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TECHNICAL NOTE: DESIGN OF A LARGE VARIABLE TEMPERATURE CHAMBER FOR HEAT STRESS STUDIES IN RABBITS

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Abstract: One of the major constraint factors for rabbit production consists of the environmental conditions and especially high temperatures that negatively affect reproduction and growth performance. For this reason, several studies have addressed the effects of heat stress and possible solutions to alleviate its impact on rabbit performance. This article describes the design and operating features of a large temperature chamber (13×4.7×3.1 m) configured to house 42 rabbits. The probes consisted of temperature sensor model DS2438 and humidity sensor model HIH-5031. The system was controlled by an Arduino platform programmed by its Integrated Development Environment (IDE) software. The system takes a decision every minute: it connects the heating if the temperature is lower than programmed and connects exhaust fans if the temperature is over the programmed setting. To renew the indoor air, every 5 min the system switches off the heating and switches on the exhaust fans for 15 s. Two experiments (with and without animals) were carried out to test the temperature control accuracy. Firstly, without animals, 2 tests were performed: (i) adjusting the temperature of the climatic chamber to the control house temperature plus 10°C and (ii) based on daily minimum (32°C) and maximum (37°C) temperatures. Secondly, with animals, does were maintained (i) between a daily minimum (32°C) and maximum (37°C) for 48 h and (ii) between a daily minimum (25°C) and maximum (35°C) temperatures for 105 d. Mortality rates were noted in both tests. The results of comparing the measured temperature deviation from programmed temperature reported a coefficient of determination of 0.9850 and 0.9947, for plus 10°C and 32-37°C curves, respectively. In the animal tests, the determination coefficients were 0.9926 and 0.9928 for programmed curve in the range of 32 to 37°C and 0.9859, 0.9900 and 0.9901 for programmed curve in the range of 25 to 35°C. Survival of females in the temperature chamber was as expected for reproductive rabbit does: 100 and 82% in the 2 and 105 d trials, respectively. Results indicate that the chamber provided precise temperature control for the development of heat stress studies in rabbits.

Key Words: heat stress, rabbit does, climatic chamber.

INTRODUCTION

Rabbit meat production has traditionally been typical of Mediterranean countries located in temperate (mainly southern Europe countries) and warm areas (mainly North Africa countries). In addition, in recent decades rabbit production has risen in many developing countries (such as China, Mexico, Egypt, Nigeria, etc.), most of them located in temperate, subtropical and tropical climate areas (Pascual and Cervera, 2010). In comparison to other species where environmental conditions are widely controlled (poultry, hens, etc.), rabbit production is characterised by the

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heterogeneity of its farming systems. Rational rabbit production therefore includes farms ranging from those with a high level of environmental control to semi-open and even open-air housing systems, where animals are highly exposed to climate changes.

One of the major constraining factors for rabbit production is the environmental conditions (Fernández-Carmona and Cervera, 2010), especially high temperatures, which negatively affect reproduction and growth performance (Maertens and De Groote, 1990; Chiericato *et al.*, 1992; Fernández-Carmona *et al.*, 2003; Yassein *et al.*, 2008; Oseni and Ajayi, 2010). For this reason, several works have focused on evaluating heat stress effects and possible solutions to alleviate their impact on rabbit performance. However, most of them were carried out by comparing the results obtained in different seasons [e.g. reproductive rabbit does (Marai *et al.*, 2002), growing rabbits (Lebas and Ouhayoun, 1987; Frangiadaki *et al.*, 2003), and rabbit males (Pascual *et al.*, 2004)]. Other studies have been done using a climatic chamber where temperature (around 30°C) was maintained constant (Fernández-Carmona *et al.*, 1995:2003; Cervera *et al.*, 1997; Amici *et al.*, 1998; Zeferino *et al.*, 2011), or for few minutes 42°C (Amici *et al.*, 2000). Large environmental chambers have previously been designed for dairy cattle (Lefcourt *et al.*, 2001; Powell *et al.*, 2007).

Thus, the main aim of this work was to develop a dynamic control system to simulate daily temperature variations in a climatic chamber, which may be used for further coetaneous comparison.

MATERIALS AND METHODS

The Ethics and Animal Welfare Committee of the Universitat Politècnica de València approved this study. All animals were handled according to the principles of animal care published by Spanish Royal Decree 1201/2005 (BOE, 2005; BOE = Official Spanish State Gazette).

Chamber layout

An overview of the chamber infrastructure is shown in Figure 1. The internal dimensions of the chamber are 13×4.7×3.1 m high, and it contains approximately 175 m^3 of air space. Mass air

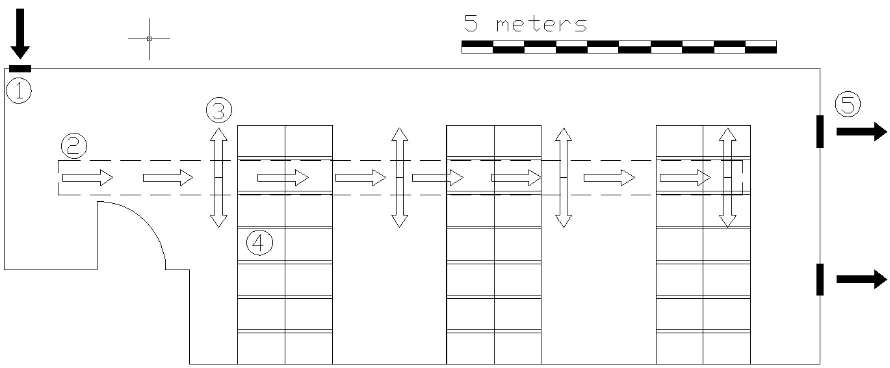

Figure 1: Schematic diagram of chamber: ① Outdoor inlet air (50×110 cm) ② Hot ceiling duct (35×70 cm) ③ Eight hot air outlets (20×50 cm) ④ One of the 42 rabbit cages (75×50×30 cm) ⑤ Exhaust fan (50 cm in diameter).

flow enters the chamber intake through one hole in the wall of 0.5×1.1 m and exhaust through 2 fans (230 V, 1-phase, and 50 Hz, 1.05 A and 240 W, Canenco 25M-450). The chamber was designed to allow volumetric air flows of 6248 m^3/h. Heating air enters the chamber through one (35×70 cm) ceiling duct that runs longitudinally along the edge of the chamber, while the hot air exits across the chamber through eight 20×50 cm holes in the duct system as shown in Figure 1. The electric resistance heating consisted of two 9 kW batteries, each with Klison thermal protection. The chamber contains 42 cages for rabbits (75×50×30 cm high) distributed as shown in Figure 1.

Description of probes: characteristics and installation

A 1-Wire bus was selected for simplicity and to permit high cable lengths. Each probe (Figure 2) contained a small-outline integrated circuit (SOIC) temperature sensor, model DS2438 (Maxim Integrated Products, Inc.) with an accuracy of ±2°C and an integrated circuitry humidity sensor (HIH-5031, Honeywell International, Inc.) with an accuracy of ±2.5 % relative humidity (RH). This SOIC is designed for on-chip measurement of battery temperature and voltage. Probes were calibrated prior to installation as described in a previous study (García-Diego and Zarzo, 2010).

Three electrical wires come out from each probe: one for 5 volt DC power supply, one for 1-Wire data transfer and one wire for ground. According to the recommendations of the 1-Wire manufacturer (Maxim Integrated Products, 2008) the installation was carried out using 4-pair Ethernet copper plated wires (category 6 cable) with a diameter of 0.5 mm, based on a linear wire configuration. This type of setup is supposed to be more robust, according to the manufacturer. The variability of incoming voltage was taken into account to make the appropriate corrections in transforming the sensor readings into RH values, using the formula suggested by the manufacturer.

Three probes were situated over the rabbit cages at a distance of 30 cm in the middle of the 3 pairs of cage rows (Figure 1). The inside temperature and RH were taken as the mean of the 3 probes. Another probe was situated in the same position in the control farm and a final one was located outside the farm.

Control system design

The Arduino electronics prototyping platform was selected to control this system because it is an open-source flexible microcontroller, easier to program and with an altruistic web community devoted to providing and spreading programming examples. The driver DS2482-100 was chosen to manage the 1-Wire bus. This chip transforms the communication protocol I2C (easily generated by Arduino through its Wire library) into a 1-Wire protocol. Data were saved in a USB memory by means of a VDIP1 module from Future Technology Devices Intl. Ltd. This module comprises a microcontroller that manages the protocol to open, close, save, create or delete files, using short commands similar to those of MS-DOS. These commands are transmitted from the Arduino platform to the module through the microcontroller serial port. As the Arduino needs to know the time, a I2C, real time clock (RTC) ds1307 was added to the system.

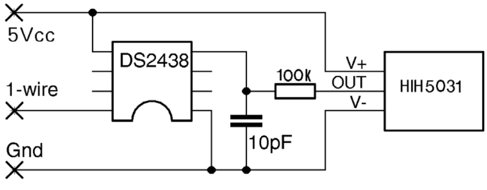

Figure 2: Humidity sensor HIH5031, temperature and analog to digital converter DS2438.

To program the Arduino we used its own free and open software called IDE; this environment is written in Java and based on Processing, AVR-GCC and other open source software and uses a language similar to C or C + +. The system takes a decision every time the minute changes. The program reads the real time minute of the day and connects the heating if the temperature is lower than the programmed setting and connects ventilation if the temperature is over the programmed level plus 0.5°C. The electric heating resistances are switched on for only 20 s per min when the heating system is working, to prevent deterioration of these resistances and move the air to achieve an equal distribution of temperatures. To change the indoor air, every 5 min the system switches off the heating and turns on the extractor ventilation for 15 s to force fresh air in. Every minute, the system saves a line in a file called MIN.txt which is a CSV comma separated file that can be opened with most common spreadsheets (e.g. Microsoft Excel or OpenOffice Calc). As this could be a large amount of data, it was decided to save another file called MEDIA.txt with the mean of every 10 min. Each line of both files contains the date, time, temperature and RH of the chamber, the outside and the control farm.

Experimental design

System test: The 1st test was performed to adjust the temperature using the temperature of the control farm as reference. In this test, the climatic chamber temperature was the conventional room temperature plus 10°C. This curve was tested to try a constant difference of temperature between both houses (Figure 3). The next test was performed to study the daily minimum (32°C) and maximum (37°C) temperatures according to a sinusoidal curve (Figure 4) as typical curve of the inside of a farm where temperatures reached a maximum during the day and a minimum at night. In both tests, the measured temperature deviation from programmed temperature was analysed, applying a linear regression to compare results.

Animal test: Two tests were done with animals. Firstly, 16 multiparous rabbit does were housed as in the previous experiment but maintained between 32-37°C according to the previously tested sinusoidal curve for 48 h. This temperature was lower than the maximum limit of rabbit tolerance (Matheron and Martial, 1981). Linear regression between programmed and real temperatures of the chamber throughout the day was performed, determining the equation and coefficient of determination (R^2). Mortality was recorded.

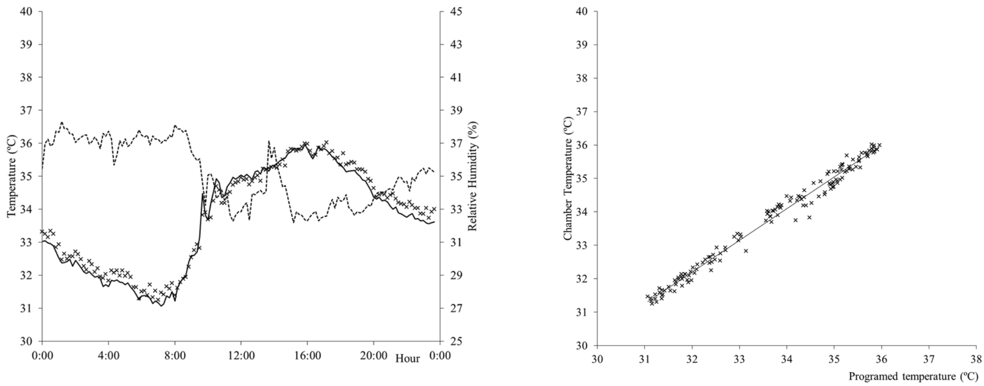

Figure 3: Test with 10°C constant difference between rooms. Temperature programmed (—) and real (×) in °C, relative humidity (---) in % and lineal regression programmed (x) and real temperature (y). y = 0,9477x + 1,8758; R² = 0,985.

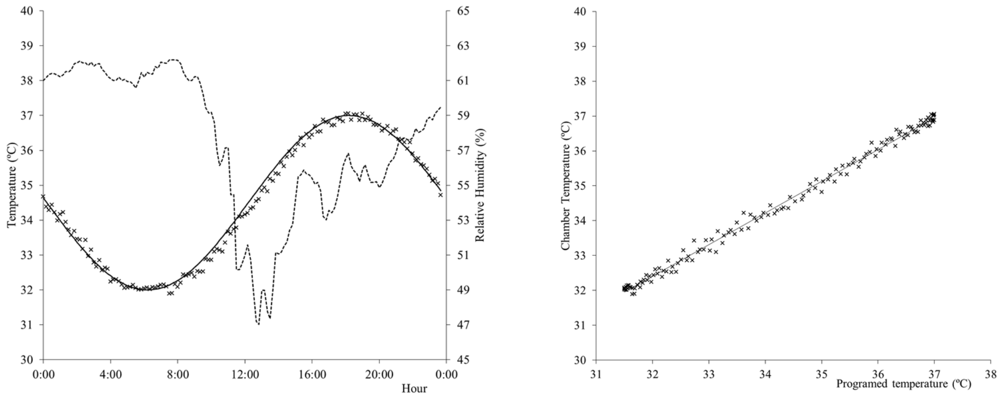

Figure 4: Test with a sinusoidal curve. Temperature programmed (—) and chamber temperature (×) in °C, relative humidity (---) in % and lineal regression programmed (x) and real temperature (y). $y = 0.9081x + 3.3451$; $R^2 = 0.9947$.

Secondly, 48 reproductive rabbit does at 1st d after 1st partum were kept in the single cages of the climatic chamber until 3rd partum (in av. 105 d). Animals were maintained with sinusoidal curve in a range of 25°C to 35°C according to the previous test. As in the previous test, a linear regression between programmed and real temperatures of the chamber throughout the day was performed, randomly selecting 3 d (30, 60 and 90 d). Mortality rate was also recorded and compared with that obtained in a coetaneous control group (153 reproductive rabbit does) housed in a conventional room (with temperature varying between 14 and 20°C) and in the same physiological state (1st to 3rd partum). Comparison was done by χ^2 test.

RESULTS AND DISCUSSION

System test

The 1st curve tested was always 10°C over the control farm. The results of the programmed curve and the climatic chamber data are presented in Figure 3. In the programmed curve, it is possible to see the noise of the reading temperature because of the sensor error plus the minimal real temperature variations in a short time. To compare both data sets, a lineal regression of the real temperature and the programmed one was carried out (Figure 4). In this regression, the dependent terms must be near one and the independent close to zero. The coefficient of determination of the linear regression was 0.9850 (Figure 3). In the second test, the temperature inside a farm followed a sinusoidal curve, as seen in Figure 4. To avoid the noise of the reading error that was found in the last curve, an ideal sinusoidal curve was used to manage the climatic chamber to prevent this error and control the thermal inertia better. In this test, the coefficient of determination was 0.9947 (Figure 4).

Animal test

The determination coefficients of linear regression were 0.9927 and 0.9928, for day 1 and 2, respectively, when the system was programmed to range between 32-37°C during 48 h. Similar results of 0.9859, 0.9900 and 0.9901 were obtained for day 15, 30 and 45, respectively, when the system was programmed to range between 25-35°C during 105 d, which showed that the system perfectly fits the set temperature programmed in the presence of animals.

In the 1st test (48 h trial), survival of females in the temperature chamber was 100%. However, in the 2nd test (105 d trial), the survival of rabbit females from 1st to 3rd partum was 82 and 90% in the temperature chamber and the conventional room, respectively (χ^2=3.83; *P*=0.06). Rosell and de la Fuente (2009) described a similar mortality rate (15-16%) between 1st and 3rd partum in Spanish farms (69944 females controlled). In any case, differences in mortality must not be attributed to the chamber design but to the temperature itself. Although there is a lack of knowledge about the effect of environmental temperature on female culling, Sánchez *et al.* (2005) observed that the relative risk of culling increased by 20% in summer, and Rosell *et al.* (2009) described how urgent visits to farms related to reproductive and respiratory troubles (main female culling reasons) increased in summer compared to spring (19.5 and 11.0% of the visits, respectively).

CONCLUSIONS

The system followed the program curve in all cases. The curve is better followed in the sinusoidal curve than in the random curve produced by adding 10°C to the conventional room. This could be explained by the absence of temperature reading error and slow changes in the temperature slope produced by the sinusoidal curve. This climatic chamber can be used for heat stress studies in rabbit does, but further humidity controls should be carried out to provide a large environmental chamber.

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