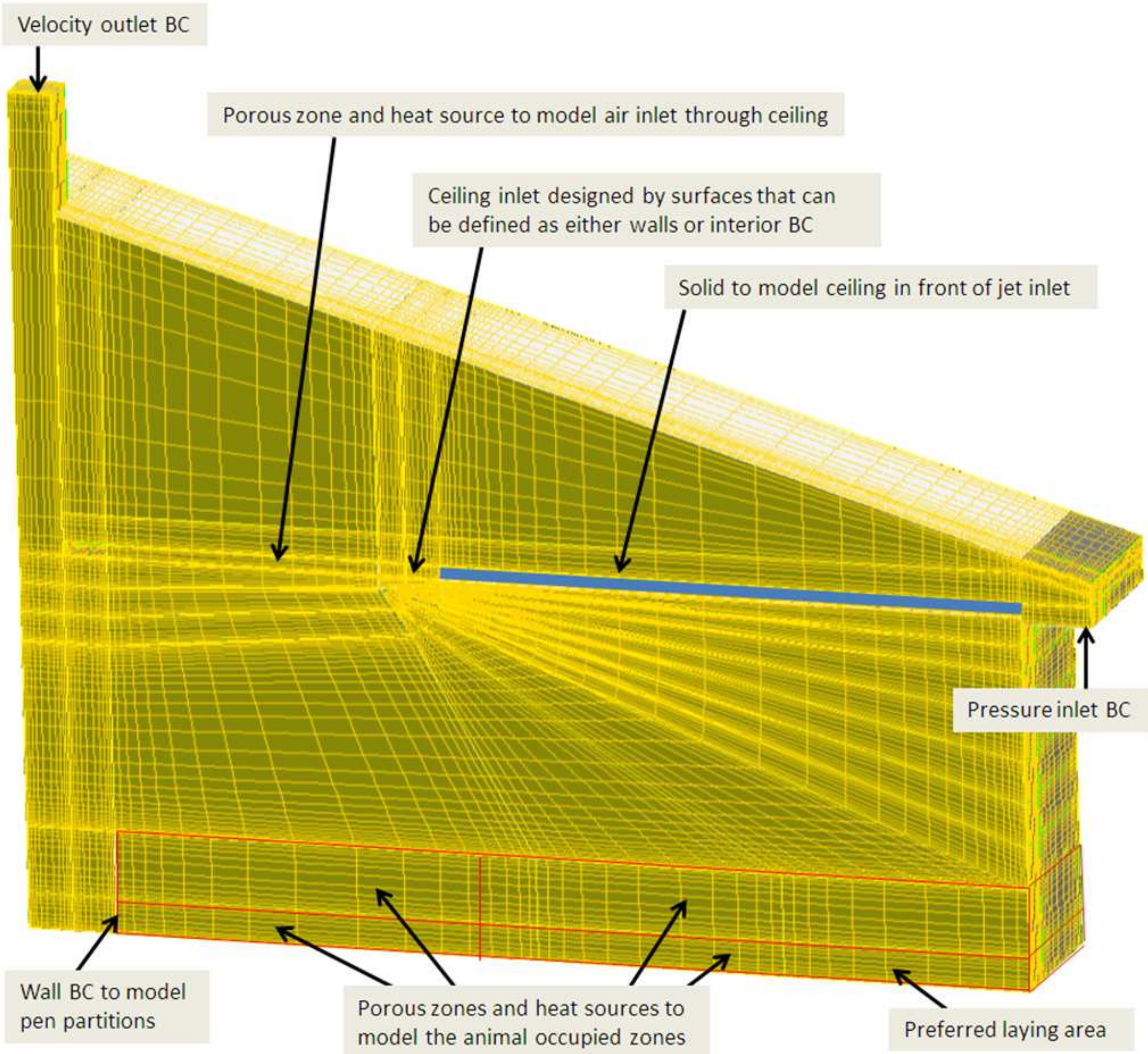

Figure 1. Grid on surfaces and boundary conditions (BC) for the used geometrical model.

The geometrical model was prepared in such a way that the inlet from the attic to the room below could either be exclusively through the porous layer in the ceiling or through the porous layer in combination with the ceiling jet inlet. The latter could be adjusted to different openings by assuming that different predefined surfaces were set to be either wall BC or interior (see Fig. 2 and Tab. 1).

The porous layer in the ceiling and the animal occupied zone where modelled as porous media cell zones as suggested by Bjerg et al (2011). Prior simulations had shown that the porous media cell zone assumption, in an unrealistically large extent, restricts the airflow along the porous zones and therefore I modelled the ceiling in front of the inlet as a solid (see Fig 2). The flow resistance parameters used in the porous cell zone part of the ceiling were selected so it resulted in a linear relationship between airflow and pressure drop over the ceiling, and so the pressure drop was 30 Pa at an air change of 100 m^3 h^{-1} pig^{-1} if the diffuse inlet was used only. Further on laminar flow conditions were assumed in the porous cell zone in the ceiling which prevented an over estimation of the heat and moisture diffusion through the ceiling.

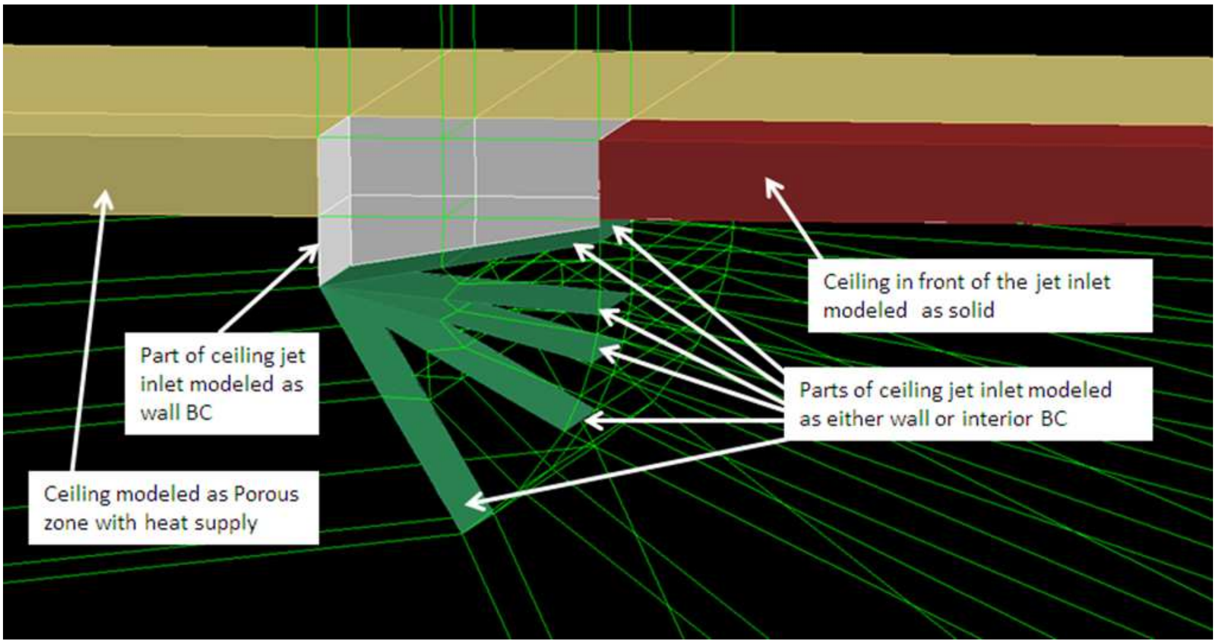

Figure 2. Boundary conditions (BC) around the assumed ceiling jet inlet. Green lines indicate the block structure of the used hexahedral grid.

Table 1. Used assumptions (yellow background) for and results (grey background) of simulation 1-9.

Simulation #	1	2	3	4	5	6	7	8	9
Outdoor temperature, °c	10.0	15.0	15.0	15.0	15.0	15.0	15.0	16.1	18.9
Inlet flap direction, degree	closed	closed	closed	-5	-15	-30	-60	-15	-15
Inlet front removed:	no	no	yes	yes	yes	yes	yes	yes	yes
Jet inlet opening height, mm:	0	0	30	121	183	274	413	183	183
Sensible heat, watt pig^{-1}:	139	117	139	139	139	139	139	139	139
Water evaporation g h^{-1} pig^{-1}:	129	150	129	129	129	129	129	129	129
Exhaust temperaure, °c:	14.0	18.4	19.1	19.2	19.2	19.2	19.2	20.2	20.2
Pressure drop over the ceiling, Pa:	30	30	25	11	8	7	7	8	23
Total air inlet , m^3 h^{-1} pig^{-1}:	100	100	100	100	100	100	100	100	200
Air inlet from ceiling jet, m^3 h^{-1} pig^{-1}:	0	0	17	57	72	76	86	72	122
Avarage temprature in PLA, °C:	17.6	21.6	19.0	18.4	18.2	19.4	19.2	19.3	20.5
Avarage air velocity in PLA, m/s:	0.18	0.17	0.26	0.40	0.42	0.23	0.22	0.42	0.63
Avarage water content in PLA, g m^{-3}	9.7	15.1	12.2	11.9	11.9	12.9	12.9	12.8	14.8
Avarage effective temperature in PLA, m/s:	**17.6**	**22.2**	**18.5**	**16.8**	**16.4**	**19.4**	**19.2**	**17.6**	**17.6**
Minimum temperture in PLA, °C:	15.5	19.8	17.7	17.2	16.9	17.8	17.7	18.0	19.7
Maximum air velocity in PLA, °C:	0.26	0.25	0.41	0.51	0.56	0.46	0.45	0.56	0.83
Minumum water content in PLA, g m^{-3}	8.6	13.6	11.8	11.7	11.5	12.0	12.0	12.5	14.4
Lowest effective temperature in PLA, °C:	**14.7**	**19.7**	**16.0**	**14.5**	**13.7**	**15.7**	**15.6**	**15.1**	**15.1**

Half of the sensible heat release from the animals was assumed to be transferred to the air in the animal occupied zone and the larger part (70 %) of it was distributed in what I defined as the preferred laying area (PLA) cowering the floor from 0 to 2.8 meter from the wall and up to 0.25 m above the floor (see Figure 1). The other half of the heat release was assumed to be transmitted out of animal occupied zone as radiation. A minor part of this share was assumed equalized by the transmission heat loss from the building and was consequently excluded in the calculation. The remaining part of the radiation was distributed in the cell zone used for modelling the porous material in the ceiling.

Seventy % of the animal moisture production was assumed to be released in PLA and the last 30 % in the remaining part of the animal occupied zone.

The assumed water content in the outdoor air originated from the linear relationship between the monthly average water content and monthly average dry bulb temperature in Danish climate data reported by Jensen & Lund, 1995, expressed in equation 2 (r^2=0.98):

$$x_{out\ door} = 0.86t - 2.0 \qquad (1)$$

where $x_{out\ door}$ is the water content in outdoor air, g m^{-3} and t is the air temperature, ºC. Equation 2 (Bjerg et al., 2016) were used to calculate the effective temperature (ET, °C) in PLA based on the average air velocity, the average temperature and the average water content in PLA predicted in the CFD simulations.

$$ET = 0.794t + 0.25t_{wb} + 0.70 – 0.42(39\text{-}t)(v\text{-}0.2) \qquad (2)$$

Where t_{wb} is the wet bulb temperature, ºC and v is the air velocity, ms^{-1}. To assess the variation of ET in PLA equation 2 were also utilized to calculate the assumed lowest ET in PLA based on the maximum air velocity, the minimum temperature and the minimum water content in PLA predicted in the CFD simulations.

Simulation 1 assumed closed jet inlet, outdoor temperature of 10 ºC and an air change of 100 m^3 h^{-1} pig^{-1}. The estimated average effective temperature in PLA for this case was 17.6 ºC and was used as upper threshold for well-functioning pens with solid flooring in the laying area. In the subsequent simulations it was investigated to which extent the use of the ceiling jet inlet could create similar effective temperature in PLA at higher outdoor temperatures.

3. Results and Discussion

Based on the results of simulation 1 the assumed upper threshold for the thermal conditions in PLA was an effective temperature of 17.6 °C. Simulations 2-7 were conducted at outdoor temperature of 15 °C (see table 1.) The ceiling jet inlet were still closed in simulation 2 whereas the 30 mm high front surface of the inlet was changed from wall BC to interior in simulation 3 which caused a reduction of the effective temperature in the PLA by 3.7 degree. From table 1 it appears that lowest effective temperature in PLA were found in simulation 5 were the inlet flap were directed 15 degree down ward. The increase of effective temperature at larger opening of the inlet flap are connected to the result that the jet no longer was attached to the ceiling. The consequence for the air velocity, temperature and moisture distributions appears by comparing simulation 5 and 7 in figure 3.

In simulation 5 the average effective temperature in PLA was 1.2 degrees below the threshold of 17.6 °C, and the result of simulation 8 showed that this threshold was meet if the assumed out door temperature was increased to 16.1 °C. This result indicated that use of the ceiling jet moves the outdoor temperature where the threshold could be met from 10 to 16.1 °C. Based on statistical data published by Jensen & Lund (1995) this will increase the share of yearly hours were the threshold can be met at Danish climate conditions from 59 to 85 %. Simulation 9 shows that doubling of the air change caused that the outdoor temperature could raise to 19.1 °C before the threshold were met and that will ensure that the threshold can be met at Danish climate conditions in 94% of the yearly hours.

The conducted simulations demonstrates a significant potential in using ceiling inlets and air jets attached to the ceiling and wall to chill the animal laying area in the wall end of pig pens. The study was based on a single design and location of the ceiling inlet and it is assessed that significant potentials exists to optimise both the inlet design and locations and the room design by making the inlet more aerodynamic in its connection to the ceiling, moving the inlet closer to the wall and implementing and aerodynamic transition between the ceiling and the wall. The used geometrical model had the advantages the it solved the question of dividing the flow between porous ceiling and the ceiling jet inlet but it has the not fully solved challenge that the porous zone, in the way it is implement in Ansys Fluent and Ansys CFX, treat the velocity gradient different close to a porous zone and close to a wall regardless the resistance parameters was set so high that the porous cell zone should react as a solid (Virding 2015). The practical implication is that air velocity along the porous media cell zone becomes unrealistically low which this study - to some extent - accounted for by assuming that the ceiling in front was a solid, see Fig 2. However the jet should expand in width and consequently a part of jet was still along the porous media and that might have contributed to decreased momentum of the jet. Therefore in further use of CFD methods to optimize the chilling effect of ceiling inlets it therefore should be considered to use wall BC (or solid) at the entire ceiling in front of the inlet, which naturally required an alternative method to handle the influence of the air intake through the porous material in the ceiling.

The resulting air velocity in PLA was unexpected low in the two simulations were the ceiling jet inlet was opened so much that the jet no longer was attached to the ceiling. It is known that the grid design close to a jet inlet are crucial for cfd simulation of the conditions in un attached jets, and Bjerg et al. (2002) showed that the cell orientations in the flow direction – as it is done in this study - was a suitable way to obtain good results without using too many cells. Bjerg et al. (2002) also showed that more cells distributed in the jet may increase air velocity even though the grid was arranged in the jet direction, and therefore in this study we made a further development of simulation 7 where all cells with air velocity above 1 m/s were divided into 8 new cells (2 in each of the 3 dimensions). The change increased the number of cells to 478011 but had no significant influence on the conditions in PLA. Therefore i assess that a further clarification of the unexpected low air velocity in the unattached jet will require comparison with measured data.

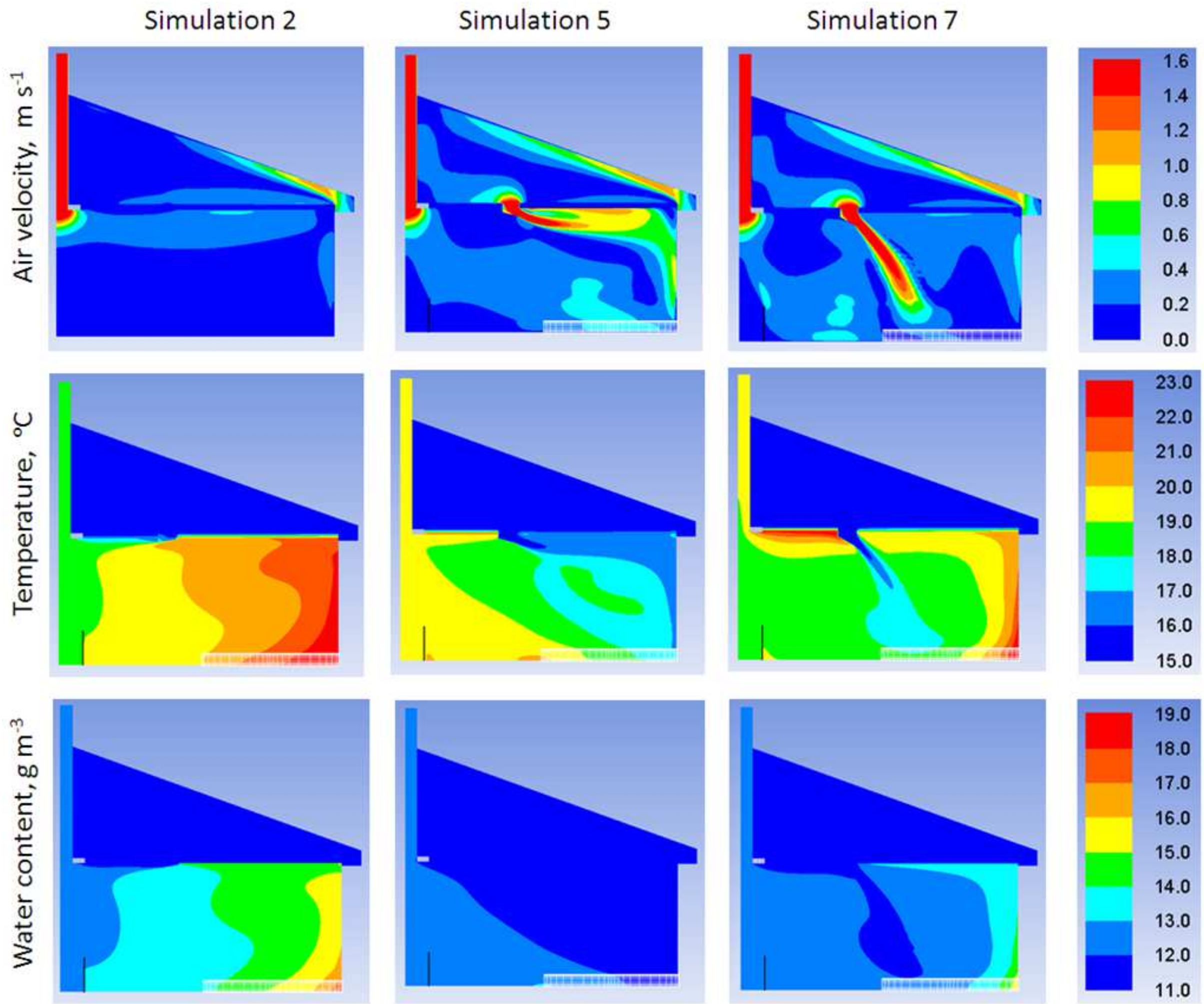

Figure 3. Simulated air velocity, temperature and water content distribution in the symmetry plan from simulation 2, 5 and 7.

4. Conclusions

The investigations showed that a ceiling jet inlet, as supplement to diffuse ceiling air inlet, could be adjusted to decrease the effective temperature in the laying area with up to approximately 6 ºC without increasing the total air change. This increased the outdoor temperature for when it began to be too warm in the preferred laying area of a partly solid floor pen from 10 to 16 ºC, and reduced periods where it was too warm from 41 to 15 % of the yearly hours.

A free jet were developed if the assumed inlet were 30 % or more open and the results showed that the largest reduction of effective temperature was obtained when the inlet where less open and generated a wall jet.

References

Bjerg, B., Zhang, G., Pedersen, P., Morsing., S. 2016. Effective temperature for poultry and pigs in hot climate. Submitted to Transaction of the ASABE

Bjerg, B., Zhang, G. and Kai, P. 2011. CFD analyses of methods to improve air quality and efficiency of air cleaning in pig production. Chapter 24 In: N. Mazzeo (ed.), Chemistry, Emission Control, Radioactive Pollution and Indoor Air Quality. InTech, ISBN 978-953-307-316-3.

Bjerg, B., K. Svidt, S. Morsing, G. Zhang and J.O. Johnsen. 2002. Modelling of a Wall Inlet in Numerical Simulation of Airflow in Livestock Buildings. Agricultural Engineering International: the CIGR Journal of Scientific Research and Development. Manuscript BC 01 001. Vol. IV. March, 2002.

CIGR. 2002. Forth report of working group on climatization of animal houses. CIGR. Research Centre Bygholm, Horsens, Denmark. ISBN 87-88976-60-2

Launder, B. E. & Spalding, D. B. (1974). The numerical computation of turbulent flows. Computer Methods in Applied Mechanics and Engineering, 3, 269-289

Møller, J. M., Lund, H., 1995. Design reference Year, DRY. Meddelelse nr 281. Laboratoriet for varmeisolering. Danmarks Tekniske Universitet.

Virding, T., 2015. Personal communication/email answer from Ansys Helpdesk, May 7 2015.