A SIMULATION MODEL TO PREDICT THE INTERNAL CLIMATIC CONDITIONS IN LIVESTOCK HOUSES AS A TOOL FOR IMPROVING THE BUILDING DESIGN AND MANAGEMENT

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ABSTRACT A model simulating the transient environmental conditions inside livestock houses has been created for building design. The software can be applied to any type of building, animal or climatic situation and gives as outputs the heat exchange trough all the building components and the internal air temperature and humidity values, per minute. From these values some useful parameters are calculated to evaluate the building thermal behaviour: Temperature Humidity Index, duration of the exposure to heat stress, possibility of recovering by nocturnal refreshment, benefit from mechanical ventilation or evaporative cooling. Its application in three study cases (a pig house, a veal barn and a shelter for cows) is presented and the possibility of improving the building design and management is pointed out.

Keywords: Livestock housing, Climate, Simulation model

INTRODUCTION Optimising the thermal behaviour of animal houses is a very important aim for design in order to obtain the best productive results. But it is a quite difficult object to achieve for two main reasons; the wide range of building solutions and the high variability of the climatic conditions. The last is mainly relevant in the hot summer climate.

To find out the optimal solutions, not only for design but for management too, reliable theoretical models are required capable of predicting the internal climatic conditions when varying the climatic external parameters (air temperature and humidity, wind speed and direction, solar radiation) and the building characteristics (materials, geometry, orientation, openings).

Many authors worked on modelling the internal environment of animal houses, but some aspects are often neglected or underestimated: i.e. the solar load, the transient thermal condition due to the thermo-inertial characteristics of the building shield, the effect of the floor and slurry evaporation. All aspects are very important in hot climate.

In order to implement the previous researches, we developed a dynamic model accurately including all the factors that influence the thermal behaviour of buildings.

MATERIALS AND METHODS The model is a dynamic and takes into account the following inputs: building geometry, building orientation, vent openings (size and position), thermal-inertial characteristics of the constructive materials (thermal conductivity, density, specific heat capacity, heat transfer coefficients), terrestrial coordinates (longitude, latitude), type of animal; as well as the local climatic conditions (direct and diffuse solar radiation, wind velocity and direction, air temperature and humidity). The model also accounts for: evaporation from wet floors; feeding management (i.e. hour of feed distribution for the fattening pigs); mechanical and natural ventilation (combining thermal buoyancy and wind effects); wall shadowing; evaporative cooling.

The model is composed of sub-models which can work separately in order to evaluate some partial aspects of the thermal exchanges (i.e. the roofing effect, direct on the animals and indirect on the internal climate) for a better choice of the geometrical characteristics and insulation degree. Moreover the benefit of introducing, in hot climate, the mechanical ventilation and/or the evaporative cooling can be estimated and optimised for different climatic conditions.

Table 1. Pig house: best and worst results for each type of building.

Building code	Ranking	Integr. DTHI >75	THI max	THI min	Stress duration (h)	Recovery duration (h)	Integr. DTHI > 85	Duration THI > 85 (h)
			Best results for each type of building					
1227	1/72	82.3	85.2	64.7	12.6	1.4	7.9	1.3
2222	5/72	84.9	85.4	64.5	13.3	1.7	34.6	2.2
12*7	13/72	87.3	86.1	64.3	12.7	2.3	96.8	3.0
22*3	18/72	90.1	85.9	64.3	13.0	2.0	114.3	3.1
			Worst results for each type of building					
11*1	72/72	133.2	89.3	68.1	14.4	0.0	1281.7	7.5
1111	70/72	126.6	88.6	68.4	14.5	0.0	1008.7	7.1
21*1	65/72	113.0	87.9	66.4	14.5	0.0	685.0	6.0
2111	58/72	106.7	87.1	66.7	14.6	0.0	439.0	5.2

bulding code legend
first position (left): 1=mono pitch; 2 - two pitches
second position: 1=standard windows area; 2=+25%
third position: 1=3 cm insulation layer; 2=6 cm insulation layer; *= without insulation, only brick layer
fourth position: main axis orientation, 1=N, 2=NE, 3=E, 4=SE, 5=S, 6=SW, 7=W, 8=NW

The application of the model to three study cases of animal houses, focused on the hot climate conditions, is here presented and discussed.

The first case, the most complete, considers a house for fattening pigs on slatted floor. The building, housing 288 pigs up to 160 kg lw. on partially slatted floor, has two versions: a monopitch roof (covered area 8 m x 45 m) and a gabled roof (11 m x 33 m). Furthermore two window areas (53 m^2 and + 25%) and three roof insulation levels (3 and 6 cm polystyrene layers and none) have been taken into account.

The second case refers to a replacement house for 15 calves (up to 6 months) and 35 young heifers (6-12 months). The building is 12 m wide and 20 m long and has a gabled roof. Three insulation layers (2 or 4 cm polystyrene and none) and two opening areas (28.8 m^2 and 56 m^2) have been taken into account, the last obtained by keeping the main door open.

Table 2. Replacement house: best and worst results for each type of building.

Building code	Ranking	Integr. DTHI >75	THI max	THI min	Stress duration (h)	Recovery duration (h)	Integr. DTHI > 85	Duration THI > 85 (h)
			Best results for each type of building					
2222	1/24	64.6	84.2	61.8	11.0	5.0	0.0	0.0
2122	7/24	68.5	84.3	63.4	11.9	3.6	0.0	0.0
21*3	15/24	74.8	85.5	61.6	11.3	5.0	47.2	2.3
22*3	20/24	98.7	86.7	62.6	12.3	4.0	266.0	4.0
			Worst results for each type of building					
21*1	24/24	105.6	88.6	63.3	12.6	3.5	810.3	5.7
22*1	21/24	87.4	86.8	62.1	11.7	4.9	310.0	4.2
2111	18/24	77.6	85.1	64.0	12.0	2.8	5.7	1.2
2211	10/24	70.0	84.7	62.4	11.2	4.7	0.0	0.0

bulding code legend
first position (left): 1=mono pitch; 2 - two pitches
second position: 1=standard windows area; 2=+25%
third position: 1=3 cm insulation layer; 2=6 cm insulation layer; *= without insulation, only brick layer
fourth position: main axis orientation, 1=N, 2=NE, 3=E, 4=SE

The third case concerns a simple shelter for cows as reported in Figure 1. Two configurations (with a gabled or a multiple shed roofing) and two different position of the animal inside the barn (B central and A lateral) have been considered. Other varied parameters are the roof slope (10, 30 and 45 %) and the eaves height (3.5 m and 4.5 m).

The evaluation of the building performance is here presented with reference to a typical summer hot day of the Italian Po valley.
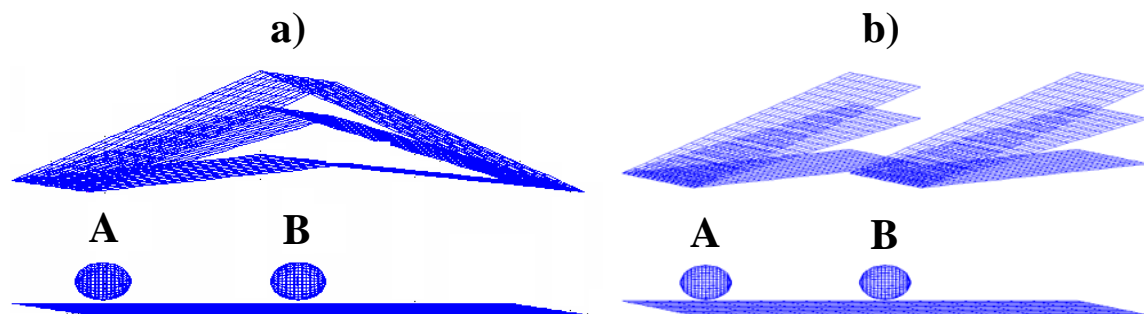

Figure 1. Shelter configurations: a) gabled roof; b) multiple shed roof. A and B, cow positions inside the barn.

RESULTS In Table 1 the main results of the model application to the pig house are reported as parametric values useful to compare the performance of the different solutions. The first column shows the integral of the THI values exceeding the acceptable

threshold (assumed as 75) to the time of their occurrence into the house. The second column shows the rank position of each solution among all the examined. The duration of the heat stress (THI over 75) is reported in *Integr. DTHI >75*; the duration of the nocturnal recovery (temperature below 19 °C) is reported in *Recovery duration (h)*. In the last two columns the integral of the THI values over 85 and the duration of the respective exposure are reported.

The analysis of these values would take too much space, but some results are self evident; especially the large difference, in the internal climatic conditions, among the best and the worst solutions for the two building shapes examined. The best absolute solution is a monopitch, for the optimum combination of the wind and sun action, but the same shape can be the worst too if not well designed.

gabled roof - cow A
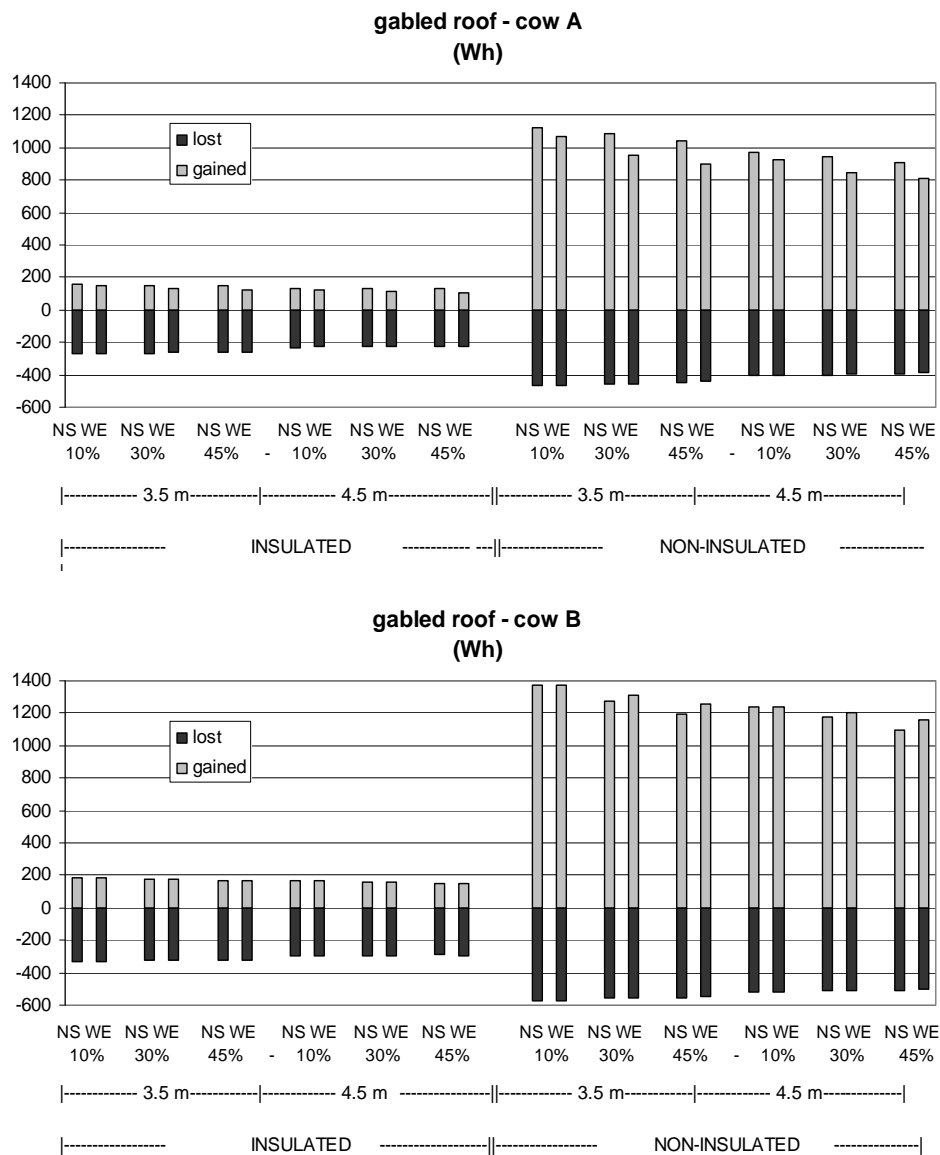**(Wh)**

gabled roof - cow B
(Wh)

Figure 2. Gabled roof; lost and gained daily energy for A and B cow positions.

In particular, increasing the window area is always a useful choice, whilst the roof insulation is not always a determinant factor. Instead the orientation, especially due to the wind action, is in general a relevant factor (all the worst solutions have the main axis North-South oriented).

In Table 2 the aforementioned parameters are reported for the case of replacement house. The differences of the various solutions are, for this building, bigger than before and one in particular (the 21*1) is much worse than the others. In this case the orientation is again a dominant factor (the North-South orientation being still the worst), but the insulation thickness has a great importance too, especially in order to reduce the more stressing conditions (THI over 85). The absence of insulation is instead a factor characterizing the solutions with the longer highly stressing period. Furthermore, keeping the doors open (code 2 in second position) is not so effective if the building is well insulated and oriented, meaning that the window size can be sufficient if a proper orientation is adopted.

multiple shed roof - cow A (Wh)
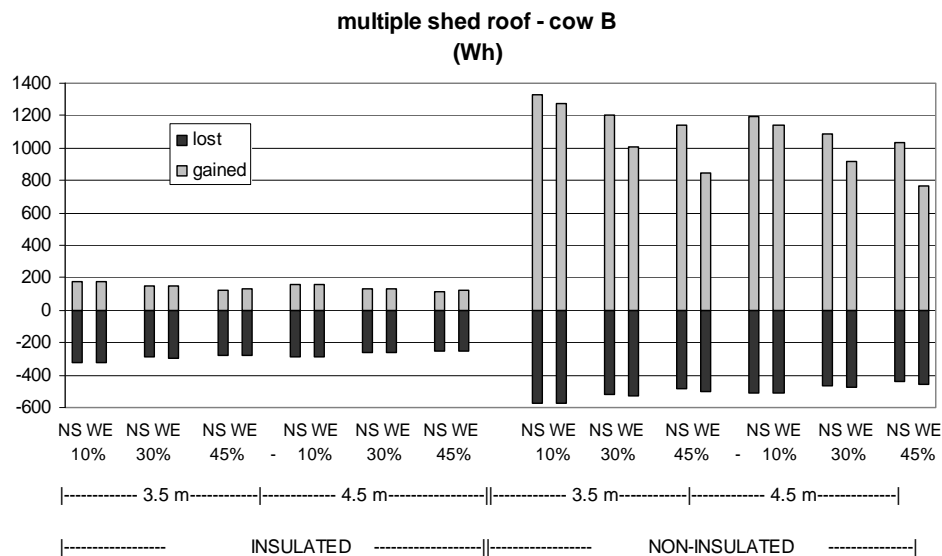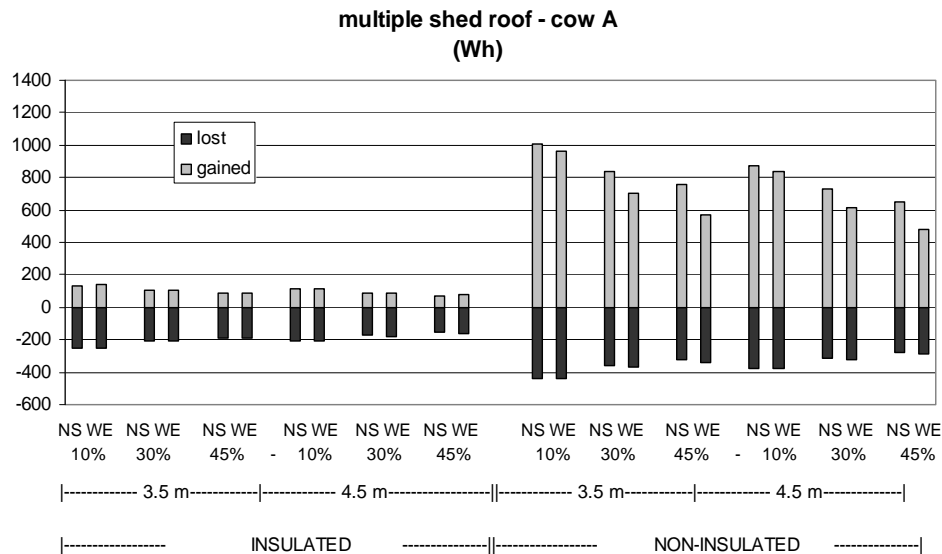

multiple shed roof - cow B (Wh)

Figure 3. Shed roofing. Lost and gained daily energy for A and B cow positions.

In the last case (shelter for cows), the radiative action of the roof on the animals is quantified for various geometric characteristics and insulation degrees (Figure 2 and 3). With this type of building the roof geometry can be important only if it is not insulated. In fact the insulation tends to uniform the thermal exchanges for all the different solutions. Instead, when the roof has no insulation not only the eaves height and the pitches slope are relevant (as grater as better), but even more important is the shape. As we can see by observing the better performance of the shed shaped solution compared to the gabled. This is mainly true for a definite orientation and a particular position of the animals. Looking at Figure 3, we can realize that the daily net heat gain (the positive value minus the negative) of the solution in the last bar (WE, slope 45%, eaves high 4.5m) is not very relevant: 208 Wh d^{-1} in lateral position (A) and 313 Wh d^{-1} in central position (B). What means that considering the additional benefit of the heat exchanged by convection, especially in a presence of good air streams, the effect of the building on the animals can be not much different whether insulated or not. On the contrary the lack of insulation could be very negative if the building geometry is not well designed.

CONCLUSION The simulation model predicting the building thermal behaviour can be a very helpful tool for the design and management of the livestock houses in order to improve the internal climate whatever the external conditions. An objective that is practically impossible to achieve without such a tool for the unlimited number of the possible different solutions and, otherwise, for the lack of parametric methods for a precise evaluation of their performance.

The model can put into evidence not only the optimal solutions for a specific type of building, but also can help to improve the thermal performance of a preferred or an existing solution through the modification of the building shield and a proper management of the climatization systems: ventilation, cooling and heating.

In perspective this kind of model, if integrated with a model capable of simulating the animal response, can realize an even more global and precise optimisation of the interrelated system animal-building-management.

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