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Energetic analysis in compost dairy barn: a case study in southeastern Brazil

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Abstract. Energy efficiency aims to optimize the energy consumption of the processes, activities, and machinery of the farm, ensuring the comfort, handling, and safety of the animals. The purpose of the study was to identify the energy consumption demanded by the activities performed at the Compost Dairy Barn facility, located in Itaguara, Minas Gerais, Brazil and to propose energy-saving alternatives, applying the Energy Audit Methodology described by the Institute for Energy Diversification and Saving (IDAE in Spanish) from Spain. The energy assessment at the facility allowed us to recognize unnecessary energy expenses in machinery uses, variations in milk production in relation to environmental conditions, waste disposal, and to propose improvement alternatives to reduce energy consumption expenses. Waste production data of 1577.7 kg per year was obtained, which corresponds to the bedding and feeding areas, and 175 kg of waste for the feeding area. Data on the temperature and humidity of the bedding area were collected to determine which of the five months of research is the most demanding in terms of energy. To maintain the animal's welfare, tracing the times of substantial use of machinery (e.g., fans, tractors) at the facility and calculating Equivalent Temperature Index (ETI) was necessary. The highest percentage consumption of energy was represented by tractors in bedding maintenance and supply, by around 95.03%. The energy analysis of the farm showed a reduction in energy consumption of 45.03%, compared to the initial consumption percentages of the overall livestock activity.

Key words: energy balance, energy consumption, livestock energy analysis, livestock sustainability.

INTRODUCTION

Energy efficiency is associated with the reduction of energy consumption, which translates into a reduction of costs and CO_2 emissions (IDAE, 2010) and, according to several authors (Hazell & Pachauri, 2006; Demirbas et al., 2009), this concept is also related to the reuse of plant and animal resources for bioenergy production. Bioenergy represents 10% of the world's energy supply, 33% of which is used in developing countries and only 3% in industrialized countries. There is also a big difference between developing regions: biomass accounts for more than 60% of final energy use in Africa, 34% in Asia and 25% in Latin America (Hazell & Pachauri, 2006).

Another important factor that is related to the concept of energy efficiency is global greenhouse gas (GHG) emissions. According to (Ang et al., 2010; FAO, 2016) the global production of CO_2 derives from livestock emissions processes and from fossil fuel use to supply agricultural machinery, representing 21% of the worldwide production. Thus, the authors mention that one of the most effective ways to reduce dependence on fossil fuels and GHG emissions is improving energy efficiency, as an important factor of sustainable development policy.

According to (Ramos et al., 2014; FAO, 2016), in an intensive dairy cattle production system, sustainability requires to be supported by improvements in the whole production chain. A better understanding of the processes and reducing on-farm losses allows for better efficiency in the whole system. To guarantee sustainability, each agroecosystem needs specific solutions according to its particularities of space, climate, and resources considering that the thermal environment is a major factor that could negatively affect milk production in dairy cows (Kadzere et al., 2002).

As for dairy cow production, it consumes many forms of energy and transforms them into milk, which is configured as the output of the energy process of the facility. According to (Shine et al., 2020), several ways to monitor, predict and analyse energy consumption on dairy farms are tackled, depending on indirect or direct usage. This is why the energy balance has the potential to improve the visibility of energy inputs, seeking greater efficiencies in consumption and driving an increase in production (Ramos et al., 2014), and at the end of improving energy efficiency in dairy systems, reduction of greenhouse impact and an achievement of sustainable development take place (Qin et al., 2017).

Growth in milk production is forecasted to increase by 22% in 2027 and many processes demand energy to carry out dairy labour (OECD-FAO, 2018). At the level of Latin America and the Caribbean, milk production is concentrated in three countries, Brazil, Argentina and Mexico, Brazil being responsible for 39% of production with a distribution represented by approximately 1,350,000 dairy farmers, representing a relative importance of 42.8% (FAO, 2012). As FAO & ONU (2012) mentioned, currently, global food production systems, consume 30% of all available energy and a significant amount of the entire production chain (about 40%) is lost, due to food waste (globally one third of all food, about 1.3 billion tons is wasted each year).

The energy expenses in dairy production are concentrated in feed, housing, and manure management and in the most of livestock systems, the dominant energy use category is animal feeding (Paris et al., 2022). In dairy systems specifically, significant energy consumption is allocated to milking processes (Paris et al., 2022; Shine et al., 2020).

According to (Paris et al., 2022), there is a dominance in fossil fuel usage in livestock rearing and a shortage of standardized methodology for measuring energy use in animal production facilities, which allows a comparison among several categories of energetic expenditures. However, Guerci et al. (2013) mention the Life Cycle Assessment (LCA) as one of methodologies used to assess the environmental impact and performance of milk production in different dairy systems across Europe. On other hand, IDAE (2010) approaches Energy Audit Methodology as a tracking of energy in relation to quantity and type of energy needed in each process, and consuming process (heating, ventilation, machinery, etc).

Paris et al. (2022) provide a review of energy use in EU livestock sector and the authors faced the production, processing, and transportation of feeds, require a significant amount of energy inputs that are mostly dependent of fossil sources, and represent a large proportion of the total energy consumed in livestock production.

According to International Energy Agency, hereinafter IEA, (IEA, 2022), modern bioenergy is the largest source of renewable energy globally, accounting for 55% of renewable energy and over 6% of global energy supply. Brazil accounts for almost 7% of planet's renewable energy production and has long been a leader in biofuels technologies (IEA, 2023).

Biomass-derived energy has a potential that contributes to one of the modern challenges. Currently, the world consumes about 400 EJ (Exajoules) of energy per year but generates an equivalent of 100 EJ of mostly unused crop residues. Energy production from biomass requires a range of technologies including combustion, gasification, and fermentation of solids. These technologies produce liquid and gaseous fuels from diverse biological resources (traditional crops such as sugarcane, corn, and oilseeds), crop residues and wastes (rice hulls, cotton waste), manure and the organic component of urban waste. The results are bioenergy products that provide services ranging from cooking fuels to transportation fuel (Hazell & Pachauri, 2006; Demirbas et al., 2009).

The present study allows an overall assessment of energy-consuming activities in a milk production facility located in Minas Gerais, Brazil, using energy balance, a stockman survey to analyse the management labours, variations in milk production in relation to environmental conditions, waste disposal, and energy-saving proposal to reduce unnecessary processes.

MATERIALS AND METHODS

Characterization of the area

For the characterization of the area, the environmental conditions of the State and the micro-region in which the farm is found were identified. This was done to carry out an energy balance that allowed us to determine the energy demands of the livestock activity and the possible alternatives for improvement.

The farm is located in one of the states with the highest milk production in Brazil (IBGE, 2021), on the report of the Brazilian Institute of Geography and Statistics (IBGE in Portuguese). Minas Gerais State accounts for about 27.11% of Brazil's milk production (Cicarini Hott et al., 2019). The farm is part of the Belo Horizonte metropolitan region, Itaguara microregion and in the municipality of Cláudio at coordinates 20° 24' 39.6" S, 44° 36' 53.24" W. Accordingly, the percentage distribution established by FAEMG (FAEMG, 2006), Itaguara represents 0.60% of milk production out of a total of 7.90%

produced by the mesoregion. The farm was identified by obtaining geographic coordinates in the Google Earth Pro program.

Data Collection

The data collection included environmental factors that develop in the facility (internal and external temperature and relative humidity), variables that affect the cows' bedding (surface temperature, at a depth of 20 centimeters, humidity percentage and pH), animal weight and milk production in the months between February 2020 and June 2020. In addition, a survey was conducted with the producer to find the energy consumption in the livestock facility through questions focused on the time the fans and tractors are turned on and the usage given to the cows' waste.

Internal and external environment of the facility

The farm has a cattle confinement system called Compost Barn, in which the production source is milk. The facility has a common bedding area and a corridor where water and feed are supplied to the cows. The study was carried out in the months between February and June 2020, during which the variables that affect animal welfare were evaluated, such as air temperature, relative humidity as well as temperature, humidity percentage and pH of the bedding. The area had a density of 70 animals with an average weight of 668 kg each. For the characterization of the internal and external environment of the facility, data were taken with six temperature and humidity sensors or INSTRUTHERM HT500 data-logger, every 10 min, distributed throughout the facility, as shown in Fig. 1, b.

Figure 1. Internal characterization of the facility: a) Front view; b) Datalogger location; c) Rear view.

Cow bedding characteristics

The bedding data was taken before the second daily bedding maintenance was performed. While this was taking place, a second operator was milking the cows. Samples collected in the field were stored in containers properly marked with the location of the respective datalogger and sampling depth, as shown in Fig. 2. After this, bedding moisture percentage tests were performed by the gravimetric method, which consists of weighing 10 g of wet sample and leaving it in the drying process for 24 hours at a temperature of 105 °C.

Figure 2. Bed maintenance and data collection: a) Bed maintenance; b) Heat release after bed maintenance; c) Incorporation of new materials into the bed; d) Recording of surface temperature; e) Recording of temperature at 20 cm depth; f) Collection of bedding material.

Milk production

For the analysis of milk production, we used data recorded by the producer of the quantity of milk produced per day and calculated the Equivalent Temperature Index (hereinafter ETI), where variations in production per month were found, depending on the wind speed present in the area, temperature, and relative humidity of the environment. For the ETI calculation, it was necessary to know the air speed in the area. For this purpose, data from the nearest meteorological station to the farm, located at 20°10′ 23.82″S and 44°52′ 29.07″W, was used according to INMET (INMET, 2020). Those stations closest to the city of Claudio in the Microregion of Itaguara were identified and data was taken from the Divinopolis meteorological station, located at an altitude of 787.42 m.

In this sense, Baêta and Souza (Baêta & Souza, 2010) refer to an equivalent temperature index, considering air temperature ranges between 16 and 41 °C; relative air humidity between 40 and 90% and air speed between 0.5 and 6.5 m s^{-1}. The ETI calculation is based on Eq. (1).

$$ETI = 27.88 - 0.456\,T + 0.010754\,T^2 - 0.4905RU + 0.00088\,RU^2 + \\ +1.1507V - 0.126447\,V^2 + 0.019876\,T \cdot RU - 0.46313T \cdot V \quad (1)$$

where T – environment temperature (°C); RU – relative air humidity (%) and V – air velocity (m s^{-1}). As shown in Eq. (1), the ETI requires values of air temperature and relative humidity. For this purpose, the monthly average results of the internal environment of the facility described in section 2.2.1 and shown in Table 1 were used.

Energetic analysis

Energy balance of the livestock facility

The energy balance seeks to establish the energy flows, identifying the total demand and efficiency, reflected in the input/output ratio. In this process, all inputs used and produced that are transformed into energy units were quantified. Estimating energy balances and energy efficiency are important tools for monitoring agriculture in the face of the use of non-renewable energy sources (Campos, 2004).

Heat transfer by convection and conduction. To calculate the transfer by convection and conduction, the equivalent resistance of the ceiling, floor and lateral zones was calculated. It is necessary to point out that the facility is open on all four sides, therefore, only the existence of columns and walls along the feeding corridor was considered, as shown in Fig. 3. The equivalent exterior and interior resistance values were taken as 0.04 and 0.1, respectively, as stated in (ABNT, 2005).

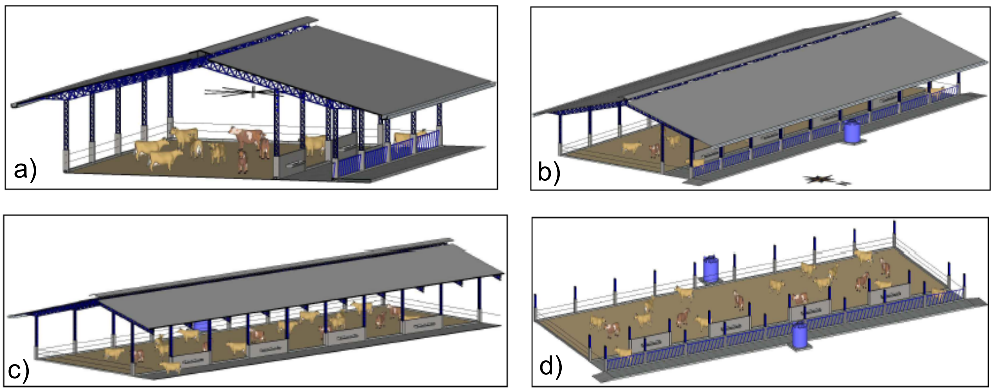

Figure 3. Livestock facility: a) Perspective cut; b) 3D perspective; c) Perspective cut of feeding troughs; d) Perspective ground floor. Source: (Damasceno, 2020).

Radiative heat transfer. To calculate the heat transfer by radiation, it is necessary to know the absorptivity of the material in which the roof is built. For this purpose, a value of $\alpha = 0.74$ is taken and a surface temperature 10 degrees Celsius higher than the outside temperature, as stated by Díaz (Díaz, 2012).

Heat balance calculations. The heat balance of a livestock house in an equilibrium situation, as (IDAE, 2010) showed, includes heat gains due to radiation, heat exchanges by convection, conduction, heat production by sensitive pathways (animals), facility equipment, exchanges due to ventilation and other forms of heat generation such as lighting, pumps, motors, etc. In the case of the present study, the heat generated by lighting was disregarded, since most of the activity is generated during daylight hours.

RESULTS

Data collection

Internal and external environment of the facility

After collecting data for five months, we proceed to analyse the daily and monthly environmental behaviour of the temperature and humidity of the internal and external environment of the building, considering that the animals present in a facility are a constant source of sensible and latent heat (respiration and transpiration heat) that influences the value of the internal temperature (IDAE, 2010).

The indoor environmental behaviour of the building was subject to two moments: periods in which the relative humidity decreased significantly and others in which the temperature was the parameter that changed the most. In this sense, it can be affirmed that, for the first case, the animals did not present a significant difference in terms of comfort because the decrease in relative humidity was not determined by a low temperature. On the other hand, in cases such as March and February (considering Fig. 4), when the temperature decreased and increased, respectively, compared to the other months, the animal comfort index is directly affected, since, according to (IDAE, 2010), heat stress conditions are associated with high relative humidity situations dependent on high-temperature situations.

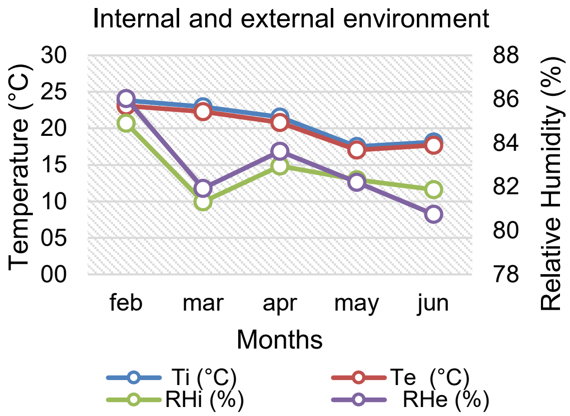

Figure 4. Monthly internal (Ti, RHi) and external (Te, RHe) environmental performance of the facility.

Cow bedding characteristics

Temperature bedding. Fig 5 shows that there were no representative variations between the months analysed and according to (Damasceno, 2020) the optimal development of the bedding is given mainly by the stirring of the material, the density of animals present in the productive activity and the material available to promote the composting process. In this case, the temperature of the bed at 20 cm depth complies with the temperature ranges proposed by (Jones & Martin, 2003) to maintain

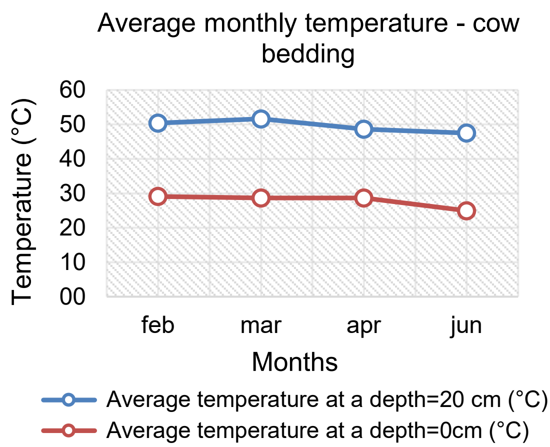

Figure 5. Average monthly bed temperature.

the compost in optimal conditions in the first stage of decomposition (2 to 5 days), as shown in Fig. 5.

Humidity and pH. Fig. 6 shows the percentage of moisture and pH of the bedding for each month, but it was not possible to track bedding data in May due to the pandemic situation. According to (ASAE, 2003), the average pH values for dairy cattle are in the range of 7.0, and Jones et al. (Jones & Martin, 2003) mentions a pH range between 6.5 and 8.0, so that composting can be conducted correctly. Thus, none of the months has an appropriate pH for this process. In addition, March is the most critical month in terms of high pH. In the case of bedding moisture, the authors (Jones & Martin, 2003) mention adequate ranges of 45% to 60% for optimal decomposition. In this case, all months comply with this range, except for March.

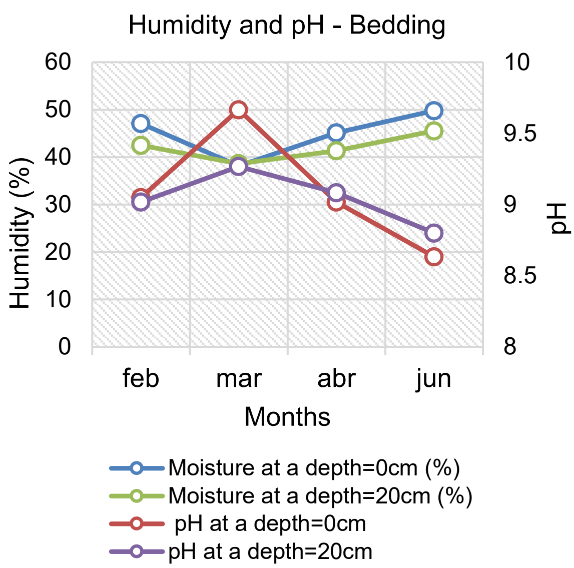

Figure 6. Monthly humidity and pH of bedding.

Milk production. Milk production at the farm varies during the five months of research. Fig. 7 shows the months in which environmental conditions do not favour milk production (January, February, March) and three other months in which milk production exceeds 2,000 litres per day, corresponding to April, May, and June.

As shown in Eq. (1), the ETI requires values of air temperature and relative humidity. For this purpose, the monthly average results of the internal environment of the facility described in section 2.2.1 and shown in Table 1 are considered. According to Table 1, it is observed that the highest temperature is recorded in February, March, and April, and consequently, a higher ETI is obtained, which indicates that the percentage of milk production decreases.

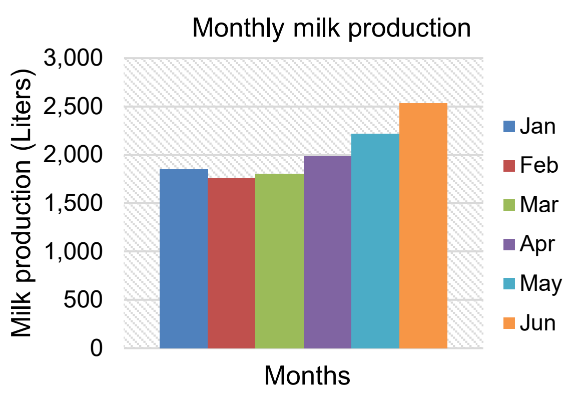

Figure 7. Monthly milk production at the farm.

Considering the percentage decrease in milk production, ambient temperature, relative humidity and ETI, (Baêta & Souza, 2010), defines different states of comfort of the animals varying from a safe state, warning state, and ending with extreme caution, danger, and extreme danger. According to Table 1, in February, milk production decreased by about 30.4% (1,762 litres) compared to the month of June, which has on average the highest production of all the months studied with 2,532 litres; placing the second month of the year it in the category of 'danger', according to (Baêta & Souza, 2010).

Thus, Aurora farm requires special attention in the summer months, where the temperature and relative humidity exceed the comfort conditions for Dutch cows described by NRC (NRC, 1981), where the temperature is in a range of 5 to 21 °C, relative humidity of 50% and wind speed of 1.4–2.2 m s^{-1}. To identify the variation in milk production, a wind speed of 2.1 m s^{-1} was chosen for the comfort zone of the animals, to comply with the comfort intervals described by (NRC, 1981) and the study parameters of (Baêta & Souza, 2010).

Table 1. Monthly equivalent temperature index

Equivalent temperature index				
Months	T (°C)	HR (%)	V (m s^{-1})	ETI
Feb	23.828	84.902	2.1	27.571
Mar	22.937	81.313	2.1	25.712
Apr	21.537	82.957	2.1	23.688
May	17. 512	82.317	2.1	17.587
Jun [1]	18.124	81.875	2.1	18.477
Comfort	21	50	2.1	21.408

[1] For the month of June, ambient temperature and relative humidity data were taken from only fifteen days due to the pandemic situation.

To analyse comfort conditions and production concerns, the bedding area was divided into a six-grid section to collect information on the internal environment and bedding area. For internal characterization, temperature, and relative humidity throughout the barn (P1 to P6) were collected. For bedding, relative humidity, surface temperature and temperature at a depth of 20 centimetres were gathered. As shown in Fig. 8, all reference points were spaced at the same distance, 5.10 meters on the y-axis and 13.48 meters on the x-axis.

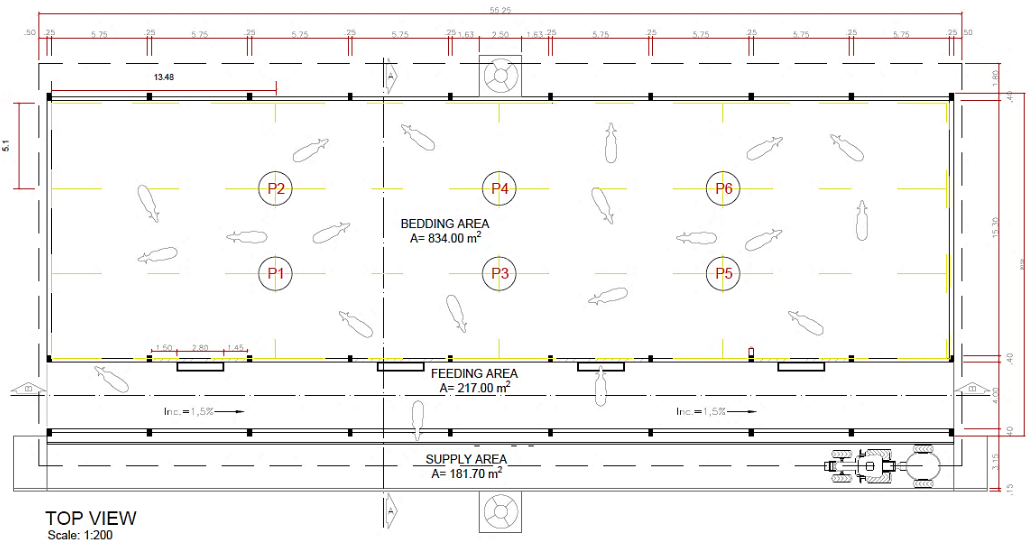

Figure 8. Distribution of measurement points in the bedding area.

Figs 8 and 9 show that points five and six were critical locations with the highest temperatures compared to the other points. Temperatures higher than 21 °C, according to (NRC, 1981) correspond to the upper thermal threshold at which Holstein cows activate their physiological mechanisms to ensure their survival, which is reflected in the decrease in the amount of milk they produce.

Points five and six presented a common denominator in their physical condition. The measurements of these two points were characterized by a higher degree of compaction compared to the other measurement references. This is because there is a drinking trough for the cows near Point five (P5), which, together with the cattle feeding activities, generated water spills along the feeding corridor and affected this sector of the bedding.

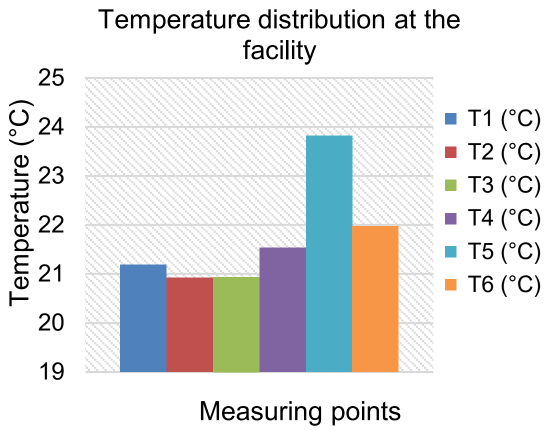

Figure 9. Temperatures per each measuring point.

Regarding the relative humidity of each datalogger location (Fig. 10), the critical point is point four, and according to NRC (NRC, 1981) the conditions presented in the facility do not correspond to the comfort standards for Dutch cows. However, it is important to point out that relative humidity does not affect adult animals when temperatures are below 24 °C, thus allowing a relative humidity range between 40% and 80%. High humidity values, associated with high-temperature situations, lead to heat stress, with negative consequences for production and animal welfare, according to (IDAE, 2010) In this context, temperature turns out to be the decisive variable in defining the state of stress or animal comfort.

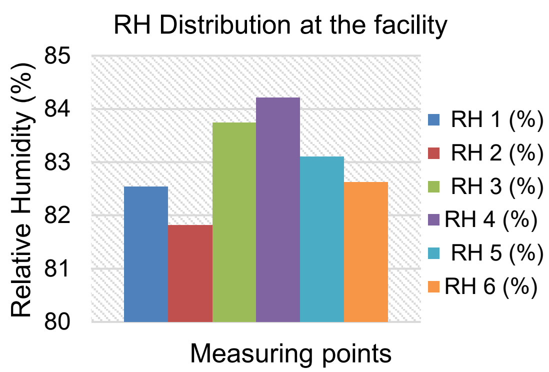

Figure 10. Relative humidity per measuring point.

Energetic analysis

The average outside temperature of the facility is 23.1 °C and the average inside temperature is 23.8 °C, which corresponds to the month of February, the most critical month as shown in Table 1. With these data and the materials used in the construction of the facility, the heat by conduction, convection, and radiation was calculated.

Heat transfer by convection and conduction. According to (IDAE, 2010; Incropera & Witt, 1999), for the calculation of heat produced by conduction and convection ($Q_{\frac{con}{conv}}$), it is necessary to know the area of the surfaces (A_T), of the facility (ceiling, walls, floor), with their respective thermal resistances. The global transmittance coefficient (U), is calculated and, knowing the internal and external temperatures (T_i and T_e, respectively), the value of heat produced is obtained, according to Eq. (2).

$$Q_{\frac{con}{conv}}=A_T \cdot U(T_i\text{-}T_e) \quad (2)$$

$$Q_{\frac{con}{conv}}=2{,}552.1\ m^2 \cdot 4.04\frac{W}{m^2K} \cdot (0.7)K=7{,}217.3\ W$$

Radiative heat transfe. Considering the heat transfer equation mentioned by (Incropera & Witt, 1999), it is necessary to know the surface temperature of the roof ($T_s = 306.1$ K) and the temperature of the external environment ($T_e = 296.1$ K). The surface area was 1,369.1 m^2. The absorptivity value taken for this material is $\alpha = 0.74$ and the Stefan-Boltzmann constant ($\sigma = 5.67E-8\frac{W}{m^2K}$). Thus, the value obtained corresponds to the following procedure:

$$Q_{rad}=\alpha\sigma A_s(T_s^4\text{-}T_e^4) \quad (3)$$

$$Q_{rad}=60{,}450.9\ W=60.451\ kW$$

Heat generated by animals. According to the (IDAE, 2010) the heat produced by dairy cattle per unit weight is 1.2 W kg^{-1} and considering that the average weight of the cows is 669 kg, the heat generated obtained is:

$$Q_{gen}=1.2\frac{W}{kg}\cdot 669\ kg\cdot 70\ cows = 56{,}196\ W=56.196\ kW \quad (4)$$

Heat balance calculations. According to the (IDAE, 2010), the heat stored in the facility was.

$$Q_{stored}=Q_{\frac{cond}{conv}}+Q_{rad}+Q_{gen} \quad (5)$$

$$Q_{stored}= 7{,}217.3\ W+ 60{,}450.9\ W +56{,}196\ W=123{,}864.2\ W=123.9\ kW$$

Characterization of energy-consuming processes. There are two common types of fans used for confinement systems: box fans and HVLS (high volume - low speed) fans (Pressman, 2010). In the case of the Aurora farm, there are two HVLS fans with a diameter of 7.31 m approximately, with an operation of 24 h per day distributed between day and night, working at maximum and intermediate power, respectively.

According to (Sanford, 2004), HVLS fans are large-diameter circulation fans, with diameters ranging from 2.43 to 7.31 m. A 7-meters HVLS fan can move the same amount of air as six 1.22-meters high-speed box fans and can save up to 3.3 KW in one hour of operation.

For the case of the farm, the daily, monthly, and five months-energy consumption of the machines involved in the daily maintenance processes of the livestock facility was calculated, as shown in Table 2. Two important energy processes were identified, ventilation and maintenance supply. Regarding the maintenance of the bed and supply of the feeding corridor, Massey Ferguson reference tractors are used, and the material mentioned by the producer for changing the bed, is sawdust whose dimensions are in a range between 5 to 30 mm, being the second material with fewer particle spaces, after sawdust, according to (Damasceno, 2020). For bed turning, a disc plough is adapted to the tractor.

In Table 2, consumption by fans and tractors was calculated considering the quantity of each machinery that has been used for facility maintenance. To ventilate the bedding area, two fans with 1.49 kW power were used and they were turned on at the maximum power for twelve hours, between 6:00 am and 6:00 pm. After that, fans worked at half-power at night. Thereby, the ventilation system operated 24 hours a day, with different power depending on temperature increases. Daily and monthly consumption was calculated according to these operational activities and finally, total consumption for the research duration (five months) was obtained.

Table 2. Energy consumption of machines before energy analysis

Energy consumption of machines	
Fans	
Reference	HVLS
Number of blades	10
Power (kW)	1.49
Quantity	2
Operating time per day (h)	24
Consumption per day (kWh)	35.76
Consumption night (kWh)	17.88
Monthly consumption (kWh)	1,609.20
Consumption for five months of research (kWh)	8,046
Tractors	
Reference	Massey Ferguson 255
Power (kW)	190.1
Quantity	2
Bed turning time (h)	0.7
Feeder supply time (h)	2
Daily consumption (kWh)	1,026.54
Monthly consumption (kWh)	30,796.20
Consumption for five months of research (kWh)	153,981.00
Total consumption by research duration (kWh)	162,027.00
Fan consumption (%)	4.97
Tractor consumption (%)	95.03

Besides ventilation, it was essential to consider the bed cultivation that occurred two times a day, one in the morning and the other in the afternoon, both after milking operations. The time spent in those labours was 0.7 hours each. During bed cultivation, the second tractor worked on feeding supply, spending 2 hours in the morning, and 2 hours in the afternoon. At the end of the day, the two tractors worked 1.4 hours cultivating the bed and 4 hours feeding the troughs. Likewise, total consumption by tractors was calculated during the research duration. The percentage of energy expenditure coming from machines was represented by 4.97% for fans and 95.03% for tractors. Energy consumption during one working time is shown by Eq. (6), and Eq. (7) shows daily consumption by tractors including morning and afternoon activities.

$$\text{Consumption}_{\text{Tractors}}(\text{kWh}) = (0.7\ \text{h} + 2\ \text{h}) \cdot 190.1\ \text{kW} = 513.27\text{kWh} \quad (6)$$

$$\text{Daily Consumption}_{\text{Tractors}}(\text{kWh}) = (0.7\ \text{h} + 2\ \text{h}) \cdot 190.1\ \text{kW} = \\ = 513.27\ \text{kW} \cdot 2\ = 1{,}026.54\ \text{kWh} \quad (7)$$

Production of waste at the facility. A cow can produce, in confinement spaces, from 5,400 kg to 7,200 kg of faeces and urine. Regarding the cleaning of the milking parlour floor and corrals, it is estimated a production of 100 litres of waste per day per head (Ramos et al., 2014) On the 'Aurora farm', according to the data provided by the producer, there are certain amounts of waste in the different sectors where the cows are kept. For the facility area, 1,577.7 kg was collected, which corresponds to the bedding and the feeding corridor; in the case of the milking parlour, an average of approximately 175 kg have been collected during the year of operation of the confinement system.

DISCUSSION

Alternative approach

According to (FICA, 2013; Gutiérrez & Ibáñez, 2011), there are saving measures that depend on the investment requirement and some techniques can increase energy savings and efficiency on farms without affecting their profitability. Those strategies that do not have an investment cost can be evidenced in the process of modifying the power of fans and tractors or making certain changes in production schedules. Below, we present some alternatives to reduce energy costs on the farm.

Waste production

For this study, proposals of both types are presented, an investment cost that is represented in the production of biogas and recommendations aligned to modifications in the maintenance of the cows' bedding along with adjustments in the daily routine of the farm's milk production. Gutiérrez & Ibáñez (2011), suggested that livestock is one of the subsectors, within the agricultural sector, which can contribute to the reduction of greenhouse gas emissions through the promotion of anaerobic fermentation manure treatment technologies. The first option for the utilization of faeces from livestock farming is the use of organic fertilizer.

Given the above, the use of materials that vary in size is proposed. Large dimensions allow the aeration of the bedding, decrease compaction, and reduce the sources of infection and, on the other hand, dimensions such as those currently used on the farm favour the composting process of the bedding.

According to authors, (Gutiérrez & Ibáñez, 2011; FICA, 2013), livestock farms produce substantial savings when new technologies are used in the facilities, such as the use of renewable energies and the reduction of the carbon footprint. According to (FICA, 2013), by implementing these techniques, energy savings are estimated at a reduction of more than 75% of fuel consumption.

According to numeral 3.2.2, it is fundamental to guarantee the humidity and pH conditions for composting to be conducted adequately. In addition to this, (Jones & Martin, 2003), also proposes a range of temperatures above 45 °C to 60 °C, which is characteristic of microbial activity. In the case of implementing a composting process on the farm, it is necessary to make an analysis of materials and spaces for optimal composting.

Milk production

The variations in the amount of milk produced, established by (Baêta & Souza, 2010) indicate that the month that best defines the concept of thermal comfort of the animal are the months of May and June when Brazil is in the winter and has colder temperatures. However, it is important to note that even when milk production improves at this time, there is a challenge that the producer faces, and that is the conservation of the bedding conditions. In times when the temperature drops, problems of bedding compaction are more likely to occur. This indicates that the frequency with which bedding needs to be changed or maintained increases, and with it, the energy expenditure.

Milk production is often related to the ventilation conditions of the facility. According to (Pressman, 2010) productivity can also be affected by respiratory ailments, mastitis, and reproductive problems of animals resulting from poor building ventilation conditions. Data in Fig. 7 showed the effect of high temperature and relative humidity (Table 1) where cows' ETI at comfort conditions was overtaken, in February and March mainly.

This performance in milk yield can be supported by authors (Kadzere et al., 2002; De Rensis et al., 2015), in which as cows' thermoneutral zone is overtaken by high temperature and relative humidity, energy and nutrients available for reproduction, milk production or growth must be deviated to body temperature regulations which result in milk production losses. Moreover, according to (Kadzere et al., 2002; Gunn et al., 2019) comfort state is influenced by a complex interplay of physical and environmental effects in the physiological functions of the cow that affect not only milk yield but also the efficiency and profitability of dairy enterprises.

Energy analysis

The processes of bedding maintenance and supply, as shown in Table 2, imply an energy consumption of 95.03% of the total percentage of the livestock facility, which allows inferring that almost all the energy investment is in maintaining the bedding in adequate conditions. Among the proposals for energy improvement, Table 3 proposes the inclusion of a fan in the middle part of the bedding area, the use of only one tractor for bed maintenance and the incorporation of the drainage system or an evaporative cooling inclusion. The latter, coupled with ventilation could, according to (Eirich et al., 2015), reduce the effects of heat stress during the summer by improving the heat dissipation of animals by evaporative pathways.

As shown in Table 2, consumption by tractors represents the highest percentage in the economic activity of the 'Aurora Farm'. After identifying the activities carried out by the producer, it was found that the inclusion of one-size material has an impact on some of the microbial processes occurring in the bedding (composting and aeration). Therefore, it is recommended to include material with larger particle diameters that allow for aeration of the bedding and absorption of moisture that is present in the critical points of the bedding. Ensuring these physical conditions, indirectly improves the state of comfort in cows and their milk production, also requires less time spent in ventilation or even a potential reduction in the time it takes the tractor to turn the bedding.

Recommendations of (IDAE, 2010) state that ventilation, in relation to the air speed of the area, is a vitally key factor. The time of the year must be considered; in winter, cold air coming from outside must be prevented from falling directly on the animals, due to the risk of contracting pneumonia. On the contrary, in the summer season, the air should be directed over the animals to increase heat transfer by convection, causing the cows to feel cool. The inclusion of another fan, or even the use of evaporative cooling, would help mitigate heat stress in months with high temperatures such as February and would favor increased milk production.

Table 3. Energy consumption machines after efficiency proposal

Energy consumption of machines - Proposal	
Fans	
Reference	HVLS
Number of blades	10
Power (kW)	1.49
Quantity	3
Operating time per day (h)	24
Consumption per day (kWh)	53.64
Consumption night (kWh)	26.82
Monthly consumption (kWh)	2,413.8
Consumption for five months of research (kWh)	12,069
Tractors	
Reference	Massey Ferguson 255
Power (kW)	190.1
Quantity	1
Bed turning time (h)	0.7
Feeder supply time (h)	2
Daily consumption (kWh)	513.27
Monthly consumption (kWh)	15,398.10
Consumption for five months of research (kWh)	76,990.50
Total consumption by research duration (kWh)	89,059.50
Fan consumption (%)	13.55
Tractor consumption (%)	86.448
Reduction (%)	45.03

In the case of livestock activity, recommendations can be considered such as monitoring the environmental conditions of the sheds to obtain maximum production due to animal welfare; physical improvement, such as the inclusion of curtains on the right side of the facility that is affected by radiation when the sun falls in the afternoon hours, increasing internal temperatures. Other options to be implemented could be the use of colored paints with high radiation reflection and materials that reduce the thermal load of the roof, as shown in (Baêta & Souza, 2010)

The inclusion of another fan, or even the use of evaporative cooling, would help mitigate thermal stress in months with elevated temperatures such as February and would favor increased milk production. In addition, the consumption data gathered according to Table 2, confirmed that the highest energy expenditure in the facility was conditioned using fossil sources, as mentioned Paris et al. (Paris et al., 2022) and as shown in Table 3, reducing the number of tractors would decrease farm consumption by 45.03%, because of using only one tractor for maintenance and supply.

For times when temperatures drop, it is important to reduce the power of the fans to prevent cold air currents from directly affecting animal behaviour. To reduce energy costs some practical strategies could be implemented in the supply area, such as the use of curtains or shadow system (e.g. increasing roof length) where sunset affect directly bedding area, specifically points P3 and P5 according to Fig. 8.

To sum up, correct insulation of a facility leads to significant energy savings, improved livestock comfort and improved conservation of the facilities. However, large investments are not necessary to achieve a decrease in energy costs (FICA, 2013)

CONCLUSIONS

The energy analysis of the Aurora farm shows a 45.03% reduction in energy consumption, proposing a reduction in the use of tractors and linking drainage alternatives, evaporative cooling, and reuse of animal bedding waste.

It is important to clarify that, for the disposal of cow waste, rigorous planning of thermal conditions, humidity, pH, and a design of the composting area according to the physical characteristics of the farm is needed.

This study allowed to present an introduction to how the methodology of the Institute for Energy Diversification and Saving from Spain, focused on energy audits in dairy cow's systems like those existing in Europe, could be implemented in Brazil. This could allow new studies to strengthen the agricultural production systems in terms of energy and economics and to adapt spaces and resources in a more sustainable way to benefit the environment, the production, and the producer. Furthermore, the above research is the benchmark to expand this methodology in more livestock productions in Brazil.

This research had any constraints due to the pandemic situation; it was not possible to track any bedding information in May and overall results were limited to five months. It would be interesting, for the next related research, to apply this methodology for a whole year, to have a thorough tracing of energy consumption, milk yield performance, and waste disposal at the facilities.

Likewise, many topics can be addressed in energy efficiency analysis in livestock systems, such as the identification of unnecessary expenses and economic impact for producers, fuel consumption by machines and how it affects the environment or include a meticulous comparison between fuel and biomass power properties with the intention of reuse plant and animal wastes.

Finally, in animal confinement systems in developing countries, the implementation of the concept of energy audits can be of great help to develop strategies, devices or processes that optimize resources and reduce the energy impact in each of the production chains.

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