UNIVERSITÀ DEGLI STUDI FIRENZE

DEPARTMENT OF AGRICULTURAL, FOOD AND FORESTRY SYSTEMS

COSTRUZIONI ZOOTECNICHE E GESTIONE DEI REFLUI AGRICOLI

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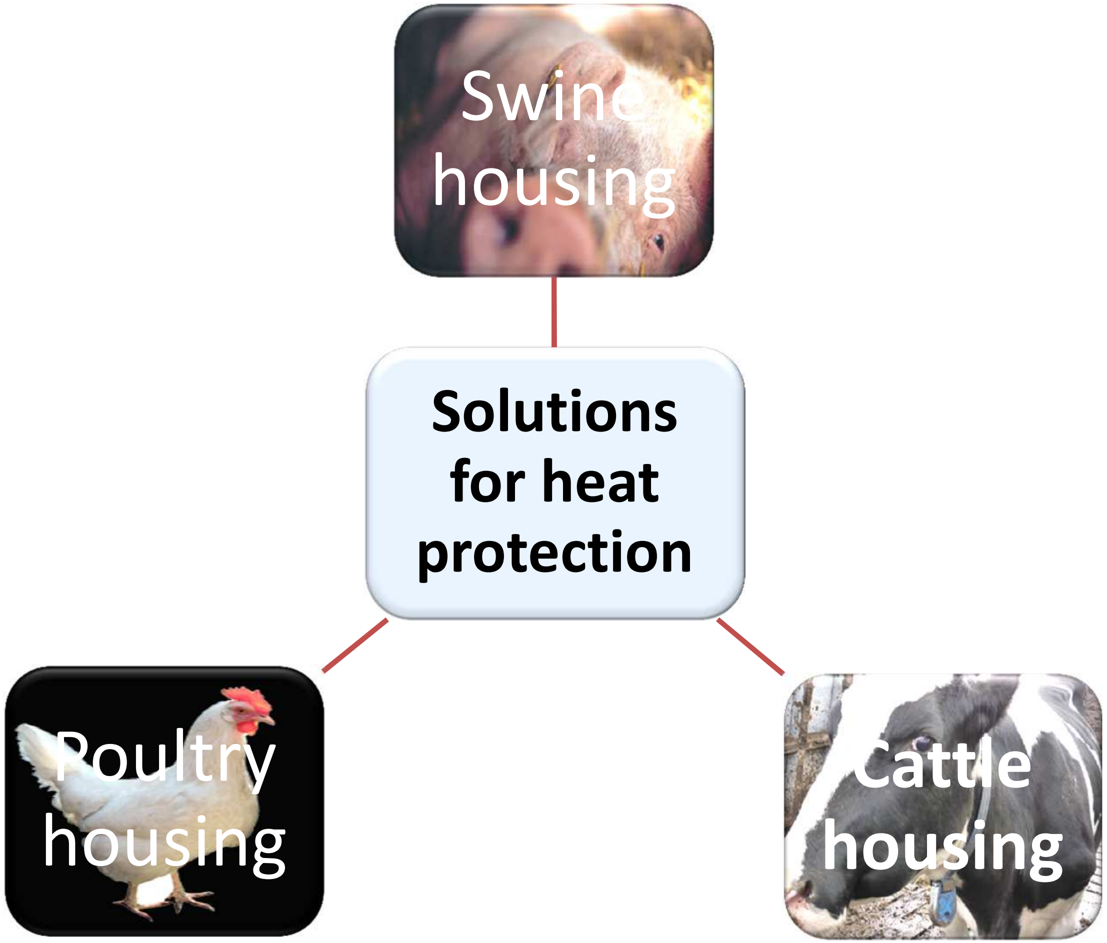
Corso di Laurea Magistrale in Scienze e Tecnologie Agrarie

Curriculum AGROINGEGNERIA

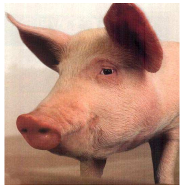
Anno Accademico 2017/2018

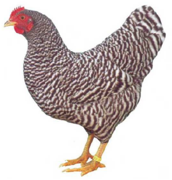
SOLUTIONS FOR HEAT PROTECTION IN LIVESTOCK BUILDINGS

Livestock farms



Which systems can we adopt to improve thermal comfort of animals inside the barn?



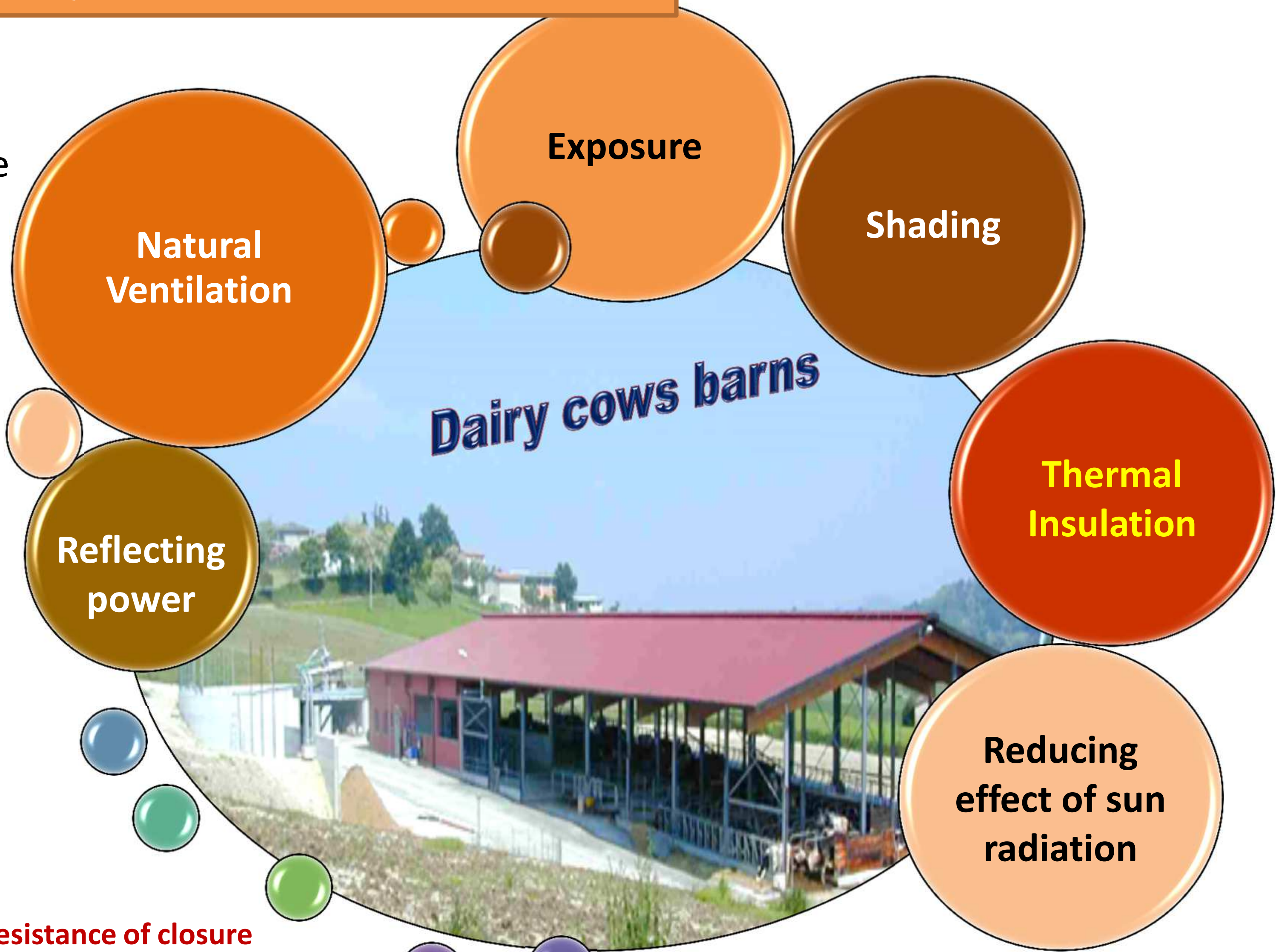


PASSIVE TECHNIQUES FOR HEAT PROTECTION

ACTIVE TECHNIQUES FOR HEAT PROTECTION

PASSIVE TECHNIQUES FOR HEAT PROTECTION

To avoid that **radiant waves** penetrate inside the building, causing an additional heating in the environment



- ➢ **Increase the thermal resistance of closure elements exposed to sunshine specially, the roof**
- ➢ **Maximize the reflecting power of outside face**

Trend to build very open barns for dairy cattle

Open barns for dairy cows

Po Plain - Italy

Which systems can we adopt to improve thermal comfort of cows inside the barn?

Open barns for dairy cows

Open barns for dairy cows

Open barns for dairy cows

Trend to build very open barns for dairy cattle

Open barns for dairy cows

Hot areas

Israel

Egypt

Brazil

Cold areas

Wisconsin - USA

Minnesota - USA

Swine housing



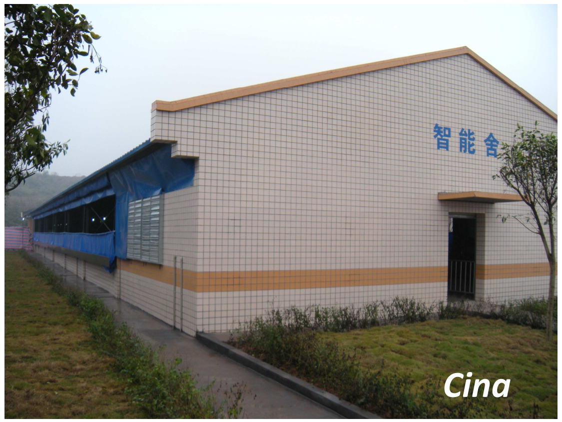







Trend to build very open barns for pigs, but only in hot climate regions

Open barns for pigs



Trend to build very open barns for pigs, but only in hot climate regions

Open barns for pigs

Poultry housing

Poultry housing

Laying hens

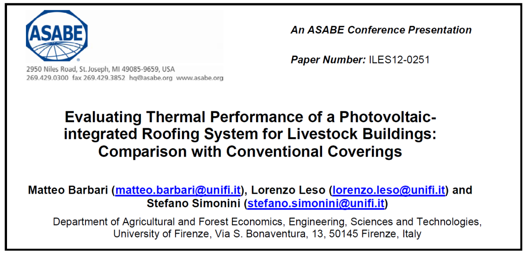
Chickens

Open facilities in Brazil

PASSIVE TECHNIQUES FOR HEAT PROTECTION

Research activities at GESAAF – University of Florence

PASSIVE TECHNIQUES FOR HEAT PROTECTION



An ASABE Conference Presentation

Paper Number: ILES12-0251

Evaluating Thermal Performance of a Photovoltaic-integrated Roofing System for Livestock Buildings: Comparison with Conventional Coverings

Matteo Barbari (matteo.barbari@unifi.it), Lorenzo Leso (lorenzo.leso@unifi.it) and Stefano Simonini (stefano.simonini@unifi.it)

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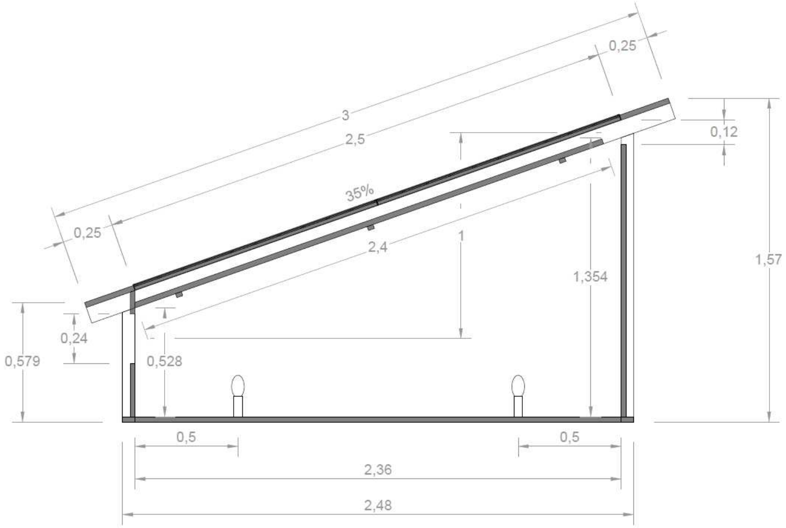
Alternative constructive solution for photovoltaic integration in the roof, which enhances thermal performance of the building during the hot period



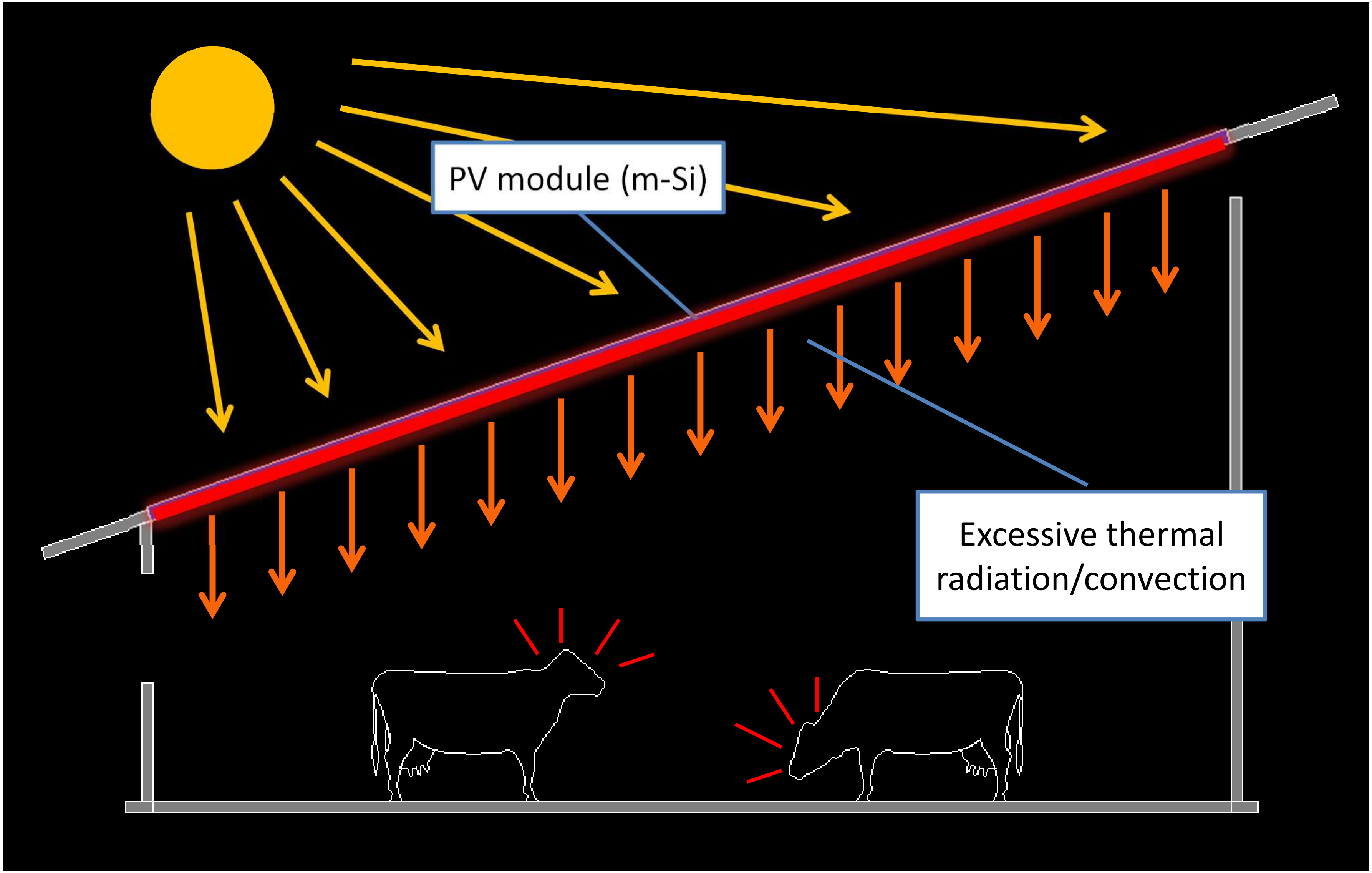
To reduce the diurnal heat load and to increase the capacity of discharging heat through the roof at night, the proposed roofing solution was equipped with a ventilated interspace.

The roof consisted of two different layers: the top cover was made up of PV modules (m-Si) and the lower layer consisted of fissured wooden boards.

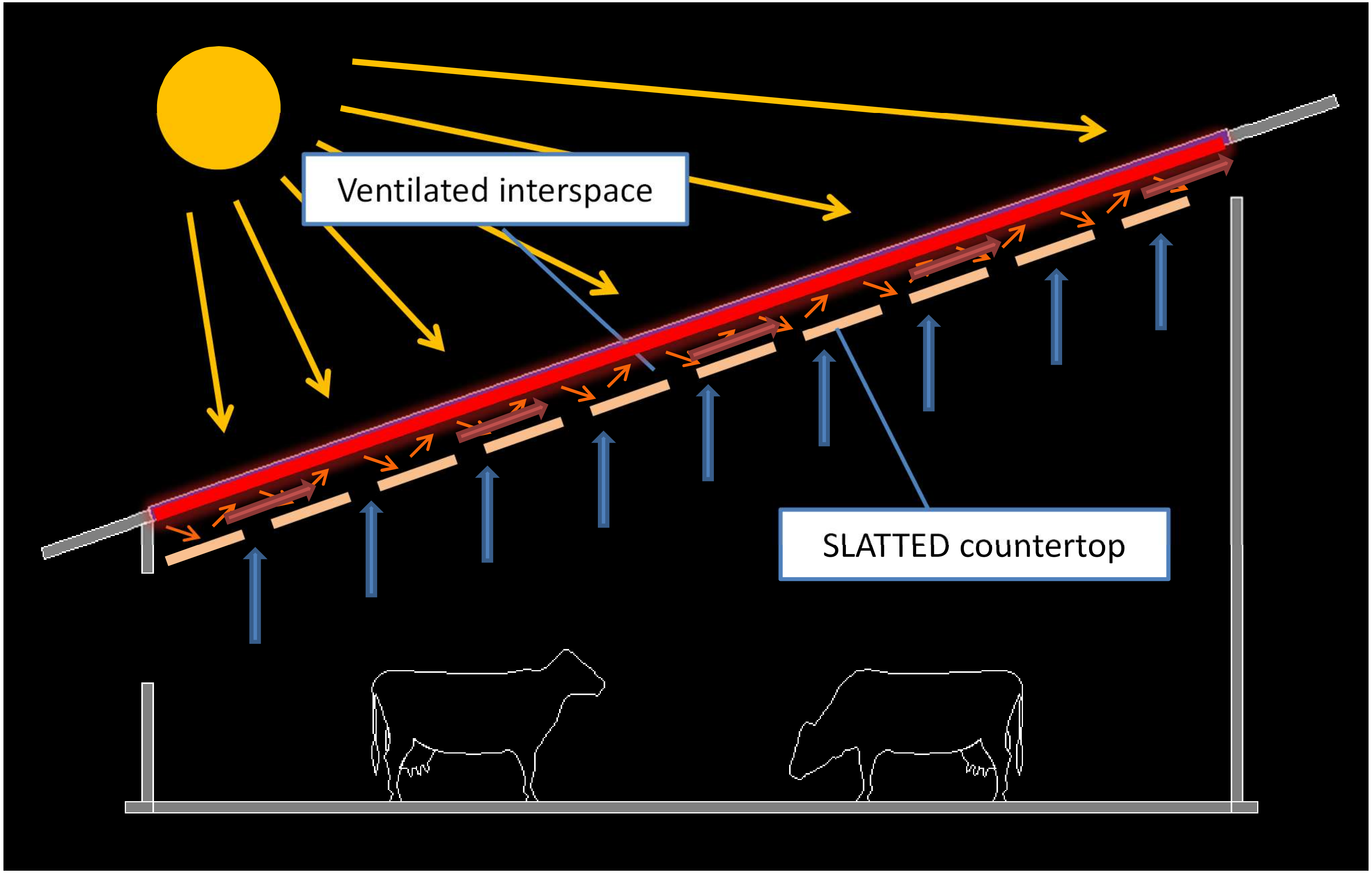
A scale model was realized to test the performance of this solution during the hot period in comparison with other two different types of covers:

- **simple PV modules**
- **insulating sandwich panels**

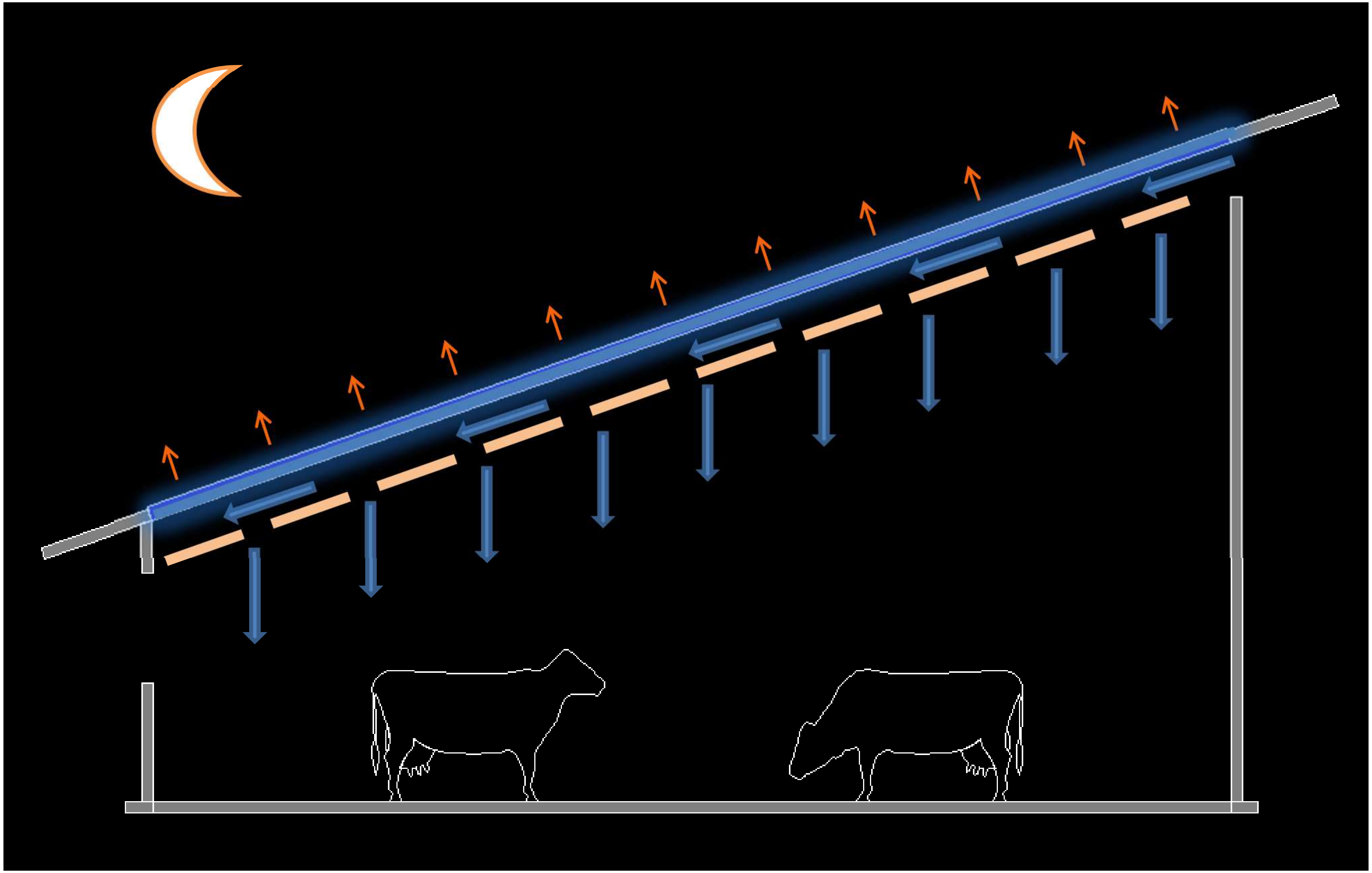
PV INTEGRATED ROOF SYSTEM



PV INTEGRATED ROOF SYSTEM (slatted countertop)



PV INTEGRATED ROOF SYSTEM (slatted countertop)



PASSIVE TECHNIQUES FOR HEAT PROTECTION

4 DIFFERENT ROOFING CONFIGURATION TESTED

WITHOUT INTERSPACE		WITH INTERSPACE	
• **Insulated sandwich panel** (40 mm)	• **PV modules** (m-Si)	• **Corrugated steel sheet** (1 mm) + interspace (light gray painted)	• **PV modules** (m-Si) + interspace

Significant differences were found among the effects of different covers towards internal microclimate ($P<0.001$)

During the hottest period of the day (13:00 h - 17:00 h)

- **simple PV modules provided an average difference between inside and outside air temperature of 8.87 ° C**
- **roofing solution made up of PV modules, equipped with ventilated interspace, gave an average gain of 6.36 ° C**
- **insulating sandwich panels offered the best thermal performance providing a mean temperature gain of 4.79 ° C**

Although insulating sandwich panel can be considered the most effective solution, ventilated interspace with lower fissured layer can offer significant improvement even when positioned under high transmittance materials such as PV modules.

THERMAL PERFORMANCE OF ALTERNATIVE BUILDING SOLUTIONS FOR DAIRY BARNS

- Compost barns/cultivated pack barns has substantial benefit toward animal welfare
- However they need increased space per cow (>9 m^2 US; >15 m^2 NL/IT) to keep cost of bedding at a reasonable level (and ease of management)
- This MAY lead to increased construction costs
- In northern countries -> Greenhouse-type structures
- Transparent cladding -> pack direct sunlight exposure -> improved evaporation

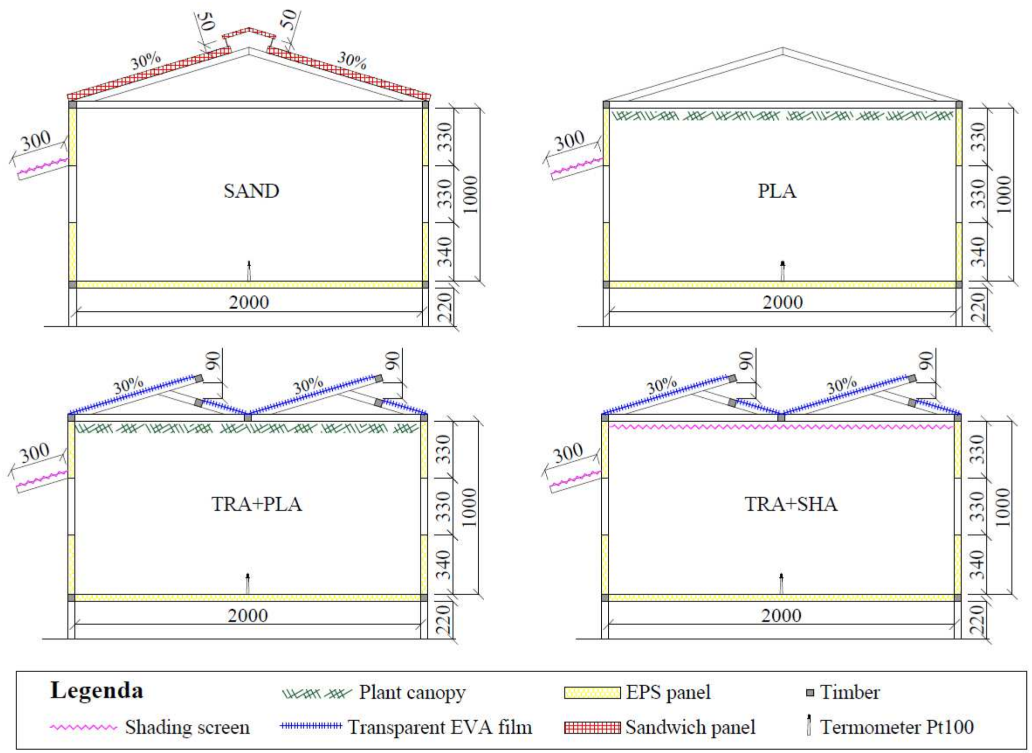
GH-TYPE STRUCTURE THERMAL PERFORMANCE

- Are GH-type structures suitable for Italian warm climate?
- Do “conventional” shading devices for GH offer adequate heat protection?

INTEGRATION OF GREENERY SYSTEMS

- GREENERY SYSTEMS (green roofs/green façades/shading trees)
  - -> effectively absorb solar radiation
  - -> reduce air temperature through evapotranspiration
- Can greenery systems be employed in GH-type dairy barns?

GREEN CANOPY (PLACED BELOW THE GH CLADDING)



SCALE MODEL

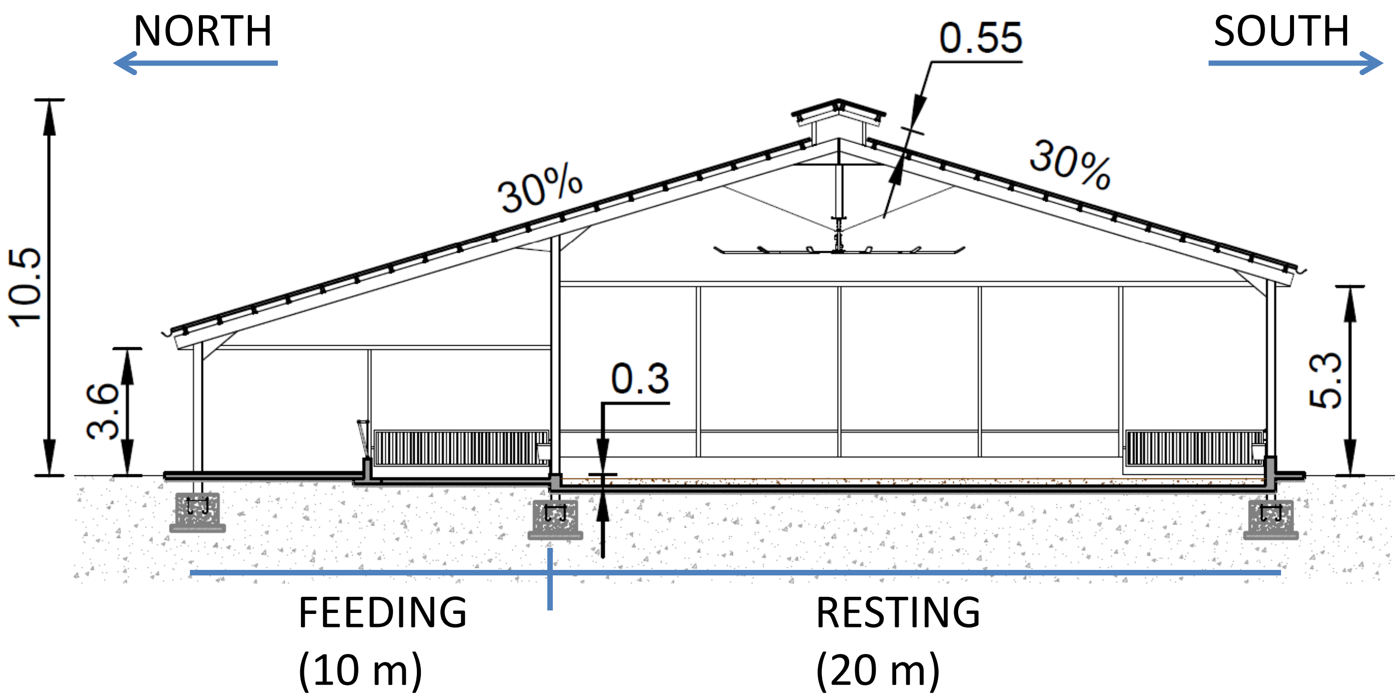
- **In hot weather conditions, the use of conventional greenhouses for housing dairy cows may result in increased heat stress**
- By providing greenhouses with plant canopies it is possible to obtain the same internal temperature as with traditional insulated coverings
- **By employing deciduous plants, direct sunlight exposure of the pack would be allowed during winter (critical period for CPB)**

DESIGNING AN OPTIMAL CPB FOR HOT CLIMATE

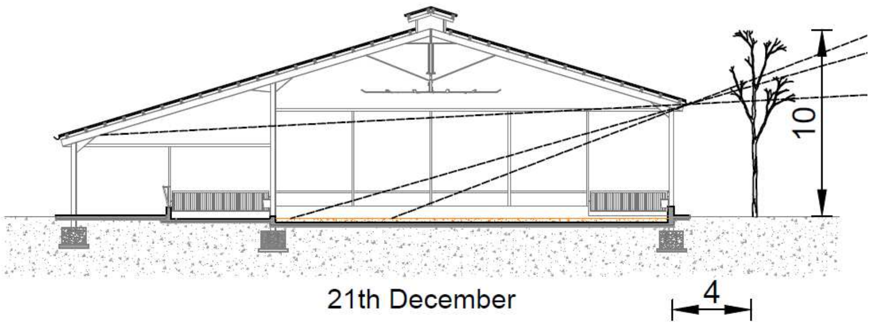
- A “conventional” structure was preferred for a commercial barn (more reliable data available).

  Aiming at->

- Minimize sunlight exposure during summer
- Maximize sunlight exposure of the pack during winter
- Using building orientation, sidewall height, and trees

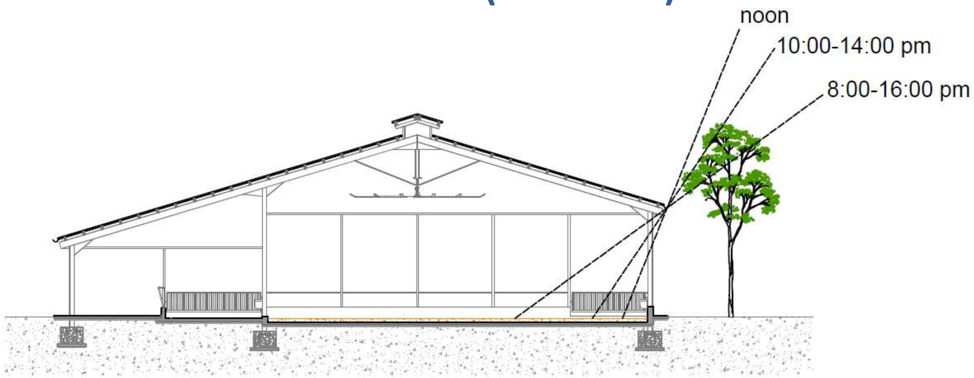


SUNLIGHT ANGLE (WINTER)

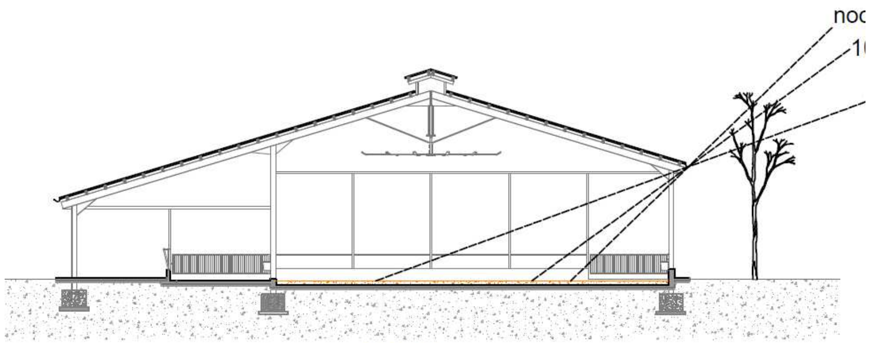


21th December

SUNLIGHT ANGLE (SUMMER)



21th June



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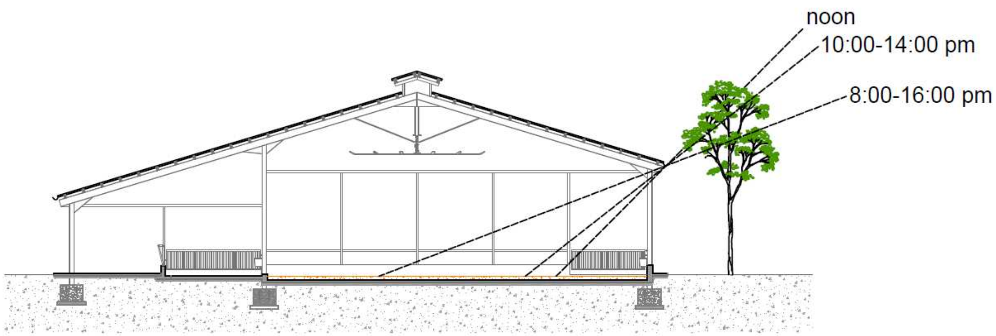
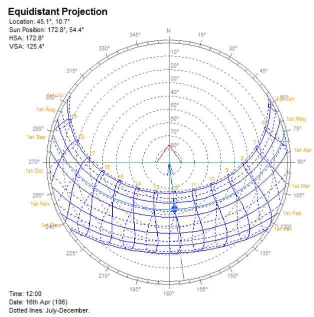
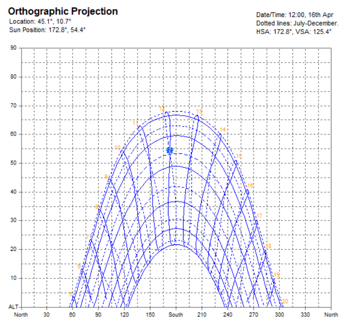


21th September

SUN ANGLES (NORTHERN ITALY; 45.1°/10.7°)





SUSTAINABLE-BUILDING MATERIAL: STRAW-BALE

Straw is an inevitable product of cereal production, available in huge quantities all over the world.

- **World cereal production:**
  - 700 million hectares
  - 2,500 million tons (*FAO, Crop Prospects and Food Situation, n°2 july 2015*).

- **Europe cereal production:**
  - 82 million hectares
  - 480 million tons (FAO, 2015)

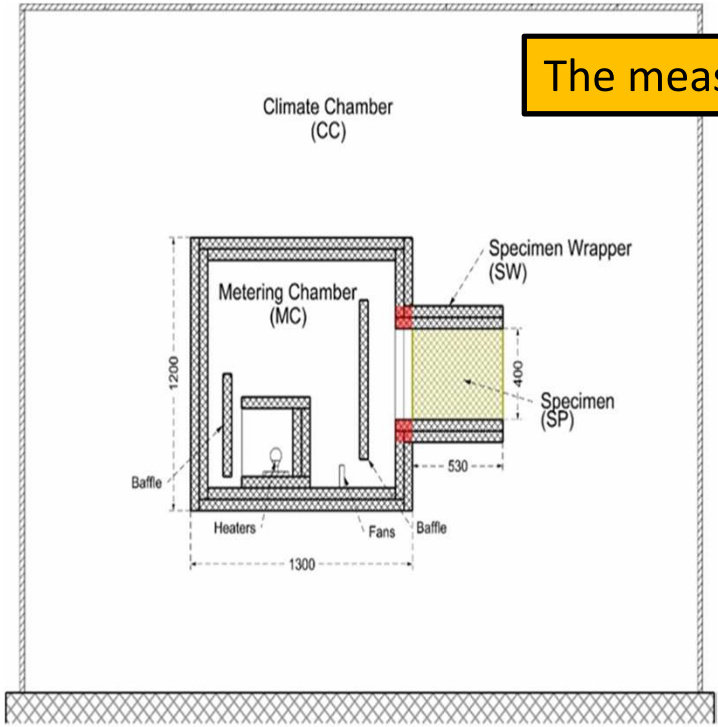
- Considering an average yield of 0.3 tons straw/ha, the amount of straw produced worldwide in the year 2015 is in the order of **21 billion tons**.

When the straw is burned or decomposed, 1.00 ton of straw produces about 1.35 tons of CO_2 (*Behzad Sodagar et al.,* 2011).

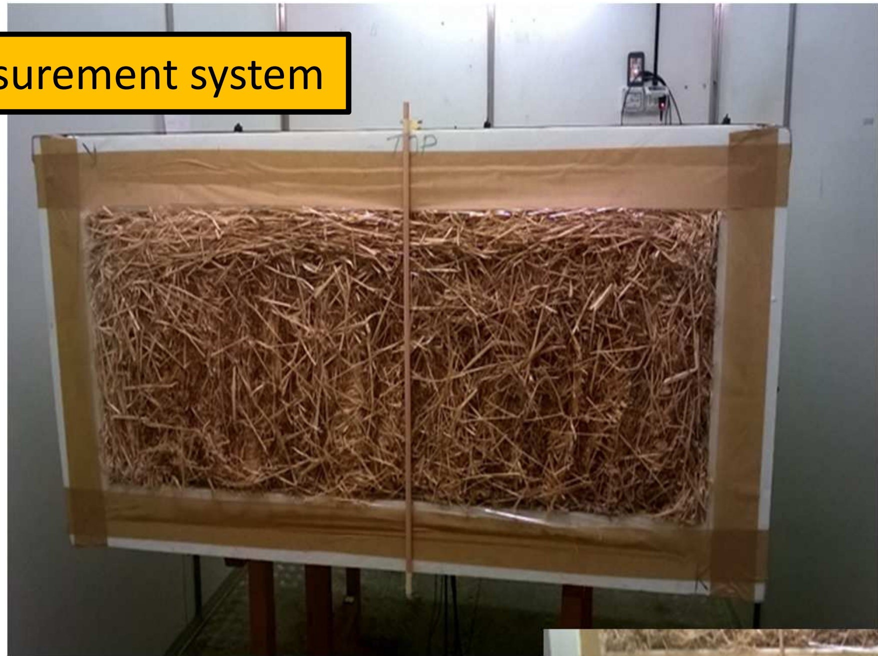
The use of straw-waste in constructions avoids the release of an amount of CO_2 greater than its weight.

Utilization of straw-waste for buildings

✓ **Thermal Properties of Rectangular Straw-Bales (RSB)** of various nature and origin produced in Tuscany Region (Italy)



The measurement system



Determination of the thermal conductivity of the specimen (λ_{sp})

$$\lambda_{sp} = \frac{Q_{sp} \cdot L_{sp}}{A_{mc,o} \cdot (t_{sp,1} - t_{sp,2})}$$

Results

Climate Chamber temperature	t_{cc}	5.815	°C
Air speed, near the hot side of the specimen	as_{sp}	0.315	m/s
Metering Chamber inside surface area	$A_{mc,in}$	8.920	m^2
Metering Chamber wall thickness	L_{mc}	0.103	m
Sum of all (total of 12) Metering Chamber interior edge lengths formed where two walls meet	Σe_i	14.800	m
Metering Chamber effective area normal to heat flow	$A_{mc,eff}$	9.750	m^2
Metering Chamber inside wall surface temperature	$t_{mc,in}$	31.727	°C
Metering Chamber outside wall surface temperature	$t_{mc,out}$	8.272	°C
Net heat added by the heaters	Q_h	56.826	W
Net heat added by the fans	Q_f	10.604	W
Net heat removed by the cooling coil	Q_c	0.000	W
Net heat flow due to the fan, heater, and cooling coil	Q_{aux}	67.430	W
Metering Chamber wall thermal conductivity	$\lambda_{mc,eff}$	0.030	W/m·K
Metering Chamber opening area	$A_{mc,o}$	0.792	m^2
Metering Chamber net area	$A_{mc,eff,n}$	8.958	m^2
Metering Chamber wall loss	Q_{mc}	61.194	W
Specimen Wrapper inside surface area	$A_{sw,in}$	1.307	m^2
Specimen Wrapper wall thickness	L_{sw}	0.103	m
Sum of all (total of 4) Specimen Wrapper interior edge lengths formed where two walls meet	$\Sigma e_{sw,i}$	1.720	m
Specimen Wrapper effective area perpendicular to the heat flow passing through it	$A_{sw,eff}$	1.409	m^2
Length of the heat flow path (test specimen)	L_{sp}	0.530	m
Specimen Wrapper wall thermal conductivity	$\lambda_{sw,eff}$	0.030	W/m·K

Thermal conductivity of the Straw-bale 01 (λ_{Wheat}):

Specimen Wrapper inside wall surface temperature	$t_{sw,in}$	16.457	°C
Specimen Wrapper outside wall surface temperature	$t_{sw,out}$	7.457	°C
Specimen Wrapper wall heat loss	Q_{sw}	3.694	W
Specimen heat flow	Q_{sp}	2.283	W
Specimen hot surface temperature	$t_{sp,1}$	31.388	°C
Specimen cold surface temperature	$t_{sp,2}$	6.698	°C
Apparent Thermal Conductivity of the Specimen	λ_{sp}	**0.062**	W/m·K

Thermal conductivity of the Straw-bale 02 ($\lambda_{Durum\ Wheat}$):

Specimen Wrapper inside wall surface temperature	$t_{sw,in}$	16.159	°C
Specimen Wrapper outside wall surface temperature	$t_{sw,out}$	7.106	°C
Specimen Wrapper wall heat loss	Q_{sw}	3.716	W
Specimen heat flow	Q_{sp}	2.520	W
Specimen hot surface temperature	$t_{sp,1}$	31.040	°C
Specimen cold surface temperature	$t_{sp,2}$	6.994	°C
Apparent Thermal Conductivity of the Specimen	λ_{sp}	**0.070**	W/m·K

λ_{cork}=0,052 W/mk

$\lambda_{polystyrene}$=0,032−0,040 W/mk

SUSTAINABLE-BUILDING MATERIAL: *NEW MATERIAL*

- ✓ Sustainable composite material for the production of bearing and non-bearing elements.

Straw

+

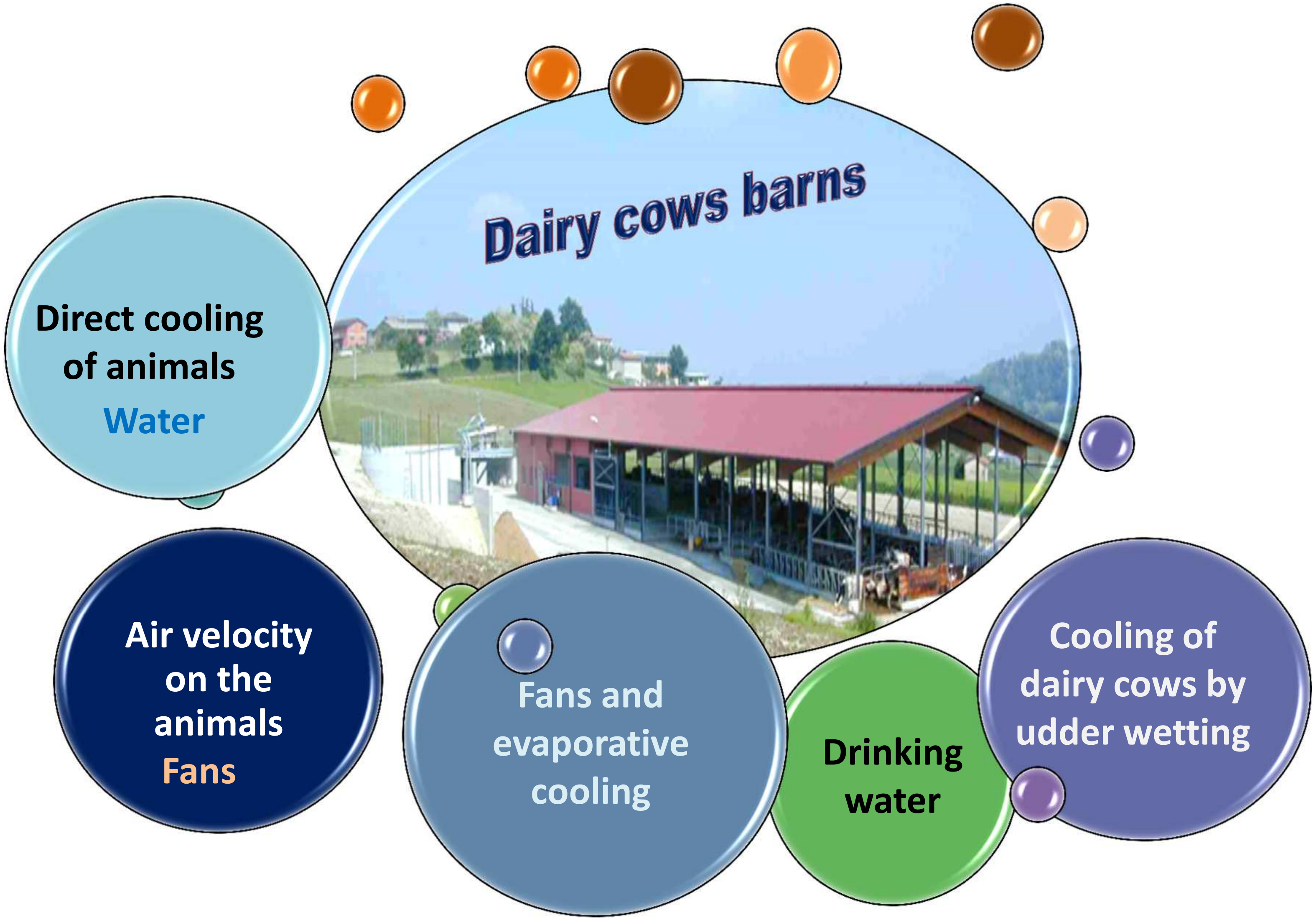
Bioplastic

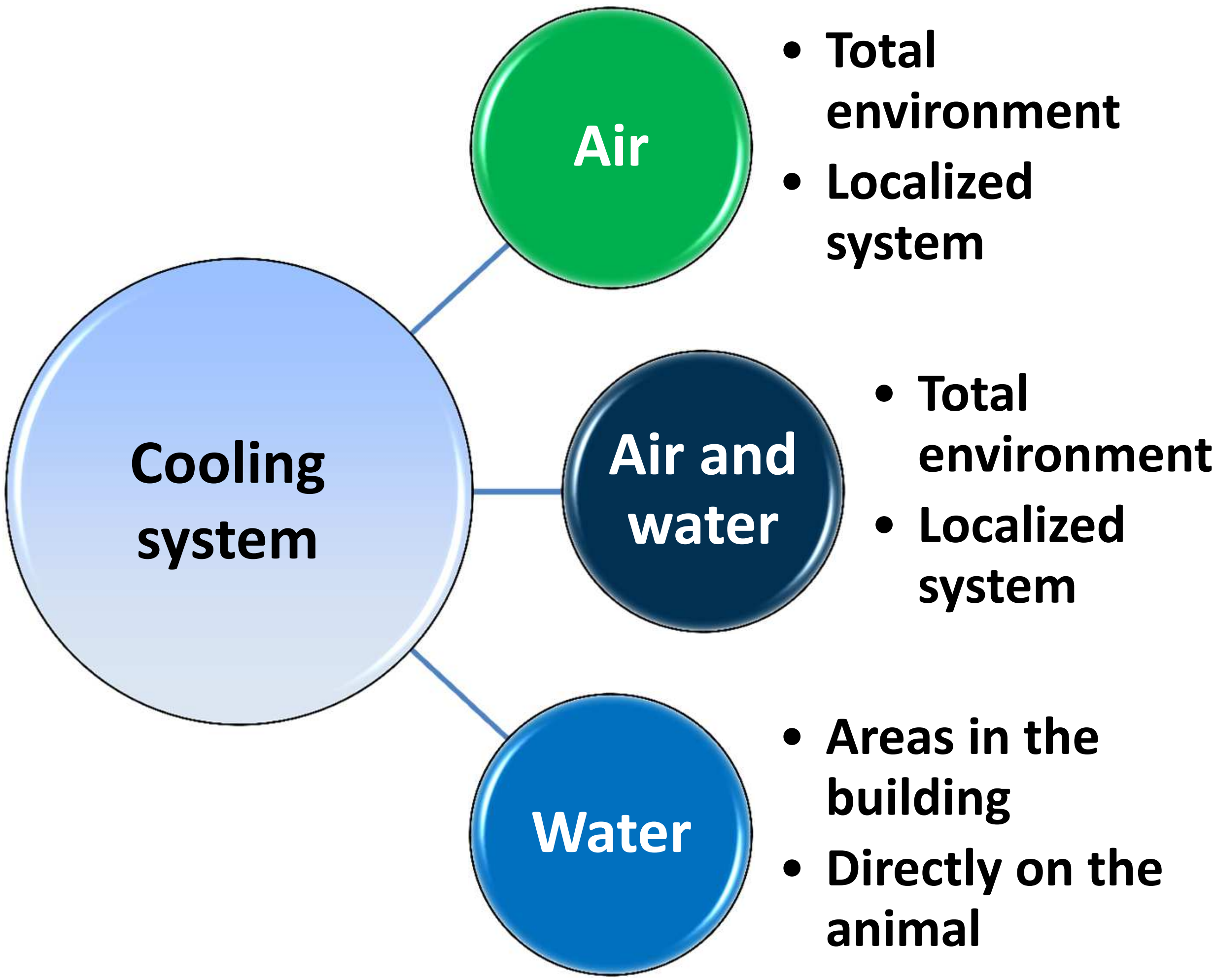
=

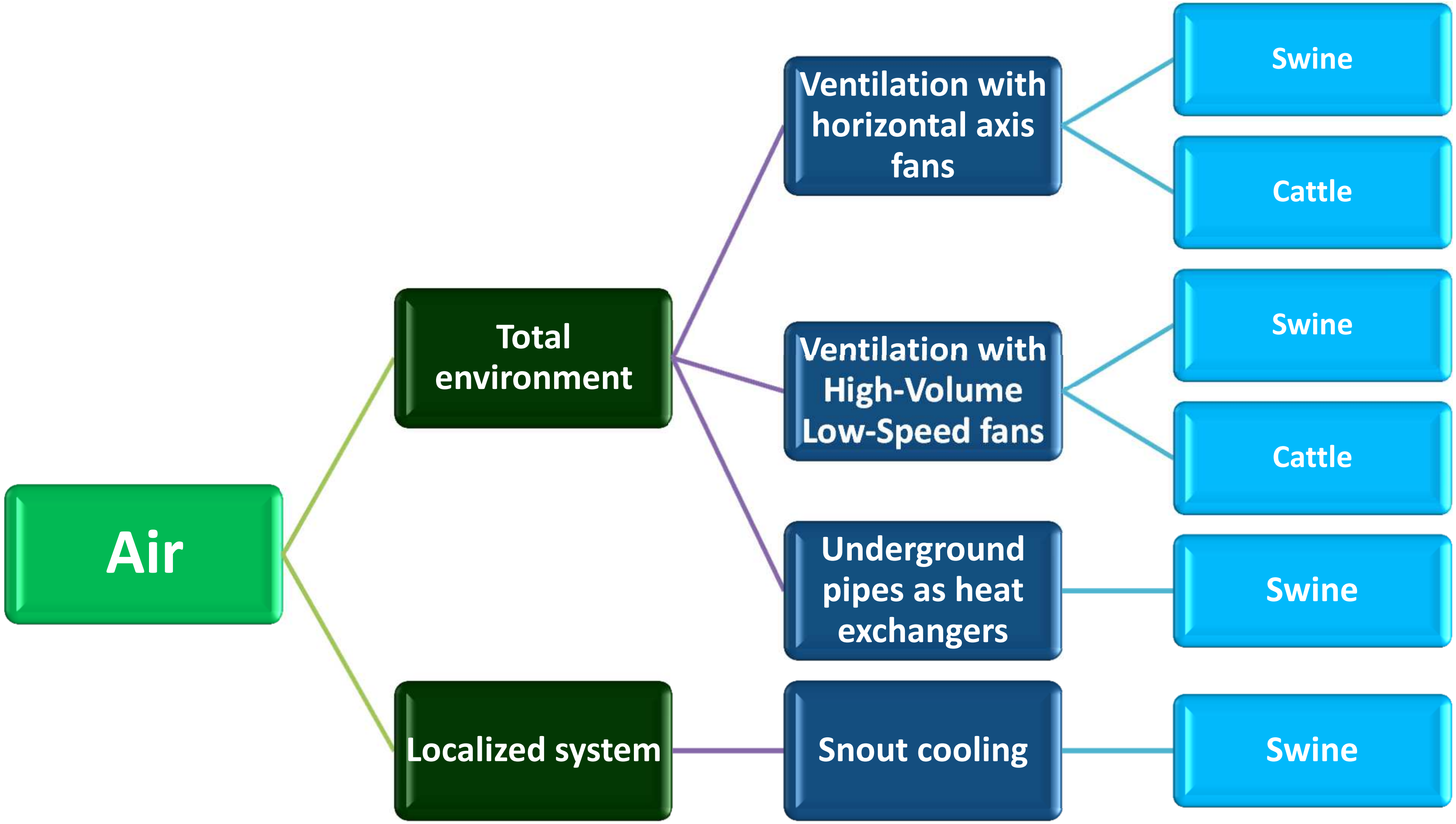
Applications:

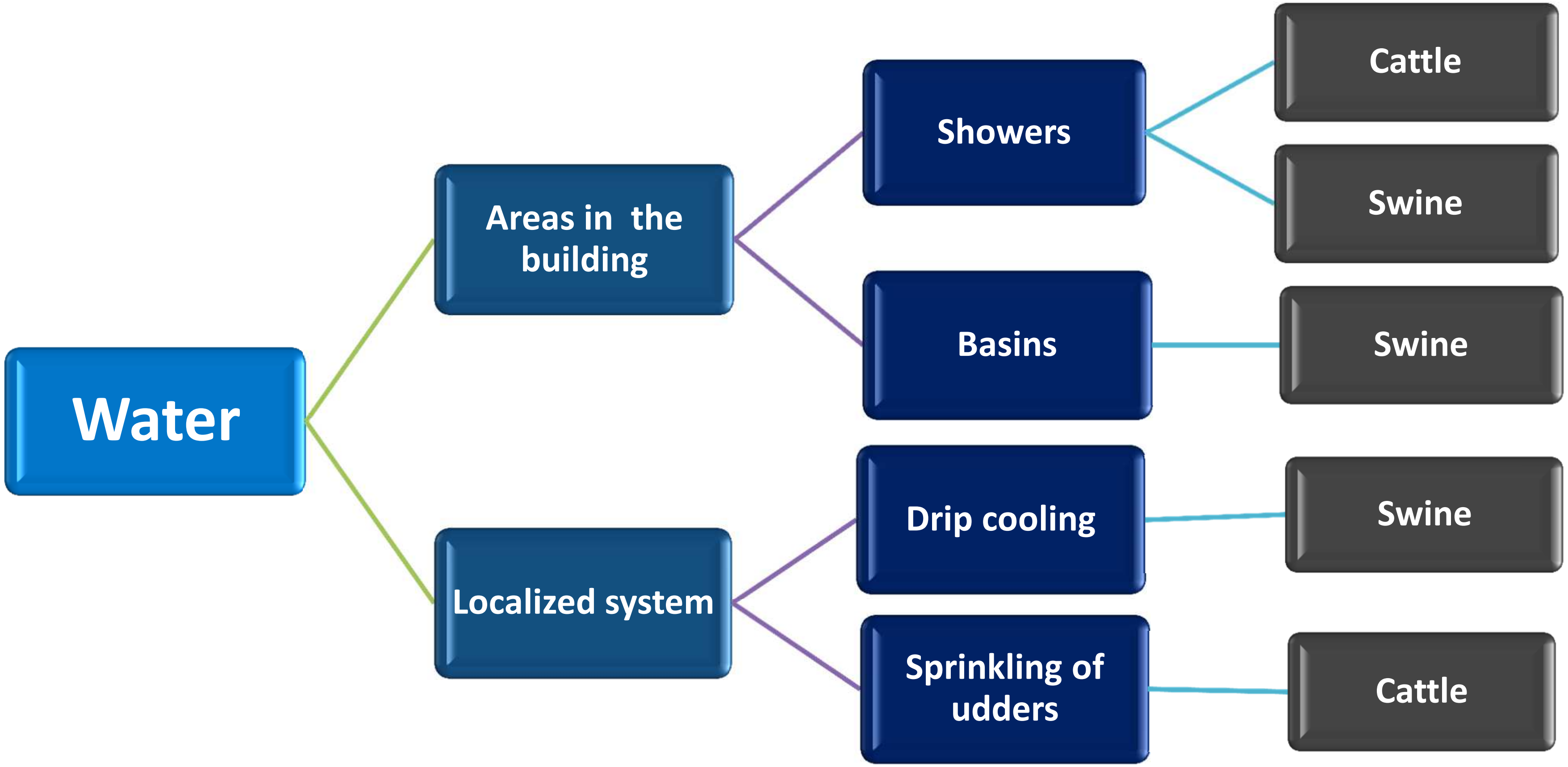
- Structural bearing blocks;
- Insulating panels;
- Packaging;
- ………

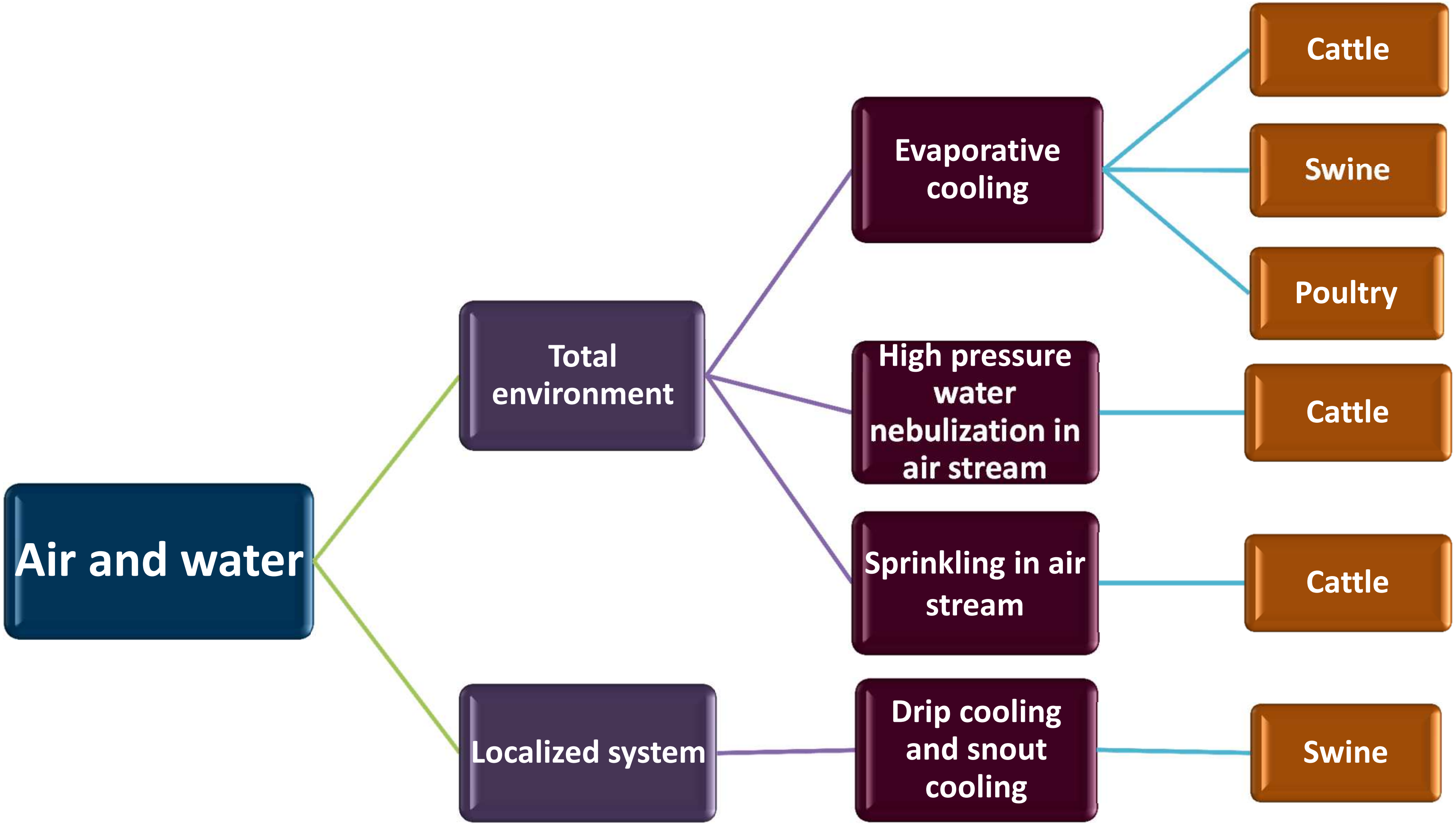
ACTIVE TECHNIQUES FOR HEAT PROTECTION

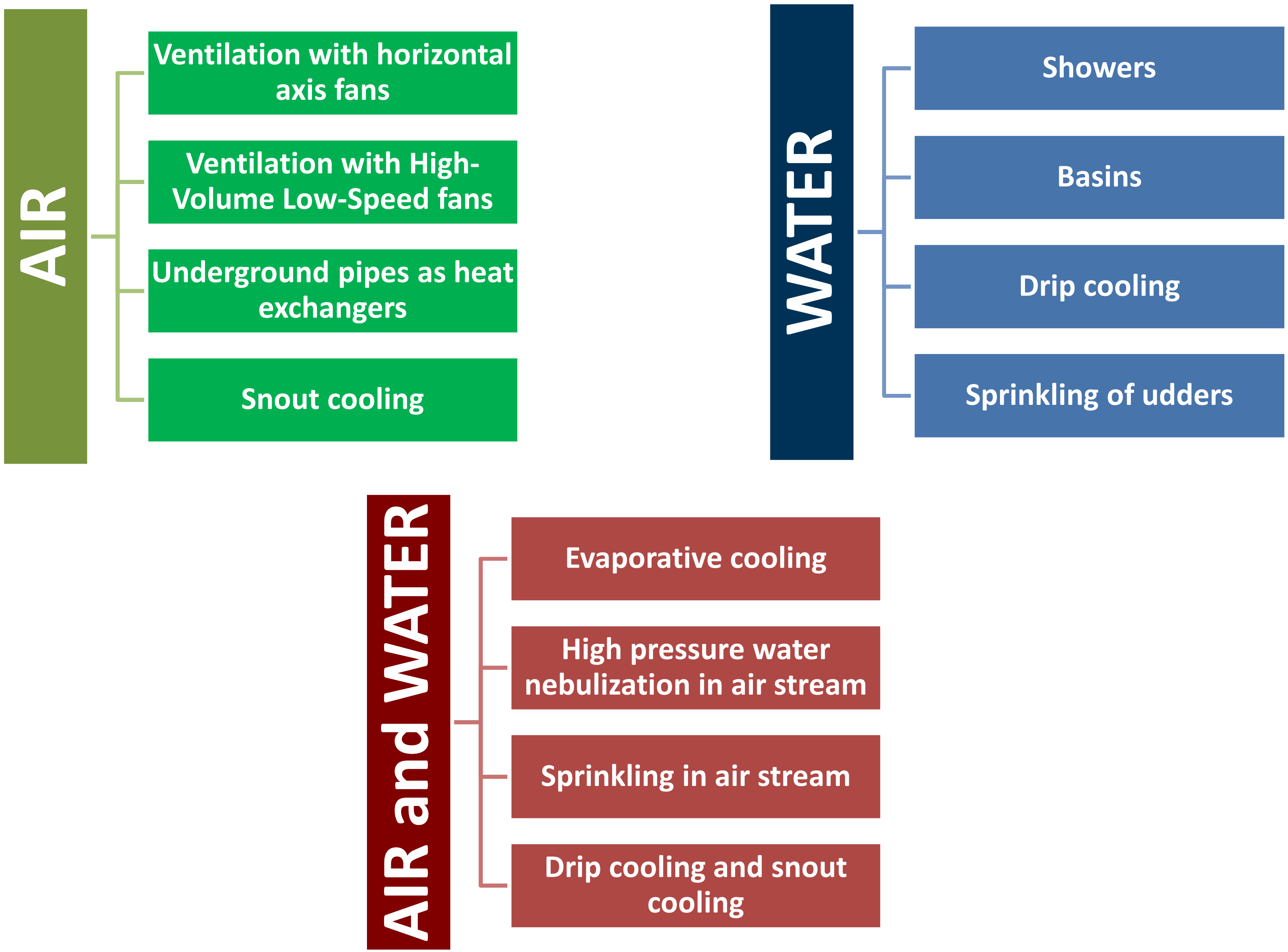



Cooling system
Air
• Total environment
• Localized system
Air and water
• Total environment
• Localized system
Water
• Areas in the building
• Directly on the animal


Air
Total environment
Localized system
Ventilation with horizontal axis fans
Ventilation with High-Volume Low-Speed fans
Underground pipes as heat exchangers
Snout cooling
Swine
Cattle
Swine
Cattle
Swine
Swine


Water
Areas in the building
Localized system
Showers
Basins
Drip cooling
Sprinkling of udders
Cattle
Swine
Swine
Swine
Cattle


Air and water
Total environment
Localized system
Evaporative cooling
High pressure water nebulization in air stream
Sprinkling in air stream
Drip cooling and snout cooling
Cattle
Swine
Poultry
Cattle
Cattle
Swine


AIR
Ventilation with horizontal axis fans
Ventilation with High-Volume Low-Speed fans
Underground pipes as heat exchangers
Snout cooling
WATER
Showers
Basins
Drip cooling
Sprinkling of udders
AIR and WATER
Evaporative cooling
High pressure water nebulization in air stream
Sprinkling in air stream
Drip cooling and snout cooling

COOLING OF ANIMALS BY AIR

AIR VELOCITY ON THE ANIMALS

The heat stress can be contained increasing the **air velocity on the skin of animals**

- ⇨ heat dissipation by convection is favored
- ⇨ skin evaporation is boosted

Air movement techniques are based on the use of **big fans** placed inside the building. In such a way **air streams** at animals' level are created.

COOLING OF ANIMALS BY AIR

VENTILATION WITH HORIZONTAL AXIS FANS

Ø 0.9 – 1.2 m
Inter-axis 9 – 12 m
Inclination 15-30°
Air velocity 3 m/s

VENTILATION WITH HORIZONTAL AXIS FANS

Placed in waiting area, feeding area

VENTILATION WITH HORIZONTAL AXIS FANS

VENTILATION WITH HIGH-VOLUME LOW-SPEED FANS - HVLS

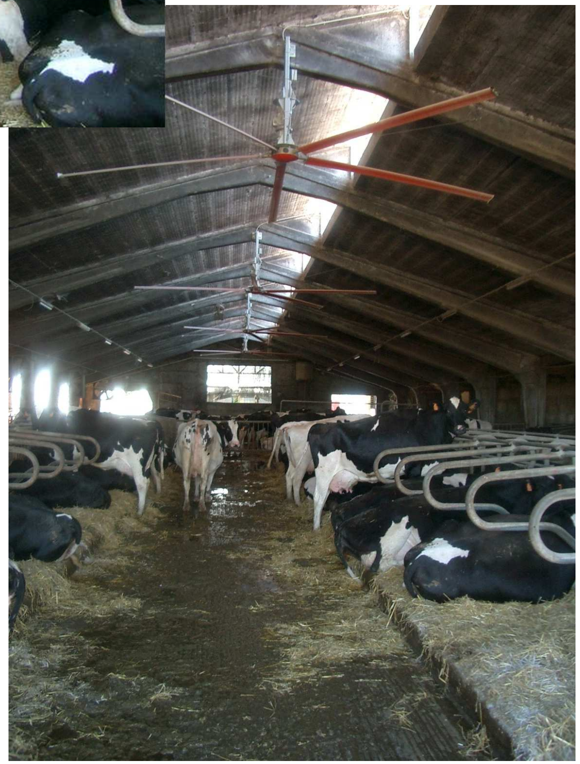
Big fans with vertical axis rotation blades, able to develop high air volumes at low speed

Ø 5 – 7.3 m
H 4.0 – 5.5 m
Inter-axis 16 – 20 m
Air flow rate till 250.000 m³/h
Air velocity 0.5 – 1.5 m/s

In the last years increasing interest on this kind of fans

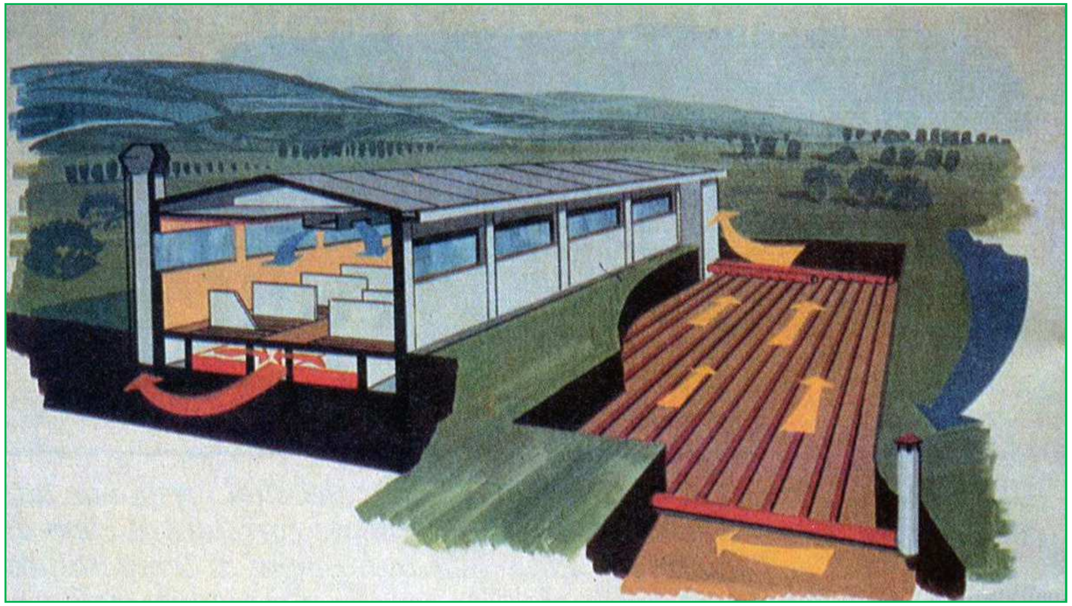
Aim to create an air flow directly towards the lower part. Then the air has a radial distribution.

Experimental trials carried out in this barn, immediately after the installation of vertical axis rotation blades



COOLING OF ANIMALS BY AIR

UNDERGROUND PIPES AS HEAT EXCHANGERS FOR AIR COOLING



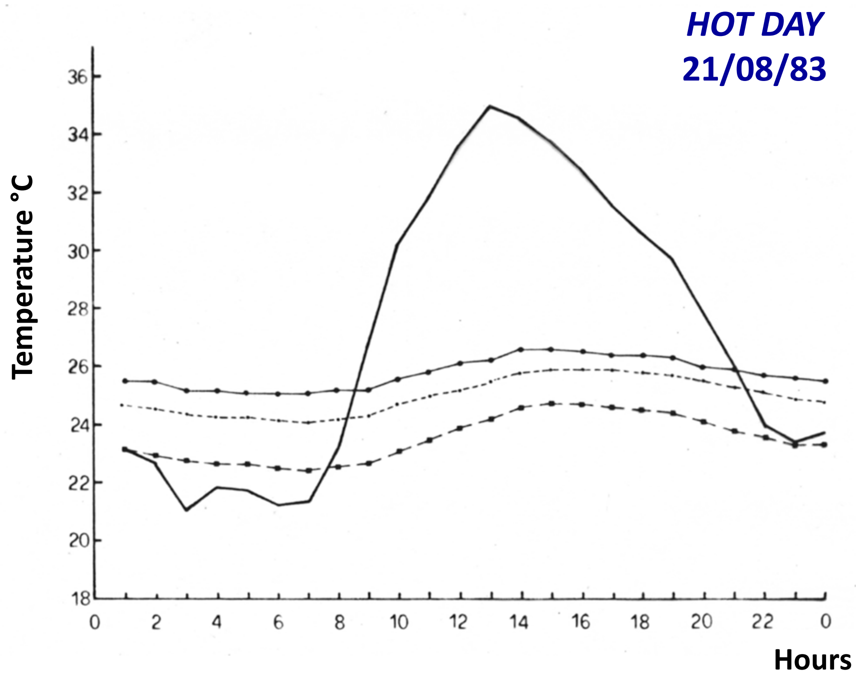
Earth-tube systems pre-heat or pre-cool incoming ventilating air by drawing it trough drainage tubing buried beneath the soil surface.

The soil at a sufficient depth maintains a more or less constant temperature during all the year.
Carrying the air inside buried pipes, which work as heat exchangers, it is possible to heat the air in winter and to cool in summer.

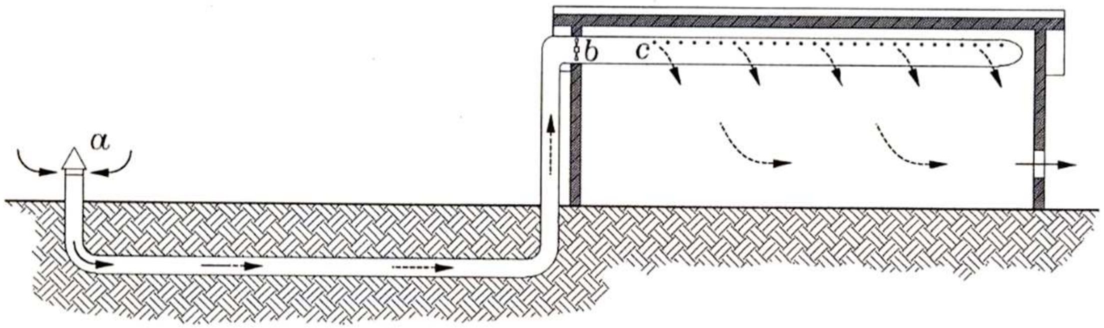
The main effect of buried pipes is to reduce the daily thermal excursions. Also the variations among different season, can be limited., without to use specific regulation electronic control unit.

Since the early exploration of its use in cooling commercial livestock buildings (Scott *et al*., 1965) there has been considerable increase in its application.
Buried pipes have been used to condition the air in livestock buildings (Spengler and Stombaugh, 1983).

First trials University of Bologna *(Barbari and Chiappini, 1983)*

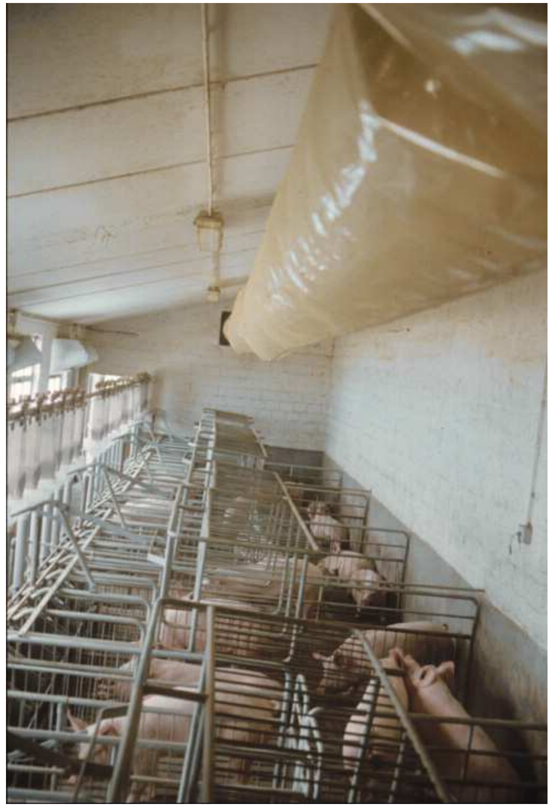


PVC, 120 mm diameter, 2.00 m depth
PVC, 120 mm diameter, 1.20 m depth
PVC, 200 mm diameter, 1.20 m depth



UNDERGROUND PIPES FOR AIR COOLING

Underground pipes plant applied in a pig farm of University of Bologna (1991)



Cooling effect - Drop of air temperature

In international literature, usually a drop of air temperature of 6 – 15°C is considered (USA, Center Europe).
The difference between the outside temperature and the temperature coming out from the pipes is as greater as higher is the outside temperature.
In relation to the period of the year: better performances at the beginning of summer.

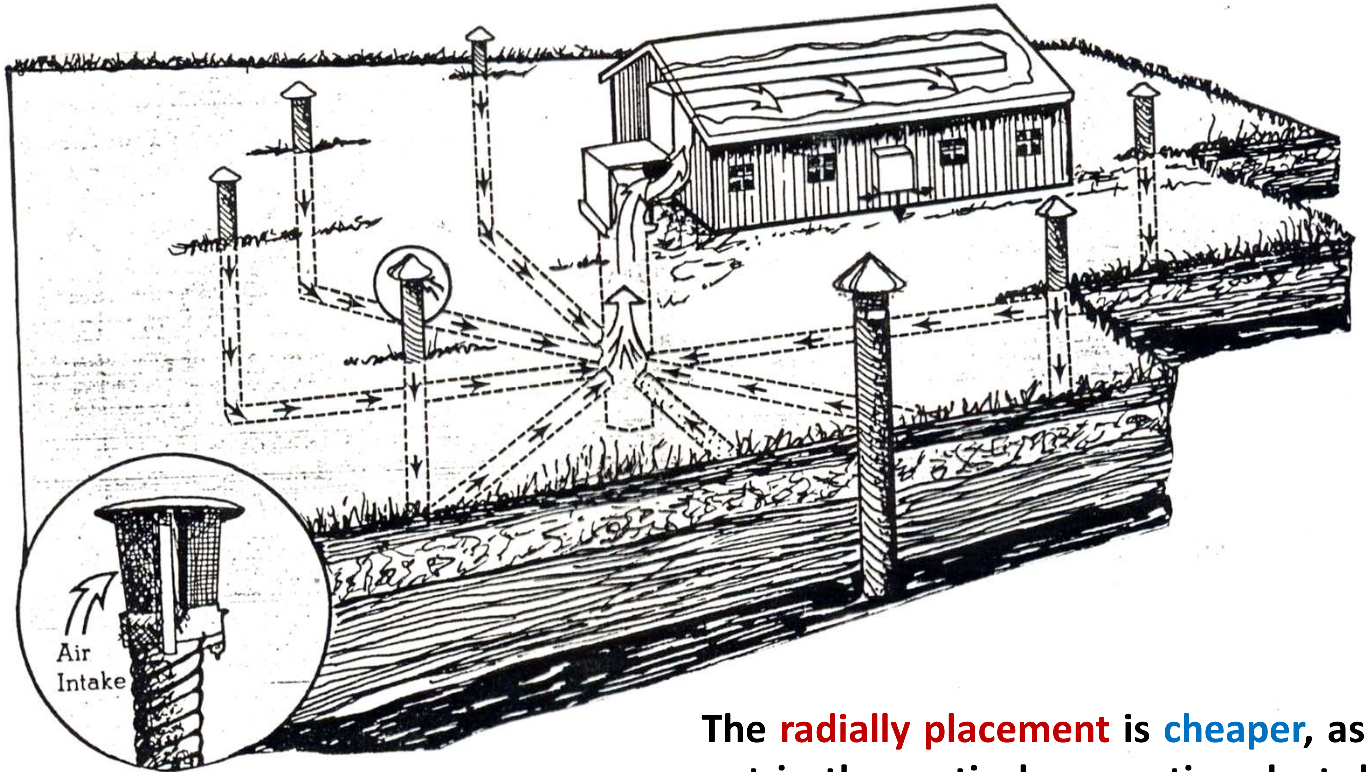
Mitigation of thermal excursions

Another positive aspect of the plant is given by the mitigation of thermal excursions.
The reduction of thermal excursions is related to the big «thermal inertia» of the soil, which gives a lag of the temperature peaks.

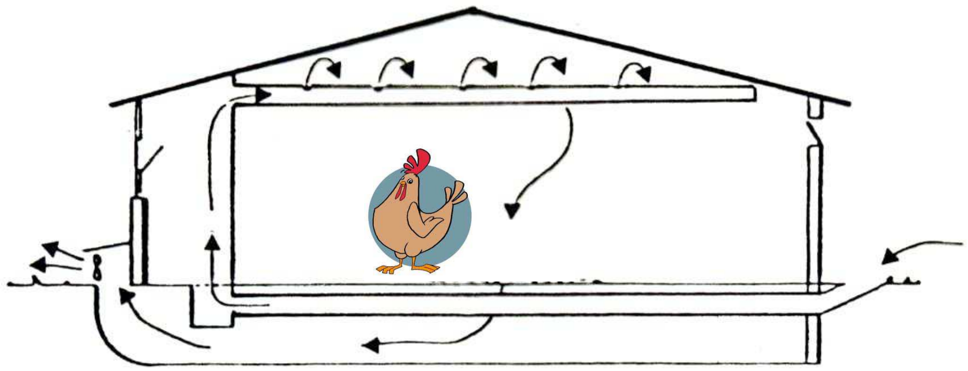
- **Lag in temperature peaks between outside air and air coming out the pipes.**
- **Greatly reduced also the excursions between the day and the night. Constant temperatures are guaranteed without using regulation systems.**

Placing of pipes in the soil in relation to the building

- In parallel
- Radially



The radially placement is cheaper, as the pipes are directly put in the vertical connection duct, but it requires a great surface of ground in the immediate vicinity of the building.



Placement in parallel under the building or placed parallely to the walls of the building. Solutions suitable in cases where it is important to heat the air, instead of to cool it.

DESIGN CRITERIA

Little quantitative design information is available to permit the specification of earth-tube systems that will perform with optimal economic effectiveness.

Parameters influencing performances

- Characteristics of the soil
- Burying depth
- Diameter of the pipe
- Length of the pipe
- Number of pipes - distance of pipes
- Materials
- Shape of the pipe
- Air velocity
- Ventilation rate
- Characteristics of the fan

Dimensioning

The sensible **heating** or **cooling** rate of the exchangers is given by:

$$\mathbf{Qexch = Mexch \cdot Cp \cdot (Tpi - Tou)}$$

where:

Qexch = heating or cooling rate of the exchanger (**kW**)
Mexch = mass air flow rate of the exchanger (**kg/s**)
Cp = specific heat of air = 1,005 (**kJ . kg-1 dry air . °C-1**)

Murray and Britton (1985), Britton (1987) measured the performance of four PVC pipes of 30 m long with diameter of 150 mm and 250 mm.
The heating rate of energy obtained varied from 1,00 to 1,26 kW per pipe for an outside temperature of -20°C.

Characteristics of the soil

a) **Geographic characteristics**: latitude, altitude, climatic conditions
b) **Local characteristics**: surface and conformation of the ground, shading, ground water table, presence of buildings or other equipment/plants
c) **Soil characteristics**: thermal properties of the soil

Data on soil temperature

In the phase of plant design, statistical data on the soil temperatures are required.
Mathematical models have been proposed, but the number of variables is very high and not easy to define.

The air temperature influences the soil temperature, but arriving in the depth layers, it is softened. So the soil never reaches the air temperature peaks.
At **2.0 – 3.0 m** the fluctuations are little significant, while the stationary state is reached at **7-12 m**, in relation to the thermal diffusivity of the soil ($m^2\ s^{-1}$, velocity at which the heat spreads inside the soil), which is maximum in heavy and humid soils.

Kind of soil	Density Kg/m^3	Thermal conductivity $W/m°C$	Thermal diffusivity m^2/day
Medium rock	854,4	7,9	10,3
Heavy wet soil	639,6	4,2	6,5
Heavy dry soil	610,3	2,8	5,2
Ligth wet soil	488,2	2,8	5,2
Ligth dry soil	439,4	1,1	2,8

Thermal properties of the soil (ASHRAE, 1978)

Thermal performance at a given flow rate is not affected significantly by tube material or diameter or by soil type for a wide variety of clay and silt-loam soils as long as **soil moisture is greater than 50% of saturation**.

Burying pipes

For our purposes particularly interesting are the temperatures between 1 ÷ 3 m

Above 1 m of depth the soil is already affected by the daily cycle of air temperature and of sun radiation.

Below 3 m of depth the yearly temperature fluctuations are very little.

In practice the analysis of the soil temperatures can be limited at depths between 1 and 2 m. Burying pipes below 2 m is excessively expensive.

International literature
In different plants cited in literature, the pipes have been placed at depths between 0.8 ÷ 3.0 m

Ground water table
Burying pipes below the level of ground water table gives greater certainty to keep constant temperatures during the whole year.

Objection: the water, which surely enters in the pipe, obstructs the air flow, compromising the good working of the plant.

Diameter of the pipe

Pipe diameter, at equal air flow capacities, does not influence very much the thermal performances, but has a considerable effect on pressure losses and consequently on the energy consumed by the system.

The choice of diameter is related to 2 main factors:

- **Length of the pipe**
- **Ventilation volume**

The diameter should be calculated taking into account the air amount necessary to cool the environment.

International literature

In different plants cited in literature, the diameter is considered between 10 ÷ 45 cm

Pipes less than 10 cm are not recommended because they give a limited air flow in relation to the costs

Length of the pipe

Soil-air heat exchange varies significantly with flow rate and tube length
Longer are pipes, bigger the possibility of heat transfer
Pipes should always be enough long to **guarantee temperature constancy** throughout the day

The optimum length of the pipe varies in relation to the diameter and to the ventilation air flow rate. Anyway other factors influence the choice of the length, such as: kind of pipes, temperature and humidity of the soil, burying depth, vegetation on the ground.

➡ *the length cannot be calculated by a simple mathematical equation.*

International literature
In different plants cited in literature, the length is variable between 12 ÷ 120 cm. On average 35-40 m. Pipes too long, coupled with a little diameter, require a powerful fan. Preferable to increase the number of pipes, reducing the length.

- **In practice, with pipes 20 cm diameter, length of 4-7 m / 100 m^3 of air flow are suggested**

Number of pipes

Install enough tubes to obtain the total ventilation rate required.

Distance of pipes

Several trials have underlined that the soil temperature fluctuations, due to the continuous passage of air, **regard only the first 25 cm of soil from the pipe**.

At **50 cm** of distance from the pipe the soil temperature is very close to the temperature collected at 1 m and 10 m.

In practice **a distance of 2 m between pipes** gives a margin of absolute safety.

Materials

Different materials can be used:

- **Aluminum**
- **Steel**
- **Concrete**
- **Bricks**
- **Plastic (PVC, Polypropylene)**

Advantageous of plastic materials:

- **Low costs**
- **Easy to install**

Shape of the pipe

Several alternative solutions are available on the market for plastic materials: different kind of materials, shape and presence or not of holes.

A lot of researchers suggest **corrugated plastic pipes**:

- **Increase of air turbulence**
- **Greater contact surface (pipe-ground)**

→ Corrugated pipe promote slightly more efficient cooling

Disadvantage – the corrugated pipe gives **high resistance to the air passage (marked increase in pressure loss)**, so the maximum ventilation volume in a corrugated pipe is considerably lower (**about 30%**) than the one obtained by smooth PVC pipes, of the same diameter.

Presence of holes in the pipe

Some researchers are favorable to the **presence of holes**, which favor the drainage of water. However, the presence of holes can favor also the entry of water (high water table).

Condensate water

To eliminate the water stored inside the pipes it is better to use a **losing sump**, in correspondence of the vertical duct placed close to the fan, in which all the pipes enter.

To favor the collection of the water in the sump, the pipes have to be put with a **light slope** from the entrance to the sump (**0.5-1.0%**).

Air velocity

Soil-air heat exchange varies significantly with flow rate and tube length.

The air velocity into inside the pipe is another fundamental element in order to optimize the performances of the plant.

The air has to flow inside the pipes
- at a **not too high velocity**, in order to not have frictions which can cause heating in the pipes,
- at a **too low velocity**, in order to overwork completely the cooling capacity of the pipe.

International literature
In different plants cited in literature, the air velocity is between 2 ÷ 6 m/s

Ventilation rate

Install enough tubes to obtain the total ventilation rate required.

Dimensioning
Cow 500 kg, milk daily yield 10 kg: 250 m^3/h (*summer situation – Qs 270 W – Δt 3*)
Pipe 20 cm diameter, 42 m length, air velocity 6.3 m/s = **3 cows**

Characteristics of fan

The choice of the fans for power and number is related to the length, to the number and diameter of pipes.
The power absorbed by the fans, under the same conditions of air flow rate, is related to the pressure drops caused by the passage of the air in the pipes.

Other characteristics of plant

The **pipe mouth** where air intake is effected should be kept **free**.
Protection from rain and interference from animals and insects should **in no way hinder air flow**.

Summary of proposed characteristics	
Air speed in the pipes	4 m/s (max 6 m/s)
Diameter of the pipes	15 – 25 cm
Length of the pipes	4-7 m /100 m^3/h
Depth of the pipes	1.5 – 2.0 m

LAST TRIALS

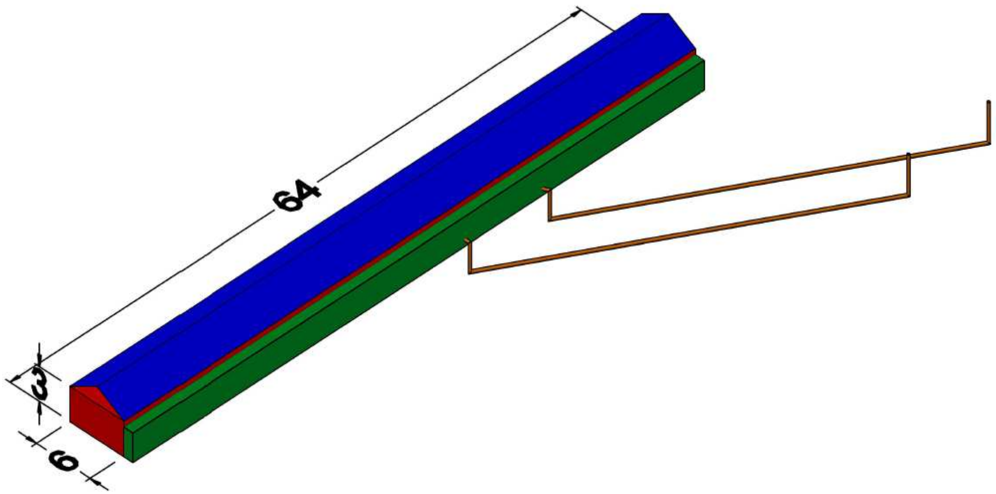
Experiment carried put in Iraq (2013-2014) – Poultry barn

Experiment consisting of 2 parallel series of pipes made up of PVC.

- **Distance between pipes: 5 m**
- **Length of each pipe: 37 m**
- **Diameter of PIPE: 20 cm**
- **Pipes buried at a depth of 2 m**

Slope of 1% given to the pipe to collect the water formed inside because of high air humidity inside.

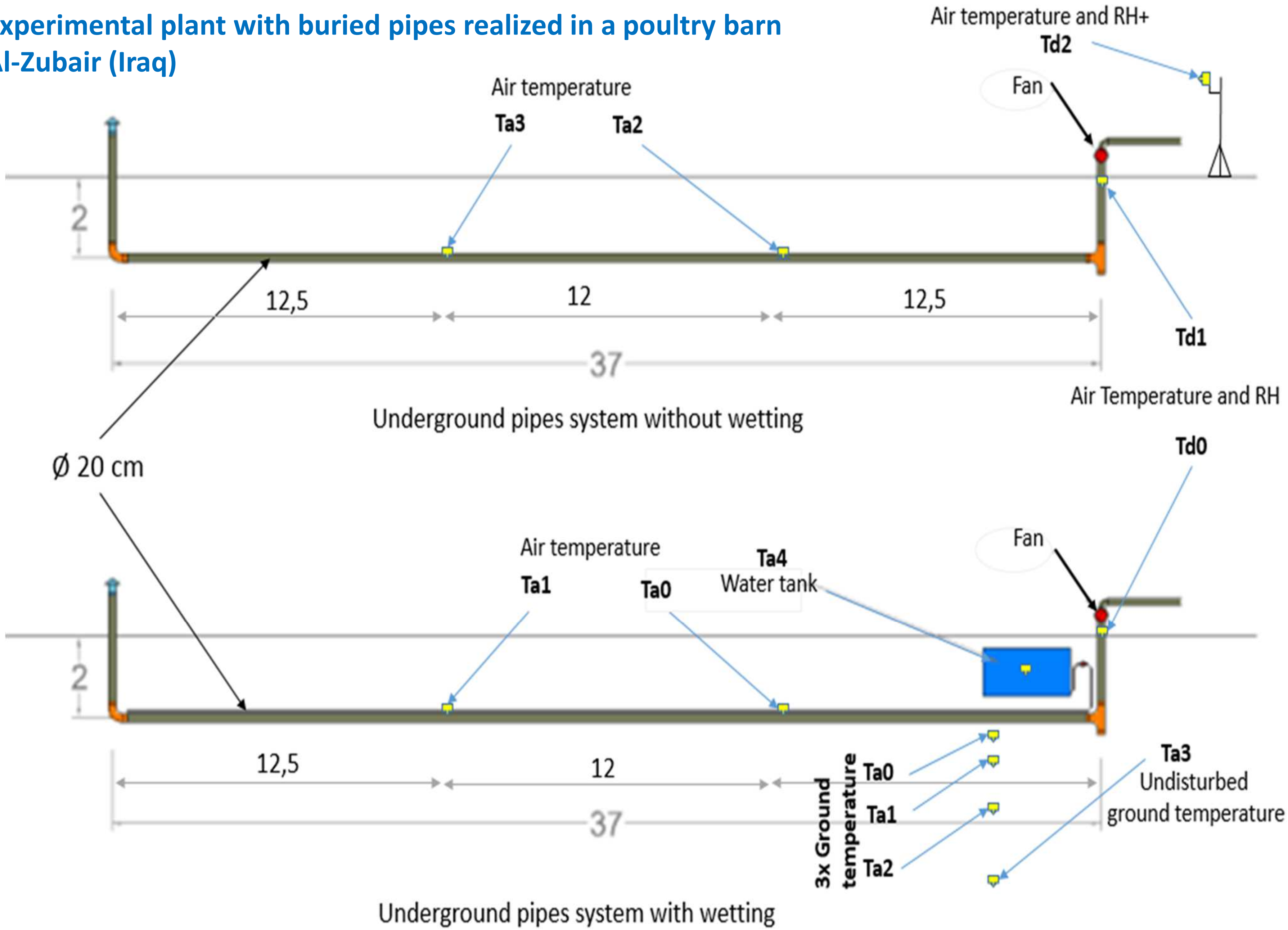
UNDERGROUND PIPES FOR AIR COOLING



A soil layer around one exchanger was wetted, using a drip tubing placed 10 cm above the air pipe, once every 48 hours for 20 minutes.

The wetting system was equipped with a tank 1 m^3 volume, able to contain the minimum amount of water necessary for the wetting of the ground for a period of 5 days.

Experimental plant with buried pipes realized in a poultry barn Al-Zubair (Iraq)



UNDERGROUND PIPES FOR AIR COOLING

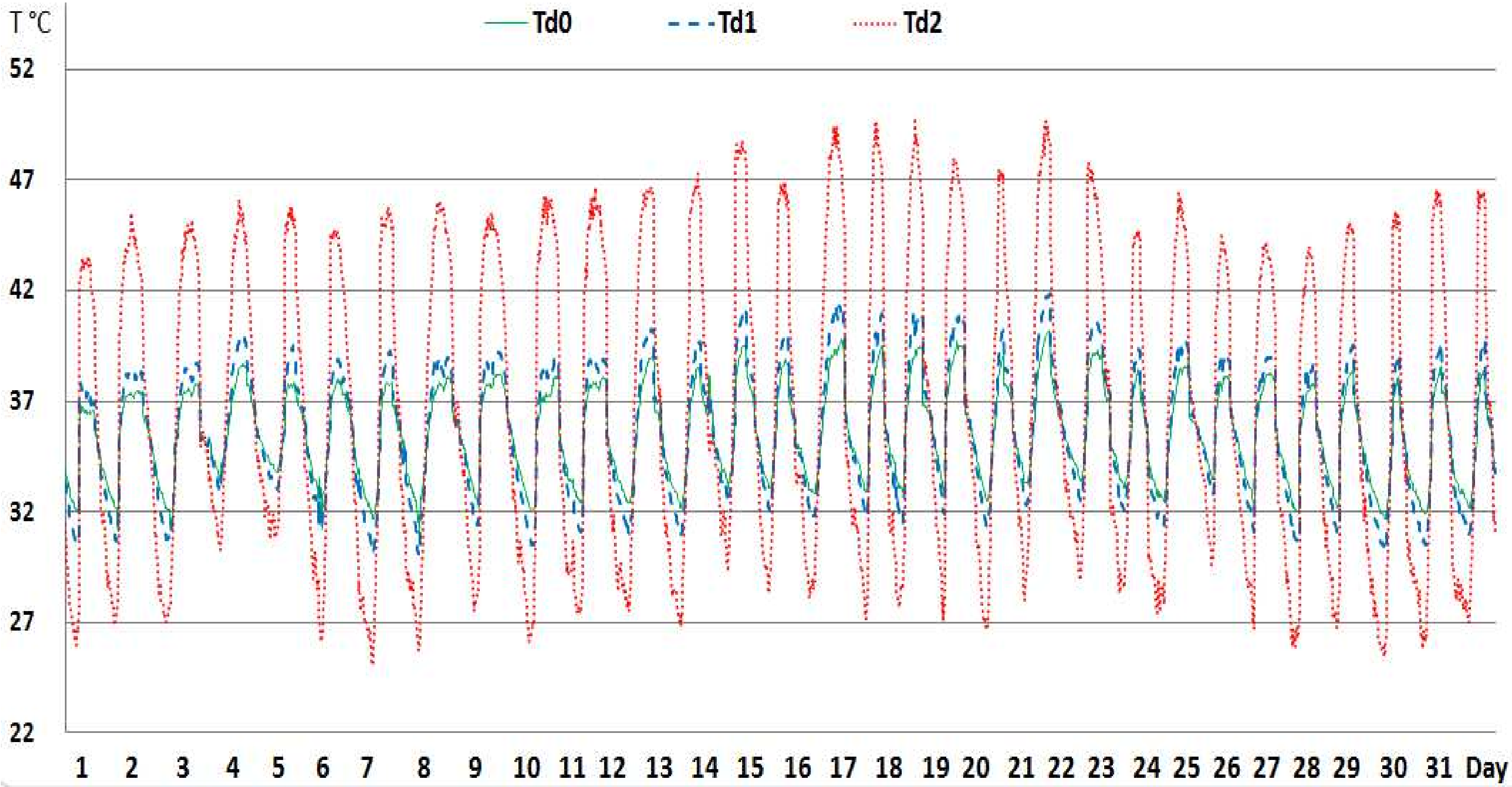
UNDERGROUND PIPES FOR AIR COOLING

Temperatures measured in the experimental period (June2013-February 2014)

	T-ext	Tgr	T-wet	T-dry	Delta_wet	Delta_dry
Mean	25,07	26,89	26,48	26,32	- 1,41	- 1,25
SD	12,24	5,11	8,63	9,09	4,88	4,13
Min	0,00	17,48	9,40	9,10	- 12,50	- 11,20
Max	52,30	32,47	40,60	42,70	12,60	11,00

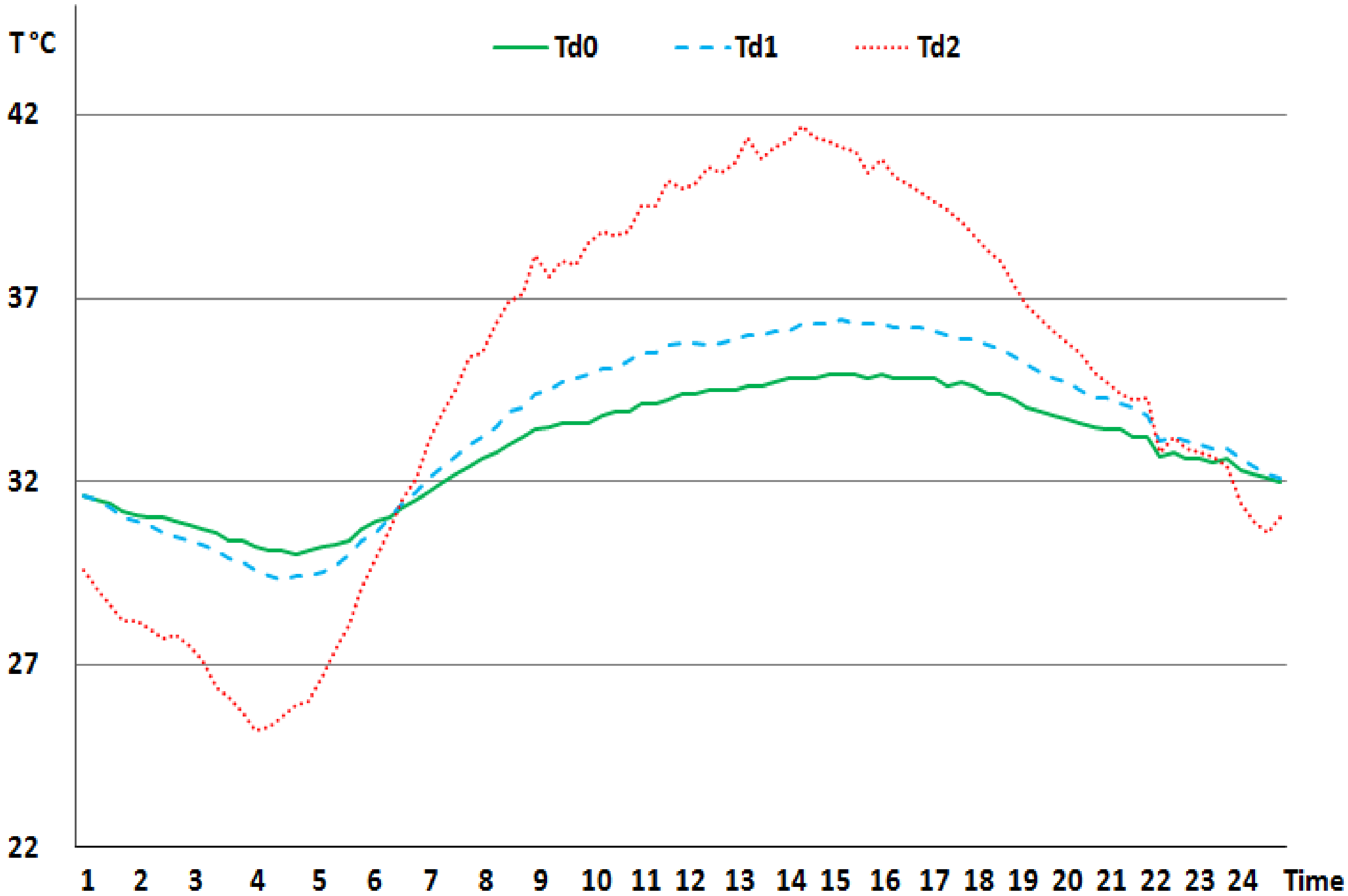
Heating

Cooling



Different temperatures between the inlet and the outlet of pipes, August 2013

Graph of temperatures (12 June, 2013)



Tdi 0: Air temperature (exit of wet pipe)
Tdi 1: Air temperature (exit of dry pipe)
Tdi 2: Outdoor air temperature

RESULTS

Soil wetting around EAHE can improve heat exchange efficiency

By adding a drip water tube, the EAHE reduces more efficiently the incoming air temperature. Thus, a lower temperature leaving the pipes is recorded during the hottest hours when a WE is used in comparison with a DE. The relatively cold soil and water help to cool the air and to reduce electrical costs related to air cooling during the hottest periods.

The underground cooling system, coupled to a wetting system, can be considered as a useful solution to reduce heat stress of animals in poultry barns in hot climate areas.

COOLING BY MEANS OF AIR AND WATER

EVAPORATIVE COOLING

Process of adiabatic saturation: the air presents a reduction in temperature without changing the total amount of heat, that is its enthalpy

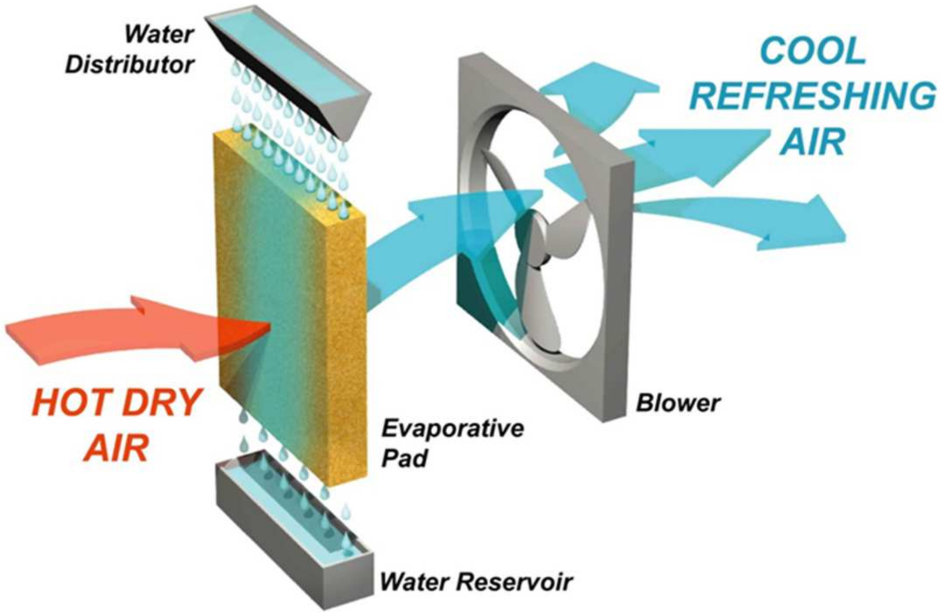
The process is based on the principle that a substance, in the passage from liquid state to vapor, absorbs heat, which is removed by the surrounding environment

The process of water evaporation requires about 680 Wh/kg

The plants of EVAPORATIVE COOLING can be very simple

- **EVAPORATIVE PANELS/PADS**
- **ADIABATIC CHESTS**
- **EVAPORATIVE MISTING**

One of the main evaporative cooling systems is the pad cooling or pad-and-fan system.
This system is based on forcing outside air into the building through a wet pad which humidifies and cools the air



Evaporative cooling systems can find application in particular conditions, provided that the plant is rightly designed and carefully managed.

The cooling results are in relation to:

- Capacity of the air to acquire vapor
- Efficacy of the humidifier equipment

The amount of thermal contraction is in relation to the hygrometric value: the lower is the hygrometric value, the more is the vapor that can be put in the air flow, then the more elevate can be the drop of temperature.

Obviously the system works better in conditions of hot dry climate.

Compared with the sprinkling and with the fogging systems some disadvantages are remarked:

- Air must be forced to the pad
- Significant temperature and humidity gradients along the buildings are created

Poultry - Laying hens
Broilers

Dairy cattle

Pigs – Growing/fattening
and Reproductive

DESIGN CRITERIA

Factors influencing performances

- Materials
- Size of pads
- Velocity of the air through the pad
- Thickness
- Position
- Water circulation
- Temperature of water
- Orientation

Materials

The simplest pads are:

double metallic or plastic net with interposed wood shavings (or other permeable materials).

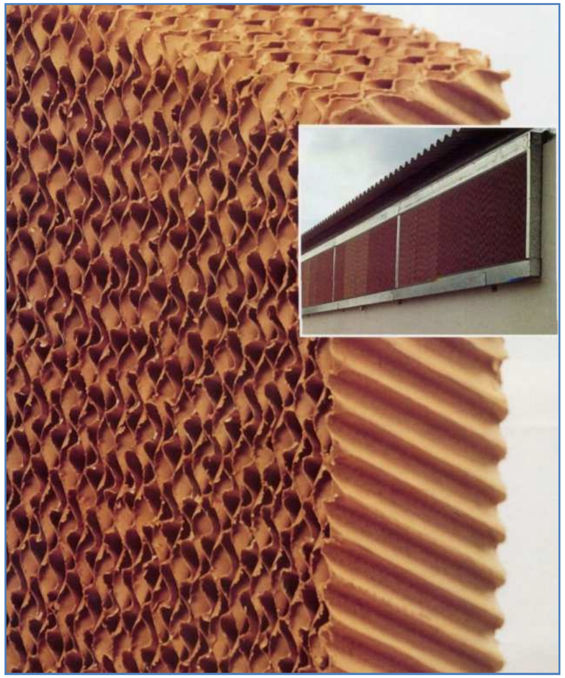
Due to the obstruction caused by dust and limestone, they have to be renewed frequently. If the inserted material becomes compact, the performances drop.

cornstalks

Other more durable materials:

Cellulosic fibers, usually treated with phenolic resins, which assure a great resistance and length to the panels (5 years) and guarantee an excellent imbibition.

Synthetic materials, with long life: glass fiber, polypropylene, PVC. In some cases, to these materials to allow a suitable water imbibition, particular fibers can be applied, such as the viscose fiber.



Air velocity

International literature: **0.65 – 1,50 m/s**, in relation to thickness of the pad. Max. values: **1.25 – 1.50 m/s**. An air velocity higher than 0.75-1.00 m/s causes a greater resistance to the flow, reducing the efficiency of the fans.

Thickness

2.5 – 15 cm (max value 30 m).
Too thick pads cause a big increase in the resistance to the air flow.

Size of pads

To proportion to the size of building. Calculated dividing the total air volume required in the building by the velocity of the air trough the panel. To calculate the length of the pad system it is necessary to divide the obtained area by the height.
Anyway the height to assure a good distribution of the water should not be higher than 2.4 m.

Position of pads

The horizontal position favors an increase of efficiency of about 5% in relation to vertical position, but the vertical position is not always easy to realize.

Water circulation

Necessary to guarantee optimum performances. Water has to be supplied in amount greater than water evaporated
Water has to distributed on the pads from a pipe in the upper part, generally 2” Ø, with calibrated holes.
To avoid excess of water on the pad’s surface, which could block the air flow reducing the efficiency.
The water in excess should be collect in a box in which also the fresh water is added. The fresh water can be distributed by a water tap with ballcock, which allows to maintain the right level of water.
A pump with high delivery capacity has to be used for water recirculation.

Other factors

PERIODICAL MAINTAINACE Pads and water system require a periodical maintenance. To avoid the growing of algae, it s necessary to place pads and water tank in dark zones.

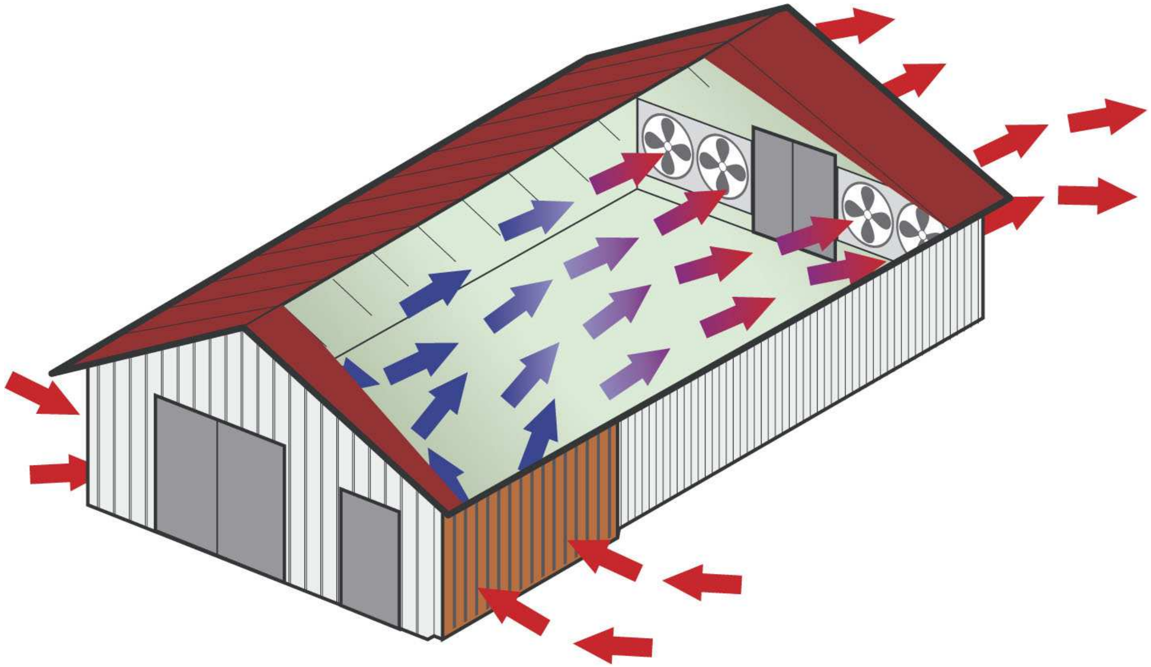
After the stop of the pump it is useful to leave the fans working, so that the pads can get dry.

Placing of pads

Mistakes in the placement of cooled pads can cause not uniform temperatures inside the building.

Shaded panels

Differences between shaded and not shaded panels can be considerable: the drop in the efficiency between a shaded pad on East side and a not shade pad on West side can be relevant (88% to 74%).



Ventilation system

The fans can operate in 2 different ways:
negative pressure or positive pressure

Negative pressure or depressure

- **Lower investment and running costs**.

Disadvantages:

- Scarce uniformity of inside temperature (air courses excessively long)
- Air comes inside the building from all the openings

Among the different solutions to adopt the solutions which reduce the way of the air

Positive pressure

The air enters inside the building, thanks to the increase of pressure.

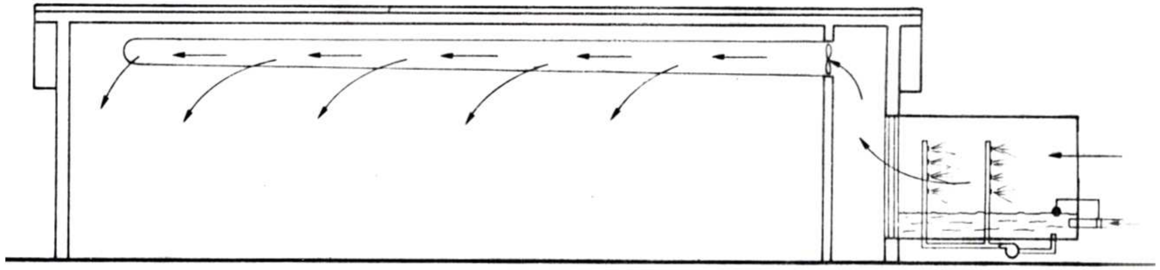
- **Uniform distribution of the air**.

In pressure system a small exercise room is arranged, placed in a end of the building, from which the air after be cooled is sent inside the building trough a duct, usually in polyethylene (fan-jet).

Outside view of cooling panels

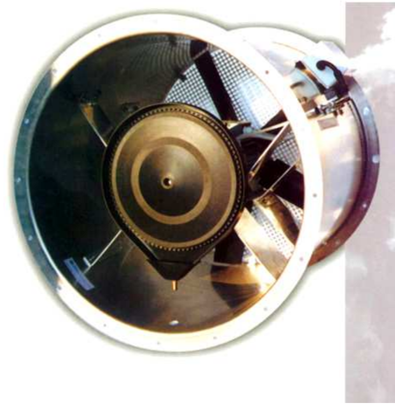
ADIABATIC CHESTS

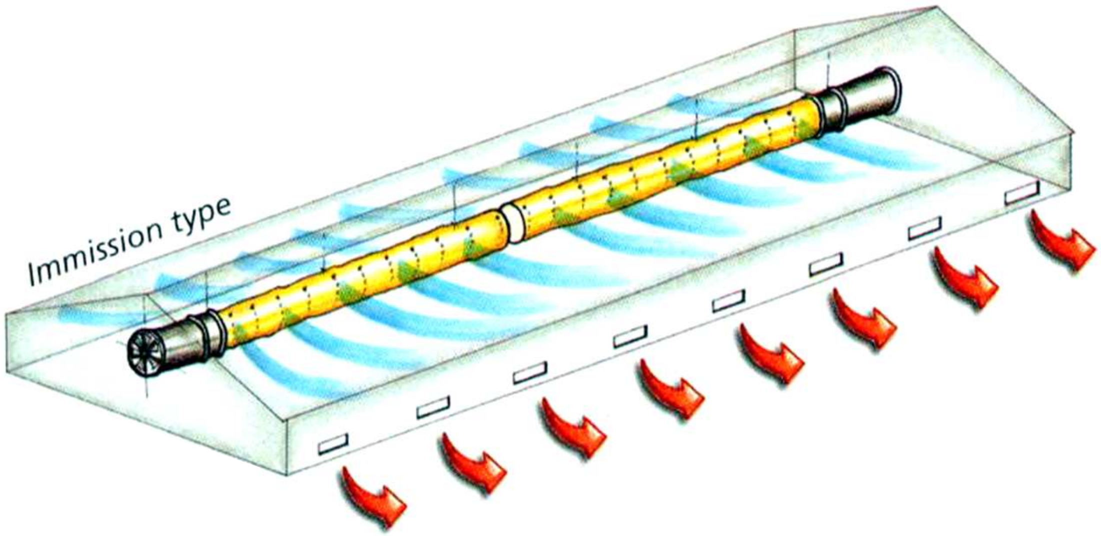
Simple plant: sprayer pipes with nozzles, which nebulize water very finely inside a chest. A high pressure ventilation system is used.
Necessary to use filters to avoid the obstruction of the nozzles.



Air velocity trough the chest not > 0,75 m/s

Efficient plant: system which addresses the water stream on a metallic rotating disk, horizontal or vertical: the rotation at high velocity causes the creation of very small particles (8-10 µ) in the stream of air entering in the building.
A small exercise room is arranged, placed in a end of the building, from which the air after be cooled is sent inside the building through a duct, usually in polyethylene (*fan-jet*).





Another system is based on rotating disk atomizers, which cause a very thin fragmentation of the water, thanks to the centrifugal acceleration given by the rotating disk, without using any nozzles.

EVAPORATIVE MISTING

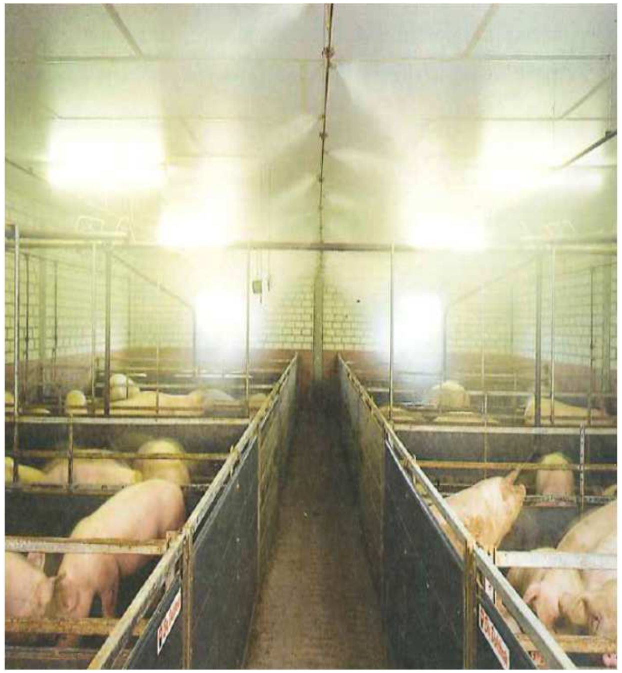
Evaporative misting (fogging) has been shown to be a viable system, effective in **poultry houses** in the **dry-hot areas**.

A misting system sprays small water droplets into the air that reduces the surrounding air temperature in the confinement structure as evaporation takes place.

Evaporative misting systems are **lower in efficiency** compared to the conventional pad systems but have a substantially **lower initial investment.**

The water is sprayed through nozzles in the air, thus very small water droplets form a cloud of fog all over the facility. This cover of small water droplets is evaporated by absorbing heat from the air, leading to a decrease in air temperature.

Evaporative misting is based on the use of nozzles at high pressure (15 ÷ 70 bars), installed on a circuit of PVC or steel pipes.
The hydraulic circuit and the nozzles can involve the full volume of the building, or, when mechanical ventilation is applied, can be placed near the inlets of the air in the building

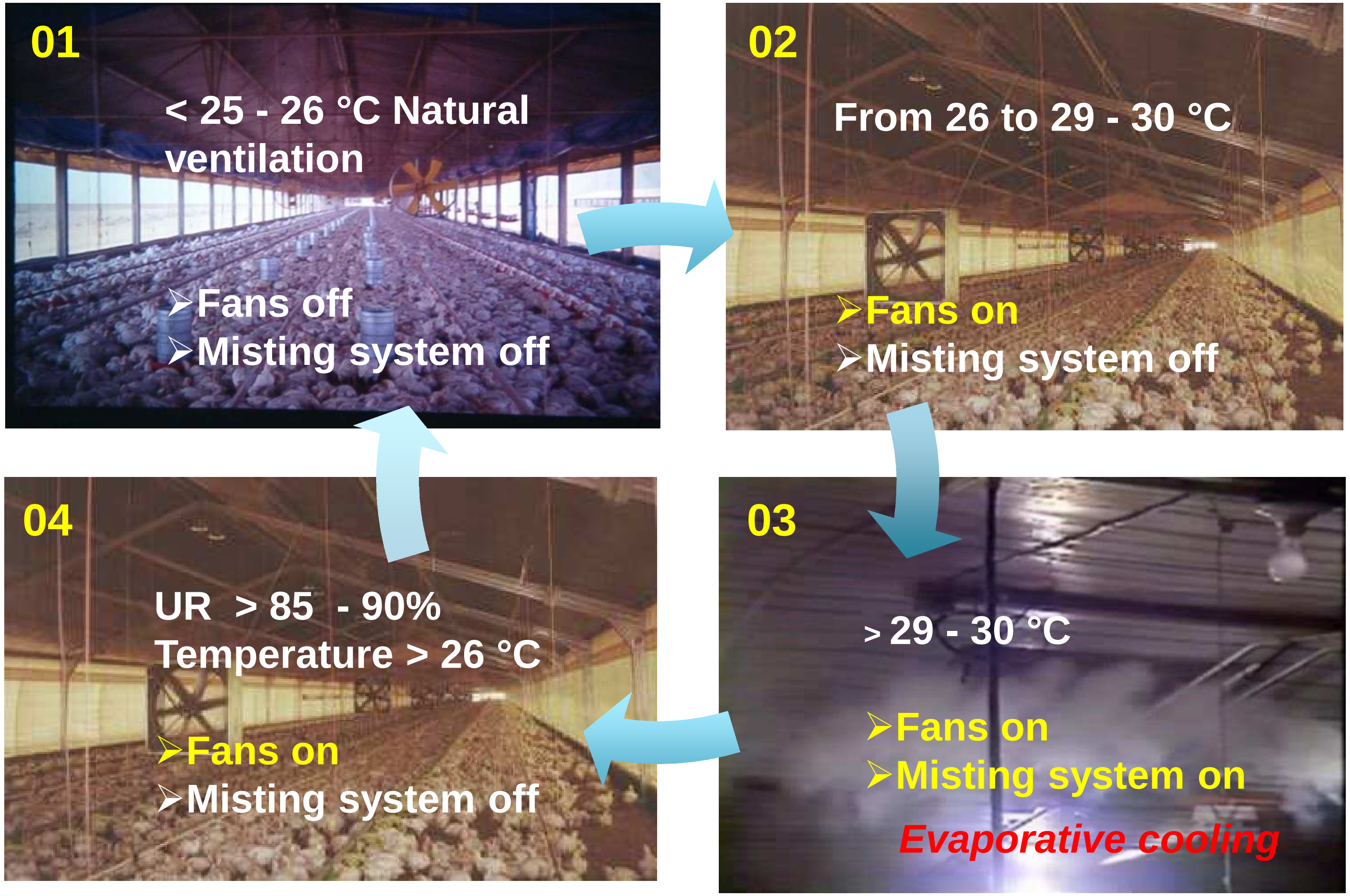


A misting unit can evaporate till 30 l/h of water and can operate directly on the environment with natural ventilation

The misting system requires an accurate control of hygrometric conditions inside the building.
An excess of humidity could cause in short times phenomenon of condensation with consequent dripping of water on the floors and on the equipment.
The water has to be accurately filtered and the circuit continuously checked to avoid obstructions or to verify bad working.

TUNNEL Ventilation System – Positive Pressure

Misting management in poultry barns – Brazil *(kept by I. Tinoco)*



COOLING BY MEANS OF AIR AND WATER

HIGH PRESSURE WATER NEBULIZATION IN AIR STREAM

Use of fans and evaporative cooling

Ø 0.9 – 1.2 m
High pressure (7÷15 bar)
Inclination 15-25°

5°

Water nebulization in air stream

Plants working with high pressure (**7-15 bar**) produce **drops of water** enough **thin** to evaporate suddenly before falling on the animals and on the housing surfaces. In this way a drop of air temperature is produced.

Attention!
If the drops deposit on the hair of cattle without being enough heavy to wet the skin, they form an air interspace, which limit the heat dissipation, instead of increasing it.

System relatively **cheap** and **easy** to be realized.

It can take advantage of the installation of **an electronic control unit** of working times. In such a way the undesirable effects of an excessive wetting of floors with the consequent need to evacuate great amount of wastes can be avoided.

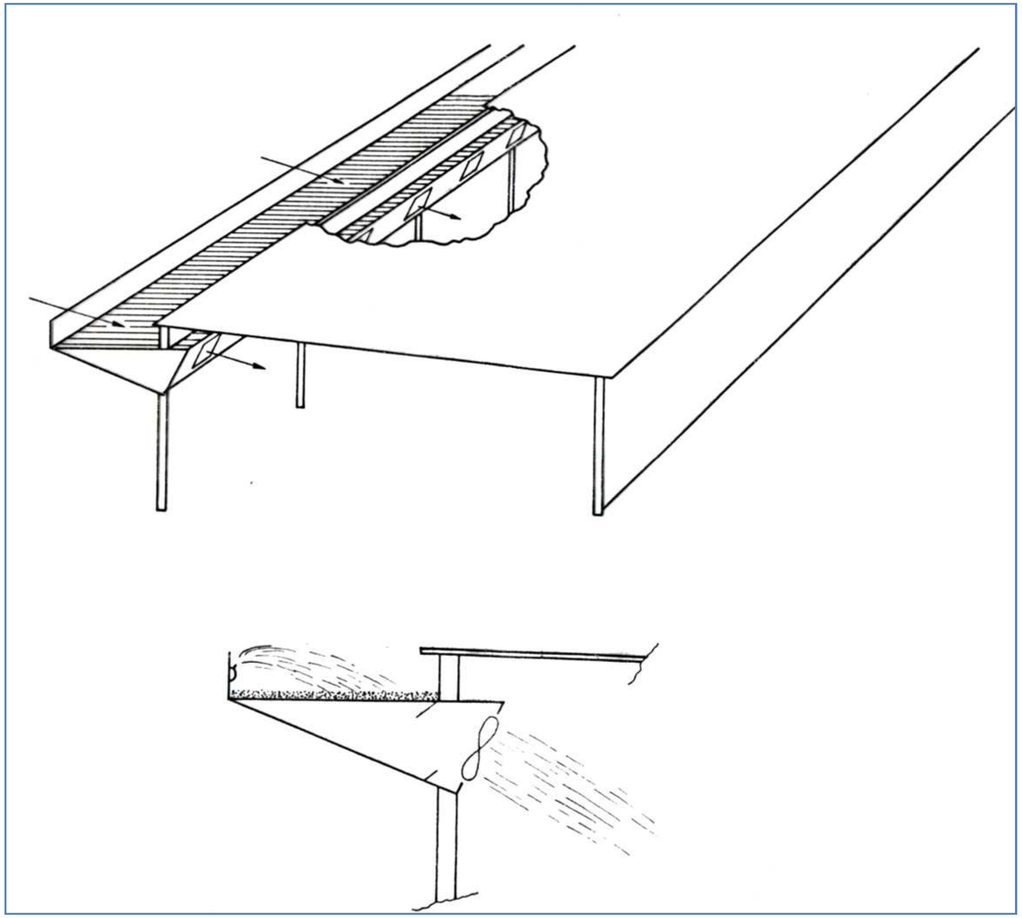
COOLING BY MEANS OF AIR AND WATER

WATER NEBULIZATION IN AIR STREAM

OPEN AREAS

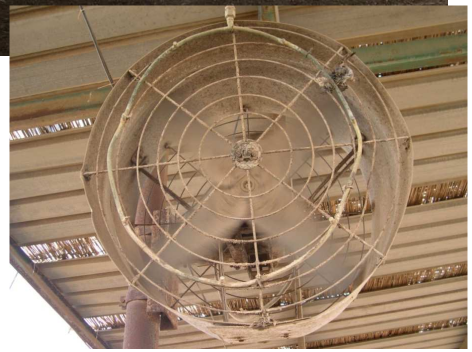
Cooled pads applied in open shelters

The combined double effect of cooling of the air and velocity of the air on the body of the animal is utilized in this system



Horizontal filters along the whole length of the building, in East side

High pressure water nebulization in air stream is a system particularly fit for open areas, to cool directly the animals thank to the stream of fresh air directed towards the body of animals



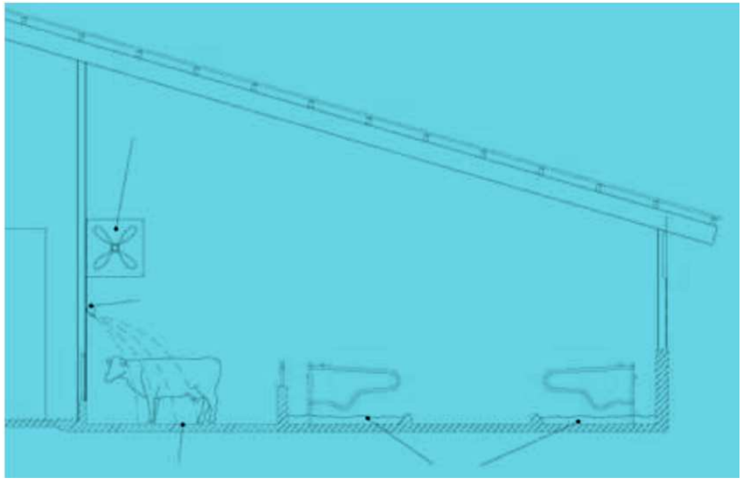
WATER NEBULIZATION IN AIR STREAM

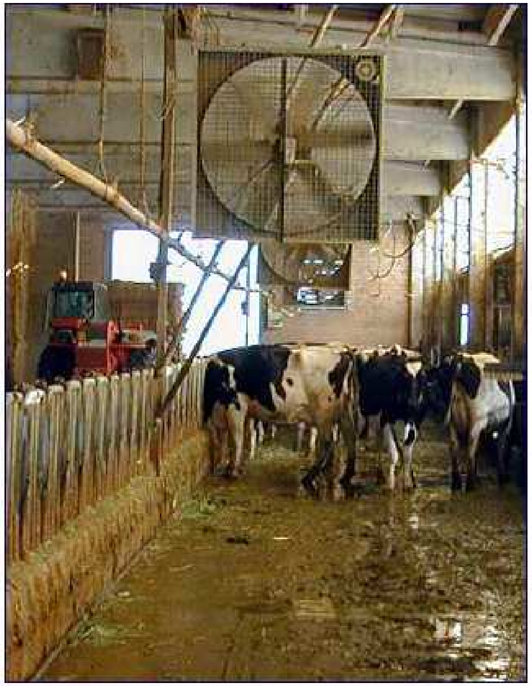
COOLING BY MEANS OF AIR AND WATER

SPRINKLING IN AIR STREAM

Water is sprayed directly on the cows.
Water evaporation causes a temperature drop both of the skin and of floor.

Ø 0.9 – 1.2
9 – 12 m inter-axis
low pressure (1,.5 - 4 bar)
cycles 1/8÷15 min
Inclination 15-30°

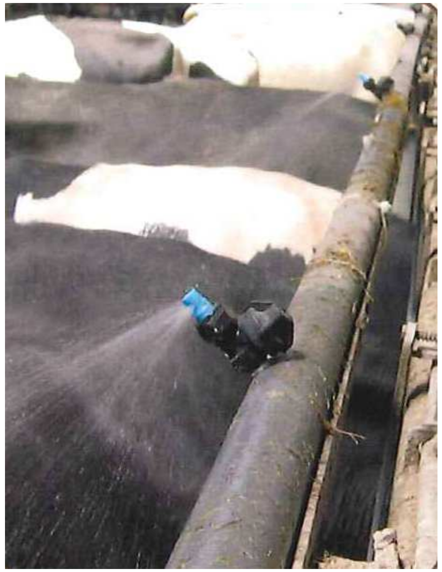




Direct sprinkling of cows

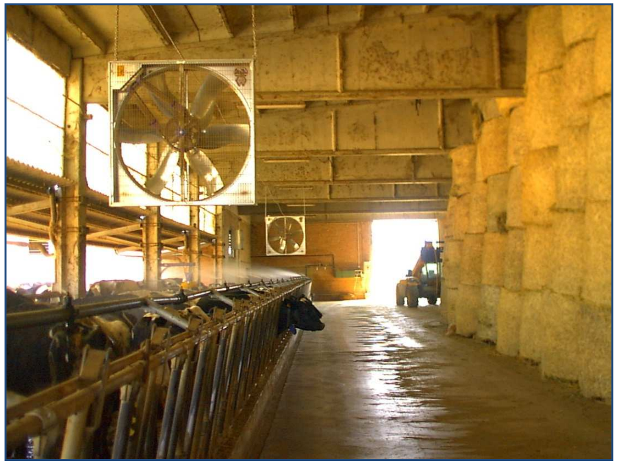
Nozzles

- **work at low pressure (1,5-4 bar)**
- **placed at a distance each other of about 2-2.4 m to irrigate uniformly the whole surface of feeding area**
- **water sprinkling, alternated to working of fans, is activated at variable intervals of 5-15 min and lasts 0.5-1.5 min**



Fans

To obtain an efficient rhythm of heat transferring and dispersion the air velocity on the animals has to be higher than 2 m/s and in hot-humid weather it has to be between 3 to 4 m/s.



Sprinkling in air stream

In barns with 3 or more free stalls a line of fans in feeding area has to be installed, while other fans can be installed on the free stalls to improve the thermal comfort of cows also in resting area.

FLOOR

To avoid problems of **slippery and health of feet** of cattle due to floor wetting, the surface of feeding area cooled by sprinkling has to be anti-slip and draining, as in the case of **slatted floors** or **full floors realized with grooves** and **min. slope** (**0.5-1%**), suitable to favor a sudden evacuation of liquids towards the sewer system of the barn.

Which is the best system?

HIGH PRESSURE WATER NEBULIZATION IN AIR STREAM	SPRINKLING IN AIR STREAM

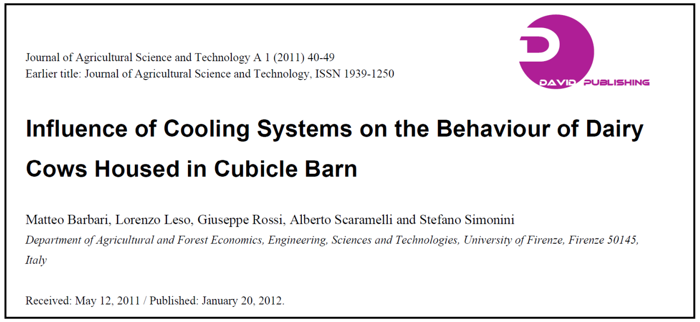
The use of **sprinkler/fan** and **fog/fan** evaporative cooling systems is common in hot and warm regions worldwide.

Experimental trials carried out in **hot-humid climates** have remarked **a greater efficacy** of plants based on **direct sprinkling of cows** than nebulization plants.

Other comparative trials between direct sprinkling and high pressure nebulization have remarked a similar reply in terms of **milk yield**, but water consumptions clearly lower in nebulization systems. The sprinkling systems cause a **water use** of **50-300 l/day*head**, against **10-20 l/day*head** of high pressure nebulization system.

It is imperative that new methods of cooling cows that require little or no water should be developed.

INFLUENCE OF COOLING SYSTEMS ON THE BEHAVIOUR OF DAIRY COWS HOUSED IN CUBICLE BARNS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Influence of Cooling Systems on the Behaviour of Dairy Cows Housed in Cubicle Barn

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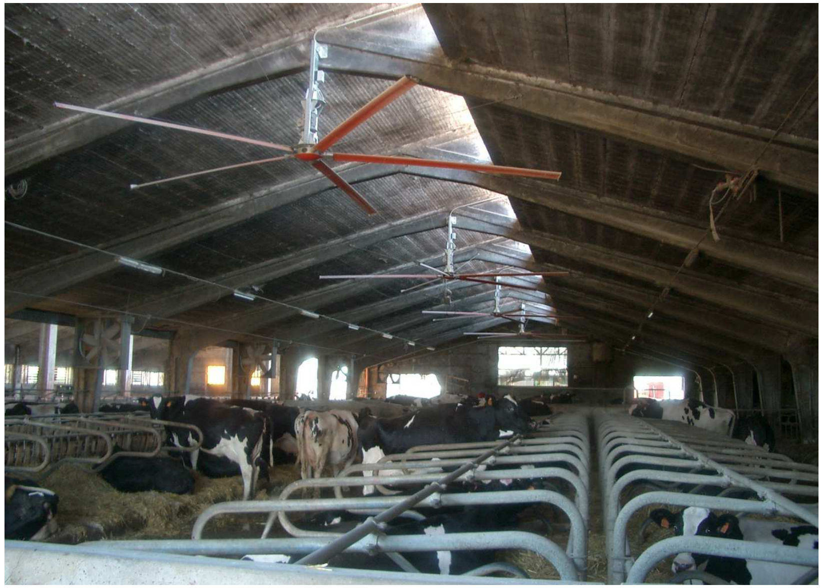
The **behavior of the cows** is strictly related to the **microclimatic conditions** inside the barn.

Particular attention has to be paid in the **design of cooling systems** in a loose barn for dairy cows.

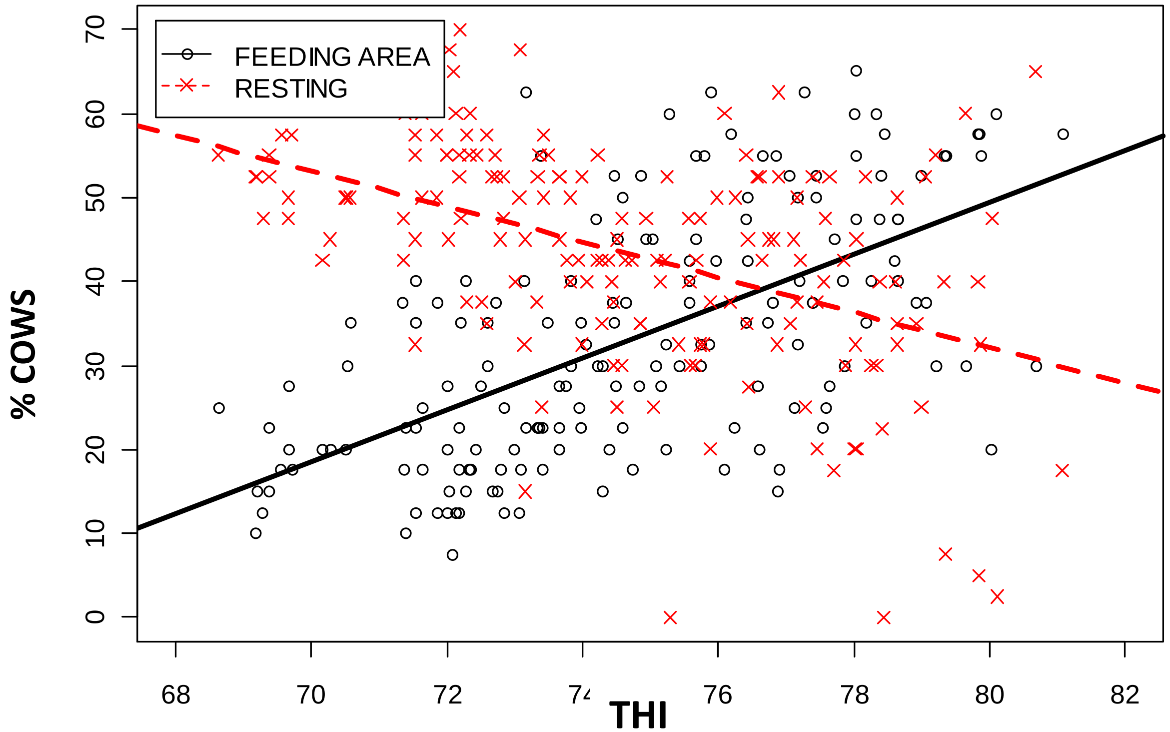
The **resting period** of the animals can be compromised if the environmental conditions are not adequate. If the **cooling systems** are **adopted only in feeding alley** the cows prefer to **use this area** limiting the resting periods.

MATERIAL AND METHODS

- Cow behavior measured with CC TV system (15 min)
- Resting time (cows lying in cubicles)
- “feeding time” (cows at the feed fence)
- Comparison of time budget:
- 2009 -> **only high speed fans + sprinklers in resting area**
- 2010 -> **added HVLS ventilation in the resting area**



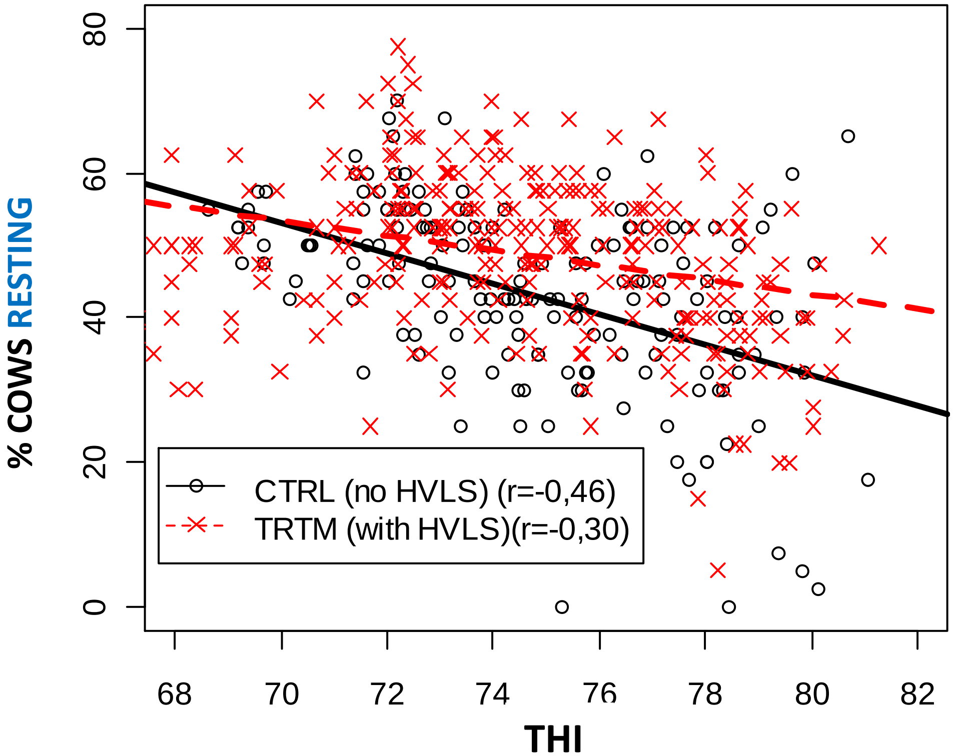
EFFECT OF ENVIRONMENT CONDITIONS ON TIME BUDGET

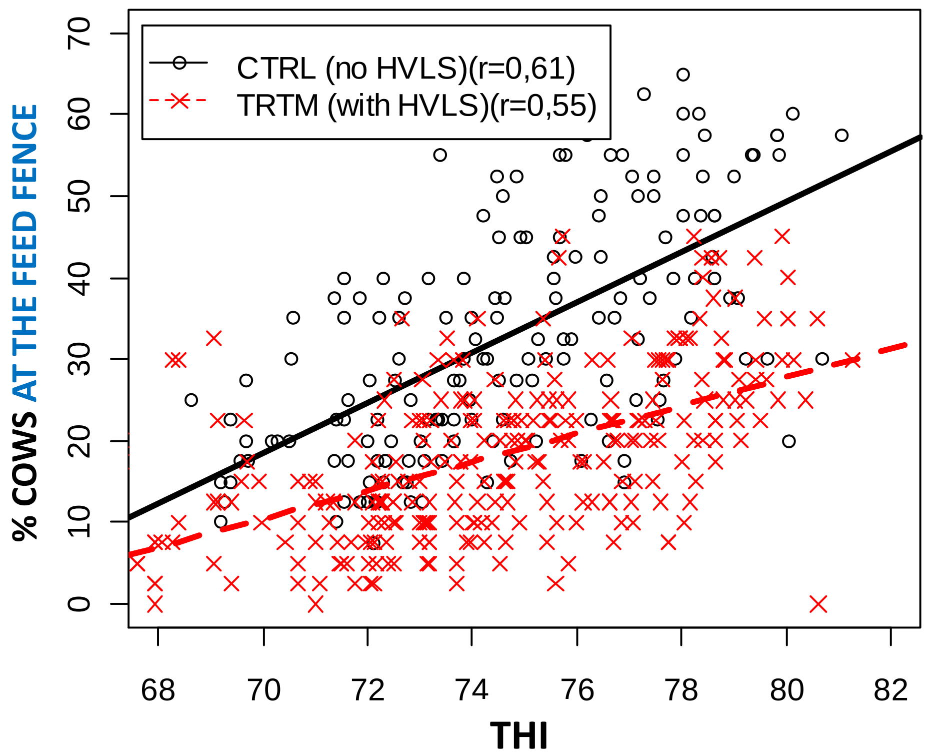


- Generally an increase in "feeding time" is positively considered by farmers.
- But are the cows really eating??
- What about the cost of reduced resting time (claw health, milk production, feed conversion efficiency)?

Day	Average internal temperature (°C)	Average time spent RESTING (hours/day*cow)	Average time spent in FEEDING AREA (hours/day*cow)
Summer typical day	26,71	9,7	8,7
Winter typical day	9,51	11,2	5,5
Summer hottest day	27,98	9,4	8,6
Winter coldest day	7,11	12,7	5,5

EFFECT OF HVLS VENTILATION IN RESTING AREA





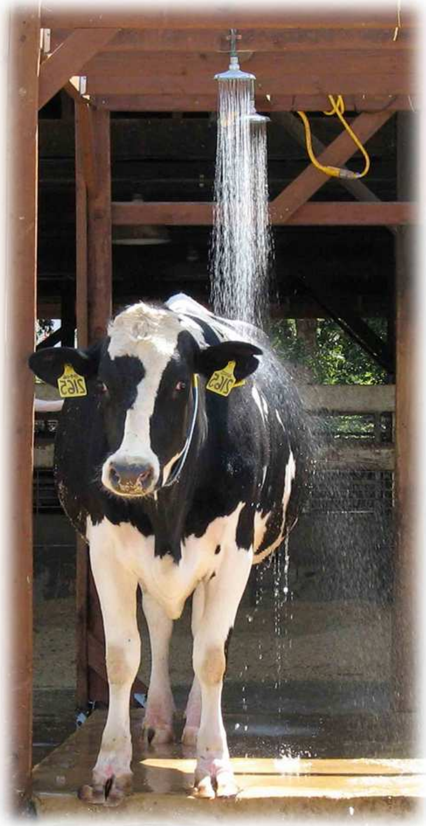
Experimental periods	Summer 2009 (CTRL, no HVLS)	Summer 2010 (TRTM, with HVLS)	P-value
Internal THI	74.77	74.57	0.5077
Resting time (h/day)	9.72	10.51	<0.001
Time spent in feeding alley (h/day)	8.47	5.35	<0.001

COOLING OF ANIMALS BY WATER

⇨ to act directly on the animals by means of **water showering.**

The water supplied with shower removes heat trough 2 ways:

- **Conduction** – due to the lower temperature of water than the body of animal. The heat loss by conduction lasts only the time of the shower.
- **Evaporation** – it lasts for whole the time employed by the animal to dry (some tens of minutes) and needs low water amounts. Therefore, to reduce the water wastes, it could be useful to push only on heat loss by evaporation.



Cows - drop of daily peak of rectal temperature (maintained at 38.2-38.9 °C) with a decrease of about 1°C after 30 min from the shower's supply.

Using water to cool cattle: behavioral and physiological changes associated with voluntary use of cow showers **(**Legrand *et al.*, 2011)

Water is commonly used to cool cattle in summer either at milking or over the feed alley, but little
research has examined how dairy **cows** voluntarily use water separate from these locations.

Half of the 24 nonlactating cattle tested had access to a "**cow shower**" composed of **2 shower heads activated by a pressure-sensitive floor.**

Cattle, when given the opportunity, will make **considerable use of a shower** to reduce **heat load**, but that individuals are highly variable in their use of this resource. The variability between **cows** indicates that the behavioral response to water is likely an important, but poorly understood, consideration in the design of sprinkler systems used for summer **cooling.**

Alternative cooling of dairy cows by udder wetting

Research (Gebremedhin *et al.*, 2013) **– comparison 4 treatments**

a) Wetting the body without blowing air

b) Wetting the body and blowing air

c) Wetting only the udder without blowing air

d) Wetting the udder and blowing air directly onto the udder

Measurements: rectal temperature, respiration rate, skin surface temperature

Cooling the udder means cooling the blood flow, which directly and effectively cools the entire body.

Conclusions

Wetting only the udder is effective as wetting the body in cooling cows to abate heat stress. Udder cooling is the first evidence of alternative and effective cooling of high-producing dairy cows, and it provides a new opportunity to develop a cooling device that works in a production setting.

COOLING OF ANIMALS BY WATER

SOWS - PREGNANCY
BOARS

➡ **Different cooling solutions can be used for sows during reproductive cycle**
➡ **Among the different systems, the ones based on the use of water have a particular importance**

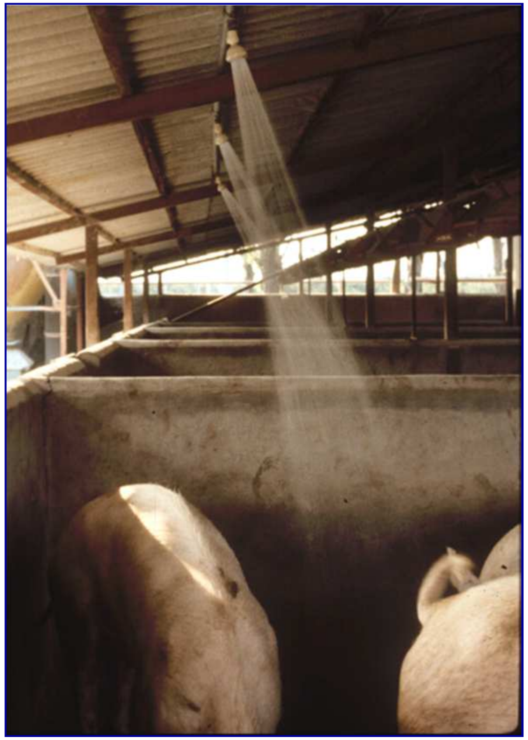
In areas where access to a wallowing pond or showering is not available, animals may wet and cool themselves with their own excreta

WALLOWS are widespread in outdoor breeding systems. Simple holes in the ground are executed; the water is put inside.

SHOWERS FOR SOWS

Water sprinkling by means of showers can be effected in dry sows groups.

In this situation the use of showers is better than the use of baths, which have hygienic contra-indications.



➡ **Water sprinkling by means of showers can be effective in dry sows groups.**

Regarding the **installation**, the shower cooling system is very simple: the showers can be controlled by a timer that induces the water sprinkling at set intervals and, in some cases, by a thermal probe that enables the equipment to work only above a fixed temperature.

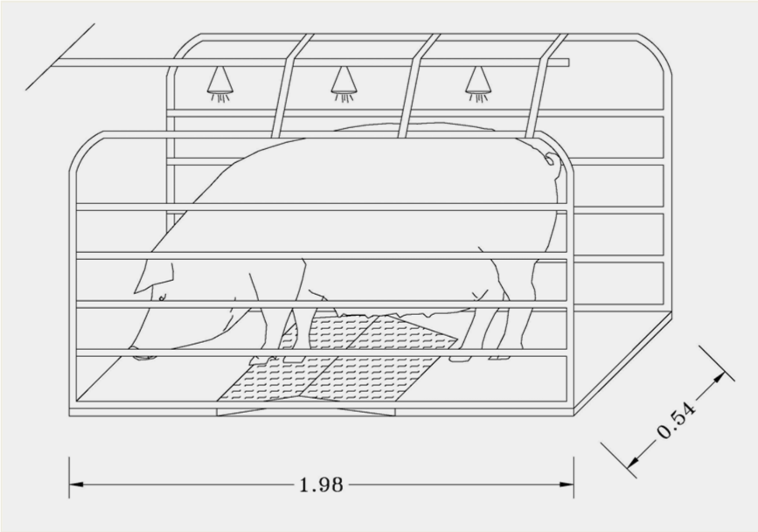
The main limit of the shower cooling system is the **heavy water waste**, with the consequent problems of spreading, if the water distributed onto the animals is collected into the slurry.

DYNAMIC GROUP

Dynamic group of sows
average number 192 pregnant sows, with min. 169 and max. 211

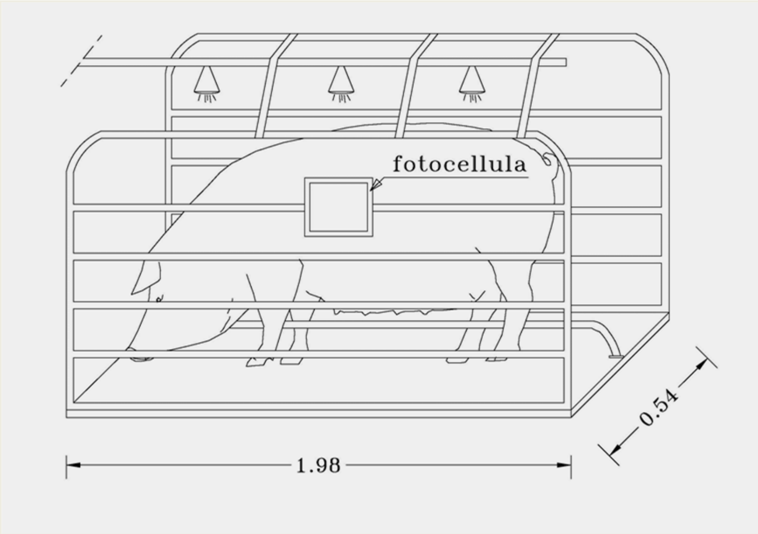
2 automatic showering cages were installed in the pen

Solution “a”



- shower starting with pressure on the *plate*
- system appreciated by sows, particularly pluriparous
- suitable system for dynamic groups of sows

Solution “b”



- shower starting with photocell
- system appreciated by sows, particularly young ones
- suitable system for dynamic groups of sows

An electronic controller regulated the shower time

- **The shower length was fixed at 6 s**
- **The water consumption was on an average 3.6 l**

The shower cages allow the animals to take the shower individually and as much as they like.

Therefore the shower cage has been called

***"Automatic Showering Cage"* (ASC)**

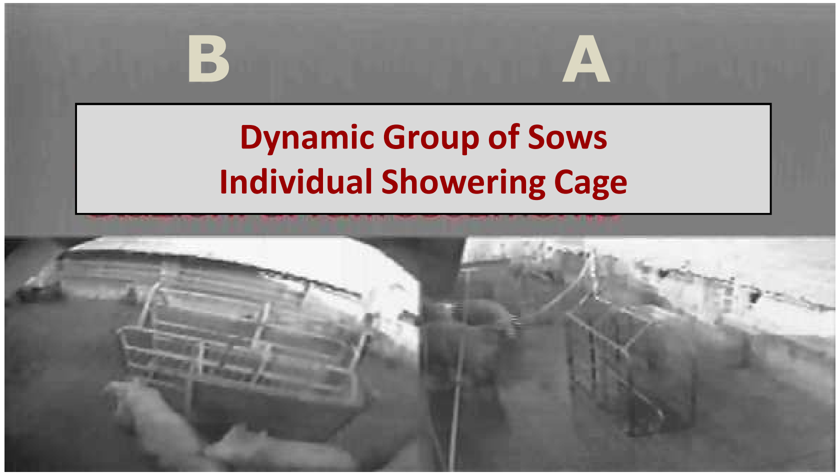
Electronic system to transfer information by cooling system to PC

- an antenna in the cooling station to recognize the single animals
- the transfer of the signal by cable from the station to a PC
- a software collects the information in a permanent way and stores the data on a file

An antenna is installed in the station to receive information by the single sows

PC is used to collect data

The behavior of the sows in the cages during the shower and near the stations was surveyed continuously by means of a close circuit infrared camera with a time-lapse recorder.



Results

Results of the use of the two automatic showering cages are very positive

The sows clearly appreciate the systems installed in the pen based on the free access by the sows (ASC) and on the possibility to take showers round the clock and also for more times consecutively.

The sows show a remarkable capacity to learn the use of an Automatic Shower Cage, whichever water system is installed. However a mechanism giving a clear "cause-effect" (such as the metal plate to push by feet) is preferred by the sows.

The experimental equipment can be used to cool sows in large dynamic groups.

- Average temperature: 23.64°C
- Daily maximum values: 29.10°C on average
- Maximum temperature: 33.93°C (in the whole examined period)

Percentage use of the ASC → Number of sows taking at least a shower during the day on the total number of sows in the group

The use was 50.39% on average (± 15.89)

Number of showers taken by the sows during the day microclimatic conditions, arriving to 788 in a hot day

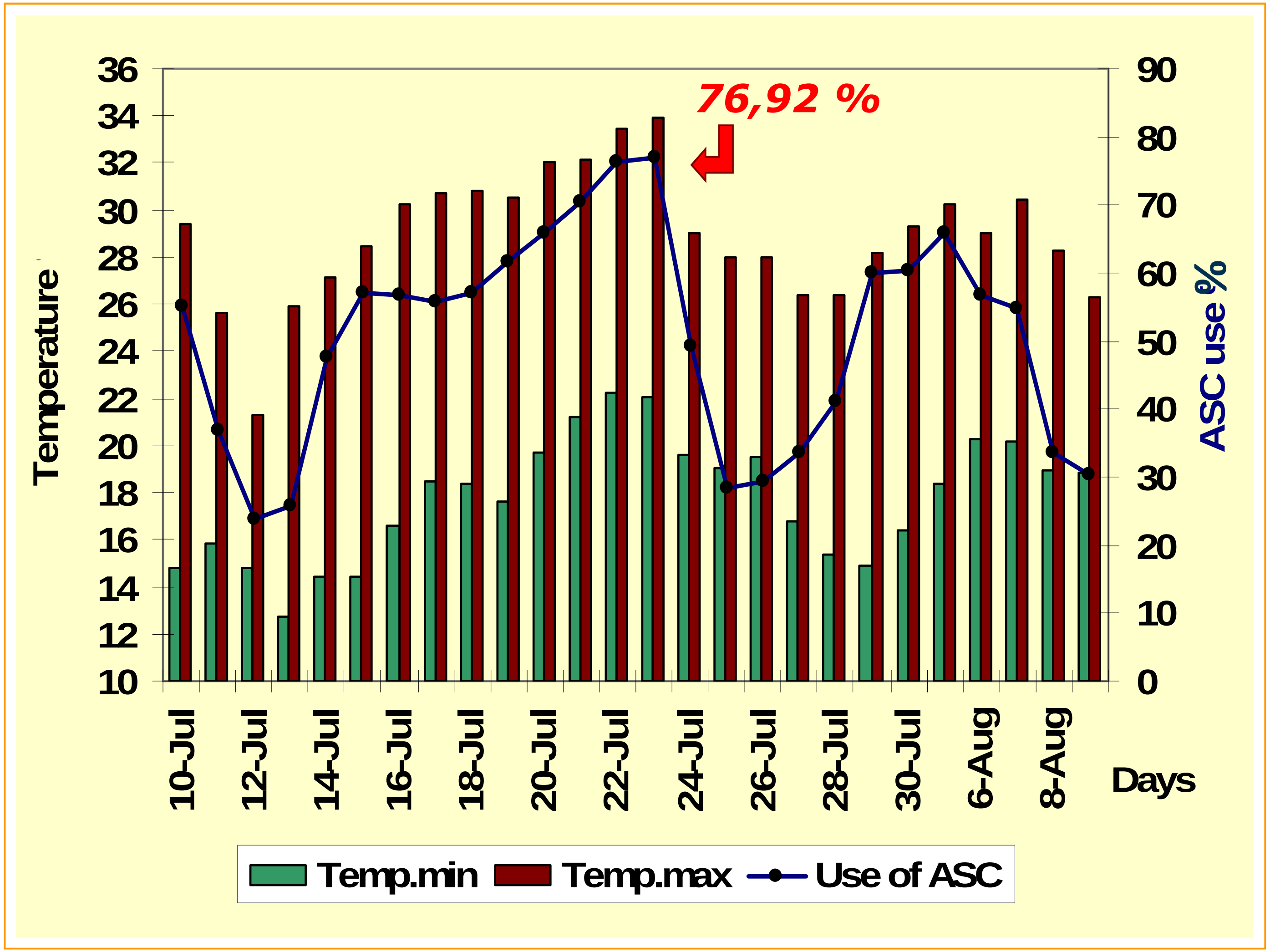
A single shower had an average length of 59 sec, but this value fluctuated from

↘ low values in the cold days (*e.g.* 54 sec on the 10th of July)

↗ high values in the hot days (*e.g.* 80 sec on the 23rd of July)

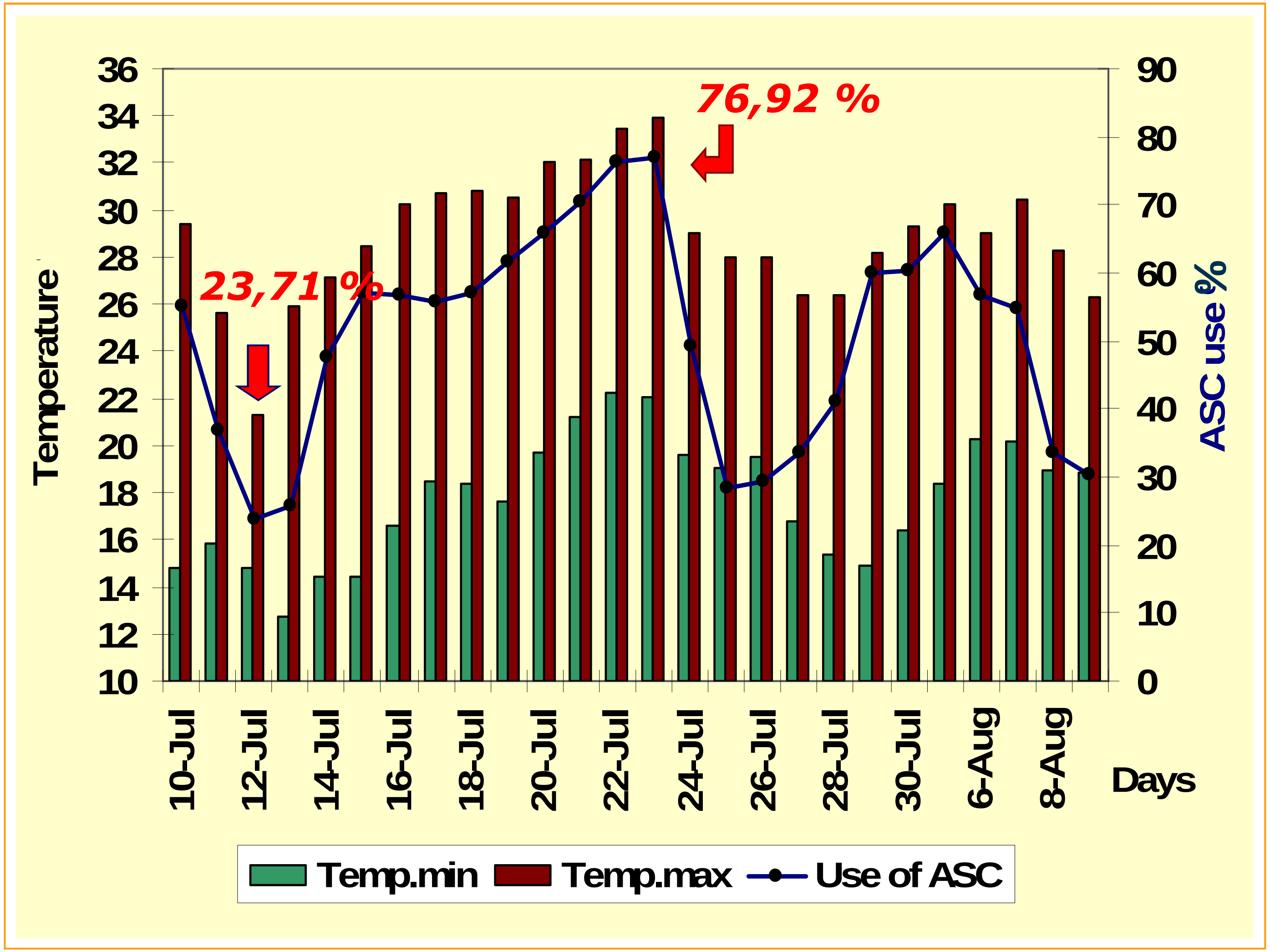
Total time spent in the ASC by the sows of the group exceeded 17.5 hours (for the 2 cages, July, 23rd)

Use of ASC (a and b) by the sows during 26 days of experimental period



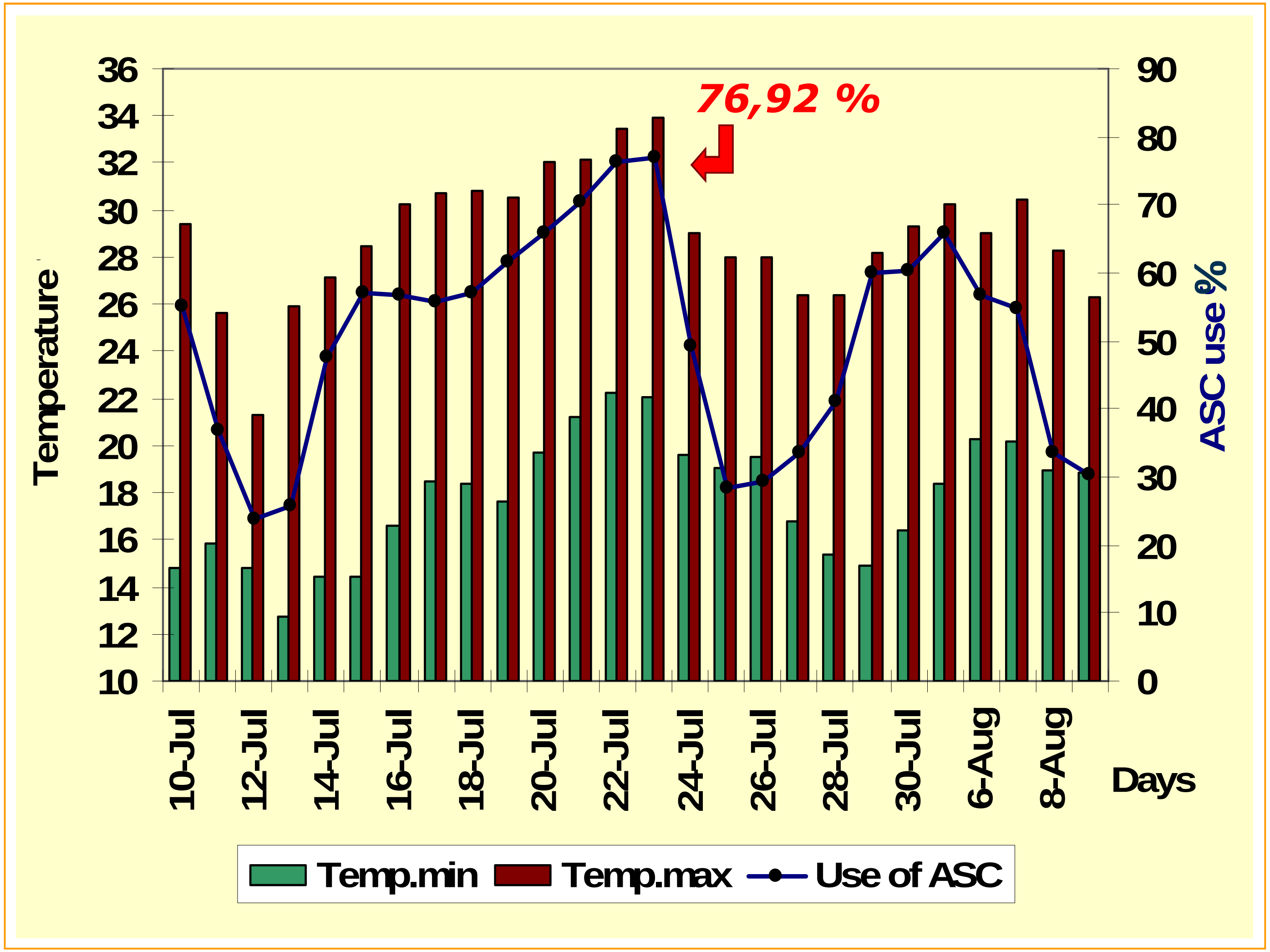
When the maximum daily temperatures reached the highest values (e.g. July, 23rd) **the number of sows taking showers considerably increased, reaching a value of 76.92%**

Use of ASC (a and b) by the sows during 26 days of experimental period

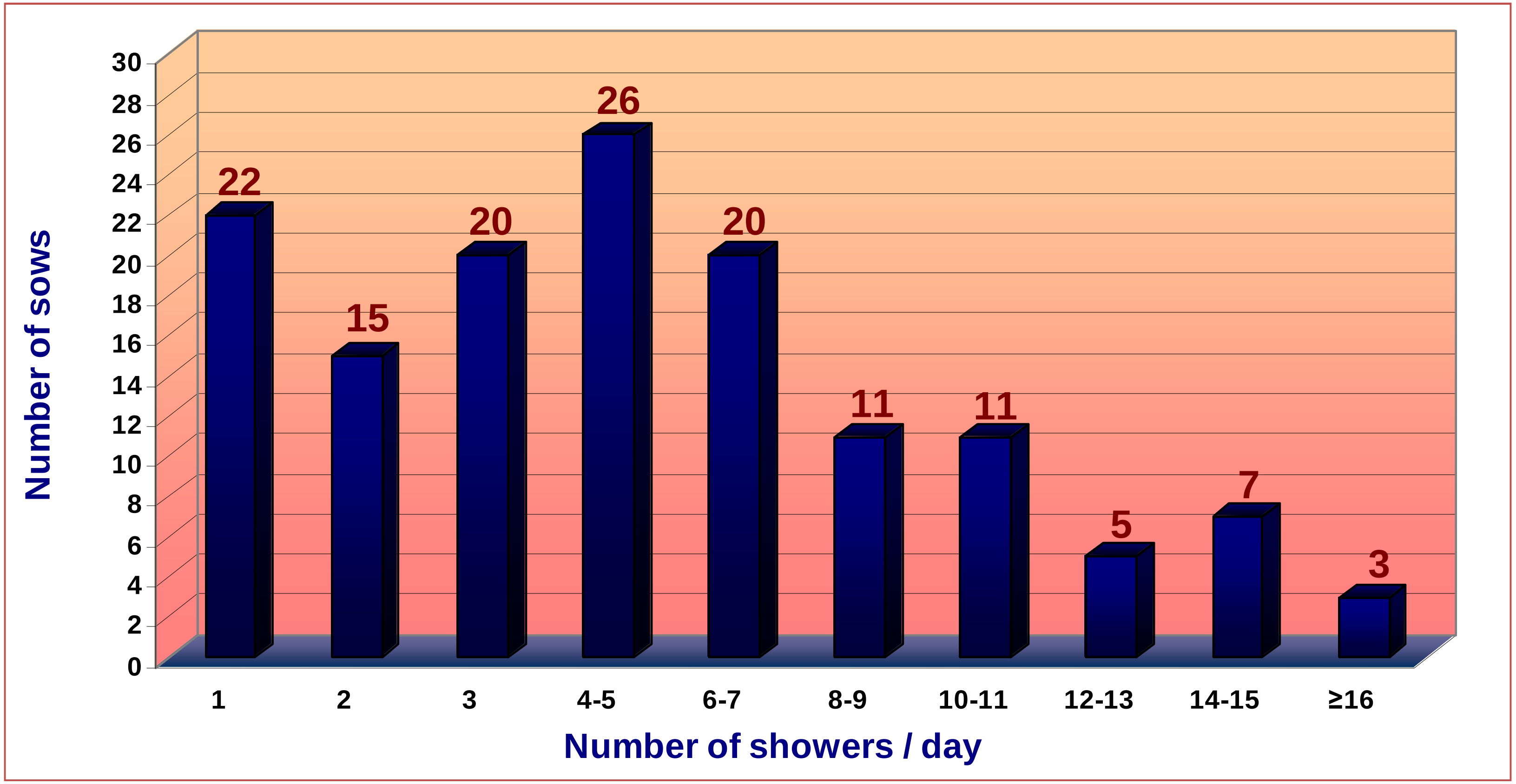


The minimum utilization of the showers was obtained in the coldest days, such as on the 12th of July: with a maximum temperature of 21.27°C the percentage of sows taking a shower was **23.71%**

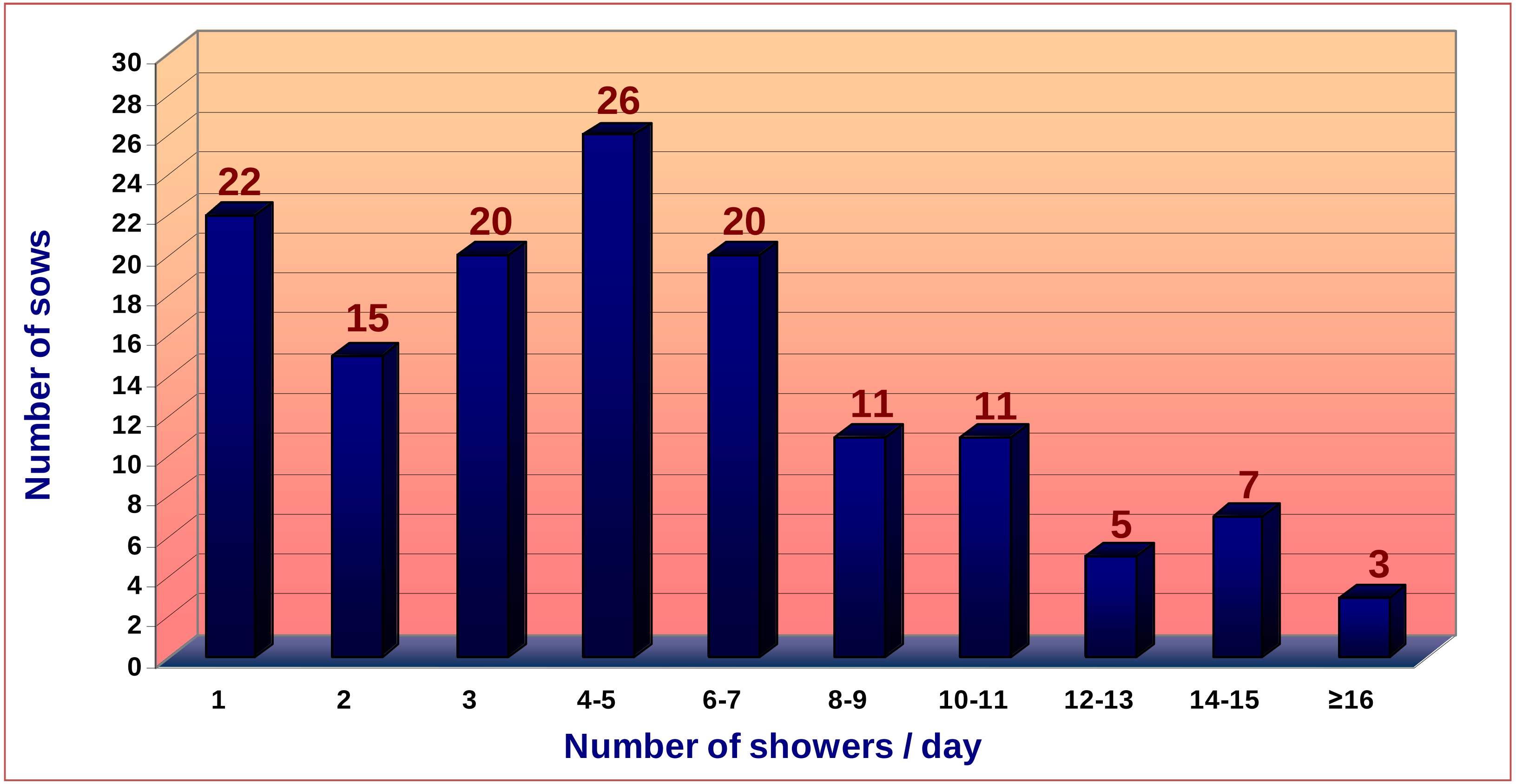
Use of ASC (a and b) by the sows during 26 days of experimental period



Therefore a **high positive correlation (r = 0.86)** was found between the daily maximum temperature and the percentage use of ASC by the sows.



Distribution of the total number of showers for the ***hottest day*** of experimental period (***July, 23rd***)

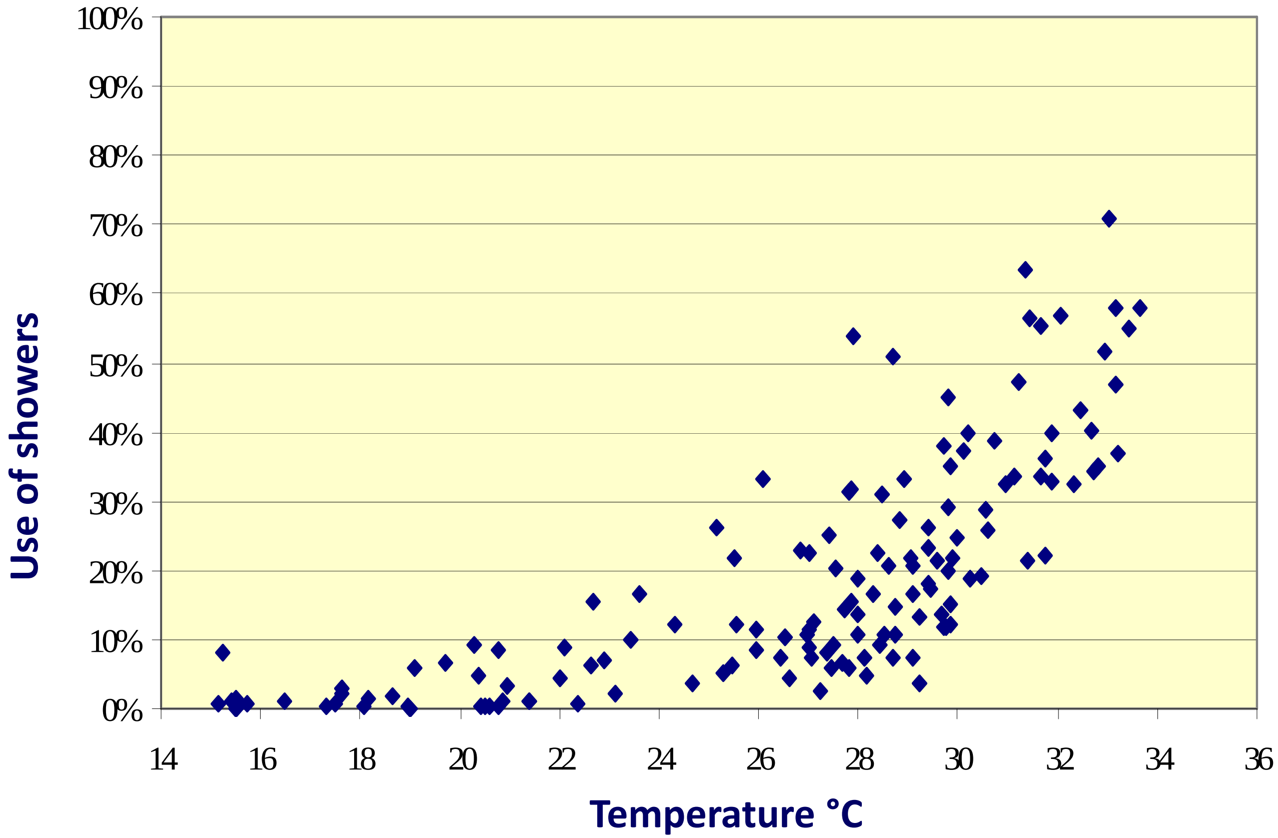


Distribution of the total number of showers for the *hottest day* of experimental period (*July, 23rd*)

When the temperature dropped the number of sows taking 6 showers or more rapidly decreased For example on the 11th of July only 2 sows (on a total of 62) took 6 showers or more.

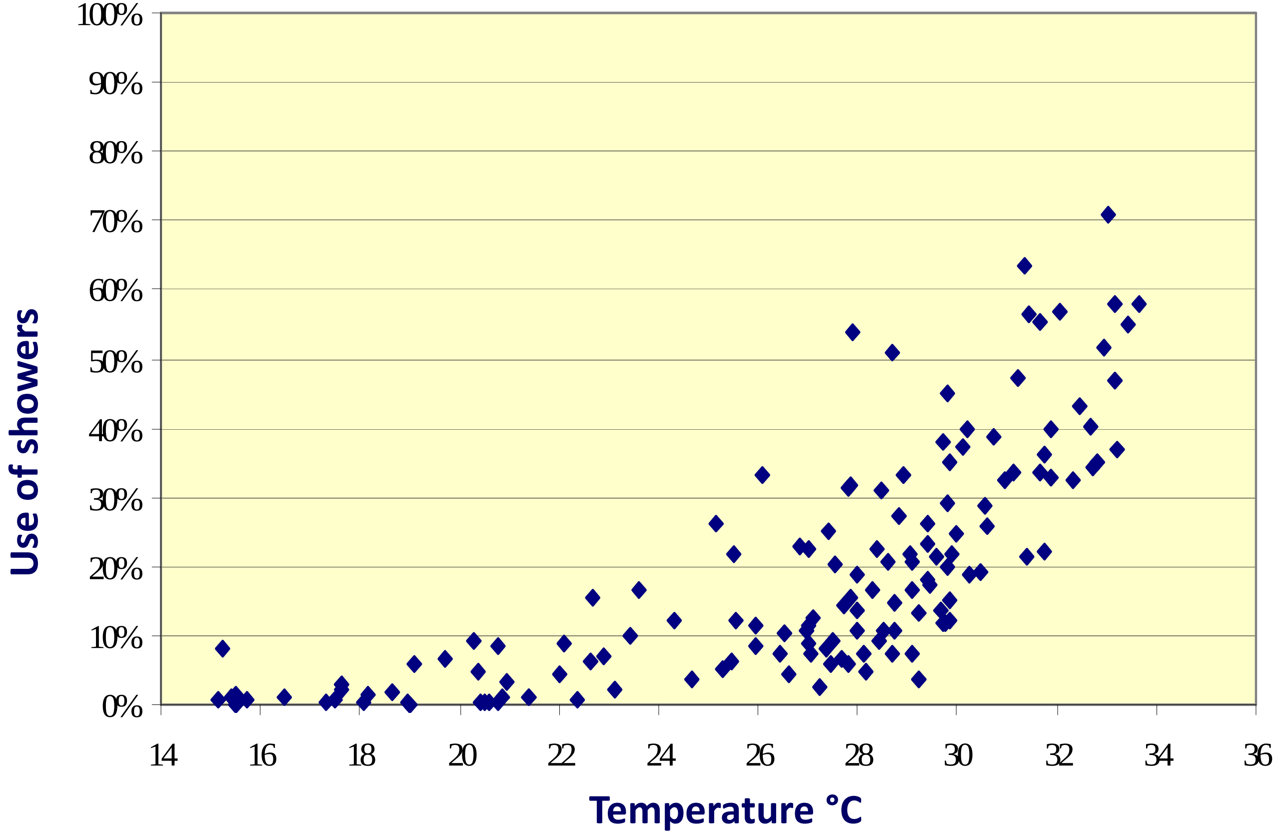
Data on the use of the showers from the sows were processed also to verify the changes in relation to the outside temperature. For this kind of processing 12 hours of the day were considered, chosen in the daylight period, including the coldest hours (5-7 a.m.) and the hottest ones (1-8 p.m.).

Use of the automatic showering cages in relation to temperatures



The analysis of the period of 12 daily hours has shown a high positive correlation between air temperature and the use of the showers from the sows (r = 0.731)

Use of the automatic showering cages in relation to temperatures



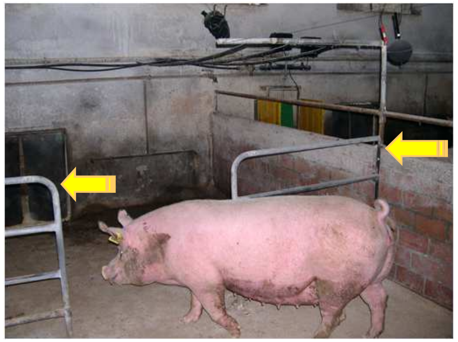
The graph clearly shows how the use increases with temperature. The rise is particularly important above the temperature of 26°C. At this temperature the use of the showers increases very quickly, in a linear way.

SOWS - PREGNANCY

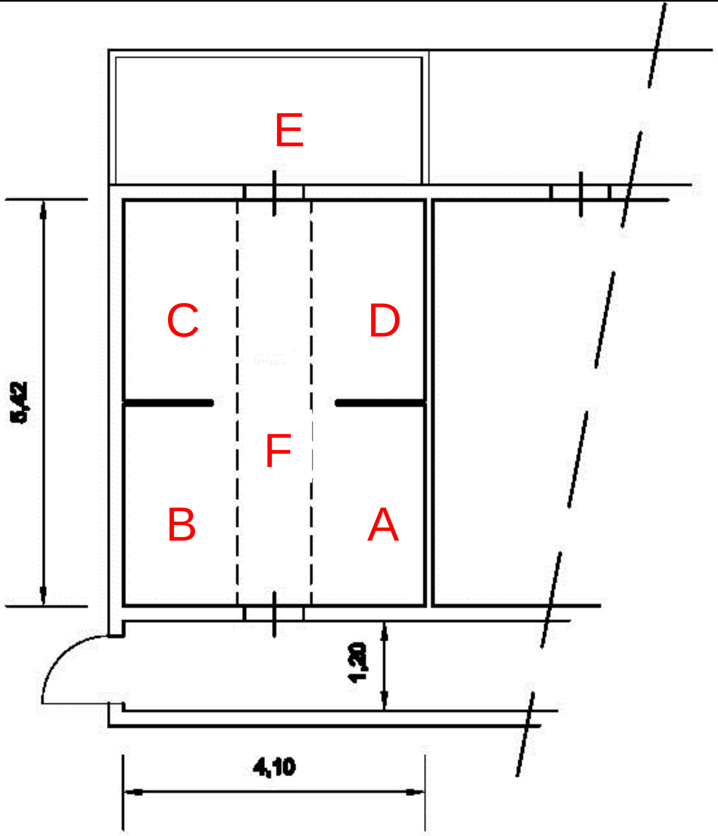
Barbari M., Conti L. 2009. Use of Different Cooling Systems by Pregnant Sows in Experimental Pen, Biosystems Engineering, 103, 2009.

STATIC GROUP

Sows are able to decide on the use of cooling systems adopted in the pen. The choice is affected by thermal conditions.
The study has remarked the presence of threshold temperatures driving sows to move to comfortable areas during the day



4 areas physically divided by metallic partitions



Pen for pregnant sows (5.42 m x 4.10 m) with different areas

A : area used as a feeding area, not cooled

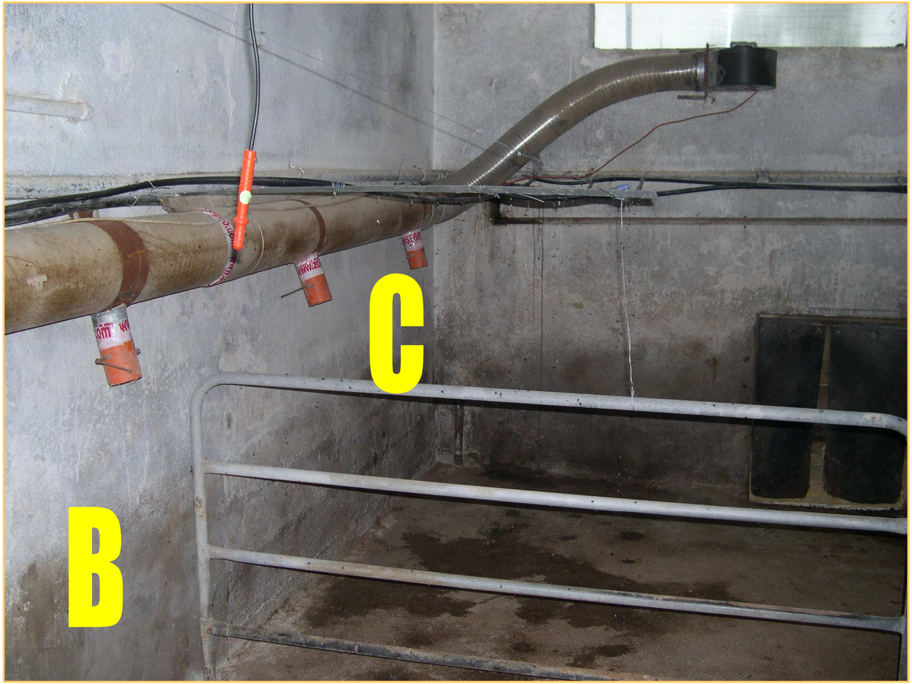
3 areas were arranged with cooling systems:
B : stream of air
C : stream of air and water on the floor
D : water-on the floor

E : dunging alley
F : passageway

Cooling systems in studied areas:

B Stream of air at high velocity, made of two pipes, whose exit diameter was 0.08 m, which blew air at high velocity towards the floor (12.5 m/sec), for a total air flow rate of 1810 m^3/h.

C Stream of air at high velocity (as zone B) and **supply of water on the floor by a drip cooling system** made using 25 drip nozzles, able to supply 3.5 l/h each, working 4 times a day for 3 minutes. Total amount of water was 36 l/day.



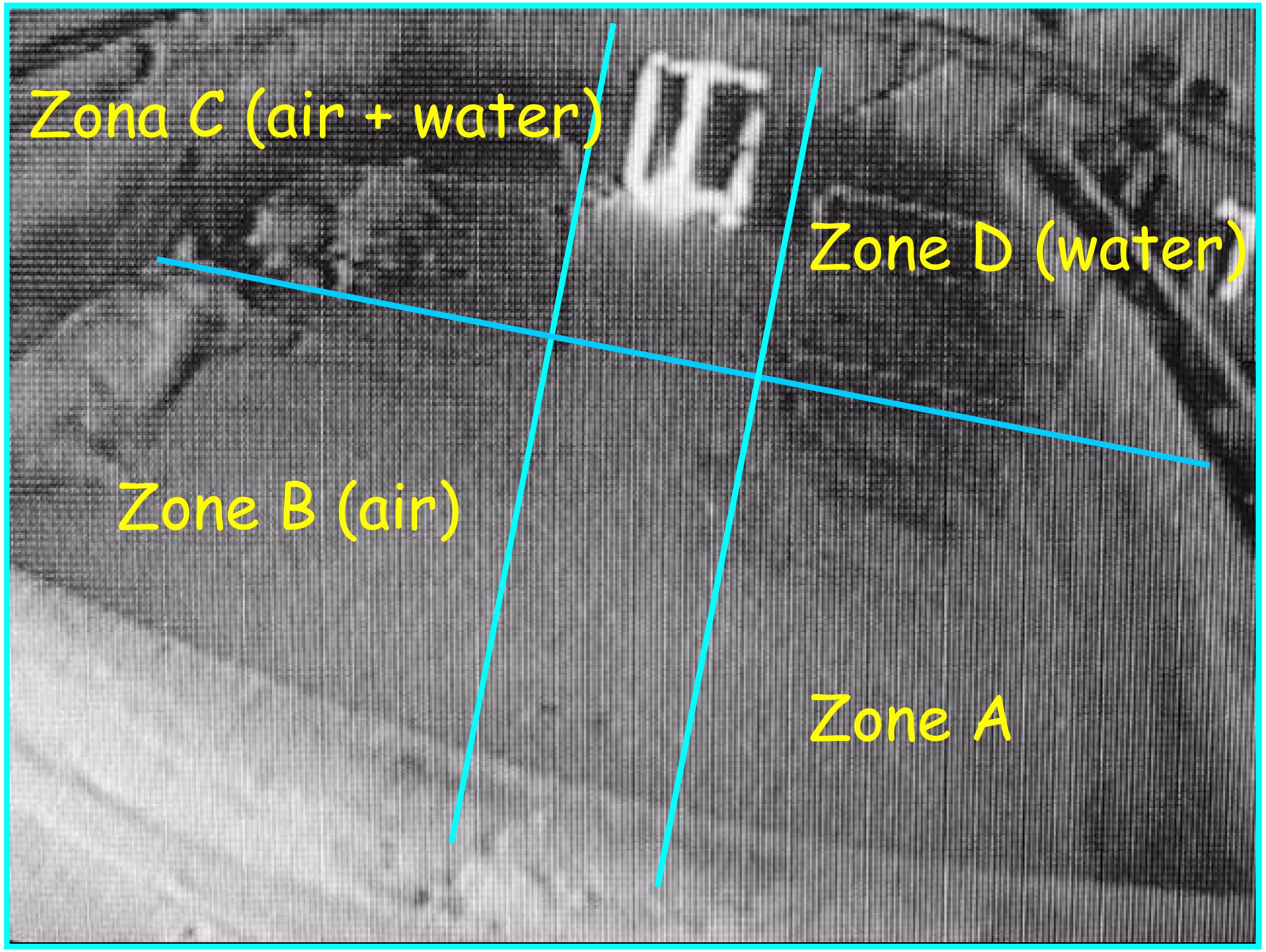
D Supply of water on the floor, made of 25 drip nozzles, with the same working way described for the zone C

The purpose of the system with drip nozzles was to keep the floor wet and cool instead of cooling directly the bodies of the sows.

6 cycles of observations were conducted (15 days each)

4 sows observed in each cycle

Thermal-hygrometer data were collected from a data logger, equipped with special probes



The behavior of the sows was continuously monitored by means of a close-circuit television system with infrared cameras

For each monitored day, the data related to the coldest and the hottest time of the day were analyzed:

- **period between 2 and 7 a.m.**
- **period between 2 and 7 p.m.**

Data of the sows in each separated area were collected every 5 min.

4 classes of temperature identified

T<22°C

22≤ T <26°C

26≤ T<30°C

T≥30°C

4 classes of THI identified

THI < 65

65 ≤ THI < 70

70 ≤ THI < 75

THI ≥ 75

EMERGENCY > 84
DANGER 79-83
ALERT > 75
NORMALITY < 75

THI (Ingram 1965)

Statistical analysis (ANOVA and test of Bonferroni; χ^2-test)

Results

1) Attendance (%) of the sows in the different areas, for the 6 cycles of observations, in relation to air temperature

Zone B, where the animals were able to benefit from the air cooling system, was the most frequented area: on average about 41.3% of the total time, during the 1st, 2nd, 3rd and 4th cycle.

Average temperature about 24°C

During the 5th and 6th cycle the behaviour was reversed, since zone A was the most frequented area (area without any cooling system, occupied 46% of the time). Such behaviour could be caused by the temperature decrease.

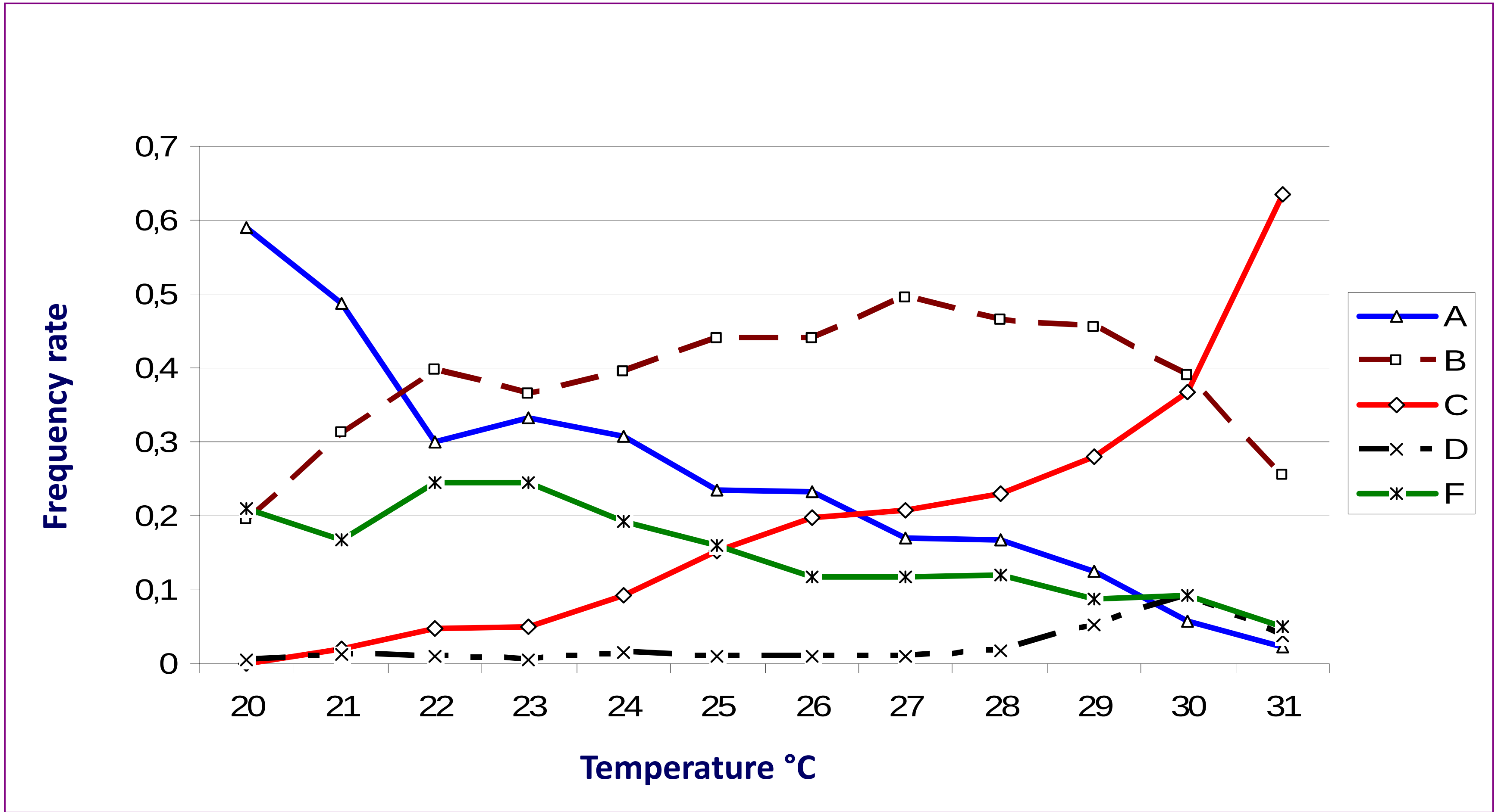
Average temperature about 20°C

Sows are able to decide on the use of cooling systems adopted in the pen.

In a pen with 4 different areas, the sows moved towards the air-cooled area with 26≤ T<30°C and towards the combined cooling zone (air-water) with T≥30°C.

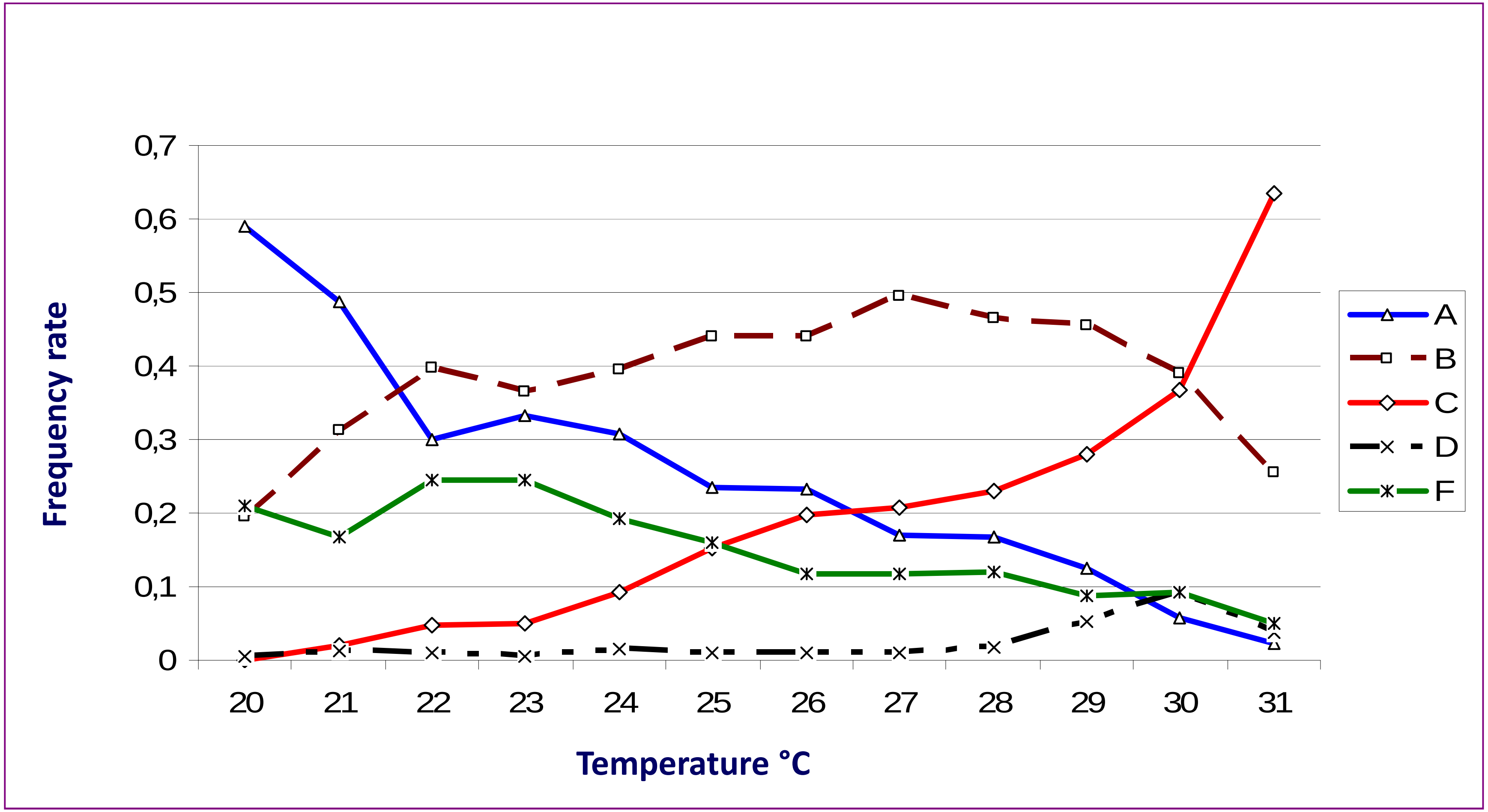
The choice is affected by thermal conditions.

The cooling system based on a stream of air at high velocity coupled with a system to wet the floor was particularly appreciated by the sows during the hottest periods of experimental tests when it had the highest occupancy.



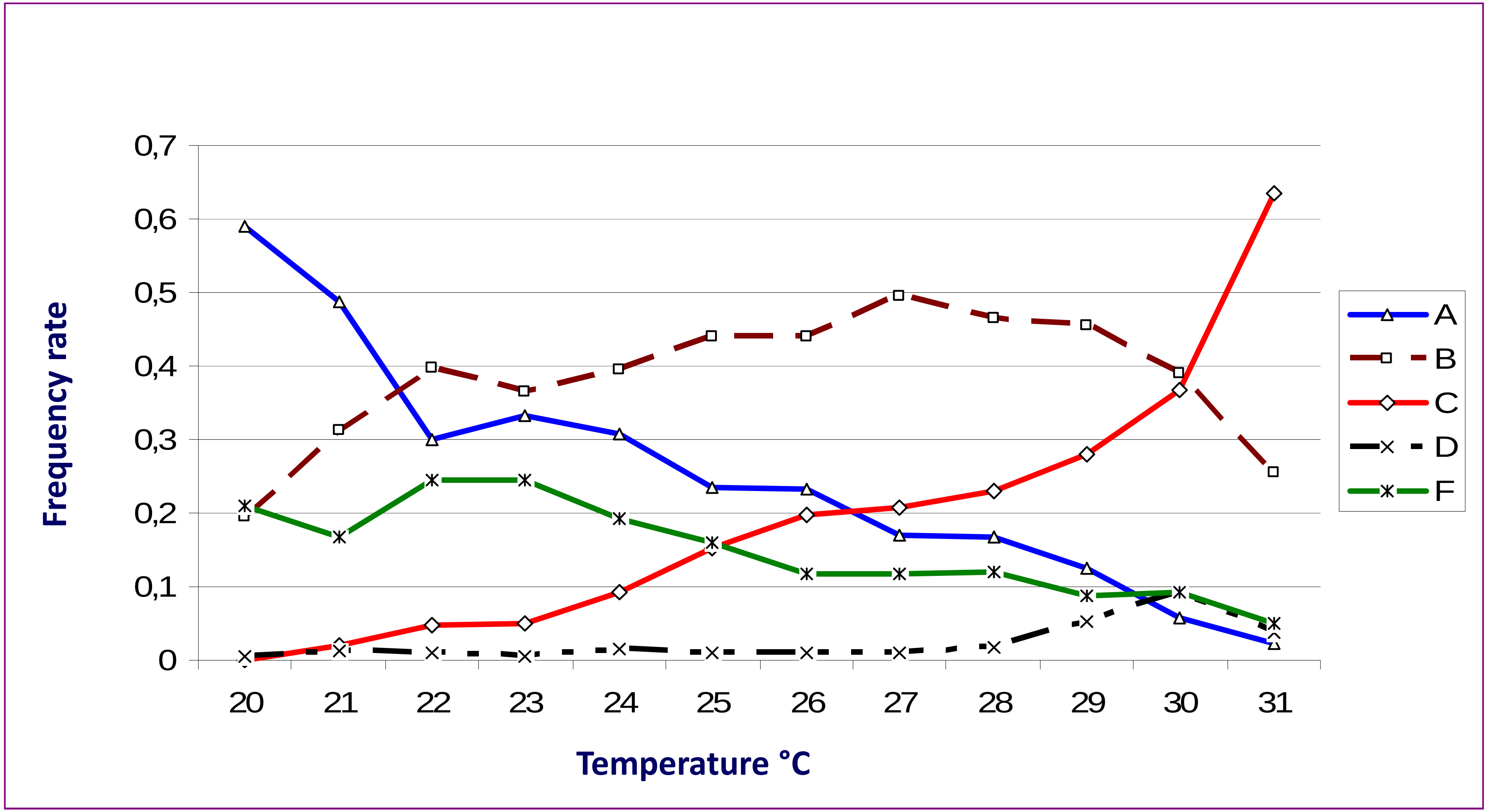
The graph clearly shows the changes in the behavior of the 4 sows kept in the static pen, when the temperature drops.

Over 20°C, when the temperature rises, the use of cooled area with air stream (zone B) constantly increases.



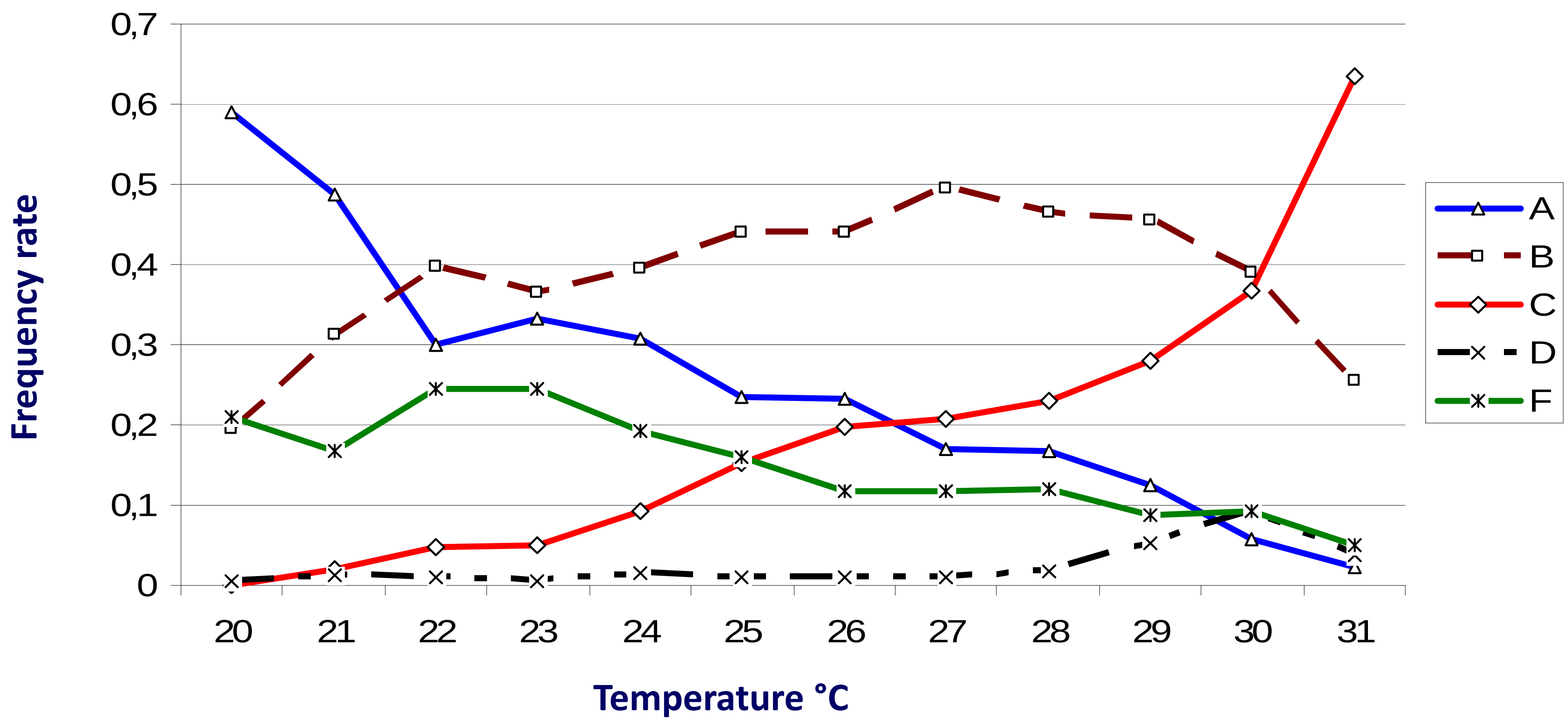
At 26-27°C the frequency rate of zone B reaches the maximum value, with the 50% of preference. Then the rate starts to decrease.

At the temperature of 30°C, the use of zone B drops below the value of zone C.



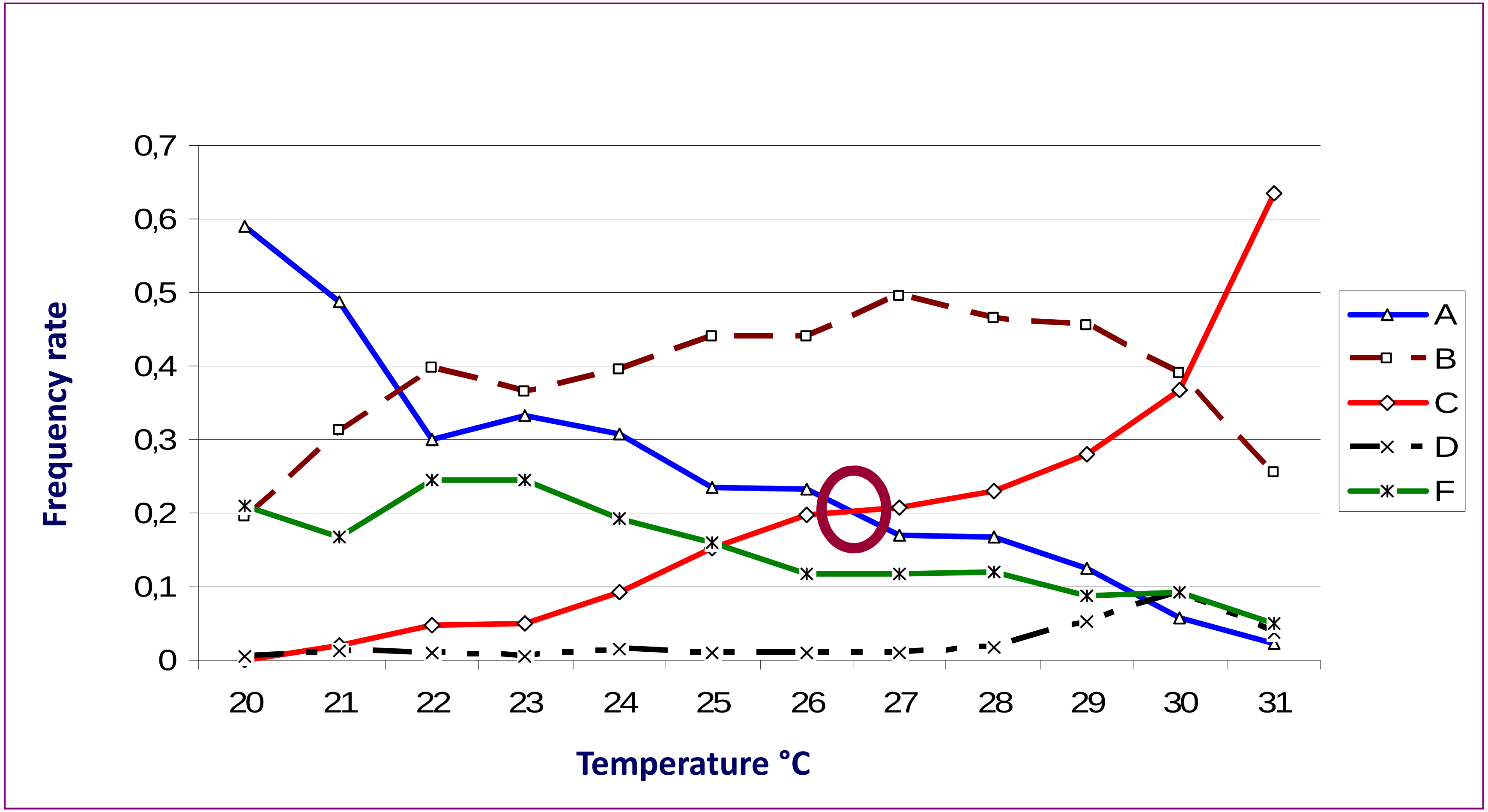
At the temperature of 26-27°C, the presence of the animals in untreated areas (A and F) declines under the 20%.

Over the value of 30°C the use of these areas drops under the value of 10% of presence.



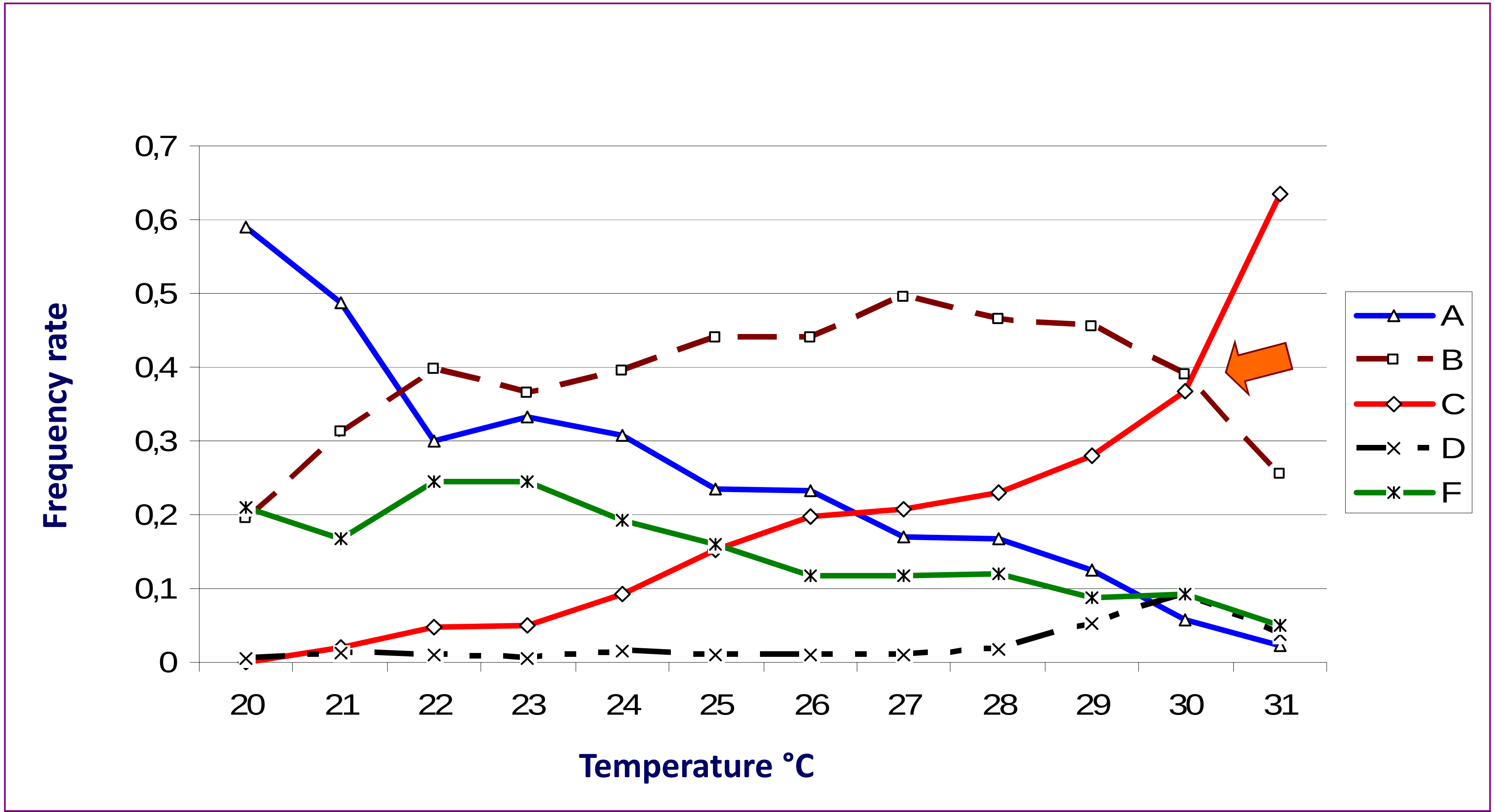
A further consideration is needed for zone C: how the graph clearly remarks, the use of cooled area with the coupled system (air and water) progressively increases in an almost linear way up to the temperature of 26-27°C.

Above such temperature the frequency rate goes on increasing and soars above 30°C.



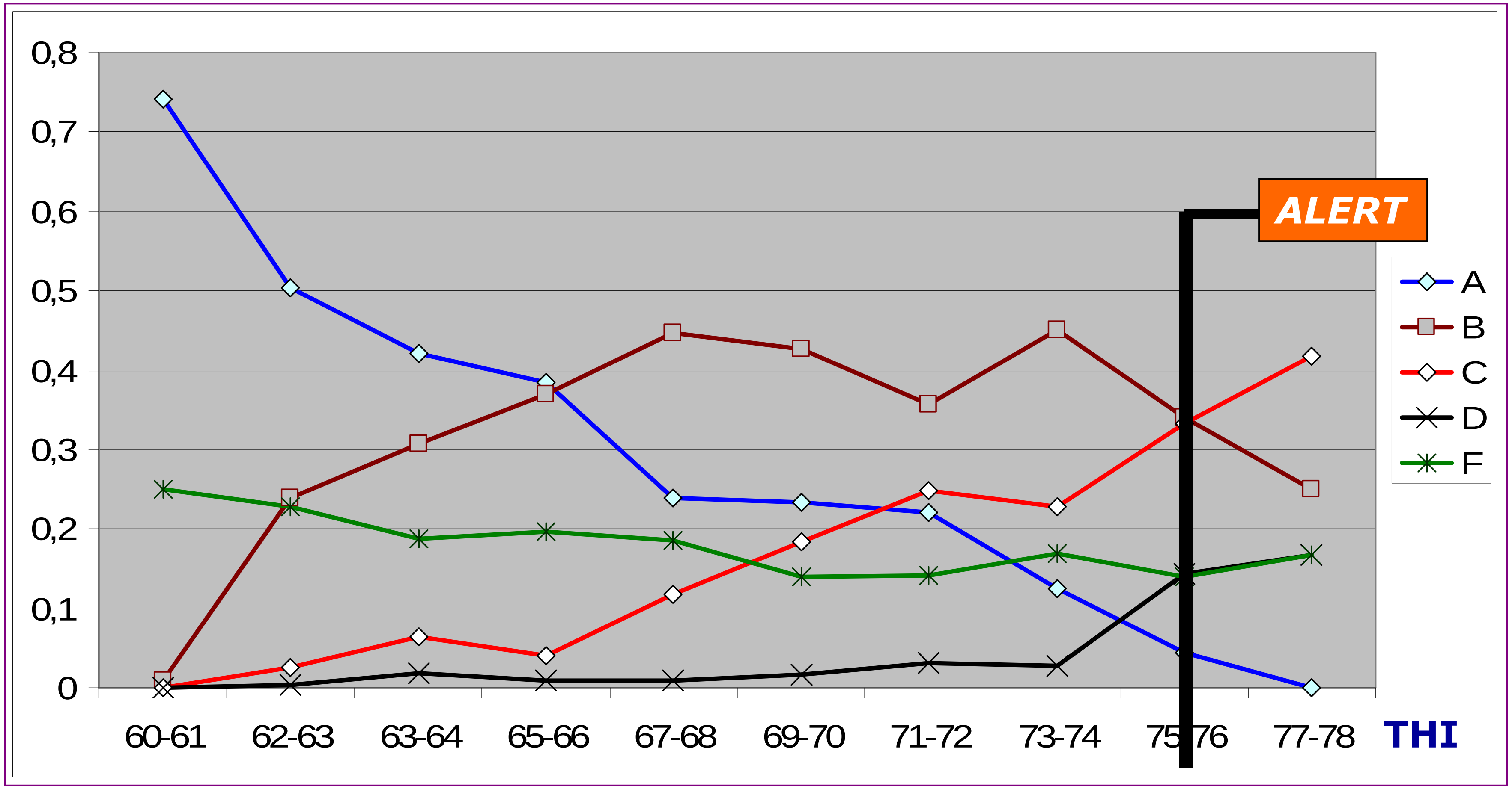
The graph clearly shows that the use of zone C has an opposite trend in comparison with zone A.

The lines of the two areas crosses at the temperature of 26-27°C, that is an important reference temperature of the behavioral changes of the sows.



Another value to take into consideration is 30°C: above this temperature the use of the cooled area with the coupled system becomes predominant.

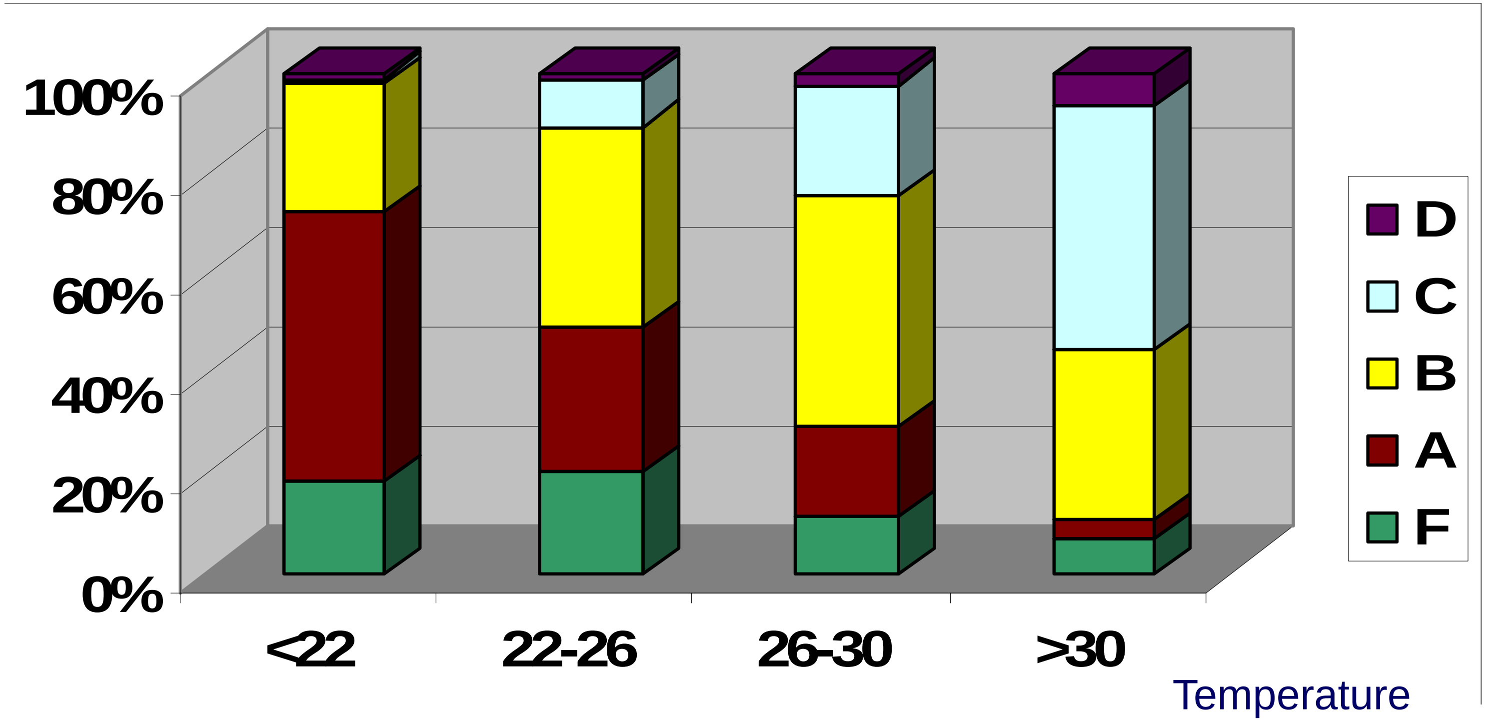
At 31°C the sows remain for the 92.6% of the time in the three cooled areas.



Similar results are obtained taking into consideration THI.

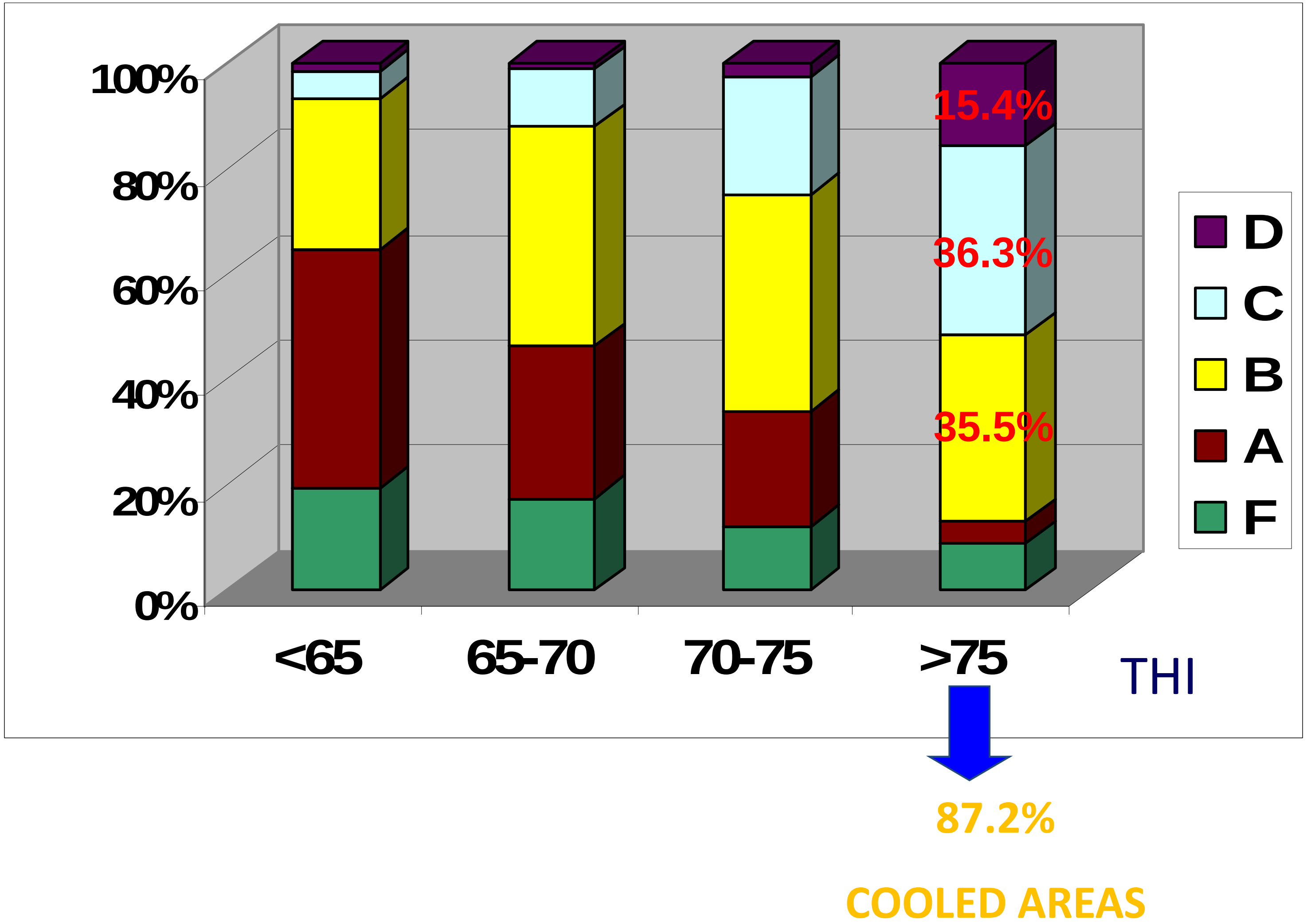
The graph clearly shows that the most frequented area is the C one, when THI passes the value of normality and gets in *ALERT ZONE*

The graph is obtained with a different way of analysis (χ^2-test).
It clearly shows that **the use of cooled areas** becomes **more and more important with the increase of temperature.**



The following considerations can be done

- Below a temperature of 22°C A and B are the favourite areas.
- The number of sows present in zone A regularly decreases with the increase of temperature.
- The presence of the sows in zone B tends to increase up to a temperature of 30°C, when the more frequented area becomes C one



100%
80%
60%
40%
20%
0%
15.4%
36.3%
35.5%
D
C
B
A
F
<65
65-70
70-75
>75
THI
87.2%
COOLED AREAS

Conclusions

- **to identify the areas in the pen where the sows preferred to stay**
- **to prove that behavior was not a merely instinctive one, but was actually related to the environmental changes occurring in the pen**

The system based on the realization of a stream of air at high velocity coupled with a system to wet the floor was particularly appreciated from the sows during the hottest periods of experimental trials

Considerations after these studies

The sows always need systems of heat protection, both in pregnancy and in farrowing phase.

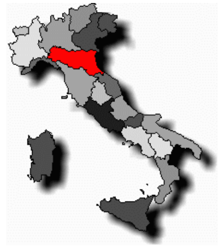
The temperature of 27°C seems to be a first critical threshold to take into consideration, as the behavioral changes of the sows can prove.

When the temperature rises above 30°C the sows strongly uses the cooling systems available in the pen.
In addition to the temperature value, relative humidity is another critic parameter.

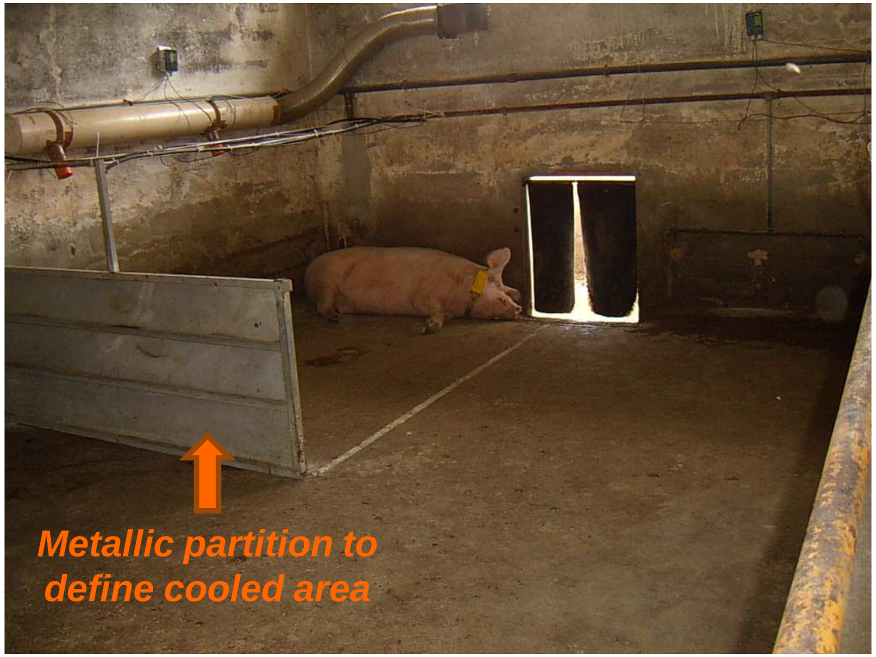
Further studies can be useful to define in a better way the relations between the behavior of the sows and comfort indexes, such as THI.

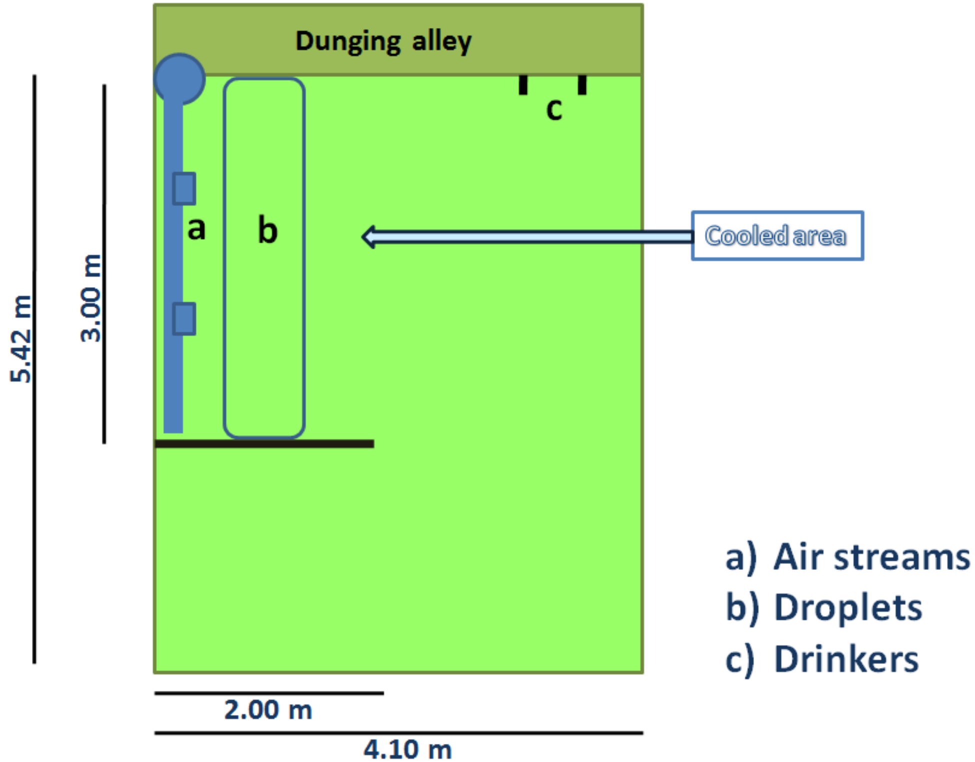
Experimental trial was arranged in order to confirm some results of previous studies

The experimental campaign was carried out in an intensive pig farm located in the Po Valley



The main aim of the study was to verify the use of the cooled area by the sows in relation to the inside air temperature and the Temperature-Humidity Index





Best system of previous research

2 combined systems

- stream of air at high velocity, made of two pipes with exit diameter of 0.08 m and blowing air at high velocity (12.5 m/s) towards the floor, for a total air flow rate of 1810 m^3/h

- supply of water on the floor by a drip cooling system, using 25 drip nozzles, able to supply 3.5 l/h each, working 4 times a day for 3 minutes. The total amount of water was 36 l/day.

Purpose of system with drip nozzles

↓

to keep the floor wet and cool instead of cooling directly the bodies of the sows.

In this case the cooled area was expanded, in order to contain all the sows of the group (4 head) to lie in position of lateral decubitus ⇨ surface/head = $0.47 \cdot W^{0.67}$
The measurements were made taking into account a live weight of 200 kg

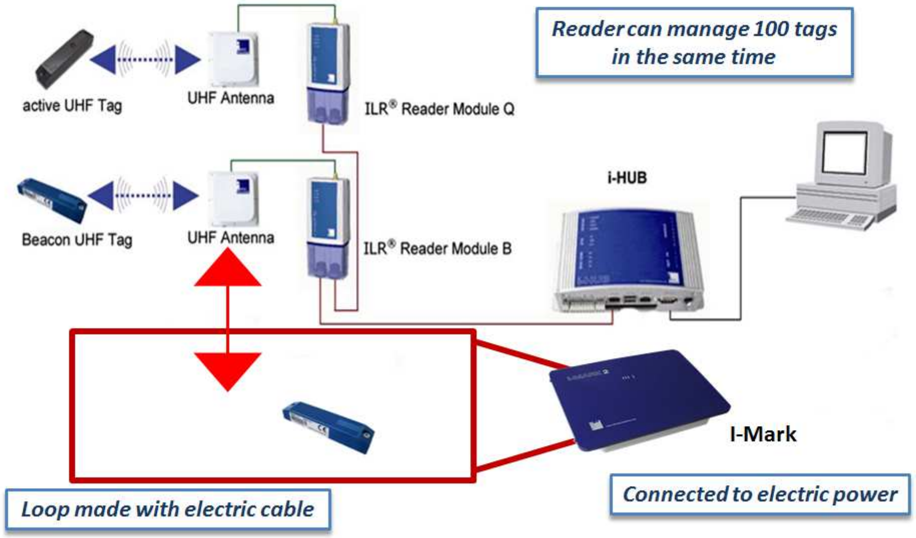
The use of the cooled area in the pen by the sows was monitored in relation to air temperature and the Temperature-Humidity Index (Ingram, 1965):

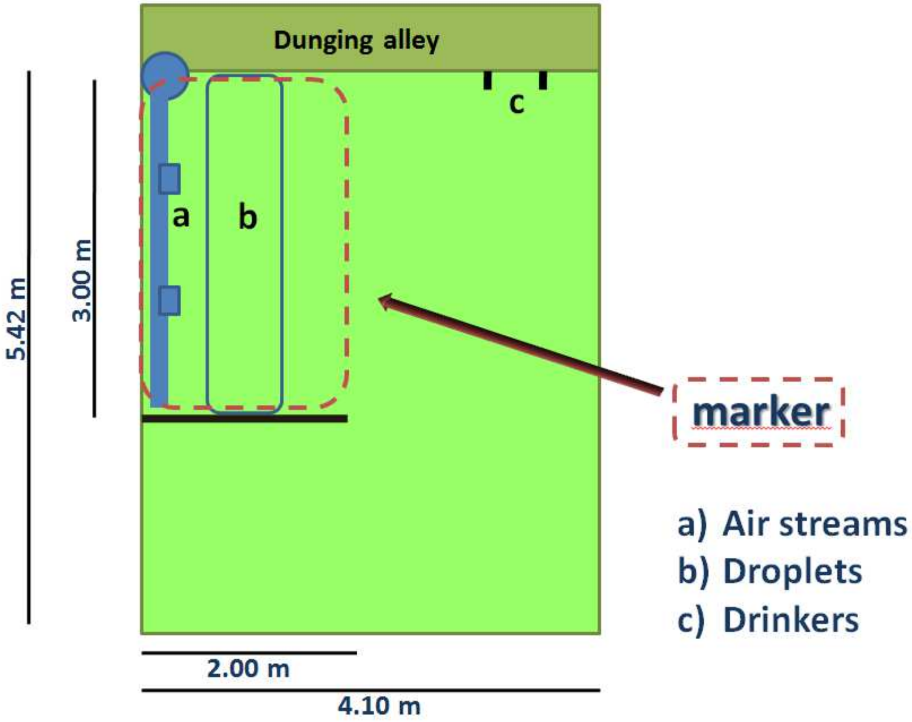
$$THI = 0.63\ T_W + 1.17\ T_D + 32$$

Data logger, equipped with specific probes. Digital close-circuit television system with infrared cameras

Active tags

RFID active tags, combined with technologies based on the use of area markers, were applied to the sows in a collar in the neck to collect information on times of permanence in the cooled area by each head





A marker device was used to bound the area of interest (cooled area)

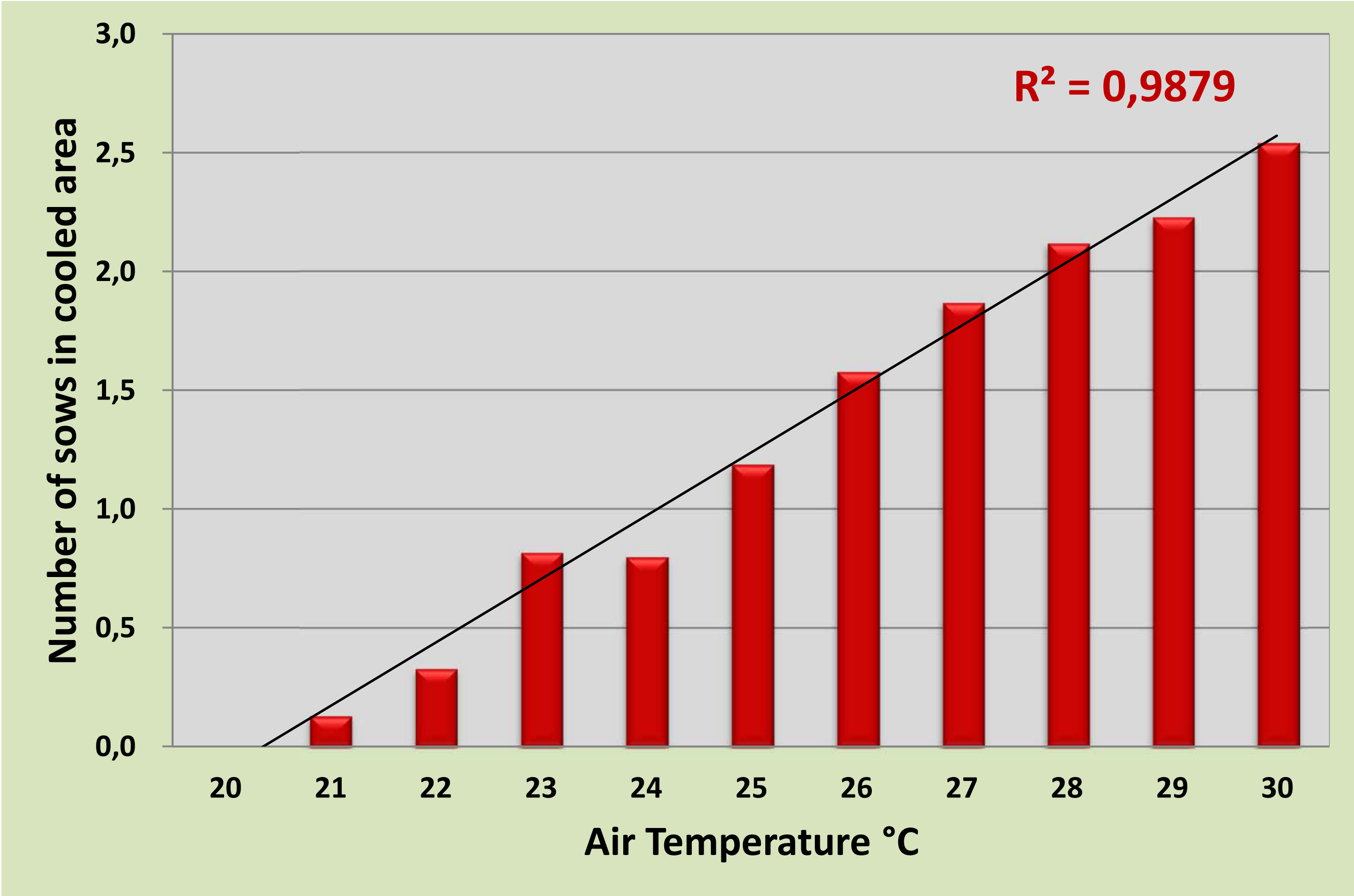
Possible to evaluate the presence of the sows in the free-access cooled area (number of presences and time of events)

2 antennas received the signal emitted by the beacon tags

4 Sows provided with tag	4 different colours:	
tag 962 (1497)	pink_n3	*- never lost during trials*
tag 966 (1440)	white_n2	*- never lost during trials*
tag 967 (1437)	yellow_n1	*- lost several times*
tag 973 (1251)	green_n4	*- never lost during trials*

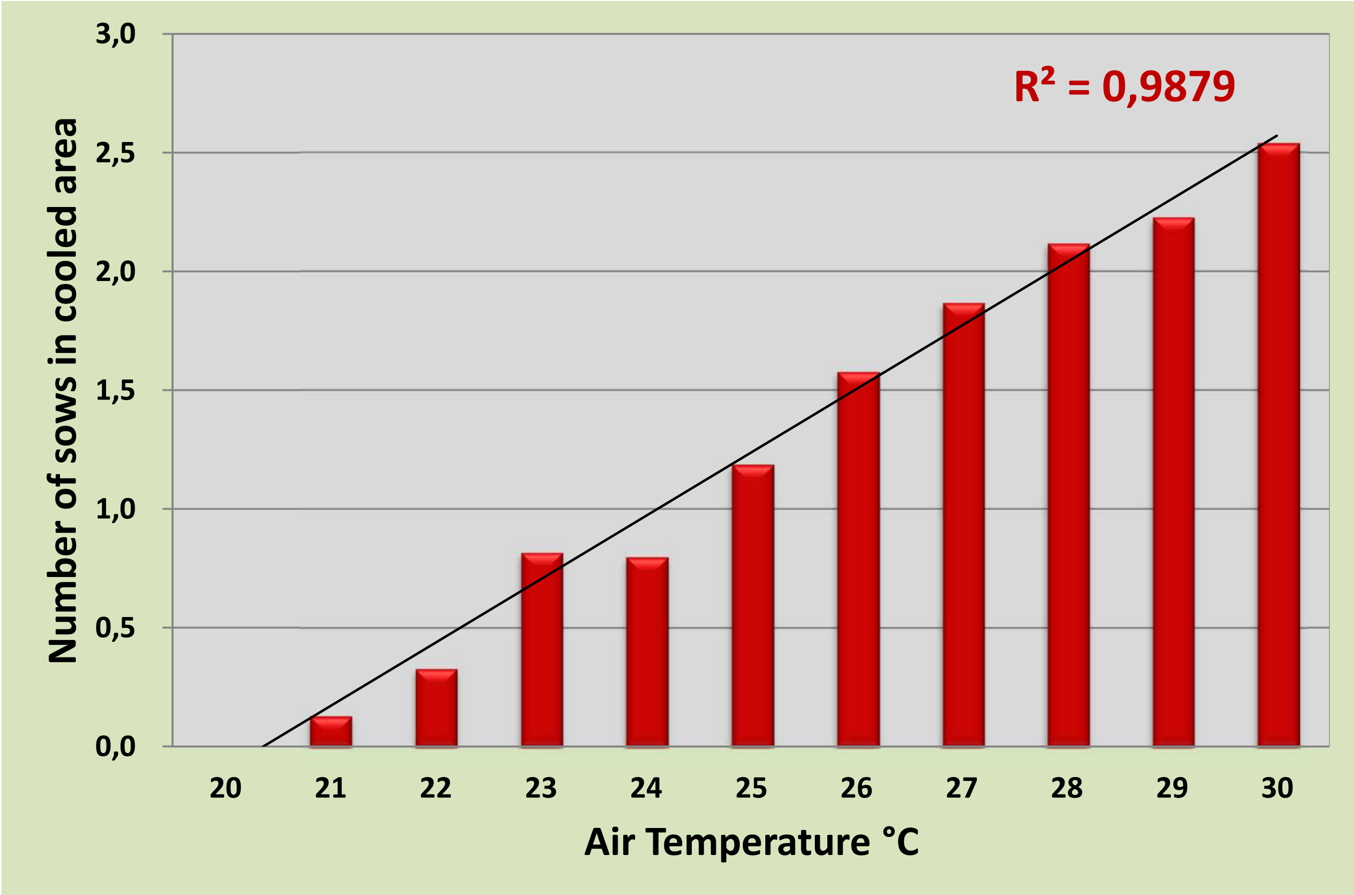
The cooled area is checked through a closed circuit television system and a RFID system

Behavior of the sows examined in relation to air temperature inside the building



The presence of sows in cooled area is strictly related to the temperature inside the building
The use of the area rises proportionately to the increase of the temperature

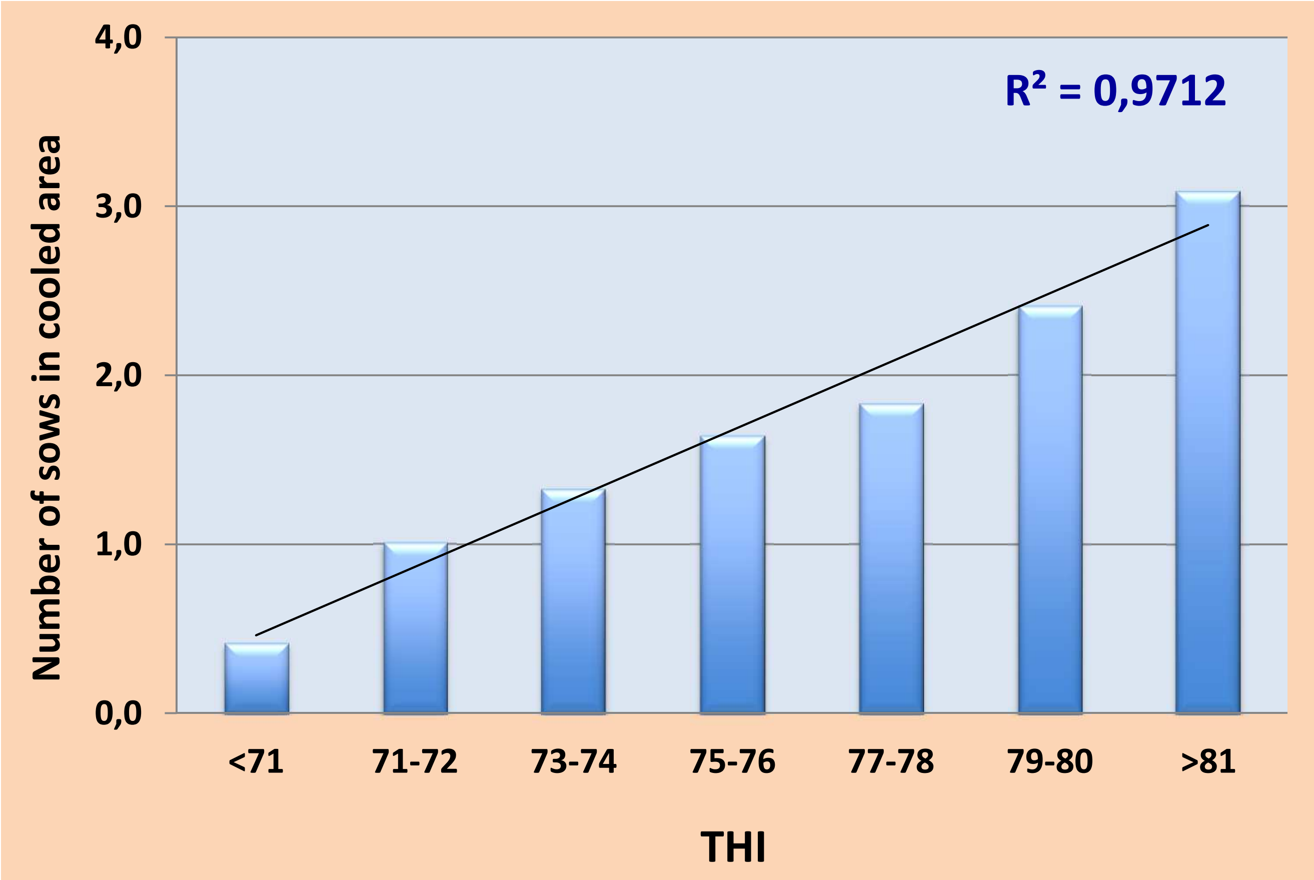
Behavior of the sows examined in relation to air temperature inside the building



When the temperature is 20°C the sows never enter the cooled area, but use other parts of the pen for resting

With temperature of more than 30°C 2.54 sows on average rest in the cooled area

Behavior of the sows examined in relation to Temperature-Humidity Index



Number of sows resting in cooled area increase with rising of THI values
When THI reaches values > 81, the use of the area is relevant
In this situation all the 4 sows are often present in the cooled area

Use of the cooled area by the single sows

In the group of four sows a hierarchic scale was established. All the sows could enter the area and lie, but the area was just a bit under-dimensioned to allow all the sows a lateral *decubitus*

If a dominant sow takes up particular positions in the area or all the other three sows are present, the last sow of hierarchic group can be overawed

The occupancy by all the sows of the group is registered only when the temperature is very high (> 30°C) or the THI reaches maximum values (> 81)

CONCLUSIONS

The cooling system based on a stream of air at high velocity coupled with a system to wet the floor was particularly appreciated by the sows during the hottest periods of experimental tests when the free-access cooled area had the highest occupancy.

A specific value of temperature or THI changing greatly the trend was not remarked. However the four sows of the group were generally present altogether in the cooled area only when temperature rose above 30° C or THI reached values of 81.

The occupancy of the cooled area increased during the last part of the day. In the evening hours the sows could remain in the cooled area also with not particularly high values of temperature or THI.

The proposed cooling solution can be suitable for static groups of sows. The solution is simple to arrange and to manage. Furthermore the costs for the equipment are reasonable.

In order to allow all the sows of the group to use the cooled area, it is very important to dimension the minimum surface taking into account the need of all the sows to lie down in lateral decubitus ($surface/head = 0.47 \cdot W^{0.67}$).
If the assigned surface is lower, some sows of the group, especially the last ones of hierarchic scale, can refrain from using the area.

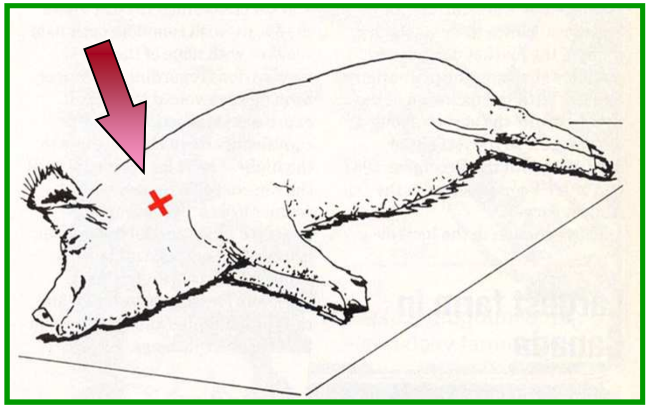
COOLING OF ANIMALS BY WATER

SOWS - FARROWING

→ **Problem of high temperatures especially felt during farrowing-lactating phase, when sows are housed in individual crates with plastic floorings**

Drip cooling can be included among the systems suitable for the heat protection of farrowing-lactating sows.

DRIP SYSTEMS - based on the drop of a **small amount of low flow water directly over the pig's head**, ears and shoulders, where blood vessels are close to the surface of the skin. The water evaporation in this area of the body induces a reduction of inside temperature and then an improving of the thermal comfort conditions of the animal.



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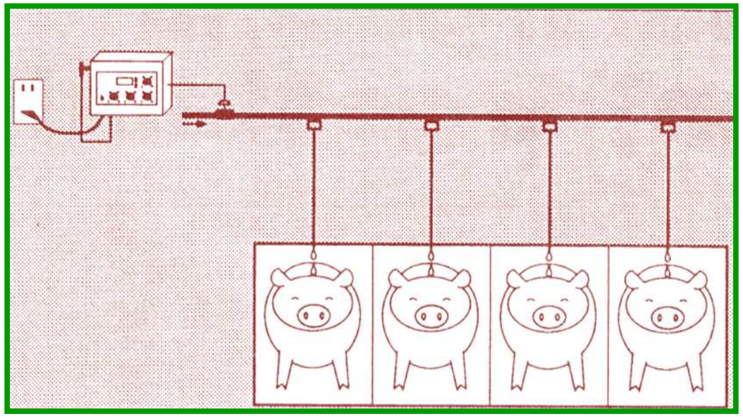


The equipment is composed of an **electronic controller**, which enables the setting out of the shower starting temperature, measured by a **thermal probe** installed in the room, and the operating times. The electronic device controls a solenoid valve, which above has a pressure regulator and a filter. The self-balancing droplet emitters are installed on a completely plastic hydraulic line.

The experience gained during suffocating hot summers pointed out that drip cooling is not enough to ensure the thermal comfort of the sows, especially with total plastic floors and with natural ventilation systems.
In such situations the drip cooling systems have to be coupled to other systems.

COOLING OF ANIMALS BY WATER

COOLING OF ANIMALS BY AIR

SOWS - FARROWING

Head–zone ventilation may provide an improved microenvironment for the thermal requirement of sows.

The output rate of the nozzles for drip cooling should range **from 2 to 3 l/h**.
For zone cooling of farrowing sows, the recommended airflow rate is **120 m^3/h/sow** for **uncooled air** and **70 m^3/h/sow** for **cooled air**.

Trials carried out in Italian pig farms – farrowing room

Farrowing room

2 different cooling systems were installed in the crates

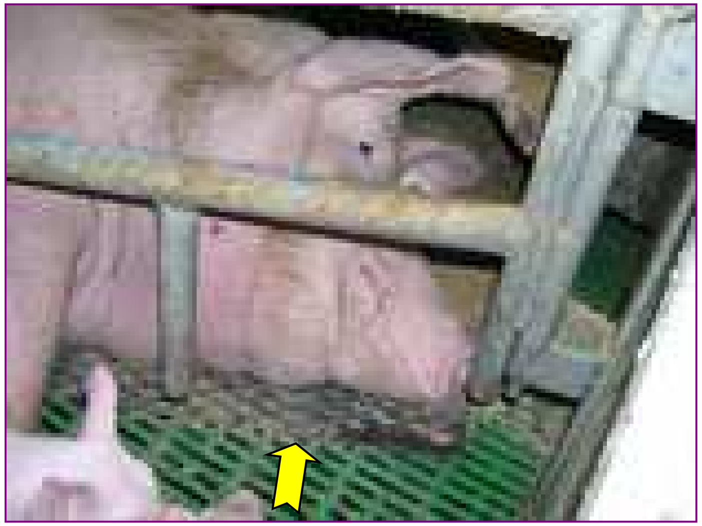
- **Drip cooling system**
- **Drip cooling and snout cooling systems**

Drip cooling system

drip nozzles, able to supply 2 l/h per sow

4 times a day for 30 min

Pipe of the drip cooling system



Full steel sheet under the head of the sow

Pipes of snout system

Air coming out from the hole

Snout cooling system coupled with drip cooling system

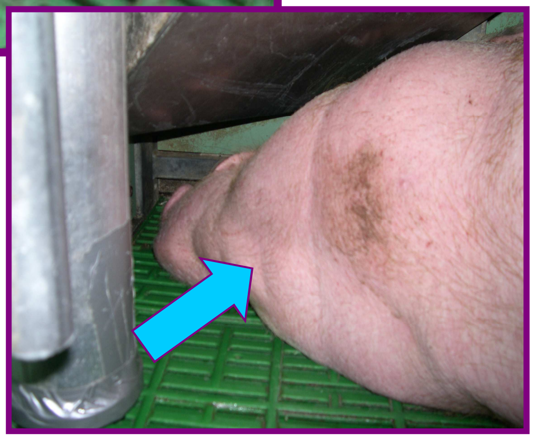
The air was directed close to the head of the sow, under the trough, with a **flow of 88 m^3/h** and a constant **velocity of 7.2 m/s**.

The air could flow over the lying sows, towards either the snout or the neck.

The farrowing crate used in the trials is long enough to allow the sows to lie in advanced or rear position. In such a way the animals freely choose to profit from cooling systems provided or not.

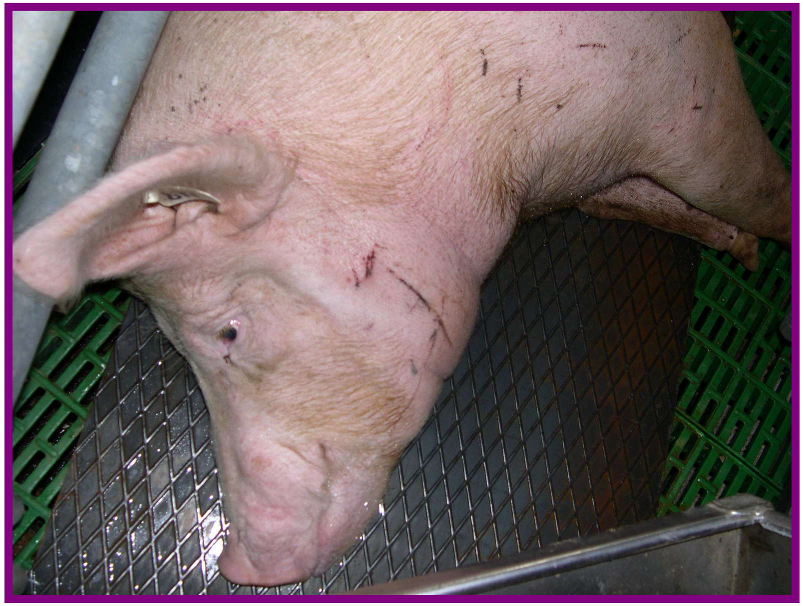
The aim of the study was
to analyze the behavior of sows in relation to air stream coming from snout cooling system in different thermal conditions

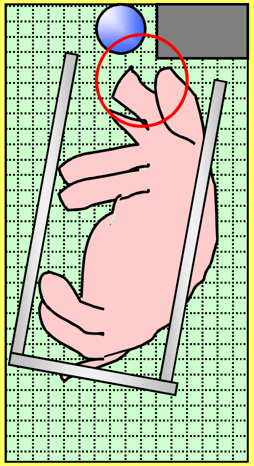
- *air temperature*
- *THI*



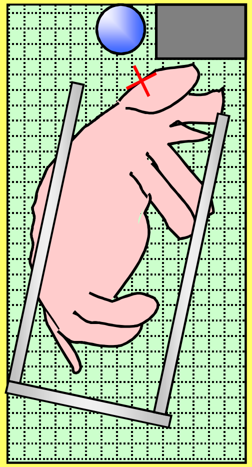
The sows seem to appreciate the air flow provided by snout cooling ducts in the front area of the farrowing crate.

The sows remained for long periods with the snout or the neck near the air outlet hole.
With long enough farrowing crates (2.50 m) the sows could freely move back, lying in such a position as to optimize the effects of the cooling systems.





Sow that profit from the air on the snout (TS)



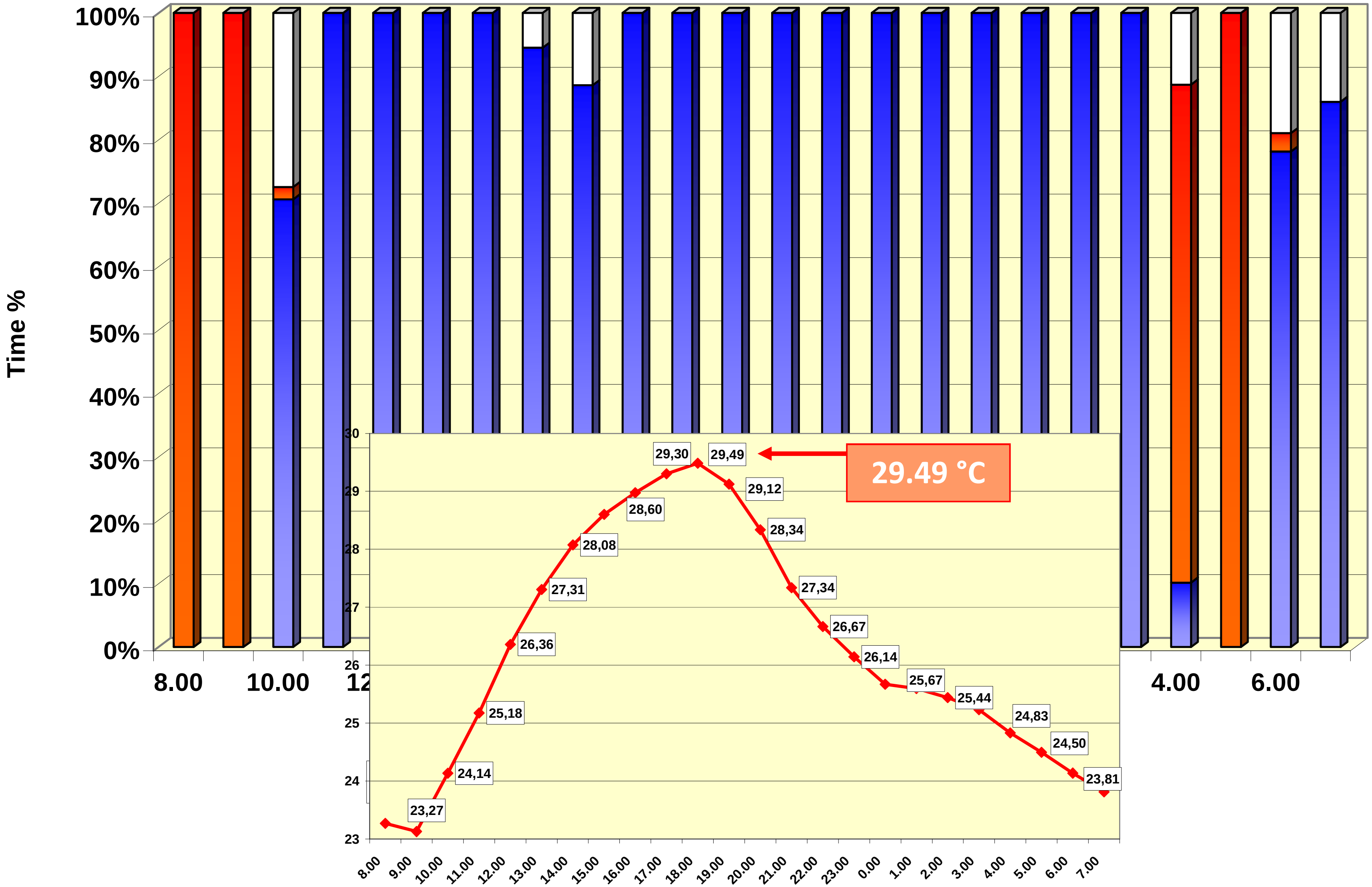
Sow that profit from the air on the neck (NTS)

- When the sow is lying ahead (with the head placed under the trough), it can choose to profit from the fresh air in 2 ways:

TS - lying towards the snout
NTS - lying not towards the snout

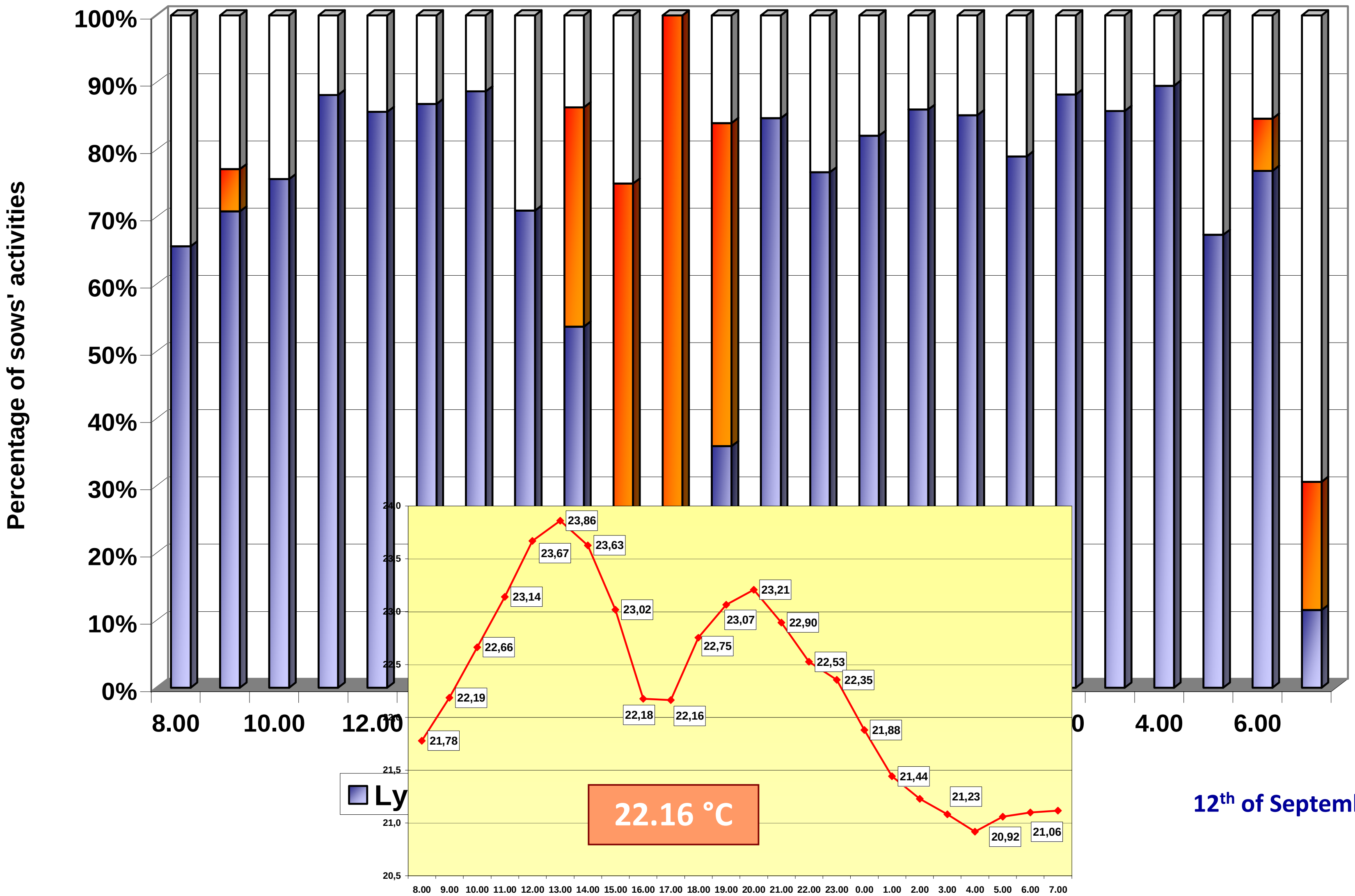
Changes in the behavior of the sow during days with different thermal conditions.

Warm day

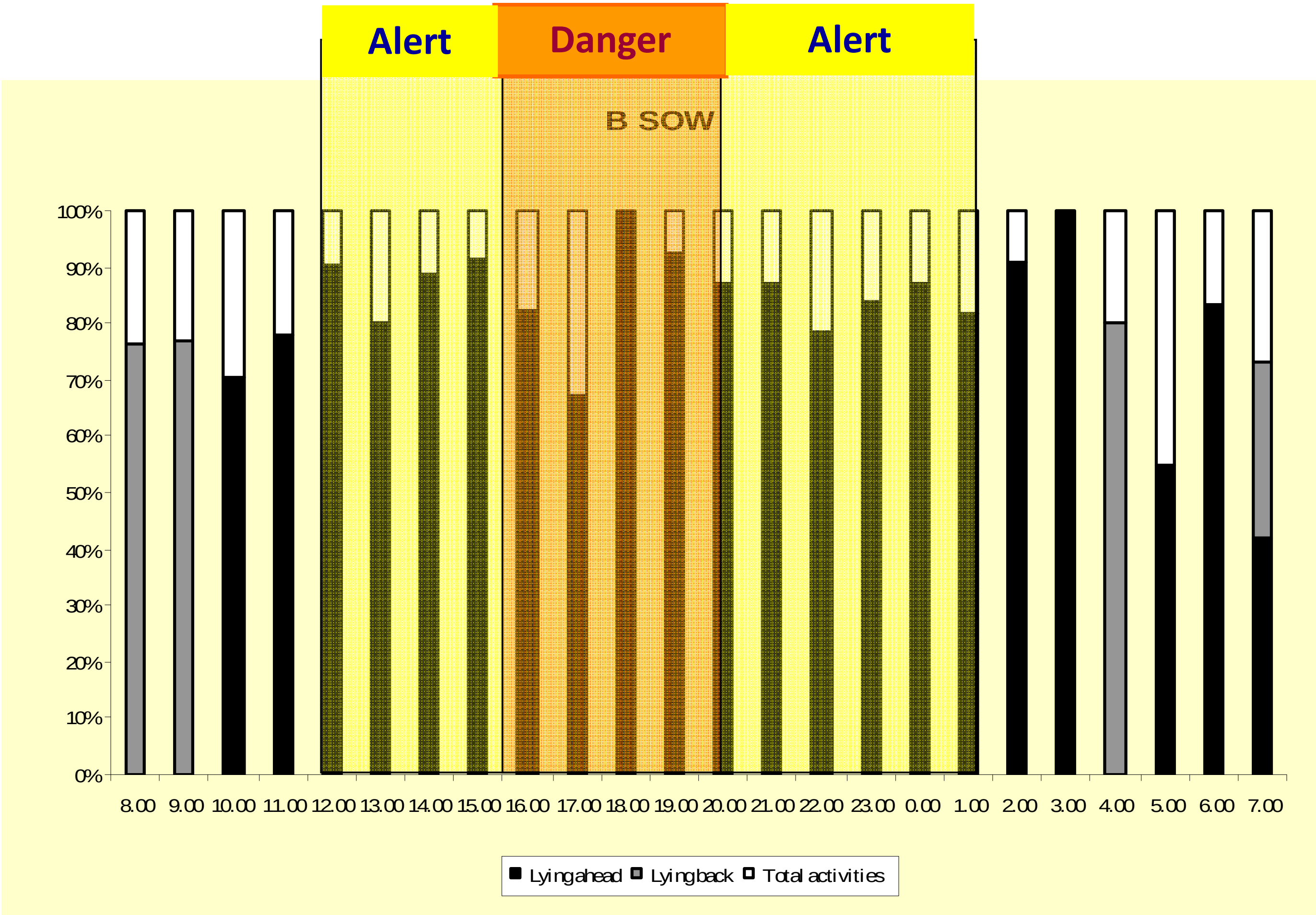


Changes in the behavior of the sow during days with different thermal conditions.

Cold day



12th of September



During the central hours of the day (mean value from 5 to 7 p.m. 30.16 °C), THI moves from comfort to alert and dangerous zones and the sow chooses to lie ahead: in this situation the fresh air coming out from the pipes is a valid help against the heat stress of the sows in farrowing room.

RESULTS

1. In the farrowing rooms it is always necessary to arrange systems for heat protection of the sows housed in single crates. It is particularly important to provide an effective cooling system for the sows when uncomfortable floors are used, such as the plastic ones.
2. The system based on the drip cooling alone did not provide satisfactory results.
3. The sows appreciated the air flow provided by snout cooling ducts in the front area of the farrowing crate. During the experimental trials the air flow rate was constantly 88 m^3/h, with an air velocity of 7.2 m/sec.
4. The sows remained for long periods with the snout or the neck near the air outlet hole, especially during the hot hours of the day. With long enough farrowing crates (2.50 m) the sows could freely move back, lying in such a position as to optimize the effects of the cooling systems.
5. The piglets did not present any problem for the air flow, because it was directed in the part of the crate diametrically opposed to the heat nest.

A ***suitable solution*** **for heat protection of the sows could be based on the combined utilization of all 3 systems adopted in the present research, that is**

- **a drip cooling system, with a fit electronic control unit**
- **a snout cooling system, placed in the front area of the crate to allow the sow to move out of the radius of action of the air**
- **a full metal floor of 0.50 x 0.60 m placed under the head of the sow**

In such a way the floor remains wet for long periods after the water supply and the sow is able to dissipate a higher heat quantity from the wet body surface.

Conclusions

On the basis of the several experimental trials ⇨ some suggestions useful in the planning of cooling systems.

The sows always need systems of heat protection, both in pregnancy and in farrowing phase.

The temperature of 27°C seems to be a first critical threshold to take into consideration, as the behavioral changes of the sows can prove.

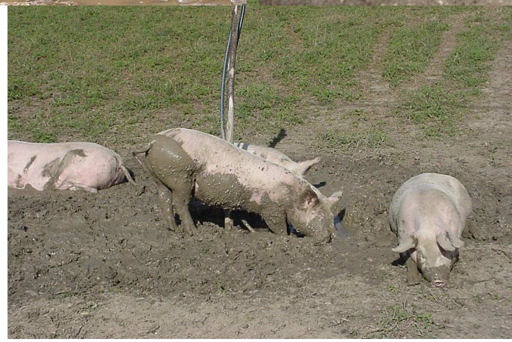
When the temperature rises above 30°C the sows strongly uses the cooling systems available in the pen.

In addition to the temperature value, relative humidity is another critic parameter.

COOLING OF ANIMALS BY WATER

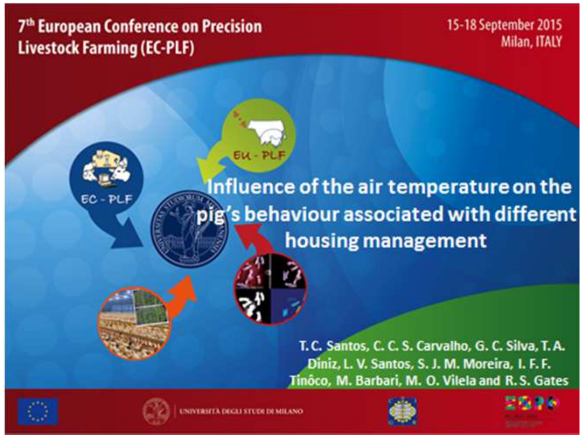
GROWING-FATTENING PIGS

The use of bath basins is an usual practice in outdoor swine farms. In such situations the system is base don simple holes filled with water.



In intensive farms tanks realized in concrete are seldom used for the bath of pigs. However these tanks have several contraindications, in particular for the poor hygiene, that can favor the spread of undesirable diseases among the animals.

Influence of the air temperature on the pig's behavior associated with different housing management (Brazil)



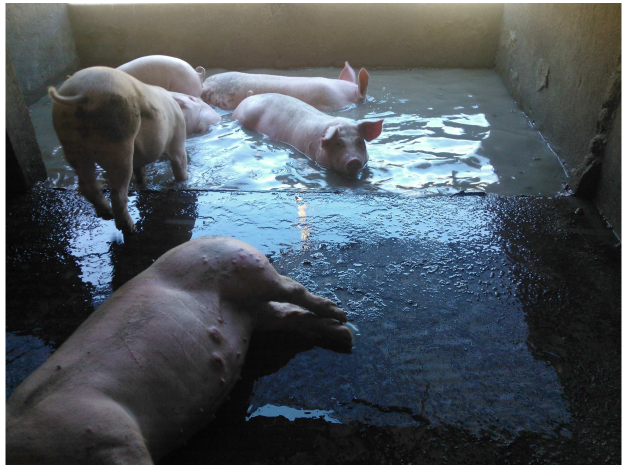
Influence of the air temperature on the pig's behaviour in different housing management
T.C. SANTOS et al.

Benefits of water basin system

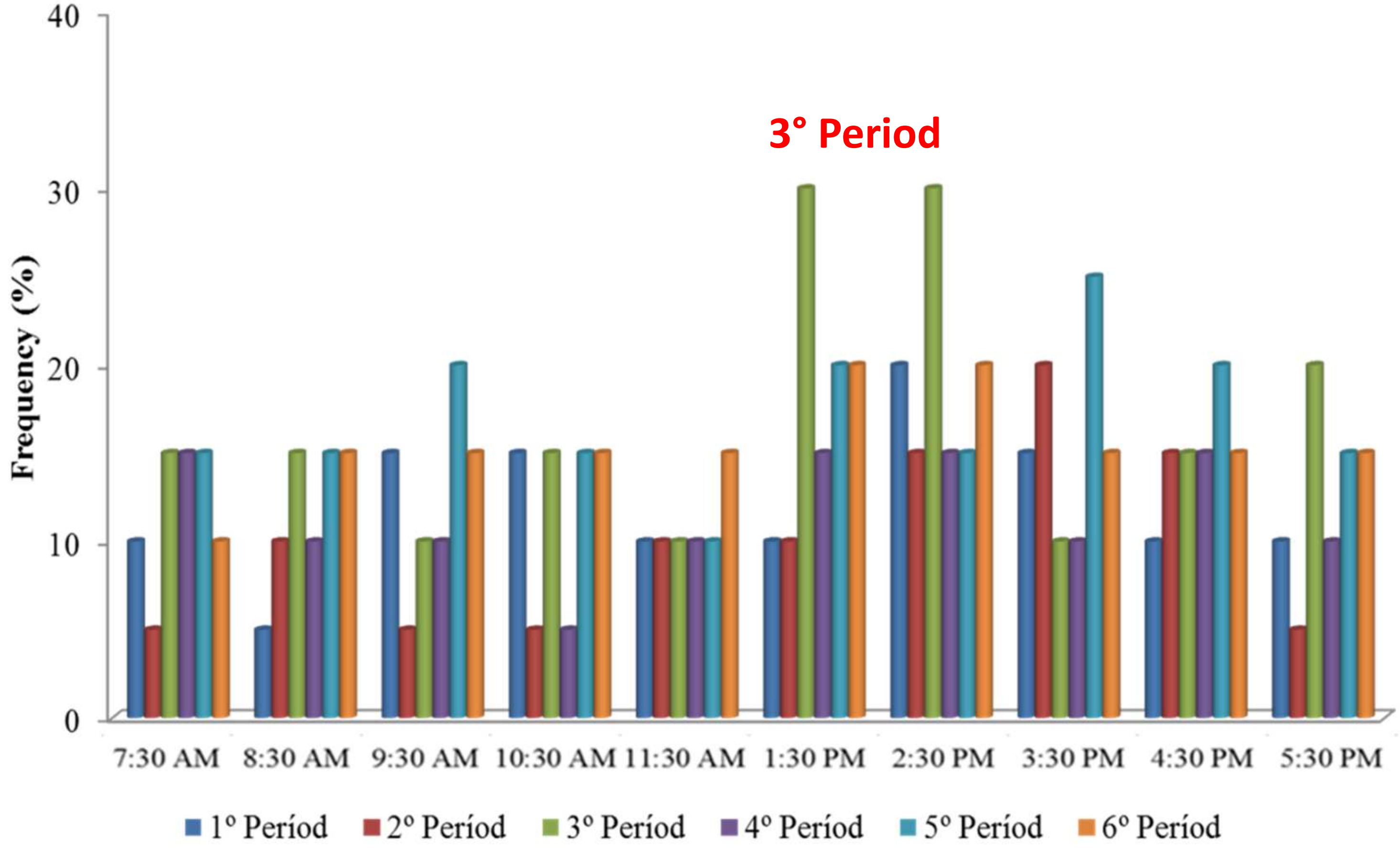
- It allows the animals to activate a cooling process by convection, conduction and evaporation.
- Comfortable environment → natural behaviour

The objective of the work was to study the effect of air temperature on the search by the animals of a cooled area during the growing and finishing phases in pens with and without access to the water basin system





Frequency of animals going the water blade system during the six periods



CONCLUSIONS

- **In the 3rd period, with the highest air temperatures, the percentage of animals seeking the water basin system was higher than in the other evaluated periods.**

- **Pigs can choose when to use a cooling system applied in the pen.**

FINAL CONSIDERATIONS

The experimental trials carried out at Federal University of Viçosa can be considered as a first step of researches concerning the use of cooling systems for heat protection of pigs.

To define:

- **Size of pen in relation to application of water basin**
- **Size of water basin in relation to number of pigs**
- **Amount of water**
- **Wastes**
- **Quality of water – relations with health state of animals**

THANK YOU