Journal of Thermal Biology 58 (2016) 43–49

Contents lists available at ScienceDirect

Journal of Thermal Biology

journal homepage: www.elsevier.com/locate/jtherbio

Thermal equilibrium of goats

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ARTICLE INFO

Article history:
Received 18 December 2015
Accepted 28 March 2016
Available online 5 April 2016

Keywords:
Goats
Sensible heat loss
Latent heat loss
Thermoregulation
Thermogenesis

ABSTRACT

The effects of air temperature and relative humidity on thermal equilibrium of goats in a tropical region was evaluated. Nine non-pregnant Anglo Nubian nanny goats were used in the study. An indirect calorimeter was designed and developed to measure oxygen consumption, carbon dioxide production, methane production and water vapour pressure of the air exhaled from goats. Physiological parameters: rectal temperature, skin temperature, hair-coat temperature, expired air temperature and respiratory rate and volume as well as environmental parameters: air temperature, relative humidity and mean radiant temperature were measured. The results show that respiratory and volume rates and latent heat loss did not change significantly for air temperature between 22 and 26 °C. In this temperature range, metabolic heat was lost mainly by convection and long-wave radiation. For temperature greater than 30 °C, the goats maintained thermal equilibrium mainly by evaporative heat loss. At the higher air temperature, the respiratory and ventilation rates as well as body temperatures were significantly elevated. It can be concluded that for Anglo Nubian goats, the upper limit of air temperature for comfort is around 26 °C when the goats are protected from direct solar radiation.

1. Introduction

Studies directed to understand the effect of air temperature and relative humidity on performance of animals and their economic impacts are of increasing importance, particularly in the face of global climate change. It is imperative to better understand the heat and mass transfer processes between animals and their environment. Calorimetric field studies can be useful in describing heat and mass transfer of animals, understanding their thermal equilibrium, and develop mechanistic models to predict the impact of meteorological and climatic events on thermoregulation. In this context, two questions are of importance: (1) how goats gain or lose heat to the environment, and (2) to determine the optimal thermal environment for goats for maximum production. To answer these questions, the First Law of Thermodynamics (conservation of energy) which describes the rate of change of energy in a control volume, which is caused by the rates of energy flowing into and out of the control volume (Incropera, 2008) is normally applied. However, the application of this principle to the study of thermal equilibrium of animals is not simple because thermal regulation of animals is the outcome of the interaction of physiological, production, reproduction, behavioural responses of the animal to their thermal environment. Thermal environment includes air temperature, relative humidity, air velocity and solar and thermal radiation, and all of them change with time. Moreover, any change in any of the environmental variables and their interactions affect the thermal equilibrium of the animal.

1.1. Objectives

The objective of this study is to determine the effect of air temperature and relative humidity conditions on thermal equilibrium of goats.

2. Material and methods

The study was conducted in the Biometeorology Laboratory at the Faculty of Agricultural and Veterinary Sciences (FCAV-UNESP), Jaboticabal, SP, Brazil (21°08′ South, 48°11′ West, 583 m altitude). Nine non-pregnant Anglo Nubian nanny goats, three years old on the average, were used for this study. The goats were distributed in three groups according to their body weight. The groups were: less than 55 kg, 55–65 kg, and above 65 kg. Nine female goats were

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http://dx.doi.org/10.1016/j.jtherbio.2016.03.012
0306-4565/

distributed in a 9 × 9 Latin square design (nine days x nine hour of evaluation). Measurements were taken from 8am to 17 pm each day at one-hour-interval. The first goat was evaluated between 08:00 and 09:00 h; the second goat between 09:00 and 10:00 h, and so on; thus, readings from the ninth goat was done between 16:00 and 17:00 h At the end of the trial, all animals had been evaluated in each of the nine periods.

During the experimental period, the goats were fed twice daily, with a forage (corn silage) and concentrate (corn, soybean and urea) at a 70:30 ratio, and water was available *ad libitum*. Daily feed consumption was approximately 2% of body weight.

Meteorological variables: air temperature, relative humidity, partial vapour pressure and black-globe temperature were recorded at ten-minute interval each day using a Data Logger (model HOBO, onset). Black-globe temperature was measured with a thermocouple (Type K) inserted into the centre of a hollow 15-cm diameter copper sphere, matt black painted placed 50 cm above the ground and close to the animals.

Oxygen (O_2) consumption, carbon dioxide (CO_2) and methane (CH_4) production, and water vapour (H_2O) of the exhaled air were measured using an indirect calorimetry with a facial mask adjusted on the animal's muzzle (Fig. 1). The facial mask was designed to make sure that the volume of the ventilated dead space (V_d) was as close to zero as possible because it affects the true concentration of the expired gases (McLean 1972). The mask was built with the lowest possible V_d ($V_d \rightarrow 0$), hence, the ratio (K) of the respiratory tidal volume (V_T) to V_d ($K = V_d / V_T$) was as large as possible. The best geometry of facial mask that reduced the V_d was a triangular shape with V_d around 0.1 L (Maia et al., 2014). Care was taken to ensure no leakage of the expired air flowing through the mask and valves. Areas around the muzzle was successfully sealed using rubber sheet (a dental product) to avoid leakage. During each breath, the inspired and expired air were carried through two valves. The expired air coming out of the facial mask was directed through a tracheal tube (MLA1015 Breathing Tube, ADInstruments, Australia) to a gas mixing-chamber (MLA246, ADInstruments, Australia) that was connected to a Field Metabolic System (FMS-1201-05, Sable System, USA) through a plastic tube (Bevaline Tubing, Sable System, USA). Inside the tube, a sample (150 mL/min) of the expired air was continuously pulled by an air pump at the FMS and was directed to a gas analyser (H_2O, O_2 and CO_2). The air sample first passed through the H_2O vapour analyser and then dried by passing it through a dryer (Magnesium perchlorate – Mg $(ClO_4)_2$) and then passed through the CO_2 and O_2 analysers; and finally through the CH_4 analyser (MA-10, Sable System, USA). The connection between the FMS and the CH_4 analyser allowed us to digitally read H_2O vapour pressure (P_{EXP}, kPa) and the percentages of carbon dioxide, oxygen and methane in the expired air (CO_{2E}, O_{2E} and CH_{4E}, respectively). A flow head (MLT1.000, ADInstruments, Australia) was placed in the outlet tube of the mixing-chamber. The flow head was connected to a Spirometer (ML141, ADInstruments, Australia) that allowed us to digitally read respiratory rate (R_R, breaths min^{-1}), ventilation rate (V_R, L s^{-1}) and tidal volume (V_T, L $breath^{-1}$).

Percentages of oxygen (O_{2A}), carbon dioxide (CO_{2A}) and methane (CH_{4A}) in the atmosphere were measured by the FMS and CH_4 analysers. These measurements were done every time the facial mask was put on the animal´s muzzle. The atmospheric vapour pressure was, however, continuously recorded by an external H_2O vapour analyser (P_V, kPa) (RH-300, Sable System, USA) connected to a pump (SS4, Sable System, USA), which continuously took an air sample (150 mL min^{-1}) from the atmosphere close to the mask.

Hair-coat temperature (T_S, °C) was measured at the flank-body region by placing a sensor (MLT 422 A, ADInstruments, Australia, Accuracy: ± 0.3 °C, height x diameter: 4.0 × 9.7 mm and thermal response time: still air 45 s) under the hair-coat surface. About 6.0 cm away from hair-coat temperature sensor, another similar sensor was attached to the skin surface by a thin plastic board (length x with x height: 6.0 × 4.0 × 0.1 cm and thermal conductivity ≈ 0.036 W m^{-1} K^{-1}) to measure skin temperature (T_{ep}, °C). The skin area was shaved. The rectal temperature (T_R, °C) was continuously recorded by a rectal Type T thermocouple (MLT 1403, ADInstruments, Australia, Accuracy: ± 0.10 °C, Shaft length and diameter: 25.4 × 1.5 mm, Ball tip diameter: 3.2 mm and thermal response time: 0.8 s) inserted 8.0 cm into the rectum of the

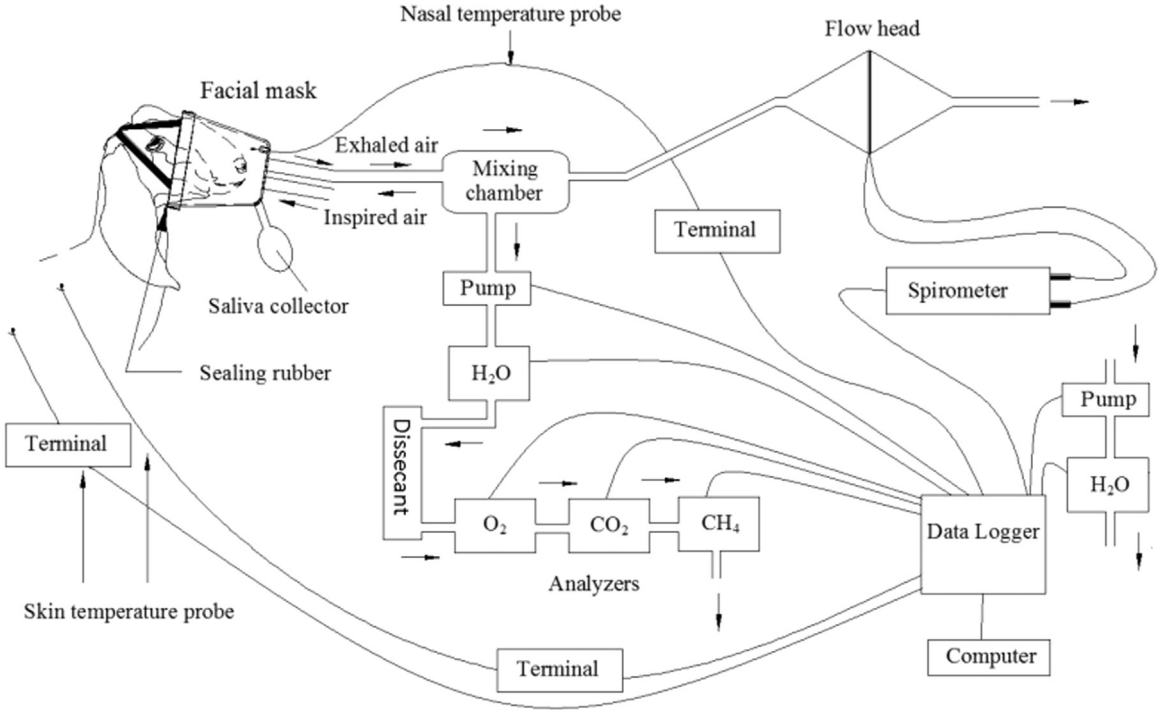

Fig. 1. Calorimetric system developed for measurements of physiological responses of goats.