Simulation of Heat Requirement and Air Quality in Weaner Houses for Three Climate Regions Using CIGR 2002 Heat Production Equations

S. Pedersen, S. Morsing & J.S. Strøm

Danish Institute of Agricultural Sciences, Research Centre Bygholm, Denmark
E-mail: soeren.pedersen@agrsci.dk

ABSTRACT

Simulation of indoor climate, air quality and energy consumption for animal confinement houses requires precise information on animal heat and moisture production at different indoor temperatures. The present paper presents the results from an analysis on the energy consumption for heating of a weaner house as well as on indoor climate and air quality in three climate regions: Finland, Denmark and Portugal. Four temperature set point levels and two strategies for acceptable levels of maximum humidity are analyzed. The analysis is based on the latest CIGR update of animal heat and moisture production at a house level, not only taking the body weight, but also the feed intake and diurnal variations in animal activity into account.

As representative of a house with no bedding, an indoor initial temperature set-point of 30 °C is used for 7 kg weaners decreasing linearly until reaching 22 °C after 44 days, when the weaners are removed at a weight of 30 kg. The effect on heat consumption by using three lower temperature levels is investigated at initial temperatures of 28, 26 and 24°C, which is representative of houses with bedding or covered pens.

In selecting set-points for acceptable levels of maximum relative humidity (RH), it is assumed, according to CIGR recommendations, that higher RH will be acceptable in the case of temperature reductions. If low energy consumption is given first priority, the sum of indoor set-point temperature in degrees Celcius and set-point maximum acceptable RH in % will be 90, i.e. for a 30 °C temperature set-point, a RH set-point of 60 % is used. An alternative would be to give air quality priority by selecting a set-point sum of only 85.

An initial temperature of 30°C and a set-point sum of 90 are used as basis for the sensitivity analysis. The effect on energy consumption and air quality for 1 °C and 1 % RH set-point offset, 20% variation in diurnal activity level as well as 10% of extra sensible heat used for humidity evaporation under wet conditions are analyzed by changing each factor individually.

The analysis shows that particularly the wetness of the house due to liquid feed, spilt water and waste management will have a major impact on the heat consumption. Under Danish weather conditions and an initial set-point temperature of 30°C, the yearly heat consumption will be 6.9 kWh per produced piglet under dry housing conditions, which is only half the heat consumption of 12.2 kWh needed per piglet under wet housing conditions.

Keywords: Weaner house, animal heat production, animal activity, feed intake, ventilation rate, energy, simulation.

S. Pedersen, S. Morsing and J. Strom “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. Vol. VII. Manuscript BC 05 001. June, 2005.

1. INTRODUCTION

For simulations of indoor climate, air quality and energy consumption for heating and ventilation of animal confinement houses, precise information is needed on animal heat and moisture production at different indoor temperatures. Also, the effect of animal activity on diurnal variations is essential. As discussed by Brown-Brandl *et al.* (2003), the animal latent and sensible heat production depends on several parameters like genetics, feed intake and composition, and housing conditions. For the period of 1984-2001 they found an increase in the maintenance heat production of 19 %, due to increased lean tissue content.

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 pigs are given, not only taking the body weight, but also the feed intake into account.

Models for diurnal variations in heat and moisture production are available (Pedersen & Pedersen; 1995, Pedersen, 1996; Pedersen & Takai, 1997; Pedersen & Rom, 1998; Morsing, 2001). The heat and moisture production will typically be about 20 to 25 % above average during the day (light period) and about 20 to 25% below average during the night (dark period). This may in some cases have a significant impact on the room climate and the energy consumption.

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, as described by Morsing & Strom (1992); Morsing *et al*. (1997) and Pedersen *et al.* (2004)

This paper deals with an analysis of the indoor environment and the energy consumption for a weaner house. The analysis is performed with the computer program StaldVent (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, e.g. based on performance data for tested ventilation equipment (Pedersen & Strom, 1995). The performance of a selected system is simulated over a three-year production period including indoor climate and air quality, power consumption for ventilation and supplementary heat consumption. Local weather data generated by Meteonorm is used for the simulations.

Results are presented for the three climate regions of Finland, Denmark and Portugal. Four temperature set-point levels and two control strategies for indoor climate and air quality are analysed.

2. PRODUCTION, HOUSE AND ANIMAL HEAT

The same weaner production, housing conditions and control strategies are assumed in the three climate regions.

2.1 Production

The simulations are based on a 200-weaner all-in/all-out production. After three days between batches, the weaners are started at an average live weight of 7 kg. They will reach their end weight of 30 kg after 44 days, assuming an average daily growth rate of 522 g, corresponding to the Danish guidelines for growth rate (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 from 7 to 30 kg versus age.

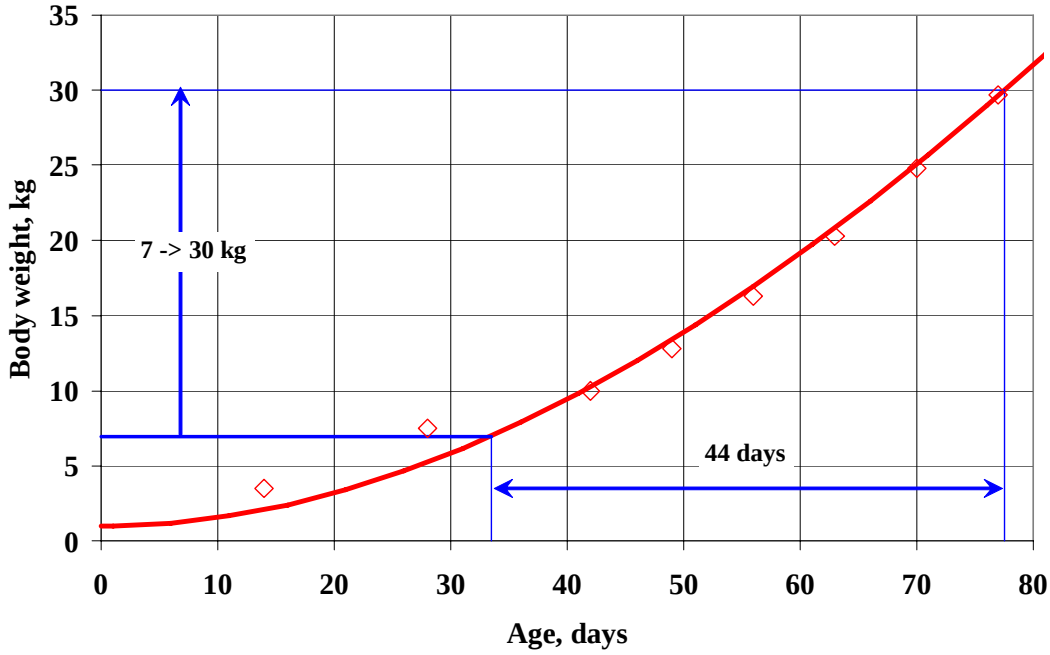

Figure 1. The period for the piglets to grow from 7 to 30 kg is 44 days, according to Danish values for piglet feeding

The initial temperature set-point is maintained for seven days before decreasing linearly by 8 °C to reach the end set-point at 30 kg. The house is assumed empty and unheated for three days between batches.

2.2 House

The insulated building is 7.5 m wide and 10 m long with 2.6 m high side walls, housing 200 pigs. The pen floor area is 0.34 m^2 per pig, assuming a 0.8 m wide inspection alley. The ceiling is flat, and the roof slope is 25° on two sides.

2.3 Weather

The outdoor temperature and RH vary considerably from one region to another. Detailed information on an hourly basis is, for instance, available world-wide in Meteonorm (2000). Figure 2

shows the outdoor temperatures accumulated over the year for the three following climatically different areas in Europe: Northern Finland (Kaajani), Denmark (Karup) and Northern Portugal (Porto), based on Meteonorm. The Figure shows that it is primarily the hours of low temperature during the winter that differ from country to country.

The 1% and 99% temperature percentiles, shown in Table 1, are used as design basis for the ventilation and heating system for the three locations. The building is insulated with U-value 0.4 $Wm^{-2}\,^{o}C^{-1}$ for the walls, 0.35 $Wm^{-2}\,^{o}C^{-1}$ for the ceiling and 0.2 $Wm^{-2}\,^{o}C^{-1}$ for the floor.

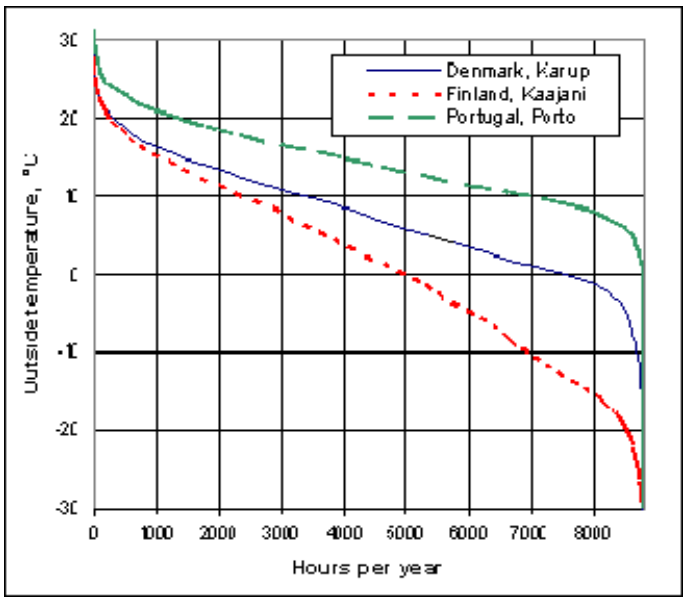

Figure 2. Outdoor temperatures in three European regions (Meteonorm, 2000)

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

	Portugal (Porto) ^{o}C	Denmark (Karup) ^{o}C	Finland (Kaajani) ^{o}C
Temperatures exceeded 1% of time	26	23	23
Temperatures exceeded 99% of time	4	-9	-23
Annual average	14.2	7.5	2.3

2.4 Summer Ventilation

The design airflow rate can be calculated on the basis of the acceptable temperature increase between outside and inside. Based on the temperatures exceeding 1 % of the time the $\Delta t_{s\ design}$, temperatures given in Table 2 are used. The resulting design airflow rate in Denmark and Finland is 10.800 m^3/h for 200 pigs. The design airflow rate in Portugal is 13.100 m^3/h for 200 pigs. The selected negative pressure ventilation system was able to provide 12.100 m^3/h at -12.6 Pa, which is 12% more than the design target for Finland and Denmark and 8 % less than the target for Portugal.

Table 2. Accepted temperature increases according to CIGR (1984) and Design Δt_s

Outside temperature, °C, exceeding 99% percentile	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	

In order to facilitate comparisons of performances, the same ventilation system is, however, used in all three countries.

2.5 Winter Heating

The design heat was determined at a 7 kg initial weaner weight and a room temperature of 30 °C. The 99 % design outside temperatures is listed in Table 1. StaldVent was used to calculate the necessary heating capacity, which was 15 kW in Finland, 10 kW in Denmark and 7 kW in Portugal.

2.6 Animal Total Heat and Moisture Production

The animal heat and moisture production was calculated on the basis of the CIGR (2002) Equation (1), where the first term expresses the total heat production due to maintenance and the second term expresses the total heat production due to production:

$$\Phi_{tot} = 7.4\ m^{0.66} + [1 - (0.47 + 0.003\ m)][n \times 7.4\ m^{0.66} - 7.4\ m^{0.66}],\ W \qquad (1)$$

where:

Φ_{tot} = total animal heat dissipation, W
m = body mass per animal, kg
n = daily feed energy intake, expressed as n times maintenance energy requirement.

The feed intake is given as n times maintenance, where the maintenance is calculated by the first term in Equation 1. Table 3 shows n-values for weaners based on Danish feeding routines assuming that 1 kg pig feed is equivalent to 12 900 kJ metabolizable energy.

Table 3. Feeding level for weaners expressed as n times maintenance

Body mass (m) Kg	Maintenance MJ/day (n=1)	Feeding level (Danish norm) (n)
5	1.85	1.93
10	2.92	2.63
15	3.82	2.96

20	4.62	3.06
25	5.35	3.08
30	5.64	3.06

Figure 3 shows the feed curves for Sweden, The Netherlands and Denmark for young pigs growing from 7 kg to 30 kg. The DK piglet curve based on Danish feeding recommendations matches well with the values given in the CIGR (2002) report.

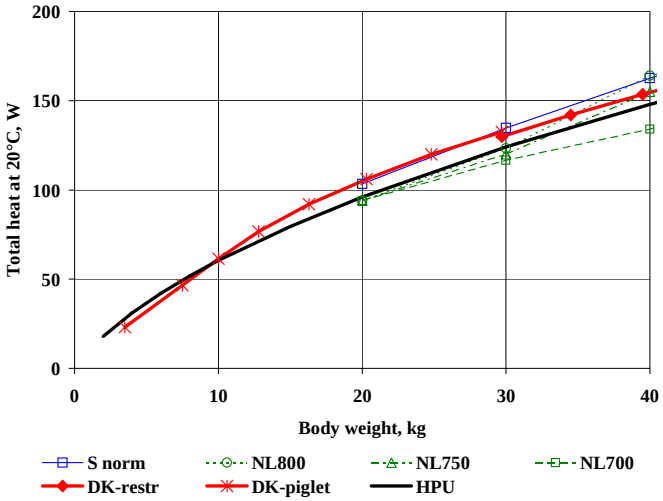

Figure 3. Feed curve for weaners

2.7 Animal Sensible and Latent Heat

The distribution of animal total heat on sensible and latent heat is important in respect to simulating both the indoor climate and the energy consumption. Figure 4 shows the distribution of total heat on sensible and latent heat for growing piglets based on results from Europe (Pedersen *et al*. 1998, CIGR 2002), where one heat producing unit (HPU) is defined as 1000 W total heat production at 20°C.

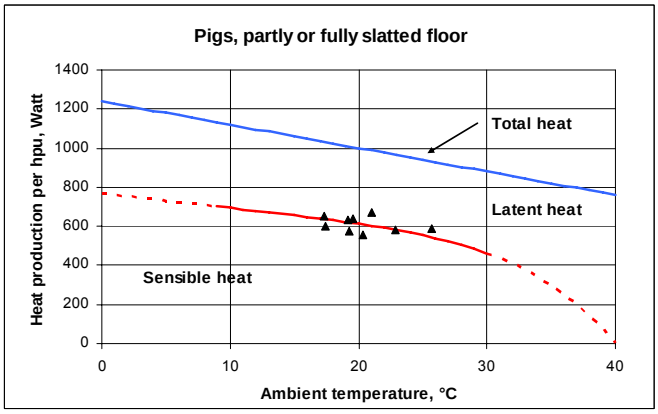

Figure 4. Total, sensible and latent heat production from pigs on partly or fully slatted floor in Europe, (CIGR 2002)

2.8 Animal Activity

The animal activity can be approximated by the following sinusoidal (dromedary) equation:

$$A = 1 - a \sin[(2\pi/24)(h + 6 - h_{min})] \quad (3)$$

where:

A = relative animal activity
a = constant
h = time of the day, hours
h_{min} = time of the day with minimum activity (hours after midnight)

Measurements (Pedersen, 1996) show that in most cases, the minimum activity occurs at about 2 a.m., and that the diurnal variations for pig houses are about 20% (a = 0.2). Figure 5 shows the diurnal variation for h_{min} = 2 and a = 0.2.

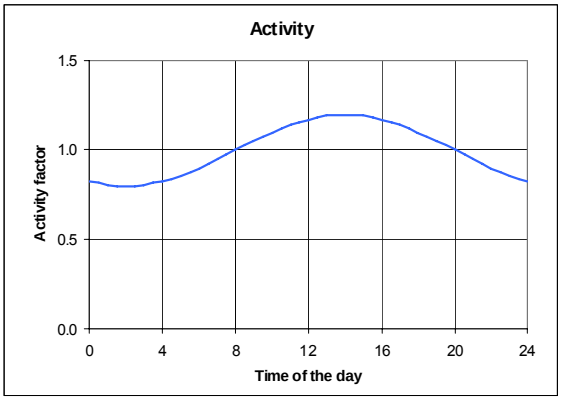

Figure 5. Standard diurnal correction of average animal heat production (dromedary model)

2.9 Design Criteria

Design criteria used are shown in Table 4. As reference for the sensitivity analysis, the temperature level of 30-22°C, representing a weaner house without bedding, is used. The Meteonorm reference year is based on hourly temperatures and RH throughout the year. In the simulations carried out in this work, the need of supplemental heat is stated hour-by-hour and summarized on a yearly basis. To equalize for different stalling times in respect to season, the calculation is carried out over a continuous three-year period, and the results are referring to the average energy consumption, meaning that the energy consumption is higher in cold periods and much lower in hot and dry periods.

Table 4. Design criteria

Constants	Unit	Weaners
Herd size, number		200
Weight range	Kg	7-30
Management		All-in/all-out
Surface area of floor	m^2	75
Surface of walls and ceiling	m^2	166
Building shell per pig	m^2	1.2
Variables		
Temperature strategies (all-in/all-out 7-30 kg)	^oC	30-22 28-20 26-18 24-16
RH % + ti $^oC \leq$		90 / 85
Feeding sheme		*Piglet ad. lib.*
Animal activity		Const./variable
Housing condition		Wet/dry

2.10 Control Strategy

The need of supplemental heat and additional ventilation capacity will, among other things, depend on the management regime, the time of the year and the control strategy. The energy and air quality effects of four temperature set point levels combined with two humidity control strategies are analyzed.

The basic relation between indoor temperature and RH (CIGR 1984) used in this paper is shown in Figure 6. As a rule-of-thumb, the figure indicates that the sum of temperature (^oC) and RH (%) should be kept below 90 to avoid too high indoor humidity. The strategy with set-point sum C + RH = 90 represents normal air quality and is referred to as Control strategy 1.

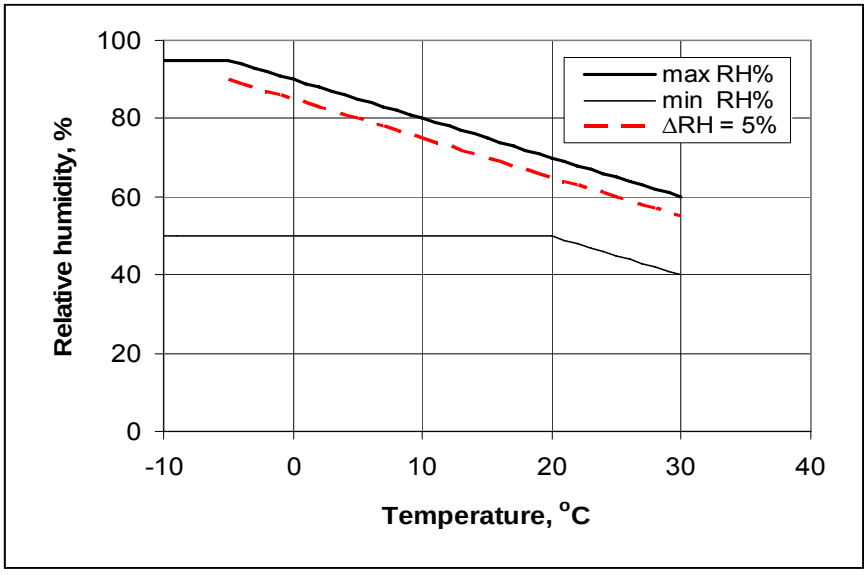

Figure 6. The recommended minimum and maximum RH as a function of inside air temperature. The dotted line indicates the improved indoor climate, by reducing the allowable maximum RH in the animal house.

The dotted curve (Control strategy 2) with set-point sum C + RH = 85 indicates improved indoor climate due to a 5% reduction in maximum accepted RH resulting in increased ventilation and reduced concentrations of carbon dioxide and other gases.

The lower curve indicates the limits of the indoor relative humidity 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 paper, however.

3. RESULTS

Figure 7 shows the need for supplemental heat on a yearly basis when the indoor climate is controlled according to Control strategy 1 for the four temperature levels. Table 5 shows the need of supplemental heat for the normal air quality Control strategy 1 and the improved air quality Control strategy 2. In some periods of the year, the humidity in the incoming air is so high that the RH cannot be kept below the set value by means of heating and ventilation. In order to avoid unnecessary waste of heat in these situations, the heating system in switched of, whenever ventilation exceeds 50%.The simulations are carried out for all-in/all-out production (7-30 kg) for the four set-point levels shown in Table 4. Houses without bedding are represented by temperatures from 30 to 22°C, while the temperatures from 24 to 16°C represent houses with bedding and houses with covered creep allowing low indoor temperatures. The simulations are carried out for a three-year period, to compensate for different batch starting times during the year.

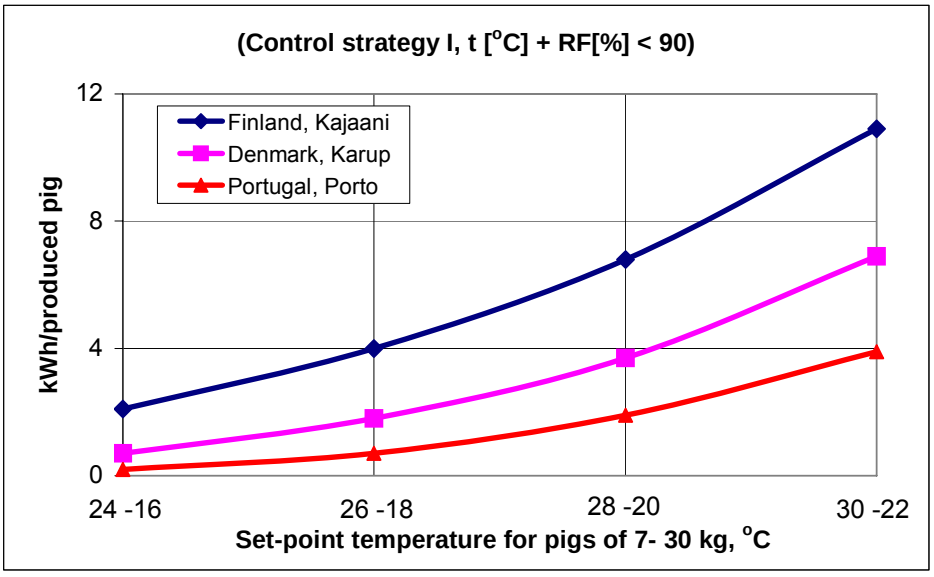

Figure 7. Supplemental heat for weaners (7-30 kg) under Control strategy I and basic conditions for constant activity and dry houses (see Table 4)

Table 5 shows that the supplemental heat requirement very much depends on the set point temperature level. It also shows that the heat requirement is much higher in Finland with low winter temperatures than in Portugal, and that the supplemental heat requirement increases from Control strategy 1 (RH % + ti ^{o}C ≤ 90) to Control strategy 2 (RH % + ti ^{o}C ≤ 85).

The table shows that the supplemental heat requirement strongly depends on the temperature strategy for Denmark and Finland, and it increases with decreased maximum acceptable RH, whereas there is no supplemental heat requirement for Portugal.

Table 5. Supplemental heat at different set temperatures and hours per year, where the carbon dioxide concentration is above 3500 ppm

Dry in accordance with Figure 2 (k_s = 1.0) and temperature and humidity control according to t,^{o}C + RH,% ≤ 85. (Control strategy 2)						
	Start	Temp/Rh	24^{o}C /61%	26 ^{o}C /59%	28 ^{o}C /57%	30 ^{o}C /55%
	End	Temp/Rh	16^{o}C /69%	18 ^{o}C /67%	20 ^{o}C /65%	22 ^{o}C /63%
Finland	Heat	kWh/piglet	3.3	5.9	9.7	14.7
	CO_2 > 3500 ppm	*h/year*	*2300*	*2750*	*3200*	*3650*
Denmark	Heat	kWh/piglet	2.3	4.2	7.0	11.1
	CO_2 > 3500 ppm	*h/year*	*200*	*300*	*400*	*500*
Portugal	Heat	kWh/piglet	1.2	2.5	4.7	7.9
	CO_2 > 3500 ppm	*h/year*	*0*	*0*	*0*	*0*
Dry in accordance with Figure 2 (k_s =1.0) and temperature and humidity control according to t,^{o}C + RH,% ≤ 90. (Control strategy 1)						
	Start	Temp/Rh	24 ^{o}C /66%	26 ^{o}C /64%	28 ^{o}C /62%	30 ^{o}C /60%
	End	Temp/Rh	16 ^{o}C /74%	18 ^{o}C /72%	20 ^{o}C /70%	22 ^{o}C /68%
Finland	Heat	kWh/piglet	2.1	4.0	6.8	10.9
	CO_2 > 3500 ppm	*h/year*	*2500*	*3000*	*3500*	*4000*
Denmark	Heat	kWh/piglet	0.8	1.8	3.7	6.9
	CO_2 > 3500 ppm	*h/year*	*350*	*800*	*1300*	*1800*
Portugal	Heat	kWh/piglet	0.2	0.7	1.9	3.9
	CO_2 > 3500 ppm	*h/year*	*0*	*20*	*50*	*50*
Wet conditions (k_s = 0.9) and temperature and humidity control according to t,^{o}C + RH,% ≤ 90 (Control strategy 1)						
	Start	Temp/Rh	24 ^{o}C /66%	26 ^{o}C /64%	28 ^{o}C /62%	30 ^{o}C /60%
	End	Temp/Rh	16 ^{o}C /74%	18 ^{o}C /72%	20 ^{o}C 70%	22 ^{o}C /68%
Finland	Heat	kWh/piglet	6.1	8.9	12.6	17.2
	CO_2 > 3500 ppm	*h/year*	*2300*	*2700*	*3050*	*3450*
Denmark	Heat	kWh/piglet	3.1	5.1	8.1	12.2
	CO_2 > 3500 ppm	*h/year*	*200*	*300*	*400*	*525*
Portugal	Heat	kWh/piglet	1.1	2.3	4.3	7.2
	CO_2 > 3500 ppm	*h/year*	*0*	*0*	*0*	*0*

3.1 Sensitivity Analyses

The influence of the most important parameters on energy consumption for supplemental heat is shown in Table 6.

Table 6. Sensitivity analyses for weaners, based on CIGR 2002 and StaldVent 2004 on a yearly basis for three climate regions

		Finland		Denmark		Portugal	
Parameter	Incre-ment	kWh/pig	%	kWh/pig	%	kWh/pig	%
Control strategy I (C+RH% ≤ 90)							
Basis (see definition in Table 5)		10.9	100	6.9	100	3.9	100
Temperature sensor offset	1 °C	12.8	117	8.3	121	4.9	123
Humidity sensor offset	1% RH	10.3	96	6.3	92	3.4	87
Animal activity, Eqn. 3 (amplitude 0.2)	0.2	10.9	100	6.9	99	3.9	99
Factor for sensible heat converted to latent heat due to wet housing conditions	0.9	17.2	158	12.2	178	7.2	182

The sensitivity analyses are carried out by changing the parameters one-by-one and keeping the others at basic values.

Referring to Danish outdoor climate and a typical production situation for weaners for the weight range from 7 to 30 kg with a linear reduction in temperature from 30 to 22 °C and Control strategy 1, the need of supplemental heat on yearly basis will be approximately 7 kWh per pig. The sensitivity analysis shows that the need of supplemental heat increases by 21 % if the temperature off-set of the thermostat is 1°C, so that at an initial set-point of 30°C, the system is actually trying to maintain a temperature of 31 °C.

If the humidity sensor is off by 1% RH at a correctly maintained temperature, e.g. indicating 60 % RH when the true value is 61 % RH, then the need of supplemental heat will be lowered by 8%.

In calculations on animal heat and moisture production, steady-state heat production is normally assumed. In real life, the activity varies in a diurnal pattern, showing lower than average activity at night and higher activity during the day. The CIGR (2002) makes it possible to take this variation into account and thus to simulate the increase in heat requirement due to lower activity and the associated heat production during the cold period of the day. Taking the diurnal variations into account, the effect on the energy consumption was less than 1 %, but the number of hours with temperatures below the set-point temperature increased due to the lower animal heat production at night, when the difference between simultaneous inside and outside temperatures is highest.

Figure 4 represents the typical production conditions for conventional farms. For very wet indoor conditions with wet feed and dirty floors, where 10 % additional animal sensible heat is converted into evaporation of water, the need of supplemental heat increases by 78%.

The sensitivity analysis clearly shows that even small errors for the sensors or small changes in set values will have a great influence on the use of supplemental heat for weaners. For Denmark,

an increase in set temperature of only 1°C will cause a 21% increase in supplemental heat, and if accepting 1% higher set value for RH, a decrease in supplemental heat of 8% will be the result. The change in supplemental heat is not linear and cannot be extrapolated far from the investigated set point values, but new calculations must be carried out. The sensitivity analysis also disclose that the need of supplemental heat is very sensitive to housing conditions. For dry conditions with only little need of heat for evaporating water from feed, manure etc., the need of supplemental heat is reduced by 78 %, compared to wet conditions.

3.2 Energy Consumption for Ventilation

The total energy consumption in animal houses comprises both energy consumption for supplemental heat and for fans in the mechanically ventilated building. The energy consumption for ventilation in weaner houses is very low, compared to the energy consumption for supplemental heat. For a mechanical ventilation system moving 18 000 m^3 of air per kWh, the energy consumption in Denmark and Finland will be around 0.7 kWh and in Portugal it will be around 0.8 kWh per pig for the production period where the pigs are weighing from 7 to 30 kg. In all examined situations the enegy consumption has been below 1 kWh. Thus, the energy consumption for ventilation will typically be about 10 % of the total energy consumption for ventilation and heating.

4. DISCUSSION

Because most experimental data on animal heat and moisture production originate from measurements in climatic chambers deviating from conventional production conditions, it is important that guidelines for climatization of animal houses are adapted to modern production systems. That is to take into account, e.g., the 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 the results from laboratory measurements could be applied directly. Under conditions with wet floors and feed, a correction factor of 0.9 for conversion of sensible heat should be used.

Today, more experimental data from production facilities is available. Instead of using correction factors, adjustments for evaporation of water is built into the design equations, as shown in Figure 4. For temperatures ranging from 15 to 30^{o}C, and under European production conditions, the partition between sensible and latent heat is documented by Pedersen *et al*. (1998). Unfortunately, little or no information is available for lower and higher temperatures under practical conditions. Another disclosure is that heat and moisture production will vary diurnally, depending on the light and feeding regimes. For pig houses in general, the heat production will be about 20-25% above average in daytime and 20-25% below average during the night.

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 will have a great influence on the optimal temperature in veaner houses. Bedding will thus allow a 4°C lower set-point temperature level at the same production level, compared to no bedding. This again, will influence the energy consumption for supplemental heat. An increase in the set temperature of 1°C will cause an increase in supplemental heat of 21% by Control strategy I. Also, the accepted maximum RH will influence the set values drastically. For example will a 1 % higher set value for RH cause a decrease of 8 % in the supplemental heat by Control strategy I.

The analyses show that only small changes in the set values may affect the supplemental heat requirement drastically. Especially the wetness in respect to spilt water and evaporation from manure, etc., will have a drastic influence on the supplemental heat requirement. A 10 % decrease in the sensible heat due to wet conditions may for instance lead to an increase in the energy consumption by about 80 %, using Control strategy 1.

5. CONCLUSIONS

The analyses show that in order to get reliable information on the energy consumption involved with heating in animal houses, precise information will be needed on housing conditions, yearly outdoor climate, animal heat and moisture production as well as diurnal animal activity and control strategy for the heating and ventilation system. For typical conditions, the following conclusions can be made:

- An increase of a few degrees of the indoor set temperatures may result in doubling of the heat consumption requirement, and vice versa.
- A decrease of accepted relative humidity of a few per cent may result in considerable increase of the heat consumption requirement due to high ventilation rate.
- 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 the outdoor climate according to Meteonorm and CIGR 2002 equations for animal heat production.
- The wetness in respect to spilt water and evaporation from manure, etc. have a drastic influence on the supplemental heat requirement. A 10 % decrease in the sensible heat due to wet conditions may for instance under Danish conditions lead to an increase in the energy consumption by about 80 %.

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. Heat and Moisture Production at Animal and House Level. Published by Danish Institute of Agricultural Sciences, 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., 2001. Heat production for weaned pigs. Danish Institute of Agricultural Sciences (unpublished).

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. & Pedersen, C.B., 1995. Animal Activity Measured by Infrared Detectors, Journal of Agricultural Engineering Research, (61): 239-246.

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., 1996. Døgnvariationer i dyrenes aktivitet i kvæg-, svine og fjerkræstalde. Delresultater fra EU-projekt PL 900703. (in Danish). National Institute of Animal Science, Denmark, Internal Report No. 66, 33 pp.

Pedersen, S. & Takai, H., 1997. Diurnal Variation in Animal Heat Production in Relation to Animal Activity. Fifth International Livestock Environment Symposium, Minnesota, USA, May 29-31. Proceedings, Volume 2: 664-671.

Pedersen, S. & Rom, H.B., 1998. Diurnal Variation in Heat Production from Pigs in Relation to Animal Activity. AgEng Oslo98. Paper 98-B-025. Published in 1999 on a CD as: pdf\b\98-B-024.pdf.

Pedersen, S., Takai, H., Johnsen, J.O., Metz, J.H.M., Groot Koerkamp, P.W.G. Uenk, G.H., Phillips, V.R., Holden, M.R., Sneath, R.W., Short, J.L., White, R.P., Hartung, J., Seedorf, J., Schroeder, M., Linkert, K.H. & Wathes, C.M., 1998. A Comparison of Three Balance Methods for Calculating Ventilation Flow Rates in Livestock Buildings. Journal of Agricultural Engineering Research. Vol. 70, No. 1, Special Issues: 25-37.

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.

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.