# Heating and Cooling Loads of a Poultry Shed in Central Coast, NSW, Australia

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## ABSTRACT

Space heating and cooling comprises 40% of the global final energy use. With more energy efficient technologies in heating and cooling, up to 10% of global energy consumption could be saved. In agriculture, poultry sheds are used to shelter poultry (broilers and layers) for the production of meat and eggs, sources of animal protein for most people. The range of acceptable indoor air temperature for poultry sheds is 15°C to 25°C for mature birds, and higher temperatures are required for young birds depending on the stage of growth. It is recognised that the costs of heating, cooling and ventilating poultry sheds constitutes a significant portion of the chicken farm operating costs. Various aspects can be considered to reduce these costs considerably. The potential improvements include better thermal performance of building envelopes, energy efficiency of HVAC systems and operational schedules or timing of the production cycle. This paper aims to reduce the cooling and heating energy consumption by identifying the most suitable operational plan. The heating and cooling demand cycles of a poultry shed in the Central Coast region has been investigated in detail by using building energy simulation software tools. This paper reveals that the operational schedule (i.e. begin dates of the cycles of production) has profound influence on energy consumption. The optimised operational schedule can save an average of 12% of overall energy expenditure and 20% on heating.

***Keywords:*** *building energy simulation, energy use, poultry shed*

## 1. INTRODUCTION

The global annual energy consumption is about 13,000 Mtoe (~544 EJ), resulting in nearly 50 Gt $CO_2$-e Greenhouse Gas (GHG) emissions. It is widely accepted that our future energy sources could not highly rely on fossil fuel such as oil and gas since these resources are finite, and more importantly the majority of GHG emission (65%) comes from them. To provide our next generations with a sustainable energy future, alternative approaches must be adopted as soon as possible.

Space heating and cooling comprises a significant part (40% - 50%) of the overall final energy use, resulting in 20 Gt $CO_2$-e GHG emissions. By using advanced technologies for space heating and cooling, up to 1,509 Mtoe of global annual energy consumption could be reduced by 2050. In order to develop sustainable buildings and improve energy efficiency in existing buildings, several approaches can be considered, which include improving the thermal performance of the building envelope, increasing the energy efficiency of HVAC system and determining the most suitable operational schedule.

The agriculture sector constitutes a significant part of Australia's economy. In year 2014/15; the overall sector was worth $51 billion, comprising 3% of Australia's total gross domestic product (GDP). However, when considering all the add-on processing industries, the overall contribution of the agriculture sector rises to 12% of the GDP. Among these industries, nearly 600 million chickens are raised every year for producing meat and a typical shed provides about 200,000 chickens annually, which means there are currently around 3,000 poultry sheds for chicken meat production in Australia. The overall costs of heating and cooling for chicken farms are estimated to be $80 million per year.

To raise chicken/ broiler efficiently, poultry sheds are designed to meet the specific requirement for chickens during different growth stages. The indoor temperature is a vital factor for the chicken to grow properly in an effective timeframe. Within each growing cycle, the indoor air temperature requirement changes from 33°C at the beginning to 21°C in the end, which results in a unique heating/cooling load cycle depending on the start date. Since outdoor air temperature changes throughout the year, a considerable amount of energy is sometimes needed to maintain the required indoor air temperature (i.e. to reach 33°C in winter).

Researchers have conducted building simulations for poultry sheds for heating/cooling load cycles in recent years. Kharseh and Nordell (2011) estimated the heating and cooling loads for a typical poultry shed in Syria in order to design a geothermal cooling and heating system for the shed. However, the assumption made for the chicken is not enough to describe the heat generation due to the growth of chicken, which may result in an inaccuracy of the heating and cooling loads. El Mogharbel et al. (2014) developed a 3D computational simulation model for the heating system of a poultry shed in East Lebanon, with various factors taken into consideration. However, this model is based on the solar assisted heating system only. At the same time, no annual data and cooling loads has been reported. Rojano et al. (2015) developed a 3D model using a CFD commercial software package, Fluent. In their study, the heat and mass transfer within a poultry shed in the US is analysed in detail. However, the aim of their work is to analyse temperature, humidity and air quality in the shed. Hence, no heating and cooling loads were reported. Besides, owing to the complexity of this 3D model computational time is long, thus a detailed model for annual heating and cooling loads is unlikely to be feasible. Hamilton et al. (2016) developed a thermodynamic model for the thermal analysis of a poultry shed in Australia. This model contributes to a theoretical analysis of chicken growth, heat generation, and water consumption during the cycle. Validation based on measured data was also made on the model. However, no models were derived in this article and there were no direct data for heating and cooling loads. From the review of the literature, it follows that limited knowledge is available to derived sheds load cycles, particularly of local settings.

Due to the different agricultural standards encountered among countries (i.e. construction materials, operational schedules) and the various climate conditions of the poultry sheds, it is essential to analyse the heating/cooling demands for local conditions, in the case presented herein, for Australia. The aim of this paper is to estimate the heating/cooling load for a specific poultry shed in NSW, Australia, as representative of current practice in the area. The estimated costs base on the current HVAC system is also reported. An optimisation of growing cycle start date for the minimum cost is investigated.

## 2. BUILDING SIMULATION MODELS

EnergyPlus is widely used for building energy performance simulations. In this paper, an EnergyPlus model was developed for a poultry shed in Central Coast, NSW. Other details of the methodology employed are included in this section.

### 2.1 Simulation parameters

The poultry shed investigated in this investigation is located in the Central Coast Region, NSW, Australia (approximately at 33°23'49"S and 150°24'09"E). Climate data are essential for the building simulation. A typical meteorological year (TMY) data generated by an algorithm based on 20 years of recorded dataset is widely used to predict the long term performance of buildings. In this paper, the TMY file generated by Meteonorm 7.1 based on recorded climate data from 1990-2010 is utilised. An average error of 6% in year sum comparing with the actual climate can be expected by using this method of hourly data generation.

| Time/Days | Weight/kg | Metabolic Weight/w | Power/W | Population of Chicken | Size of Shed | Required Temperatue/°C |
|---|---|---|---|---|---|---|
| 1 | 0.04 | 0.09 | 0.68 | 40,000 | Small | 33.0 |
| 7 | 0.16 | 0.25 | 1.82 | 40,000 | Small | 30.7 |
| 14 | 0.42 | 0.52 | 3.82 | 40,000 | Small | 27.5 |
| 21 | 0.84 | 0.88 | 6.43 | 40,000 | Large | 24.8 |
| 28 | 1.39 | 1.28 | 9.36 | 40,000 | Large | 22.0 |
| 35 | 1.97 | 1.66 | 12.13 | 40,000 | Large | 21.0 |
| 42 | 2.43 | 1.95 | 14.21 | 30,000 | Large | 21.0 |
| 49 | 2.74 | 2.13 | 15.55 | 20,000 | Large | 21.0 |
| 56 | 2.90 | 2.22 | 16.23 | 10,000 | Large | 21.0 |

*Table 1: Poultry shed simulation parameters*

As shown in Table 1, there are two building models to meet the different space requirements as chickens grow. The small area within the shed is for the first three weeks of growth with dimensions of 18 x 18 x 3m$^3$. Later, the bigger chickens are redistributed into a larger space within the shed, with dimensions of 18 x 160 x 3m$^3$. The building is constructed with 75mm 'Coolroom' walls (thickness: 0.075m, thermal conductivity: 0.039 W m$^{-1}$·K$^{-1}$, density: 16 kg m$^{-3}$, specific heat: 340 J kg$^{-1}$·K$^{-1}$) with no windows. A chicken usually attains 2.8 to 3kg at the age of 8 weeks. The mass of chicken for the first 35 days is provided by our industry partner (Ground Source Systems Pty Ltd) while the following 21 days data is generated through a quadratic function. Heat produced by a living creature is proportional to the metabolic weight, which is the unit of 0.75 power of kg. The heat rate generated by an adult chicken is 160 kcal d$^{-1}$ w$^{-1}$ (7.75 W w$^{-1}$).

### 2.2 Operational schedules

In Australia, it usually takes about 55 to 60 days for a recently hatched chicken to develop fully for the market. Meat broilers reach the mass of harvest at the age of 5 weeks, and partial harvest of chicken happens up to four times in one batch on a chicken farm due to the different demand for light and heavy chicken meat. After that, there are 5 to 14 days for clean-up and preparation for the next batch. The simulation in this paper is based on the operational schedule shown in Table 1.

As shown in Table 1, during the first 21 days, chicks are kept in a small area with controlled temperature inside the shed to save energy. At the 22$^{nd}$ day of each batch, the shed is expanded to the full area. At the 35$^{th}$ day, the average mass of a chicken reaches about 2 kg, meeting the requirement for the market. The first harvest happens in the midnight of the 35$^{th}$ day, when one-fourth of the overall population, which is 10,000 chickens, are taken away. Later, in every following week chickens are taken away at different stages in order to suit the demand of the market. The partial harvesting significantly decreases the internal heat gain, hence influencing the heating and cooling loads. The final harvest happens at the end of the eighth week, followed by two weeks of clean-up and preparation for the next batch.

## 3. TITLE HEATING/ COOLING LOADS AND COSTS ESTIMATION

By utilising 'Ideal Air Load' option in EnergyPlus, the hourly heating and cooling loads were estimated. The algorithm applied is the third order backward difference method. Estimation of costs based on the current HVAC system has also been conducted.

### 3.1 Heating and cooling loads for different starting dates

In order to determine the heating and cooling loads for the different starting dates, 52 batches starting at different weeks for one year were investigated. The first week starts at 3$^{rd}$ of January, the first working day in a year in Australia. As an example, Figure 1 and Figure 2 describe a typical eight-week batch starting at the 19$^{th}$ of December. The indoor temperature requirement is set every day to meet the temperature requirement for raising broilers. During this batch, the heating load decreases as a result of increasing heat generated by the chickens. After that growth stage, the cooling load significantly increases during the following first five weeks. After each harvest, the internal gain (heat produced by chicken) reduces, which results in a reduction of cooling loads.

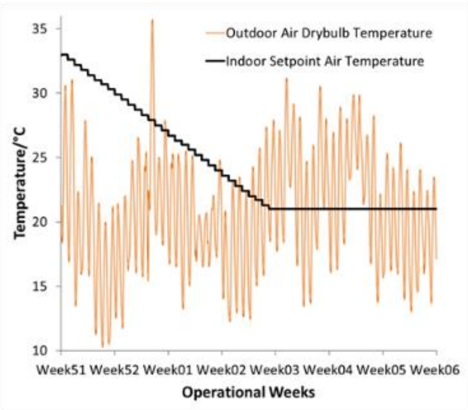


*Figure 1: Indoor and outdoor air temperature*

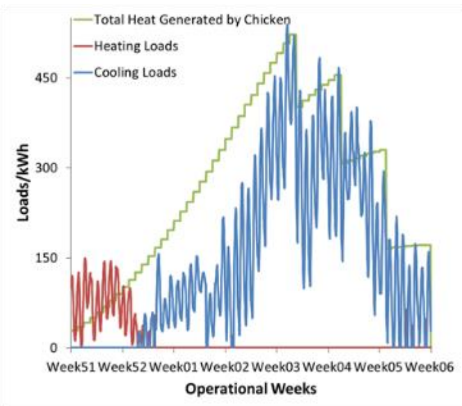


*Figure 2: Hourly heating and cooling loads*

After hourly heating and cooling loads for 52 starting weeks were acquired, the overall energy consumption for each batch was obtained by summing up the heating and cooling loads. As shown in Figure 3, at the beginning of the year (summer), raising a batch requires much more cooling than heating (nearly eight times higher). Later, as the outdoor air gets colder, the heating loads increase while the cooling loads decrease. At the middle of July (winter), the heating load reach the peak (105,108kWh) for one batch, while the minimum cooling load, 23,366kWh, appears in the 24th week. After the coldest periods of the winter, the heating load begins to reduce together with the boost of cooling demand. The highest cooling demand happens at the end of the year, corresponding to the minimum heating demand of only 11,575kWh for one batch.

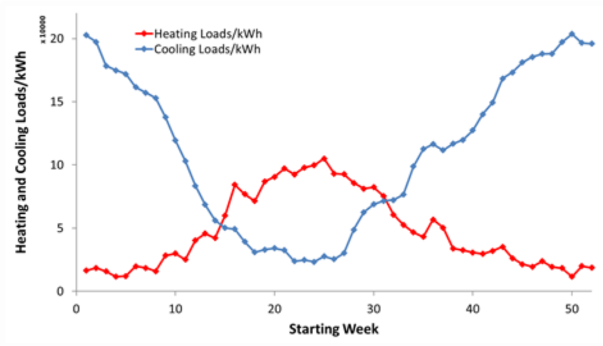


*Figure 3: Loads for different starting weeks*

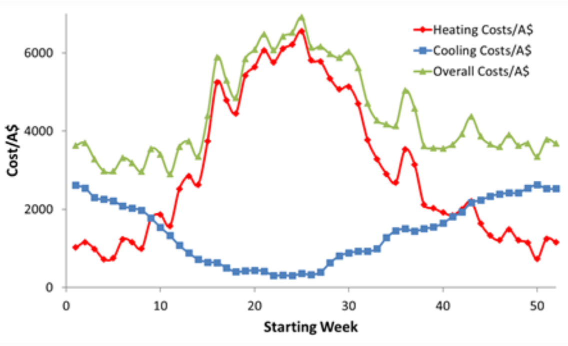


*Figure 4: Costs for different starting weeks*

### 3.2 Estimation of costs

Chicken sheds are typically equipped with gas heaters for heating and evaporative coolers for cooling in NSW. The gas heaters were assumed to have an efficiency of 0.85. It was hard to determine the operating efficiency of evaporative coolers because their performance highly relies on the relative humidity and ambient air temperature. However, it is known that evaporative cooling usually saves around 75% of the cost compared with standard air conditioning. This paper assumed one-fourth of the cost of air conditioners with COP of 2.5 as estimation. The prices of energy applied for the analysis are 12.9c/kWh for electricity and 5.3c/kWh for gas.

Figure 4 shows the heating and cooling costs for the different starting week. Corresponding to the loads, the heating cost rises from AU$ 722 to more than AU$ 6,500 in the mid-year while the cooling cost reduces from AU$ 2,614 to AU$ 301. After winter, the heating cost decreases and the cooling cost increases. Since the evaporative cooler is cheaper to operate, the cooling cost is much less than heating in the year total, despite the nearly doubled cooling load's peak. The results also show that raising a batch in winter costs much more than in summer. The most cost-effective period for starting a batch is from late September to early April.

## 4. OPERATIONAL OPTIMISATION

As fully-grown chickens generate large amounts of heat, i.e. 40,000 chickens in a shed could generate heat up to 600kW, raising a batch in summer consumes a large amount of energy for cooling. In winter, due to the low outdoor temperature and the relatively high initial temperature requirement (33°C on the first day), the heating loads could also be large. By avoiding raising chicks in the coldest time of winter as well as adult chickens during the hottest weather in summer, a suitable yearly operational schedule reduces the heating loads in winter and the cooling loads in summer.

A typical batch takes eight weeks duration. It is almost impossible for a shed to run six whole batches in one year due to the time required for cleaning and preparation. In this paper, five batches were considered for one year. Assuming a minimum break of one week for cleaning and preparation, the possible intervals between each batch are one to six weeks. Assuming at least a one week break between the last batch and the first one, there are overall 3,248 possible operating schedules. In this paper, the costs of all of the 3,248 possible schedules have been estimated using a Matlab code developed.

Figure 5 shows that the annual costs for all operating schedules resemble the normal distribution pattern, with an average of AU$ 22,126 and the standard variations of AU$ 852, which is calculated with the Maximum Likelihood

Estimation (MLE). MLE is a method that estimates parameters of statistical models based on given data. The distribution has also passed the Kolmogorov-Smirnov test in Matlab, a hypothesis test for normal distribution, at a 1% significance level.

In statistics, for the normal distribution, the three standard deviation (sigma) rule treats the values within the region of the distance of three times of the standard deviation to the mathematical expectation as a practical certainty. By starting at 5$^{th}$, 14$^{th}$, 28$^{th}$, 39$^{th}$ and 48$^{th}$ week of the year, the most economical schedule costs only AU$ 19,514, which is out of the three-sigma region (AU$ 19,570 to AU$ 24,681). This result reveals the significance of the optimisation because it is improbable for a farmer to operate the chicken shed with the minimum cost if the optimised schedule identified is applied.

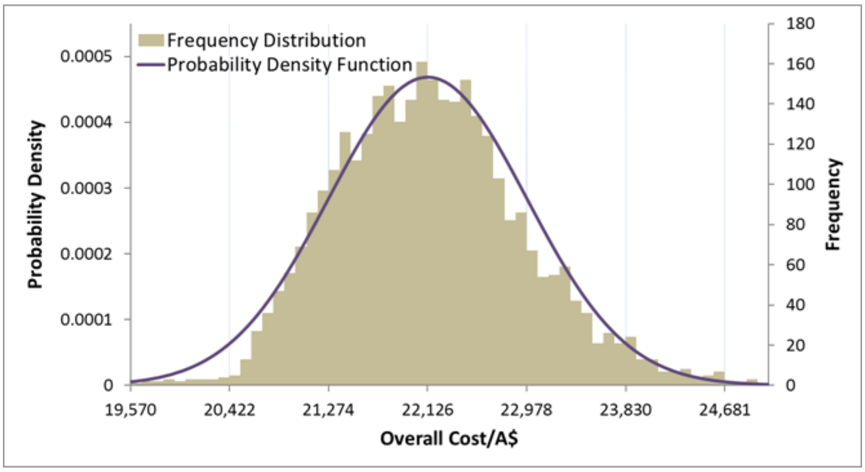


*Figure 5: Costs distribution for all operating schedules*

More specifically, the optimised schedule costs are AU$ 11,972 for heating and AU$ 7,542 for cooling. Although the cooling cost is 5.5% higher than average, this schedule nevertheless consumes 11.8% lower than the overall average and saves more than 20% on heating. Since gas heaters produce GHG emissions, adopting this schedule would also reduce the GHG emissions. For the typical poultry shed investigated, approximately 10 t $CO_2$-e would be reduced annually, equivalent to the removal of two cars or the planting of more than 600 trees per year.

## 5. CONCLUSION

This paper investigated the heating and cooling load cycles of a typical poultry shed in Central Coast Region, NSW, Australia by using EnergyPlus simulation engine. The simulations considered the chicken growth rate and metabolic heat generation, operating schedules, building envelop materials, orientation and climate conditions.

The two vital factors that influence the energy consumptions for heating and cooling the chicken shed are internal gains from the metabolic heat of chickens and the climate conditions. The energy consumption could be reduced by changing the operating schedules. By evaluating the heating/cooling load profiles for batches starting at 52 different weeks throughout a year, the relationship between energy consumption and operating schedule has been discussed. The results reveal that the period from late September to early April is the most economical time for starting a batch.

Considering the estimated cost based on the current HVAC system, an operational optimisation for the minimum cost is suggested. The results show that operational optimisation would significantly reduce the heating/ cooling loads as well as the costs for heating and cooling. By applying the lowest cost schedule, on average 20% of the heating cost and 12% in total cost could be saved.

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