Chapter

Cost Effectiveness of Poultry Production by Sustainable and Renewable Energy Source

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Abstract

Poultry farming is one of high energy consumption and energy-intensive industries that requires significant amount of fuel fossil to provide the desired internal temperature for health and production level of chicken, which results in high running cost and growth of greenhouse gas (GHG) emissions. Renewable and sustainable energy technologies are being employed in the area of poultry farming in order to achieve energy saving, GHG emission reduction and to some extent supply potential selective benefits for farmers. Therefore, it is very necessary for generalizing the state-of-the-art technologies including the solar photovoltaic, solar photovoltaic/thermal, ventilation and wind turbine, air/water/ground sources heat pump and thermal energy storage. It is demonstrated that the system energy saving could achieve up to 85% with a payback time of 3–8 years, compared to the conventional heating system.

Keywords: Poultry farm, Renewable and sustainable energy technology, Energy efficiency, Cost-effective, Payback period

1. Introduction

The ongoing coronavirus disease 2019 (COVID-19) global pandemic brought a few extreme challenges to the world including public health crisis, political, environmental, social and economic domains [1, 2]. Meanwhile, it reveals how population growth, globalization, urbanization, and mass travel give rise to a complex externality with far-reaching global impacts [3–5]. Notably, the COVID-19 has expounded the importance of addressing another global issue: global warming. The increasing atmospheric concentration of GHG is thought as the biggest contributor of global warming. This has exerted negative effect on plants, animals, human activity, ecosystems and economy around the world, which are largely associated to alterations in climate extremes [6]. Therefore, energy efficient and energy consumption saving have become more than important nowadays because of energy resource shortage, soaring energy prices as well as pressing environmental problems [7].

Notably, livestock production is responsible for GHG emission attaining 20–25% of global entire emission, of which approximately 70–80% stems from animal farm industries [8–10]. Poultry farm is an important sector that consumes large quantities of fuel all over the world. This is due to that the internal temperature, relative humidity, chemical environment, ventilation and lighting inside a chicken house would dramatically affect the growth of broilers, which should be kept within a reasonable scope [11]. The growth of broilers mainly depended on the internal environmental condition variation which may impede the meat and eggs production, such as heat or cold stress [12]. The desirable temperature and relative humidity requires to be kept between 26°C and 35°C and between 60% and 70%, respectively [13, 14]. The ammonia concentrations must be controlled below 25 ppm. This is because that high ammonia level may cause respiratory damages to the chicken [15]. Hence, the heating, cooling, lighting, temperature and ventilation need to be supervised accurately for better production [16, 17]. Traditional poultry farming seriously consume fossil fuel and gas via the power and heating systems for heating, cooling, lighting, ventilation and running electric motors for feed lines [18, 19]. Therefore, the usage of the renewable and sustainable energy technologies, including wind energy, solar energy, geothermal energy and air/water sources [20, 21], plays vital role on the poultry farm owing to their potential to a reduction of energy demand and welfare losses, economy and profitability, GHG reduction and conservation of resources [22–24]. Hence, in this chapter, these advanced technologies is investigated and summarized for easier tracking and better understanding of energy-efficient renovation for typical poultry houses.

2. Renewable and sustainable energy technologies for poultry farm

2.1 Solar energy technology

Solar energy is a very enormous, environment friendly and inexhaustible renewable energy resource. It is divided into solar photovoltaic (PV) technology, which convert the solar radiation into power generation, and solar thermal technology, which utilize the solar radiation directly for space heating, water heating, drying and cooking [25, 26].

2.1.1 Solar photovoltaic

Solar PV module is regarded as the electrical production element, and its performance is associated with the category and temperature of PV cell [27, 28]. When the PV cell temperature rises 1°C, the electrical conversion efficiency is reduced by approximately 0.4–0.5% for the crystalline silicon cell and about 0.25% for the amorphous silicon cell [29, 30]. Additionally, solar radiation is converted into direct current electricity by the PV module, thus is transformed into alternating current by an inverter. Notably, about 36% of mono-silicone and 55% of poly-silicone types as PV cell materials are broadly utilized to provide artificial light for poultry farm [31, 32]. This contributes to extending the day and improving the meat and egg production. Generally, solar PV module can either be roof installed or ground mounted for chicken houses [33–35]. Specifically, the Allen Family Foods Inc. mounted a 42 kW PV array with 314 m^2 area in the USA [31]. This PV array could output approximately 56112 kWh/year electrical energy, which could save about 78% energy consumption and £5700 operating expense per annum. Similarly, a 50 kW ground mount and a 49.82 kW roof mount solar PV arrays are utilized at the Cramble cross poultry farm. It is demonstrated that the power energy saving could achieve about 85% per annum compared to conventional heating system. The S.A. & D.E. poultry farm in the UK installed a 50 kW solar PV array, and found that the electrical energy production by the PV array could reach 42200 kWh/year, resulting in a 75% energy savings, £10854 operating cost ·savings and 11.03 tons CO_2 emission reduction per annum [36]. Additionally, in hot areas, the solar PV pumping system is needed for providing livestock watering usage and energy storage in the form of water in a water reservoir [37].

2.1.2 Solar thermal collector

Another vital factor for chicken house in some fields is heat to decrease the mortality rate of chicken [38]. Heat gains and losses from chicken and other resources are the core issue for the chicken house. Gad et al. [35] designed a flat plate solar thermal collector module to evaluate the system thermal efficiency and poultry production. The system composes of 12 horizontal copper tubes with 7 mm diameter which are embedded at the absorber surface plate. It is found that the system thermal efficiency is about 71.6% which can fulfill the poultry thermal demand. Brewer et al. [39] designed and installed three solar thermal collector modules to investigate the feasibility of heating poultry house. To be more specific, each module consists of twelve double glazed, copper plate collectors with 65 m^2 area, which is mounted on the roof with an angle of 45°. It is found that about 100% thermal energy demand can be fulfilled and about 75% energy consumption can be saved compared to traditional heating system.

2.1.3 Solar photovoltaic/thermal

Solar photovoltaic/thermal (PV/T) module can simultaneously produce heat and electricity for poultry farming by fully using the solar radiation lies in the overall solar spectrum ranging from 0.2–3 μm [40, 41]. Normally, the flat plate PV/T module is the most common category because of its constructional simplicity and building integration easiness [42, 43]. Meanwhile, it can shorten the payback time compared to the traditional PV module. Cui et al. [44] developed and installed an innovative PV/T integrated with ground copper pipe array system to decrease energy consumption and CO_2 emission for a poultry house in Newark, UK. It is revealed that the electricity and thermal output of the hybrid system could reach 11867 kWh and 30747 kWh, respectively. This contributes to obtaining about 70% electricity savings and 40% gas savings per annum, resulting in 6.23 tons for electricity and 5.65 tons for gas CO_2 emissions reduction.

2.2 Ventilation and wind turbine

The health level of the chicks is largely reliant on the indoor environmental temperature of the chicken shed. In winter, the indoor air temperature for broiler houses should be maintained ranging from 21 to 32°C, whereas the overheating and heat stress issues should be avoided in summer [45, 46]. Meanwhile, the ammonia (NH_3) and CO_2 are the two main harmful gases that must be controlled below their corresponding critical concentration levels of ~25 ppm and ~ 2500 ppm, respectively [47]. They can be removed from the poultry house by the ventilation fans. It is reported the energy consumption for the ventilation and cooling of a chicken shed can consume about 39.5% of the entire power energy usage and this value rises by 43.7% in laying hens [48, 49]. Specifically, Fawaz et al. [47] developed a parabolic concentrator solar thermal assisted with localized ventilation system for chicken brooding in Lebanon, and confirmed that the system is able to overlap 84% of thermal energy demand resulting in about 74% of energy savings and obtain a payback period of less than 5-year. Additionally, the wind turbine technology can be utilized to produce the power for the poultry farm. The energy could be generated by the force of the wind, and thus move the mills that are connected to electricity generators [50]. Small wind turbine, ranging from 0.4–40 kW, can fulfill the electrical demand of a whole poultry farm [50, 51]. Du et al. [51] designed and test a small-scale ventilation integrated with wind turbine energy system for a poultry house in China, and concluded that the electrical energy could be steadily produced 270 W/year by the wind turbine system, meanwhile, approximately 2074kWh/year renewable energy could be obtained, making up around 10.2% of entire energy demand and leading to 3.01 tons/year GHG emission reduction. Kapica et al. [52] developed a hybrid solar-wind turbine system for a chicken shed in the Central Europe. It is obtained that the system is conducive to a CO_2 emission reduction ranging from 0.11 to 0.22 kg/per kg in comparison with typical heating system. In addition to these typical cases, some other solutions have also been investigated involving the insulation thickness of chicken shed wall [53] and passive cooling system [54] to boost energy efficiency and save energy consumption.

2.3 Heat pump technology

Heat pump technology is commonly utilized in chicken house due to its advantage that can attain heating from one source including air/water/ground, and rise it to a suitable temperature for space water and heating. In the meantime, heat pump is one of the optimum solutions to heat shed in heating season with a fast return on investment [55].

2.3.1 Ground source heat pump

A ground source heat pump (GSHP) is able to extract heat source from soil for heating the chicken shed to obtain the optimum production performance, which is conducive to guaranteeing a desired indoor temperature for poultry shed and decreasing fuel requirement and CO_2 emissions. To be more specific, Choi et al. [56] developed a GSHP system utilized to provide the heating for a poultry house in Korea. It is concluded that the GSHP system could decline the operating cost since it could obtain more heating from ground for heating the shed. About 82% energy consumption could be saved in comparison to the conventional poultry shed during the operation period. Moreover, the concentration of the CO_2 in the GSHP poultry house is reduced by 2150 ppm compared to the traditional shed. Furthermore, the system COP is in the range from 3.5 to and 4.2, and the payback period is expected to be about 8-year. Kharseh and Nordell [57] built a GSHP integrated of the solar energy system to provide the thermal and electrical energy requirements for a chicken shed in Syria. It is indicated that the chicken weight is enhanced by about 5% ~ 6.8% on average. What is more, the energy consumption could be declined by 57% and has a payback time of about 6-year.

2.3.2 Water source heat pump

Water source heat pump (WSHP) is an effective approach of supplying water and space heating, meantime, it can be adapted to a range of bodies of water including canal, lake and river. The S.A. & D.E. Dixon chicken farm installed a WSHP system for rearing poultry house as a desired heat source for a heat pump operation in the UK [58]. The surface temperature of the lake is 4°C on average all over a year. It is obtained that about 33% of energy cost could be saved, which contributes to creating a 22% return on initial investment with a payback period of 5-year.

2.3.3 Air source heat pump

ASHP technology is the most common used in the chicken shed, which could extract heat from ambient air in heating season, meanwhile, it could reject heat outside in cooling season. Generally, the efficient of the ASHP technology is in the range from 300 to 400% [59]. For example, stonehouse farm installed six 14 kW ASHP units to supply the required heating to sustain the indoor temperature for two poultry sheds with a capacity of 20000 birds in the UK [60]. It is demonstrated that the energy consumption of each chick could reach below 1kWh, and system COP is in the range from 3 to 4. What is more, the economic benefit is approximately £11250 per annum with a payback period of 4.5-year.

2.4 Thermal energy storage technology

Thermal energy storage (TES) technology is typically considered for not only alleviating thermal demand of chicken shed but also stabilizing the indoor temperature variation for broilers growth. Hence, it is very important for keeping the stability of the temperature and relative humidity within poultry shed.

2.4.1 TES with phase change material

Phase change material (PCM) is usually regarded as a heat storage materials owing to its high thermal storage capacity that typically depends on latent heat in phase transition process. Additionally, PCM could absorb latent heat at a constant temperature, which is also the key factor for their application in TES with PCM system for poultry house. Zanaty [61] installed a thermal storage tank with PCM system to explored the influence of PCM latent heat on indoor environmental condition inside a chicken shed, and found that the replacement of the thermal tank from sensible water storage tank to latent heat water with embedded PCM results in a reduction of around 2% of the auxiliary energy demands. Moreover, there is a payback time of about 4-year in this case.

2.4.2 Trombe wall

A classical Trombe wall is used to absorb solar radiation for providing the indoor space water and heating, in the meantime, the external surface of the wall is colored black in order to increase the absorption rate. Additionally, the Trombe wall is usually mounted facing south to collect the solar thermal energy [62]. Currently, two categories of Trombe wall are usually adopted for the poultry shed because of low heat losses, high energy efficiency and convenient installation. Okonkwo and Akubuo [63] designed and built a Trombe wall heating unit to control the thermal energy requirement for the shed in Nigeria. Results concluded that the exterior surface temperature of the Trombe wall could achieve the maximum values of 60°C and the minimum values of 25°C, respectively, whereas the internal surface temperatures could reach ranging from 29.73 to 39.1°C. This indicates that this Trombe wall technology could accumulate and store adequate heat for the chicken shed in the tropics environmental condition.

3. Key findings and recommendations for future development

The development and usage of renewable and sustainable energy technologies are significant challenging research fields of poultry rearing. These technologies are advanced in power and heat production, fuel and gas savings, and the reduction of operating expense and GHG emission for poultry house. Meanwhile, they are conducive to sustaining the required indoor environmental conditions. Current researches have been identified obviously that the demand of the electrical and thermal energy could be fulfilled about 20–30% and 80–90% compared to the conventional heating system applied in poultry house, which therefore decreases fossil fuel consumption and GHG emission. Currently, the two renewable sources of energy production are wind and solar energy, both of which are seeing growing popularity for poultry healthy and high production. Specifically, wind power can generate huge electricity to meet the demand of poultry house, and wind turbine has a very low influence on the chick growing and environment. However, wind turbines need to be performed annual mechanical checks and servicing. In comparison, solar energy technology can be utilized for providing continuous heating, cooling, ventilation and lighting in poultry house, which requires less maintenance compared to other renewable energy technologies and supplies a potential long-term alternative available to anyone with a rooftop. Nevertheless, it cannot produce much electricity and heat energy when it is dark or cloudy, and there is a high installation costs. Despite these small issues, solar and wind energy are still the most preferable renewable energy sources for poultry house in the world. This is because they are the cheapest, fastest-growing, most reliable and do much less damage to nature and wildlife surrounding their sites as opposed to fossil fuels. In spite of being a vanguard and promising techniques, some perspectives and challenges for future technique investigation applied into the poultry house are put forward to formulate the framework for the future research interests as follows:

- Most existing technologies are relatively single, hence, more works should spend on the development of hybrid technologies. This contributes to enhancing the whole system performance and obtaining better production for the poultry farming.

- More concentration should be paid on the innovative solutions to break through the obstacles thus accelerate the practical application of these advanced technologies, instead of the fundamental theoretical researches those have been by far well done. Furthermore, the future of technical development forcefully relies on the latest study progress with regard to solar energy, wind energy, geothermal energy, PCM technologies as well as their dual roles for heating and cooling services.

- The accurate numerical models should be developed via the computer software in view of the influences of air temperature variation, wind speed, relative humidity, heating and cooling loads, building U-value, and ventilation rate. The aim is to provide a valuable instrument for researchers and engineers that make use of it to evaluate design alternatives and retrofit measures for various sizes and categories of chicken sheds under different environmental conditions.

- Similar technologies should be demonstrated and utilized to fattening sheep, fattening cows and fattening pigs for different national and regional fields. This is conducive to boosting usage of energy, reducing GHG emission as well as saving operating expense for livestock farming.

4. Conclusions

In this chapter, the state-of-the-art of the renewable and sustainable energy technologies are retrospected to replace for the traditional heating, ventilation, and air conditioning system within the poultry house. This can help to decline energy demands, operating expense, GHG emission and enhance farmers' profits. Consequently, some crucial outcomes are exemplified as follows:

- Solar energy technology could achieve electrical cost saving ranging from 30 to 85% for the poultry rearing. Moreover, the service lifetime of the solar energy technologies is able to maintain approximately 25 years with low maintenance cost for the poultry house.

- Ventilation and wind turbine technology could produce about 2000 kWh/year electrical and fulfill the energy demand of the whole poultry shed, which results in about 3.0 tons/year GHG emission reduction.

- Energy cost and average chicks weight of the GSHP poultry shed could be saved about 92% and raised by around 6.8% in comparison to the normal poultry shed, and the payback period is less 5-year. By contrast, the initial investment of the WSHP system is less than that of the GSHP because it does not need amount of ground works, and the payback time is around 6-year. Additionally, the ASHP is comparatively easy to be mounted, and needs low maintenance cost but often regarded as noisy.

- TES with PCM is a new usage in chicken shed to maintain indoor environmental quality during night time or cloudy day. This technology could store amount of heat with merely slight temperature variation, improve the effectiveness of TES and sustain the thermal storage for a long-term period.

- To sum up, these renewable and sustainable energy technologies can help save up to 85% energy consumption compared to the conventional chicken shed, and have a payback time of 3–8 years.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] Perkins KM, Munguia N, Ellenbecker M, Moure-Eraso R, Velazquez L. COVID-19 pandemic lessons to facilitate future engagement in the global climate crisis. Journal of Cleaner Production 2020; 125178.

[2] Martorell-Marugán J et al. DatAC: A visual analytics platform to explore climate and air quality indicators associated with the COVID-19 pandemic in Spain. Science of The Total Environment 2021; 750: 141424.

[3] Barouki R et al. The COVID-19 pandemic and global environmental change: Emerging research needs. Environment International. 2021; 146: 106272.

[4] Mofijur M et al Impact of COVID-19 on the social, economic, environmental and energy domains: Lessons learnt from a global pandemic. Sustainable Production and Consumption 2021; 26: 343-359.

[5] Manzanedo RD, Manning P. COVID-19: Lessons for the climate change emergency. Science of The Total Environment 2020; 742: 140563.

[6] Wang Y, Sun X, Wang B, Liu X. Energy saving, GHG abatement and industrial growth in OECD countries: a green productivity approach. Energy 2020; 194:116833.

[7] World Meteorological Organization. Global Climate in 2015-2019. Available from: < https://public.wmo.int/en/media/press-release/global-climate-2015-2019-climate-change-accelerates>[Accessed: 2019-09-22].

[8] Wiedemann SG, McGahan EG, Murphy CM. Resource use and environmental impacts from Australian chicken meat production. Journal of Cleaner Production 2017; 140: 675-684.

[9] Pereira JLS. Assessment of ammonia and greenhouse gas emissions from broiler houses in Portugal. Atmospheric Pollution Research 2017; 8 (5): 949-955.

[10] Zareei S. Evaluation of biogas potential from livestock manures and rural wastes using GIS in Iran. Renewable Energy 2018; 118: 351-356.

[11] Kapica J, Pawlak H, Ścibisz M. Carbon dioxide emission reduction by heating poultry houses from renewable energy sources in Central Europe. Agricultural Systems 2015; 139: 238-249.

[12] Zanaty HE. A techno-economic study for heating poultry houses using renewable energy. Available from: <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.843.2738&rep=rep1&type=pdf> [Accessed 2015-11-02].

[13] Rojas-Downing MM, Nejadhashemi AP, Harrigan T, Woznicki SA. Climate change and livestock: Impacts, adaptation, and mitigation. Climate Risk Management. 2017; 16: 145-163.

[14] Huang D, Guo H. Diurnal and seasonal variations of greenhouse gas emissions from a commercial broiler barn and cage-layer barn in the Canadian Prairies. Environmental Pollution. 2019; 248: 726-735.

[15] Vitt R, Weber L, Zollitsch W, Hörtenhuber SJ, Hörtenhuber J, Niebuhr K, Piringer M. Modelled performance of energy saving air treatment devices to mitigate heat stress for confined livestock buildings in Central Europe, Biosystems Engineering 164 (2017) 85-97.

[16] Tamvakidis S, Firfiris VK, Martzopoulou A, Fragos VP, Kotsopoulos TA. Performance evaluation of a hybrid solar heating system for farrowing houses. Energy and Buildings 2015; 97: 162-174.

[17] Ghahramani A, Bowran D. Transformative and systemic climate change adaptations in mixed crop-livestock farming systems. Agricultural Systems. 2018; 164: 236-251.

[18] Sneessens I, Sauvée L, Randrianasolo-Rakotobe H, Ingrand S. A framework to assess the economic vulnerability of farming systems: Application to mixed crop-livestock systems. Agricultural Systems 2019; 176: 102658.

[19] Purdy A, Pathare PB, Wang Y, Roskilly AP, Huang Y. Towards sustainable farming: Feasibility study into energy recovery from bio-waste on a small-scale dairy farm. Journal of Cleaner Production 2018; 174: 899-904.

[20] Torshizi MV, Mighani AH. The application of solar energy in agricultural systems. Journal of Renewable Energy and Sustainable Development (RESD) 2017; 3 (2): 2356-8569.

[21] Ali SM, Dash N, Pradhan A. Role of renewable energy on agriculture. International Journal of Engineering Sciences & Emerging Technologies 2012; 4 (1): 51-57.

[22] Seyfi SU. Comparison of the energy efficiency of dairy production farms using different housing systems. Environmental Progress & Sustainable Energy 2012; 32: 1202-1208.

[23] Bell MJ, Cloy JM, Rees RM. The true extent of agriculture's contribution to national greenhouse gas emissions. Environment Science & Policy 2014; 39: 1-12.

[24] Ghahramani A, Bowran D. Transformative and systemic climate change adaptations in mixed crop-livestock farming systems. Agricultural Systems 2018; 164: 236-251.

[25] Sharif A, Meo MS, Chowdhury MAF, Sohag K. Role of solar energy in reducing ecological footprints: An empirical analysis. Journal of Cleaner Production 2021; 292: 126028.

[26] Behura AK, Kumar A, Rajak DK, Pruncu CI, Lamberti L. Towards better performances for a novel rooftop solar PV system. Solar Energy 2021; 216: 518-529.

[27] Das D, Kalita P, Roy O. Flat plate hybrid photovoltaic- thermal (PV/T) system: A review on design and development. Renewable and Sustainable Energy Reviews. 2018; 84: 111-130.

[28] Zhou B, Pei J, Nasir DM, Zhang J. A review on solar pavement and photovoltaic/thermal (PV/T) system. Transportation Research Part D: Transport and Environment 2021; 93: 102753.

[29] Sharaf OZ and Orhan MF. Concentrated photovoltaic thermal (CPVT) solar collector systems: part I – fundamentals, design considerations and current technologies. Renewable and Sustainable Energy Reviews. 2015; 50: 1500-1565.

[30] Zhou J, Zhang Z, Ke H. PV module temperature distribution with a novel segmented solar cell absorbance model. Renewable Energy 2019; 134: 1071-1080.

[31] First solar-powered poultry house set 2007. Available from: < http://www1.udel.edu/PR/UDaily/2007/dec/solar121806.html> [Accessed: 2007-02-04].

[32] Byrne J, Glover L. The potential of solar electric applications for Delaware's poultry farms, Center for Energy and Environmental Policy. University of Delaware, USA; 2005.

[33] Cramble cross (poultry) farm (Ground and Roof mounted). Available from: < https://duncanrenewables.co.uk/projects/view/63/cramble-cross-farm> [Accessed: 2013-06].

[34] Misbrener K. Southern solar system adds solar-plus-storage to poultry house for Auburn University experiment. Available from: < https://www.solarpowerworldonline.com/2019/06/tyson-foods-auburn-university-off-grid-solar-poultry-house/> [Accessed: 2019-06].

[35] Gad S, El-Shazly MA, Wasfy KI, Awny A. Utilization of solar energy and climate control systems for enhancing poultry houses productivity. Renewable Energy 2020; 154: 278-289.

[36] S.A. & D.E. Dixon Poultry Farm, Shropshire. Available from: < http://www.salopenergy.com/commercial/case-studies/sa-and-de-dixon-ltd-vownog-porth-y-waen-oswestry-shropshire/> [Accessed: 2015-07].

[37] Rota A. Livestock and renewable energy. Livestock Thematic Papers Tools for project design. Available from: <https://www.ifad.org/documents/38714170/39148759/Livestock+and+renewable+energy.pdf/61af921d-a886-4558-b2d1-b97a0650ce06> [Accessed: 2012-10].

[38] Hussein MS, Burra KG, Amano RS, Gupta AK. Effect of oxygen addition in steam gasification of chicken manure. Fuel. 2017; 189: 428-435.

[39] Brewer RN, Flood CA, Koon JL. Solar Heating of Poultry Houses: 3. Design and Testing of Research Facilities. Poultry Science 1981; 60(8): 1802-1806.

[40] Mukunda N, Praveen KK, Sachin MV. Role of renewable energy on agriculture. International Journal of Scientific & Engineering Research 2018; 9 (7): 2229-5518.

[41] Al-Waeli AHA, Sopian K, Kazem HA, Chaichan MT. Photovoltaic thermal PV/T systems: A review. International Journal of Computation and Applied Sciences 2017; 2 (2): 62-67.

[42] Cui Y, Zhu J, Zoras S, Zhang J. Comprehensive review of the recent advances in PV/T system with loop-pipe configuration and nanofluid. Renewable and Sustainable Energy Reviews 2021; 135: 110254.

[43] Das D, Kalita P, Roy O. Flat plate hybrid photovoltaic-thermal (PV/T) system: A review on design and development. Renewable and Sustainable Energy Reviews 2018; 84: 111-130.

[44] Cui Y, Elmer T, Gular T, Su Y, Riffat S. Feasibility of hybrid renewable heating system application in poultry house: a case study of East Midlands, UK. International Journal of Low-Carbon Technologies 2020; 00: 1-16.

[45] ASHRAE, 2011. Handbook-Heating, Ventilating and Air-Conditioning Applications (I-P Edition). American Society of Heating, Refrigerating and Air-Conditioning Engineers.

[46] Zhao Y, Shepherd TA, Li H, Xin H. Environmental assessment of three egg production systems–Part I: monitoring system and indoor air quality. Poultry Science 2015; 94: 518-533.

[47] Fawaza H, Abiad MG, Ghaddar N, Ghali K. Solar-assisted localized ventilation system for poultry brooding. Energy and Buildings 2014; 71: 42-154.

[48] Costantino A, Fabrizio E, Biglia A, Cornable P, Battaglini L. Energy use for climate control of animal houses: the state of the art in Europe. Energy Procedia 2016; 101: 184-191.

[49] Costantino A, Fabrizio E, Ghiggini A, Bariani M. Climate control in broiler houses: A thermal model for the calculation of the energy use and indoor environmental conditions. Energy and Building 2018; 169: 110-126.

[50] Hong SW, Lee IB, Seo IH, Kwon KS. The design and testing of a small-scale

wind turbine fitted to the ventilation fan for a livestock building. Computers and Electronics in Agriculture 2013; 99: 65-76.

[51] Du L, Hu C, Yang c, Yang L, Du H, Li Q, Yu C, Xie L, Jiang X. Investigation of a preliminary ventilation energy-recovery system for poultry houses. Computers and Electronics in Agriculture 2020; 175: 105521.

[52] Kapica J, Pawlak H, Ścibisz M. Carbon dioxide emission reduction by heating poultry houses from renewable energy sources in Central Europe. Agricultural Systems 2015; 139: 238-249.

[53] Kucuktopcu E, Cemek B. A study on environmental impact of insulation thickness of poultry building walls. Energy 2018; 150, 583-590.

[54] Firfiris VK, Martzopoulou AG, Kotsopoulos TA. Passive cooling systems in livestock buildings towards energy saving: A critical review. Energy and Building 2019; 202: 109368.

[55] Heat pumps for pig- and poultry houses. Available from: < https://inno-plussystems.com/en/products/heatpump/> [Accessed: 2014-04].

[56] Choi HC, Salim HM, Akter N, Na JC, Kang HK, Kim MJ. Effect of heating system using a geothermal heat pump on the production performance and housing environment of broiler chickens. Poultry Science. 2012; 91: 275-228.

[57] Kharseh M, Nordell B. Sustainable heating and cooling systems for agriculture. International Journal of Energy Research. 2011; 35: 415-422.

[58] Davies J. Carp lake used to heat poultry sheds. 2014 Available from: < https://www.fwi.co.uk/livestock/poultry/broilers/carp-lake-used-to-heat-poultry-sheds> [Accessed: 2014-04].

[59] Davies J. Air-source heat pumps power poultry shed. Available from: < https://www.fwi.co.uk/business/air-source-heat-pumps-power-poultry-shed>[Accessed: 2014-05].

[60] Stonehouse poultry farm. Available from: <https://library.mitsubishielectric.co.uk/pdf/download_full/1051> [Accessed: 2014-07].

[61] Zanaty HE. A techno-economic study for heating poultry houses using renewable energy. The American University in Cairo. 2015. Available from: <http://dar.aucegypt.edu/bitstream/handle/10526/4281/MSc%20Thesis%20Report_HZ.pdf?sequence=1> [Accessed: 2015-10-02].

[62] Hu Z, He W, Ji J, Zhang S. A review on the application of Trombe wall system in buildings. Renewable and Sustainable Energy Reviews. 2017; 70: 976-987.

[63] Okonkwo WI, Akubuo CO. Trombe wall system for poultry brooding. International Journal of Poultry Science. 2007; 6: 125-130.