Scenario Based Heating and Cooling Load Profiles in Piglet Production Systems

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Abstract

Highly industrialized factory farming of pigs is energy-intensive, because efficient pig production is only possible under optimal climatic housing conditions, as the highly bred breeds are temperature-sensitive. To keep production costs as low as possible, the heating and cooling supply must be operated as efficiently as possible. However, as regulatory requirements are constantly adjusted and market demand changes, pig farmers need to adapt and improve their pig production, which affects the efficiency of the heat and cooling supply concept. A case study in a large piglet farm is used to develop a tool for predicting annual heating and cooling requirements that can be used in other farms with similar boundary conditions. The tool allows a quick classification of changes in the production system in terms of their impact on heating and cooling demand. The forecast of the scenario-based heating and cooling load profiles provides an important starting point for increased efficiency and further development of a renewable heating and cooling supply concept.

Keywords: Heating demand, Cooling demand, Pig farming, Pig housing, Piglet production systems

1. Introduction

Today's world requires constant adaptation and further development of the operating conditions of piglet production systems because the demands of the market are changing, and legal requirements are constantly being increased. The pig farmers must react to the volatile conditions to be able to hold their market share. This can include structural changes to the pig housing, with an impact on the number of animal places and thus an increase in heat demand. But also optimising the housing climate through cooling during the summer months to increase the efficiency of production and wellbeing of the animals can be a measure. Each measure has an impact on the heating and cooling demand and can thus affect the efficient operation of existing heating and cooling systems. Solar cooling as cooling system could be an interesting solution, as the stables are equipped with enough roof area and thus offer good conditions for solar thermal energy. Based on measurement data collected at a piglet production system, a tool is developed as a decision-making basis for the improvement and further development of the heating and cooling supply concept. This tool aims at helping piglet farmers to consider and compare different scenarios for the heating and cooling demand in order to have a decision-making basis for the expansion, conversion, or new construction of the heating and cooling supply systems. For this purpose, the tool determines future heating and cooling load profiles based on current heat demand and housing climate data. The focus is exclusively on intensive pig production systems with an emphasis on piglet production.

2. Pig production system and requirements of indoor environment in pig housing systems

The process of pig production can be divided into piglet production/rearing and fattening of pigs. The gestation period of the sow is between 112 and 115 days. The weaned piglets remain with the sow for 21 to 28 days and are suckled by her. After weaning, the piglets are taken to the piglet housing for about 5 weeks. At a live weight of 30 kg, they are transferred from the piglet housing to the fattening housing. Piglet production/rearing extends overall over about 170 days and is thus a main driver of heat demand in the value chain of pig production (Giner Santonja et al., 2017). In all process steps of pig production, heat demand has the largest share with respect to the total energy demand (Seifert et al., 2009): Within the piglet production system, heat demand accounts for 87% of

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the total energy demand. In sow housing, heat demand has a share of 66% (Seifert et al., 2009). In consequence, heat supply has a significant impact on the energy efficiency of pig production systems.
Depending on the process stage and the age of the piglets, different house climates are optimal for the performance of the animals (Blaha et al., 2010). Tab. 1 shows the performance-oriented optimal temperatures. Those optimal air temperatures are the main reason for the heating and cooling demand in the housing.

Tab. 1: Optimal air temperature in pig housing (DIN 18910, 2017)

Pig Housing	Optimal air temperature of the stable air [°C]
Mating and gestating sows	20 to 16
Farrowing sows	20 to 16
Weaners	32 to 20
Piglets	30 to 20

3. Head demand scenario

The case study is about a German pig farm which includes 5,000 sows and 160,000 piglets per year with an annual heat demand of 5 GWh and an annual electricity demand of 2.6 GWh. Like most farmers with highly industrialised factory farming, the case study only had data about the annual electricity consumption but no information on the heat consumption. In this case study, measuring the heat demand is only possible by retrofitting appropriate heat meters, which involves a great deal of effort and costs. Due to sector-typical restrictions, mobile heat flow meters cannot be used within the stables ensuring that the animals do not get in contact with human germs. This means that mobile heat flow meters can only be installed outside the stable, for example at the heating distributer, which does not allow measurement of the individual compartments. The electricity consumption or the electricity load profile can be obtained from the energy supplier and with this, it is easily accessible. Thus, the first step is to use the electricity load profile and come to first conclusions. Focus here is the ventilation system because it impacts the housing climate and depends on the stable temperature and the outside temperature. This allows initial conclusions to be drawn about the daily/weekly/seasonal heat demand based on the electricity load profile.

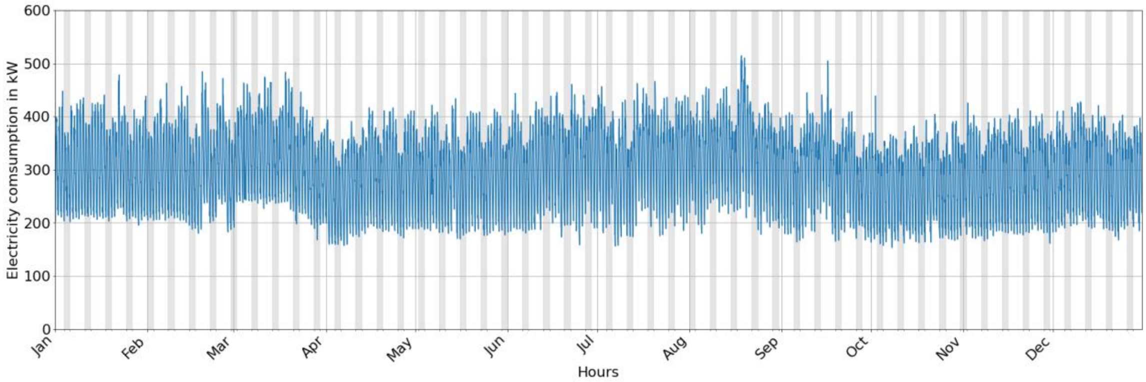

Fig. 1: Annual electricity load profile of the investigated piglet frame in hourly resolution for the year 2020

Fig. 1 shows the electricity load profile for the year 2020, which is representative in comparison to the years before. The comparison also shows that there are no significant differences between the years, which also indicates constant production and a regular cycle at farrowing, which is also assumed for the determination of the heat demand. The analysis of the profile does not indicate a strong seasonality of the electricity profile.

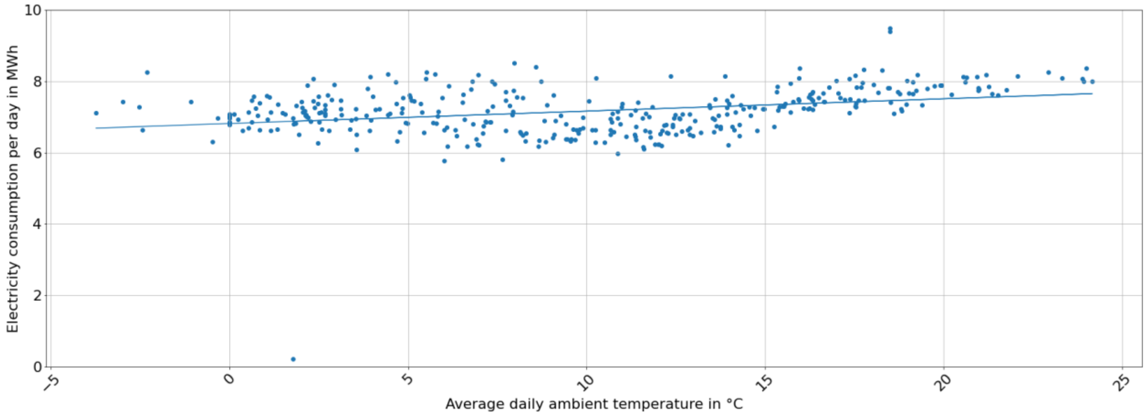

Fig. 2: Dependence of the electricity consumption on the average ambient temperature of the investigated piglet frame

In contrast to Fig. 1, Fig. 2 shows that the electricity consumption is slightly dependent on the ambient temperature. This dependency is due to the rising ambient temperatures, which leads to increased stable temperatures. To ensure the well-being of the pigs and to maintain the optimal air temperatures, the air exchange rate of the ventilation systems is increased. This dependency is also supported by the fact that in winter the air exchange rate is deliberately reduced by the farmers to reduce heat losses. Thus, the electricity load is subject to the climatic regulations of the stable and is therefore related to the heat demand. This means that the heat demand is also subject to an ambient temperature dependency as shown in Fig. 3.

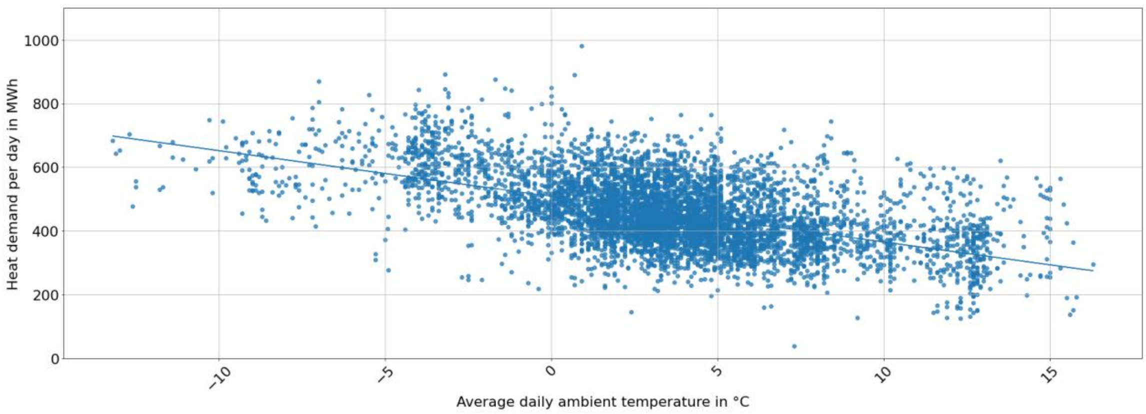

Fig. 3: Dependence of the heat demand on the average ambient temperature of the investigated piglet frame, hourly resolution

The annual load profile for the heat demand is created based on a heat flow measurement over a shorter period. The results show that there is an ambient temperature dependency of the heat load profile as found by Jesper et al., (2021). So, the heat load profile of the investigated piglet farm is calculated for the entire year as shown in Fig. 4.

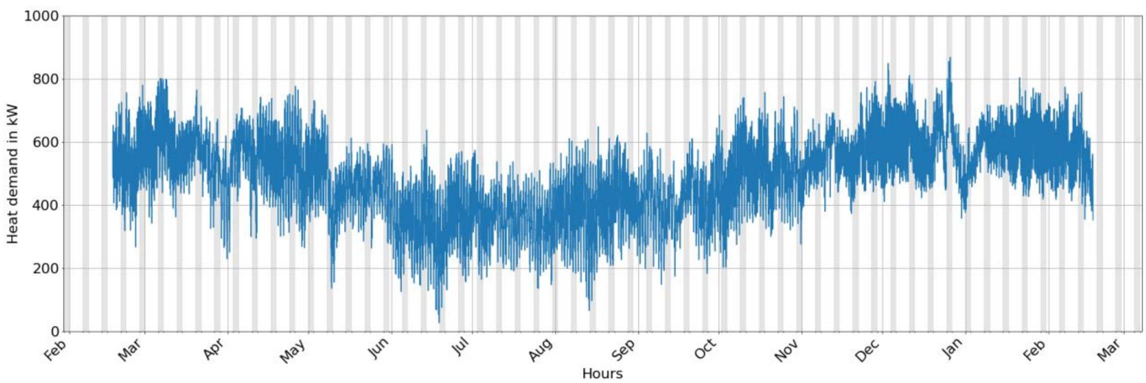

Fig. 4: Annual heat load profile of the investigated piglet frame in hourly resolution for the year 2021/22

4. Cooling demand scenario

Fig. 5 exemplifies the farrowing stable temperature of the investigated piglet frame. It shows a year-round deviation between set and stable temperature. This is probably due to faulty control, but nevertheless the deviation increases in the summer months despite the increased air exchange rate. This temperature overshoot is the main reason why some farmers have already installed cooling systems and why the cooling demand must be considered when designing an efficient energy concept.

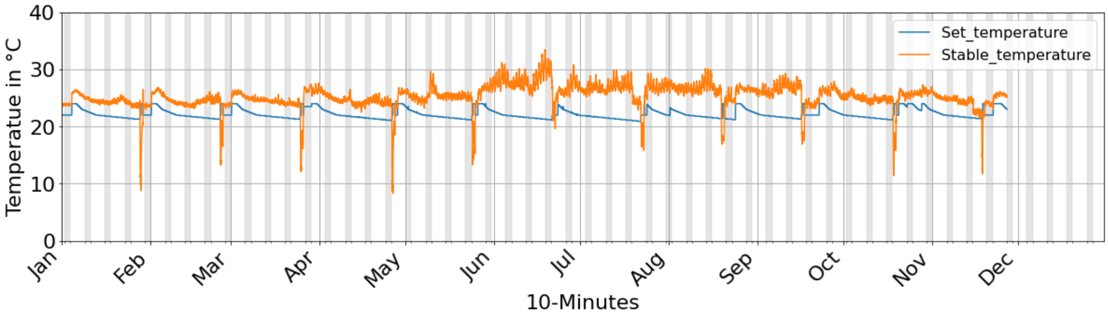

Fig. 5: Example of set temperature and stable temperature for one farrowing stable of the investigated piglet frame in 10 minutes resolution

In addition to the ambient temperature, the sensitive heat production of the animals must be taken into account when calculation the cooling demand of a stable. The decisive factors for the sensitive heat production are the number of animals per compartment, their weight, and their daily weight gain. Considering those factors, the sensitive heat production can be determined with eq. 1 according to (DIN 18910, 2017). For the case study the farrowing pen and the gilts pen are most interesting for cooling, in order to avoid overheating of the farrowing sows and to optimise production and growth of the gilts.

Sensitive heat production:

$$q_{sen} = 0.62 * q_{\ tot,cor} - \frac{q_{tot}}{1000} * (1.15 * \ 10^{-7} * T_i^6) \qquad \text{(eq. 1)}$$

Corrected Heat production on ambient temperature

$$q_{tot,cor} = \ q_{tot} * \left(1 + G * (20 - T_i)\right) \qquad \text{(eq. 2)}$$

Farrowing pen (DIN 18910, 2017):

$$q_{tot} = \ 4.85 * \ m^{0.75} + 28 * \ Y_1 \qquad \text{(eq. 3)}$$

Gilts (DIN 18910, 2017):

$$q_{tot} = 4.85 * m^{0.75} + 8 * \ 10^{\ -5} * \ p^3 + 78 * \ Y_2 \qquad \text{(eq. 4)}$$

$G = species\ specific\ gradient$
$T_i = Stable\ Temperature\ in\ °C$
$m = Weight\ animal\ in\ kg$
$Y_1 = Milk\ outpu\ in\ l/d$
$p = Pregnat\ phase$
$Y_2 = daily\ weight\ gain\ in\ kg/d$

The cooling demand for the investigated piglet farm is shown in Fig. 6, with a reasonable peak during the summer period, what makes solar cooling a suitable option to meet the demand. But must intensive pig production systems, as well as this case study have a biogas plant with an CHP unit. For the case study the cooling demand overlaps with the excess heat of the CHP unit, for most of the time as shown in Fig. 6. This makes it possible to use the excess heat for cooling the air supply by absorption cooling and adjust the stable temperatures to the optimal temperatures. This solution has the advantage of better housing climate without or only few additional energy input, as the excess heat is currently dissipated during the summer period. In the current situation, with the current incentives, solar cooling is not an attractive solution for the farms, because the excess heat from the CHP is available during the summer period.

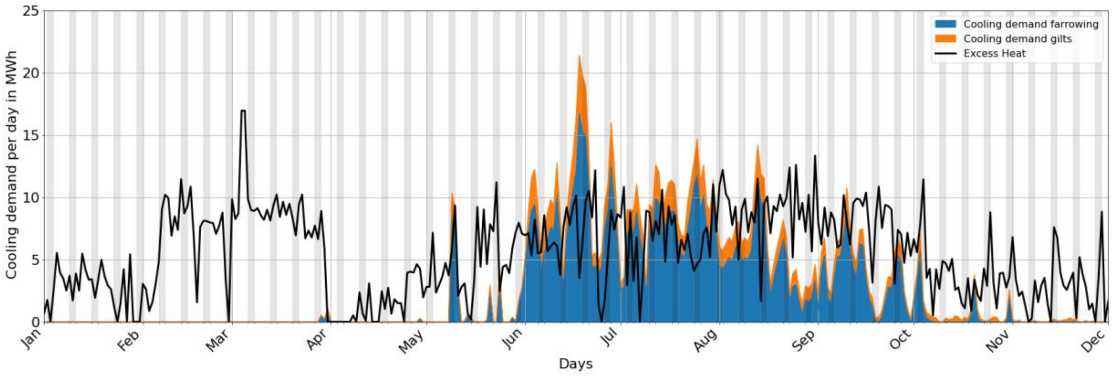

Fig. 6: Cooling demand of the stables and excess heat of the CHP of the investigated piglet farm

5. Conclusion

The consideration of different heating and cooling demand scenarios in the design of a heating and cooling supply concept offers the advantage that future changes can already be considered. Likewise, the forecast of the heating and cooling load profiles can serve as a basis for decision-making for planned measures. For detailed planning, the specific conditions of the operation site must be considered. The full paper presents the methodology how the heating and cooling load profile for a piglet farm can be calculated based on different boundary conditions such as size of the housings, number of pigs, and location as well as the installed facilities for heat recovery, cooling, etc. This methodology is exemplified by the case study but can be transferred to other intensive pig production systems, as the circumstances such as the layout of the stables and the presence of a biogas plant are very similar. The results show that the profile of the excess heat of the existing CHP, which is currently dissipated during summertime, goes along with the calculated cooling demand for the stables. In consequence, an absorption cooling process with the excess heat of the CHP is a more attractive solution to increase breading efficiency and animal welfare at the same without additional energy input, as solar cooling.

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