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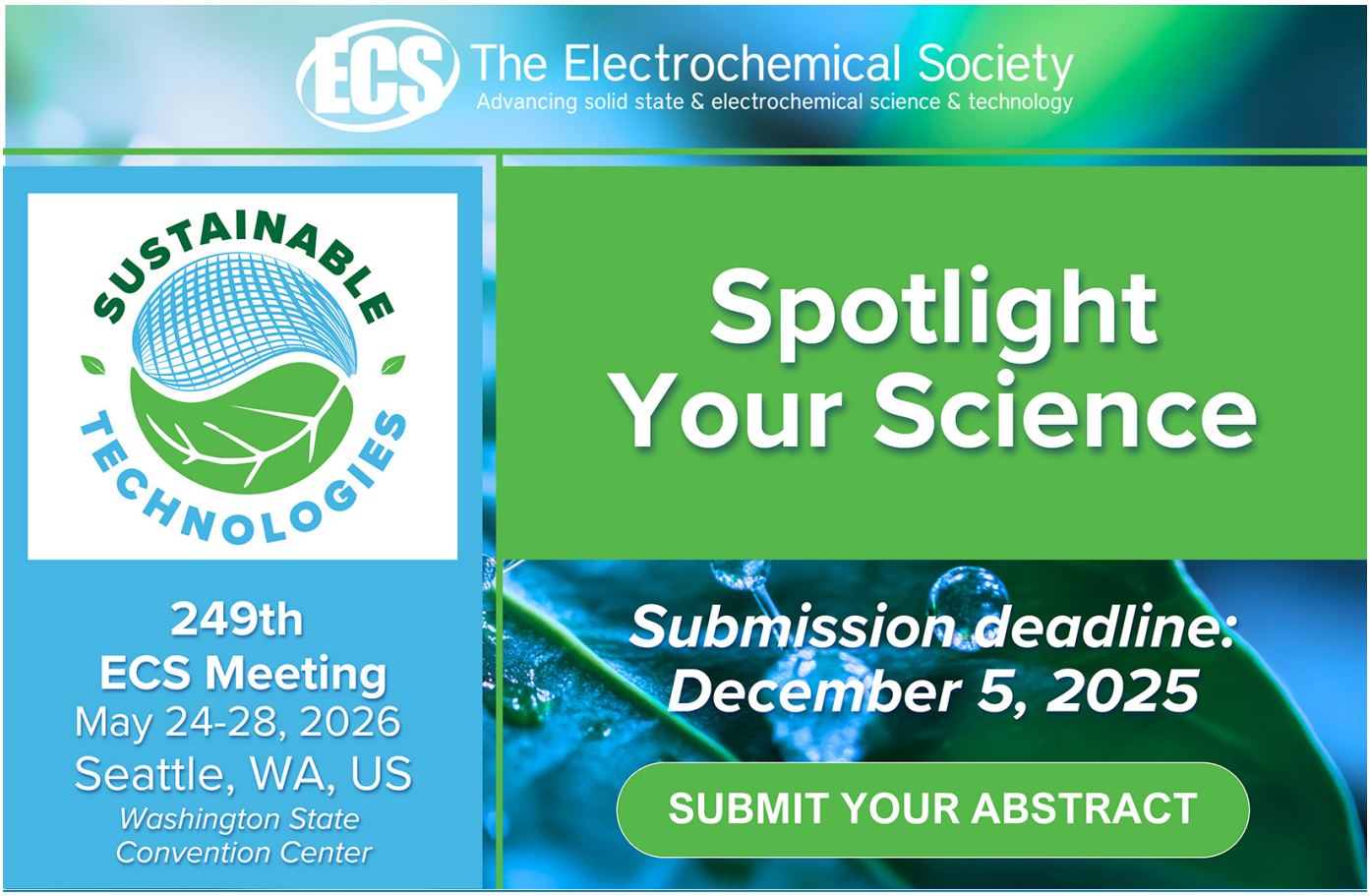
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Energy required to transfer heat through the radiant floor of a pig nursery module

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Abstract. In the present work, the principle of underfloor heating used to maintain the temperature condition inside a pig nursery module is applied. The studied system uses gas generated in a biodigester to heat water that flows through the surface of the floor and transfers heat to the interior of the module where the piglets are located. The necessary thermal load is determined based on thermodynamic analysis considering the space where the pigs are as the control volume, which presents energy losses due to temperature difference with the outside through pairs and roof, in addition to those originated by renewal of air, in the same way, the heat losses during the flow of hot water through the pipes caused by convection between the pipe and the floor and by conduction in each of these materials are determined. The water flow and temperature required in the supply line are determined to transfer adequate heat to the interior and maintain the 33 m² space at the desired temperature according to the life stage of the piglets.

1. Introduction

There are artificial systems designed and built to maintain enclosures with an adequate air conditioning system to control the environments and thus to accelerate processes in product development such as in agriculture and livestock. For this particular case there is a technique of radiant systems which have been applied for many years but have been improving according to automation and the application of more complex theories and principles that make this technique, is one of the most applicable today for various production systems, At this point it is important to emphasize that for this project we worked on the design of a system for the production of pigs, which need high temperatures in the early stages, especially in the first weeks of life, while the optimum temperature is lower towards the end of the breeding period [1].

Based on the principle of underfloor heating, it is proposed to adjust it to the thermal comfort needs according to the ages and stages of the animals [2]. The basic principle of the traditional system consists in the impulsion of water at medium temperature through polyethylene pipe circuits, these circuits are embedded in a layer of cement mortar. Underfloor heating systems (FHS) have attracted renewed interest due to their energy efficiency. They allow a good indoor thermal comfort since they provide a homogeneous surface temperature and a low value of the operating temperature [3].

In order for the temperature to stabilize, it is necessary to employ temperature controls, which are widely used in a wide variety of processes in which there are differences in magnitude that generate heat flows. Since heat is the form of energy used for transformation into different types of work, it is necessary to monitor and control the temperature variations that eventually become heat flows [4].

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2. Materials and methods

This section starts with a flow chart of the analysis of an enclosure for the calculation of the heat energy present inside the enclosure and the effects of the enclosure floor as shown in Figure 1.

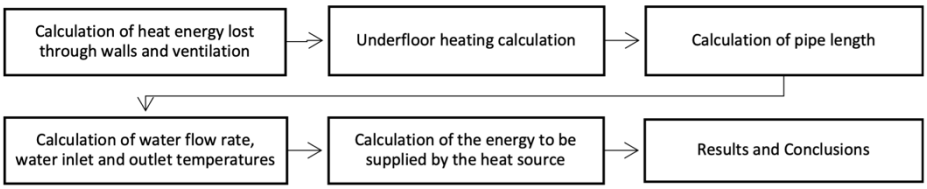


Figure 1. Work methodology diagram.

2.1. Calculation of heat energy lost through walls and ventilation in then closure

Pig farms are not thermally insulated enclosures and much of the heat energy is lost. To estimate these thermal load losses, the DIN EN 12831 standard will be followed, in which basically two parameters must be calculated [5]:

- Losses due to temperature difference
- Losses due to air renewal

These losses are added according to Equation (1) according to DIN EN 12831 [5], involving heat by temperature difference in the Equation (2) and heat by ventilation losses in the Equation (3) and correction coefficient by thickness, where **k** is the thermal conductance and **λ** is the thermal conductivity coefficient is calculated in the Equation (4).

$$\dot{Q}\text{total} = \sum\left(\dot{Q}\text{temperature} * \text{Fk} + \dot{Q}\text{ventilation}\right), \tag{1}$$

where:

$$\dot{Q}\text{temperature} = \text{Area} * \text{k} * (\text{Tint} - \text{Text}) * \text{Fk}, \tag{2}$$

$$\dot{Q}\text{ventilacion} = 0{,}34 * \text{Vmın} * (\dot{\text{T}}\text{int} - \text{Text}), \tag{3}$$

$$\text{k} = \frac{\lambda}{\text{width}}. \tag{4}$$

2.1.1. Losses due and ceiling of the enclosure to temperature difference in walls, floor. To start this calculation, it is necessary to know the materials of which each of the elements involved in heat transfer is composed, so Table 1 was prepared to know element by element, in this case only the elements that are not insulated are considered:

Table 1. Temperature correction factor fk, by the simplified calculation method, according to the DIN EN 12831 Standard [5].

Thermal loss	fk	Observation
Directly to the outside	1.40	If thermal bridges are not insulated
Directly to the outside	1.00	For Windows, doors
Towards an unheated space	1.12	If thermal bridges are not insulated
Towards the field	0.42	If thermal bridges are not insulated

To start the calculation, it is necessary to know the dimensions of the floor of the hatchery. That is 33 m², areas of walls and ceiling, and calculate the heat losses per zone of the hatchery, the losses are shown in Table 2. Then they are wasted 1482 W are used between the outside temperature and the inside temperature with conduction of the materials with which the hatchery is built.

Table 2. Heat loss per hatchery zone.

Zone	quantity	fk	Area (m^2)	k (W/m^2 °C)	Text (°C)	Tint (°C)	Q (W)
North wall	1	1.40	18.24	0.51	10	30	260
South wall	1	1.40	18.24	0.51	10	30	260
East wall	1	1.40	10.56	0.51	10	30	151
West wall	1	1.40	10.56	0.51	10	30	151
Roof	1	1.26	33.44	0.51	10	30	430
Ground	1	0.42	33.44	0.51	10	30	78
Doors	2	1.00	2.28	0.28	10	30	101
Windows	5	1.00	1.00	1.11	10	30	51
Losses through walls and roof							1482

2.1.2. Air renewal losses inside the enclosure. The volume of the room to be heated is 100 m^3, the lattices are open 24 hours, so it is calculated with Equation (5).

$$\mathrm{Vmin} = \frac{\mathrm{Volume}}{\mathrm{time}} = 100\frac{\mathrm{m}^3}{24\,\mathrm{h}} = 4.2\frac{\mathrm{m}^3}{\mathrm{h}}. \tag{5}$$

Equation (3) is then used to calculate the ventilation heat requirement, Equation (6).

$$\mathrm{VQventilation} = 0.34 * 4.2\frac{\mathrm{m}^3}{\mathrm{h}} * (30-10)°\mathrm{C} = 28\,\mathrm{W}. \tag{6}$$

Therefore, the total amount of energy that is lost through the walls, floor, and ceiling, as well as for ventilation of the enclosure and to maintain the enclosure at the 30 ºC that the pigs need for comfort represented in Equation (7).

$$\dot{\mathrm{Q}}\mathrm{total} = 1482\,\mathrm{W} + 28\,\mathrm{W} = 1510\,\mathrm{W}. \tag{7}$$

2.2. Underfloor heating calculation

From DIN EN 1264 [6] we have the Equation (8) to calculate the maximum heat flux per unit area, knowing the average floor temperature (Tfloor) and the design temperature of the interior of the place to be heated (Tint).

$$\mathrm{q_{max}}\left(\frac{\mathrm{W}}{\mathrm{m^2}}\right) = 8.92(\mathrm{T_{floor}} - \mathrm{T_{int}})^{1.1}. \tag{8}$$

Replacing in Equation (8) the values of the temperature in the floor and in the interior, we obtain Equation (9).

$$\mathrm{q_{max}} = 8.92(30-10)^{1,1} = 240.72\frac{\mathrm{W}}{\mathrm{m^2}}. \tag{9}$$

But in Equation (7) the total thermal loads were calculated so that the temperature that the enclosure requires to be maintained at 30 °C, dividing by the floor area we obtain the design heat in the Equation (10). By comparing $\mathrm{q_{max}}$ in the Equation (9) is higher than $\mathrm{q_{design}}$ in the Equation (10), it is ensured that the floor can provide the necessary energy to maintain the floor at the temperature needed by the hatchlings in the first weeks of life, 30 °C.

$$\mathrm{q_{diseño}} = \frac{\mathrm{Q\,total}}{\mathrm{AREA\,suelo\,radiante}} = \frac{1510\,\mathrm{W}}{33\,\mathrm{m2}} = 46\frac{\mathrm{W}}{\mathrm{m^2}}. \tag{10}$$

2.3. Calculation of pipe length

The temperature on the ground should be uniform in all zones, it is installed 20 cm apart, and the pipe material is polyethylene with aluminum middle layer and ½ inch diameter. The length of the pipe is calculated in Equation (11) for an area of 33 m^2.

$$L = \frac{\text{area (radiant floor)}}{\text{separation (pipe)}} = \frac{33\ m^2}{0.2\ m} = 165\ m. \tag{11}$$

This session also specifies the thicknesses of the layers of the materials, which heat conduction from one material to another behave as resistors, as shown in Figure 2; the dimensions of these layers are also specified in Table 3.

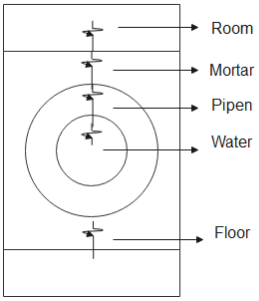


Figure 2. Layers of materials through which heat is conducted.

Table 3. Dimensions of radiant floor components.

Characteristics	Size (mm)
Insulation (thickness)	25
Pipe	12
Towards an unheated space	16
Concrete (thickness)	100

2.4. Calculation of water flow rate, water inlet and outlet temperatures

For the calculation of the flow rate and the inlet and outlet water temperature, the heat transfer analysis will be made and then checked with UNE EN 1264 (Water based surface embedded heating and cooling systems Part 3: Dimensioning) [6]. First the thermal resistances in the whole system must be identified as shown in Figure 2. The water flows in the pipe at temperatures ranging from 50 ºC at the inlet and 40 ºC at the outlet, a heat transfer to the lower floor (ground) and the upper floor (indoor environment) will occur. For this we have Equation (12).

$$\dot{Q}_{total} = \dot{Q}_{ground} + \dot{Q}_{room}. \tag{12}$$

To calculate the heat transfer it is necessary to know all the thermal resistances, therefore it will be important to know the Nusselt Number of the water [7] to find its convective coefficient and it is also known that the temperature of the floor of the room must be at 30 ºC. The water is impelled at a rate of 0.12 m^2/h, through the polyethylene pipe of ½ inch equivalent 12 mm internal diameter, the water velocity will be in the calculated in Equation (13), the mass flow in the Equation (14), Reynolds number and Prandtl number in the Equation (15) and Equation (16) are also calculated respectively [8,9].

$$v_{water} = 0.2947\ m/s, \tag{13}$$

$$flowo_{massic} = \frac{\pi * D^2_{int}}{4} * v_{water} * \rho = 0.033\ Kg/s, \tag{14}$$

$$Re = \frac{\rho * \upsilon * D_{int}}{\mu}, \tag{15}$$

$$Pr = \frac{\mu * Cp}{k_{water}}. \tag{16}$$

After determining the Reynolds number and the Prandtl number with Equation (15) and Equation (16) respectively, the values are replaced in Equation (17) to determine the Petukhov, Gnielinski relation, and with Equation (18) the Nusselt number is calculated.

$$\zeta = \frac{1}{1.82\log(\mathrm{Re}-1.64)^2}, \tag{17}$$

$$\mathrm{Nu} = \frac{\mathrm{Pr}\,(\mathrm{Re}-1000)(\zeta/8)}{1+12.7(\mathrm{Pr}^{2/3}-1)\sqrt{\zeta/8}} * \left[1 + (\mathrm{D_{int}}/\mathrm{L})^{2/3}\right]. \tag{18}$$

Finally, the converted coefficient of water is represented in the Equation (19).

$$\alpha = \frac{\mathrm{Nu}*\mathrm{k}}{\mathrm{D_{int}}}. \tag{19}$$

The physical characteristics of water are Table 4 [10].

Table 4. Characteristics and properties of water.

Characteristics of water		Value
Water viscosity	μ	$6.53 * 10^{-4}\ \mathrm{Kg/m} * \mathrm{s}$
Specific heat of water	Cp	$4.179\ \mathrm{KJ/Kg} * °\mathrm{C}$
Thermal conductivity of water	k	$0.58\ \mathrm{W/m} * °\mathrm{C}$

With the above values, the factors of Equation (15), Equation (16), Equation (17), Equation (18) and Equation (19) are calculated, and their values are shown in the Table 5. The values in Table 4 are replaced in Equation (19) and the converted water coefficient is calculated by Equation (20) [11].

$$\alpha = \frac{\mathrm{Nu}*\mathrm{k}}{\mathrm{D_{int}}} = 2889\,\frac{\mathrm{W}}{\mathrm{m}^2}°\mathrm{C}. \tag{20}$$

2.5. Calculation of the total energy to be supplied by the heat source

Again, taking Equation (12) is separated for the heat flux into the room, Equation (21).

$$\dot{\mathrm{Q}}_{\mathrm{habitación}} = \frac{\mathrm{T_{half-water}}-\mathrm{T_{room}}}{\frac{1}{\alpha}+\frac{\ln(\mathrm{D_{ext}}/\mathrm{D_{int}})}{2\pi\mathrm{L}\lambda_{\mathrm{pipe}}}+\frac{1}{\mathrm{k_{mortar}Área_{ground}}}+\frac{\mathrm{T_{floor}}-\mathrm{T_{room}}}{\varepsilon\mathrm{Area_{floor}}\sigma(\mathrm{T_{floor}}^4-\mathrm{T_{room}}^4)}}. \tag{21}$$

Equation (21) can be simplified by changing the denominator terms to resistances of each of the zones, Equation (22) [12].

$$\dot{\mathrm{Q}}_{\mathrm{room}} = \frac{\mathrm{T_{half-water}}-\mathrm{T_{room}}}{\mathrm{R_1}+\mathrm{R_2}+\mathrm{R_3}}. \tag{22}$$

For the development of Equation (22) the thermal resistances in each of the materials must be calculated and are summarized in the Table 5.

$$\dot{\mathrm{Q}}_{\mathrm{room}} = \frac{\mathrm{T_{half-water}}-\mathrm{T_{room}}}{\mathrm{R_1}+\mathrm{R_2}+\mathrm{R_3}}, \tag{22}$$

The energy lost to the bottom of the earth must also be calculated with Equation (23).

$$\dot{\mathrm{Q}}_{\mathrm{tierra}} = (\mathrm{T_{half-water}} - \mathrm{T_{floor-room}}) * \mathrm{Área_{ground}} * \frac{\lambda_{\mathrm{insulstion}}}{\mathrm{thickness_{insulation}}} = 924\ \mathrm{W}. \tag{23}$$

And finally, the energies conducted into the room and into the earth are added, Equation (24).

$$\dot{\mathrm{Q}}_{\mathrm{total}} = \dot{\mathrm{Q}}_{\mathrm{tierra}} + \dot{\mathrm{Q}}_{\mathrm{habitación}} = 4954 + 924 = 5878\ \mathrm{W}. \tag{24}$$

Table 5. Thermal resistance.

Thermal resistance in each zone	Value
R1: Pipe resistance	$0.9914 * 10^{-3}$ °C/W
R2: Resistance of mortar	$2.3310 * 10^{-3}$ °C/W
R3: Resistance in the room	$1.72368 * 10^{-3}$ °C/W
$T_{half-water}$	55° C
T_{room}	30°C

3. Results

In the DIN EN 12831 [5], the heat transmission factors fx are tabulated according to the material with which the enclosure is constructed and by means of it the heat losses in the walls and ceiling could be calculated.

With the wall and roof losses together with the ventilation losses calculated in Equation (6). The total losses in the entire enclosure are shown in Table 6; With Equation (21) and taking into account the physical characteristics of water for heat transfer, it was calculated from the passage of hot water through the pipe and conduction through the concrete to reach the floor of the room, you can calculate the total heat energy in Table 7, to be supplied to the water by heating to reach and maintain the proper temperature, also depends on the parameters of floor area, volume of the room and building materials.

With the calculation of the total energy in Table 7 will be used as a reference to select the heat generating equipment that is capable of supplying that amount of heat energy.

Table 6. Total losses through walls and ventilation.

Thermal loss	Q(W)
Losses through walls and roof (1)	1482
Ventilation losses (6)	924
Total losses in the enclosure (7)	1510

Table 7. Energy to be supplied by the heat generator.

Heat energy	Q(W)
Heat energy directed to the enclosure	5952
Heat energy directed to the earth	924
Total energy required	5878

4. Conclusions

The application of Equation (10) given by UNE EN 1264 standard, guarantees that the enclosure can be heated to the programmed temperature, because the design load exceeds the thermal load due to losses. This work can also be readjusted to calculate any surface and temperature conditions that are comfortable or most advantageous for the development and growth of the piglets. It is also a technique of heating or cooling of living units for the comfort of the people.

In this work it is presented that once the programmed temperature is reached, the floor also works as a heat storage that is why the radiant floor technique is also an energy saving system. In order for the floor to reach the programmed temperature and stabilize, it is necessary to use automation and control. Techniques, which are responsible for regulating the temperature, once the total energy is calculated, it is used as a comparison to select the size of the equipment (water heater).

Underfloor air conditioning systems base their operation on a network of plastic pipes that, installed under the pavement and a layer of mortar, circulates hot – or cold – water throughout the surface, causing heat or cold to radiate from the ground. In the case of heating, this causes the air temperature at foot level to be somewhat high earthen the air temperature at head level, improving the feeling of comfort.

As it is the heating system that uses the lowest water supply temperature (between 30 and 45º), it generally uses renewable energy sources for its operation, such as aerothermal or geothermal energy through the heat pump or solar thermal energy through hybrid systems. This makes it one of the most environmentally friendly heating systems. With a conventional water heater of 5 liters as commonly used in homes, heat energy can be supplied with the dimensions 33 m^2 of area and 10 m^3 of volume.

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