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Version: Accepted manuscript

HOW TO CITE

Ortega, JA., Losada, E., Besteiro Doval, R., Arango López, T., Ginzo-Villamayor, M.J., Velo Sabín, R, Fernández Rodríguez, MD., Rodriguez Rodríguez, MR. (2018). Validation of an AutoRegressive Integrated Moving Average model for the prediction of animal zone temperature in a weaned piglet building Biosystems Engineering. I74. pp. 231-238. Elsevier.

FUNDING

The authors are grateful to the regional government Xunta de Galicia for funding this research through the "Programme of consolidation and structuring of competitive research units" (GPC2014/072).

Validation of an AutoRegressive Integrated Moving Average Model for the Prediction of Animal Zone Temperature in a Weaned Piglet Building

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Abstract

An AutoRegressive Integrated Moving Average model was validated for the prediction of temperatures in the animal zone of conventional weaned piglet barn. The validation period covered seven cycles and recorded values at 10-min intervals for 292 days. Average weight was 5.75±0.86 kg at the beginning of the production cycle and 18.41±2.12 kg at the end of the cycle. Mean outdoor air temperatures ranged 6.14 to 17.85ºC with deviations in the range 2.49ºC to 5.24ºC, which involved marked differences in the operation of the ventilation system. The Mean Average Percentage Error was below 4%, with a mean error of ≤1ºC. The Root Mean Square Error was in the range 0.77ºC to 1.19ºC, whereas the coefficient of determination ranged between 0.52 and 0.81. Despite the changes in environmental conditions and in animal weight and management, the accuracy of the model remained stable with low dispersion of values.

The model showed good accuracy and reliability covering all the seasons under changing meteorological conditions because it considered the operation of the heating and ventilation systems and changes in animal weight. The residuals obtained from the validation of the seven production cycles were Gaussian distributed, which confirmed the validity of the model. The generated model can be used for more effective environmental control systems that are capable of anticipating events and show a better response, which helps improve energy savings and animal welfare.

Keywords: weaned piglets; *ARIMA*; validation; temperature; indoor climate; livestock buildings.

Nomenclature

ARIMA	AutoRegressive Integrated Moving Average
CFD	Computational Fluid Dynamics
$COV_{X\tilde{X}}$	covariance of X and $\tilde{X}$
d	backshifts for degree of differencing of the *ARIMA* model structure
MAPE	Mean Absolute Percentage Error, %
ME	Mean Error
n	number of records
p	backshifts for lag order of the *ARIMA* model structure
q	backshifts for averaging window of the *ARIMA* model structure
R^2	coefficient of determination
RMSE	Root Mean Square Error
S_{ao}	air outlet section area, m^2
SD	standard deviation

T_{ao}	outdoor air temperature, ºC
T_{az}	animal zone temperature, ºC
V_{ao}	volume of extracted air by the fan, m^3
W_a	body mass of the animals, kg
X_t	value measured at time *t*
$\tilde{X}_t$	value predicted by the model at time *t*
σ_X	standard deviation of *X*
$\sigma_{\tilde{X}}$	standard deviation of $\tilde{X}$

1. Introduction

The increasingly restrictive environmental and animal welfare regulations for the pig industry, along with the increase in energy demand, have significant effects on farm competitiveness and environment. In this context, the productivity of farms must be improved, which calls for an improvement in energy efficiency and animal welfare.

In piggeries, a major effort is required during birth and weaning, which are the most sensitive phases of swine production and the phases with the highest energy requirements (Dolz *et al.*, 2015). Weaning in particular is a sensitive phase characterised by simultaneous stresses including separation from the sow, mixing of litters, and changes in diet and environment (Le Dividich & Herpin, 1994; Dong & Pluske, 2007). During weaning, piglet weight triples over a short period, animal welfare demands are strong, and the climatic demands of the piglets show important variations. Consequently, environmental control systems must be adapted to the growth needs of piglets.

Models for the prediction of environmental variables in diverse scenarios require extensive validation before use. Moreover, the global increase in temperature caused by climate change demands flexible and adaptable models that provide error estimates. Similarly, the increasing need for energy efficiency in buildings demands predictive control systems that include environmental models that can be applied to diverse geographical locations. Accordingly, the validation of indoor environment models becomes essential to ensure the accuracy and robustness of the models, and consequently, their use.

Overall, the literature reveals a lack of validated models for the prediction of environmental variables in livestock buildings. Many models have been developed but not validated at all (Diesch & Froehlich, 1988; Axaopoulos *et al.*, 1992; Lambert *et al.*, 2001; Besteiro *et al.*, 2017). Other models have been validated over short periods, which does not ensure the robustness of the model or the incorporation of the effects of animal growth. For instance, Upachaban *et al.* (2016) validated their model for three days, whereas Liberati and Zappavigna (2007) or Seo *et al.* (2012), used two days for model validation and Daskalov (1997) used only one day. *CFD* model validation requires stable boundary conditions and this can shorten validation times even more. For the model developed by Rojano *et al.* (2016), the total validation time amounted to 26 h 50 min.

Also, most authors do not considere the heterogeneity of the air volume and assume a perfect gas mixture inside the building. To predict the model output variables, these models have often used a probe or selected a specific reference spot inside the building far from the animal occupied zone, in which air volume is a key factor for environmental control. Guo *et al.* (2001) placed humidity and temperature probes at 1.6 m height above the floor, Daskalov (1997), at 1 m height above the floor, and Cooper *et al.* (1998) at 1 m below the roof. Yet, other authors have focused on the animal occupied zone (van Wagenberg & De Leeuw, 2003, Upachaban *et al.*, 2016).

In addition, the input variables are not uniform. Many authors neglected the effects of solar radiation or the contribution of the evaporation of water from manure (Axaopoulos *et al.*, 1992; Lambert *et al.*, 2001).

The goal of this paper is to extensively validate an AutoRegressive Integrated Moving Average (*ARIMA*) model for the prediction of indoor temperature in the animal occupied zone of a conventional pig farm. The model, designed by Besteiro *et al.* (2017), predicts temperature inside a building for weaned piglets in the range 6 to 20 kg live body mass. The model predicts 10-min values and allows for the analysis of complete 40-day rearing cycles, which makes it suitable for use in predictive systems for climate control. Accordingly, the validated model must adapt to the increase in piglet weight and to the changes in the environmental conditions inside the building over the period of interest, which vary from 30 – 32ºC for 5 kg live body mass to 19 – 25ºC for 20 kg live body mass in rooms with plastic slatted floors (Muirhead & Alexander, 1997). The model incorporates predictor variables that are representative of outdoor conditions, operation of the systems and animal weight. The 292-day validation period used allowed for analysis of model accuracy and its robustness. Accuracy was analysed by comparing model-predicted values with real values, whereas robustness was analysed in terms of the capacity of the model to maintain accuracy under different environmental and management conditions.

2. Materials and Methods

2.1 Model

The *ARIMA* method is based on the assumption that past observations can explain the present and future evolution of a time series. In *ARIMA* models, exogenous variables related to the study dependent variable, known as predictor or independent variables, can be incorporated. There are three basic components to an *ARIMA* model: Auto-Regression, Integration and Moving Average. The *ARIMA* model investigated in this paper was designed by Besteiro *et al.* (2017). The model allowed for the prediction of 10-min values of animal zone temperature for a complete production cycle of approximately 6 weeks. The model included the following predictor variables: (1) the outdoor climate, as defined by outdoor air temperature (T_{ao}), (2) the operation of the ventilation system, as defined by air outlet section area (S_{ao}) and volume of extracted air (V_{ao}) and (3) the body mass of the animals (W_a). The most usual models of pig growth show an underlying exponential fit (Wellock *et al.*, 2003; Vincek *et al.*, 2012). Exponential fit was used for the three weighings performed at three different times: when the animals entered the room, when the animals left the room and at an intermediate growth stage, between days 9 and 22, in order to obtain 10-min values of animal body mass.

The model shows a 2,1,2, structure (*p, d, q*), which indicates the highest order of each component, two backshifts for the lag order (*p*), only one backshift for the degree of differencing (*d*) and two backshifts for the averaging window (*q*) of the predicted variable. The model structure shows the maximum backshifts needed for each component of the predicted variable. Table 1 shows the backshifts applied for each component (*p, d, q*) of the study variables. Thus, the series for all the variables have been differentiated from the previous values ($d = 1$). To predict T_{az}, we used the first and second backshifts for the autoregressive component and only one backshift for the moving average component. For the predictor variables, we used the current values and one backshift for the autoregressive component. The moving average was not applied to the predictor variables. From among the models developed by Besteiro *et al.* (2017), Model 4.4 was chosen because it showed a level of significance of 0.055, which allowed for the assumption of the randomness of its residuals at a 95% confidence level. This model was the only model that described the evolution of the variable, insofar as it produced a series of residuals with a structure that was similar to that of Gaussian white noise.

Table 1. Backshifts for each component, lag order (p), degree of differencing (d), and averaging window (q) of the predicted variable, animal zone temperature (T_{az}); p and d of predictor variables outdoor air temperature (T_{ao}), air outlet section area (S_{ao}), volume of extracted air (V_{ao}) and animal body mass (W_a)

Component	T_{az} *(ºC)*	T_{ao} *(ºC)*	S_{ao} *(cm²)*	V_{ao} *(m³)*	W_a *(kg)*
p	1	0	0	1	0
	2	1	-	-	-
d	1	1	1	1	1
q	1	-	-	-	-

2.2 Experimental test

To obtain the variables required for model validation, experiments were conducted on a commercial pig farm located in Northwest Spain (ED50: 43º10’15’’N 8º 19’ 24’’ W). The farm, which housed weaned piglets of 20 kg live body mass, was representative of the type of farm found in the study area.

The weaner room, with an area of 69.26 m^2 and a volume of 164.50 m^3, consisted of twelve 2.55 × 1.97 m pens, six on each side of a central aisle. The room was capable of holding a maximum of 300 piglets; in this case, commercial hybrids obtained by mating a Landrance-Large White F1 sow with a German Piétrain boar. The room had completely slatted plastic flooring over a 450 mm deep pit. The ventilation system was composed of a 500 mm helical extractor fan with 480 W power and an outlet section area of 0.20 m^2. Fan speed was adjusted by changing the voltage using a digital controller based on temperature. The air outlet section area was modulated by two manually-operated sliding panels according to the age of the animal. Fresh air entered the room through two 0.70 m^2 windows with air deflectors. The water underfloor heating system was composed of two 1.20 × 0.50 m polyester spreader plates for water.

To validate the model, seven production cycles with an average duration of 41.71 days were used between the 21st of November, 2011 and the 20th of May, 2013 (Table 2), which did not include the periods used to design the model. The following variables were measured: T_{az}, T_{ao}, S_{ao}, V_{ao} and W_a.

Temperatures were measured using an S-THB-M002 sensor (Onset Computer Corporation©, Bourne, MA, USA). Speed of the air extracted through the ventilation system was measured using a HD2903TTC310 (Delta Ohm, Caselle, PD, Italy) active air speed transmitter (Besteiro et al, 2017). Volume of extracted air was calculated from air velocity and fan section according to the method proposed by Hinz and Linke (1998). These variables were sampled every second and recorded at 10-min intervals. Live mass of the animals was obtained by applying the exponential growth model (Nóvak et al, 2014, Vincek et al, 2012) using the three weighings performed along the cycle.

2.3 Statistical analysis

To determine the accuracy and robustness of the model, the differences between measured and predicted values were analysed for each validated cycle using a number of statistics. The following statistics were used to determine the accuracy of the model:

- Mean Average Percentage Error (*MAPE*):

$$MAPE = \frac{\sum_{t=0}^{t} \frac{|X_t - \tilde{X}_t| \cdot 100}{X_t}}{n} \qquad (1)$$

where: X_t is the value measured at time *t*, $\tilde{X}_t$ is the value predicted by the model at time *t* and n is the number of records.

- Mean error (*ME*)

$$ME = \frac{\sum_{t=0}^{t} (X_t - \tilde{X}_t)}{n} \qquad (2)$$

- Root mean square error (*RMSE*):

$$RMSE = \sqrt{\frac{\sum_{t=0}^{t} (X_t - \tilde{X}_t)^2}{n}} \qquad (3)$$

- Coefficient of determination (R^2)

$$R^2 = \frac{\left(cov_{X\tilde{X}}\right)^2}{\sigma_X{}^2 \sigma_{\tilde{X}}{}^2} \qquad (4)$$

where: $COV_{X\tilde{X}}$ is the covariance of *X* and $\tilde{X}$, σ_X is the standard deviation of *X*, and $\sigma_{\tilde{X}}$ is the standard deviation of $\tilde{X}$.

The parameters and structure of the *ARIMA* model were estimated using the Expert Modeler module included in SPSS Statistics 19 (SPSS Inc., Chicago, IL, USA).

3. Results

Table 2 shows the means and standard deviations of 10-min measurements of the predictor variables for each validated cycle, namely outdoor air temperature (T_{ao}), air outlet section area (S_{ao}), volume of extracted air (V_{ao}) and animal weight (W_a). Mean outdoor air temperatures were in the range 6.14 to 17.85ºC with deviations between 2.49ºC and 5.24ºC. Such variations involved marked differences in the operation of the ventilation system, with air outlet section areas between 0.080789 m^2 and 0.173724 m^2, and a mean volume of extracted air between 110.45 and 457.85 m^3. Volume values were sampled at 10-min intervals. The average body mass of piglets was 5.75±0.86 kg at the beginning of the cycle and 18.41±2.12 kg at the end of the cycle, with an average daily gain of 0.300±0.038 kg day^{-1}.

Table 2. Cycle number, cycle dates and durations, and mean and standard deviation (*SD*) values of 10-min data of outdoor air temperature (T_{ao}), air outlet section area (S_{ao}) and volume of extracted air (V_{ao})

Cycle	*Animal entry date*	*Cycle duration* (d)	T_{ao} (ºC)		S_{ao} (m^2)		V_{ao} (m^3)	
			Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
1	21/11/2011	43	8.86	2.49	0.080789	0.044055	110.45	54.03
2	09/01/2012	43	6.14	3.16	0.093501	0.056685	145.16	75.58
3	27/02/2012	38	11.38	5.24	0.125439	0.043898	221.21	224.46
4	12/04/2012	40	10.43	4.35	0.090795	0.058367	171.15	161.98
5	31/05/2012	44	15.58	4.37	0.168623	0.095329	457.85	420.53
6	19/07/2012	44	17.85	4.12	0.173724	0.093626	397.59	354.69
7	11/04/2013	40	10.38	4.22	0.151489	0.082696	204.04	138.23

Validation of the model for the different cycles showed high accuracy (Table 3). *MAPE* values were low, always below 4%, with a *ME* of ≤1ºC. The *RMSE* values for the different cycles were between 0.77ºC for cycle 7 and 1.19ºC for cycle 2, and maintained an average accuracy of 0.99ºC throughout the validated cycles. The coefficient of determination ranged from 0.52 for cycle 1 to 0.81 for cycle 7. The analysis of the variability of accuracy for the different cycles revealed that accuracy remained stable and with low dispersion of values despite environmental and management changes.

Table 3. Errors obtained from cycle validation for animal-zone temperature. Mean Absolute Percentage Error (*MAPE*), Mean Error (*ME*), Root Mean Square Error (*RMSE*) and coefficient of determination (R^2)

Cycle	*MAPE (%)*	*ME (ºC)*	*RMSE (ºC)*	R^2
1	2.62	0.46	0.86	0.52
2	3.82	1.01	1.19	0.77
3	3.32	0.85	1.11	0.64
4	2.27	0.15	0.78	0.72
5	3.48	-0.58	1.13	0.72
6	3.26	-0.48	1.09	0.71
7	2.39	-0.05	0.77	0.81

4. Discussion

Most of the models for the prediction of indoor environment variables inside livestock buildings found in the literature are aimed at estimating the ventilation rate needed to obtain suitable values of temperature, relative humidity and pollutant concentrations. To date, models for the prediction of indoor temperature have been seldom validated.

The statistical model designed by Daskalov (1997) for weaned piglet buildings with natural ventilation measured temperatures at 1 m above the floor and obtained an *ME* of 1.12ºC. Compared to this value, the values reported in this paper are in the range -0.05 to 1.01º and therefore offer a substantial improvement. The model validation conducted by Daskalov (1997) used 720 records that consisted of average temperatures measured at

2-min intervals during three 8-h experiments carried out in winter, summer and spring, which amounted to 24 h of discontinuous measurements. By contrast, this model covers seven complete production cycles that amount to 292 d.

Schauberger and Pilati (1998) validated an analytical model for temperature estimation based on steady-state balances of sensible heat, humidity and CO_2. Such models have been widely used to calculate air exchange rates (Blanes & Pedersen, 2005; Garcimartín *et al.*, 2007; Samer *et al.*, 2011). Schauberger and Pilati (1998) used the hourly average indoor temperature values recorded in a cattle building with natural ventilation over 51 d. An *ME* of -1.40ºC was obtained, with an overestimation of indoor temperature, which is in agreement with our results for cycles 5, 6 and 7, but with a greater magnitude of error.

Other authors have proposed analytical methods for indoor temperature predictions that rigorously analysed the variables included in the model. Cooper *et al.* (1998) developed a model to calculate hourly steady-state heat balances in naturally ventilated livestock buildings, but neglected animal heat. Average temperatures were measured at nine locations at a height of 1 m below the roof. To validate the model, 168 records were used. The mean absolute error was 0.41ºC, with a magnitude similar to that of the values reported here. Yet, the validation was performed in a building with good natural ventilation using fewer records.

Van Wagenberg *et al.* (2004) focused on the animal occupied zone in a pig building with forced ventilation. They measured temperature at 10-min intervals at 0.15 m height and 0.05 m distance from the pen partitions, such that sensor location was very similar to the locations used in our study. The numerical model was validated for three hours, one hour a day, with piglets of an approximate average body weight of 13.10 kg. The *ME* reported by van Wagenberg *et al.* (2004) for the validation of the model was 0.83ºC, which is close to the maximum errors obtained for complete cycles in our validation.

The *CFD* model proposed by Seo *et al.* (2012) measured temperature at 1 m above the floor in a commercial pig building with forced ventilation that housed pigs from 20 to 50 kg live body mass. A 20-h validation of the model yielded an *ME* of -0.68ºC and an *MAPE* of -4.4%. Also, Rojano *et al.* (2016) developed a computational model of thermal gradient for a naturally ventilated poultry house. The experimental and simulated datasets contained 90 values obtained at 15 locations with 6 measurements each. Results yielded *RMSE* values between 0.5 and 1.3ºC. In both models, the validation period required stable outside conditions. These simulations provide a large amount of data about the building, but do not allow for the estimation of temperatures for long periods because of the large amount of data points to be processed.

Upachaban *et al.* (2016) validated a physical heat and moisture balance model for three days and compared the predicted temperatures with the temperatures measured at 0.3 m height at three locations along a closed-poultry house. The results showed *RMSE* values between 0.46 and 1.77ºC, which is in agreement with the results reported in this paper.

The validations of the reviewed models were performed for very short periods and, generally, using discontinuous measurements. In contrast, our model was validated for 292 d, using over 36 000 records of continuous measurements. Except for the models developed by van Wagenberg *et al.* (2004) and Upachaban *et al.* (2016), the aim of the models discussed was to predict indoor temperature outside the animal occupied zone. However, prediction of indoor temperatures is more meaningful in the animal occupied zone where suitable conditions for growth need to be guaranteed.

Predictions in our model are based on previous data of indoor temperature and the predictor variables, namely outdoor air temperature, outlet section area, volume of extracted air and animal weigh, which can be easily measured. In addition, this method is applicable because determining the values of these variables is a part of farm management routines. In addition, model validation during 7 cycles under different environmental conditions, management regimes and animal live periods guarantees the robustness and accuracy of the model.

Also, the model can adapt to the substantial variations in the environmental requirements observed during this stage of breeding (Le Dividich & Herpin, 1994; Dong & Pluske, 2007), which result from the increase in animal weight in a very short time (e.g. 6 weeks). Finally, this dynamic, rapid-response model (10-min) is highly useful for the analysis and optimization of ventilation and heating systems, in spite of the higher inertia of heating.

It should be noted that the model investigated here has been designed for one particular barn set-up in one particular set of climatic challenges, which limits its use to only the validation conditions. However, *ARIMA* modelling can be used to obtain reliable models for buildings with other facilities or under other climatic conditions using similar predictors (outside temperature, ventilation and animal weight).

The generation of our model provides a 0.55 level of significance for the Ljung-Box statistic, which allows for the assumption of the randomness of its residuals at 95%

confidence level (Besteiro *et al.*, 2017). As a result of error randomness, no clear trends were found for the errors in predictions. For instance, during the first period, both underestimations (cycles 2, 3, 4) and overestimations (cycles 1, 5, 6) are found (*Fig. 1*). Important temperature changes (*Fig. 2.*) often result in underestimations, particularly under high temperatures (Cycle 4), but also in overestimations (Cycle 5) or good fits (Cycle 7). Similarly, different responses have been observed under slight temperature changes (*Fig. 3*). Consequently, analyzing the errors becomes essential.

According to the graphical analysis of the distributions of residuals obtained from model validation, residuals tend to be Gaussian (normally) distributed, although the distributions obtained from prediction residuals are not identical to those of Gaussian white noise (*Fig. 4*). The *ME* values suggest that the distributions of residuals for the cycles with average temperatures (cycles 4 and 7) are almost centred on zero. By contrast, during the cold cycles (1 and 2), the distribution of histograms was skewed to the right, *i.e.,* temperature is underestimated (positive *ME*), whereas during the warm cycles (6 and 7), the distribution is skewed to the left (negative *ME*). Accordingly, there appears to be some dependence between residuals and outdoor temperature, which in turn affects the operation of the ventilation system, both included as predictor variables in the model. However, overall the errors were quite symmetrically distributed. For cycles 2 and 6, the central area of the histogram is slightly skewed. This behaviour is more frequent for the values near and below the mean.

5. Conclusion

The statistical model validated in this paper provides a relevant improvement in terms of accuracy and reliability compared to the existing models because of its extensive and continuous validation under changing meteorological conditions and because it considers the operation of the heating and ventilation systems, as well as changes due to animal body mass. However, the model predicts only the temperature of the building, whereas numerical models can provide a more detailed description under stable conditions for short periods. The residuals obtained from the validation of the seven production cycles can be considered to be Gaussian (normally) distributed, which confirms the validity of the model. The generated model can be used in more effective environmental control systems that are capable of anticipating events and show a better response, which can improve energy savings and animal welfare.

Acknowledgment

The authors are grateful to the regional government Xunta de Galicia for funding this research through the "Programme of consolidation and structuring of competitive research units" (GPC2014/072).

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Figure Captions

Fig. 1. Measured (discontinuous) and simulated (continuous) temperatures in the animal zone for the first three days

Fig. 2. Measured (discontinuous) and simulated (continuous) temperatures in the animal zone for periods with important temperature changes

Fig. 3. Measured (discontinuous) and simulated (continuous) temperatures in the animal zone for periods with slight temperature changes

Fig. 4. Distribution of residuals of temperature in the animal zone (ºC) for the validated production cycles