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EXPERIMENTAL ASSESSMENT OF THE PERFORMANCE OF RENEWABLE ENERGY TECHNOLOGIES IN BROILERS PRODUCTION

by
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ABSTRACT
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The increased cost of fuel oil cause an upward pressure on the poultry production sector where heating is vital during the first weeks of operations. The use of renewable energy in poultry brooding is being investigated as it may significantly reduce the energy bills and GHGs emissions in poultry farms. This research evaluates the use of renewable energy in broilers production at the Advancing Research Enabling Communities (AREC), at the American University of Beirut (AUB). The study aims at determining the effectiveness of a solar assisted localized heating system, aided by biogas energy produced from the anaerobic digestion of manure, in heating a poultry house. For this aim, two brooding cycles were conducted during the warm and cold seasons in a conventional and a green poultry house equipped with photovoltaics, solar heaters, anaerobic digester, and a geothermal system. The brooding cycles were replicated in a control house running on conventional electricity.

The results revealed that the green system covered a significant part of the heating and ventilation, but additional heating sources remained necessary. The total energy input in the green and conventional houses were about 34000.50 and 40662.09 MJ, respectively, in the warm season, as compared to 32345.42 and 41069.84 MJ, respectively, in the cold season. As for the energy output it was found to be 20116.23 and 20629.04 MJ in the green and conventional houses, respectively, in the warm season, and 14725.35 and 15681.81 MJ, respectively, in the cold season. In addition, energy analysis study showed more efficiency in consuming the energy in the green system (0.60 and 0.46 in the warm and cold season, respectively) than in the conventional one (0.52 and 0.40 in the warm and cold season, respectively). The results from this study proved that operating poultry houses using renewable energy technologies significantly decreases the energy consumption. The results also suggest that combining several energy sources could provide the total energy needs with a proper system design. Further research focusing on optimizing the green system would ultimately encourage investments in this sector for a sustainable broilers production.

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ABBREVIATIONS

AREC	Advancing Research Enabling Communities
AUB	American University of Beirut
GPH	Green Poultry House
CPH	Conventional Poultry House
RE	Renewable Energy
FAO	Food and Agricultural Organization
GHG	Greenhouse Gases
PV	Photovoltaic Panels
HRES	Hybrid Renewable Energy Systems
DEA	Data Envelopment Analysis
BCR	Benefit to Cost Ratio
FCU	Fan Coil Unit
TSS	Total Suspended Solids
VSS	Volatile Suspended Solids
VFA	Volatile Fatty Acids
EC	Electrical Conductivity
SD	Standard Deviation
IRI	Industrial Research Institute
LARI	Lebanese Agricultural Research Institute
LEAF	Laboratory for The Environmental, Agriculture and Food
VIF	Variance Inflation Factors

CHAPTER 1

INTRODUCTION

Energy is the capacity to do work, it represents the core of human activities and production processes (1). It is found in several interchangeable forms, including mechanical, thermal, chemical, electrical, gravitational and nuclear (2). Energy occupies an important part in the economic sector of all countries, being the key input in all the activities, consumptions and production processes. Energy has, therefore, a crucial impact on the nation's improvement and development (3).

The fast-paced global development and economic growth have led to a rapid increase in demand for energy (2). The global energy consumption is expected to increase by 53% over the coming decades (4), leading to a global deterioration of the environment by depleting the natural resources and threatening the stability of the global climate (4).

To ensure sustainability of the natural resources and the environment, there is a growing awareness to move towards the use of renewable energy resources (4). Renewable energy (RE) has many benefits, including a reduction in global warming emissions and diversification of energy sources from wind power, solar power, hydropower, tidal power, geothermal energy, and biofuels. Countries are searching to maximize their reliance on renewable resources through the adoption of RE systems of increased efficiency and affordability (5).

Anaerobic digestion is another proposed energy source that is currently under study (6, 7, 8). Methane biogas from anaerobic digestion of biomass is a promising energy source, with the potential of reducing reliance on fossil fuels and decreasing the related adverse environmental impacts. Biomass can be any kind of organic materiel resulting from plants, animals, or other organic wastes. The energy resulting from the process is in the form of biogas rich in methane (9, 10).

Energy Analysis is a method used to determine the amount of energy consumed in a given process. Thermodynamically, it is defined as the study of the change in free energy within an operation (11). Energy analysis allows the comparison between different systems and production lines, by calculating the energy cost in each process (12). Thus, it offers the ability to study the production lines and optimize them according to their energy cost (13).

Although Lebanon is rich in renewable resources, the main energy source used is fossil fuels. In 2011, 94% of the primary energy consumption was from oil, 2% from coal, and only 4% from hydropower (14). Solar energy is considered the best RE source to harness, from physical and economic perspectives (5). The government aims at covering 30% of the electricity and heat demand from renewable sources by 2030, which encourages solar PV projects and wind farms to stand up and develop (15).

Agriculture is a vital sector in all countries and is considered as an energy user and supplier at the same time. This sector profitability and productivity rely on energy consumption in the production processes (1). The Food and Agricultural Organization (FAO) defines sustainable agriculture as the one which “is environmentally non-degrading, technically appropriate, economically viable and socially acceptable” (16).

Poultry production is considered a very important livestock sector, and it is in continuous growth. Broiler occupies the third place among the most consumed meat worldwide, after beef and pork (12). The chicken industry focuses on its main purpose, and that is to maximize growth, feed efficiency and profitability. Therefore, energy-saving approaches are implemented to ensure sustainability in poultry production (18).

As for the Lebanese agricultural sector, poultry production is one of the main contributors. The poultry production can be categorized into two types according to their aims, either chicken layers for egg production or broilers for meat production. The growth of this sector is facing a main challenge, being the continuous increase in energy cost, which causes a drastic decrease in the profit of poultry farms (19).

In the brooding period in broilers production, which is the period immediately after the hatch, special care and attention should be given to the chicks in order to support their development. One of the main parameters that affect the recently hatched chicks is temperature, since they cannot regulate their own body temperature especially in the first weeks (20). For this reason, heating systems are considered the consumers of the biggest amount of energy in the production process, especially in the cold seasons (18). Fossil fuels are extensively used in farms, to ensure that the required heating needs are met, in addition to electrical energy that is established on fossil fuel energy (19).

Moreover, in a poultry house, several gases are produced including ammonia (NH_3), carbon dioxide (CO_2), and others, contributing to the total greenhouse gases (GHGs) emissions. 6.4% of the U.S. GHG is produced by the agriculture sector out of which poultry accounts for 0.6%. GHGs emissions can significantly be reduced if broiler heating utilizes renewable and clean energy sources along with an efficient heating system (21).

This study aims at implementing different RE technologies to decrease the dependency of poultry production in Lebanon on fossil fuels. As a way of demonstrating the utilization of a highly reliable and sustainable system for brooding year-round in Lebanese farms, it is proposed to operate and study a poultry house, running on hybrid RE systems, by conducting brooding cycles in the warm and cold seasons. The green poultry house exists at AREC, AUB, in the arid region of the Bekaa valley and is equipped with solar heaters and photovoltaic (PV) panels, a geothermal heat exchange system, and an anaerobic digester.

The main objective of this research is to assess the use of renewable energy in the poultry production sector in Lebanon. The specific objectives of the project are to:

- Test and operate the green poultry house at AREC.
- Evaluate the performance of the different RE technologies in operating the poultry house.
- Assess the energy consumptions and savings in the poultry house equipped with RE systems, as compared to the use of conventional energy in a control poultry house.
- Assess the reduction in GHGs emissions in poultry production using clean RE sources.
- Study the system performance under different weather conditions.
- Examine the economic feasibility of implementing RE technologies in poultry production in the Bekaa area in Lebanon.

CHAPTER 2

LITERATURE REVIEW

Nowadays, studies are focusing on the implementation of renewable energy in the different aspects of life and integrating several renewable energy sources into hybrid renewable energy systems (HRES), which have been considered more economical and reliable than single energy source systems (4, 22).

The HRES application in poultry farms is still under investigation. Jacek et al. (23) studied the impact of using a hybrid solar-wind system in poultry houses on the reduction of GHGs and showed that large hybrid systems will have a high reduction in CO_2 emissions. Van Dyne (24) studied, using a simulation model, the economic feasibility of the use of solar heating in Maryland's poultry houses, and showed that solar energy could cover up to 42% of the heating requirements, presenting a cost effective heating source as compared to the commonly used propane gas.

Ramos-Suárez et al. showed that biogas resulting from anaerobic digestion of around 495 thousand tons of animal manure generated yearly, could be used for heat and electricity production contributing to 55 thousand tons of CO_2 ad GHGs emission savings (25). Ouhammou et al. (26) studied a system of an anaerobic digester coupled with solar energy and reported 94% coverage of heating requirements of the digester throughout the year, 100% in the summer, and 88% in the cold period.

Hassanein et al. showed that heating a biogas digester by using a solar energy system increases biogas revenue. The authors computed a payback period of the system in the studied location of 14 months (27). Ernest et al. (28) showed that the adoption of photovoltaic solar technologies in poultry industry could be financially beneficial according to the size of the system, especially with the provided incentives to polluting industries to reduce their GHGs emissions.

Studies have indicated that conservation energy measures coupled with RE usage can significantly reduce the energy consumption in poultry brooding. The implementation of such actions will have a positive impact on production costs as well as the environment (29, 30, 31, 32). To effectively study the energy usage in agriculture, the most reliable method in the INPUT-OUTPUT Analysis Method (1, 17, 33).

Ozkan et al. (34) conducted an INPUT-OUTPUT energy analysis on Turkish agriculture for the period between 1975 and 2000 and found that energy consumption is continuously increasing and highlighted the necessity of adopting energy saving policies and new energy-saving technologies. Abdi et al. (35) investigated the energy consumption and CO_2 emissions in wheat, corn silage, cucumber, and tomato production in Iran and reported energy use ratio of 0.74, 2.55, 0.46 and 0.73 respectively, and CO_2 emissions of 2.07, 4.35, 4.99, and 4.66 tons per ha, respectively.

In poultry production, among the direct energy inputs, heating is the most important (18). Feed, machinery, and fuel for heating are considered major energy inputs in poultry brooding cycles (17).

Amid et al. (36) used a data envelopment analysis (DEA) to study and optimize the efficiency of 70 broiler farms in Northern Iran and found that 14.53% of the total energy used could be conserved if the production units implement optimal procedures. They registered a conservation in fuel energy as high as 72%. Sefeedpari et al. (29) also examined the efficiency of poultry farms in Iran, using DEA, and indicated that 22% of total energy could be conserved if proper production patterns were taken.

Atilgan et al. (17) analyzed the energy consumption in broiler production in poultry houses with different capacities in Turkey, and the results showed that increasing the housing capacity decrease the input energy up to a certain capacity, with the same production methods. Similarly, Najafi et al. (13) assessed energy efficiency in poultry farms of different sizes and reported higher efficiency and better productivity in the larger farms.

Firouzi (18) conducted an energy audit in 25 broiler farms in Northern Iran and compared the energy use indices during the warm and cold seasons. Energy efficiency during the warm season was 0.26, with feed and diesel fuel constituting the highest energy inputs of 43.44% and 33.43%, respectively. However, the efficiency dropped to 0.2 in the cold season, with an energy input of 51.58% from diesel fuel, and 31.73% from the feed. Amini et al. (1) evaluated energy consumption and conducted an economic analysis in traditional and modern farms for broilers production. The fuel and feed were the major contributors to the energy inputs in both farms. The efficiency in the traditional and modern farms was 0.16 and 0.17, respectively. As for the economic analysis, the fixed capital cost for traditional farms was higher than for modern farms, however, the benefit to cost ratio (BCR) was 2.1 in modern farms, versus 1.88 in traditional farms.

Heidari & Akram (12) conducted an energy efficiency and econometric analysis in broilers farms. Diesel fuel had the major contribution for the total energy input. The budgetary analysis of broiler farms resulted with a BCR of 1.38. Table 1 represents a summary of the energy analysis of broilers production reported from the different cited studies. The analysis in each case is based on 1000 raised birds.

Table 1: Summary of the studies on energy analysis in broilers production

Reference	Experimental conditions	Total Inputs (MJ/1000 birds)	Total Outputs (MJ/1000 birds)	Energy Use Efficiency
Amid et al. (36)	70 farms in Ardabil province, Iran	154283	27447	0.18
Firouzi (18)	25 farms in the warm season	93544.65	24418.36	0.26
Firouzi (18)	25 farms in the cold season	128254	25757	0.2
Amini et al. (1)	70 traditional farms	178343	29100.14	0.16
Amini et al. (1)	70 modern farms	188798	32576	0.17
Heidari & Akram (12)	44 farms in Yazd province, Iran	186885.87	27461.21	0.15
Kalhor et al. (38)	40 farms in summer season	94783.00	24341.93	0.26
Yamini Sefat et al. (39)	50 farms in winter season	220020.00	30250.00	0.15

CHAPTER 3

MATERIALS AND METHODOLOGIES

3.1. Study Area

The study is performed at AREC, Advancing Research and Enabling Communities, an AUB facility located in Haush-Sneid in the heart of the Beqaa Valley, Lebanon. It is 80 kilometers from Beirut and 25 kilometers from Zahleh, at an elevation of 1200 m above sea level. AREC has an area of 100 hectares, it includes agricultural land for teaching, research, and demonstration of food production, in addition to a research farm, an agricultural library, classrooms and laboratories.

The climate in the Bekaa is continental, characterized by cold and rainy winters and hot and arid summers. The temperature varies between -1°C in winter, where snow could last for a month, and could attain 40°C in summer.

3.2. Heating and Ventilation Systems in the Green and Conventional Poultry Houses

Two poultry houses were used for broilers production, each with an area of 140 m^2. One of the poultry houses, the green poultry house (GPH), is equipped with a solar assisted localized heating system, while the other, the conventional poultry house (CPH), uses a conventional heating system. Figure 1 and 2 show respectively the GPH and CPH at AREC.

Figure 1: Green poultry house (GPH) at AREC

Figure 2: Conventional poultry house (CPH) at AREC

3.2.1.Green Poultry House (GPH)

The green house consists of 2 sections (figure 3). The first section includes the entry, storage area to put the feed, feeders and drinkers, heating system equipment including the water storage tank, PV batteries, pumps, data logger and system controllers. The second section is the study zone, an open area where brooding cycles are conducted.

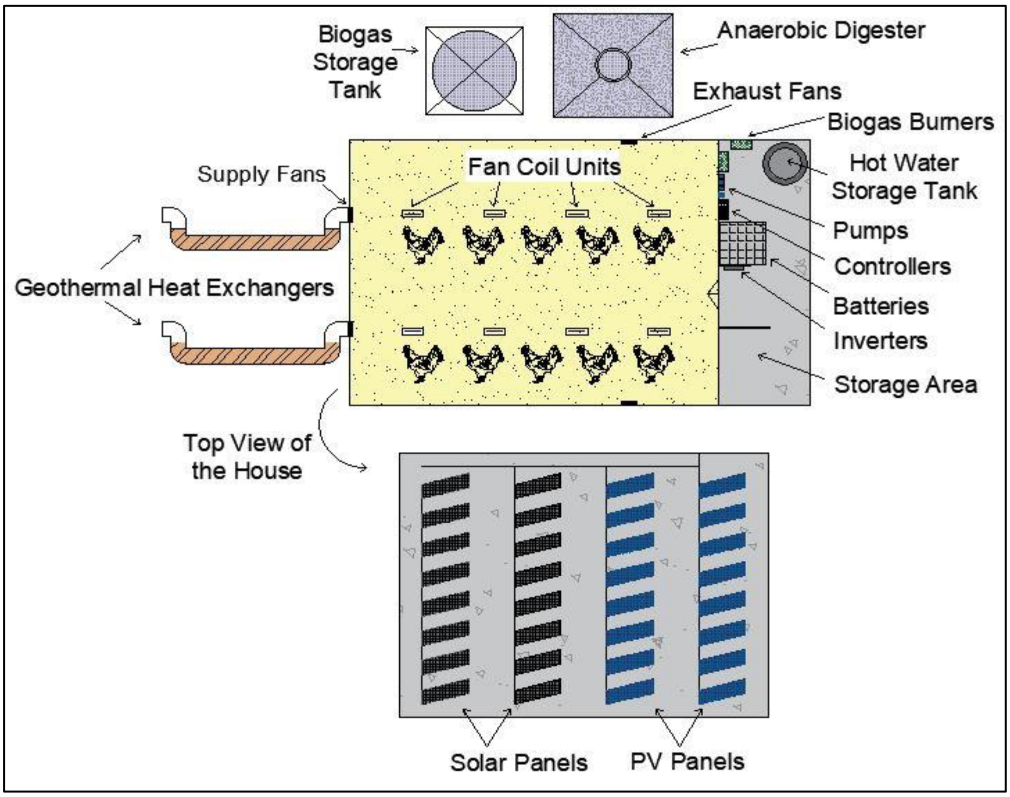

Figure 3: GPH components

The GPH is equipped with a green system composed of photovoltaic panels and solar heaters, geothermal heat exchangers, and a 100 m^3 anaerobic digester. Figure 4 shows the different components of the green system, followed by a detailed description of each of these components.

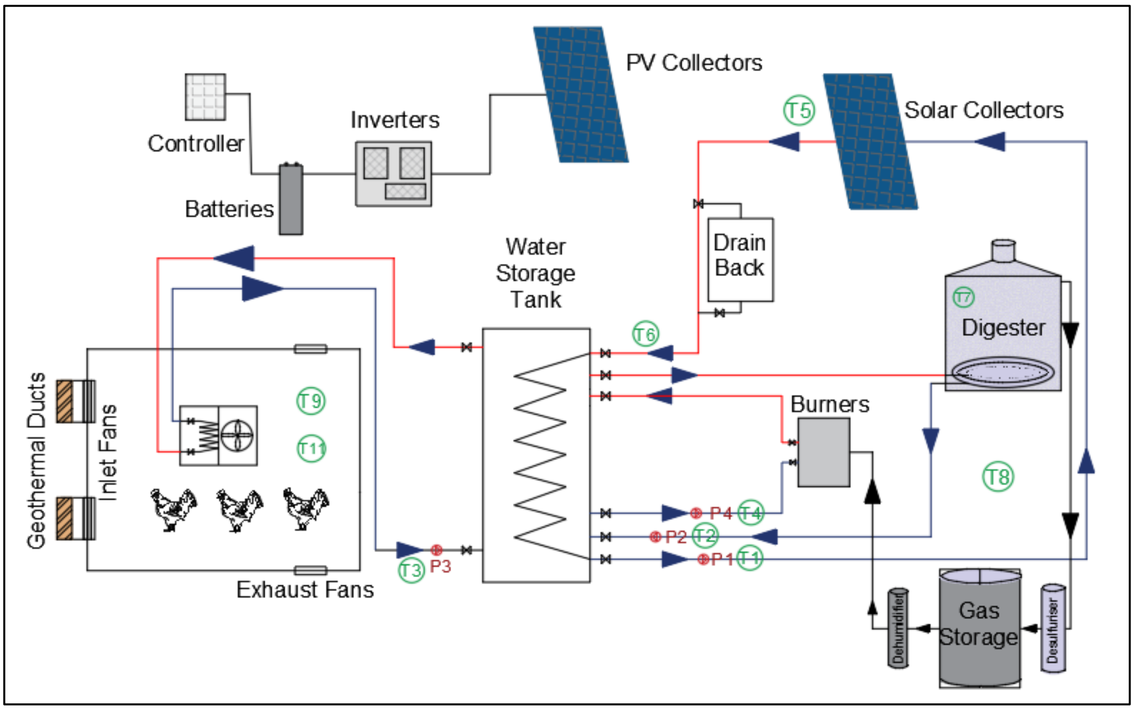

Figure 4: Scheme of the heating system in the GPH

3.2.1.1 Solar Heaters

The heating system in the GPH (Figure 4) is composed of 16 solar collectors (superline high performance flat plate solar collectors, USB series size of 1.891m*1.204m*0.099m each) of a total area of 32 m^2, installed on the roof of the poultry house at an inclination of 45° to maximize the profit of sun irradiation. The solar collectors are connected to a 1000 L thermal water heating storage tank equipped with a coil heat exchanger and a built in electrical backup heat. The solar collectors concentrate solar radiation in order to heat the circulating solution, which is used in turn to exchange heat with the water inside the storage tank. A 50 L gravity storage tank is installed for drain back purpose of the circulating solution to prevent freezing problems.

The hot water in the storage tank is employed for distributing heat to 8 fan coil units (FCU) (YHK 25-2/ CR 03-2R HB) distributed in the brooding area of the poultry house, at 1 m elevation from the ground. Hot water circulating in the FCU heats the surrounding air and provides the required temperature at the chicks' level.

3.2.1.2 Photovoltaics

16 photovoltaic (PV) collectors (STP280 - 24/Vd, 280 Watt) are installed on the top of the GPH and used to provide the needed electric energy for the system. The PV panels convert solar energy into electricity which is stored in 24 batteries (OPzS Cell batteries with a total capacity of 656 Ah). The generated electricity is used to light lamps in the poultry house (total of 300W) and operate the system pumps and controllers. The installed PV system generates a yearly average electricity of 6800Wh, which is calculated to cover the electrical energy use of the house.

3.2.1.3 Geothermal Heat Exchangers

To further mitigate energy consumption in the system, the temperature of the ventilation air was moderated using geothermal heat exchangers composed of 2 galvanized pipes of 12" diameter and 12 m length each. These were buried in the soil at the rear of the poultry house at a depth of 1.7 m, and were supplied with 1cm wire mesh on both sides to prevent animals and big size items to get into them (Figure 5).

Figure 5: Geothermal heat exchanger

The geothermal ducts utilize the soil as a heat source and sink to moderate the temperature of the outdoor air entering the house during the warm and cold seasons. Two inlet fans (TD 2000/315, 355W, 2420 rpm) placed at the ground level of the poultry house allow air to move from the geothermal ducts to the inside of the house. Two outlet fans (HCM-225N, 40 W, 1320 rpm) placed at a higher position on the walls of the 2 opposite sides of the poultry house, provide air circulation and prevent the accumulation of toxic gases in the house.

3.2.1.4 Anaerobic Digester

In order to support solar-based heating at certain times of the year when solar radiation may not be available, a 100 m^3 biodigester (Figure 6) was built next to the green poultry house to provide auxiliary heating through the generation of biogas from the anaerobic digestion of cows manure. Figure 7 shows a scheme of the anaerobic digester.

Figure 6: The anaerobic digester next to GPH

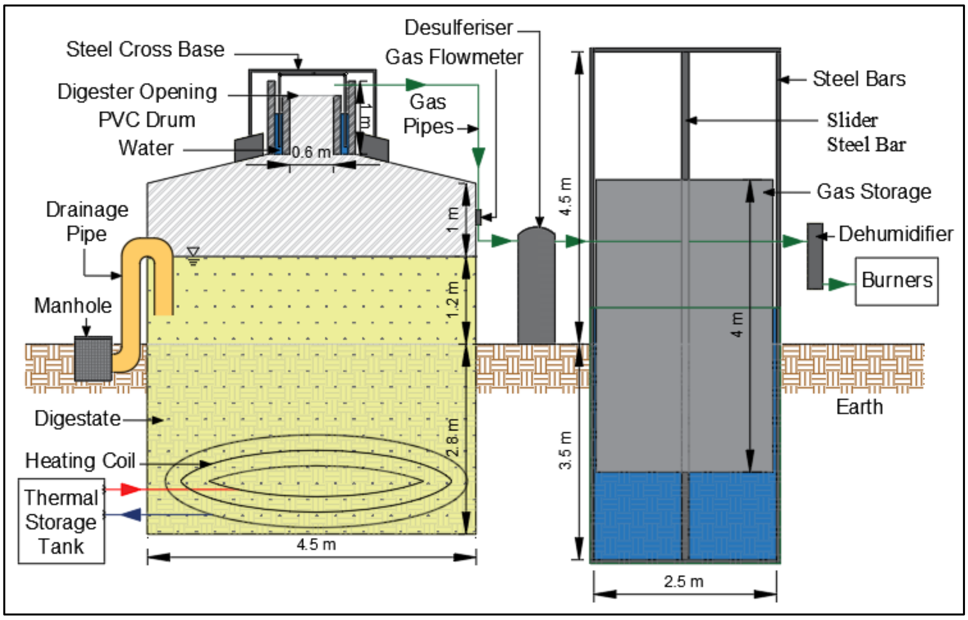

Figure 7: Scheme of the anaerobic digester

The anaerobic digester is made of sulfur resistant concrete type II and is completely water and gas tight with a total volume of about 100 m^3, and it is equipped with water stops on all its joints. It is partially embedded underground (2.6 meters) to minimize heat loss between the walls and the outside medium.

The digester is square shaped. The feed is pumped inside the digester using a pump placed is a nearby manure pit, using an adequate pump to prevent accumulation of solids inside the pipe. The manure slurry height level is designed to be at 1 m below the top of the digester, the remaining space is left intentionally free for biogas accumulation. The drainage pipe is connected to a watertight manhole of about 0.5 m^3, filled with water as a gas sealant. In addition, the outflow pipe is immersed in the slurry inside the digester at a depth of 80cm below the slurry level.

The top opening of the digester is 60cm in diameter to allow access to the inside for cleaning and maintenance purposes. Gas tightness was achieved by using clean water as a sealant. The cover is a PVC drum, put in the upside-down position and water is added around it.

The gas from the digester flows naturally into the desulfurization unit then to the gas storage tank. Gas storage is achieved by means of a floating steel tank in clean water (Figure 7). The floating tank is 250 cm in diameter and about 4m in height with about 1000 kg in weight. The tank is put in the upside-down position and fits in a circularly cored square concrete pit of 2.55x4 m filled with clean water for gas sealing.

Figure 8: Gas floating storage tank

Once gas accumulates, the induced gas pressure will force the tank to float accordingly. The floating tank is guided by a slider cylindrical steel bar fixed in the middle along the sliding distance of the tank. The gas from the storage tank flows through the dehydration unit then to the two boilers. Once the tank is in its highest position due to less use of gas, gas will flow freely through a perforation in the middle pipe exposed above water level, until the gas pressure is again reduced to seal the gas path. This is a natural gas valve with fail-safe technique.

3.2.1.5 Controllers and Data Acquisition System

The system is equipped with a controller (Resol Germany) allowing the measurement of the temperature and energy flows. The model is able to read 12 temperature measurements, the location of the sensors ensures first the proper operation of the system as well as proper measurement of temperature and energy flows, and they are presented in table 2 and illustrated in figure 3. The controller is fully programmable and flexible. During the brooding cycles, the operation of the system is set according to the needed temperature in the house.

Table 2: Sensors location

#	Descriptions
T1/P1	Solution temperature and drain back pump from solar collectors
T2/P2	Water temperature and circulation pump to the digester heating coil
T3/P3	Water temperature and circulation pump to fan coils
T4/P4	Water temperature and circulating pump to the thermal water storage tank
T5	Temperature at solar collectors
T6	Water Temperature at the top of the thermal water storage tank
T7	Temperature inside the digester
T8	Outdoor temperature
T9	GPH temperature
T10	CPH temperature
T11	GPH temperature
T12	Control room Temperature

3.2.2. Conventional Poultry House (CPH)

The CPH is divided into 10 pens of 4x2.5m^2 each. Heating in the CPH is provided by five sided quartz electrical heaters of 2000 W each, distributed inside the house. Cooling is provided by two evaporative cooling pads (Figure 8) of 1.5mx1.5m installed in the wall and a fan that pulls the hot air into the unit, sending it through a series of pads that help evaporate the liquid into a gas which then blows out cooler than it was when it entered the unit.

Figure 9: Cooling pad in CPH

3.3. Broiler Production

3.3.1. *Brooding cycles*

The brooding cycle consists of raising newly hatched chicks for 42 days, until they become well developed and ready to be delivered to the market. Two poultry houses are operating simultaneously, the green and the conventional house. The tested chicks are Ross 308, an Aviagen brand, with a total of 1000 chicks per brooding cycle per house.

Prior to conducting a brooding cycle, the 2 green and conventional poultry houses are cleaned and disinfected, to ensure a pathogens free environment for the vulnerable newly hatched chicks. Small feeders and drinkers, specified for chicks of age 1 to 14 days, are placed inside the brooders, and filled with feed and water. The temperature is maintained at 32°C, in both houses, 48 hours before the arrival of the chicks. Table 3 shows the temperature that needs to be provided in the houses during a brooding cycle.

Table 3: Chicken thermal comfort design conditions

Days	Temperature in °C
First day	32
3	30
6	28
9	26
12	25
15	24
18	23
24	21
27	20

Source: Aviagen. (2014) Ross Broiler Management Handbook (40)

The floor of the poultry houses is covered with fine wood shaving as bedding material, to a thickness of 5 cm (40). During the brooding cycle, the hygiene of the poultry house is maintained by cleaning every tool entered to the houses with disinfectant. Feed and water are provided daily in enough quantities. Five vaccines are given to the chicks, by eye drops, on days 4, 6, 10, 16, and 18 for Marek's disease, Newcastle disease, and infectious bronchitis. In case of occurring diseases, treatment was given to the chicks according to the diagnosis.

On day zero of the cycle, the chicks are counted and placed inside the brooders, in a way providing enough space to move, while being close to feed, water and heating sources. Each day, feed is distributed in the feeder, and water is added to the drinkers in both houses. Feeders and drinkers are cleaned and disinfected each 3 days. The bedding material is checked each day and changed when it becomes wet, on average every two days especially around the drinkers. The temperature is checked regularly during the day, and the necessary number of heaters is turned on accordingly.

3.3.2. *Environmental Sampling*

During the brooding cycles, several parameters were recorded to study the overall performance of the chicks and the system. Production recording sheets were filled daily, recording the bird's mortality, feed consumption, electricity consumption and any other remarks on the broilers (41). Chicks were weighed 5 times during the brooding cycle, based on a 12% representative sample. Inside and outside temperatures of the poultry houses were recorded in the data logger every 1 min. Poultry houses inside and outside relative humidity measurements were performed daily using psychrometers. Humidity inside the poultry houses should be maintained between 50 and 75%, to avoid respiratory disorders due to the high or low humidity levels (42).

Carbon dioxide (CO_2) and ammonia (NH_3) levels were supposed to be measured daily during the brooding cycle, from multiple locations in the houses at the height of the chicks (41). However, delays in getting the CO_2 and NH_3 gas meter prevented these measurements. Carbon dioxide (CO_2) results from the air exhaled by the chicks, with the maximum level of CO_2 allowed in the poultry house being set to 3000 ppm to prevent respiratory diseases. Ammonia (NH_3) is a gas produced from the bacteriological reactions in the manure that could irritate the mucous membranes if it is found in high concentrations. Therefore, it should be less than 10 ppm in the poultry house (43).

3.4. Biogas Production

3.4.1. *Anaerobic Digestion*

The anaerobic digester was operated as a completely mixed reactor. Cow manure was used as feed to produce biogas. Heating was provided by solar energy, aided by conventional electricity when needed, to achieve an optimal temperature of 35 C for the manure digestion.

3.4.2. *Sample Analysis*

Manure samples were collected from the digester and analyzed for few weeks before the sampling port was completely obstructed, and no further sampling was conducted. Total and volatile suspended solids (TSS and VSS) were measured, using standard methods. 20g of the sample were dried at 110°C for 24 hours to get the TSS (44), then burned at 550°C to measure the VSS (40). Total and organic carbon, total nitrogen and sulfur were measured using the elemental analyzer (45).

Density of the liquid manure was determined by measuring the volume of manure sample of known mass in a 100 mL graduated cylinder. As for solid samples, density was determined as dry bulk density, then wet density by adding water to fill the pores volume (44). pH and electrical conductivity (EC) were measured directly with a pH and EC meters for liquid samples and after dilution of the solid samples with distilled water (44).

Before starting the digester, and to avoid the inhibition of the reactions, metals in the manure were measured using atomic absorption spectrophotometry according to EPA method 7000a, after microwave digestion of the sample with 99% nitric acid at

170°C according to EPA method 3051 (44). Biogas production was monitored using a biogas flowmeter.

3.5. Energy Analysis

In order to calculate the energy consumption during a brooding cycle, the input and output energy sources are specified. The inputs include the newly hatched chicks, feed, machinery, electricity, diesel fuel, and human labor. While the output includes the broilers and the manure (1, 4, 12, 13, 17, 18, 36).

The energy of chickens are calculated as follow:

$$E_{ch} = n_{ch} \times ec_{ch} \times w_{ch}$$

Where E_{ch} is the total energy from the chicken input (MJ), n_{ch} is the number of chicken, ec_{ch} is the energy equivalent of chicken (MJ Kg^{-1}), and w_{ch} is the average weight of chicken.

The energy of feed is obtained taking into consideration the diet composition and the energetic values of each feed ingredient component. It is calculated as the summation of energy of all the feed components and it is expressed in terms of metabolizable energy per unit weight of feed (MJ Kg^{-1}). It is calculated as follows:

$$E_F = \sum W_{ci} \times ec_{ci}$$

Where E_F is the total energy from the chicken input (MJ), i is the number of components, w_{ci} is the weight of the component ingredient i of the feed, ec_{ci} is the energy equivalent of component ingredient i (MJ Kg^{-1}).

Similarly, the machinery energy is calculated as the sum of energy consumption from the electric motor, steel, and polyethylene used during the cycle, considered as the raw materials of all the equipment used during the brooding cycle. The machinery in the conventional and green poultry houses in our experiment refers to feeders, drinkers, pumps, and electrical fans. Due to the insufficient technical and structural description of the equipment in the houses, an average energy equivalent of the machinery was assumed from the literature.

The energy of electricity is that used by the system including lighting and evaporative coolers, and it is expressed in terms of MJ per KW h^{-1}. The electricity consumption is that consumed from AREC's grid and is measured using two electricity meters placed in the green and conventional houses. The energy of electricity used from the chargeable batteries is considered renewable and do not enter in the calculation. The energy consumption of diesel fuel usually refers to the combustion of fuel for heating and operational purposes in the farms and it is expressed in MJ per liter. This energy is zero in our case because we did not use diesel fuel for operation.

The energy consumed by human labor is calculated using:

$$E_{la} = h \times n_d \times n_{la} \times ec_{la}$$

Where E_{la} is the total energy from the human labor input (MJ), h is the number of work hours spent per day, n_d is the number of workdays during the cycle, n_{la} is the number of human labors, and ec_{ch} is the energy equivalent of human labor (MJ h^{-1}).

The output energy for the brooding cycle includes the broiler meat and the chicken manure. Broiler meat have a preference as a healthy and high-quality food. Chicken manure is a very good fertilizer, it is kept dry by the farm to preserve the minerals present in it, especially nitrogen. The output broiler is calculated according to the total weight of broilers sold. The manure output is the energy equivalent to the manure taken and weighed from the house, during the brooding cycle and is calculated by multiplying its weight by the energy equivalent coefficient.

The energy equivalents used to estimate the energy inputs and outputs are summarized in table 4.

Table 4: Energy equivalents of inputs and outputs in broiler production (1, 4, 12, 13, 17, 18, 36)

Inputs	Units	Energy Equivalent (MJ/Unit)
Chick	Kg	10.33
Human labor	h	1.96
Machinery		
Polyethylene	Kg	46.3
Galvanized iron	Kg	38
Steel	Kg	62.7
Electric motor	Kg	64.8
Fuel diesel	L	47.8
Feed		
Maize	Kg	7.9
Soybean meal	Kg	12.06
Di-Calcium phosphate	Kg	10
Minerals and vitamins	Kg	1.59
Fatty acid	Kg	9
Electricity	kWh	3.6
Outputs		
Broiler	Kg	10.33
Manure	Kg	0.3

Based on energy equivalents of inputs and outputs, energy data of the green and control poultry houses is computed, and energy indices are calculated per initial 1000 birds in the brooding cycle. Calculated energy indices include: 1) energy use efficiency or energy ratio, which is the ratio of the output and input energy; 2) energy productivity, which is the amount of yield produced per 1 MJ of input energy; 3) specific energy, which is the amount of input energy per each kg of output yield; and 4) net energy, which is the difference between the input and output amount of energy. The indices are calculated as follows:

$$\text{Energy use efficency} = \frac{\text{Energy output }(\text{MJ}(1000\text{ bird})^{-1})}{\text{Energy input }(\text{MJ}(1000\text{ bird})^{-1})}$$

$$\text{Energy productivity} = \frac{\text{Yield }(\text{Kg}(1000\text{ bird})^{-1})}{\text{Energy input }(\text{MJ}(1000\text{ bird})^{-1})}$$

$$\text{Specific energy} = \frac{\text{Energy intput }(\text{MJ}(1000\text{ bird})^{-1})}{\text{Yield }(\text{Kg}(1000\text{ bird})^{-1})}$$

$$\text{Net energy} = \text{Energy output }(\text{MJ}(1000\text{ bird})^{-1}) - \text{Energy intput }(\text{MJ}(1000\text{ bird})^{-1}$$

The energy inputs are divided into direct and indirect energy, and in renewable and non-renewable energy. Direct energy is the energy consumed directly inside the project boundaries, and includes human labor, diesel, and electricity while indirect energy covers chick, machinery and feed, that are produced outside the project boundaries and consumed on site. On the other hand, renewable energy, includes chick, human labor and feed, whereas non-renewable energy, or energy sources available in limited quantity on earth, consists of diesel fuel, machinery and electricity.

3.6. Economic Analysis

The economic analysis entails comparing the benefits and costs of the project through a comparison between the green and control house. This is achieved by calculating the economic indices, namely, 1) gross return, which is the difference between the gross and variable production value (in $), 2) net return, which is the difference between the gross and total production value (in $), 3) benefit-cost ratio (BCR), which is the ratio between the benefit and cost value, and 4) productivity, which is the amount of yield produced per each $ (in Kg/$). These economic indices depends on broiler yield, gross production value, variable cost production, fixed cost production and total production cost, and are calculated as follows:

$$\text{Gross Production Value} = \text{Yield } (\text{Kg}(1000 \text{ bird})^{-1}) * \text{Broiler price } (\$ \text{ Kg}^{-1})$$

$$Gross\ return = Gross\ Production\ Value\ (\$\ (1000\ bird)^{-1}) - Variable\ Production\ Value\ (\$\ (1000\ bird)^{-1})$$

$$\text{Net return} = \text{Gross Production Value } (\$ \ (1000 \text{ bird})^{-1}) - \text{Total Production Value } (\$ \ (1000 \text{ bird})^{-1})$$

$$\text{BC} = \frac{\text{Gross Production Value } (\$ \ (1000 \text{ bird})^{-1})}{\text{Total Production Value } (\$ \ (1000 \text{ bird})^{-1})}$$

$$\text{Productivity} = \frac{\text{Broiler yield } (\text{Kg } (1000 \text{ bird})^{-1})}{\text{Total Production Value } (\$ \ (1000 \text{ bird})^{-1})}$$

Where gross production value is the price of selling the outcome of a brooding cycle of 1000 bird initially, yield is the total weight produced from all the chicks during the brooding cycle, broiler price is the sell price of 1 kg of broiler, variable production value is the cost spent per a brooding cycle, and the total production value is the variable production cost and the capital cost of the project.

3.7. Statistical Analysis

The differences between seasonal (cold vs warm weather) and heating conditions (renewable vs conventional energy) in the green and conventional poultry houses are assessed using Minitab 17.1.0. T-Test is used to test for statistically significant differences in temperatures, humidity, birds' weights and mortality. Furthermore, linear regression is used to model the green system using the recorded temperatures during the cycles, to predict the response of the system in the green house to other weather conditions. For statistically significant, a P-value of 5% is considered.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Brooding Cycles

Two brooding cycles were conducted, in the warm and cold seasons, in the green and conventional poultry houses at AREC. The first cycle in the warm season started on June 28, 2019 and lasted 37 days. The second cycle in the cold season started on March 12, 2020 and lasted 35 days. Tables 5 summarize the results of broilers production from the two brooding cycles at AREC.

Table 5: Brooding Cycles Summary

Houses	Cold Season		Warm Season	
	GPH	CPH	GPH	CPH
Total number of chicks	1000	1000	1000	1000
Mortality	283	252	38	72
Cycle duration	35 days		37 days	
Average final weight	1.796 Kg/chick	1.927 Kg/chick	1.979 Kg/chick	2.105 Kg/chick
Total number of chicks sold	1150		1900	

The temperature data recorded during the cold and warm brooding cycle is presented in appendix A.

4.1.1. Warm Season

4.1.1.1. Heating and Cooling Requirements

The first brooding cycle started at the end of June during the hottest weather in Lebanon. A total of 1000 chicks were bought from Tanmia Farm, Lebanon, and put in each of the green and conventional houses and raised as indicated in the methodology. The brooding cycle was successful and went as planned. The main problems faced during this cycle were in the ventilation and cooling systems.

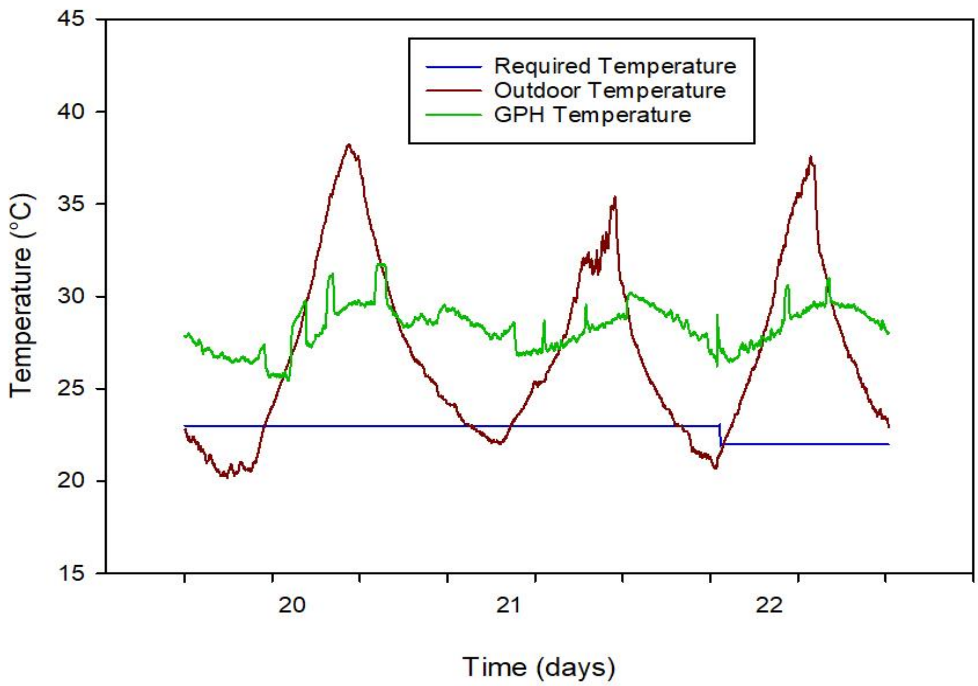

Figure 10: Temperature variation in day 20, 21 & 22 of the brooding cycle (GPH, Warm Season)

Figure 10 shows the variation in temperature during three consecutive days of the brooding cycle. Temperature data collected throughout the brooding cycle is available in Appendix A, Table A. During this cycle conducted in the warm season, the outside temperature averaged 27 °C, increasing above 35 °C during daytime to attain 40

°C in very hot days. Thus, there was no need for the localized heating system during this cycle, which was mainly conducted to test the system operation. Cooling and ventilation constituted a main challenge during the summer brooding cycle.

In the conventional house, the ventilation system, which is composed of two fans in the front wall of the CPH was efficient in aerating the house and preventing respiratory diseases. The cooling system composed of the two evaporative cooling pads provided acceptable temperature to the chicks during the hot weather with on average 2 °C higher than the required one, which is acceptable in developing healthy chicks.

In the green house, ventilation and cooling were provided by the geothermal system. The two geothermal ducts were equipped with inlet fans placed at the entry of the geothermal ducts to the poultry house. The exhaust fans were placed on the walls in the front side of the GPH, and 1.75 m above the ground level. Based on the acquired data, the fans were not efficient in cooling the poultry house and the temperature required could not be reached keeping the chicks under the stress of high temperatures.

In the first few days (day 1 to day 4), the required temperature at the poultry house for a healthy development of chicks was attained (30°C). The localized units were providing heating requirement at night when necessary as dictated by the controller system. During the day, the geothermal inlet fans and the outlet fans were on to provide the necessary cooling. Several days later, when the required temperature decreased to 29°C, the system could not achieve this minimal drop in temperature, mainly due to the gap in the ventilation and cooling systems. Therefore, several solutions were proposed. First, the geothermal inlet fans were turned off. Indeed, the air entering through them was almost at the same temperature of the outside air (around 33°C), as the geothermal ducts could not decrease the temperature by more than 1 degree. This also caused the humidity to increase in the house. This is due to the shallow position of the geothermal ducts at only 1.7 m beneath the ground level.

Second, the windows of the GPH were opened to provide fresh air from the outside. Although the entering air in this case was hot during day period and contributed to the unwanted increase in the inside temperature, it provided fresh air to prevent accumulation of humidity inside the house and thus helped in the ventilation of the GPH.

Third, the localized fan coil units initially envisioned for heating the GPH, were used as cooling units. Instead of hot water flowing through the fan coils, the storage tank was filled with regular water which was circulated through the localized units. This solution provided air with medium temperature (around 29°C), but not low enough to cool the house, especially when temperature requirements inside the PH further decreased.

Finally, the geothermal fans were switched to be outlet fans in addition to the two original outlet fans, and helped in ventilation by removing hot air from the inside. As for cooling, it was ensured through buying an evaporative cooling unit (Model AZL06-ZY13G, air flow 6000m^3/h). Evaporative cooling was applied starting day 24 when temperature requirements in the PH were 21°C while the reported temperature remained above 29°C. However, this solution helped decreasing the temperature to 25°C but was not enough to reach the required one towards the end of the cycle. Additional evaporative cooling units might have been required to cool down the PH to the required temperatures.

4.1.1.2. Indicator Parameters of Broilers Healthy Development

The total feed consumed was 1500 kg of starter for each house, and 1800 & 2000 kg of finisher, for the GPH and CPH, respectively. Feed consumption in the conventional house was around 200 kg higher than in the green house, and this overconsumption of food in the conventional house resulted in higher number of deaths. The cumulative feed consumption according to the Ross 308 manual at day 37 is expected to be 3705Kg (32).

The chicks were weighed 5 times throughout the cycle, based on a 12% representative sample, and the weights were conform to Ross standards (32). Table 6 Shows the average weight of the chicks along with the standard deviation. During the last 10 days, the chick's weight was slightly below the average in the green house.

Table 6: Weight records in grams

Day	Chicks	GPH	SD[a]	CPH	SD[a]	Expected (40)
0	120	43.334	0.77	43.208	1.15	43
4	120	99.458	2.75	99.333	7.28	98.5
14	120	437.875	19.25	460.485	19.28	461.5
24	200	945.746	84.37	1078.667	50.75	1152.5
36	200	1979.264	247.68	2105.965	180.75	2325

[a] Standard deviation of the chicks weight

The mortality (Figure 10) in the conventional house (7.2%) was more than that in the green house (3.8%). The expected acceptable mortality rate is between 3 and 5 % (40). The death was either caused by an initial hatching problem in the acquired chicks (this especially explains mortality during the first 2 weeks of the cycle), a disease such as coccidiosis which affected the chicks at day 21 of the brooding cycle, or a respiratory problem due to high temperatures in both the conventional house and green houses.

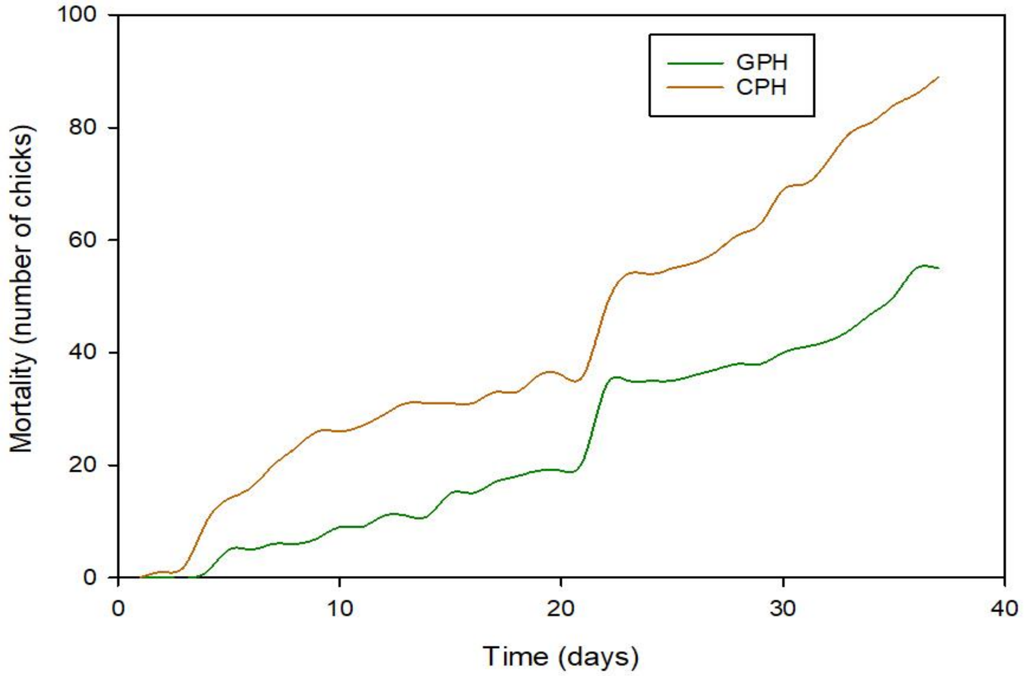

Figure 11: Mortality in GPH and CPH in the warm season

4.1.1.3. Electricity Consumption

The total electricity consumption in the conventional house was 1898 kWh. It was used to operate the heaters at the beginning of the cycle especially during nighttime, as well as the ventilation fans and cooling pads, to maintain the required temperature. However, in the green house, the photovoltaic panels charged the batteries, which were used as the electricity source to run the system. Additional electricity was needed when the batteries were not charged enough. The total amount consumed from the batteries was 643 kWh, and the rest (44 kWh) was supplied from AREC’s electricity, which was mainly used to operate the evaporative cooling unit when the batteries couldn’t provide sufficient electricity.

4.1.2. Cold Season

4.1.2.1. Heating and Cooling Requirements

The second cycle took place during March-April, when the weather was still cold, with temperatures as low as 3.2 °C being registered during nighttime. During daytime, outside temperatures reached 25 °C. The variation in temperature in this cycle allowed the testing of the system's functionality and efficiency under various outside temperature conditions.

2000 chicks were bought from Hawa chicken farm, Lebanon. 1000 chicks were put in each of the green and conventional control houses and raised as indicated in the methodology. While changing the chicks' supplier is not recommended for comparison purpose between the different cycles, securing 1-day-old chicks is not possible at any time of the year. As such, and to avoid missing the cold season, chicks from Hawa chicken were purchased but they were of the same species (Ros 308) purchased from Tanmia for the first brooding cycle. The main problem faced during this cycle was the high mortality rates at early stages (day 2) of the brooding cycle. This was a consequence of the poor hatching of the chicks, which affected their immune system and made them prone to different diseases throughout their development.

During this cycle, heating was required, and the green system was unable to raise the temperature to the set required temperature, especially when outside temperatures were too low. Thus, heaters were used as additional heating source to meet the heating requirements. As for the ventilation of the house, it was decided to minimize the operation time of the inlet fans, because they allow cold air to enter the PH affecting the inside temperature. Figure 11 and 12 shows respectively the variation in temperature during three consecutive days of the brooding cycle, and the number of heaters provided inside the GPH and CPH during the cold season brooding cycle. . Temperature data collected throughout the brooding cycle is available in Appendix A, (Table B)

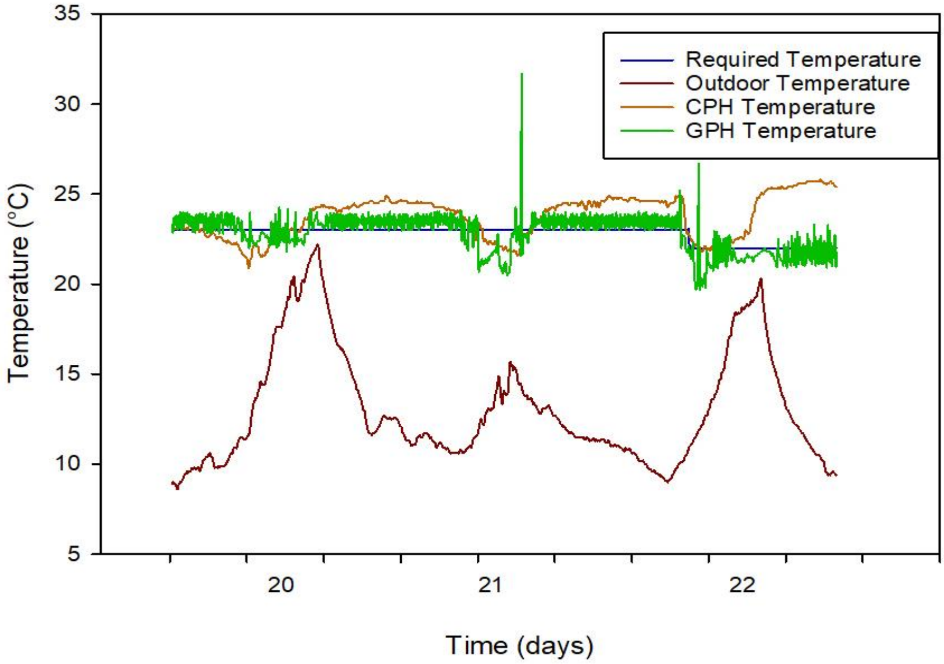

Figure 12: Temperature variation in day 20, 21 & 22 of the brooding cycle in the cold season

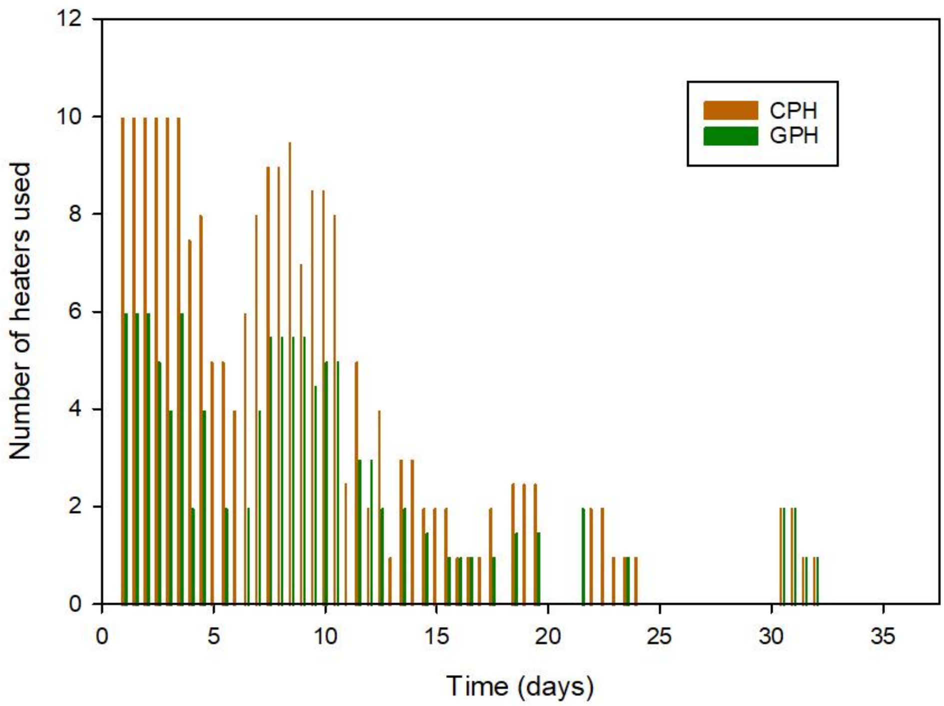

Figure 13: Number of heaters used in GPH and CPH in the cold season

Note that the number of heaters is varying depending on the outside temperature and the required temperature inside the PHs. When the weather is cold, more heaters are used to meet the heating requirements of the chicks. We can notice that the number of heaters required in the green house is always less than in the conventional house. The heating in the green house is provided mainly by the green heating system and aided by the heaters. When the weather is sunny, the green system was sufficient in heating the house.

4.1.2.2. Indicator Parameters of Broilers Healthy Development

The mortality (Figure 13) in the green and conventional houses was 28.3 % and 25.2 %, respectively, and was due to different diseases from which the chicks suffered throughout the brooding cycle. This is a consequence of the poor hatching of the chicks. Mortality started at day 2 of the cycle affecting 94 chicks (9.2%) in the green house and 136 chicks (13.34%) in the conventional house. At Day 3, the chicks were administered, by the veterinarian, the antibiotic colisol. This entailed postponing the first envisioned vaccination. Vaccines were given to the chicks on days 9, 11 and 13 for Bronchitis and Newcastle disease, Gumboro and Bronchitis booster, respectively.

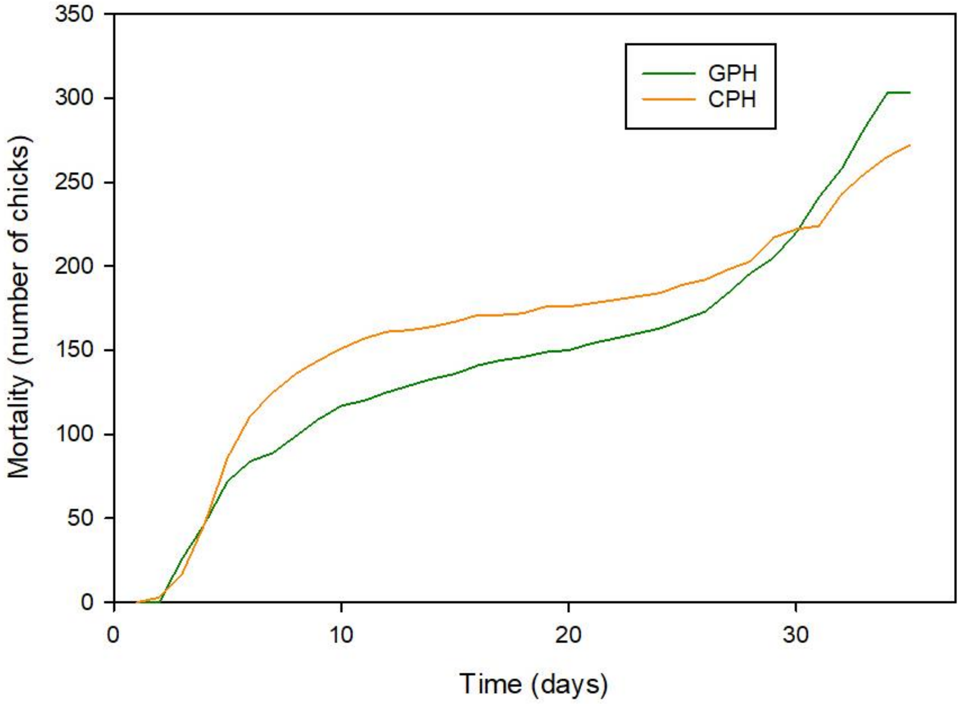

Figure 14: Mortality in GPH and CPH in the cold season

Symptoms of diseases continued to show throughout the whole cycle. At day 14, the chicks were given the medicine oxytetracycline for 5 days. The chicks continued to show fatigue and tiredness and the vaccine booster for newcastle disease and infectious bronchitis were postponed. At day 25, because the chick's immunity was minimal, further administration of antibiotics was avoided and the chicks were given vitamins. Panda AD3, Vitamin E and K3 were provided for 6 days.

The total feed consumed was 1500 kg of starter and 1000 kg of finisher, for each house. This low consumption is justified when considering the unhealthy status of the chicks. The chicks were weighed 5 times, on days 0, 7, 17, 27, and 37. Table 7 shows the results.

Table 7: Average chicks weight (in grams) during the brooding cycle in the GPH and CPH

Day	Number weighed	GPH	SD[a]	CPH	SD[a]	Expected (40)
0	200	41.13	0.768	41.9	0.942	43
7	200	205.52	24.93	190.27	4.81	190
17	200	656,5	32.66	696.6	35.77	677
27	200	1172.29	241.1	1491.67	137.3	1509
35	200	1796.66	287.7	1927.3	328.6	2050

[a] *Standard deviation of the chicks weight*

Higher chicks' weights were measured in the CPH in both brooding cycles in the warm and cold seasons, with slightly higher food consumption than in the GPH. Due to the layout of the house, and the clustering of chicks in pens in the CPH as compared to the open space in the GPH, the chicks were closer to the feeders and drinkers, and that resulted in more feed consumption. However, at a certain point in the CPH, overweight caused the mortality of some chicks.

4.1.2.3. Electricity Consumption

Figure 14 shows the cumulative electricity consumption in both houses during the cold cycle. The total electricity consumption in the conventional house was 4344 kWh. It was used mainly to operate the heaters and was provided by AREC's grid. In the green house, total electricity consumption was 2184 kWh, in addition to 432 kWh which were provided by the photovoltaic system. The green system operated using the electricity produced from the PV collectors. The heaters were used as an additional heating source and consumed electricity from AREC's grid.

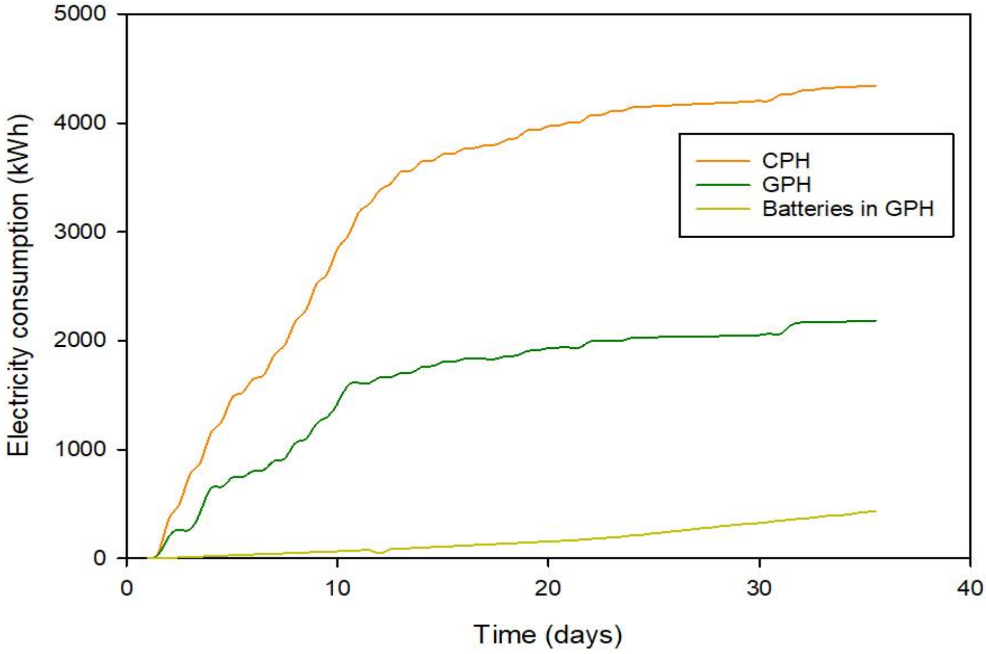

Figure 15: Cumulative electricity consumption in GPH and CPH in the cold season

4.1.3. Assessment of the performance of the GPH in both warm and cold seasons

Table 8 summarizes the results of the temperature data collected from the two brooding cycles in the GPH and CPH at AREC.

Table 8: Temperature data at different locations in the system (°C degree Celsius)

	Season	Mean	Standard Deviation	Minimum	Maximum
Temperature inside the GPH	warm	29.194	2.393	22.167	35.4
	cold	25.52	3.128	18.5	34.7
Temperature of outside air	warm	27.438	5.566	16.9	41.2
	cold	12.453	4.201	3.2	25.9
Temperature of solar collectors	warm	34.224	17.241	11.1	79.8
	cold	19.012	18.585	-0.8	95.4
Temperature of water in the water storage tank	warm	27.818	0.668	25.9	29.2
	cold	46.385	9.808	30.8	68.3
Difference in temperature between actual & required temperatures in the GPH	warm	8.0062	2.8972	0.2	15.6
	cold	1.2131	0.9834	0	10.7
Temperature inside the CPH	cold	26.733	3.108	19.9	34
Difference in temperature between the actual & required temperatures in the CPH	cold	2.0164	1.355	0	6.5
Number of heaters used in the CPH	warm	0	0.578	0	4
	cold	4	4	0	10
Number of heaters used in GPH	warm	0	0	0	0
	cold	2	2	0	6

In summary, the green system in the green poultry house was efficient in achieving some of its objectives, but it also had problems and gaps in attaining fully its purpose. The system was not sufficient in both heating and cooling the house and needed additional sources to meet these requirements.

In the warm season, the green system failed in cooling the GPH. In the cold season, the green system provided a good portion on the heating supply, but auxiliary heating systems were still needed. Thus, the green system is not enough on its own for heating the house during cold seasons.

On another hand, the green system provided the required electricity to run the system (controller, pumps, fans), with shortage in electricity supply being registered at the end of the warm season cycle, when the evaporative cooler was operated. In this latter case, electricity consumption from the PVs exceeded the model design. Optimization of the heating and cooling systems of the GPH are recommended to ensure full requirements coverage.

4.2. Anaerobic Digester

4.2.1. Digester Testing

Manure samples from AREC and LibanLait farm were collected and tested for heavy metals, carbon and nitrogen content. Namely, two samples were collected from LibanLait (from the manure collection pond and directly from the barn) and one sample from AREC (from the collection pit) in plastic containers after complete mixing of the manure. The results are shown in table 9.

Table 9: Manure analysis results

	Collection pit, AREC		Manure collection pond, LibanLait		Directly from barn, LibanLait	
Parameter		**Unit**		**Unit**		**Unit**
%Moisture	75.00	%	65.00	%	58.00	%
%Total solids	25.00	%	35.00	%	42.00	%
Total carbon	41.59	%	24.50	%	36.09	%
Total nitrogen	1.48	%	2.00	%	2.14	%
C/N	28.11		12.23		16.86	
Metals analysis						
Zn	0.02	%	<0.0001	%	0.00	%
Cd	<0.0001	%	<0.0001	%	<0.0001	%
Cu	<0.0001	%	<0.0001	%	<0.0001	%
Fe	5.08	%	0.04	%	0.15	%
Ni	0.05	%	0.01	%	0.01	%
Pb	<0.0001	%	<0.0001	%	<0.0001	%
Cr	<0.0001	%	<0.0001	%	<0.0001	%
As	<0.0001	%	<0.0001	%	<0.0001	%
Hg	0.60	%	0.11	%	0.08	%
K	7.06	%	0.52	%	>7	%

According to the C/N ratio, which should be between 20 and 25 in optimum conditions (9), the barn manure from LibanLait was selected to be used as feed in the digester. The digester was also tested with water for leakage, and a sensor was installed inside the digester to monitor its temperature.

4.2.2. Digester Startup

On July 15, 2020, 14 tons of manure were bought from LibanLait farm for the anaerobic digestion process. Filling the digester constituted a problem since the originally planned use of AREC's manure pit to pump the water-manure slurry to the digester was not allowed. Thus, small quantities manure and water were manually mixed in a PVC container in small quantities, and gradually fed to the digester using a loader. It took two days to have the 30 m^3 of manure from LibanLait loaded in the digester. Additional water quantities were added through pumping water provided in a water tanker.

Figure 16: Loader emptying the manure in the digester

Table 10 presents the added manure characteristics

Table 10: Characteristics of the feed manure

	Unit	Total slurry	TS[a]	Water content	VS[b]
Volume	m^3	68	9.277	58.723	-
mass	tons	67.45	8.73	58.723	5.13
% by volume	%	100	13.64	86.36	-
% by mass	%	100	12.94	87.06	7.6

[a] *Total Solids*
[b] *Volatile Solids*

On the first week, the drum covering the opening of the digester was pushed upward. Thus, a steel cross base was fabricated in the MSFEA shops and installed on the opening of the digester on Sept. 22, 2020 (Figure 16). A tube was also installed, using the outflow duct to the inside space of the digester, to allow taking sample during the anaerobic digestion, and a 0.12 HP pump was purchased for this aim. However, the sampling port was soon obstructed and no additional sampling was possible.

Figure 17: Steel cross base on the opening of the digester

Due to Covid-19 pandemic, all operations were delayed due to the lockdown. It took more than a month to successfully operate the digester under anaerobic conditions.

In order to monitor the operation of the digester for biogas production, the Industrial Research Institute (IRI) at the Lebanese University was contacted for biogas analysis. Similarly, the Lebanese Agricultural Research Institute (LARI) was contacted for carbon and nitrogen analysis, and the Laboratory for the Environmental, Agriculture and Food (LEAF) at AUB for the elemental analysis of carbon and nitrogen. However, because of the pandemic and the lockdown in the country, the different contacted labs either didn't answer, rejected our request for sample analysis, or were not providing lab services at the time the analysis was due.

As for gas production, the flowmeter did not detect any gas flow produced from the digester, and no gas accumulation in the gas floating tank was observed. Indeed, the digester is designed to operate as a continuous flow reactor where continuous feeding is necessary. This was impossible with the prohibition of use of AREC's manure pit for feeding the digester. Currently, manure from AREC's cattle in being stored for feeding the digester if not diverted to the planned composting facility at AREC. Ultimately, to complete the study objectives, biogas shall be used a sole source of energy, and in combination with the solar energy for providing the heat and electricity requirements of the GPH.

4.3. Analysis of Input-Output Energy

Input-Output energy analysis was conducted on the conventional and green poultry houses, in the warm and cold seasons. In the following "GPH-WS;" and "CPH-WS" refer to the green and conventional poultry houses in the warm season respectively, and "GPH-CS" and "CPH-CS" refer to the green and conventional poultry houses in the cold season, respectively.

Table 11 and 12 show the quantity of inputs and outputs with their energy equivalents in the green and conventional poultry houses, in the warm and cold seasons, respectively. Note that renewable energies are not considered among the inputs.

Table 11: Amounts of inputs, outputs, and their energy equivalences in the warm season

		GPH-WS		CPH-WS	
Items	**Units**	**Quantity per unit (Unit/1000 birds)-**	**Total energy equivalent (MJ/1000 birds)**	**Quantity per unit (Unit/1000 birds**	**Total energy equivalent (MJ/1000 birds)**
Inputs					
Chick	Kg	44.04	454.89	42.80	442.08
Human labor	h	111.00	217.56	111.00	217.56
Machinery[a]	Kg	-	200.00	-	200.00
Fuel diesel	L	0.00	0.00	0.00	0.00
Feed[b]	Kg	-	32969.65	-	32969.65
Electricity	kWh	44.00	158.40	1898.00	6832.80
Total energy input	MJ		34000.50		40662.09
Outputs					
Broiler	Kg	1903.80	19666.23	1953.44	20179.04
Manure[c]	Kg	1500.00	750.00	1500.00	750.00
Total energy output	MJ		20116.23		20629.04

[a] *Machinery energy is assumed based on values from the literature.*
[b] *Total feed energy is calculated as sum of the energy resulting from each component of the feed composition*
[c] *Manure energy is estimated from the produced manure weight and is assumed equal in both houses for comparison purposes*

Table 12: Amounts of inputs, outputs, and their energy equivalences in the cold season

		GPH-CS		CPH-CS	
Items	**Units**	**Quantity per unit (Unit (1000 birds)$^{-1}$)**	**Total energy equivalent (MJ (1000 birds)$^{-1}$)**	**Quantity per unit (Unit (1000 birds)$^{-1}$)**	**Total energy equivalent (MJ (1000 birds)$^{-1}$)**
Inputs					
Chick	Kg	41.13	424.89	41.94	433.27
Human labor	h	150.00	294.00	150.00	294.00
Machinery[a]	Kg	-	200.00	-	200.00
Fuel diesel	L	0.00	0.00	0.00	0.00
Feed[b]	Kg	-	23564.13	-	24504.17
Electricity	kWh	2184.00	7862.40	4344.00	15638.40
Total energy input	MJ		32345.42		41069.84
Outputs					
Broiler	Kg	1352.89	13975.35	1445.48	14931.81
Manure[c]	Kg	1500.00	750.00	1500.00	750.00
Total energy output	MJ		14725.35		15681.81

[a] *Machinery energy is assumed from based on the literature values*
[b] *Total feed energy is calculated as sum of the energy resulting from each components of the feed composition*
[c] *Manure energy is estimated from the produced manure weight and is assumed equal in both houses for comparison purposes*

The total energy inputs varied from season to season, and between the GPH and CPH (Figure 17).

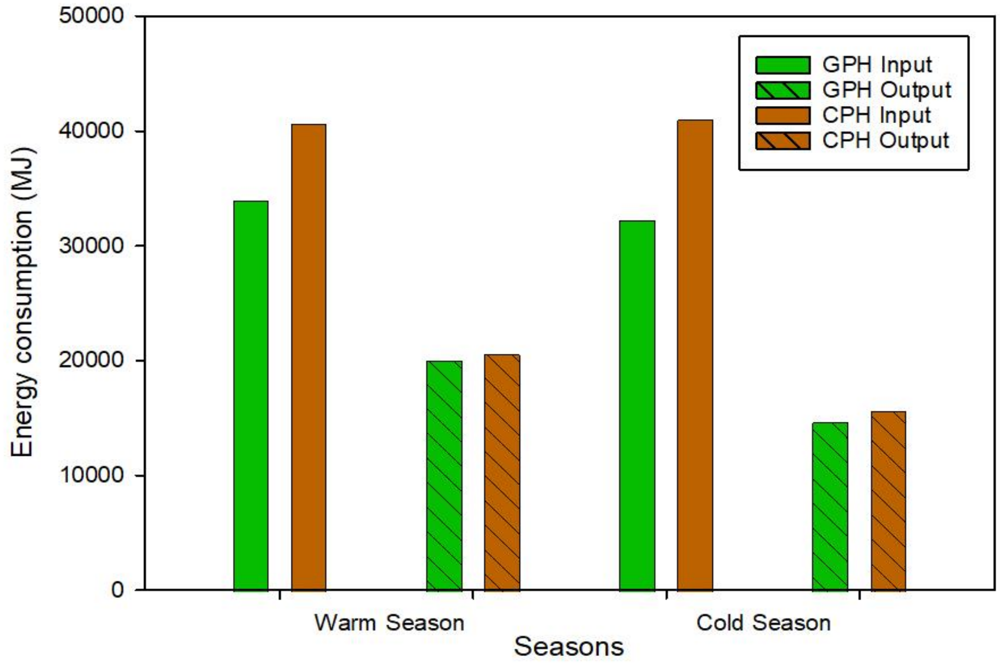

Figure 18: Total energy input and output in GPH and CPH in the warm and cold seasons

Based on the results, the total energy consumption of GPH and CPH was found about 34000.50 and 40662.09 MJ (1000 birds) $^{-1}$, respectively, in the warm season. However, in the cold season, it was found to be about 32345.42 and 41069.84 MJ (1000 birds) $^{-1}$, in the green and conventional houses, respectively.

Under the same weather conditions, in the 2 brooding cycles, the energy consumed in the green house is always less than the conventional house. The quantity of energy input in the warm season is more than that in the cold season, because the second brooding cycle had high mortality rates due to several diseases, being 4.8 times higher than in the case of the first cycle. This entailed stopping the brooding cycle at day 35, and by that the quantity of feed consumed in the second cycle was less than the first one. On another hand, the energy consumed by electricity is always less in the GPH than the CPH.

All the energy input values are less than those reported in the literature (Table 1). Mainly, no fuel diesel was directly used in our experiments in both houses, contrary to other farms, where fuel diesel occupies the biggest share in the inputs.

The share of energy inputs and outputs for broilers production in the two cycles is presented in table 13.

Table 13: The share of inputs and outputs in the brooding cycle

	Warm season		**Cold Season**	
Items	**GPH**	**CPH**	**GPH**	**CPH**
Inputs %				
Chick	1.34	1.09	1.1	0.9
Human Labor	0.64	0.54	0.8	0.6
Machinery	0.59	0.49	0.5	0.4
Fuel diesel	0.00	0.00	0.0	0.00
Feed	96.97	81.08	76.3	64.0
Electricity	0.47	16.80	21.2	34.0
Outputs %				
Broiler	96.88	97.07	94.91	95.22
Manure	3.12	2.93	5.09	4.78

Results show that the broilers' feed ranked the first in energy input in both houses and under both climatic conditions, except in the conventional house during the cold season where it ranked second after energy consumption from electricity use. Similar results were reported by Heidari et al. (12) and Amid et al. (36) where feed and fuel had the highest share of energy consumption.

The share of chicken energy among energy inputs ranged between 1.09 and 1.34, according to the weight of the chicks at day zero. The human labor work required per 1000 birds is approximately 3 hours per day throughout the cycle. Labors are responsible to ensure the hygiene and adequate environmental conditions inside the poultry houses, in addition of feeding, weighing, and vaccinating the chicks among other duties. The machinery used in both houses is assumed from the literature to be 200 MJ/house (1, 12, 18, 36).

The electricity consumption from AREC's grid is recorded using electricity meters placed in both houses, More energy is consumed in the conventional house than the green house, even when the electricity consumed from the PV batteries is considered in the latter case. This affirms that the green system consume less electricity than the conventional one, in both seasons.

As for the outputs, the differences in the mortality rates between the green and conventional houses affected the number of broilers sold in each house, and thus affected the broilers energy output in each case. The manure energy output was calculated according to the quantity removed from the poultry houses and weighed throughout the brooding cycle. It is approximately the same for both the GPH and CPH.

4.4. Analysis of Energy Indices and Forms

Table 14 shows the energy efficiency ratios in the green and conventional houses "GPH-WS;" and "CPH-WS" refer to the green and conventional poultry houses in the warm season respectively, and "GPH-CS" and "CPH-CS" refer to the green and conventional poultry houses in the cold season, respectively.

Table 14: Energy indices and forms of green and conventional houses in the warm and cold seasons

Items	Units	GPH-WS	%	CPH-WS	%	GPH-CS	%	CPH-CS	%
Energy use efficiency	-	0.60	-	0.52	-	0.46		0.40	-
Energy productivity	Kg MJ^{-1}	0.58	-	0.50	-	0.45		0.39	-
Specific energy	MJ Kg^{-1}	1.73	-	2.01	-	2.21		2.57	-
Net energy	MJ (1000 $birds)^{-1}$	-13584.27	-	-19533.05	-	-19837.83		-27602.51	-
Direct energy	MJ (1000 $birds)^{-1}$	375.96	1.11	7050.36	17.34	8156.40	22	15932.40	35
Indirect energy	MJ (1000 birds)-1	33624.54	98.89	33611.73	82.66	28901.85	78	30038.28	65
Renewable energy	MJ (1000 $birds)^{-1}$	33642.10	98.95	33629.29	82.70	28995.85	78	30132.28	66
Non-renewable energy	MJ (1000 $birds)^{-1}$	358.40	1.05	7032.80	17.30	8062.40	22	15838.40	34
Total energy inputs	MJ (1000 $birds)^{-1}$	34000.50	100.00	40662.09	100.00	37058.25	-	45970.68	-

During the warm season, energy ratio (or energy use efficiency) for broilers production was estimated to 0.6 and 0.52 for the green and conventional houses, respectively. As for the cold season, the ratio was 0.46 and 0.40 for the green and conventional houses, respectively. This indicated a higher energy efficiency in the green poultry house. The difference between the warm and cold seasons ratios is mainly due to a lower feed consumption during the cold season, due to the high rate of mortality.

Moreover, the specific energy calculated for the GPH is less than that for the CPH in both seasons. In other terms, for each 1 Kg of broiler produced, the amount of energy consumed in the green house was less than that consumed in conventional one, during both the warm and cold seasons. This confirms the efficient use of energy in the green house as compared to the conventional house, and the higher energy productivity in the former case (0.58 Kg MJ^{-1} vs 0.5 Kg MJ^{-1}).

The net energy produced was negative for both houses in the warm and cold season, indicating that the output energy was always less than the input energy consumed, and energy is lost in this production. Some energy was wasted during broilers production under both conditions, irrespective of its use efficiency in each of the houses. In the absence of diesel consumption, both green and conventional houses showed energy efficiency values higher than those reported in the literature (table 1).

On another hand, the direct and indirect energy, as well as the renewable and non-renewable energy were calculated. The share of direct energy is less than the indirect energy, except in the conventional house in the cold season. In another category, the share of renewable energy is more than the non-renewable energy, except in the conventional house in the cold season.

Additionally, the green house is operating on a green system based mainly on solar energy. Thus, a significant amount of energy used in the system is considered to be fully renewable, in addition to the part calculated.

4.5. Economic Analysis Results

For this study, the economic indices are calculated in GPH and CPH in the warm and cold seasons and elaborated in table 15. During the experiments, Lebanon was facing economic crisis and a revolution in addition to covid-19 pandemic. The prices were largely varying, especially with the continuous change in the exchange rates in currency from Dollars to LBP. As such, and with no clear vision on the economy for the upcoming years, the indices will be compared between houses in the same season.

For this aim and taking into account the continuous variation in the cost of green technologies, the fixed production cost is assumed 2000 $, the same for both houses which is used in several brooding cycles.

Table 15: Economic indices of GPH and CPH

		Warm Season		Cold Season	
Items	**Units**	**GPH**	**CPH**	**GPH**	**CPH**
Gross Production Value	$/(1000bird)	2037.00	2158.20	862.60	1322.40
Variable Production Cost	$/(1000bird)	3565.22	3743.21	3259.66	3697.02
Fixed Production Cost[a]	$/(1000bird)	2000.00	2000.00	2000.00	2000.00
Total Production Cost	$/(1000bird)	5565.22	5743.21	5259.66	5697.02
Total Production Cost	$/kg	2.00	1.98	3.59	2.65
Gross Return	$/(1000bird)	-1528.22	-1585.01	-2397.06	-2374.62
Net Return	$/(1000bird)	-3528.22	-3585.01	-4397.06	-4374.62
Benefit to Cost Ration BCR	-	0.37	0.38	0.16	0.23
Productivity	Kg/$	0.32	0.33	0.17	0.24

[a] *The Fixed production cost was assumed equal for comparison purposes*

The gross production value is higher for the conventional house during both seasons. Indeed, the weight of the chicks in the CPH was higher than that in the CPH and resulted in more chicks being sold in the former case. On another hand, the variable production cost was less in the green house due to lower electricity consumption in this house.

The total production cost is higher in the CPH, as is the case for the BCR which is lower than 1. In addition, the gross and net returns are negative. Hence, broilers production under the tested experimental conditions was non-lucrative from an economic point of view.

4.6. Environmental Cost

On another hand, the green house uses renewable and environmentally friendly energy in poultry production. The environment bill has a large impact on decision making and the implementation of new industries and projects. Its value is not yet clearly quantified in terms of amount money, as is the case in Lebanon. The environmental costs are the costs connected to the actual or potential deterioration of environment from the installation and use of the system.

The environmental cost in this project includes the CO_2 and NH_3 emissions produced during poultry production and which are considered GHGs that have negative impact on the environment. In addition, CO_2 emissions result indirectly from electricity production in Lebanon. While regulations defining limits on the environmental cost of a project are still lacking in Lebanon and many other developing countries, a global awareness is rising and governments are encouraging renewable energy through providing incentives for its use and imposing taxes on GHGs emissions.

In the following analysis, the environmental bill will be confined to the CO_2 emissions from the electricity, for lack of data on gases produced in the poultry houses. This is due to delays in receiving the gas analyser necessary to measure CO_2 and ammonia emissions inside the PHs. The electricity in Lebanon is produced from fuel diesel and the amount of CO_2 produced is 0.8 Kg of CO_2 per each 1 kWh produced (46). Table 16 shows the CO_2 emissions during the brooding cycles conducted.

Table 16: CO_2 emission due to electricity consumption

Season	Poultry house	Electricity, in kWh	CO_2 emissions, in Kg	Electricity from solar energy	Total electricity, in kWh
Warm season	GPH	44	34.4	643	686
	CPH	1898	1518.4	-	1898
Cold season	GPH	2184	1747.2	432	2616
	CPH	4344	3475.2	-	4343

The amount of emissions is larger in the case of the conventional house as compared to the green house which minimizes the consumption of electricity and maximizes the efficiency in heating/cooling the house. In addition, a portion of the consumed electricity is ensured by the solar energy using the PV panels. Thus, the green system is environmentally friendly and have advantage over the conventional system.

4.7. Data Analysis Results

Statistical methods were used to study the performance of the green system, its gaps and its efficiency. The data is analyzed using Minitab 17.1.0 software. Throughout the brooding cycle in the cold season, data was collected on the controller from the different sensors and saved on a 1 min time interval. The green system wasn’t used in the warm season thus, data analysis was done in the cold season cycle, considered representative of the system due to the variation in the weather conditions, namely, variability in temperature values throughout the day and during nighttime.

At 5 % significant level, the temperature in the green house was found different than in the conventional house, at the same time, the temperature in both houses is statistically different than the required temperature. However, the difference between the achieved temperatures in the poultry houses and the required temperature was lower in the case of the green house (1.2 °C in the GPH as opposed to 2.2 °C in the CPH).

On another hand, the green system is automatically set to the required temperature, contrary to the conventional one, which is controlled by the labors. To avoid drop in temperature during night-time when the poultry houses are not monitored, additional heaters were being turned on (in both houses) by the end of the working day. This was usually causing higher temperatures than the requirements. In broiler production, 2°C difference in temperature is allowed in poultry houses. However higher temperature variations cause health problems for the chicks, especially if the thermal stress lasts for a period.

The heating system is mainly divided into 3 components. First, we have the solar panels which heat the water circulating inside them. Second the heated water will circulate inside the coil in the boiler to heat all the water in the storage. Finally, the FCU units will be operating to heat the house. Because the system was not functioning at all times, each component is studied alone when it was operating.

The temperature of the water entering and exiting the solar panels is recorded and analyzed when the associated pump was on. That corresponds to 5.7% of the brooding cycle time and 11.4% of the daytime. The efficiency of the solar panels was found to be 86.69%. Thus, the solar panels operate perfectly. In the cold season, some days were sunny, but some were cloudy and rainy, which caused the pump to stop, and stop heating the water in the storage tank. Thus, another heating method for the boiler can be used and tested, either electricity or biogas.

As for the boiler, the variation in the temperature of water inside it and the temperature of the water entering from the solar panels was examined. No significant pattern was detected between the two data, also, the correlation was found to be 48.5% between the variation of the temperature and its actual value. In other words, the boiler temperature is affected by several factors, including the sunlight and solar panels functioning, the outside temperature, the operation of the FCU units, and the initial temperature existing in the storage.

As for the FCU units, they operated 5.44% of the time. This is caused by the low temperature in the storage, especially at night where no source is heating the boiler, and the temperature drops below the needed one. The heaters were used along with the FCU to meet the requirements. Even when the FCU were on, the house could not attain the required temperature without using the additional heating sources.

The data shows that the green system has gaps and the mechanical design of the entire system can be much improved if some parameters are taken into consideration including the size of the house, the weather in the area, and the required temperature in a poultry house during a brooding cycle.

On another hand, the data of the system is analysed using a regression model, to examine the relationship between the different components in the green system, and the impact of each factor on the temperature inside the house. The model was done on the inside temperature, outside temperature, the boiler temperature, and the required temperature to be ensured during a brooding cycle.

The temperature inside the house is the response for the other predictors. The required temperature is considered categorical predictor, as it changes throughout the cycle, and the controller is set according to its values. A regression model was fit, and results are presented in table 17, where Ti is the inside temperature in °C, Tb is the temperature of water in the boiler in °C, and To is the outside temperature in °C.

Table 17: Regression model results

Required temperature (°C)	Regression equation
21	$T_i = 23.276 - 0.03905\ T_b + 0.0420\ T_o$
22	$T_i = 23.081 - 0.03905\ T_b + 0.0420\ T_o$
23	$T_i = 23.920 - 0.03905\ T_b + 0.0420\ T_o$
24	$T_i = 24.754 - 0.03905\ T_b + 0.0420\ T_o$
25	$T_i = 27.793 - 0.03905\ T_b + 0.0420\ T_o$
26	$T_i = 28.352 - 0.03905\ T_b + 0.0420\ T_o$
28	$T_i = 28.851 - 0.03905\ T_b + 0.0420\ T_o$
29	$T_i = 31.863 - 0.03905\ T_b + 0.0420\ T_o$

The regression model shows a significance in fitting the data, with a Coefficient of Determination adjusted (R square adjusted) of 90.8%. Thus, the linear relation between the variable and the predictors strongly exists, and the three predictors affirm that relation The Variance Inflation Factors (VIF) values are less than 5, thus the collinearity between the predictors is not significant.

As a result, the boiler temperature have a negative coefficient in the regression equation, in other terms, negative effect on the inside temperature, however, the increase in the outside temperature always cause increase in the inside temperature and they should positively correlate. The residuals are normal and centered on zero, with a variation between -2 and 2.

Although this model is significant from a statistical perspective and could be used to predict the variation of the inside temperature, from an application perspective the FCU units using the hot water in the boiler have a positive effect on the inside temperature, and have an objective to heat the poultry house. The outside temperature will affect the inside one due to the effect to heat transfer through the walls.

On another hand, the green system was not operating continuously in time, even if we have collected enough data but it is from different dates, and that has its effect on the model presented. Thus, this model have gaps in representing the green system.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

As a conclusion, the green house offers the opportunity to integrate the renewable energy in poultry farms. The results from this study showed that such system is more efficient than the conventional one, from an energy consumption perspective. On another hand, the system shows gaps in its design, and was non beneficial from an economic perspective. Also, the green system presents mitigated environmental impacts as compared to the conventional methods used in poultry production.

Therefore, renewable energy resources could be used for heating broiler farms to enhance the energy efficiency and mitigate the negative environmental impact of poultry farms. The green system needs some modification, to be able to fully operate alone without supplemental conventional heating source being used. The proposed biogas production from the anaerobic digestion of manure, is further to be studied, as an additional component to the green system.

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APPENDIX

Table A and B represent a summary of the temperature data collected during the warm and cold brooding cycles. In the following, daytime refers to the period from 7:00 am to 7:00 pm and nighttime refers to the period from 7:00 pm to 7:00 am.

Table A: Temperature data of the warm brooding cycle*

Time		Temperature	Outdoor	GPH
Day 19	Nighttime	Average	22.664	27.381
		Minimum	20.200	26.000
		Maximum	28.000	29.400
		SD[a]	2.137	1.063
Day 20	Daytime	Average	31.177	28.360
		Minimum	21.600	25.200
		Maximum	38.200	31.500
		SD	4.992	1.743
	Nighttime	Average	24.891	28.321
		Minimum	22.000	27.000
		Maximum	31.100	31.400
		SD	2.479	0.686
Day 21	Daytime	Average	28.579	27.924
		Minimum	23.000	26.600
		Maximum	35.400	29.700
		SD	3.374	0.965
	Nighttime	Average	23.363	28.101
		Minimum	20.700	26.200
		Maximum	27.300	29.700
		SD	1.828	0.917
Day 22	Daytime	Average	29.479	28.062
		Minimum	21.200	26.200
		Maximum	37.600	30.500
		SD	4.853	1.223
	Nighttime	Average	24.078	28.191
		Minimum	20.700	26.200
		Maximum	28.800	29.500
		SD	2.405	0.950
Day 23	Daytime	Average	29.479	28.062
		Minimum	21.200	26.200

		Maximum	37.600	30.500
		SD	4.853	1.223
	Nighttime	Average	23.343	27.942
		Minimum	19.200	25.700
		Maximum	28.800	29.500
		SD	2.688	1.073
Day 24	Daytime	Average	30.537	28.959
		Minimum	21.100	26.400
		Maximum	38.800	31.700
		SD	5.178	1.705
	Nighttime	Average	24.213	28.963
		Minimum	20.200	27.000
		Maximum	30.100	31.500
		SD	2.776	1.205
Day 25	Daytime	Average	31.819	30.960
		Minimum	23.100	28.800
		Maximum	40.400	33.400
		SD	5.143	1.570
	Nighttime	Average	24.649	29.389
		Minimum	20.500	26.700
		Maximum	31.000	32.000
		SD	2.885	1.494
Day 26	Daytime	Average	32.040	30.448
		Minimum	22.800	26.700
		Maximum	41.200	32.600
		SD	5.250	1.735
	Nighttime	Average	23.932	27.440
		Minimum	19.300	23.100
		Maximum	31.000	31.700
		SD	3.171	2.500
Day 27	Daytime	Average	30.649	29.689
		Minimum	21.100	25.600
		Maximum	39.300	32.300
		SD	5.079	1.715
	Nighttime	Average	22.371	26.086
		Minimum	18.000	22.700
		Maximum	29.900	29.900
		SD	3.484	2.019
Day 28	Daytime	Average	29.565	28.802
		Minimum	19.800	22.000
		Maximum	38.800	32.200

		SD	5.282	2.086
	Nighttime	Average	22.119	25.577
		Minimum	16.900	22.100
		Maximum	29.600	29.400
		SD	3.596	2.133
Day 29	Daytime	Average	29.643	29.142
		Minimum	18.400	23.700
		Maximum	39.900	34.100
		SD	6.120	2.690
	Nighttime	Average	22.837	26.494
		Minimum	19.000	23.700
		Maximum	30.200	31.300
		SD	2.980	1.948
Day 30	Daytime	Average	30.948	30.088
		Minimum	20.500	24.800
		Maximum	40.400	34.400
		SD	5.797	2.315
	Nighttime	Average	25.306	28.630
		Minimum	22.000	26.000
		Maximum	31.200	31.500
		SD	2.641	1.320
Day 31	Daytime	Average	30.734	31.035
		Minimum	23.100	27.700
		Maximum	37.900	34.300
		SD	4.330	1.534
	Nighttime	Average	24.087	27.964
		Minimum	20.200	25.000
		Maximum	29.700	30.900
		SD	2.899	1.782
Day 32	Daytime	Average	30.377	30.694
		Minimum	21.600	26.300
		Maximum	38.600	35.800
		SD	4.879	1.870
	Nighttime	Average	23.402	27.923
		Minimum	19.600	24.500
		Maximum	29.900	31.300
		SD	2.853	1.796
Day 33	Daytime	Average	30.673	30.665
		Minimum	20.500	26.200
		Maximum	39.600	35.800
		SD	5.564	2.133

	Nighttime	Average	24.926	29.335
		Minimum	21.300	27.100
		Maximum	31.300	31.900
		SD	2.821	1.405
Day 34	Daytime	Average	32.358	32.215
		Minimum	22.100	27.700
		Maximum	40.800	35.600
		SD	5.604	1.869
	Nighttime	Average	25.409	29.439
		Minimum	20.700	26.100
		Maximum	32.500	32.700
		SD	3.332	1.858
Day 35	Daytime	Average	32.036	31.754
		Minimum	22.000	27.000
		Maximum	40.600	36.100
		SD	5.316	2.110
	Nighttime	Average	25.235	29.757
		Minimum	21.700	28.000
		Maximum	32.300	32.500
		SD	2.906	1.123
Day 36	Daytime	Average	32.372	32.230
		Minimum	22.900	28.500
		Maximum	40.100	36.300
		SD	4.943	1.843
	Nighttime	Average	23.392	28.544
		Minimum	19.000	24.300
		Maximum	31.300	32.300
		SD	3.641	2.127
Day 37	Daytime	Average	29.973	31.060
		Minimum	19.900	26.800
		Maximum	38.400	36.100
		SD	5.473	2.298

[*] *Data from day 1 to day 18 is not available.*
[a] *Standard deviation of the temperature recorded*

Table B: Temperature data of the cold brooding cycle

Time		Temperature	Outdoor	CPH	GPH
Day 1	Daytime	Average	17.120	31.650	29.924
		Minimum	12.500	28.900	27.600
		Maximum	23.400	33.900	34.200

		SD[a]	2.777	1.304	1.579
	Nighttime	Average	15.474	33.401	31.808
		Minimum	11.900	32.600	31.200
		Maximum	17.000	33.800	32.100
		SD	1.370	0.273	0.180
Day 2	Daytime	Average	15.430	33.183	30.998
		Minimum	12.100	30.900	28.500
		Maximum	17.800	34.000	33.900
		SD	1.564	0.525	0.723
	Nighttime	Average	12.009	33.234	31.694
		Minimum	11.000	32.800	31.200
		Maximum	13.100	33.600	32.200
		SD	0.556	0.239	0.295
Day 3	Daytime	Average	13.760	32.474	31.146
		Minimum	11.300	30.700	29.900
		Maximum	17.400	33.300	32.200
		SD	1.606	0.361	0.477
	Nighttime	Average	9.903	32.290	31.194
		Minimum	7.300	31.400	30.500
		Maximum	12.000	32.700	31.600
		SD	1.511	0.350	0.279
Day 4	Daytime	Average	16.004	32.508	30.542
		Minimum	7.700	30.700	26.600
		Maximum	20.900	33.900	32.500
		SD	3.710	0.829	1.078
	Nighttime	Average	12.086	33.335	30.085
		Minimum	9.200	32.200	27.900
		Maximum	14.900	34.000	32.300
		SD	1.488	0.525	1.044
Day 5	Daytime	Average	16.846	30.847	29.226
		Minimum	9.700	28.600	27.000
		Maximum	21.200	32.700	32.300
		SD	3.120	1.171	1.534
	Nighttime	Average	11.554	29.615	27.873
		Minimum	10.000	28.500	27.000
		Maximum	14.900	30.700	29.700
		SD	1.254	0.591	0.494
Day 6	Daytime	Average	13.066	27.672	27.579
		Minimum	9.200	25.800	25.300
		Maximum	18.700	28.900	29.400
		SD	2.728	0.925	0.895

	Nighttime	Average	8.116	28.383	27.186
		Minimum	6.900	27.700	25.900
		Maximum	9.200	28.900	29.100
		SD	0.588	0.451	0.730
Day 7	Daytime	Average	9.468	27.545	25.922
		Minimum	7.700	27.000	23.300
		Maximum	12.500	28.300	28.200
		SD	1.176	0.323	1.248
	Nighttime	Average	8.115	28.423	27.555
		Minimum	7.600	27.900	27.100
		Maximum	8.600	28.700	27.900
		SD	0.234	0.120	0.185
Day 8	Daytime	Average	8.864	28.277	26.928
		Minimum	5.800	26.300	24.200
		Maximum	13.100	28.900	28.500
		SD	2.014	0.417	1.006
	Nighttime	Average	5.135	28.322	28.161
		Minimum	4.400	27.900	27.500
		Maximum	6.700	28.700	28.700
		SD	0.510	0.221	0.160
Day 9	Daytime	Average	7.710	27.973	26.377
		Minimum	5.000	27.300	25.300
		Maximum	9.700	28.700	28.400
		SD	1.007	0.350	0.881
	Nighttime	Average	4.122	27.688	26.956
		Minimum	3.200	27.100	26.300
		Maximum	6.700	28.200	27.400
		SD	0.941	0.207	0.244
Day 10	Daytime	Average	9.086	27.980	26.816
		Minimum	4.800	27.100	23.900
		Maximum	12.500	28.800	28.800
		SD	2.241	0.487	1.109
	Nighttime	Average	5.702	28.070	28.530
		Minimum	3.900	27.100	27.700
		Maximum	8.500	28.900	29.400
		SD	1.261	0.498	0.313
Day 11	Daytime	Average	12.499	28.147	27.275
		Minimum	5.700	27.200	23.800
		Maximum	17.200	28.800	28.900
		SD	3.364	0.379	0.885
	Nighttime	Average	7.035	27.361	27.442

		Minimum	4.400	26.000	26.300
		Maximum	11.000	28.500	28.400
		SD	1.845	0.723	0.507
Day 12	Daytime	Average	15.662	27.581	26.617
		Minimum	6.000	25.700	23.700
		Maximum	20.900	29.000	28.200
		SD	4.204	0.679	1.103
	Nighttime	Average	10.690	28.326	27.522
		Minimum	8.100	27.400	26.600
		Maximum	15.300	29.100	28.200
		SD	1.920	0.542	0.461
Day 13	Daytime	Average	17.085	26.665	26.413
		Minimum	10.100	25.100	21.400
		Maximum	21.300	28.400	32.000
		SD	3.233	1.003	1.685
	Nighttime	Average	10.683	27.740	27.540
		Minimum	8.200	26.700	25.900
		Maximum	14.600	28.500	28.000
		SD	1.802	0.533	0.419
Day 14	Daytime	Average	15.847	26.113	26.258
		Minimum	9.200	25.300	21.200
		Maximum	20.500	27.400	32.200
		SD	3.269	0.682	1.816
	Nighttime	Average	9.897	26.549	27.314
		Minimum	8.300	25.600	26.000
		Maximum	13.400	27.400	28.000
		SD	1.245	0.553	0.397
Day 15	Daytime	Average	16.638	25.083	24.869
		Minimum	9.200	24.300	21.900
		Maximum	21.500	27.600	33.200
		SD	3.539	0.521	1.257
	Nighttime	Average	13.541	26.043	25.473
		Minimum	12.200	25.600	24.900
		Maximum	15.900	26.500	26.000
		SD	0.945	0.206	0.313
Day 16	Daytime	Average	19.017	26.138	25.197
		Minimum	12.800	25.100	23.700
		Maximum	22.900	27.200	34.400
		SD	2.971	0.683	0.837
	Nighttime	Average	13.603	26.888	25.508
		Minimum	12.000	26.100	24.800

		Maximum	17.000	27.300	26.000
		SD	1.379	0.377	0.318
Day 17	Daytime	Average	15.574	25.132	24.457
		Minimum	11.800	23.700	23.000
		Maximum	18.900	26.500	32.000
		SD	1.976	0.897	1.044
	Nighttime	Average	10.031	25.829	25.515
		Minimum	9.100	24.800	24.000
		Maximum	11.800	26.300	26.000
		SD	0.648	0.399	0.341
Day 18	Daytime	Average	14.612	24.726	24.315
		Minimum	10.500	21.600	23.000
		Maximum	18.600	26.700	30.600
		SD	2.075	1.409	1.012
	Nighttime	Average	10.261	26.485	25.474
		Minimum	9.000	25.600	24.300
		Maximum	11.800	26.800	34.700
		SD	0.859	0.222	0.506
Day 19	Daytime	Average	13.231	23.661	23.361
		Minimum	10.000	22.300	21.900
		Maximum	16.600	25.600	33.100
		SD	1.624	0.626	0.921
	Nighttime	Average	10.194	22.986	23.483
		Minimum	8.600	22.200	22.800
		Maximum	12.600	23.400	24.100
		SD	0.972	0.336	0.352
Day 20	Daytime	Average	17.129	23.036	22.983
		Minimum	11.000	20.900	21.900
		Maximum	22.200	24.400	27.600
		SD	3.198	1.030	0.621
	Nighttime	Average	12.027	24.445	23.503
		Minimum	10.500	23.900	22.900
		Maximum	15.800	24.900	24.000
		SD	1.189	0.182	0.312
Day 21	Daytime	Average	12.960	23.111	22.658
		Minimum	10.600	21.600	19.600
		Maximum	15.800	24.500	32.200
		SD	1.263	0.898	1.157
	Nighttime	Average	10.583	24.600	23.493
		Minimum	9.000	24.100	23.000
		Maximum	11.800	25.000	27.200

		SD	0.833	0.164	0.341
Day 22	Daytime	Average	15.183	23.422	21.572
		Minimum	10.100	21.800	19.700
		Maximum	20.300	25.400	30.600
		SD	3.001	1.368	0.808
	Nighttime	Average	9.103	25.154	21.725
		Minimum	6.900	24.300	20.900
		Maximum	12.600	25.800	23.400
		SD	1.636	0.455	0.608
Day 23	Daytime	Average	14.306	23.656	21.660
		Minimum	9.400	21.900	21.000
		Maximum	18.300	25.300	23.100
		SD	1.749	1.038	0.353
	Nighttime	Average	9.392	24.665	21.594
		Minimum	6.600	23.700	21.000
		Maximum	12.800	25.300	23.200
		SD	1.912	0.469	0.505
Day 24	Daytime	Average	17.948	24.251	23.360
		Minimum	8.800	20.700	20.600
		Maximum	25.900	26.000	25.800
		SD	4.693	1.419	1.425
	Nighttime	Average	12.979	25.992	23.042
		Minimum	11.800	25.600	22.000
		Maximum	15.800	26.300	24.200
		SD	0.917	0.210	0.447
Day 25	Daytime	Average	20.543	26.087	25.378
		Minimum	13.400	24.500	22.700
		Maximum	24.200	27.500	26.900
		SD	2.836	0.972	0.883
	Nighttime	Average	12.911	26.273	23.278
		Minimum	10.500	25.000	21.200
		Maximum	17.200	27.200	25.700
		SD	1.727	0.657	0.982
Day 26	Daytime	Average	17.953	24.345	23.273
		Minimum	11.700	21.500	20.900
		Maximum	23.700	26.300	25.000
		SD	3.394	1.437	1.061
	Nighttime	Average	10.655	25.103	22.174
		Minimum	7.000	23.700	20.900
		Maximum	15.100	26.200	23.900
		SD	2.268	0.737	0.694

Day 27	Daytime	Average	16.784	23.463	22.126
		Minimum	8.500	21.100	21.000
		Maximum	23.600	25.700	23.300
		SD	4.010	1.633	0.490
	Nighttime	Average	9.425	24.821	21.653
		Minimum	6.400	23.800	20.900
		Maximum	14.300	25.700	23.300
		SD	2.151	0.623	0.539
Day 28	Daytime	Average	15.861	22.765	22.263
		Minimum	8.700	19.900	18.500
		Maximum	21.200	25.200	24.200
		SD	3.459	1.749	1.240
	Nighttime	Average	10.101	24.764	22.166
		Minimum	7.400	23.900	20.900
		Maximum	14.400	25.500	23.700
		SD	1.992	0.457	0.712
Day 29	Daytime	Average	14.985	22.570	22.262
		Minimum	9.500	20.200	20.700
		Maximum	19.100	24.800	23.500
		SD	2.769	1.429	0.485
	Nighttime	Average	10.175	24.158	21.876
		Minimum	9.200	22.900	20.900
		Maximum	12.400	24.900	23.600
		SD	0.856	0.450	0.553
Day 30	Daytime	Average	12.173	22.998	21.727
		Minimum	9.900	21.200	20.900
		Maximum	14.800	24.800	23.800
		SD	1.054	1.175	0.430
	Nighttime	Average	8.773	24.708	21.618
		Minimum	6.900	24.400	20.900
		Maximum	10.800	25.100	22.700
		SD	1.184	0.141	0.354
Day 31	Daytime	Average	14.285	22.954	22.113
		Minimum	9.400	21.800	20.900
		Maximum	18.700	25.000	23.900
		SD	2.333	0.879	0.561
	Nighttime	Average	8.013	27.895	26.231
		Minimum	6.600	27.300	25.300
		Maximum	9.700	28.600	27.500
		SD	0.801	0.324	0.711
Day 32	Daytime	Average	8.032	27.893	26.246

		Minimum	6.600	27.300	25.300
		Maximum	9.700	28.600	27.500
		SD	0.802	0.328	0.714
	Nighttime	Average	8.482	23.016	21.743
		Minimum	5.900	21.600	20.800
		Maximum	12.100	24.500	24.400
		SD	1.775	0.888	0.566
Day 33	Daytime	Average	16.367	22.543	22.533
		Minimum	8.100	20.300	20.500
		Maximum	23.500	25.300	24.400
		SD	4.478	1.565	1.088
	Nighttime	Average	10.084	25.019	22.033
		Minimum	7.600	24.300	21.000
		Maximum	14.100	25.600	23.600
		SD	1.857	0.414	0.640
Day 34	Daytime	Average	20.429	25.329	24.298
		Minimum	11.300	23.000	22.300
		Maximum	27.800	27.700	26.400
		SD	4.774	1.438	1.214
	Nighttime	Average	13.881	26.941	22.850
		Minimum	11.000	25.800	21.100
		Maximum	18.900	27.800	24.900
		SD	2.196	0.616	0.993
Day 35	Daytime	Average	20.658	24.702	24.409
		Minimum	13.300	21.900	22.100
		Maximum	25.300	26.200	26.200
		SD	3.507	1.028	1.120

[a] *Standard deviation of the temperature recorded*