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Investigation of some energy characteristics of pig farm

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Abstract. Energy characteristics obtained as a result of project analysis of popular building structures designed for raising sows with piglets are presented in this study. Setting the energy features is achieved (Ordinance 15 by calculating dry, cooling and humidity load of the studied building). The parameters of the outside air according to the project calculations are temperature 36°C and relative humidity 31% (Livestock sites – design standards). After analysis on the dimensionality of the values which affect the heat flows of the building, it resulted in the following relation – showing the volume of heat incoming in the building at these particular conditions brought to 1 m³. The results obtained for the total cooling load are 1 m³ in different limited conditions. These results will allow to make a material model of the studied building, which is a premise for receiving dependences that could be used for each building. Data are obtained for specific cooling power and thermal resistances of the components in different constructional versions. The results are directed to the practice of making a suitable microclimate when using renewable energy sources in livestock buildings.

Keywords: pig’s building, energy, cooling power, criterion of similarity, analysis of dimensionality

Introduction

The main ways of coping with high temperature in the summer season in rooms for growing piglets are ventilation and the systems for evaporative cooling (Collin, 2001). These systems have substantial disadvantages. In ventilation systems the main problem is the need of large air flows, which leads to increasing the speed of air over the boxing systems (Jacobson et al., 2000, 2004; Andonov et al., 1989; Ugwushiwu, 2014). In systems for evaporative cooling a problem is the increase of relative humidity (Huynh et al., 2007; Lucas et al., 2000). At present, information for using an absorption refrigeration machine for cooling livestock buildings is scarce. This report will set early analyzing the particular case and especially the use of an absorption refrigerating machine which uses biogas as energy source.

The results of the present study are aimed at the use of renewable energy sources for cooling pig’s buildings by biogas and absorption refrigerating machine. Thereby, first off all we need to determine the needed cooling power which could cope with the heat indrafts of the building. That’s why the heat indrafts of the studied building must be calculated. So far some results regarding the heating and ventilation of a pig’s building have been published. The present work will initiate a possible solution of the problem with high temperatures during summer in pig’s buildings with the help of biogas. Biogas is derived from the waste of animals in the cooled rooms.

A research was made in cases of cooling pig’s buildings by ventilation (natural or forced) and was described in literary sources. There is no information about a detailed study of the temperature and speed fields when using an absorption refrigeration machine. The results of this study and also future studies for which the present work is a prerequisite, will give more information about the possibility of using renewable energy sources in livestock breeding, and in particular biogas as a source of energy for an absorption refrigerating machine which will be used to keep optimum temperature for animal breeding.

Recently renewable energy sources have been more and more widely used in livestock production. Lately air conditioning is considered a major factor in swine-breeding. The possibility of using biogas for air conditioning of industrial rooms with the help of absorption refrigerating machine is considered. A preparatory researches were made with positive results regarding the use of gas for such purposes. At the moment the current topic are the main energy features for helping the microclimate in industrial sites.

The goal is to get relations which could allow to predict the approximately needed power of the absorption refrigerating machine. These relations actually show the influence of different factors which determine the heat load of the building – temperature difference between the ambient air and the air in the room, the organic heat of the animals, the wind speed, intensity of the sun shine, thickness and structure of the surrounding walls and roof. The results will be received by the project calculations for the typical buildings in different conditions. Setting these relations will give us an idea about the significance of each of the listed factors. The final goal of this report is to get a dependence which contains the factors mentioned above.

Material and methods

The following is a scheme of a commonly used type of building with dimensions (Georgiev, 1983). In this case its dimensions are L – 23.5m length, D – 12m width and H1 – 3.5m, H – 2.5m height (Figures 1 and 2).

The parameters of the outside air according to the project calculations are temperature 36°C and relative humidity 31%. The desired parameters of the microclimate in the reviewed building are 25°C and relative humidity 60% (Nenov 1986). These are values...
satisfying the requirements of the Regulation for designing livestock sites. The specified temperature and relative humidity of the air are in range covering the requirements for nursing pigs and piglets (from 1 to 56 days old), shown in a table in the Regulation for designing livestock sites. When calculating the cooling load of the building the following is taken into consideration heat flow by heat transfer through thick building structures (suntlit), heat flow and sunlight through glass elements, heat flows of the animals and also humidity cooling load. There is a possibility of compensation for any heat flows of radiant heating or other animals imposed by climatic conditions.

On Figure 3 is the structure of the surrounding walls. The layers of walls are 20 mm plaster λ = 0.87 W/(m.K), 200 mm concrete λ = 1.63 W/(m.K), 50 mm insulation extruded polystyrene λ = 0.041 W/(m.K) and 20 mm plaster λ = 0.70 W/(m.K).

### Table 1. Charge on αₐ depending on the wind speed

<table>
<thead>
<tr>
<th>Wind speed (m/s)</th>
<th>αₐ W/(m².K)</th>
<th>q₁ W/(m².K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>9.5</td>
<td>21.48</td>
</tr>
<tr>
<td>10</td>
<td>12.4</td>
<td>23.89</td>
</tr>
<tr>
<td>12</td>
<td>15.92</td>
<td>26.13</td>
</tr>
</tbody>
</table>

### Figure 1. Building scheme

### Figure 2. Vertical section of building

### Figure 3. Structure of outer walls

The roof is built from metal sheets with insulation 50 mm with approximately overall heat transfer coefficient U = 0.704 W/(m².K). In determining the ratio of heat transfer from the environment, two relations are used accordingly for forced and for free convection (in no wind conditions and in case of wind). In both cases the sun shine is taken into consideration, cases for wind speed – 2, 4, 6, 8, 10, 12 m/s have been considered. The values obtained for αₐ (α – heat transfer coefficient W/(m².K)) are shown in Table 1. The cooling load of the exact building is calculated by a known method (Livestock building, 2006).

**Determining the heat flows**

Heat flux in dense building structures and elements in the sun

\[
\Phi_{i} = U A \Delta \theta_{ci} \tag{1}
\]

where U is heat transfer coefficient W/m².K, A is area of the item m², \(\Delta \theta_{ci}\) is temperature difference for cooling load (under conditions other than 35°C outside temperature and inside temperature 25.5°C \(\Delta \theta_{ci}\) is calculated).

\[
\Delta \theta_{ci} = [(\Delta \theta_{ci} + K_{q}) K_{s} + (25.5 – \theta_{i}) + (\theta_{i} – 29.4)] K_{t} \tag{2}
\]

where \(K_{q}\) is correction for a given month of the year, \(K_{s}\) is correction for color surface, \(\theta_{i}\) is air temperature in the pig livestock buildings, \(\theta_{s}\) is average temperature of the outside air and \(K_{t}\) is correction for ventilated attic space with outdoor air.

Average temperature of the outside air \(\theta_{s}\)

\[
\theta_{s} = \theta_{s}^{*} – \Theta / 2 \tag{3}
\]

where \(\theta_{s}^{*}\) is outdoor July temperatures, \(\Theta\) is daily variations of temperature for different months and regions in Bulgaria.

For reasons enough natural light, the area of influence in the windows heat flux \(\Phi_{i,F,L}\)

\[
\Phi_{i,F,L} = U A' (\theta_{s}^{*} – \theta_{ci}) \tag{4}
\]

where U is thermal transmittance through the glass elements W/m².K, A’ is area glazing elements m².

Outside air temperature for the hour of the day \(\theta_{ci}\)

\[
\theta_{ci} = \theta_{s}^{*} – \Theta \frac{K_{t}}{100} \tag{5}
\]

where \(\Theta\) is daily variations of outside temperature, \(K_{t}\) is correction of the outside temperature.

**Cooling load from solar radiation through the sunned of the glazing element** \(\Phi_{i,F,S,L}\)

\[
\Phi_{i,F,S,L} = A_{g} \Phi_{in} F_{S, SC} F_{L} \tag{6}
\]

where \(A_{g}\) is area of the glazing elements m², \(\Phi_{in}\) is maximal heat flux of diffuse radiation (w/m²), \(F_{S, SC}, F_{L}\) are correction factors.
Cooling load from internal sources \( \Phi_{\text{int}} \) of animals

\[
\Phi_{\text{int}} = n \Phi_{\text{int}}^a,
\]

where \( n \) is number of animals, \( \Phi_{\text{int}} \) is heat flux of one animal (W).

Heat flux of evaporated humidity \( \Phi_{\text{evap}} \)

\[
\Phi_{\text{evap}} = 1000 \Sigma \dot{m}_w h_w j,
\]

where \( \dot{m}_w \) is separate steam from a pig (kg/h), \( h_w \) is enthalpy of the steam at temperature equal to the temperature of the skin of the pig (kJ/kg).

Heat flux of ventilation \( \Phi_{\text{vent}} \)

\[
\Phi_{\text{vent}} = n V_{\text{a}} (h_s - h_{\text{ref}})
\]

where \( n \) is number of animals, \( V_{\text{a}} \) is required amount of fresh air for one animal (m³/s), \( h_s \) is the enthalpy of the outside air (kJ/kg), \( h_{\text{ref}} \) is the enthalpy of the air inside the building (kJ/kg).

The distribution of all heat flows is the following: dry, cooling, heat transfer - walls - south - 826.81W, north - 604.4W, east - 363.11W, west - 214.91W, ceiling - 15013W, windows - 12181W.

By sun shining - through the transparent and opaque elements - 7728.42W. Organic separated heat by animals - 12194.26W (also the heat by heating the newborn pigs is added). Humidity load - by the separated moist of animals - 4617W and by wet floor - 2579W.

The final results after processing and showing in graphic form will be useful for determination of the cooling load of such types of buildings, which is the intended final result of this work.

### Results and discussion

Currently the considered solutions of the problem dealing with high summer temperatures in buildings for raising the piglets are not so particularly reviewed in terms of energy effectiveness of the buildings. Different solutions for natural ventilation of farms for raising piglets and evaporative cooling of this type of buildings have been studied. The possibility of maintaining the desirable microclimate in buildings for raising piglets with the help of refrigerating machine, will allow to eliminate the disadvantages of the other two methods shown above. To be able to choose more powerful refrigerating machine for this case, it is necessary to determine the energy features of the building.

After the calculations made for the exact building, which is an object of the present study, we have a few dependences which will allow us to determine the specific needed quantity cold for cubic meter of volume for any building when the main features are known (thickness and structure of the surrounding walls, temperature of the ambient air in the hottest summer month, average and maximum speed of the wind for the exact region, and also the number and type of pigs which will be fedged in the building).

The distribution by shares of the heat flows in the studied building is clearly seen in the chart (Heat flows). The need of the required heat insulation of the roofs on this type of buildings, the effect of heat insulation of the surrounding walls become evident, the largest heat flow w- the animals- is also seen.

When determining the heat flows of the building three design options are considered in Table 2. To summarize the reaction of the studied building with the environment in a cooling regime, dimensionless complexes are displayed which contain specific values based on the analysis of the dimensions. In general form the dependence has the following appearance:

\[
Q = f(\Delta t, \alpha, q, \lambda, \delta)
\]

where \( \alpha_s \) is heat transfer coefficient W/(m². K), \( \lambda \) is thermal conductivity W/(m.K), \( \Delta t \) is temperature difference, \( K, \delta \) is thickness of the surrounding walls (m), \( q \) is specific individual biological heat of a farrow (W/m³), \( \Phi \) is specific cooling power (W/m³) (by taking into consideration heat flows of the radiant heating designed for the piglets in the initial period of their growth).

<table>
<thead>
<tr>
<th>Option</th>
<th>Insulated walls</th>
<th>South</th>
<th>North</th>
<th>East</th>
<th>West</th>
<th>( Q_{2}, W )</th>
<th>( Q_{2}, W/m³ )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 1</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>33235</td>
<td>47.14</td>
</tr>
<tr>
<td>Option 2</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>31668</td>
<td>44.92</td>
</tr>
<tr>
<td>Option 3</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>30641</td>
<td>43.46</td>
</tr>
</tbody>
</table>

Dependence (1) can be represented as a function depending on the type:

\[
Q = C \cdot \Delta t^a \cdot \alpha^b \cdot \delta^c \cdot \lambda^d \cdot q^e
\]

As a parameter heat transfer coefficient includes radiant components. Also different conditions are reviewed (wind speed) from 0 to 9 m/s (HVME Guide Book A, 2000) according to the recommendations.

Given the targets, it looks an acceptable equation to be submitted as a generalized dependence in accordance with recommendations. Given the existing dependence with the look of dimensionality (Huntley, 1970), the equation is written in the following way:

\[
T^{-1} \cdot H^{-1} = \Omega^{-1} (L^{-1}, T^{-1}, H, \Theta^{-1})^{-1} (L^{-1}, T^{-1}, H, \Theta^{-1}) (12)
\]

where \( T \) is dimensionless time, \( H \) is dimensionless weight, \( L \) is dimensionless length, \( \Theta \) is dimensionless temperature, these indications are common in dimensional analysis.

Finally from the equation (11) the following was derived:

\[
Q = \frac{\Delta t}{\delta} \left( \frac{q \delta}{\alpha} \right) \left( \frac{\lambda}{\alpha} \right)^d : [W/m²] \]

Formula (4) presented in dimensionless form

\[
Q \delta = \left( \frac{q \delta}{\alpha} \right) \left( \frac{\lambda}{\alpha} \right)^d \]

On Figure 4 the limited results at \( \lambda \alpha, \delta \) - min and \( \lambda \alpha, \delta \) - max, are shown. The minimal values of \( \alpha \) are in case of lack of wind, and the maximum values are at wind with speed up to 12 m/s (often reached in the area of the designed building). R-coefficient of correlation is between \( \lambda \alpha, \delta \) - min and \( \lambda \alpha, \delta \) - max The graphics show the nature of the equations describing the interval of all heat flows of the studied building.
The graphics shown on Figure 5 actually define the possible interval of the needed cold production of the accepted building standards and potential weather conditions.

**Conclusion**

The percentage alignment of the heat flows of the studied building clearly shows that the largest part is by organic heat produced by the animals. Insulation of the surrounding walls could reduce the heat flows from 4% to 8% in this particular case. The largest share of the heat flows in heat transfer are through the roof which confirms its mandatory thermal insulation. During the project calculations the influence of wind speed, and especially the increase of the outside coefficient of heat transfer up to several times have become clear. The graphics shown on figure 4 actually define the possible interval of the needed cold production of the accepted building standards and potential weather conditions. They can be used for quantitative motivated choice of absorption refrigeration installations; possible combination of such installations and also their absolute quantity.

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