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EFFECT OF A SOLAR-POWERED HEATING SYSTEM ON GROWTH PERFORMANCE IN WEANED RABBITS DURING WINTER REARING

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ABSTRACT

The present study aimed to evaluate the effect of an autonomous solar-powered heating system on the growth performance of weaned rabbits using heat convection. The experiment was conducted in February at the Institute of Animal Science – Kostinbrod, using two groups of 15 rabbits each, matched by breed, sex, and age. All animals were housed in identical cages within the same type of modular room (volume 182.91 m^3) and fed with a standard pelleted diet. The control group was reared under standard microclimatic conditions without heating, while the experimental group was maintained under improved thermal conditions provided by the heating system. Body weight was recorded on a specific days. On day 90, the experimental group showed a trend toward higher average body weight (2558 g) compared to the control group (2412), with $p = 0.0556$. Sustainable energy solutions had a positive impact on rabbit growth and welfare during the early fattening period.

Key words: rabbits, growth, heating, microclimate, feed conversion.

Introduction

In the current animal husbandry, maintaining optimal environmental conditions within enclosed production systems is critical for ensuring animal welfare, productivity, and sustainability. Climate control, optimal temperature, humidity, ventilation, and air quality management, forms the core system of efficient livestock production. Animals confined and raised in closed spaces are heavily dependent on human intervention to maintain their microclimatic environment, as natural mechanisms for thermoregulation become insufficient or compromised under intensive production conditions. Without adequate control systems, deviations from optimal thermal ranges can lead to physiological stress, reduced feed conversion ratio and efficiency, impaired growth performance, and higher mortality rates. Consequently, the design and implementation of reliable microclimate management systems have become a nesessity to both animal science and agricultural engineering disciplines.

Temperature is the most influential environmental factor affecting animal metabolism and overall performance. Excessive heat leads to reduced feed intake and increased water consumption, while cold stress triggers elevated energy expenditure for thermoregulation. Int both cases the metabolic resources are relayed away from growth and reproduction, resulting in economic losses and welfare concerns. Proper ventilation is equally crucial, as it maintains air quality by removing excess moisture, ammonia, and carbon dioxide while supplying fresh oxygen. Humidity control prevents respiratory diseases and maintains the structural integrity of bedding materials, reducing the incidence of bacterial, viral and fungal contamination. Collectively, these factors highlight that microclimate regulation is not merely a matter of comfort but a prerequisite for sustainable animal production.

Rabbits (Oryctolagus cuniculus), as a livestock species, are particularly sensitive to environmental variations due to their limited physiological capacity to dissipate heat and their high surface-area-to-body-weight ratio. Unlike larger livestock, rabbits cannot sweat and rely mainly on behavioral adaptation and vasodilation of their ears to regulate body temperature. This makes them vulnerable to both cold and heat stress, especially during critical life stages such as kindling, weaning, and fattening. For instance, kits require warm and dry conditions immediately after birth, as hypothermia can quickly lead to mortality. During the weaning stage, maintaining a stable thermal environment reduces stress and disease susceptibility, supporting steady growth and feed efficiency. In the fattening phase, stable and moderate temperatures – typically between 18–22°C – promote optimal weight gain and meat quality. Deviations from these conditions often result in slower growth, higher feed conversion ratios, and greater economic losses for farmers.

The process of raising rabbits involves a sequence of environmentally sensitive stages that must be managed with precision. Breeding females (does) require a calm and thermally stable environment to ensure successful conception and kindling. Excessive heat can lead to decreased fertility and embryonic losses, while cold stress may reduce milk production and maternal care. Growing rabbits benefit from controlled humidity and air circulation to prevent respiratory and digestive diseases. Finally, during the fattening period, the goal is to achieve maximum growth efficiency and carcass quality, both of which are heavily dependent on environmental stability. Consequently, the microclimate within rabbit housing area becomes a determining factor in production outcomes.

Traditional climate control methods, such as mechanical ventilation and electric heating, are effective but often energy-intensive and costly, limiting their sustainability in small to medium-sized farms. In recent years, attention has shifted toward energy-efficient and renewable-based climate regulation systems. Solar heating, geothermal air exchangers, and thermal insulation materials such as polycarbonate panels have emerged as viable solutions. These systems can provide consistent thermal support with minimal environmental impact, aligning with global goals for reducing carbon emissions and promoting sustainable agriculture. Additionally, the integration of automated control units and IoT-based monitoring systems enables real-time adjustments in temperature, humidity, and airflow, ensuring optimal conditions while minimizing energy consumption.

Implementing sustainable climate control technologies in rabbit production facilities not only improves animal welfare but also enhances productivity and profitability. A well-regulated environment minimizes susceptibility to diseases, supports faster growth, and ensures more predictable production cycles. From an ethical standpoint, providing animals with stable and comfortable living conditions reflects the growing societal expectation for humane and responsible farming practices. Furthermore, optimizing energy use through renewable systems contributes to long-term environmental and economic resilience in the agricultural sector.

Materials and Methods

The presented study was conducted on the summer of 2024 for the period of 3 moths (90 days) – from Februrary to the end of April. The experiment took place in the rabbit farm at the Institute of Animal Science – Kostinbrod, using two groups of 15 rabbits each, matched by breed, sex, and age. The animals were housed in identical wire cages and equal sized rooms for the experimental and the control groups. The provided feed was a standard pellet mix for growing rabbits. The control group was reared under standard microclimatic conditions without heating, while the experimental group was maintained under improved thermal conditions provided by the heating system. For the construction of the heating system in combination with ventilation of another build system for ammonia reduction we used several items: 6 solar panels rated at 550w, 1 hybrid inverter – 6kW, 4 accumulator batteries 25Ah each, a solar controller, a thermostat with a sensor were used. The assembly of 2 solar convectors was carried out with metal foil on a wooden frame measuring 1800x600x300mm and a polycarbonate sheet for covering and retaining heat through a greenhouse effect, with the base of the convector painted with black paint. Four axial fans at 120 mm forcing the hot air were used. The temperature is automatically regulated with a thermostat to the desired parameters. The generated temperature is 2 times higher than the outside temperature under ideal conditions. To reduce losses, pipe insulation was used around the intake collector pipes. Each of the studied animals were measured at 35, 70 and 90 days of age and compared with the control group. The statistical data and analysis were performed using SPSS software.

Results and Discussions

The control group was raised under standard microclimatic conditions without additional heating, whereas the experimental group was kept in an environment with enhanced thermal conditions provided by the heating system. Body weights were measured at 35, 70, and 90 days of age. Statistical evaluation was carried out using an independent samples t-test. By day 90, rabbits in the experimental group exhibited a tendency toward greater mean body weight (2558 g) compared to those in the control group (2412 g), with a p-value of 0.0556. These results indicate that optimizing the microclimate through sustainable heating solutions can positively influence rabbit growth and welfare during the early fattening phase.

The registered results demonstrated that the improved temperature conditions of the growing rabbits has a potentially positive effect of the faster early development and even after weaning regarding weight parameters. This can be contributed to the reduced need of energy distribution for generating body heat in the animals from their daily nutrient intake. The measured temperature and relative humidity index were with slight differences with average daily temperature amplitude between -8 and +11 degrees celsius outside temperature. The collected data were taken indoors in the rabbit farm in of the experimental and control room. According to the provided results we can determine that using solar heating units as heat convectors can have slight positive effect on the temperature in the rabbitry. A major contributing factor is the size of the convectors and of course the maximum exposure of solar radiation in a clear day, the materials of which the buildings is made, volume and the number of animals in a room.

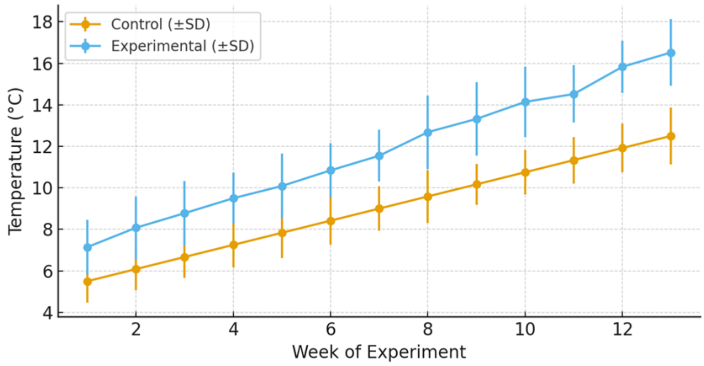

Figure 1: Weekly Average Temperature with Standard Deviation.

Figure 1 illustrates the weekly mean indoor temperature values with standard deviation (±SD) error bars for both the control and experimental groups over the 13-week period.

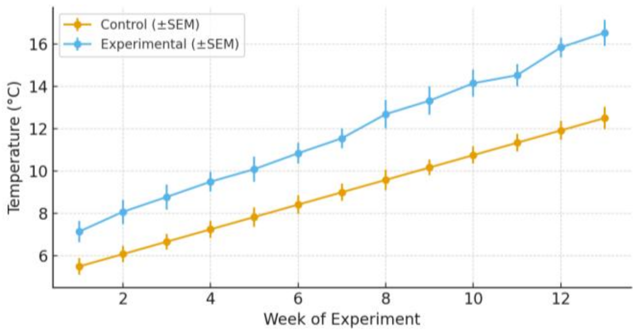

Figure 2: Weekly Average Temperature with Standard Error of the Mean.

Figure 2 shows the weekly mean indoor temperature values with standard error of the mean (±SEM) error bars, highlighting the precision of the estimated weekly averages.

Table 1 presents weekly average indoor temperatures recorded for the control and experimental groups during the 90-day study period. Values are expressed as mean ± standard deviation (SD) and standard error of the mean (SEM).

Table 1: Weekly average indoor temperatures.

Week	Control Mean (°C)	Control SD	Control SEM	Experimental Mean (°C)
1	5,50	1,03	0,39	7,14
2	6,08	1,01	0,38	8,08
3	6,67	1,01	0,38	8,78
4	7,25	1,08	0,41	9,50
5	7,83	1,21	0,46	10,09
6	8,42	1,16	0,44	10,84
7	9,00	1,07	0,41	11,55
8	9,58	1,27	0,48	12,68
9	10,17	0,98	0,37	13,32
10	10,75	1,08	0,41	14,14
11	11,33	1,12	0,42	14,52
12	11,92	1,17	0,44	15,83
13	12,50	1,37	0,52	16,52

Table 2: *SD – Standard Deviation; **SEM – Standard Error of the Mean

Experimental SD	Experimental SEM
1,32	0,5
1,51	0,57
1,56	0,59
1,23	0,46
1,56	0,59
1,3	0,49
1,24	0,47
1,77	0,67
1,78	0,67
1,69	0,64
1,38	0,52
1,26	0,48
1,61	0,61

There is a significant amount of research related to climate control in livestock farming.

In a performed study by Costantino *et al.* 2022, they introduced and validated a dynamic energy simulation model specifically developed for growing–finishing pig houses with mechanical ventilation, addressing the need for accurate tools to assess the energy performance of livestock buildings. The model incorporates both building physics and livestock physiology by simulating heat and mass transfer processes, pig body heat production, feed energy metabolism, and mechanical climate control systems. Input parameters include animal age, number, body weight, feed intake, and heat exchange coefficients for walls and surfaces. The model was constructed using the Modelica programming language and validated on a real pig house in Northern Italy, using field measurements of indoor temperature, heating system operation, and ventilation rates.

The validation process demonstrated a strong agreement between simulated and measured data, with a mean bias error of –2.4% for heating energy consumption and a mean absolute percentage error (MAPE) of 8.9%. In the experimental scenario, 64 fattening pigs were housed over 105 days, with climate conditions ranging from –2°C to 15°C external temperatures. The system used fan-assisted mechanical ventilation and a water-based radiator heating system. The model showed its capability to simulate complex interactions between outdoor climate, pig growth stages, and the building envelope. It also allowed evaluation of different energy-saving measures and technology retrofits through scenario analysis (Costantino *et al.* 2022).

One scenario using enhanced insulation and variable ventilation rates showed a 31% reduction in heating demand, while another scenario involving heat recovery ventilation led to a 17% energy saving. The study's results emphasize that dynamic modeling is superior to static methods for capturing temporal variability in energy use and animal-environment interactions. This model represents a valuable decision-support tool for farm design and renovation, enabling tailored analysis based on geographic, technical, and operational constraints (Costantino *et al.* 2022).

The experimental study performed by Ignatkin *et al.* 2023 focuses on the design, modeling, and testing of a hybrid climate control system with water-evaporative cooling for pig farms. The system uses sprayed water over fiberglass panels to increase relative humidity while reducing air temperature through adiabatic cooling. The goal was to stabilize internal thermal conditions during hot weather while minimizing energy use. The authors developed a mathematical model that calculates air temperature reduction as a function of inlet air humidity, flow velocity, and water spray density. Parameters like droplet size, contact time, and evaporation coefficient were included to improve accuracy.

The experimental setup was tested under initial conditions of 31.2°C air temperature and 30.4% relative humidity. At an air velocity of 2.9 m/s, the system achieved cooling of 8.3°C when increasing humidity to 90%, and 11.7°C when increasing it to 100%. The results were confirmed by real-world trials in a piggery over several weeks. The water consumption per kW of cooling was 0.24 liters/min, and the energy efficiency ratio (EER) reached values of 333, since only 0.003 kW electric power was needed to achieve 1 kW of cooling effect. This represents a significant advantage compared to conventional mechanical refrigeration (Ignatkin *et al.* 2023).

Besides temperature reduction, the used system also contributed to a drop in airborne dust concentrations and improved respiratory comfort for the animals. The authors concluded that for continental and arid climates, water-evaporative systems represent a low-cost and energy-efficient option to support animal welfare and productivity. The system's simplicity, combined with its low energy demand, makes it viable even for small to medium-sized farms (Ignatkin *et al.* 2023).

The review of Costantino *et al.* 2021, combines the effects of climate control systems in monogastric farming, particularly for pigs and poultry. The authors systematically examined the interactions between building ventilation, heating, air quality, and animal physiology. They reported that in intensive pig farms, indoor temperatures must remain between 18–22°C for optimal weight gain and feed conversion. Air velocity should be under 0.3 m/s for young animals and can reach up to 0.5 m/s in finishing pigs. Relative humidity should be maintained between 50–70% to reduce respiratory infections and ammonia accumulation.

In terms of emissions, studies cited by the authors show that each pig produces 7.2 to 18.9 g/day of ammonia, depending on ventilation type and housing design. Effective climate control can reduce ammonia by 30–60%, while also lowering energy demand if properly managed. The review highlights the role of radiant heating systems in nurseries, where local thermal zones for piglets reduce total building heat demand by 20–25%. Energy use in pig farming can reach 30–60 kWh per pig per production cycle, with up to 75% used for heating and ventilation. Climate control systems that include automated feedback loops based on temperature, humidity, and CO_2 are increasingly standard in modern facilities (Costantino *et al.* 2021).

The authors supports the integrated design strategies, including multi-zone control, use of renewable energy sources, and predictive simulation tools. They also emphasize the trade-offs between optimizing for animal welfare and minimizing operational costs. Improved models are needed to quantify these effects and design site-specific interventions. The review concludes that future advances should center on coupling climate control systems with automated and sensor-based precision farming to ensure both sustainability and animal performance (Costantino *et al.* 2021).

The report by Hörndahl 2008 for the energy use in Swedish farm buildings across 16 farms representing dairy, pig, poultry, and arable operations. Data were collected through direct interviews, measurements, and analysis of electric bills and fuel logs. Pig production was one of the most energy-intensive sectors examined. Energy use in farrow-to-sow systems averaged 689 kWh/sow/year, while farrow-to-finish systems averaged 2,431 kWh/sow/year. In the latter, heating made up 66% of energy consumption, followed by ventilation (18%), and feeding systems (9%). The study concentrate the stark differences based on housing design, insulation, and automation levels.

In broiler production, total energy use was 6.3 kWh per produced bird, with heating accounting for 84%, largely due to propane use. In contrast, laying hens in cage systems consumed only

3.1 kWh/hen/year, compared to 5.0 kWh/hen/year for free-range housing. Energy breakdowns showed that lighting was a relatively small share (3–5%) in most operations, but air handling systems in pig and poultry buildings could consume 2000–7000 kWh/year per unit. Farms with grain drying operations saw seasonal energy peaks, especially those using older oil-fired dryers. One farm that upgraded to a heat recovery-based drying system reduced energy costs by over 35% (Hörndahl 2008).

The work of Hörndahl 2008, provides technical guidance for benchmarking and optimizing energy performance. It recommends heat recovery from ventilation air, improved insulation of slurry pits, and using variable frequency drives (VFDs) on fans. A significant finding was that integrated heating systems with external energy sources (e.g., wood chips or district heating) had significantly lower operating costs and better carbon profiles. The report concluded with a call for establishing energy auditing programs for Swedish agriculture.

In different work of Słyś *et al.*, 2020 focuses on the technical and economic feasibility of waste heat recovery (WHR) from agricultural wastewater, especially manure effluents. The researchers designed a system involving a closed-loop heat pump that extracts heat from liquid manure or wastewater, raising it to usable temperatures for space heating, hot water, or feed preparation. Four scenarios were modeled: (1) heating cleaning water, (2) irrigation preheating, (3) grain drying, and (4) domestic hot water for farm residences. Calculations assumed slurry with an inflow temperature of 15°C and extraction of 5–8°C for heat recovery, producing 45–55°C outlet water.

The used system achieved coefficients of performance (COPs) between 3.4 and 4.1 depending on temperature lift and flow rate. Scenario (3), involving grain drying, was the most cost-effective, with an annual energy recovery potential of 29.5 MWh and a payback period of 2.1 years. In livestock operations with 500 pigs, the wastewater system could provide 64–78% of hot water needs and 25–30% of space heating during transitional seasons. The study also noted environmental co-benefits: reduced methane and ammonia emissions due to lower slurry temperatures, improved anaerobic stability, and decreased nitrogen volatilization by up to 20% (Słyś *et al.*, 2020).

The researchers performed a life-cycle cost analysis and found that capital investment in WHR systems was €8,000–€12,000 for mid-sized farms, with a net present value (NPV) of €14,000 over 10 years. Emission savings were estimated at 5.3 tonnes of CO_2 equivalents annually. The paper concludes that integrating heat recovery into existing manure management systems provides both environmental and economic returns and should be prioritized in national agricultural energy strategies (Słyś *et al.*, 2020).

In an article regarding this concepts Omarov *et al.*, 2017, outlines the design and implementation of a multi-source energy system for livestock buildings in Kazakhstan, integrating solar thermal collectors, a heat pump, and an energy storage tank. Their system was implemented in a cattle facility and used for water heating, space heating, and milk cooling. The solar collector area was 100 m^2, paired with a heat accumulator of 8 m^3 volume, and supported by an auxiliary air-to-water heat pump. The system was governed by a microcontroller that optimized energy flows based on solar irradiance, ambient temperature, and building load.

The system stored excess solar energy during daylight hours and redistributed it for nighttime use or for milk cooling during the day. Over one year, solar collectors provided 58% of heating demand, with the heat pump covering the remaining 42%. The coefficient of performance (COP) of the heat pump averaged 3.6. Total annual energy savings were 45.2 MWh, corresponding to a

CO_2 emissions reduction of 13.7 tonnes. Payback analysis estimated a return on investment within 6.2 years based on energy cost savings alone (Omarov *et al.*, 2017).

Conducted detailed performance analysis showed the importance of thermal inertia in storage tanks to buffer solar intermittency. During the coldest months (January to February), collector efficiency fell to 34%, but storage combined with the heat pump maintained thermal comfort inside livestock buildings. The authors emphasized that the modular system could be scaled to other climates and production systems, particularly where grid power is unreliable or fossil fuel prices are high (Omarov *et al.*, 2017).

The research of Jeong *et al.*, 2020 compares a conventional electric heating system with an air heat pump (AHP) system in pig housing over a 16-week winter period. The goal was to evaluate the systems' impact on energy use, environmental emissions, and pig productivity. The study found that AHP maintained higher indoor temperatures and reduced electricity use by approximately 40 kWh per cycle.

The experiment was performed in a swine nursery barn compared to a conventional electric heating system over a 16-week winter period. Both energy use and environmental indicators were measured. The AHP system maintained more stable indoor temperatures (average 25.4°C vs. 22.3°C in the control), especially during low external temperatures. The AHP reduced electricity consumption by approximately 40.1 kWh/day per barn (from 101.3 to 61.2 kWh/day), yielding a 39.6% energy savings (Jeong *et al.*, 2020).

Environmental monitoring showed that ammonia (NH_3) and hydrogen sulfide (H_2S) concentrations were consistently lower in the AHP barn. During the growing period, NH_3 averaged 7.1 ppm in the AHP barn versus 9.8 ppm in the electric-heated barn. H_2S levels were also reduced by 29%. No significant differences were found for PM2.5, VOCs, or formaldehyde concentrations. Productivity traits showed a slight improvement: the average daily gain (ADG) was 6.1% higher in the AHP group, though this did not reach statistical significance. Feed conversion ratio (FCR) was slightly better, suggesting reduced metabolic stress in pigs (Jeong *et al.*, 2020).

The study underlines the dual benefits of heat pump systems: environmental enhancement and energy efficiency. The authors recommend further trials in large-scale operations and highlight potential government support for initial investment costs. Given the global trend toward carbon-neutral farming, the use of AHPs in climate-sensitive livestock systems appears increasingly viable (Jeong *et al.*, 2020).

Conclusion

Managing the environmental conditions and the microclimate are significant factors for the faster increase in weight gain of the rabbits and their well-being. Including and adapting such systems are easy to implement and the investment for their efficiency pays of in the long run. Improving the conditions for raising farm animal's results in higher yields of the desired product. Also maintaining precise microclimatic control in closed animal housing is vital for achieving high standards of welfare and production efficiency. Rabbits, due to their physiological sensitivity, serve as a prime example of the necessity for such systems. The adoption of sustainable and technologically advanced heating and ventilation methods represents a forward-looking approach to animal husbandry—one that balances productivity, welfare, and environmental responsibility.

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