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A surface geothermal system application to improve the lacting sow welfare

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Abstract: In this study, a thermally controlled sow nursery was developed and implemented using surface geothermal energy for sow ventilation and photovoltaic energy for heating the suckling piglets. The geothermal system consisted of two fans that sucked ambient air and conducted it through the coil buried at 3 meters, cooling the ambient air through heat transfer to the ground. A hot environment was simulated, achieving an air input temperature of 40°C for the geothermal system. Additionally, a heating system was installed with electric resistances on a metal plate to provide heat to the babies. At temperatures between 33 and 42°C, the tendency of the temperature difference between inlet (environment) and outlet is greater and its tendency to growth (meaning cooling); while during the use of the bypass (the coil is not used) the difference shows a stable and horizontal trend without growth. The temperature of the surface of the heating bed fluctuated between 28 and 33°C, with piglet preference observed for the heating bed, which suggests that the space provided adequate temperatures for its growth stage. The results suggest that the buried coil cools the hot intake air and could help in areas with high environment temperatures.

Keywords: *Geothermal cooling, Photovoltaic heating, Piglet, Renewable energy, Sow maternity.*

1. Introduction

Intensive animal production systems allow high productive yields to be obtained in smaller production areas; however, in this system, providing a comfortable environment is a challenge due to the greater dependence on the use of external resources to achieve it [1]. Nowadays, where the consumer increasingly demands an animal product produced in a system that applies the concept of animal welfare, they demand the development of new functional technologies with renewable energy that improve animal comfort.

Effective management of temperature and humidity in a pig cage is crucial to improve animal welfare [2]. Heat stress in pigs caused by high ambient temperature increases respiration rate, negatively affects voluntary feed intake, changes feeding patterns and causes a decrease in reproductive performance and growth [3]. The pig's thick subcutaneous fat and its relatively undeveloped sweat glands make it very sensitive to environmental changes such as air temperature and relative humidity [2].

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Geothermal heat exchange is one of the growing alternatives in environmentally friendly technologies for animal production. Heat exchange is carried out with ground tubes and is based on fresh air being intake from environment and forced through tubes placed on the ground [4]. The supplied air is conditioned by transferring thermal energy between the supply air and the ground, based on the temperature gradient [5]. Likewise, a photovoltaic electrical energy system is one of the least aggressive ways to affect the environment [6] and in small-scale farms it is a favorable option to decentralize the generation of electrical energy among dispersed users [7].

The search for technological innovations that improve animal comfort during the reproductive stage of the sow are key to success in the pork production industry. In this situation, where the aim is to increase productivity while being environmentally friendly, the implementation of lactation module prototypes for pregnant-lactating sows functional with geothermal and photovoltaic energy are an alternative to take into consideration [8]. The present innovation seeks to supply the breeding sow with fresh, geothermally tempered air and provide the piglet with a warm environment generated by photovoltaic energy.

2. Methodology

The experiment was carried out during the month of June 2023 at the facilities of the Department of Zootechnics (Animal Production Engineering) from the José Faustino Sánchez Carrión National University, city of Huacho, Lima Region, Peru. The geographical coordinates of the research site are -11.1258 latitude, -77.6087 longitude and 67 m altitude.

The cage had a functional forced ventilation system with geothermal surface energy, where a 3” iron coil was buried three meters deep (Figure 1A-1B). The type of soil where the coil was buried is clay/silt. According to Ballester [9] this type of soil, in a condition saturated with water, has a volumetric thermal capacity between 1.6 to 3.4 $MJ/m^3.K$. The floor of the cage was built with a 3 x 2 m concrete slab, which provided stability to the installed cage and facilitated its cleaning.

The design of the lactation module considered a photovoltaic system: four 100-Watt solar panels (Figure 4A), with a battery bank of 2400 Wh capacity arranged in 24 VDC. This system feed two 4-inch axial fans running at 24VDC. One of the fans forced hot ambient air into the coil and the other expelled the cooled air.

Considering 5.5 effective hours of sunshine per day (PSH), the requirement of a photovoltaic system with 300 to 400 Wp with a voltage of 24 V, a 20 Amp/24 Volt controller and four 12V-100Ah gel batteries was estimated. A control system was installed for the photovoltaic system, charging the battery bank and distributing electrical energy to the components of the lactation module. This system was represented by a self-supporting metal cabinet where the control system and the battery bank used were placed. The photovoltaic system fed a PLC system that was configured to record ambient temperatures and at the coil outlet, for this purpose PT100 temperature sensors were used.

A heating system was installed to provide heat to the babies, with electrical resistances installed on a metal plate. The heating system or heating bed, 40 cm wide by 40 cm long, had 24 V electrical resistances of 19 Watts, and used energy from the photovoltaic system.

The surface geothermal system was designed considering three ball valves (Figure 1C), which allow to let the air go through the bypass or the coil, so it lets to test and compare the effect of air flowing through the coil, which was in contact with the ground, transferring heat to the ground. A “Bypass” bridge was installed with the following purpose: if air is required to flow through the coil, valves 1 and 3 must be opened and valve 2 closed, while if air is required to flow through the coil, “Bypass” bridge, valves 1 and 3 must be closed and valve 2 must be opened.

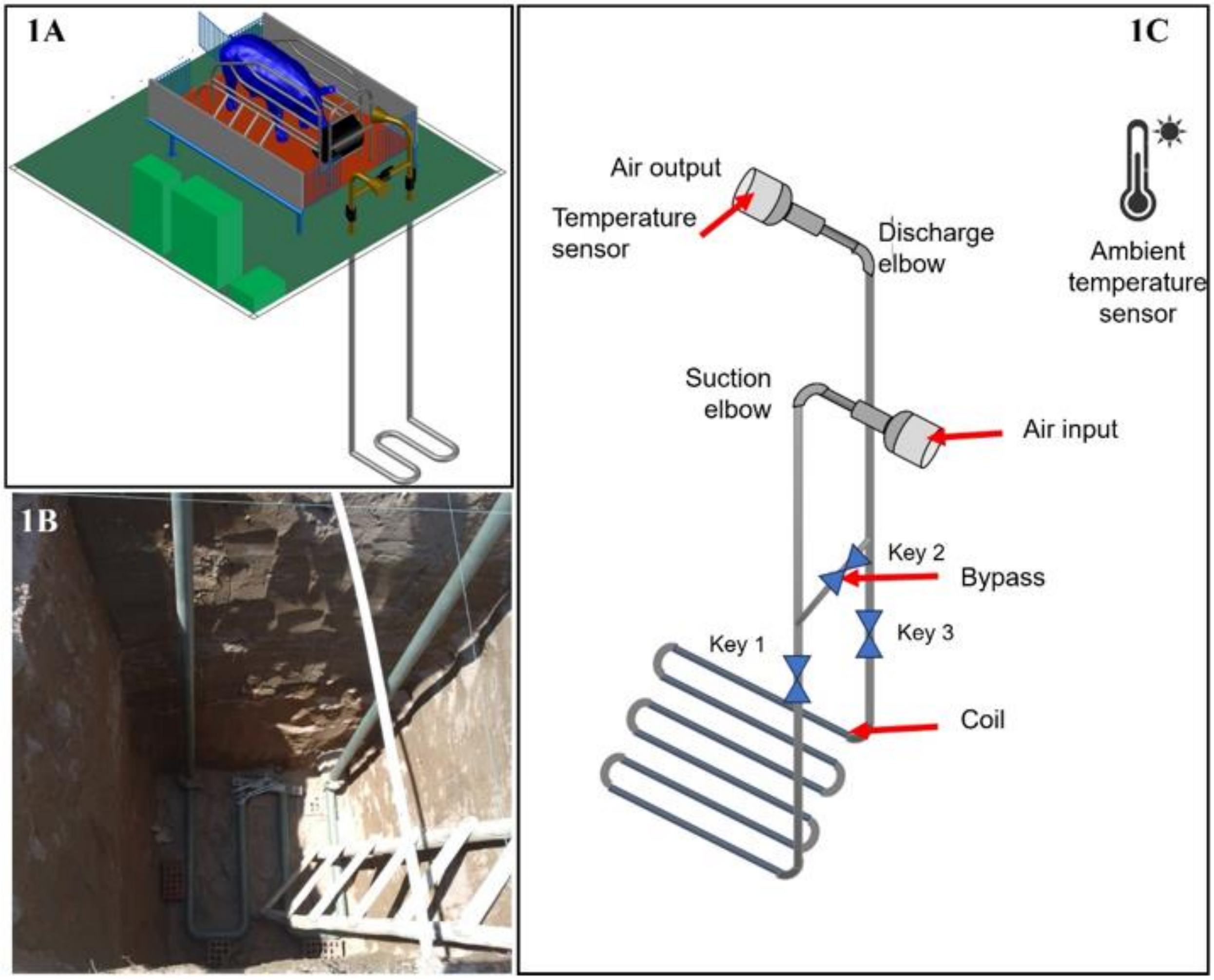

Figure 1.
Geothermal coil system. (1A) Lactation module showing the geothermal coil, (1B) 3 m deep trench showing the coil to be buried, and (1C) Functional parts of the geothermal coil.

3. Results and Discussion

The functionality of the geothermal system was tested by generating warmer environments, because in the installation area the temperature does not usually exceed 30 °C. To do this, a heat environment was generated using a suction cabin where a reflector increased the temperature of the air entering the coil up to 40°C. To perform the cooling coil test, the hot air generated enters the suction cabin, passes through the suction elbow, and continues through the buried iron coil, and then exits through the discharge elbow, which would make the air cool down. To do this, valve 2 remains closed, while valves 1 and 2 remain open. Environment and discharge temperatures were measured. To perform the "Bypas" bridge test, valves 1 and 3 were closed, and valve 2 was open, thus the air flows directly without passing through the buried coil.

Figure 2 shows the temperature fluctuations in the cage when the surface geothermal coil is applied. When the temperature fluctuates between 33 and 42°C (cabin temperature with reflector), the tendency of the temperature difference between suction and discharge is greater and tends to growth (it could be understood as cooling); while during the use of the bypass (the coil is not used) the difference shows a stable and horizontal trend without growing, which could be considered a temperature stabilization. Likewise, when the difference of the discharge with respect to the ambient temperature is analyzed, a negative difference is noted that suggests cooling; while the difference with respect to the bypass is positive and close to zero, suggesting stabilization with respect to the ambient temperature without cooling.

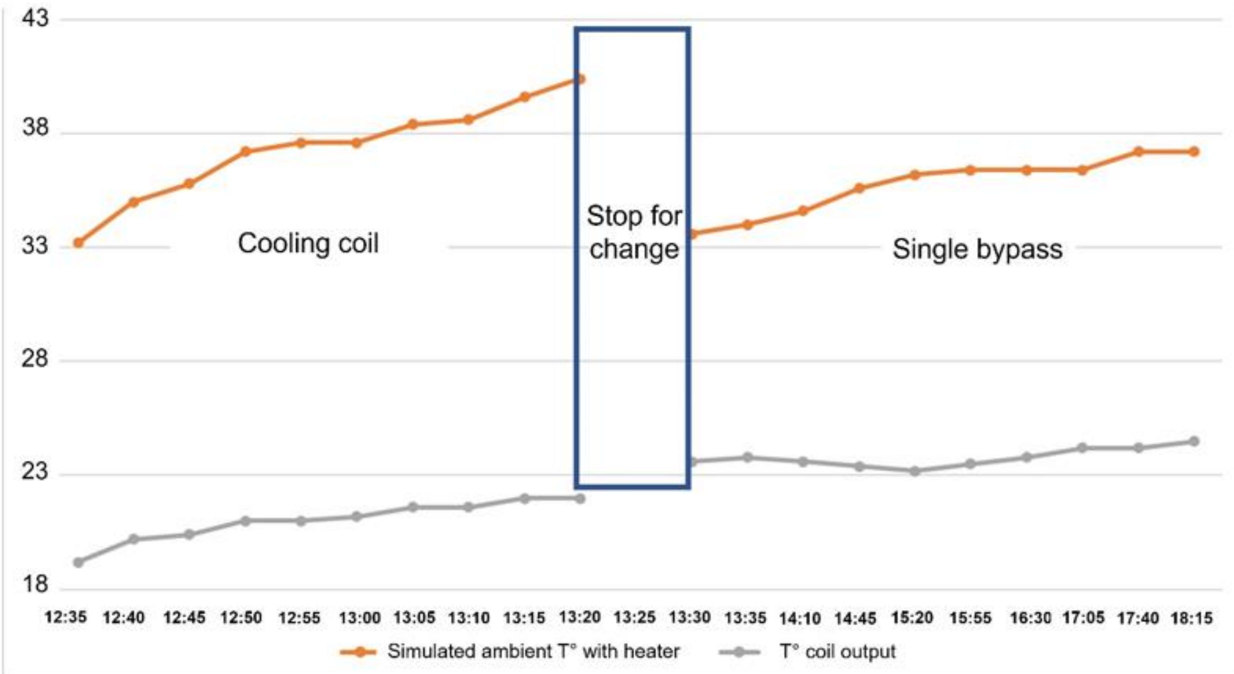

Figure 2.
Temperature fluctuations using the surface geothermal coil system and the by-pass. (A) Temperature differences between suction and discharge, (B) Analysis of the difference of the discharge related to environment temperature.

Additionally, the temperature difference between the suction cabin and the discharge elbow was analyzed. In the case of the coil, an average of 16.32 ± 1.30 °C is achieved, while, in the case of the bypass, an average of 11.98 ± 1.15 °C is obtained. These results would confirm the trend presented in the graphs presented above, where it would be presumed that heat transfer is achieved between the hot air that enters and the ground temperature, which is approximately 20°C. In that sense, it would be demonstrated that there is a cooling potential for the implemented surface geothermal energy.

The intention of the measurements is to understand how much the temperature of the air taken from the environment and flowing through the geothermal coil can be reduced in order to be cooled through heat transfer between the coil and the ground, which at 3 meters said soil has colder temperatures. As can be seen in Figure 3, there is a difference in both temperatures, showing a behavior depending on the time of day, and at these times it is shown that the coil outlet temperature is always lower than the ambient temperature. showing that it is possible to lower the temperature through surface geothermal cooling.

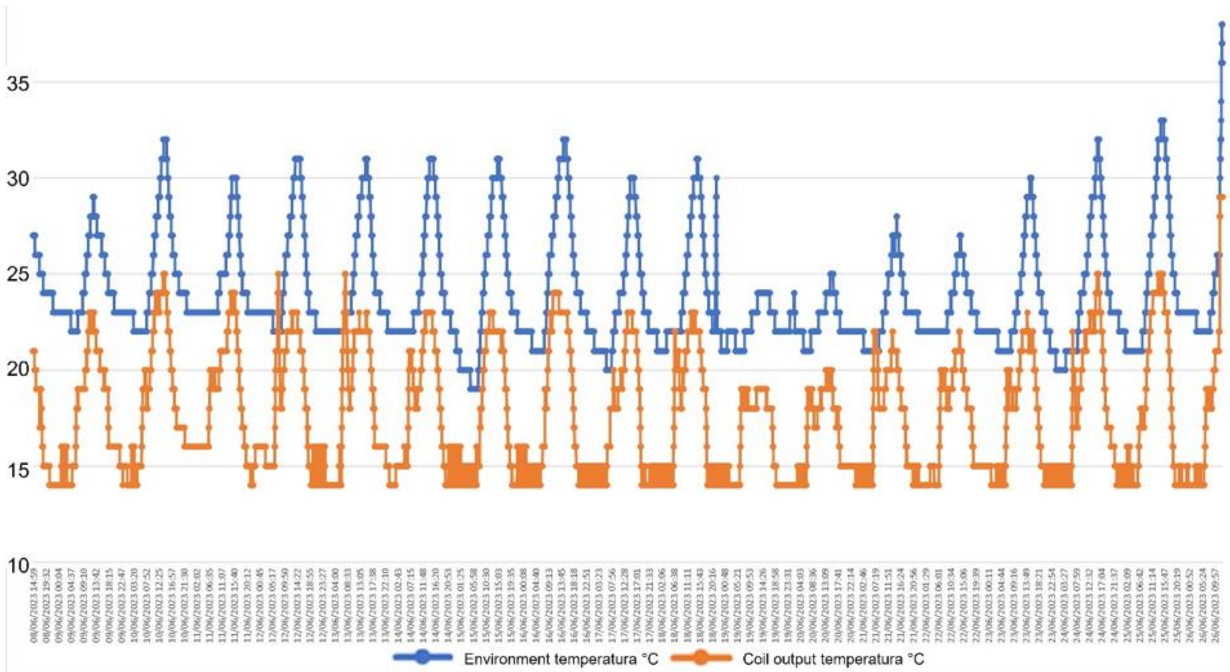

Figure 3.
Environment temperature difference outside the cage (in blue) and temperature coming from the geothermal coil. Averages Temperatures in triplicate measurements.

Al-Samari and Ali [10] define surface geothermal energy as a clean and sustainable energy, which allows the exchange of heat between the earth's surface and the environment, through the flow of a fluid and indicates that the collector or coil is a closed loop, made of pipes, where a certain fluid flows through it and the heat exchange transfer is generated. Although the environmental temperature can be very changeable, on earth it remains stable and allows heating or cooling depending on the season, having the advantage that the same circuit or system is used [11]. In Germany, installing collectors or coils is appropriate because at this depth the temperature is adequate compared to the environment during winter Assad, et al. [12]. Al-Samari and Ali [10] in Iraq, managed to reduce an environment where the environment temperature was 48°C by up to 30°C, using surface geothermal energy. Based on what these authors described, the surface geothermal system with forced ventilation reduced the ambient temperature inside the lactation module. The recorded results suggest that the coil with iron pipes has good conductivity and allows better heat transfer between the ground and the air flowing through it.

Figure 4 shows creole piglets in comfort sleeping on the heated bed of the farrowing cage. The heating system or heating bed for the piglets provided a surface temperature of up to 35°C, and allowed the litter to be kept warm at a temperature of approximately 28 to 30°C. The system, being low voltage and amperage, did not represent a danger. The piglets showed preference for the heated bed, suggesting that the space provided adequate temperatures for their growth stage.

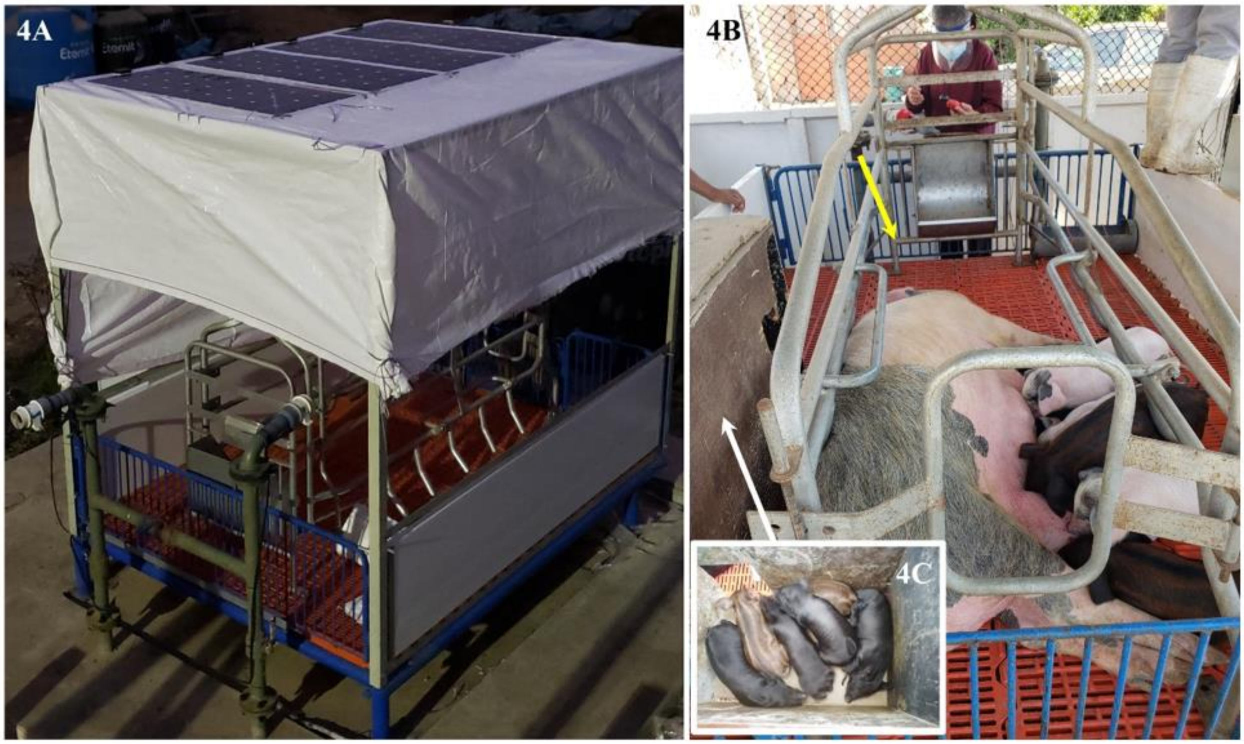

Figure 4.
Functional breastfeeding module with geothermal system energy. (4A) UNJFSC Breastfeeding Module. (4B) Sow in comfort. The yellow arrow shows the exit of the cooled air from the geothermal coil. (4C) Piglets sleeping in comfort on a functional resistance plate with photovoltaic energy. The white arrow indicates the piglets' nest.

4. Conclusion

The results suggest that the buried coil cools the hot intake air and could help in areas with high environment temperatures. Considering that the performance and efficiency of heat exchange is influenced by different factors such as climatic conditions, geographical location, geometric characteristics of the system, type of soil, properties of the tube (material, length, diameter, burial depth, spacing between different tubes), the air flow rate and the variation of the outside temperature, it is recommended to continue the study of the temperature with other simulations at laboratory level considering these factors.

Author Contribution:

J.C. Valencia Bardales: Research, resource management, geothermal system design. H.N. Pujada Abad: Research, Methodology, and monitoring of the sow in the maternity prototype. D.I. Villanueva Cadenas: Logistics and project management. L.M. Chávez Barbery: Soil depth investigation and cooling coil conditioning. E.C. Gallardo Bazán: Research, geothermal cooling monitoring. M.E. Lucho Cerga: Research idea approach, analysis of animal behavior data. E. Pujada Gamarra: Research idea, design of the geothermal system and data processing. F.E. Airahuacho Bautista: Research idea, writing, revision and editing.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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