Energy Consumption and Air Quality in Growing-Finishing Pig Houses for Three Climate Regions Using CIGR 2002 Heat Production Equations

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ABSTRACT

Simulation of indoor climate, air quality and energy consumption for animal houses requires precise information on animal heat and moisture production at different housing conditions. In this article results are presented from an analysis of energy consumption for heating and ventilation of a dry and a wet growing-finishing pig house as well as on indoor climate and air quality in three climate regions in Finland, Denmark and Portugal. The analysis is based on the latest CIGR models of animal heat and moisture production on house level, not only taking the body weight, but also the feed intake into account.

Four temperature set-point levels were analyzed. As representative of a house with no bedding, an indoor start temperature set-point of 22^{o}C was used for 30 kg growing-finishing pigs. After 7 days the set-point was decreased linearly until reaching the lower temperature set-point of 18^{o}C at an end weight of 100 kg. The effect on energy consumption for heating and ventilation of houses with bedding or covered pens was investigated using three lower temperature set-point levels with start set-points of 20, 18 and 16^{o}C with the corresponding end set-points of 16, 14 and 12^{o}C.

In selecting set-point strategies for maximum relative humidity (RH), it is assumed according to CIGR recommendations, that higher RH is acceptable at lower temperatures. When normal air quality and low energy consumption is given first priority, the set-point sum of temperature (°C) and RH (%) is 90, e.g. for a 22-18°C temperature set-point level a RH set-point of 68-72 % is used. An alternative would be to use extra energy to achieve good air quality by selecting a set-point sum of 85.

The energy consumption for ventilation decreases nearly linearly with about 20 % when the start temperature for pigs of 30 kg decreases from 22 to 16^{o}C. For fans with the energy efficiency 20 000 m^3 per kWh, the energy consumption for ventilation is between 6.6 for Finland and 8.7 kWh per produced pig for Portugal for start set-point temperature of 22^{o}C. Compared to Finland the energy consumption for ventilation is approximately 6 % higher in Denmark and 32 % higher in Portugal, due to higher outdoor temperatures and hence increased ventilation need.

The energy consumption for heating under dry housing conditions is less than 1.5 kWh per produced pig in Denmark and Portugal at start temperatures up to 22^{o}C, and less than 10 kWh per produced pig in Finland. The heat consumption under wet indoor housing conditions is higher and up to 8 kWh for Denmark and up to 23 kWh per produced pig for Finland at a start temperature of 22^{o}C.

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Keywords: Pig housing, animal heat production, feed intake, ventilation rate, energy, simulation.

1. INTRODUCTION

Precise information is needed on animal heat and moisture production in simulations of indoor climate, air quality and energy consumption for growing-finishing pigs. Energy simulations were presented by Pedersen et al. (2005) for heating of a weaner house while this article is primarily dealing with the energy consumption for ventilation and heating of a growing-finishing pig house.

As discussed by Brown-Brandl *et al.* (2003), the animal latent and sensible heat production depend on several parameters like genetics, feed intake, feed composition, and housing conditions. For the period 1984-2001 they found an increase in the maintenance heat production of 19 %, due to increased lean tissue content and consequently less fat insulation.

Information on the partition of total heat on sensible and latent heat is needed at house level, taking evaporation of spilt water and water evaporated from feed and manure into account. The heat required for evaporation is taken from the sensible heat supplied by the animals. In the CIGR (2002) report, equations for heat production for growing-finishing pigs are given, not only taking the body weight, but also taking the feed intake into account.

Design rules for animal heat and moisture production have been available for decades, e.g. in Strøm (1978), ASHRAE (2001a and 2001b) and CIGR (1984, 1992, 1999 and 2002). Today, manual simulations are replaced by computer simulations, e.g. as described by Morsing & Strom (1992), Morsing et al. (1997), and Pedersen et al. (2004)

This article deals with the results from an analysis of indoor environment and energy consumption in a growing-finishing pig house using the computer program StaldVent version 5.0 (Morsing et al., 2003), in which the CIGR (2002) design equations are implemented. The program contains algorithms for the design of ventilation and heating systems based on performance data for ventilation equipment (Pedersen & Strom, 1995). The performance of the selected system is simulated over a three-year production period for all inn/all out production. The long simulation period is used to compensate for different starting time in the year. Local weather data generated by Meteonorm (2000) are used for the simulations.

Results are presented for dry and wet housing conditions in three climate regions in Europe. Four temperature set-point levels and two control strategies for indoor climate and air quality are analysed.

2. PRODUCTION, HOUSING CONDITIONS AND ANIMAL HEAT

In order to facilitate comparisons of performance, the same growing-finishing pig production, housing conditions, heating and ventilation system, and control strategies are assumed in all three climate regions.

2.1 Production

The simulations are based on a 200 pig all-in/all-out production. After three days between batches, the pigs were started at an average live weight of 30 kg. They reach the end weight of 100 kg after 84 days, assuming an average daily growth rate of 830 g, Figure 1. The relation between age and body weight is based on a smooth curve starting with a body weight of 1 kg for new-born piglet and body weights for growing-finishing pigs from 30 to 100 kg according to Danish recommendations.

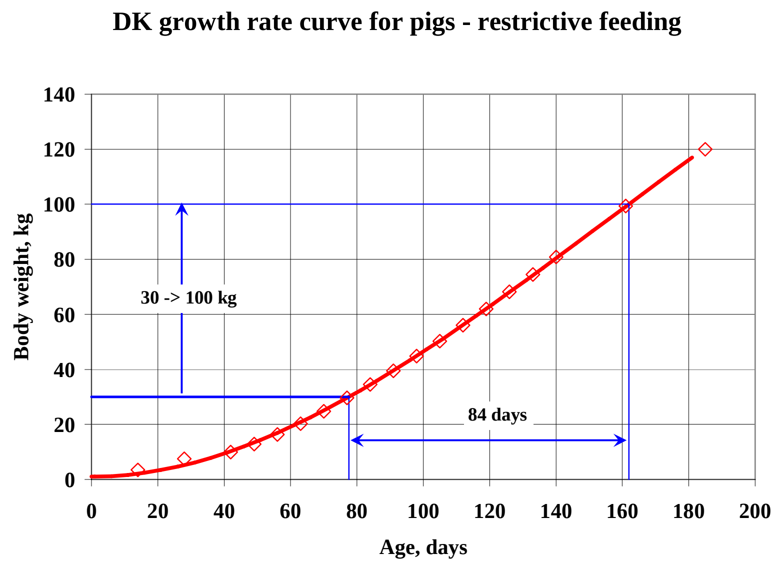

Figure 1. The time for the growing-finishing pigs to grow from 30 to 100 kg is 84 days, according to Danish recomendations for growing pigs.

The start temperature set-point was maintained for seven days before decreasing linearly to a 4 °C lower end set-point at 100 kg. The house was assumed to be empty and unheated for the three days between batches.

2.2 House

The insulated building was 10.0 m wide and 19.4 m long with 2.6 m high side walls. Assuming a 0.8 m wide inspection alley the total pen floor area was 178.5 m^2 equal to 0.89 m^2 pen floor area per pig. The ceiling was flat, and roof double sided sloped 25°.

2.3 Weather

The outdoor temperature and the relative humidity vary considerably from one region to another. Detailed information on an hourly basis is available world-wide, e.g. Meteonorm (2000). Figure 2 shows the outdoor temperatures accumulated over the year for the three following climatically different regions in Europe: North inland (Kaajani, Finland), North coastal (Karup, Denmark) and South coastal (Porto, Portugal) according to Meteonorm.

Based on the accumulated outdoor temperatures the percentiles may be calculated and used for design of the ventilation and heating system. The 1% and 99% temperature percentiles, shown in Table 1, are used in this article, i.e. on average, the heating and ventilation capacity will be insufficient only 1% of the time, corresponding to 88 hours per year, assuming constant diurnal animal heat and moisture production.

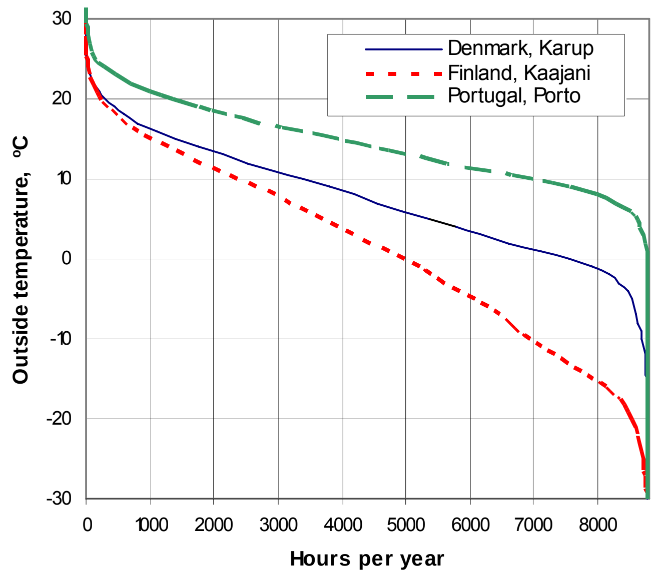

Figure 2. Outdoor temperatures in three European regions (Meteonorm, 2000)

Table 1. 1% and 99% temperature percentiles for the three selected regions

	Portugal (Porto) °C	Denmark (Karup) °C	Finland (Kaajani) °C
Outdoor temperatures exceeded 1% of time	26	23	23
Outdoor temperatures exceeded 99% of time	4	-9	-23
Annual average	14.2	7.5	2.3

2.4 Design Airflow Rate

The design airflow rate was calculated on the basis of the acceptable temperature difference between outside and inside, $\Delta t_{s\ design}$, given in Table 2. The resulting design airflow rate in Denmark and Finland was at $\Delta t_{s\ design}$ = 2.5 °C 18 900 m^3/h and in Portugal at $\Delta t_{s\ design}$ = 2.0 °C 23 700 m^3/h.

Table 2. Accepted temperature increases according to CIGR (1984) and Design Δt_s, used in this article.

Outside temperature, °C, exceeding 99% percentile CIGR (1984)	CIGR (1984) Δt_s °C	Design $\Delta t_{s\ design}$ °C	Location
18.0-20.9	4	3.5	
21.0-23.9	*3*	*2.5*	*Karup, Kaajani*
24.0-26.9	*2.5*	*2*	*Porto*
27.0-30.9	2	1.5	

2.5 Selected Ventilation System

A negative pressure ventilation system was designed based on the performance data for selected wall inlets and roof-top exhaust units. The operating point in the ventilation diagram for a system with18 inlets and 4 exhaust units was computed with StaldVent. As shown in Figure 3 the ventilation system was able to provide 23 500 m^3/h at -14.7 Pa, which is 24% more than the design target $\Delta t_{s\ design}$ = 2.5 °C for Finland and Denmark and only 1 % less than the target $\Delta t_{s\ design}$ = 2.0 °C for Portugal.

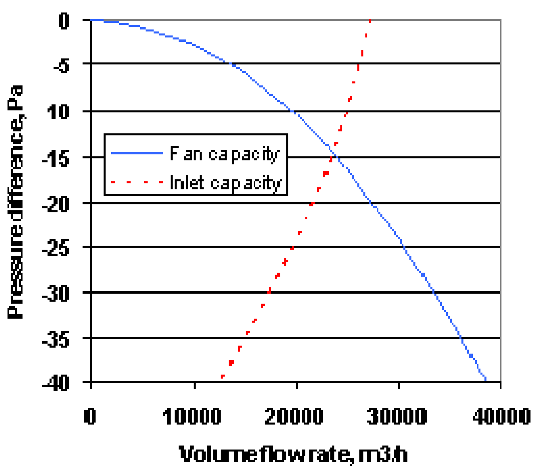

Figure 3. Ventilation diagram for a system consisting of 18 inlets and 4 exhaust units.

To keep temperature at the set–point value, the airflow rate can be controlled in different ways, e.g. using on/off fans, damper control, staged fans or frequency or voltage controlled fans in combination with damper control. The connection between air flow rate and energy consumption will depend on the chosen control strategy.

In this article the airflow rate is adjusted by fan speed, fan damper and inlet opening. At 100 % airflow rate with maximum fan speed and fully open damper and inlets the energy consumption for the four fans is 1175 W (100 %) decreasing linearly with airflow rate to 470 W (40 %) at no airflow rate as shown in Figure 4.

2.6 Design Heat Requirement

The design heat requirement was determined with 30 kg pigs in a room with a temperature set-point of 22°C. StaldVent was used to calculate the necessary heating capacity. The results were 15.350 W in Finland, and 5.600 W in Denmark. To make sure that enough heat was available to cover the requirement in all cases an over designed heating capacity of 20 kW used in the simulations.

2.7 Animal Total Heat Production

The total heat production at 20 °C for growing-finishing pigs was calculated on the basis of the CIGR (2002) equation for the total heat production due to maintenance and growth taking daily feed energy intake into account.

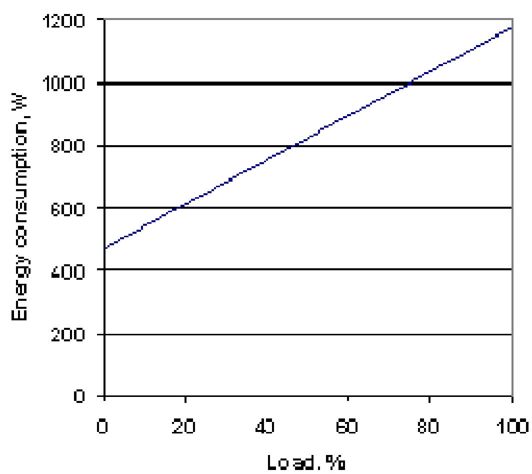

Figure 4. Energy consumption at different ventilation loads (100% = maximum fan capacity and fully open dampers and inlets)

The feed intake can be specified individually or as standard values. Table 3 shows the used n-values for restricted feeding based on Danish feeding recommendations assuming that 1 kg pig feed is equivalent to 12 900 kJ metabolizable energy. The maintenance was calculated in accordance with CIGR 2002.

Table 3. Feeding level for growing-finishing pigs expressed as n times maintenance

Body mass (m) Kg	Maintenance (n=1) MJ/day	Restricted feeding (n) (Danish recommendations)
30	5.64	3.30
40	6.99	3.31
50	8.27	3.26
60	9.48	3.19
70	10.64	3.09
80	11.76	2.98

90	12.85	2.75
100	13.91	2.54

Former recommendations for total heat production for pigs was based on a heat producing unit (HPU) that was defined as 1000 W total heat production at 20°C (Strøm, 1980). It was given as a function of live weight only and did not include the possibility to adjust for the daily feed energy intake.

Comparison between the old and the new values may be done by converting the specified feeding levels to total heat production according to the CIGR 2002 equation. The result is given in Figure 5 using the feed curves for Sweden (S-norm) and The Netherlands (NL700, NL750 and NL800) compared to the Danish recommendation (DK-restr) for growing-finishing pigs from 20 kg to 120 kg. The three curves for The Netherlands refer to 700, 750 and 800 g of average daily growth rate, and the DK-restr curve matches well with the NL750 curve. The DK-restr curve was selected as the representative for restricted feeding. It is seen that the old values for heat production as a function of body mass is close to the new DK-restr. values for pigs up to about 70 kg, but is not taking restrictive feeding for pigs above 70 kg into account.

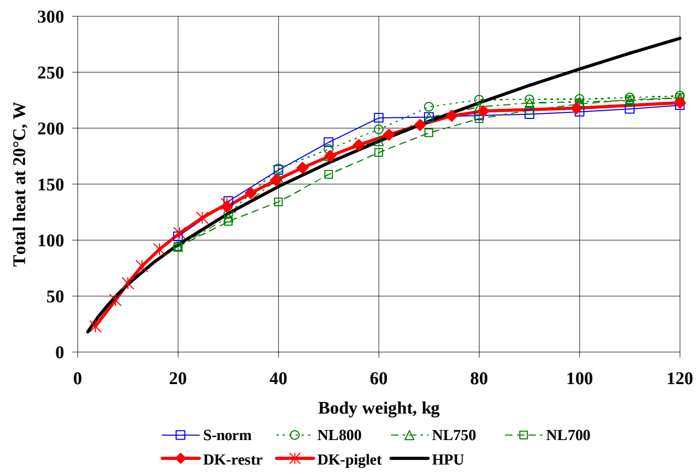

Figure 5. Total heat production for growing/finishing pigs according to heat producing units and the new CIGR 2002 recommendations.

2.8 Pigs' Sensible and Latent Heat

The distribution of pigs' total heat on sensible and latent heat is important for simulaton of both the indoor climate and the energy consumption. Figure 6 shows the distribution of total heat on sensible and latent heat for growing-finishing pigs based on results from Europe (Pedersen *et al.* 2005, CIGR 2002).

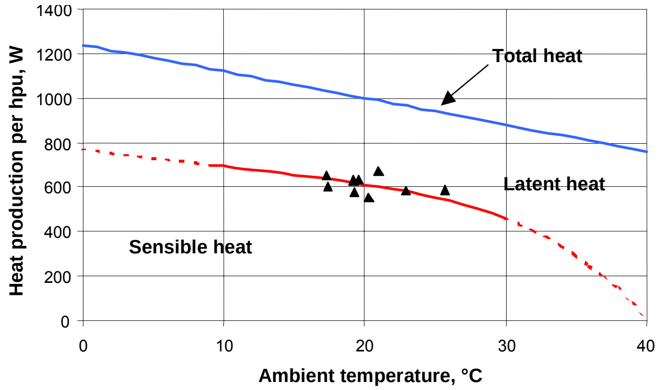

Figure 6. Total, sensible and latent heat production from fattening pigs on partly or fully slatted floor in Europe, CIGR (2002)

2.9 Set-Point Strategy

The basic set-point strategy for indoor temperature and RH specified by CIGR (1984) is used in this article (Figure 7). The set-point sum of temperature (°C) and RH (%) should be kept below 90 to avoid too high indoor RH. The strategy with set-point sum 90 will be referred to as normal air quality. The dotted curve indicates improved indoor climate with a 5% reduction in maximum, accepted RH. This strategy with set-point sum 85 is referred to as improved air quality because it results in increased ventilation and consequently reduced concentrations of carbon dioxide and other gases.

The lower, solid curve indicates the lower limit for the indoor RH in order to avoid too dry room air, which can occur during winter with increased minimum ventilation compensated with supplemental heat. This curve is not used in this article, however.

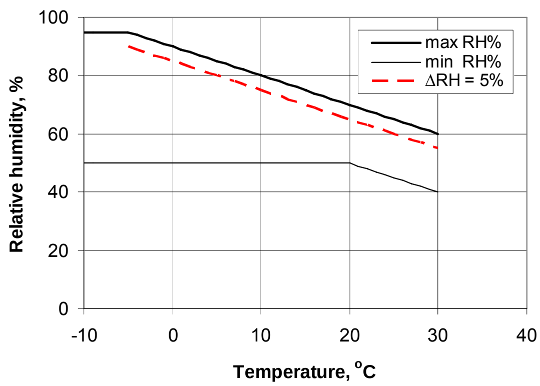

Figure 7. Recommended minimum and maximum RH as a function of room temperature. The dotted line indicates improved indoor climate by reducing the humidity set-point by 5 %.

2.10 Dry and Wet Housing Conditions

At house level some of the sensible heat from the animals may be used for evaporation of water from wet surfaces, feed, and manure. In this article it is assumed that all the sensitive heat production from the pigs is available for heating of ventilation air and covering transmission heat losses in a dry house. This is roughly the case for houses with dry feeding systems and dry floor surfaces. For wet houses it is in this article assumed that 10% of the animals sensible heat production is used for evaporation of water, i.e. a sensible heat correction factor of 0.9.

2.11 Design Criteria

An overview of the design criteria is shown in Table 4. The Meteonorm reference year provided the hourly ambient temperature and RH throughout the year. In the simulations, the need for supplemental heat is calculated hour-by-hour and summarized on a yearly basis. To equalize for different production start times, the simulations were carried out over a three-year period. The results are referring to the average energy consumption per pig during this period.

Table 4 Design criteria

Constants		Unit	Values
Herd size			200
Live weight	Start End	Kg	30 100
Management			All-in/all-out
Building dimensions	Length Width Ceiling height	m	19.4 10.0 2.6
Ceiling slope		°	0
Heat transmission coefficients	Floor Wall Flat ceiling	$Wm^{-2}\,{}^{o}C^{-1}$	0.20 0.40 0.35
Variables			
Temperature set-points		^{o}C	22-18 20-16 18-14 16-12
Set-point sum	Normal air quality Improved air quality	C + RH ≤	90 85
Feeding principle			*Restricted*
Housing condition (Sensible heat used for evaporation)	Dry Wet	Sensible heat factor	1.00 0.90

In some periods of the year, the outside air is so humid that the RH cannot be kept below the set-point value by means of heating and ventilation. Heating is therefore not applied when the ventilation airflow rate exceeds 50 % of the maximum capacity.

3. RESULTS

3.1 Energy Requirement

The energy consumption for ventilation and supplemental heat is shown in Figure 8. Energy consumption for ventilation is shown as solid lines and the supplemental heating as dotted lines. It is seen that the effect of temperature set-point level on energy consumption for ventilation is reltively small, while the requirement for supplemental heat is highly dependent on the temperature set-point levels.

3.1.1Ventilation

As expected the energy consumption for ventilation increases with increasing outside temperature. Compared to Finland the energy consumption for ventilation is 6 % higher in Denmark and 32 % higher in Portugal for a set-point temperature level of 22-18°C. In all cases the energy consumption decreased linearly with about 20 per cent for set-point temperatures level increasing from 16-12 to 22-18 °C.

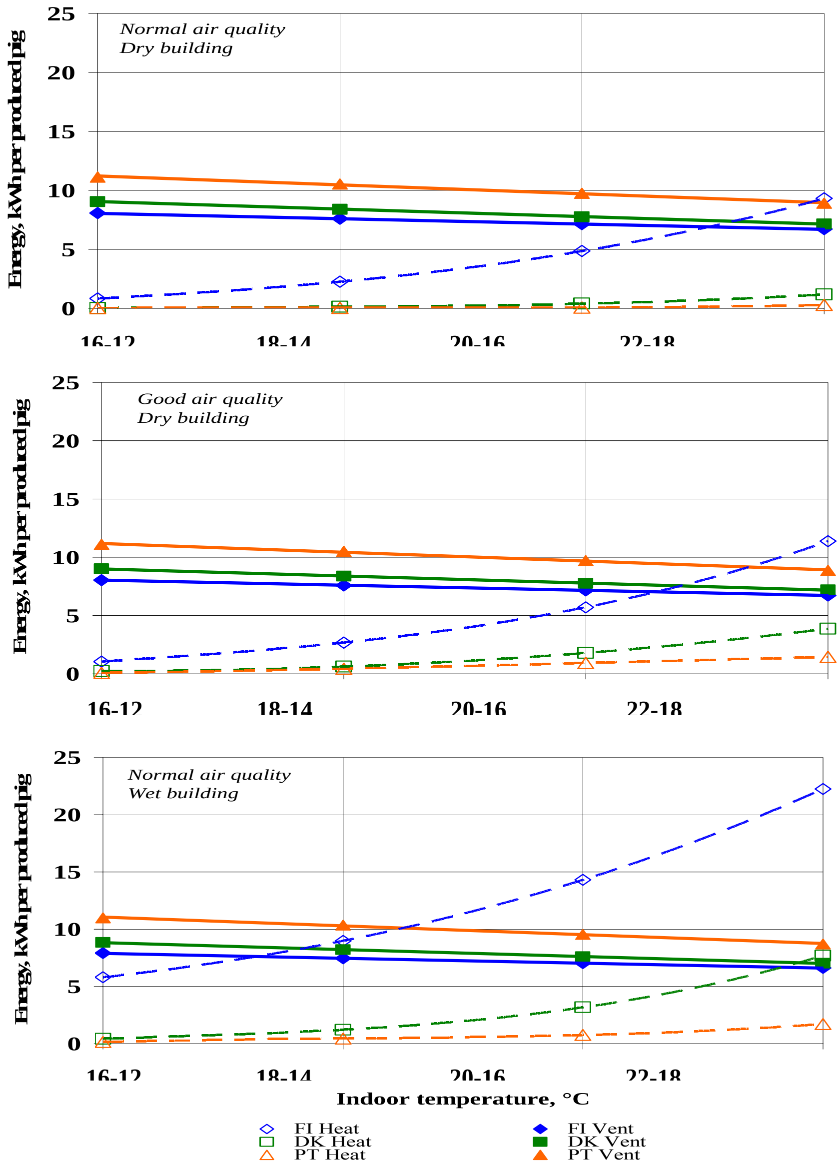

Figure 8. Energy consumption for ventilation and heating for three combinations of air quality set-points and building wetness in the three climatic zones.

With fan energy efficiency of 20 000 m^3 per kWh, the energy consumption for ventilation is between 6.6 kWh for Finland and 8.7 kWh per produced pig for Portugal for a set-point temperature level of 22-18°C. Furthermore the figures show that the energy consumption for ventilation is nearly independent of the wetness condition of the animal house.

3.1.2 Supplemental Heating

The requirement for supplemental heat is much higher in Finland than in the two other climatic zones due to lower winter temperatures. The figure also shows that the supplemental heat requirement is much higher in a wet than a dry building. Due to the mild weather insignificant supplemental heat was required for Portugal in a dry building, using normal air quality set-point strategies, but in the other two regions some heat was needed particularly at high temperature set-point levels.

As seen in the upper diagram in Figure 8, the energy consumption for heating under normal air quality strategy and dry conditions is below 1 kWh per produced pig for Denmark and negligible for Portugal for the investigated temperature set-points. For Finland the energy consumption is approximately 10 kWh per produced pig and is of the same size as the energy consumption for ventilation at set-point temperature levels of 20-16 and 22-18°C.

In the middle diagram it is seen that the energy consumption for heating at improved air quality by using a set-point sum of 85 is only slightly higher than for a set-point sum of 90.

In the lower diagram is shown the consumption of supplemental heat under wet housing conditions. The heat consumption under wet conditions is up to 8 kWh for Denmark and up to 23 kWh per produced pig for Finland at a set-point temperature level of 22-18°C.

3.1.3 Total Heat Consumption for Ventilation and Heating

In Table 5 is summarized the total energy consumption for ventilation and heating under dry respectively wet housing conditions for a set-point temperature level of 22-18°C.

Table 5. Total energy consumption for ventilation and heating at start set-point temperature of 22 °C

Country (location) Yearly average outdoor temperature	Finland (Kaajani) 2 °C		Denmark (Karup) 8 °C		Portugal (Porto) 14 °C	
Housing condition	Dry	Wet	Dry	Wet	Dry	Wet
Supplemental heat	9,3	22.3	1.2	7.7	0.3	1.7
Ventilation	6.7	6.6	7.2	7.0	8.9	8.7
Total	16.0	28.9	8.4	14.7	9.2	10.4

The table shows that the total energy consumption for ventilation and heating is 16.0 kWh per produced pig in Finland, 8.4 kWh in Denmark and 9.2 kWh in Portugal under dry housing conditions. The lowest consumption occurs in Denmark and the highest in Finland. Especially in Finland the total energy consumption is very sensitive to housing conditions, where the total heat consumption is up to 28.9 kWh per produced pig.

3.2 Air Quality

The number of hours with room CO_2 concentrations exceeding the recommended 3000 ppm limit (CIGR 1984) is shown in figure 9. Carbon dioxide concentrations above 3000

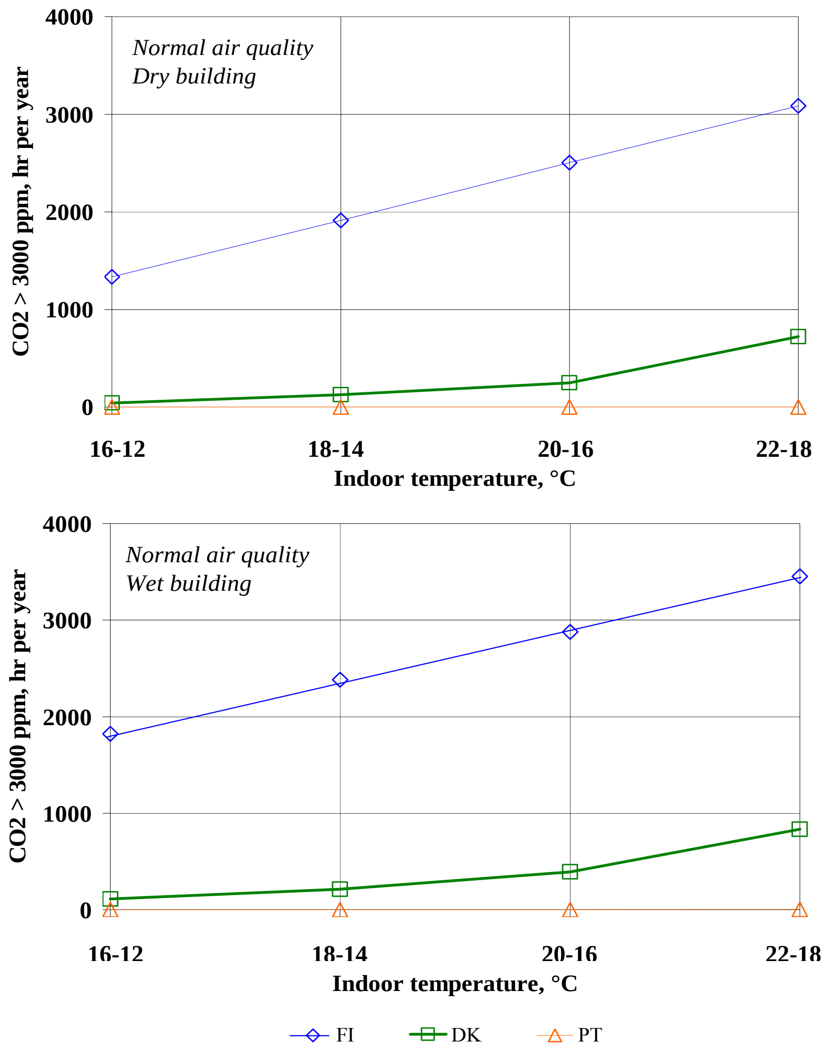

Figure 9. Hours with CO_2 > 3000 ppm for different air quality set-points and building humidity in the three climatic zones.

ppm are not critical in respect to the carbon dioxide concentrations in itself, but it is a good indicator for the indoor air quality in general. In practically all the simulated cases the air quality was acceptable in Portugal and problematic primarily in Finland.

Using the limit 3000 ppm CO_2 for acceptable air quality, unacceptable air quality occurred less than 5% of the time in Denmark, except for a temperature set-point level of 22-18°C that resulted in unacceptable conditions 10% of the time. In Finland unacceptable air quality was much more frequent, and increased linearly with set-point temperature. For the dry building it increased from 1300 hours per year at 16-12°C set-point temperature level to 3100 hours at 22-18°C. For the wet building the time with unacceptable air quality increased from 1800 to 3500 hours a year for the same temperature set-point levels.

4. DISCUSSION

In the simulations, care was taken to use realistic input assumptions, but a number of simplifications were made to be able to generalize.

4.1 Climate Zones

The three climate regions of Finland, Denmark and Portugal were selected to get specific weather data for costal climate in Southern Europe and coastal and inland climate in Northern Europe. According to Meteonorm the maximum outside temperature was fairly similar while it was primarily the number of hours with low temperature that differed. It should be noted that for inland areas in Southern Europe the summer temperatures are often considerably higher than for the coastal area selected.

4.2 Adaptation of Facility

In order to facilitate comparisons the same growing-finishing pig production, housing conditions, heating and ventilation system, and control strategies were assumed in all three climate regions. In praxis less insulation is normally used in Portugal and more insulation is used in Finland than assumed in the simulations. Regarding the maximum ventilation capacity it was close to the design target for Portugal but 24% more than the design target for Finland and Denmark.

4.3 Energy Efficiency of Fans

In order to get a system that was stable and wind resistant it was assumed that the fan dampers were adjusted proportionally to the fan voltage. In the simulations this system was characterized by energy consumption that decreased linearly from 100 % at maximum airflow rate to a minimum of 40 % at no airflow rate with fully closed fan damper and inlets. The energy consumption of a specific ventilation system can only be determined in simulations with specific performance and weather data.

The average energy efficiency in Denmark for 47 tested fans was 23 000 m^3/kWh at a pressure difference of 20 Pa (Pedersen and Strøm, 1995). Since then many of the fans in Denmark have achieved energy efficiencies better than 30 000 m^3/kWh, corresponding to a lower energy consumption than estimated. In the simulations fans with an energy efficiency of 20 000 m^3 per kWh in the whole control range were used. The yearly energy consumption will change proportionally for fans with better or worse energy efficiency.

4.4Air Quality

The strategy with set-point sum 85 is referred to as improved air quality, because the lower maximum RH set-point results in increased ventilation and reduced concentrations of carbon dioxide and other gases. The use of carbon dioxide sensor for minimum ventilation control would be more suitable for this purpose, but has so far been considered too expensive for practical use.

The number of hours with room CO_2 concentrations exceeding the recommended 3000 ppm limit (CIGR 1984) is specified for the simulated situations. Carbon dioxide concentrations above 3000 ppm are not critical with respect to the carbon dioxide concentrations in itself, but it is considered a good indicator for the indoor air quality in general. For humans, the upper limit for CO_2 is e.g. often set to 5000 ppm.

4.5 Bedding

Previously, it was common in Europe to use bedding in pig pens with solid floors. In recent decades, the tendency has been towards using slatted floors and to avoid the bedding, owing to problems involved with manure handling. However, the present opinion in Europe, in accordance with EU directives, tends to be that rooting materials are necessary. As such, it is likely that pig pens with bedding will again become common. The use of bedding has a great influence on the optimal temperature in pig houses. Bedding will thus allow a 4°C lower set-point temperature at the same production level, compared to no bedding. This again, will influence the energy consumption for supplemental heat.

Today some types of pig pens have a cover over the laying are to make a warmer micro climate than in the house. Therefore the simulations are carried out in the range from high indoor temperature set-point level of 22-18°C, corresponding to pens without bedding, down to 16-12°C, referring to pens with bedding, in combination with covered laying area.

4.6 Housing Conditions

Most experimental data on animal heat and moisture production originate from measurements in climatic chambers, where conditions deviate from conventional production conditions. It is important that guidelines for climatization of animal houses are adapted to modern production systems including water evaporated from feed, floors, spilt drinking water and the diurnal rhythm in respect to light and feeding routines. Until the ‘eighties, laboratory scale results were used directly as guidelines in practice.

In CIGR (1984), some provisory correction factors were introduced, expressing that under very dry conditions with dry floors and feed with low water content, the results from laboratory measurements could be applied directly. Under wet conditions with wet floors and feed, a correction factor of 0.9 for conversion of sensible heat should be used, i.e. 10% of the animal sensible heat is used for evaporation of water. A 10 % decrease in the sensible heat due to wet conditions may for instance lead to a considerable increase in energy consumption for supplemental heat.

An inland climatic zone with extremely high summer temperatures was not included in the simulations. The main reason for this is that little or no information is available on total heat production and the partition between sensible and latent heat particularly under practical conditions. More knowledge on animal heat and moisture production in hot climate can be expected in the coming years from a CIGR working group established in 2005 on “Animal Housing in Hot Climate”.

5. CONCLUSION

In order to get reliable information on the energy consumption for ventilation and heating of animal houses, precise information is needed on housing conditions, yearly outdoor climate, animal heat and moisture production as well as control strategy for temperature and RH set-points. For typical production conditions, the following conclusions can be made:

- The energy consumption for ventilation for growing-finishing pigs is decreasing nearly linearly with about 20 per cent when the set-point temperature level increases from 16-12 to 22-18^{o}C.
- For a fan with energy efficiency 20 000 m^3 per kWh the energy consumption for ventilation is between 6.6 kWh for Finland and 8.7 kWh per produced pig in Portugal.
- The energy consumption for supplemental heat is very sensitive to the wetness of the housing conditions. For a wet house the energy consumption for heating may be more than doubled compared to a dry house.
- The heat consumption for supplemental heat increases progressive by increased set-point temperature level and is for a dry house up to 1.5 kWh per produced pig in Portugal, 7 kWh in Denmark and 11 kWh in Finland.
- A decrease of a few per cent in maximum indoor RH set-point may result in a small increase of the heat consumption requirement due to a higher ventilation rate.
- Simulation results on supplemental heat requirements cannot be transferred from one climatic region to the other, because of complicated interactions of different parameters.
- Estimations of the supplemental heat requirement under different climatic and production conditions can easily be made by means of a computer program on the basis of specific outdoor climate according to Meteonorm and CIGR 2002 equations for animal heat production.

6. REFERENCES

ASHRAE, 2001a, Handbook, Standard.. American Society of Heating, Refrigerating, and Air-conditioning Engineers: Atlanta, GA, USA.

ASHRAE, 2001b, Handbook, Fundamentals.. American Society of Heating, Refrigerating, and Air-conditioning Engineers: Atlanta, GA, USA.

Brown-Brandl, T.M., Nienaber, J.A., Xin, H. & Gates, R.S. 2003., A Literature Review of Swine Heat and Moisture Production. Proceedings of the 2nd International Conference on Swine Housing II, October 2003: 31-40.

CIGR, 1984. Climatization of Animal Houses. Report of working group. Scottish Farm Building Investigation Unit. Craibstone, Aberdeen, Scotland.

CIGR, 1992 Climatization of Animal Houses. Second working group report. Faculty of Agricultural Sciences, State University of Ghent, Belgium.

CIGR, 1999. CIGR Handbook of Agricultural Engineering, Volume II. Animal Production & Aquacultural Engineering. Published by American Society of Agricultural Engineers.

CIGR, 2002 Climatization of Animal Houses; Working Group Report on: Heat and Moisture Production at Animal and House Level. Published by DIAS, Denmark.

WWW.agrsci.dk/jbt/spe. ISBN 87-88976-60-2.

Meteonorm, 2000. Version 4, Meteotest, Fabrikstrasse 14, CH-3012 Bern, Switzerland.

Morsing, S. & Strøm, J.S. 1992. Using test data for ventilation units for computerized system selection. International Winter Meeting. Nashville, Tennessee. ASAE Paper No. 92-4534. St. Joseph, Mich. USA.

Morsing, S., Strom, J.S. & Jacobson, L.D. 1997. StaldVent – A Decision Support Tool for Designing Animal Ventilation Systems. Proceedings from the Fifth International Livestock Environment Symposium. ASAE publication 01-97. (2): 843-850.

Morsing, S., Strom, J.S., Zhang,G.Q. & Jacobsen, L., 2003. Prediction of Indoor Climate in Pig Houses. Proceedings of the 2nd International Conference on Swine Housing II, October 2003, 41-47.

Pedersen, S. and Strøm, J.S.,1995. Performance Testing of Complete Ventilation Units, ASAE, Applied Engineering in Agriculture, Vol. 11(1):131-136., 1995

Pedersen, S., Morsing, S., Strøm J.S. & Jacobsen L. 2004. Simulation of Indoor Climate in Animal Houses using CIGR 2002 Heat Production Equations. International symposium of the CIGR Section II in Évora, Portugal, May 2004.

Pedersen, S., Morsing, S. and Strøm, J.S. 2005. Simulation of Heat Requirement and Air Quality in Weaner Houses for Three Climate Regions Using CIGR 2002 Heat Production Equations. Agricultural Engineering International: the CIGR Ejournal. Manuscript BC 05 001. Vol VII June 2005

Strøm J.S., 1978. Heat loss from cattle, swine and poultry as basis for design of environmental control systems in livestock buildings (in Danish). SBI-Landbrugsbyggeri 55, Danish Building Research Institute, Denmark. CIGR Evora, January 2005, version 1.

Strøm, J.S., 1980. Farm building design and animal heat loss. Building Research and Practice, Vol. 8(2):28-37