PASSIVE COOLING IN LIVESTOCK BUILDINGS

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ABSTRACT

The application of a passive cooling system to animal housing was evaluated. For this purpose a model was developed that allows to foresee the temperature and relative humidity of the air inside a livestock building where the natural ventilation is assisted through a solar chimney and the air is cooled through its circulation in buried pipes. The degree of satisfaction of the thermal environmental requirements is evaluated through a synthesis parameter named thermal comfort index, expressed by the percentage of time of the period of study (June to September) where the temperature and the relative humidity of the indoor air belong to the thermoneutral zone.

INTRODUCTION

Livestock housing must provide environmental conditions favourable to the preservation of the animal health and welfare and, consequently, to the efficiency of animal production. The thermal environment has a particular relevance due to the fact that its effects on the energy balance of an animal affects its welfare.

The attainment of the thermal environment required, through the use of conventional conditioning systems, have very high investment costs and particularly maintenance costs. Indeed, the use of these systems have to be considered with care due to the need to reduce the environmental impacts, which are a consequence of burning fossils fuels.

In order to reach the best environmental thermal conditions inside a building with lower conventional energy consumption during the summer period it is advisable to make use of passive cooling strategies, including the reduction of the cooling loads of the building.

For livestock housing latent and sensible heat production is very high due to the high concentration of animals in the building. Therefore, ventilation requirements are such that it is necessary to keep high values of airflow rate. This fact limits the applicability of some passive cooling strategies.

Since the required airflow rate is very high, mechanical ventilation systems are used and, in some conditions, ventilation by natural means, which are less demanding in terms of energy consumption and have a reduced impact in the environment. However they present a major difficulty to control the required rate of ventilation, since they depend on a lot of variables, namely on the external conditions.

During the summer season the highest airflow rates are needed inside the livestock housing. At the same time the difference between the inside and the outside air temperatures is very small and, in the absence of wind, the natural ventilation is insufficient. Therefore there is the need to explore mechanisms and processes leading to an enhancement of the natural ventilation rates.

One of the means to enhance the natural ventilation in a building is the existence of a solar chimney, where the air is heated in contact with a surface, which has absorbed solar radiation. This heating induces a bigger pressure difference between the inlet and the outlet of the chimney, thus increasing the rate of natural ventilation significantly (Afonso and Oliveira 2000, Awbi and Gan 1992, Bansal et al. 1993).

It is quite interesting the solar chimney ability to control the airflow rate: the higher the solar irradiation, the higher the rate of natural ventilation, so this rate increases with cooling needs.

The need to remove the high thermal loads inside the buildings during the summer season, by natural ventilation, demands a precooling of the external air before let it inside the building.

This process can be done by natural means, such as, the circulation of the external air through buried pipes (Givoni 1994, Santamouris and Asimakopolous 1996), before entering the building where is then sucked due to the solar chimney. As a matter of fact as the ground exhibits a high thermal inertia its temperature at a certain depth is almost constant all year around and it can be used either as a heat sink or a heat source. In this study the ground will be considered as a heat sink.

DESCRIPTION OF THE MODEL

A model was developed which can predict the air temperature and the relative air humidity inside a livestock building where the natural ventilation is enhanced by the existence of a solar chimney and the air entering the building is precooled by circulating through a grid of buried pipes.

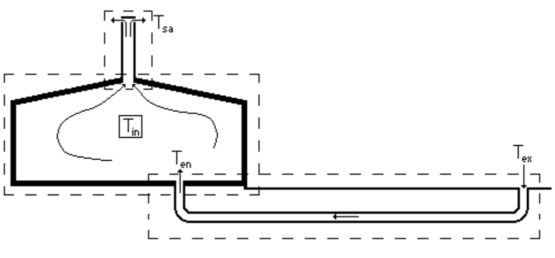

Fig. 1 – Building, solar chimeney and buried pipes.

With this model the latent and sensible heat fluxes released by the animals can be determined as a function of its species and weight and of the air temperature and relative air humidity inside the building.

The model has three sub models: the one predicting the behavior of the solar chimney, another one describing the ground-air heat exchange system (buried pipes, where the external air is circulating before entering inside the building) and another one predicting the overall natural ventilation rate of the building, which includes the grid of buried pipes, the air inside the building and the solar chimney. With the first model the temperature of the air leaving the chimney can be determined; with the second one the temperature of the air entering the building can be evaluated and with the third model the rate of ventilation, from which the air temperature and relative air humidity inside the building, can be evaluated.

The interdependence among the values of the related variables, compelled us to use an iterative process of calculation.

The degree of comfort can be determined by the calculation of a parameter - thermal comfort index- which gives the fraction of time, between June and September, where the thermal environment inside the building belongs to the so called thermoneutral zone, represented in the psychometric diagram, as shown in Figure 2.

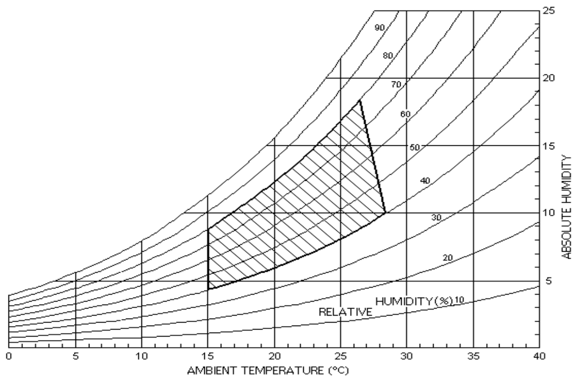

Fig. 2 – Thermoneutral zone for growing and finishing pigs.

The working group on “Climatization of Animal Houses” of the CIGR – The International Commission of Agricultural

Engineering, had concluded that thermal environment in swine housing must be limited by maximum values of the enthalpy of air, that are function of the air temperature, in accordance with the equation (C.I.G.R. 1992):

$$h_{in,max} = 321 - 9{,}44 T_{in}$$

Through this equation the maximum values calculated for the air temperature were from 26,5ºC (corresponds to 80 % of relative humidity) to 28,4ºC (corresponds to 40 % of relative humidity).

SIMULATION

The model was then applied to evaluate the influence of the main parameters of the solar chimney and of the grid of buried pipes on the thermal environment inside the livestock housing for growing and finishing pigs.

The simulations were performed considering a building with the following dimensions: 15m length by 8m wide and by 2,6m height, occupied with 100 young pigs with an average weight of 60kg.

The grid of buried pipes has 15 PVC pipes, each of them having 30m long, with an internal diameter of 0,384m and the grid is located at 2,5m depth.

The solar chimney has a transparent vertical surface facing the south direction, is 15m long, 2m high and 0,2 m width.

The climate variables that were used in the simulations were taken from the "Test Reference Year" (TRY) of Lisbon and they correspond to the hourly mean values of temperature and relative humidity of the air, wind speed and flux density of solar irradiation (direct beam and diffuse) observed in a horizontal surface.

The period of time considered for the computation of the air temperature and relative humidity inside the building was from June to September. The hourly values of these variables are represented in the Figures 3, 4 and 5 with the line that limits the thermoneutral zone.

Figure 3 represents exterior air temperature and relative humidity from June to September. These variables belong to the thermoneutral zone in 64% of time.

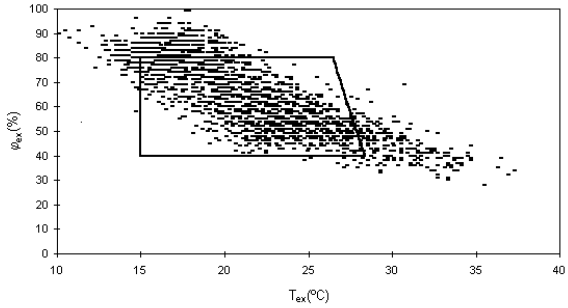

Fig. 3 –Exterior thermal environment in summer period.

The computation of the temperature and the relative humidity of the air was made for the inside of the building without the solar chimney and without the grid of buried pipes (earth-to-air heat exchangers). These conditions, that Figure 4 represents, belong to thermoneutral zone during 76% of the period of time considered.

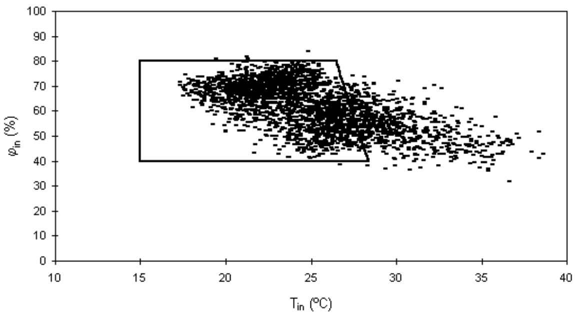

Fig. 4 - Thermal environment , inside the livestock building without solar chimeney and buried pipes, in summer period.

In Figure 5 the computation of the temperature and the relative humidity of the air was made for the inside of the building with solar chimney and earth-to-air heat exchangers and in this case the thermal environment inside the building stay about 91% of the time within the thermoneutral zone. Therefore both systems increase significantly the fraction of time during which the comfort conditions are met for the animals and even for the thermal conditions outside the thermoneutral zone these are closer to this zone that the ones obtained without the solar chimney and the earth-to-air heat exchangers. The relative air humidity is in this case higher than before, since there was a decrease of the temperature of the inside air.

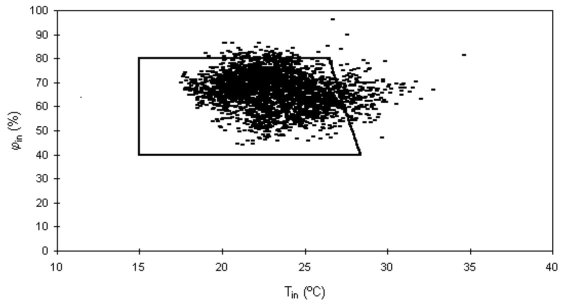

Fig. 5 - Thermal environment , inside the livestock building with solar chimeney and buried pipes, in summer period.

CONCLUSIONS

The model developed can predict the inside environmental conditions in a monozone building where a passive cooling system was considered if the outside climatic conditions, the geometry of the building and the concentration of animals inside it are known. The model allows the dimensioning of the pipe grid, namely in respect to the diameter, length and number of pipes. The model enables the dimensioning of the solar chimney, as well.

The use of a solar chimney is quite interesting since the rate of natural ventilation induced by it is not depending on the wind speed. Its efficiency increases as the solar irradiation increases, during the day time period where it is most necessary the increase of the ventilation rate to ensure a temperature of the inside air lower than the outside one. It is a very suitable system for regions where the solar irradiation is high and the wind speed is normally low.

The use of earth-to-air heat exchangers reduces the thermal amplitude of the air that is admitted inside the building, thus reducing the extreme values of the air temperature inside the building. This system is particularly suitable for regions where the annual thermal amplitude of the air is high, which is the case for the southern part of Portugal.

With the application of this model to a livestock housing for pigs, located in the region of Lisbon, it was possible to predict environmental conditions which were inside the thermoneutral zone for 91% of the time during the summer season, provided the two passive cooling systems are considered: solar chimney and a grid of buried pipes. If these systems are not considered the environmental conditions inside the livestock housing would only be 76% of the time inside the thermoneutral zone.

Another conclusion to be taken is that only with the use of passive cooling systems is possible to reach a temperature of the inside air lower than the outside one, for such a high thermal load produced by the animals, unless an active cooling system would be installed to do it.

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