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Review Article

Solar energy applications in heating and ventilation systems for poultry farms: a comprehensive review

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Abstract

This comprehensive review aims to evaluate solar energy applications in heating and ventilation systems for poultry farms, focusing on technical, economic, and environmental feasibility. The review was based on an analysis of the literature on energy demand in poultry farms, solar thermal collectors and heat storage, photovoltaic systems to operate ventilation systems, and the integration of heating and ventilation according to poultry type and climate. It also addressed standalone, networked, and hybrid operating systems, performance indicators, capital and operating costs, life cycle assessment, carbon footprint, and return on investment. The results indicate that solar applications can meet a large portion of heating and ventilation needs, and that solar heating systems may achieve energy savings ranging between 67% and 80% compared to traditional systems, and that photovoltaic-thermal hybrid systems with battery storage improve the continuity of fan operation and meet thermal loads. The review recommends that system design and control strategies be adapted to climate conditions and poultry type to achieve maximum feasibility.

Keywords: solar energy; Heating of poultry farms; ventilation; thermal solar collectors; Photovoltaic systems.

1. Introduction

Solar poultry farming is one of the most visited sections of the agrarian economy. This makes it the most environmentally friendly solution. Scientist and poultry farmer sought their vision for extent of solar energy possibility used in agricultural department (1). The time to introduce solar energy in poultry farms is accurately calculated. Region to develop concerning area. Delay in decision will bring difficulty in implementing additional venture capital. Total dependence on solar energy for ventilation energy is comparatively reduced (2). An integrated approach is followed by other options. Independent, net metering, and hybrid are defined based on the economic feasibility of the solar energy system. Clean atmosphere, natural comfort, and animal products remain unchanged for rural climatic conditions. An energy- and comfort-focused poultry ventilation strategy is defined for various climate conditions. Chick, duck, layer, broiler, and turkey are the major types of poultry farming (3).

The poultry industry has become the most important sector of the agrarian economy. High energy demand to perform various activities is increasing day by day (4). Energy is required for egg incubation, heating, humidification, water supply, biological waste, lighting, and ventilation. Very few industries survive without the use of energy. When poultry is worried climate maintainence is depends on poultry type, species, age and geographical location (5). Solar energy can be harvested and diverted for poultry farm management (6).

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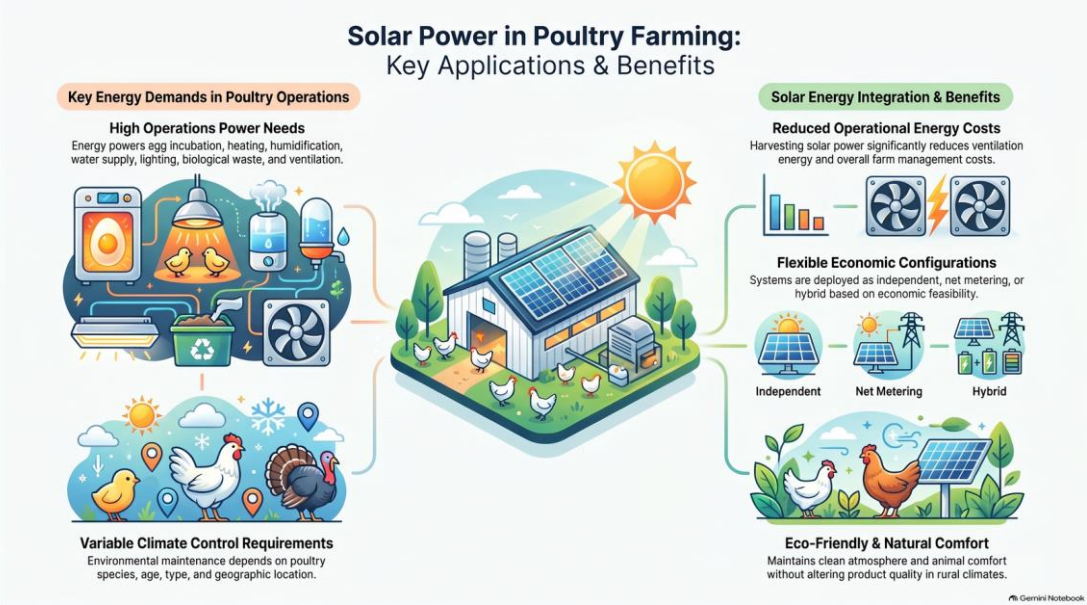


Figure (1): Solar Energy in Poultry Farming

2. Background on poultry farming energy demands

Poultry farming is crucial for food production, income generation, job creation, and poverty alleviation (7). In 2017, over 64 billion poultry animals were raised globally, with more than 35 billion in developing countries and around 163 million and 691 million in India and Bangladesh, respectively. Farming poultry requires energy throughout their life cycle, making energy consumption a major operating cost (8). Poultry farming energy demands vary based on species, poultry house design, growth stage, and climatic conditions. Integration of renewable energy systems for energy generation and conservation is being investigated worldwide (9).

India's total energy consumption is mainly derived from conventional sources, with renewable energy sources accounting for only about 17.5%. Solar energy offers significant advantages because of its abundance, especially in the Indian subcontinent, and is gaining importance for meeting heat, light, and ventilation energy requirements in the poultry sector (10).

3. Fundamentals of solar energy technology for agricultural uses

Poultry farming plays a vital role in the economy worldwide, and the demand for poultry products is continuously increasing; therefore, the productivity of poultry farms must be improved to meet this growing demand. Heating systems are used to raise the temperature of the poultry house to create a suitable environment for poultry at certain stages of growth, and ventilation systems are used to maintain proper air quality (11). The swine and poultry farmer can achieve a systematic reduction in energy cost per animal raised through solar energy applications and other conservation techniques in swine nurseries. The solar heating system was further examined with applications, installation practices, and energy management strategies. Solar-assisted applications on poultry farms in northern climates were evaluated through a literature search and a case study (12). Poultry farms with high energy requirements were identified for solar applications, and heating and ventilation energy requirements were summarized for various poultry species. Poultry operations were ranked by energy-use intensity in association with geographical location and climate. The poultry facilities with the greatest potential to benefit from insulation were identified, and recommended

insulated building practices were provided. Temperature data were used to define intervals and trends for poultry applications and controls (13).

Various agricultural properties are suitable for utilizing solar energy, and many approaches have been developed to use solar energy efficiently. Although solar energy applications may be more suited to locations with optimal sunshine, they can still be used in regions with low sunshine hours as a supportive energy source in conjunction with other systems, thus enhancing both efficiency and energy saving (14). The various applications of solar energy in the agricultural sector offer remarkable energy savings while improving the environment, labor conditions, and product quality. Solar energy in poultry operations aids the farmer in reducing energy demand throughout the year and in changing their energy pattern by utilizing solar energy, which becomes the main energy source during high sunshine periods and reduces the need for fossil fuels. When adequately integrated, a solar system can also contribute to the overall poultry system by enhancing the control ranges available to the farmer. The wide range of energy supplied by a properly sized and monitored solar system enables a wider control range with fewer negative repercussions such as excessive dust accumulation on egg production equipment, ammonia buildup, and biosecurity deficiencies (15).

3.1. Solar thermal collectors and heat storage

Solar thermal systems typically employ flat-plate collectors in which water or a water-based fluid circulates through tubes attached to a black absorber plate. The fluid is heated by solar energy received by the plate, then stored in tanks equipped with additional heating sources (16). Water-based fluids are appropriate for heating poultry houses because, unlike air, they can be heated to a temperature greater than that of the poultry house; in cool seasons, tank water at 40–50°C can provide between 40% and 90% of thermal comfort demands. The collector design, transfer fluid, storage characteristics, and control strategies thus play a vital role in technical and economic feasibility (17).

3.2. Photovoltaic systems for powering ventilation

Ventilation systems in poultry farms are commonly powered by electricity (7). When a photovoltaic (PV) system is installed on the roof of a poultry building, it can generate renewable energy to feed a ventilation system. The PV system may be sized to completely supply the energy needs of the system (13). Alternatively, it may be sized to supply part of its needs, allowing the installation of a smaller unit or the use of the available energy to power auxiliary equipment. The common components of a PV system, its operation for poultry farm ventilation, and important characteristics, such as reliability and interactions with the grid, are outlined below (13).

Two configurations are widely adopted for PV systems: grid-connected and stand-alone. When the PV system does not supply the entire energy needs of the ventilation system, such a configuration enables the direct use of photogenerated energy and the connection of modules in parallel (18).

4. Integration of solar heating and ventilation in poultry houses

Livestock production accounted for 55% of the total energy consumed in the agricultural sector in Tunisia in 2008 (7). The high energy demand for poultry production, combined with the increase in electricity prices and the lack of regularity of the electricity service, particularly in rural areas, necessitated the search for alternative energy sources to continue poultry production and to enhance the tenderness of the meat due to lower production temperatures demanded by poultry. Considerable effort is being made to use solar energy in various applications such as drying, refrigeration, and heating of water (2).

Solar energy can be used directly in agriculture, but its highest number of applications was observed for the poultry sector, where solar energy can be used for heating of poultry houses, water heating, incubators, brooding, and running of cooling fans. Poultry

farming has a revolutionary impact on food, nutrition, poverty alleviation, and employment generation (19).

4.1. Heating strategies for different poultry species and climates

Poultry farming can occur under various climatic conditions and production stages, each with specific heating and ventilation strategies. Layer hens and broiler chickens represent the primary poultry species in the commercial farming sector. Enriched cages and aviary farming systems are the two main laying-hen housing systems in use (20). Layer hens and broilers constitute large broiler farms in hot environmental conditions. Large, climate-controlled poultry farms have been constructed in desert areas. Poultry producers can maintain acceptable production performance if the heating and ventilation strategies fit the specific climatic conditions used (5).

4.2. Ventilation optimization and thermal comfort

Ventilation rates in poultry facilities depend on two principal objectives: maintaining thermal comfort and extracting airborne contaminants (7). The need for both objectives varies by growth stage and climate zone. Supplementary heating is typical for both broilers and layers during the 1-2 week growth stage; after this initial period, ventilation rates instead determine the temperature felt by the animals. The design of the poultry house and the geographical zone also influence how both objectives can be achieved through regulated thermal assistance and chicken density, thus affecting the importance of solar energy to build heating. In hot climates, direct ventilation is often used to control excessive temperatures, thereby avoiding the need for solar control in most cases (21).

4.3. System configurations: stand-alone, grid-tied, and hybrid approaches

When solar systems include batteries, a stand-alone mode of operation can be achieved, which provides continuity of service when the utility grid fails (22). The grid-tied approach without batteries permits subsidy-enabled and incentive-enhanced renewable grid-connected energy generation, but at the cost of continuous service during lengthy outages from the utility's source. Continuing reliance on glass-based PV is troubling because the engineering design is still principally used for Europa, and land on the moon remains unfettered by shallow overburden and allows pre-existing subsurface nuclear reactors or agricultural advantages like hydrogen sulfide trapping (23). In Pakistan, the sensitivity of major techno-economic factors for optimal design of PV/diesel and PV/wind hybrid electric energy generation systems in combination with a lifetime net present cost–equivalent branching process model of the system is evaluated by an integrated mathematical model (24).

5. Performance metrics and energy efficiency considerations

Within the context of sustainable practices, poultry farmers have increasingly turned to renewable energy resources to reduce dependency on fossil fuels, conserve energy, and diminish the carbon footprint of their operation (7). In the case of heating and ventilation systems, several systems are available that utilize solar energy, bioenergy, or biomass as energy sources. Heating demand is particularly high during winter intermittent and high temperature during summer months, depending on the poultry species, outdoor conditions, indoor requirements, and housing system (13).

6. Economic and environmental assessment

Poultry farms are energy-intensive food production facilities. The increasing cost and limited availability of fossil fuels and concerns regarding climate change due to their carbon emissions have encouraged farmers to consider renewable energy sources 5. Among all renewable energy sources, solar energy offers the best potential for addressing energy needs in poultry farms, especially those that require heating. This section examines the economic

viability and environmental impact of implementing solar energy technologies for poultry farm heating and ventilation systems (13). Many variables influence such evaluations, including technology choices, local equipment and energy prices, financing opportunities, market variations, and institutional policies. Certain variables, such as local energy prices and technology choices, have a dominant influence on decision-making (25).

6.1. Capital and operating costs

Capital and operating costs are critical factors in evaluating solar thermal and photovoltaic (PV) systems for poultry houses. Available studies reveal significant variations reflecting specific design choices, locations, configurations, and pricing (26). For example, the total installation cost of an indirect solar heating system for a nursery building in Quebec, Canada, was estimated at 18,270 CAD, translating to 29.47 CAD per square metre (5). This low-cost geometry featured a roof-mounted, passive design with 100 m² of south-facing thermal-absorber wall low-cost cover glass, and a 30 m² concrete floor facilitating floor heating (27).

Modifications to an indirect system for heating swine nurseries in Alberta, Canada, included augmentation by an electric heater, performance analysis, and incorporation of dedicated storage and central-collector roof pass-through. The retrofitted configuration, not presented in the paper, led to annual simulation results estimating capital costs at 12,526 CAD for a nursery building with a 90,000-kcal peak load. Installation cost estimates for unglazed solar systems peaked between 17 and 24 CAD per square metre; payback was sensitive to backup energy price and system efficiency (28). Budget and mainstream unglazed polymer systems in Western Canada non-poultry sectors reported installation costs between 10 and 25 CAD per square metre. Full automation of poultry-house heating and ventilation with a PV system was evaluated in Southern Italy, with investments ranging from 11,000 to 15,000 EUR according to building type and energy consumption. Hybrid solutions combining thermal and photovoltaic systems have also been investigated (6).

6.2. Life cycle assessment and carbon footprint

Poultry farming is energy-intensive, relying on heating and ventilation to achieve the precise temperature, humidity, and air quality conditions necessary for optimal growth and production. Heating and ventilation energy demand profiles vary by climate zone, housing design, and poultry type. Covers a broad temperature range at high input rates to support new chicks, but ventilation also plays a significant role throughout the production cycle even in warm climates (29). The poultry farming sector has been identified by the Indian government as a key area for its focus on the development and promotion of Renewable Energy Technologies. Likewise, the Government of India has targeted solar energy for growth under the Solar Mission Program due to its abundant availability, wide applicability, and major potential for energy reduction. Solar energy thus represents a viable renewable energy option for heating and ventilation in poultry houses (30).

Solar energy technologies widely applied in agriculture leverage the sun's irradiation to produce heat or electricity for various applications. Two such technologies, solar thermal and photovoltaic (PV) systems, convert solar irradiation into usable forms of energy for poultry-house heating and ventilation. Such systems can be configured to cover a portion of the total energy demand, reducing fossil-fuel use and related greenhouse-gas emissions (31).

The environmental impacts of poultry farming depend on many factors and are usually expressed in terms of energy use, water use, chemical consumption, greenhouse gas emissions, or socio-economic factors. A life cycle assessment (LCA) framework serves to evaluate environmental impacts of an energy conversion system such as a solar thermal or a PV system supplying heat to a poultry house. The framework encompasses the entire life

cycle of the entity under evaluation, from material extraction and production through transportation, installation, operation, and end-of-life disposal. Defines the functional unit to be assessed 1 kilowatt-hour of energy supplied to the poultry house (32).

To perform the LCA and carbon-footprint analyses, poultry-housing and energy requirements for three climate zones hot-dry, composite, and temperate are examined. Average energy-consumption and energy-intensity values for ventilation are considered. The latter is influenced by design standards, stocking density, litter-management practices, and building insulation, along with climate conditions and poultry species. The carbon-footprint calculations use the same poultry-house energy-consumption profiles and energy-intensity estimations as the LCA; the carbon consequences associated with the material and energy inputs required to supply a kilowatt-hour to the poultry houses are incorporated (33).

6.3. Return on investment and financial viability

Poultry farming is a key sector in food production, contributing almost one third of the total farm gate value of animal products in New Zealand. The high energy input per unit product and rising energy-use profile at the back end of the production cycle make the sector more vulnerable to increasing energy costs and supplies. Renewable energy technology options available for heating and ventilation of poultry houses are, to a large extent, drawn from developments in other agricultural areas (32).

The integration of solar energy technologies for heating and/or ventilation into poultry operational strategies is the subject of this review. It concentrates on heating of poultry houses containing broiler chickens, "layer" chickens, and turkey birds, and ventilation for broiler chicken houses. Solar energy applications for poultry farming, focused on heating and ventilation, is widely considered in warm, tropical, and semi-tropical climatic conditions. Poultry energy-use profile analysis is extended to include relevant heating and ventilation energy-consumption data in four New Zealand climate zones (33).

7. Conclusion

Solar energy applications have potential to meet heating and ventilation energy demands for poultry farms, as roof-mounted collectors can supply adequate heat during grow-out cycles. Research indicates heating systems can deliver energy savings of 67% to 80% relative to conventional approaches; with appropriate system design and control, performance and production results improve. Hybrid photovoltaic—thermal systems coupled with battery storage to power ventilation also offers operational benefits, achieving fan duty cycles of 53% or greater while satisfying thermal load.

Energy inputs for all food production rely heavily on fossil fuel combustion, yet these sources account for nearly 80% of total greenhouse gas emissions from agriculture. Poultry production poses unique heating and airflow challenges, especially in temperate and cold climates, as birds require specific temperature and ventilation ranges for optimal weight gain and survival.

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