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Calculation method for the annual thermal heat requirement of farrowing units

The method developed for the calculation of the thermal heat requirement for farrowing units is based on the thermal energy balance in which energy gains and energy losses are compared. While the heat dissipation from animals and electrical devices, and solar heat gains positively influence the balance, transmission heat losses and ventilation heat losses have the opposite effect. In comparison to the target values the results of the calculation provide information about the energy efficiency and weaknesses of the thermal performance of buildings. At the same time, the potential of energy saving measures can be assessed.

Keywords
Annual thermal heat requirement, energy balance, farrowing unit, energy conservation

Abstract
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A lot of energy is needed to heat farrowing pens. On the one hand special attention has to be paid to the heat requirement of piglets reared in strawless pens, but on the other hand rising energy prices are increasing the pressure to economise on energy. Conclusions as to the thermal energy efficiency of a building can be drawn by comparing the thermal heat requirement calculation with target values.

The method used to calculate thermal heating requirement in existing technical standards (e.g. SIA 380/1) is not applicable to livestock housing because, by contrast with residential and functional buildings, room temperature and air flow rate are animal-dependent and hence not constant. The heat produced and dissipated by the animals, which in turn depends on housing temperature, has a considerable influence on the energy balance.

In the present study a calculation method was developed to allow the annual thermal heating requirement of farrowing units to be determined under practical conditions.

Material and method

The calculation of the annual thermal heating requirement for strawless forced ventilated livestock housing systems is based on the thermal energy balance, in which energy gains are set against energy losses. (**Figure 1**). The gains comprise internal (heat dissipation by animals and electrical devices) and solar contributions. The losses include heat lost through the building shell (transmission heat losses) and ventilation (ventilation heat losses).

Thermal heat requirement

Q_h, the thermal heat requirement to be calculated, defines the annual amount of heat required to maintain a building of a fixed area at a certain temperature level (Eq. 1). The total transmission and ventilation heat losses Q_T and Q_V need to be replaced by thermal heat in order to keep the temperature constant inside the pen. The requisite thermal heat requirement is reduced by internal and solar energy gains Q_i and Q_s [1].

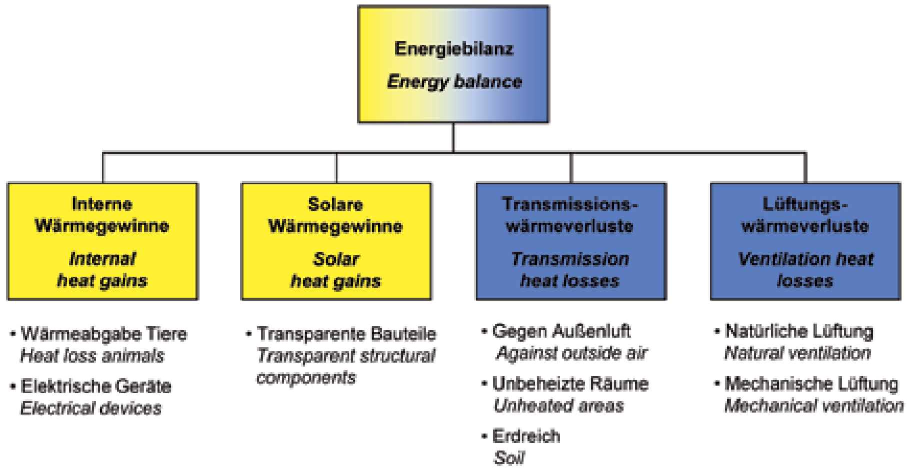
$$Q_h = \Sigma\, Q_T + Q_V - \eta_g\, (Q_i + Q_s) \quad \text{(kWh or MJ)} \qquad \text{(Eq. 1)}$$

The annual thermal heat requirement is calculated from the total thermal heat requirement for all the months in which a positive overall heat loss is incurred. Heat gains can only be used when they are less than the losses in the period under examination. The ratio of heat gains to losses and the building's heat storage capacity are accounted for using the utilisation level of heat gains η_g in Equation 1. A utilisation level figure of 1.0 can be assumed for buildings of solid construction and one of 0.9 for those of lightweight construction [2].

Transmission heat losses

Heat losses through an airtight or windproof building shell and transmission heat losses occur when there is a temperature drop between the inside and outside of the building. Specific transmission heat loss H_T defines stationary heat dissipation

Fig. 1



Heat gains and heat losses in the thermal energy balance of housing units

throughout the building shell at one degree of difference between the inside and outside temperature. It is calculated by multiplying the areas A_j, the heat transfer coefficients U_j and, if applicable, the correction factors F_{xi} for the individual structural components being totalled (Eq. 2).

When structural components are not next to outside air but adjoin unheated areas (e.g. internal wall to feed store) or soil (e.g. flooring), heat dissipation is reduced due to the smaller temperature difference between inside and outside. Correction factors conforming to the standards applicable (e.g. SIA 380/1 [1]) should therefore be taken into account when dealing with such structural components.

$$H_T = \Sigma\,(A_j \cdot U_j \cdot F_{xi}) \quad \text{(W/K)} \qquad \text{(Eq. 2)}$$

The U-value is an indicator for the heat transmission rate of structural components made from different layers of material. The mathematical determination of the heat transmission coefficient U (W/m²K) is carried out using internal and external thermal transfer resistances R_{si} and R_{se} as well as the thickness d_j (m) and specific thermal conductivity λ_j of the component layers (W/mK) (Eq. 3). Internal thermal transfer resistance is 0.13 m²K/W, the external thermal transfer resistance for components against outside air 0.04 m²K/W. The numerical values for thermal conductivity are based on manufacturers' data or building material standards.

$$U = \frac{1}{R_{si} + \sum \frac{d_j}{\lambda_j} + R_{se}} \quad \text{(W/m}^2\text{K)} \qquad \text{(Eq. 3)}$$

The annual transmission heat loss Q_T of a building defines the total amount of heat lost by transmission at a given temperature differential between pen and outside air over a period of one year. The calculation is based on a dynamic simulation in which the year is divided into time intervals (e.g. of half an hour). The heat lost from the building for all intervals is determined by multiplying the specific transmission heat loss H_T, the difference between the pen air temperature and outside air temperature ΔT (K), and the time interval Δt (h). The partial results, totalled over all the time intervals, give the monthly or yearly transmission heat lost by the housing unit (Eq. 4).

$$Q_T = H_T\,\Sigma\,(\Delta T \cdot \Delta t) \quad \text{(kWh or MJ)} \qquad \text{(Eq. 4)}$$

Ventilation heat losses

In addition to transmission heat losses, forced ventilated pens also undergo heat loss from ventilation systems which remove gases and moisture from the pen areas. Ventilation heat losses via pen fans describe a dynamic heat flow caused by the differential between the temperature of the pen air and the air supplied. Specific ventilation heat loss H_V is calculated by multiplying the requisite air rate V_{erf} (m³/h) and the specific heat storage capacity of the air $c_{pa} \cdot \rho a$ (Wh/m³K or J/m³K) (Eq. 5).

$$H_V = V_{erf} \cdot c_{pa} \cdot \rho_a \quad \text{(W/K)} \qquad \text{(Eq. 5)}$$

As a rule the CO_2 concentration of the air in the pen serves as a measure of the requisite air flow rate V_{erf}. The maximum permissible CO_2 concentration of pen air is 2 000 ppm [3].

The values of the requisite air rate are valid at an altitude of 500 m above sea level. For higher locations the numbers should be increased by 1 % per 100 m.

Table 1 shows the requisite air rate V_{erf} per animal and animal category at this maximum concentration, subject to animal body weight. The air rate required for the pen unit is obtained by multiplying the requisite air rate per animal and animal category by the number of animals in each animal category.

The specific heat storage capacity of the air, $c_{pa} \cdot \rho a$, can be calculated using Equation 6, inserting the altitude h of the housing unit above sea level in metres [1]. The specific heat storage capacity of the air is given in $J/m^3 K$. 1 000 $J/m^3 K$ correspond to 0.277 Wh/m^3K.

$$c_{pa} \cdot \rho_a = 1\,200 - (0.14 \cdot h) \quad (J/m^3K) \qquad \text{(Eq. 6)}$$

Annual ventilation heat loss Q_V is calculated along similar lines to annual transmission heat loss by multiplying the specific transmission heat loss H_V (W/K), the differential between the unit air and the air supplied ΔT (K), and the time interval Δt (h). The annual ventilation heat loss of the unit is obtained by adding up the partial results over all the time intervals (Eq. 7).

$$Q_V = H_V \, \Sigma \, (\Delta T \cdot \Delta t) \quad \text{(kWh or MJ)} \qquad \text{(Eq. 7)}$$

Internal heat gains

The internal heat gain Q_i in farrowing units includes gains from the heat produced and released by the animals Q_{iA} as well as from heat sources in piglet nests Q_{iN} (Eq. 8). This method does not take account of heat released by other electrical sources such as fans and lighting.

$$Q_i = Q_{iA} + Q_{iN} \quad \text{(kWh or MJ)} \qquad \text{(Eq. 8)}$$

Table 1

Requisite air rate V_{erf} per animal required for limitation of the CO_2-concentration to 2 000 ppm in pens [modified from 3]

Tierkategorie *Animal category*	**Körpermasse** *Body weight kg*	**Erforderliche Luftrate V_{erf}** *Requisite air rate V_{erf}* $m^3/h \cdot$ animal[1)]
Ferkel *Piglets*	2	2
	5	4
	10	7
	20	11
Jung- und Wartesauen *Gilts and pregnant sows*	150	26
	200	32
Laktierende Sauen ohne Ferkel *Lactating sows without piglets*	200	49
	250	55

[1)] Die Werte der erforderlichen Luftrate sind für eine Höhe von 500 m über Meer gültig. Für höher liegende Orte sind die Zahlen um 1 % pro 100 m zu erhöhen.
The values of the requisite air rate are valid at an altitude of 500 m above sea level. For higher locations the numbers should be increased by 1 % per 100 m.

The heat produced by an animal varies with its activity. It comprises sensible heat and latent heat. The former is released to the animals' surroundings by the transmission mechanisms of convection, radiation and conduction, the latter by transpiration and respiration. Only sensible heat features as a gain in the energy balance. The annual internal heat gain from animal heat dissipation Q_{iA} is calculated by multiplying the sensible heat released by each animal Φ_s (W) at pen temperature T, the number of animals n_j in the pen during a particular time interval, and the time interval Δt (h). Time intervals are created on the basis of a dynamic simulation and the partial results of all the intervals are added up to give the final result (Eq. 9).

$$Q_{iA} = \Sigma \, \Phi_s \cdot n_j \cdot \Delta t \quad \text{(kWh or MJ)} \qquad \text{(Eq. 9)}$$

The calculation of the sensible heat released by each animal Φ_s includes the total heat produced by each animal at 20°C Hp (W) at a pen temperature of 20°C. This is corrected to allow for the actual ambient temperature of the pen T (°C) (Eq. 10).

$$\Phi_s = [0.62 \, (1 + 0.012 \, (20\text{-}T)) - 1.15 \cdot 10^{-10} \cdot T^6] \, Hp \quad (W) \qquad \text{(Eq. 10)}$$

The total heat Hp produced by an animal at an ambient temperature of 20°C can be determined using the approach of the C.I.G.R. Working Group on the "Climatization of animal houses. Heat and moisture production at animal and house levels" [4]. Here the total heat production Hp of lactating sows with piglets is calculated by incorporating the animal's body weight m (kg) and milk yield Y1, which is inserted into the equation at 6 kg/day (Eq. 11).

$$Hp = 4.85 \cdot m^{0.75} + 28 \cdot Y1 \quad (W) \qquad \text{(Eq. 11)}$$

Total heat production Hp for pregnant sows and gilts is calculated using the animal's body weight m (kg), gestation day p (day) and daily weight increase Y2 (Eq. 12). The daily weight increase is 0.18 kg/day for pregnant sows and 0.62 kg/day for gilts.

$$Hp = 4.85 \cdot m^{0.75} + 8 \cdot 10^{-5} \cdot p^3 + 76 \cdot Y2 \quad (W) \qquad \text{(Eq. 12)}$$

The animals' body weight m (kg) is likewise taken into account when determining the total heat production of piglets from the 20th day of life. Equation 13 also includes the daily energy intake in feed based on the maintenance requirement n and assumed by the value 2.

$$Hp = 7.4 \cdot m^{0.66} + [1 - (0.47 + 0.003 \cdot m)] \, [n \cdot 7.4 \cdot m^{0.66} - 7.4 \cdot m^{0.66}] \quad (W) \qquad \text{(Eq. 13)}$$

In addition to the heat released by the animals, internal heat gains are also delivered by heat sources in piglet nests. The annual internal heat gain from electric piglet nest heating Q_{iN} is calculated by multiplying the heat released annually from each piglet nest Φ_N, taken as a flat rate of 700 kWh, by the number of piglet nests n_j (Eq. 14).

$$Q_{iN} = \Phi_N \cdot n_j \quad \text{(kWh or MJ)} \tag{Eq. 14}$$

Solar heat gains

Solar heat gains occur when solar radiation enters the building through transparent surfaces and is converted into heat. Values to be included when calculating annual solar heat gain Q_s are the specific radiation energy constant $I_{s,j}$ (kWh/m²a or MJ/m²a), reduction factors for shading F_S, frames F_F and non-perpendicular incident radiation F_W, the overall energy transmittance of glazing systems during perpendicular incident radiation $g_{\perp i}$, and the shell dimensions of window openings $A_{i,j}$ (m²) (Eq. 15).

$$Q_s = \Sigma\,(I_{s,j}\,\Sigma\,F_S \cdot F_F \cdot F_W \cdot g_{\perp i} \cdot A_{i,j}) \quad \text{(kWh or MJ)} \tag{Eq. 15}$$

The figure for the specific radiation energy constant $I_{s,j}$ will vary depending on the orientation of the transparent structural components (**Table 2**). The reduction factors for shading F_S, frames F_F and non-perpendicular incident radiation F_W are 0.9, 0.7 and 0.9 respectively. The amount of total energy transmitted by glazing during perpendicular incident radiation $g_{\perp i}$ through clear glass can be reckoned at 0.75 for double insulation glazing and 0.70 for triple insulation glazing [1], or the manufacturer's figures can be used.

Conclusions

The calculation method developed is a simple way of determining the annual thermal heat requirement for farrowing pens. The method makes reference to special livestock husbandry conditions which have not so far been taken into account by energy-saving thermal insulation. Conclusions as to a building's energy efficiency can be drawn by comparing the key values calculated with the limit and target values from technical standards. This method also permits comparison of the energy efficiency of different types of construction.

The integrated determination of the U-values of different structural components provides information on possible weak points or heat bridges in the building. The annual thermal heat requirement and its subcomponents can also be used to assess the potential for energy saving measures. Based on the amount of heat loss, for example, it is possible to estimate the energy savings and associated cost reduction achievable by installing thermal insulation or a heat recovery ventilation system.

Further research is needed into the mathematical computation of heating technology losses (final energy requirement) as well as the losses incurred when producing, processing and conveying the energy source to the point of use and distributing and storing it in the building (primary energy requirement). The use of renewable energy in covering the energy requirements of livestock housing units is particularly important in this context.

Table 2

Specific solar radiation energy constant $I_{s,j}$ for different orientations of transparent structural components [5]

Orientierung des Fensters *Window orientation*	**Spezifische Strahlungsenergiekonstante $I_{s,j}$** *Specific solar radiation energy constant $I_{s,j}$* **kWh/m²a**
Südost bis Südwest *Southeast to southwest*	270
Nordwest bis Nordost *Northwest to northeast*	100
Andere Richtungen *Other orientations*	155

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