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Artículos

# Comfort and energy consumption in a hybrid tunnel-type broiler barn in different bioclimatic zones of Brazil

Confort y consumo energético en galpón híbrido tipo túnel en diferentes zonas bioclimáticas de Brasil

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**Abstract:** Poultry production is influenced directly by its environmental conditions and, therefore, the conditions of comfort, animal welfare, and energy consumption of the facilities. The objective of this study was to carry out an assessment of the acclimatization needs of a negative pressure ventilated broiler barn (hybrid) in 12 Brazilian cities, located in the 8 bioclimatic zones of the country. It was found that cities located in bioclimatic zones 1 and 2 require a higher energy consumption of heating during the chicks phase (0-21 days), while zones 7 and 8 require more energy for cooling during the chickens phase (22-42days). The cities located in zones 3, 4, 5 and 6 present the best comfort conditions and the greatest energy savings for the two phases.

**Keywords:** bioclimate, climate classification, acclimatization, thermal comfort, poultry production.

**Resumen:** La producción avícola está influenciada directamente por sus condiciones ambientales, y por ende, las condiciones de confort, bienestar animal y consumo energético de las instalaciones. El objetivo de este estudio fue realizar una evaluación de las necesidades de climatización para un galpón de presión negativa en modo túnel (hibrido), en 12 ciudades brasileras ubicadas en las 8 zonas bioclimáticas del país. Se encontró que las ciudades ubicadas en las zonas bioclimáticas 1 y 2 requieren mayor consumo de energía para la calefacción durante la primera fase (0-21 días), mientras que las zonas 7 y 8, requieren más energía para enfriamiento durante la segunda fase (22-42 días). Las ciudades ubicadas en las zonas 3, 4, 5 y 6 presentan las mejores condiciones de confort y el mayor ahorro energético para las dos fases.

**Palabras clave:** bioclima, clasificación climática, climatización, confort térmico, producción avícola.

## 1. Introduction

The Brazilian poultry sector has made great efforts in the investment and use of tools to optimize the production of chicken meat [1], and its advances in genetics, nutrition and healthcare are indisputable. However, the great climatic variations in its territory, and sometimes, with facilities that do not favor an adequate ventilation and renewal of the air, can compromise its productivity [2].

The intensive production of chickens is directly influenced by their conditions of comfort and animal welfare. These conditions can cause difficulties to maintain the thermal balance and, therefore, affect the productive performance of the birds[3,4].

Since Brazil has a predominantly warm climate, its poultry industry opted to have facilities with little thermal insulation in side walls (of curtains made of polymeric materials). These facilities use natural ventilation, and making it possible in other cases to use mechanical ventilation (hybrid ventilation systems), that is, opening side curtains for natural ventilation when the external weather allows it [5,6]. This ventilation system reduces the investment costs in its construction, and energy consumption in its operation [7].

This type of facilities have been economical in their construction and to some extent, efficient to solve heat stress problems in adult chickens. However, during the chicks phase (or first phase), there are doubts about whether the lack of lateral thermal insulation compromises the internal environment and its productive performance or not [7-10].

When the birds are in the adult stage during periods with temperatures that oscillate between 10 and 15° C, the producers have generally adopted the practice of closing the curtains to maintain the internal temperature, keeping some openings located in certain points for the renewal of the air. Hygienic ventilation is carried out by means of natural ventilation with the opening of part of the curtains, or with minimal mechanical ventilation systems [11].

This does not mean that in the adult phase the broilers are in permanent comfort conditions. In fact, one of the main factors that negatively interfere in the production of broilers has to do with the high values of dry bulb temperature [3]. Mechanical ventilation (positive or negative pressure) promotes the dissipation of sensible (mainly by forced convection) and latent heats inside the installation.

However, this effect is null when the temperature of the dry bulb is equal to the body temperature of the bird, and there is a need to use evaporative cooling methods. The use of these systems allows the reduction of the temperature of the dry bulb up to 11°C in some regions, particularly in Brazil, the average of this reduction is 6°C [12-14]. The evaporative cooling systems have been used in thermal environmental control applications to improve human, plant and animals comfort conditions [15].

According to [16], only in the regions with climate Af of the Köppen classification (high annual temperature and constantly high humid), evaporative cooling is not recommended. In the other regions, its use is possible with a previous analysis of its temperature reduction potential. This method of air conditioning has as main feature the increase of its efficiency when the temperatures are higher and the climate drier, that is, when the need for temperature reduction and humidification is greater [17-19].

The objective of this study was to analyze the acclimatization needs of a broiler barn with negative pressure ventilation (type tunnel, hybrid) for the production of broilers, in different bioclimatic zones of Brazil.

## 2. Material and methods

The research was developed in 12 Brazilian cities: Curitiba - PR, Chuí - RS, Florianópolis - SC, São Paulo - SP, Brasília - DF, Governador Valadares - MG, Campo Grande - MS, Cuiabá - MT, Petrolina - PE, Salvador - BA, Porto Velho - RO, and Fortaleza - CE, These cities belong to 8 climatic zones of Köppen, located in the 8 bioclimatic zones of Brazil [20]. Table 1 and Fig. 1 present these zones and the area of the country corresponding to each of them.

**Table 1**

Köppen climate classification and bioclimatic zoning for 12 Brazilian cities.

| City | KCC | BZ | BZA |
|---|---|---|---|
| Curitiba PR | Cfb | 1 | 0.8 |
| Chuí RS | Cfa | 2 | 6.4 |
| Florianópolis SC | Cfa | 3 | 6.5 |
| São Paulo SP | Cwa | | |
| Brasilia DF | Aw | 4 | 2.0 |
| Governador Valadares MG | Aw | 5 | 5.6 |
| Campo Grande MS | Aw | 6 | 12.6 |
| Cuiabá MT | Aw | 7 | 12.6 |
| Petrolina PE | Bsh | | |
| Salvador BA | Af | 8 | 53.7 |
| Portovelho RO | Am | | |
| Fortaleza CE | As | | |

Source: Adapted from [20] and [22]
KCC: Köppen climate classification, BZ: bioclimatic zone, BZA: bioclimatic zone area (%).

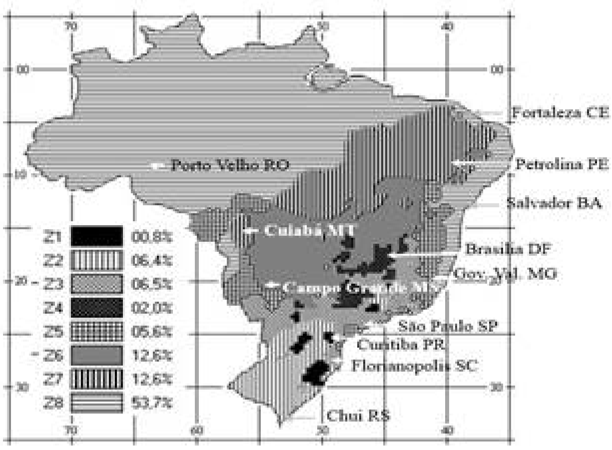


**Figure 1**

The 12 cities selected within Brazilian bioclimatic zoning.

Source: Adapted from [20]

For this study, climatic archives were used with hourly data (8760 data of each variable in .epw format) of each of the cities. These files were taken from [21], based on historical data, and analyzed whit Climate Consultant 6.0 free software.

The type of broiler barn used for this study was extracted from the research carried out by [7]. This type of broiler shed is typical of Latin America, and its use is being extended as a hybrid alternative for naturally and mechanically ventilated poultry houses.

This broiler shed is oriented in east - west direction, with dimensions of 14m wide and 110m long, ceiling height of 2.5m; with an approximate population of chickens of 23,000 Cobb line birds, and coffee husk beds of first use. Fig. 2 shows a scheme of the broiler barn used in this study.

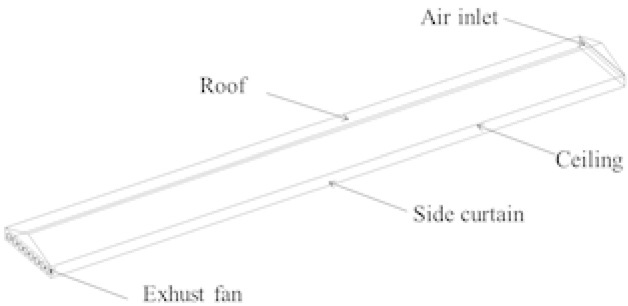


**Figure 2**

Poultry house with negative pressure ventilation in tunnel mode.

Source: Adapted from [7]

As this type of broiler sheds have little thermal insulation, the external environment plays an important role in its performance from the point of view of thermal comfort and energy efficiency.

Thus, the external environmental conditions were evaluated initially from the point of view of animal comfort.

A box plot of the thermal behavior and another for the temperature and humidity index (THI) were made from hourly weather data for each city, in order to observe its thermal behavior, variability and differences. The THI was calculated from the Equation 1 developed by [23].

$$THI = 0.72(T_{db} + T_{wb}) + 40.6 \quad (1)$$

where THI is the temperature and humidity index, dimensionless; $T_{db}$ is the dry bulb temperature, °C; and $T_{wb}$ is the wet bulb temperature, °C.

For the thermal comfort analysis, the ideal values of temperature and THI suggested by [23] are within a range of 68 to 80 for the chicks phase, and from 56.6 to 68 for the adult phase.

The percentage of hours of comfort and thermal stress during the year was calculated for each of the cities. The comfort range for the chicks phase was from 28 to 33°C, and for the adult phase, from 16 to 23°C [24,25].

In order to perform the energy balances of the facility, the thermal properties of the construction materials were considered (Table 2).

**Table 2**
Thermal properties of the construction materials of the hybrid broiler barn.

| Material | A | λ | t | R |
|---|---|---|---|---|
| Fiber cement roof tile | 1635.26 | 0.65 | 0.0040 | 0.01 |
| Roof air chamber | 1636.26 | 0.21 | 1.2000 | 5.71 |
| Ceiling | 1540.00 | 0.04 | 0.0004 | 0.01 |
| Masonry wall | 282.00 | * | 0.1400 | 0.54 |
| Curtain | 492.50 | 0.04 | 0.0004 | 0.01 |
| Floor | 1540.00 | 1.75 | 0.1000 | 0.06 |

Source: Adapted from [26]
A: area (m2), λ: thermal conductivity (W.m-2°C-1), t: thickness (m), R: thermal resistance (m2°C.W-1).

The simplified equations 2 and 3 proposed by [27] were used for the calculation of the energy balances for animal installations. Equations 4 and 5 were used for the calculation of the heat transferred by the construction to the environment and the heat removed by the ventilation. In this case, the external temperature was lower than the internal one.

$$Q_{cal} = Q_{cc} + Q_{ven} - Q_{an} - Q_{il}, \;\; si\; T_e < T_i \qquad (2)$$

$$Q_{ref} = Q_{cc} + Q_{ven} + Q_{an} + Q_{il}, \;\; si\; T_e > T_i \qquad (3)$$

$$Q_{cc} = A.U.(T_i - T_e) \qquad (4)$$

$$Q_{ven} = Cv.\rho.C_p(T_i - T_e) \qquad (5)$$

In these equations, $Q_{cal}$ is the heat required for heating (W), $Q_{ref}$ is the heat to be removed to cool the broiler barn (W), $Q_{cc}$ is the heat transferred by the construction (W), $Q_{ven}$ is the heat removed by ventilation (W), $Q_{an}$ is the heat generated by animals (W), $Q_{il}$ is the heat generated by illumination, and # is the element area (m2). Additionally, U represents the global coefficient of heat transfer ($W.m^{-2}{}^{\circ}C^{-1}$), ## is the ventilation flow ($m^{-3}s^{-1}$), ρ is the density of the air ($kg.m^{-3}$), $c_p$ is the specific heat of the air ($J.kg^{-1}{}^{\circ}C^{-1}$), $T_e$ represents the external temperature (°C) and $T_i$ is the Internal temperature (°C).

The heat generated by the animals ($Q_{an}$) is a function of its body mass (M). For this calculation, equation 6 and 7 proposed by [26] were used, where $Q_{an20°C}$ is the heat generated by animals at 20°C and $Q_{an}$ includes a correction factor for temperature. This calculation was made for the two phases of the life of the birds, taking a mass of 0.07kg for the chicks phase, corresponding to the first week of life, and a mass of 1.5kg for the adult phase, corresponding to the fifth week of life.

$$Q_{an20°c} = 10.62M^{0.75} \qquad (6)$$

$$Q_{an} = Q_{an20°c} + 0.02(Q_{an20°c})(20 - T_i) \qquad (7)$$

From the data of the energy balances, a graphical analysis was carried out of the needs of energy addition (heating) and energy removal (cooling) for the two phases of life of the birds for each of the cities studied.

The indicator gas method was used to calculate the minimum or hygienic ventilation rate [28], using carbon dioxide as a tracer. This method states that when the mass in which the gas is introduced or generated in the installation is known, the mass conservation equation can be used to calculate the rate of ventilation (Eq. 8).

$$niv = \dot{m}_{CO2} \cdot [(m_{CO2\,i} - m_{CO2\,e}).10^{-6}]^{-1} \quad (8)$$

where:

niv: Ventilation rate calculated from $CO_2$ ($m^3h^{-1}$)

$m_{C02}$: $CO_2$ production of animals ($m^3h^{-1}$)

$m_{C02i}$: Concentration of $CO_2$ inside the facility (ppm)

$m_{C02e}$: Concentration of $CO_2$ outside the facility (ppm).

The $CO_2$ generated from animals within the facility was calculated from the heat generated by them ($Q_{an}$ ). According to [28], the production of $CO_2$ is estimated between 0,17 and 0,20 $m^3$/h/ , and the suggested value is 0,185 $m^3$/h/

## 3. Results and discussion

Fig. 3 shows the maximum and minimum external temperatures in the four stations, for the 12 cities analyzed. In the fall and winter periods, the lowest temperatures occur, especially in the subtropical zone, where it can be close to 0°C at night and to 30°C on the day. This variation brings challenges for the bioclimatic handling and the design of the facilities, in order to improve and/or optimize their thermodynamic behavior, especially in these bioclimatic zones (mainly, 1 and 2).

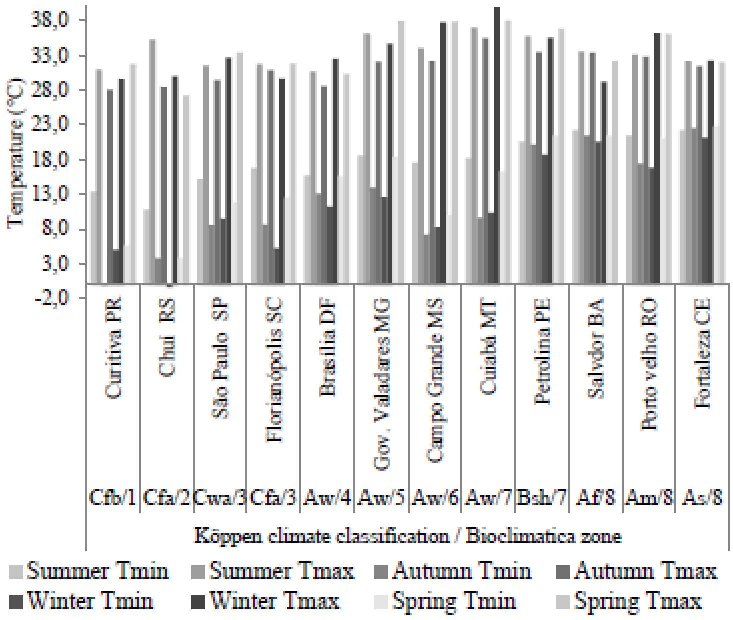


**Figure 3**

Maximum and minimum temperatures in the four seasons.

Source: The Authors.

For the bioclimatic zones 1 and 2, the ideal is to build with materials of high thermal capacity, in order to store energy during the day, and reduce the energy consumption at night, mainly for heating in the chicks phase. The reason is that side walls with curtains are not the best option in these areas, due to their minimal thermal capacity.

Fig. 4 shows a box plot of the behavior of the ambient temperature, based on data of each of the cities analyzed (8760 hourly). It can be observed that the cities of greatest thermal amplitude are located in the subtropical part of Brazil (south), i.e. bioclimatic zones 1 and 2.

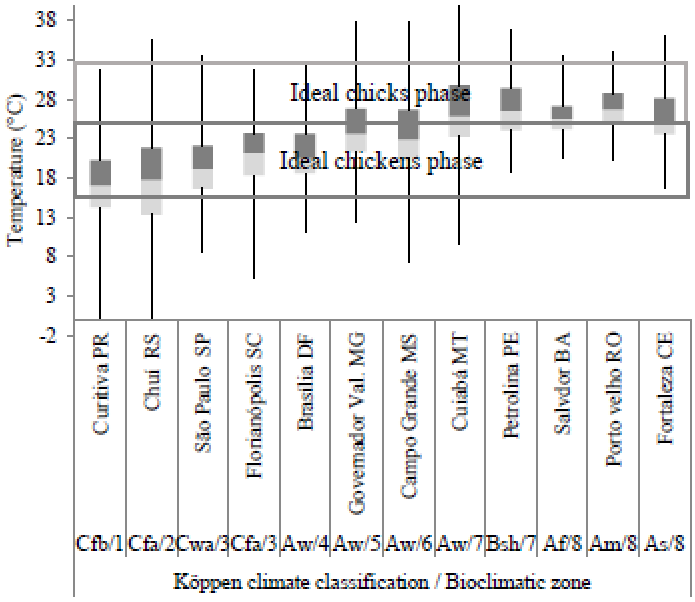


**Figure 4**

Average hourly temperature box plot in the different cities and bioclimatic zones.

Source: The Authors.

The cities with the most stable, warm climate are those located to the north, in the tropical part of Brazil, especially the cities of bioclimatic zones 7 and 8. In all the bioclimatic zones, nights and early mornings are cold for the first phase of the birds (temperatures lower than 28°C), during most of the year.

During the day, in the warmest hours of all the bioclimatic zones, the temperatures are higher than 23 ° C, which indicates that these temperatures can generate heat stress in the final part of the second or adult phase [25].

The THI presents a similar behavior to that of the temperature (Fig. 5), showing a more dispersed behavior in the bioclimatic zones 1 and 2, and a more uniform behavior in the bioclimatic zones 7 and 8. It is observed that the external conditions of the zones 7 and 8 are favorable for the chicks phase, but heat stress conditions predominate in the chickens phase. In general, the most adequate comfort conditions for the second phase are presented in bioclimatic zones 3, 4, 5 and 6.

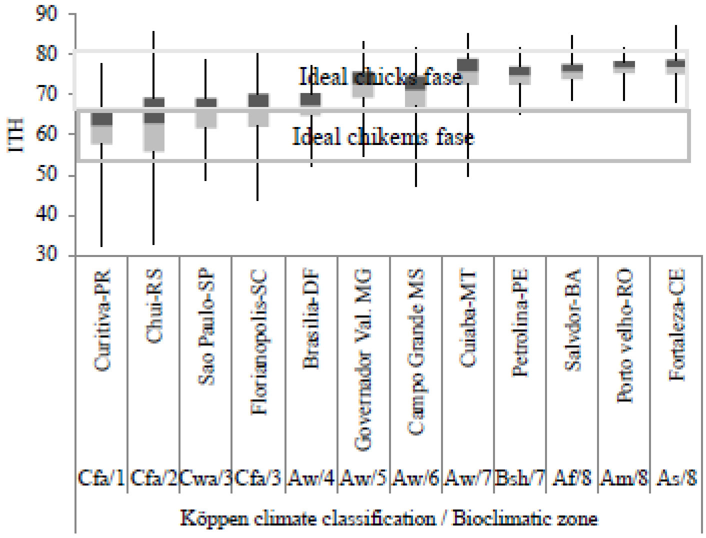


**Figure 5**
Average hourly THI box plot in the different cities and bioclimatic zones.
Source: The Authors.

Table 3 shows the comfort and stress hours of the birds during the chicks and chickens phases throughout the year, based on the external air temperature data. The bioclimatic zones 1 to 4 present the worst conditions of cold stress for the chicks phase, with more than 80% of the time under this condition. However, for chickens, these same cities have better conditions.

**Table 3**
KCC: Köppen climate clasification, BZ: Bioclimatic zone, BZA: bioclimatic zone area (%), C: Confort (%), CS: Cold stress (%), HS: Heat stress (%).

| City | KCC | BZ | *First three weeks* | | | *Weeks 4, 5 and 6* | | |
|---|---|---|---|---|---|---|---|---|
| | | | C | CS | HS | C | CS | HS |
| Curitiva PR | Cfb | 1 | 1,3 | 98,6 | 0,0 | 47,7 | 40,4 | 11,9 |
| Chuí RS | Cfa | 2 | 1,3 | 98,6 | 0,0 | 42,1 | 42,5 | 15,4 |
| São Paulo SP | Cwa | 3 | 3,3 | 96,6 | 0,1 | 60,6 | 19,6 | 19,8 |
| Florianop. SC | Cfa | | 2,4 | 97,6 | 0,0 | 56,4 | 11,7 | 31,9 |
| Brasilia DF | Aw | 4 | 2,3 | 97,7 | 0,0 | 64,9 | 5,5 | 29,57 |
| Gov. Val. MG | Aw | 5 | 16,5 | 82,2 | 1,3 | 40,8 | 1,8 | 57,4 |
| Campo Gr. MS | Aw | 6 | 15,9 | 81,9 | 2,1 | 44,8 | 5,3 | 49,8 |
| Cuiabá MT | Aw | 7 | 25,6 | 65,6 | 8,9 | 21,4 | 1,6 | 77,0 |
| Petrolina PE | Bsh | | 30,3 | 63,5 | 6,2 | 14,1 | 0,0 | 85,9 |
| Salvdor BA | Af | 8 | 17,8 | 82,2 | 0,1 | 7,8 | 0,0 | 92,7 |
| Porto velho RO | Am | | 22,9 | 74,18 | 2,9 | 15,06 | 0,00 | 84,9 |
| Fortaleza CE | As | | 28,3 | 71,68 | 0,0 | 2,17 | 0,00 | 97,8 |

Source: The Authors.

The bioclimatic zones 7 and 8 present the worst heat stress conditions for the chickens phase with more than 75% of the time under this condition. It should be mentioned that, when the external environment provides non-adequate conditions to maintain animal comfort, passive and / or active acclimatization strategies of the broiler barns are required [29].

In general, the bioclimatic zones that present the best external conditions of comfort temperature for broilers are the bioclimatic zones 3, 4, 5 and 6. The foregoing is important, since most of the broiler sheds in Brazil and Latin America are open or have very little thermal insulation on the side walls. These walls are made with curtains, which makes their construction more feasible in these areas.

Fig. 6 shows the energy requirements for the acclimatization of hybrid broiler barns for different cities in the 8 bioclimatic zones of Brazil. There is a greater need for heating energy for the chick phase in the cities of bioclimatic zones 1 and 2, due to the colder periods of autumn and winter than in the rest of the zones. It should be noted that these periods of heating are needed during the night and early morning periods in all the bioclimatic zones, which is in agreement with [8] and [9].

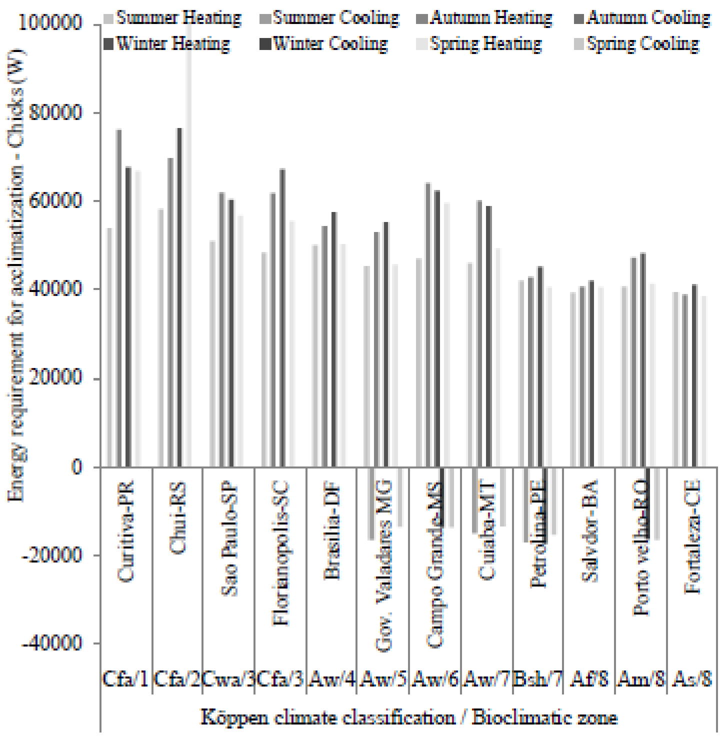


**Figure 6**

Energy requirements for thermal conditioning of hybrid broiler barns in different cities of the 8 bioclimatic zones of Brazil during the first phase.

Source: The Authors.

On the one hand, with regard to the need for thermal conditioning in the chicks phase, the lower energy requirement for ventilation is presented in zones 1 to 4, which are able to use natural ventilation to save energy mainly during the day [5,6,30]. On the other hand, this hybrid broiler barn in the bioclimatic zones 5 to 8, requires mechanical ventilation for thermal conditioning in the chicks phase, especially in the spring and summer seasons.

Fig. 7 shows that, during the chickens phase, it is necessary to remove energy to cool the environment during the day in all the bioclimatic zones (natural and/or mechanical ventilation). In the cities of the bioclimatic zone 8, mechanical ventilation is required during the whole day, and also for the most part at night, due to its always warm environment, demanding greater energy consumption for this purpose. Especially, in the zones of high temperature throughout the day, the use of evaporative cooling systems is feasible, in order to reduce the temperature to values close to the temperature of the wet bulb and thus obtain a higher efficiency [12,13]. It must be considered that this system is only restricted to Af climates (as in the case of Salvador -BA), due to having high relative humidity during the greater part of the year [16].

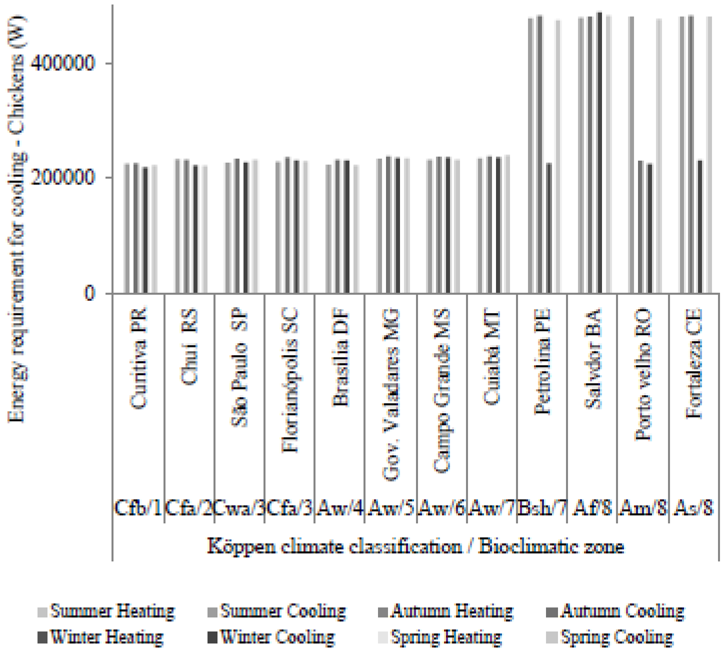


**Figure 7**

Energy requirements for cooling of hybrid broiler barn for different cities in the 8 bioclimatic zones of Brazil during the first phase.

Source: The Authors.

In the second phase, the hybrid operation of the broiler barn is also feasible in some seasons [5,6,30]. For example, mechanical ventilation during the day and natural ventilation at night can be used on summer for bioclimatic zones 3 to 7, and on the spring for zones 6, 7 and 8.

In Brazil, during the chickens phase in cold conditions, producers choose to close the broiler barns and only perform minimum ventilation [11], since the productive performance of the chicken behaves better in "cold" environments. The reason is that the thermoregulatory system is better adapted to retain heat than to dissipate it [13], thus, in general, heating is not done in the adult phase.

In heating conditions in the chicks phase, and when the broiler barn must be closed during the adult phase, due to low temperatures for the animals, the use of minimum or hygienic ventilation is required [2,29].

Minimum ventilation is necessary during the chicks phase at night and early morning in all the bioclimatic zones. For the chickens phase during the autumn, winter and spring, it is necessary in the cold nights and dawns for the bioclimatic zones 1 to 6. In the summer, it is only required in the bioclimatic zones 1 and 2.

The standard NBR 15220-3 [20] suggests some constructive guidelines for the 8 bioclimatic zones. These guidelines are focused on the increase of energy efficiency in air conditioning and human comfort, but this could be applicable to poultry production, and it is necessary to carry out future research on the subject to corroborate this hypothesis. These guidelines suggest that in zones 1, 2 and 3, heat losses must be reduced in the winter with the sun entering the openings (natural ventilation in the day) and with insulating covers, in addition to increase the thermal inertia of construction. This last recommendation would not be possible in this type of hybrid broiler barn, with side curtains.

Besides, the standard NBR 15220-3 [20] proposes for zones 4, 5, 6 y 7 shadow in the openings (or air intakes), thermal insulation of the roof, evaporative cooling and differentiated ventilation during the winter and summer seasons. For zone 8, it formulates the same previous recommendations, adding the need for reflective covers, to reduce the thermal load on the construction [20].

## 4. Conclusions

It was found that the cities located in bioclimatic zones 1 and 2 require greater energy addition for heating during the chicks phase, while zones 7 and 8 are the most demanding in the need of cooling during the chickens phase.

The cities located in zones 3, 4, 5 and 6 present better comfort conditions and greater energy savings for the two phases using a hybrid broiler barn.

Under the Brazilian conditions, it is possible to perform a hybrid ventilation, mechanical and natural, in order to reduce the energy consumption in air conditioning of aviaries, especially in bioclimatic zones 3, 4, 5 and 6.

The standard NBR 15220-3 [20] suggests some constructive guidelines for the 8 bioclimatic zones. These guidelines are focused on the increase of energy efficiency in air conditioning and human comfort, but this could be applicable to poultry production, and it is necessary to carry out future research on the subject to corroborate this hypothesis.

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