Use of multi-agent systems and the Internet of Things to monitor the environment of commercial broiler poultry houses through specific air enthalpy

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3 authors:

Glauber da Rocha Balthazar
University of São Paulo

Robson Mateus Freitas Silveira
University of São Paulo

Iran Oliveira da Silva
University of São Paulo

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Use of multi-agent systems and the Internet of Things to monitor the environment of commercial broiler poultry houses through specific air enthalpy

Glauber da Rocha Balthazar[ab] | Robson Mateus Freitas Silveira[a] | Iran José Oliveira da Silva[a]

[a]Ambience Research Center (NUPEA), Department of Biosystems Engineering - Luiz de Queiroz College of Agriculture, University of São Paulo. Av. Pádua Dias, 11 – CEP 13418-900 – Cx. P. 09 – Piracicaba. Brazil.
[b]Analysis and Development Department, Federal Institute of Education, Science and Technology of São Paulo (IFSP), R. Heitor Lacerda Guedes, 1000-Cidade Satélite Íris, Campinas 13059-581, Brazil.

Abstract The intensive production system for broilers requires the availability of an environment (aviary) that promotes an artificial microclimate that favors both animal well-being and productive performance; therefore, monitoring this environment is critical for production success, especially in tropical countries. This criticality opens up a range of research opportunities for monitoring because of the currently available technologies, especially in the areas of the Internet of Things and Expert Systems. Thus, this study presents a proposal for the environmental monitoring of an aviary using an Internet of Things technological apparatus combined with multi-agent systems to monitor climatic variables with the guidance of thermal comfort indicators. The experiment took place in a Cobb broiler aviary located in the countryside of the State of São Paulo, Brazil. With this objective in mind, the production period of Cobb broilers was analyzed through the construction of an Internet of Things system to collect air temperature, relative humidity, and atmospheric pressure variables combined with a data transfer mechanism for cloud recording. These variables were then analyzed by computational agents using the Java programming language with the Jade framework, which generated animal comfort indicators. The results showed that real-time monitoring of environmental variables is possible with the combination of the Internet of Things with agents that can determine animal comfort conditions according to the specific enthalpy of the air through the orchestration of a deliberative agent and with the participation of several reactive agents.

Keywords: precision livestock farming, computational agents, specific enthalpy air

1. Introduction

Chicken meat is highly appreciated because of its low value for purchase by consumers, especially compared to other animal protein sources, which have the lowest cost (Dias et al 2021). For example, in Brazil, there is a high consumption of 45.27 kg of meat per capita compared to beef (34 kg) and pork (18 kg) (Gov.br 2021). This occurs because its productivity is considered fast and profitable since the animal has a short life cycle (42 days), which allows the delivery of a protein source in a short time (Cobb 2019), which reduces the risk of losses due to production time, as faced in cattle production, for example.

For broiler production in a confined environment, it is necessary to provide an artificial environment (aviary) that is suitable for each productive phase of the animal. This environment is critical because it needs to be monitored and controlled to produce a microclimate that meets the different production phases of chickens to avoid productive losses. This criticality provides great interest for research on the use of multi-agents, as it allows monitoring of the environment through the use of the Internet of Things (IoT) and intelligent systems (ISs). Several studies have used the IoT and ES to monitor this productive environment (Mitkari et al 2019; Abreu et al 2020). This demonstrates the importance and impact of these technological products in this production chain, aiming to reduce costs, bottlenecks, and losses.

This study presents the use of the IoT to monitor an aviary by combining it with an IS based on multi-agent systems (Juchem and Bastos 2001; Wooldridge 2009), where the agents function to monitor this environment according to indices of animal comfort. An agent is characterized as a software entity capable of solving problems through social skills (such as interaction with humans, other agents, and IoT sensors) and with the ability to act and react intelligently (it can make decisions alone through its initiatives), provided that it is guided by the objective of its life purpose (Wooldridge 2009; Juchem and Bastos 2001). Therefore, in this study, a multi-agent system is used (with the presence of an orchestrator agent that exchanges messages with other agents that monitor, through the use of the IoT, the environment in which everyone is inserted) as an autonomous decision-making tool for the company.

Owing to this problem, the objective of this study is to construct an environmental monitoring system for a

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broiler aviary using IoT objects and a computational architecture based on multi-agent systems to monitor conditions according to the productive phases of the animals, aiming at a real-time response of animal thermal comfort. It presents a minimum viable product (MVP) from a) electronic prototyping using a microcontroller and sensors to capture air temperature, relative humidity, and atmospheric pressure signals, transforming them into digital data for transmission over a WiFi network; and b) a computational architecture based on multi-agent systems that can transform the captured data into useful information that demonstrates, through the analysis of the specific enthalpy of the air and according to the production phase, situational reports in real time.

2. Materials and methods

For the development of the aviary environmental monitoring system, a construction method consisting of three stages was established (Figure 1).

Figure 1 Steps of the monitoring system construction method.

The three steps are described below:

1) The IoT device consists of first assembling a set of sensors to capture atmospheric pressure, air temperature, and relative humidity signals from the aviary; second, transforming those signals into digital data using a microcontroller platform; and third, transferring the signals to the cloud through a wireless network.

2) The multi-agent architecture consists of building a hybrid architecture containing both reactive computational agents capable of monitoring air temperature, relative humidity, and atmospheric pressure and a deliberative agent that acts as an orchestrator in asynchronous communication with the other agents to provide further analysis of the environmental conditions of the animal comfort index.

3) The monitoring display consists of the development of a software (web application) that works as an interface between the results produced by the deliberative agent, presenting a real-time response of the aviary condition and an alert signal to the end user.

The microcontroller chosen was the ESP8266 NodeMCU because it has good processing and memory capacity, software and hardware compatibility with the chosen air temperature, atmospheric pressure, relative humidity sensor, and native internet connectivity through a built-in Wi-Fi antenna. The chosen sensor was the BME/P 280 because it has good accuracy in acquiring environmental data, compatibility with the ESP8266 NodeMCU, and an application program interface (API) for programming in the C++ language (Table 1).

Table 1 Electronic devices used in the project.

Name/Manufacturer	Function	Description	Image
ESP8266 NodeMCU Espressif	A microcontroller which can capture and process signals obtained by analog and digital sensors.	Processor Tensilica L106, Clock:80Mhz, RAM: 128kB, Flash: 4Mb	
BME/P 280 BOSCH	Digital sensor module which allows high precision pressure, humidity, and temperature measurements.	Temperature: -40 to 85°C (±1°C), humidity: 0 a 100% (±3%)	

The creation of four agents was proposed for software development: three reactive agents and one deliberative (orchestrator) agent. The agents were used to monitor the air temperature, relative humidity, and atmospheric pressure. The deliberative agent was responsible for orchestrating the communication with the agents, analyzing the data received according to the productive phase (by week) of the chicken (Table 2), and for inserting this information. The choice of reactive agents was due to the environmental variables that serve as monitoring for the environment of broilers; the choice of the deliberative agent was based on the ambience analysis index through the Specific Enthalpy of Air. In this way, the reactive agents simply capture the environmental variables, and the deliberative agent has the intelligence of analysis.

In addition, the deliberative agent calculates the specific enthalpy of air (h) and presents the animal comfort index as a result. Therefore, the model proposed by Rodrigues et al. (2011), presented in Eq. 1, was used.

$$h = 1.006 * t + \left(\frac{RH}{Pa}\right) * 10^{(7.5*t/237.7+t)} * (71.28 + 0.052 * t) \qquad (1)$$

h - enthalpy in kJ kg^{-1} dry air;
t - air temperature in °C;
RH - relative humidity in %;
Pa - atmospheric pressure in mmHg.

Table 2 Productive environmental conditions for broilers.

Age	Air temperature (°C)				Relative humidity (%)	
	Excellent		Critical		Excellent	Critical
	Maximum	Minimum	Maximum	Minimum		
1ª Week	35	33	42	30	60	<40 and >80
2ª Week	33	30	40	25		
3ª Week	30	27	38	23		
4ª Week	27	24	37	20		
5ª Week	25	21	36	17		
6ª Week	24	21	35	15		

Source: Macari and Furlan (2001); Abreu (2011);

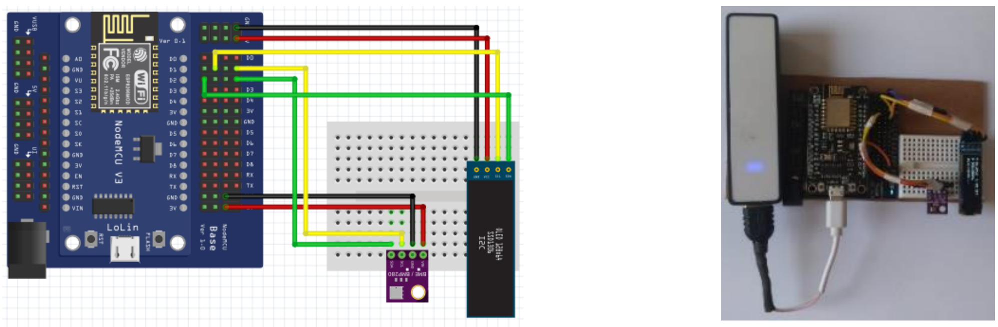
3. Results and discussion

3.1. System prototype

The construction of Step 1 (IoT device) was performed after diagramming the electrical circuit. Subsequently, an algorithm was developed in the C++ programming language to manipulate the BME/P 280 sensor in the ESP8266 NodeMCU microcontroller. In addition, a 0.96' OLED display was inserted to display the data captured by the BME/P 280. Figure 2 shows a drawing of the electrical schematic (Figure 2A) and instantiation of the physical model (Figure 2B). A 2000 mAh PowerBank-type battery was used to power the physical model.

Step 2 (multi-agent architecture) followed the Scrum methodology, in which software artifacts were produced in an interactive and incremental cycle. These artifacts were coded using the Java programming language in the Eclipse Interface Development Environment version 2019-09 R 4.13.0, using the Jade framework in version 4.5.0. For the monitoring interface, a WebService was implemented to receive the data collected by the ESP8266 NodeMCU, and a web interface using a servlet and Java server pages (JSP) was used to visualize the information. This WebService was built in the Java programming language and implemented in a web container supported by Apache TomCat in version 8.5.0 in a private cloud service.

For step 3 (monitoring interface), a web page with the ability to present data from the monitoring of both the reactive and deliberative agents was implemented. The real-time values collected by the IoT device (air temperature, humidity, and atmospheric pressure) and the reaction of the monitoring agents during the third week of production are shown in Figure 3.



(a) (b)

Figure 2 IoT device wiring diagram (a) and physical implementation (b).

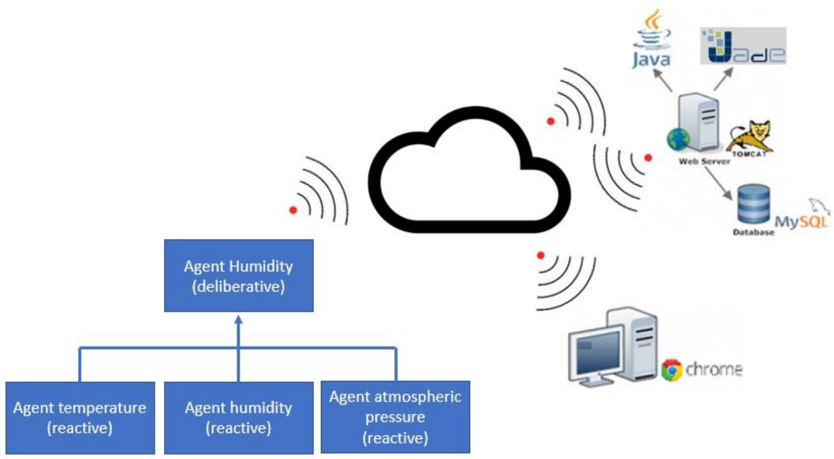


Figure 3 Logical system architecture.

3.2. Field execution

The project was carried out in partnership with a Cobb broiler breeder located in the countryside of the State of São Paulo, Brazil (latitude: –23.0068, longitude: –46.8387, 23° 0 24″ South, 46° 50 19″ West; altitude 771 m; and characterized as having a humid subtropical climate with Köppen-Geiger climate classification: Cfa). The aviary had the following dimensions: 135 m long × 14 m wide × 3 m high, and contained an adiabatic evaporative cooling system (SRAE) and an electronic system to monitor relative air humidity and dry air temperature (inoBram brand, model SMAAI 3 PE). The animals were in the third week of production. Therefore, the parameters of air temperature and relative humidity in the agents were programmed as shown in Table 3.

The specific enthalpy of air was used as a reference to determine the thermal comfort of the animals, and its practical table was used to evaluate the environment of broilers in the third week through the adaptation of Boolean logic made by Castro Júnior (2024), as shown in Table 4.

Table 3 Thermal parameters used in the project.

Air temperature			Humidity		
Excellent	Critical	Attention	Excellent	Critical	Attention
≥ 27 and ≤ 30	≤ 23 and ≥ 38	> 23 and < 27 or > 30 and < 38	≥ 55 and ≤ 65	≤ 40 and ≥ 80	>4 0 and < 55 or > 65 and < 80

Table 4 Enthalpy parameters used in the project.

Enthalpy		
Critical	Attention	Excellent
≤ 48.5 or ≥ 101.4	≥ 48.6 and ≤ 80.0	≥ 80.1 and ≤ 101.3

Source: Castro Júnior (2024)

The IoT device was shipped in a sealed container, taken to the aviary, and positioned at the geometric center, two meters above the ground. It was then powered and connected to a 4G network for data transmission. The readings from the BME/P 280 sensor were performed with an interval of 15 minutes during a period of one week of production (corresponding to the 3rd week of broiler production). In addition, the data collected by the BME/P sensor were compared with the same data collected by the HOBO industrial sensor (model U12-012) to verify whether or not both reliably recorded the same information. Figure 4 shows the sensor inserted into the production environment (aviary).

The air temperature, relative humidity, and atmospheric pressure data collected by the IoT device are transferred to the software and subsequently stored in the MySQL database. When the sensor obtained the data, an agent server (Framework Jade) was initialized to instantiate the agents. Figure 5 shows the graphical interface for instantiating three reactive agents (air temperature, humidity, and atmospheric pressure) and one deliberative agent (agent orchestrator).

Figure 4 IoT device for collecting data in the aviary.

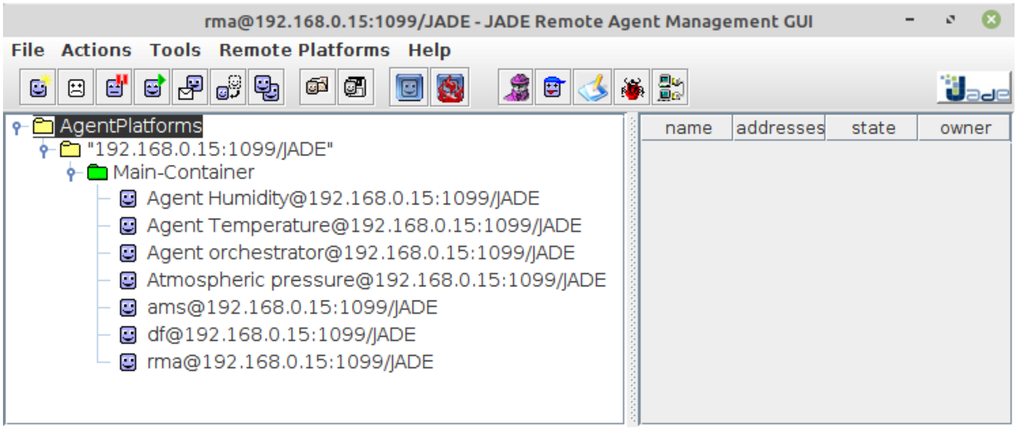


Figure 5 Agent instantiations using Jade.

The management of the agents took place in two ways. The first was the analysis of the internal messages generated by the agents. The second provided a web interface, as shown in Figure 6. This interface presents the real-time values collected by the IoT device and its sensors of air temperature, relative humidity and atmospheric pressure, as well as the reaction of the monitoring agents according to the programmed parameters of the third week of broiler creation (Table 3). Thus, as the IoT device monitored the environment, the agents received this information and displayed their analysis on the website.

3.3. Evaluation

The experiment was carried out in the third week of production, and 591 records of the temperature, humidity, and atmospheric pressure were collected. During this period, the agents analyzed the collected data in real time and recorded their perceptions in the database. This allowed the monitoring and visualization of productive status through the web interface.

The BME/P sensor was calibrated in advance with the Hobo U12-012 certified sensor through statistical analysis, which revealed correlations via the Pearson test and linear regression. The air temperature and relative humidity data collected by the BME/P sensor were analyzed from the data collected by the industrial Hobo sensor using statistical analysis with Pearson's test (p). The test revealed that the air temperature was $p = 0.987$, and the relative humidity was $p = 0.975$. This result corroborates correlated research that points to a strong correlation between the Hobo sensor and sensors similar to the BME/P, such as DHT22, where Leon et al. (2021) presented a correlation of 0.999 and 0.998 (temperature and humidity) and Bayhan and Turhan (2021) a correlation of 0.977 and 0.996 (temperature and humidity), thus ensuring both the effectiveness of the method and the efficiency of the sensors in environmental analysis. The experimental data were statistically analyzed via linear regression, which generated an equation that determined the asymmetry between the environmental variables of the equipment. For air temperature, the equation $y = 1.0018x + 0.1169$ with $R^2 = 0.9984$, and for relative humidity, the equation $y = 1.0003x + 0.0071$ with $R^2 = 0.9998$ was obtained. Both equations were later used to validate the data as a calibration factor between Hobo and BME/P. Figure 7 shows the changes in air temperature and relative humidity over seven days of the third week of rearing.

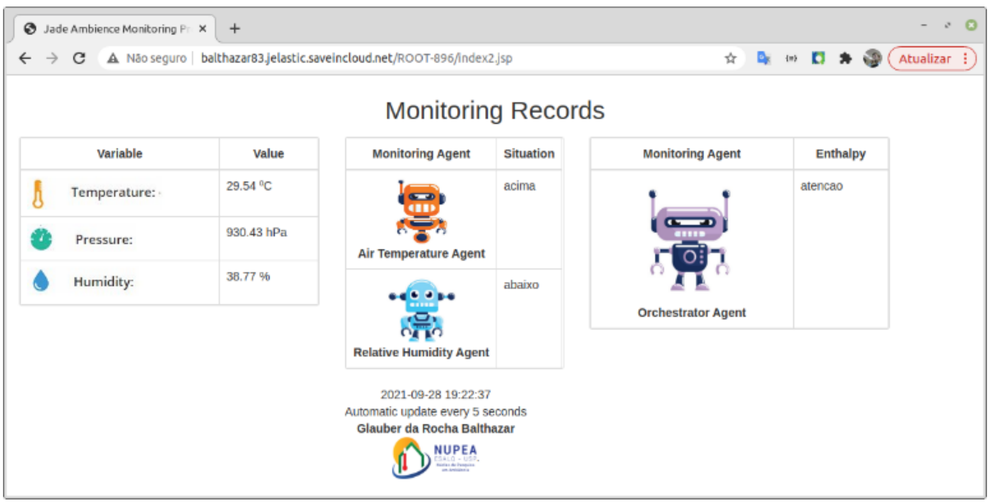


Figure 6 Monitoring web client-side interface.

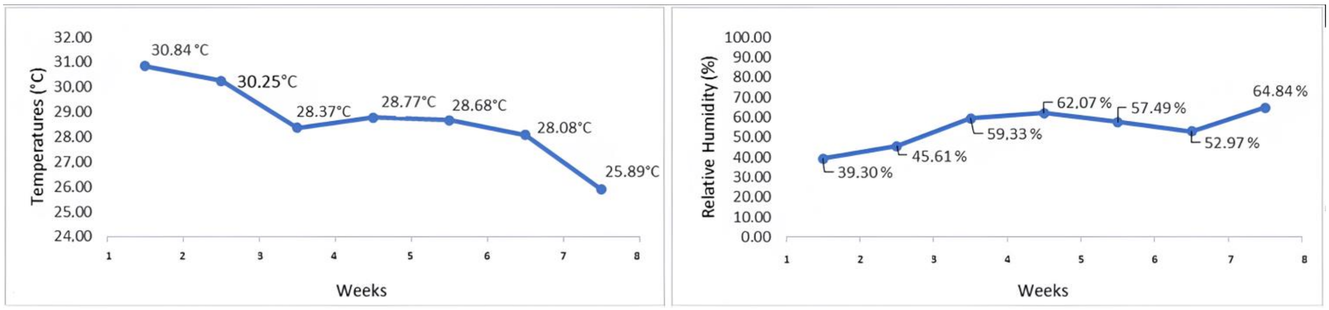


Figure 7 Average air temperature and humidity per day.

The temperature agent identified 272 “EXCELLENT" situations, 308 "ATTENTION" situations, and 11 "CRITICAL” situations, considering that Macari and Furlan (2001) and Abreu (2011) claim that the temperature should be between 24 and 27°C. The humidity agent identified 151 “EXCELLENT" situations, 374 "ATTENTION" situations, and 66 "CRITICAL” situations, considering that Macari and Furlan (2001) and Abreu (2011) claim that the humidity should be approximately 60%. These results are summarized in Figure 8.

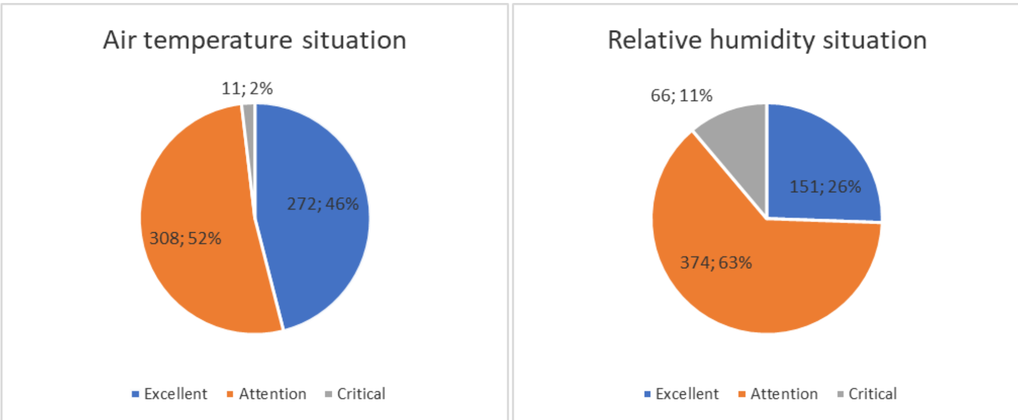


Figure 8 Situations are identified by the reactive agents.

The deliberative agent analyzed the air temperature, relative humidity, and atmospheric pressure datasets based on the specific enthalpy of the air equation and recorded the result of the equation for each set within the established seven-day interval. Thus, a median of 56.65 kcal kg^{-1} of dry air was identified. This value is very close to the 67.0 kcal kg-1 limit presented by the Scientific Committee on Animal Health and Animal Welfare of the European Union (Scahaw 2020). Sakamoto et al. (2020) recommended increasing ventilation, reducing feed supply, water cooling, and using fogging features up to a maximum relative humidity of 80%. Figure 9 shows the median enthalpy per day.

The orchestrating agent identified 6 (1%) “EXCELLENT" situations for the Specific Enthalpy of air, 545 (92%) "ATTENTION", and 40 (7%) "CRITICAL" situations (Figure 10).

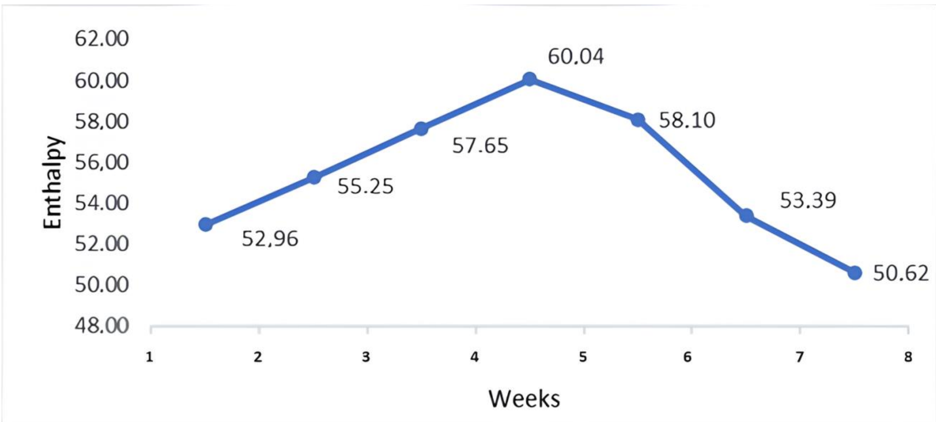


Figure 9 Median daily enthalpy calculated by the deliberative agent (orchestrator).

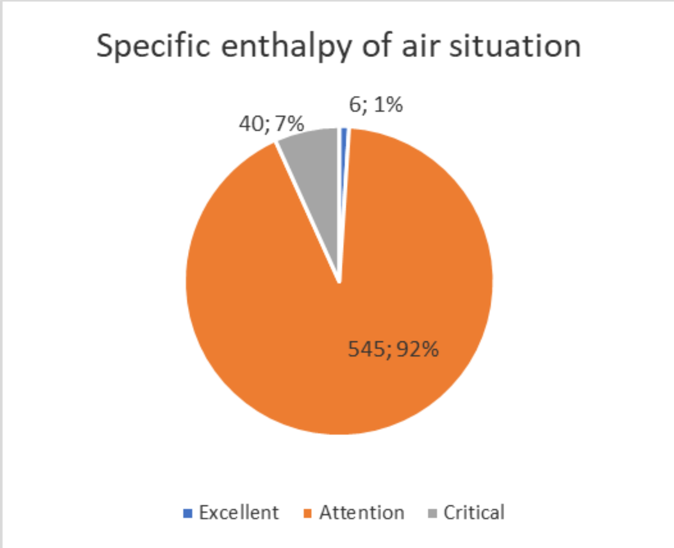


Figure 10 Situations identified by the deliberative agent.

4. Conclusions

The Internet of Things device, configured by the NodeMCU microcontroller and BME/P 280 sensor, satisfactorily performed the acquisition and data transfer tasks.

A comparison of the data collected by the BME/P sensor and the HOBO industrial sensor showed a strong correlation between the variables evaluated (air temperature p=0.999 and relative humidity p=0.998), and the calibration equation presented an R^2 of 99.84% for temperature and 99.98% for humidity, which indicates that both expressed high values in the adjustment between the Hobo device and BME/P.

The framework Jade correctly performed the task of instantiation and management of reactive and deliberative agents. Jade managed the data obtained from the IoT device (through reactive agents) by implementing data manipulation techniques that allowed the deliberative agent to calculate the enthalpy. The results of the deliberative agent fed the data visualization system, which allowed real-time access and understanding of the poultry situation. Decision making became more assertive due to the reliable information that was delivered.

Individually, the agents were able to receive Internet of Things data and analyze it according to embedded intelligence; the deliberative agent identified and qualitatively classified the production environment as a function of the animal comfort index. It was concluded that the proposed IoT device can be used as a tool coupled with intelligent decision-making systems in smart farms.

The results of the data collected and processed by the reactive agents and transformed into the specific enthalpy of air by the deliberative agents were compared with the literature. The data found corresponded with the data defined in the literature, indicating that the system showed fidelity to its proposed objective.

Acknowledgments

All data collected by agents and the source code of IoT applications are freely and openly available and can be used in other research, as long as the authors are maintained and referenced. To gain access, you may contact the authors.

Ethical Considerations

This work was submitted, analyzed and approved by the Ethics Committee in the Use of Animals of the Luiz de Queiroz College Agriculture, University of São Paulo, under protocol number 7364090322. The experiment was carried out in a Cobb broiler aviary located in the interior of the State of São Paulo, Brazil (latitude: –23.0068, longitude: –46.8387, 23° 0 24″ South, 46° 50 19″ West; altitude 771 m; characterized as a humid subtropical climate with Köppen-Geiger climate classification: Cfa).

Conflicts of Interest

The authors declare no conflicts of interest.

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