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Original Research

Agricultural uses in a greenhouse structure with an integrated solar desalination system on the roof

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Abstract

Background: Today there is a variety of desalination systems supporting the production of water for agricultural uses. However, these systems are still characterized by relatively high installation and operation costs and are not particularly suitable for isolated areas. The present work proposes the development and operation of an innovative and sustainable greenhouse structure that utilizes simultaneously its roof to produce irrigation water, with the method of solar desalination, and its inside space to house livestock and poultry.

Aims: The main objective of this work is to study the agricultural livestock uses that can be welcomed by this greenhouse-solar desalination construction. The design and operation of this unit aims to produce irrigation water in arid areas, creating significant environmental and social benefits by protecting the water resources of these areas as well and by developing agricultural economic activity in drought conditions. Moreover, multiple land use such this case offers the possibility to urban and spatial planners to take decisions towards sustainability.

Methods: This study examines the design of such structures in combination with the internal environmental conditions (temperature, humidity, ventilation, lighting) that are required for animal production, in order to propose the proper design techniques and modifications needed for the animals' welfare. The optimum environmental conditions and control systems of each type of productive animal differ and thus those are studied separately.

Results & Conclusion: Regarding productive animals due to the special conditions required for maximum yields with a satisfactory level of well-being, the greenhouse-type construction with the solar desalination system can be adapted accordingly. The environmental control systems that affect the initial study and design of the construction are mainly those of ventilation and cooling, while heating and lighting systems affect basically the structural analysis and not the design. The operation of such an innovative system for combined agricultural use and irrigation water production creates the opportunity for local communities to benefit from the increase of locally produced products at lower prices, and from the upgrading and utilization of arid areas that are not suitable of any other land use or they previously had no other use.

Keywords: Solar desalination agricultural structures; Arid areas; Irrigation water; Greenhouse; Enhancement of agricultural economy; Sustainable land uses

1. Introduction

The regions of the Mediterranean and North Africa are characterized by intense sunshine with a simultaneous lack of rainfall resulting in a significant reduction in water reserves and limited agricultural activity. In the Era of Climate Change, aridity and risks related to agricultural production, unpredictability of harvests and shifts in rainfall patterns, are expected to increase [1]. Drier areas may not be suitable for agricultural production, since land qualities for agricultural land uses such as moisture availability will deteriorate, and the worst case is that they may go out of production altogether. Agricultural management requirements will change and in particular the need for irrigation will increase [2].

Land use planning is based on land qualities and characteristics for suitability such as moisture availability *etc*. [3]. Water resources are seriously connected to many land qualities for agricultural uses and not only. Aridity and water resources depression problematize urban and spatial planners when they have to define the land uses and land mapping units (housing, production, agricultural uses *etc*.), especially for arid areas. Restricting development is a crucial drawback of land use planning which might hurt local economies seriously. Water and land support agricultural production systems, which are considered as systems at risk [1], and unfortunately water availability depletion may lead to such restrictions. Combined and multiple land use is not a new idea for sustainable land use, but new utilizations of land such as water production and renewable energy applications and new combined utilization techniques such as Agrivoltaics [4,5] may lead to a new idea of thinking towards sustainable land use planning.

A great solution especially for coastal arid and semi-arid regions is that of water desalination. The solution of desalination is a topic of global discussion and its application is constantly increasing in order to meet the needs of fresh water in arid areas with a lack of rainfall or a significant reduction in water reserves [6], such as the Mediterranean and North Africa. According to the United Nations World Water Development Report of 2014, "Water and Energy" [7] there were over 16,000 desalination plants worldwide with a total global operating capacity of approximately 70 million m^3/day. Today desalination is widely used mainly in the Middle East and North Africa (70% of world capacity).

Desalination is a rather energy consuming process resulting in quite high operating costs. In general, investment and operating costs are particularly high, making desalination unsuitable for high water consumption sectors such as irrigation in the agricultural sector [7]. The International Desalination Association sets targets for reducing energy consumption through technologies such as solar desalination which is considered ideal for arid areas [7].

The main objective of this work, which results from the research project "Innovative Greenhouse System for Combined Agricultural Use and Irrigation Water Production - IRISS", is the creation of an innovative greenhouse construction for water production for agricultural uses with low investment and operation costs and simultaneous utilization of the inside space for housing farm animals. The inside space may also be used for plant cultivation or storage. Due to the nowadays phenomena of the effects of climate change (drought, lack of water supply, meeting nutritional needs for an exponentially growing population and given the need for energy transition to transform the economy using Renewable Energy Sources, the idea of developing agricultural activities with simultaneous production of irrigation water by solar desalination, in a single space is a key innovation in this context. The idea is also important as it achieves the implementation of a desalination system with reduced installation and operation costs compared to other desalination systems.

In order to achieve the combined use of this construction model, the possible uses of the greenhouse space that exists under the installed solar desalination unit are investigated by studying the suitability of the conditions inside this space (temperature, humidity, ventilation, *etc.*) for its proper exploitation. The cases investigated in the project fall into the categories of productive animal housing, storage and farming activities. The present work focuses on the study of housing productive animals in a greenhouse type construction with a solar desalination system on the roof. The idea came up because of the latest trend to house productive animals in light structures as greenhouse type livestock buildings. The advantages of these structures *versus* the traditional livestock buildings (Figure 1) are already recognized and are of great importance in terms of competitiveness.

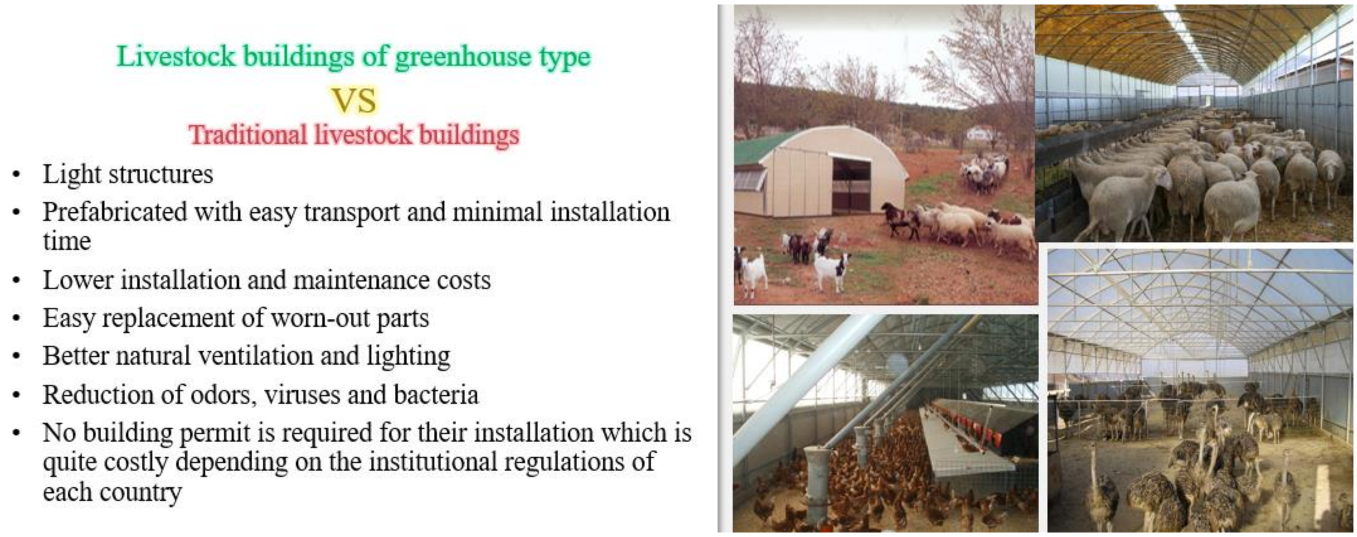

Figure 1 The advantages of livestock buildings of greenhouse type compared to the traditional livestock buildings.

2. Materials and Methods

This study examines the design of the greenhouse -type structure with the solar desalination system on its roof by taking into account the internal environmental conditions (temperature, humidity, ventilation, lighting) that are required for animal production and welfare. Results are expected to indicate the proper design techniques and modifications to the prototype structure needed for the animals' welfare. The optimum environmental conditions and control systems of each type of productive animal differ and thus those are studied separately.

2.1 The greenhouse type construction with the solar desalination system

The standard innovative unit, in the form of a greenhouse, whose roof functions as a solar desalination plant to produce irrigation water that may be needed either inside or outside the greenhouse, was installed in a coastal area of the Aristotle University of Thessaloniki 's farm, which is located at the eastern suburban area of Thessaloniki in Greece.

The proposed construction unit (Figure 2) consists of the following three parts: (i) the seawater or brackish water evaporation system, (ii) the heat exchange-condenser system for the simultaneous preheating of seawater and the condensation of pure water vapors and (iii) the greenhouse construction. The greenhouse type structure comprises a double frame, triple cover material and insulation. The outer frame is covered with a single transparent polyethylene plastic with high light transmittance (over 93%). The inner frame is covered by two sheets of opaque plastic polyethylene, with one side white and one black. The outer leaf has the black side up and the inner, depending on the use of the interior, either white or black. Between these two sheets of plastic, there is fiberglass insulation. The seawater or brackish water passes through a heat exchanger, where it is preheated, and then dispersed in a large number of droplets in a polyethylene tube for evaporation which is placed in the gap between the double frame where the increase in temperature due to solar radiation is achieved (Figure 2).

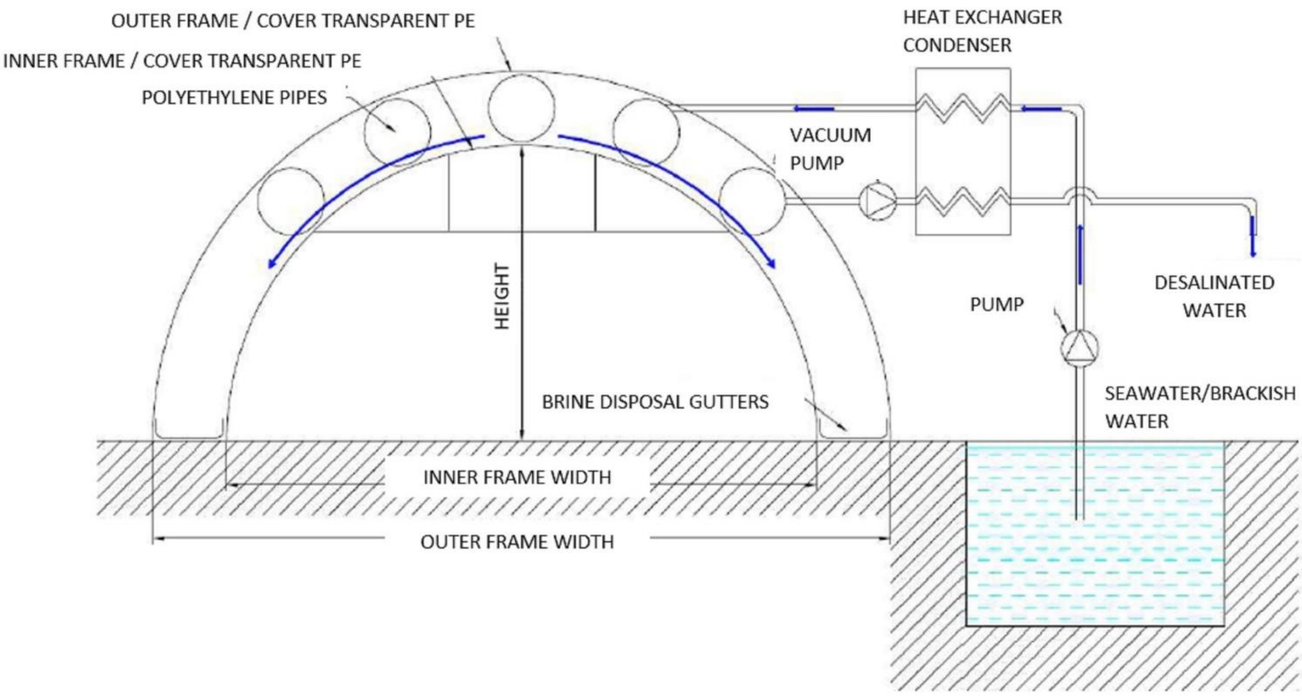

Figure 2 Vertical section of the greenhouse construction, with the solar desalination system installed on the roof.

To facilitate the study for the use of the interior space of the standard greenhouse desalination unit, a corresponding unit was constructed in the area of the Aristotle University Farm, which is illustrated with its dimensions in Figure 3.

Figure 4 shows the section and the low energy consumption equipment of the construction to maintain the conditions inside it (avoid high temperatures and regulate humidity). The experimental device consists of a galvanized steel frame and is covered with white-black polymer with a coefficient of thermal conductivity U = 6.7 W / m^2K.

Dimensions	Value	Greenhouse Area and Volume
Length	8m	Area: 32m^2
Width	4m	
Gutter Height	2m	Volume: ≈70m^3
Ridge Height	2,4m	

Figure 3 The experimental construction with its dimensions and the external and internal appearance of the ventilation ducts.

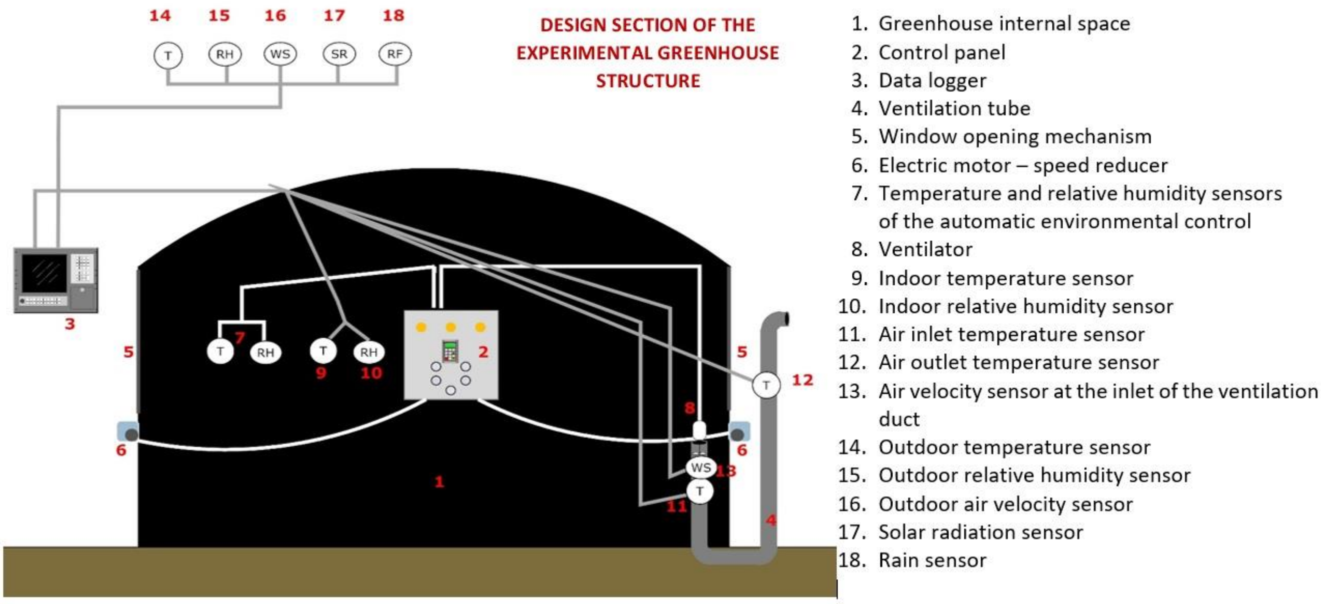

Figure 4 Section of the experimental greenhouse and the low energy consumption equipment of the construction to maintain the conditions inside, to avoid high temperatures and regulate humidity.

2.2 Housing conditions of productive animals

As already mentioned, the aim of this work is to achieve the combined use of this standard construction for the parallel housing of productive animals. The design modifications that are necessary to maintain the optimum conditions in this space (temperature, humidity, ventilation, *etc*.) required for the welfare and productivity of various categories of farm animals are investigated and proposed.

In general, the energy, health and productivity of farm animals depend to a large extent on the direct effects of their climatic environment. The parameters of the climatic environment act individually or in combination with each other and are distinguished in thermal and chemical. The thermal environment includes temperature, humidity, the intensity of sunlight and the movement of air, while the chemical environment includes gases, vapors, dust and odors.

The thermal balance of an animal and its environment is regulated by the effect of the above elements as well as by the heat exchange between the animal and the environment. The thermal balance of animals is expressed based on the laws of thermodynamics and specifically by the following equation [8] (Used with permission):

$$MHP \ \pm J \pm q_{rt} \pm q_{cv} \pm q_{cd} - EHL = WC_p \frac{dT_b}{dt}$$

Whereas:

MHP	= rate at which thermal energy is produced by metabolism
J	= rate of mechanical work
q_{rt}	= rate of heat transfer by radiation
q_{cv}	= rate of heat transfer by convection
q_{cd}	= rate of heat transfer by conduction
EHL	= rate of heat loss by evaporation of water
W	= body weight
C_p	= specific heat of the body mass
T_b	= body temperature
t	= time

Thus, the first law of thermodynamics is used to express the thermal energy balance of the animal and is a fundamental expression which links the physiological state of the animal and the thermal environment as it is presented in Figure 5.

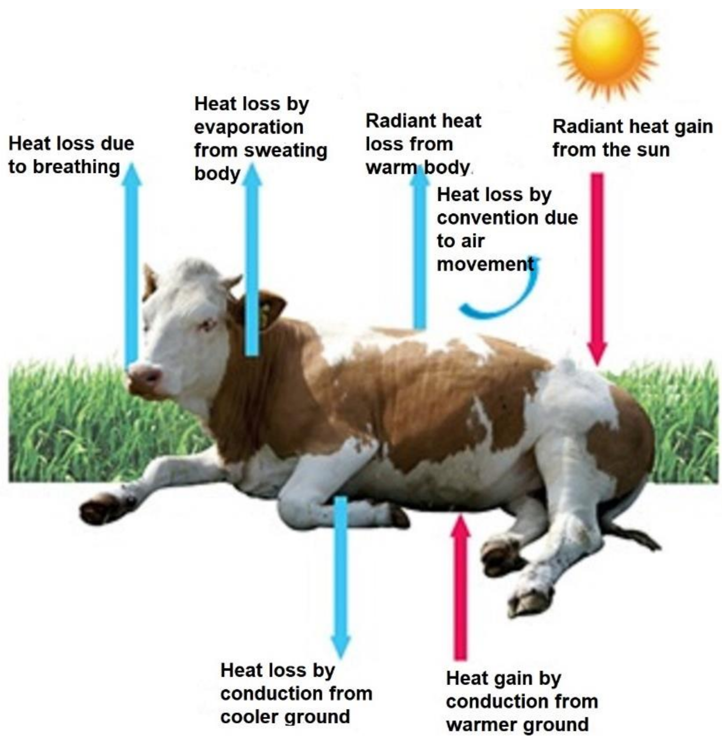

Figure 5 Heat exchange between animals and their environment [9].

2.2.1 Effect of ambient temperature

Ambient temperature directly affects the heat loss of the animals. These heat losses inside the stable then affect the temperature and humidity of the environment. Figure 6 shows a highly simplified diagram showing the correlations between metabolic heat production (MHP), sensible heat loss (SHL), heat loss due to evaporation (EHL) and body temperature (Tb), all as a function of ambient temperature.

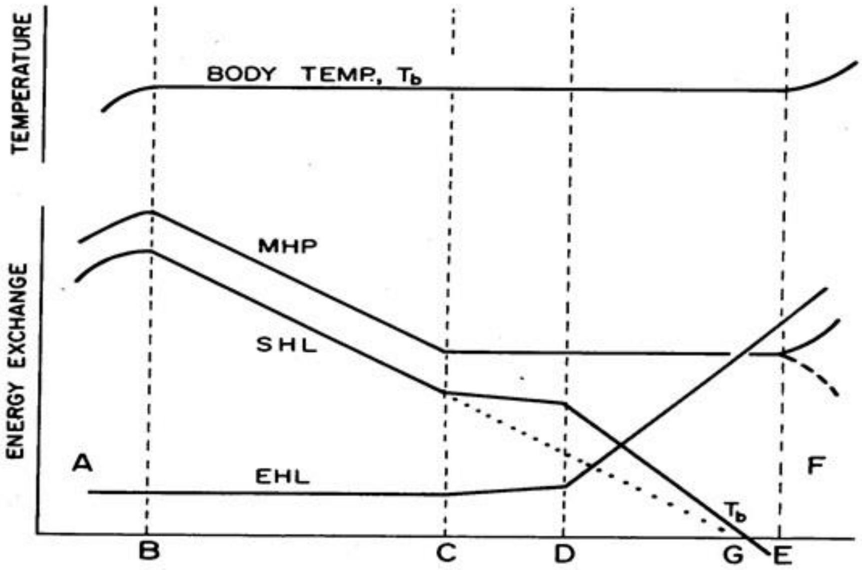

Figure 6 General schematic diagram showing the energy exchanges of an animal in relation to the ambient temperature [8,10] (Used with permission).

This diagram also shows the energy exchanges between farm animals and the thermal microenvironment in general. Actual prices depend on the species, diet, age, behavior and housing systems. In the diagram the zones of the environment are defined as follows:

Ζώνη A:	zone of hypothermia
Ζώνη CD:	zone of minimum effort for thermoregulation (thermoneutral zone)
Ζώνη CE:	zone of minimal metabolism
Ζώνη BE:	thermoregulation zone
Σημείο B:	temperature at which the maximum of the metabolic heat is produced and the starting point of the hypothermia occurs
Point C:	critical temperature, below which metabolism increases
Point D:	temperature at which evaporative heat loss begins to increase
Point E:	onset temperature of hyperthermia
Point G:	the point where SHL = 0 because the ambient temperature is equal to Tb

When designing the environmental control systems of livestock facilities, the primary goal is to maintain an optimum temperature throughout the production cycle. From the study of the diagram of Figure 6, it is understood that the "optimum" ambient temperature is within the thermoneutral zone, because within it, the total heat produced by an animal is independent of the ambient temperature and depends mainly on its living weight and food intake.

2.2.2 Humidity

The humidity of the air as well as its temperature, give the basic characteristics of the environment of the specific space. These two factors are governed by certain thermodynamic properties, generally called atmospheric air "psychrometrics".

High relative humidity (over 80%) creates serious problems in housed farm animals, because it prevents them from emitting heat by evaporation and in some species, such as birds, it causes the feathers to get wet. High relative humidity also facilitates the deposition of moisture in the form of drops on the construction materials, resulting in the development of wood rot, metal oxidation and diseases in the respiratory system of animals. When the percentage of relative humidity of the air increases, then larger water droplets are created, which, as heavier, are difficult to remove with ventilation.

The equilibrium equation of humidity is [11]:

$$Y_{\mathrm{FB}} = Y_{\mathrm{air}} + Y_{\mathrm{an}}$$

where,
Y_{FB}: the humidity inside the farm building,
Y_{air}: moisture contained by the incoming air and,
Y_{an}: the humidity provided by the animals.

The regulation of the relative humidity in the livestock buildings is done by using insulation and ventilation. If the relative humidity is high (rainy day), then heating should be combined with ventilation. If the relative humidity is a permanent problem, the fans must also be commanded by a humidistat.

2.2.3 Chemical environment

The components of the chemical environment in a farm animal installation come from the dust of the food systems, the water vapor from the function of the breath and the poisonous gases from the biological decomposition of the organic substance (manure, urine, *etc*.). The main characteristics of the gases detected in livestock buildings are carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), hydrogen sulfide (H_2S) and sulfur dioxide (SO_2). Limit values have been set for the gases found in livestock buildings, above which their concentration is dangerous. This definition was not made for animals or people working in livestock buildings, but for industrial workers. Table 1 gives the maximum permissible values for the concentration of toxic gases.

Table 1 Maximum allowable values of toxic gases concentration [12].

Gas	Maximum Value (p.p.m)	Flammability Limits (% of Volume)	
		Lower Limit	Upper Limit
Carbon dioxide (CO_2)	5000		
Methane (CH_4)		5.0	15.0
Ammonia (NH_3)	100	15.5	26.6
Hydrogen sulfide (H_2S)	20	4.3	45.6
Sulfur dioxide (SO_2)	5		

The chemical environment has been found to reduce animal production yields, but it can also be deadly to many animals. Therefore, natural or artificial ventilation is necessary in a livestock construction.

2.2.4 Ventilation

The main reason for ventilation is on the one hand the control of temperature and humidity inside the livestock building and on the other hand the renewal of the natural composition of the air. The animals' breath consumes the oxygen in the air, while at the same time dangerous amounts of carbon dioxide, ammonia, water vapor, microorganisms and dust accumulate, with all the known unpleasant consequences. Ventilation is one of the key factors in controlling the environment of livestock buildings. A farm animal house installation cannot be considered complete without controlled ventilation, because the creation of suitable bioclimatic conditions of the environment results in an increase in animal yields and the economy of the company.

There are two ventilation systems, natural and artificial-mechanical ventilation. Natural ventilation is done through the windows. So it does not require energy, nor expensive machines. However, it is satisfactory only for small farms, while it is insufficient for large and intensive ones. Also it cannot be considered cheap, because it requires constant monitoring and hard work, to open and close the windows. Artificial ventilation is more effective, because it provides the ability to systematically control the volume of incoming air.

Regardless of the ventilation system, there must always be an air inlet stream and an outlet stream respectively. The main problem is the way air enters because no currents must be generated. The wind is especially dangerous when it has a low temperature and high speed. In this case it must be avoided falling on the body of the animals. For the incoming air to reach the temperature inside the livestock building, it must be mixed gradually. This is achieved by using small inlets and diverting incoming air towards the roof.

The air outlets- exit openings can be placed anywhere without affecting the climate of the livestock structure, but in areas with strong winds, leeward sides or the roof are preferred. In artificial-mechanical ventilation there are three basic systems, which are: (a) under pressure ventilation, (b) balanced ventilation and (c) overpressure ventilation [11].

2.3 Optimum climatic conditions in cattle farm buildings

2.3.1 Ambient temperature in cattle farm buildings

The critical temperature for cattle is very low compared to pigs and chickens. So in our country, Greece, we have no problem with the low temperatures of winter. There can be a problem only when low temperatures are combined with strong air currents. On the contrary, high summer temperatures, and in particular temperatures higher than 25 °C, can adversely affect the performance of animals. Experimental work, conducted in various parts of the world, has concluded that cattle are not affected by both low and high temperatures.

In dairy cows there are three temperature zones, which affect milk production accordingly: (a) the low temperature zone, which adversely affects production, is below 0 °C for the Jersey breed and −12 °C for the Holstein and Brown Swiss breeds; (b) the zone with the optimum temperatures which is about 0–24 °C for all species and c) the zone of high temperatures in which the reduction of production begins, and is above 24 °C. Table 2 gives the required temperature for cattle.

Table 2 Required temperature for cattle.

Cattle Type	Temperature Range °C
Dairy cow	Optimum: 10 to 20 °C, but temperature from 6 to 25 °C has little effect on production
Beef cow	Optimum: −6 to 25 °C
Calves	10 to 15 °C at birth. This temperature decreases successively with time. For meat-producing calves, a temperature of 15 to 22 °C is preferred.

The zone with the best temperatures for beef cows is wider. The "upper critical temperature" is about 25 °C for European breeds and 35 °C for tropical, while the range of appropriate temperature is −7 to 15 °C and 10 to 26 °C, respectively.

For calves, abrupt changes in temperature have a particularly adverse effect. The most suitable temperature for them is 10 ^{o}C, and the temperature range they tolerate is from 4–29 °C [13] but in a dry environment, free of currents.

2.3.2 Ambient humidity in cattle farm buildings

The high relative humidity does not affect the milk production of dairy cows, when the temperature ranges from −8° to 24 °C. However, when the temperature exceeds 24 °C, high relative humidity enhances the adverse effects of high temperature [14].

2.4 Optimum climatic conditions in pig houses

2.4.1 Ambient temperature in pig houses

The ambient temperature has a direct effect on the heat loss from the pig body. The pig's body temperature is 39 °C and it lives in an environment much colder than that temperature. Thus, it constantly loses heat with conduction, convention, radiation and evaporation. Heat loss increases as the difference between body temperature and ambient temperature increases, according to the laws of thermodynamics. Table 3 shows the critical temperature of young pigs.

Table 3 Critical temperature of young pigs (air velocity: 15 cm·s $^{-1}$) [11].

Pig's Weight (kg)	Critical Temperature (°C)
Newborn	35
4	29
10	24

The pig, under any circumstances, produces heat as an inevitable consequence of metabolism which is sufficient to maintain a constant body temperature when the ambient temperature is very close to the critical temperature. If the ambient temperature is lower than the critical temperature, the pig must increase the heat production, while if it is higher, then it must remove some of the heat generated. It achieves the increase of heat production by the increase of the food intake, while the decrease with the increase of the evaporation. It should be noted that the pig does not have sweat glands. Table 4 gives the required temperatures to ensure the animals suitable environmental conditions [11].

The critical temperature for a newborn piglet is 35 °C. Thus, as a rule, heating lamps are used, which provide the little ones with the necessary heat. Ambient temperature also affects the convertibility of food to weight (units of food per unit of added weight) as well as the quality of meat.

Apart from low temperatures, also high temperatures, above the permissible levels, have an adverse effect on pig farming. In many parts of the world with high temperatures, the growth and efficiency of pigs is severely limited. In these cases, the pig farms must have appropriate equipment for the temperature to drop to normal levels, e.g., water basins on the ground for pigs to roll in, water sprinklers, shading, sheds and finally, mechanically cooled concrete screed floors.

Table 4 Required ambient temperatures for pigs of all ages.

Pig Type	Required Temperature, °C
Piglets one week old	30–32
Piglets 2 weeks old	28
Piglets 3 weeks old	24
Piglets 4 weeks old	22
Sows during pregnancy	12–20
Sows during breastfeeding	16–20
Boars	10–20
Fattening pigs	
Body weight 30−65 kg	20 optimum
Body weight 65−100 kg	18 optimum

2.4.2 Ambient humidity in pig housesv

If the pigsty maintains the required temperature, the air humidity usually does not have a direct effect on the pigs, as it ranges from 45–95% [15]. But when the temperature exceeds the allowable levels, then the increasing humidity reduces the weight gain significantly and progressively. Table 5 lists the indicative relative humidity for all categories of pigs.

Table 5 Proper relative humidity for every pig type.

Pig Type	Relative Humidity %
Boars	70
Sows	60–70
Sows with piglets	60
Fattening pigs of 20–50 kg body weight	60–70
Fattening pigs of 50–100 kg body weight	70–80

2.5 Optimum climatic conditions in sheep houses

2.5.1 Ambient temperature in sheep houses

Inside a building apart from protecting animals from rain, wind and sun, it is possible to maintain the temperature in a range of 5–25 °C, which is the temperature range considered as the limits of the comfort zone. It is very important that the temperature is kept within these limits and especially not to fall below the "critical point", because then the food provided is used to maintain body temperature and consequently the degree of production efficiency decreases.

Sheep hair-sheepskin functions as a protective insulating cover and under special conditions can affect the milk yield for the same amounts of feed. The critical temperature varies and basically depends on the level of nutrition and the insulating properties of the hair. The insulating property of the hair is determined by the construction of the hair, the wind speed and the degree of its wetting. So the adaptability of the animal to an environment depends to a large extent on its fur. In general and for the various physiological stages, suitable temperatures can be considered those ranging from −3 °C to 31 °C.

2.5.2 Ambient humidity in sheep houses

In addition to the temperature, the humidity is also controlled, which should not exceed 80%. When it grows more, it adversely influences the environment. High humidity combined with low temperature has a negative effect on the respiratory organs of the sheep. High humidity and high temperature have a more indirect but no less dangerous effect, as they favor the growth of all kinds of pathogens and parasites. The risk is high because sheep usually live and lay on straw or other kind of litter which can become a source of infection. When the surface starts to get very wet, new straw-litter and perphosphates must be added. This ensures hygienic conditions and prevents the softening of the hooves and further adverse consequences, such as infections (foot dermatitis, *etc*.). Table 6 gives the appropriate temperature and humidity for the various sheep categories.

Table 6 Appropriate temperature and humidity for the various sheep categories.

Sheep Type	Optimum Temperature (°C)	Relative Humidity (%)
Sheep	10–17	60–80
Ram, ewe, fat sheep	8–17	60–80

2.6 Optimum climatic conditions of poultry houses

The basic parameters of the environment for poultry are temperature, relative humidity, air composition and lighting.

2.6.1 Optimum ambient temperature in poultry houses

Poultry do not have a defense mechanism against high temperatures, and also against low ones when they are young. Extreme temperatures affect egg production, food exploitation and egg quality. Temperatures higher than 20–28 °C adversely affect the thickness of the egg shell.

Adult hens, however, do not strain below wide ambient temperature limits. The neutral thermal zone of the hen is between 16.5 °C and 27 °C, but also in the temperature range from 7.2 °C up to 32.2 °C they manage to survive without noticeable stress. The most favorable temperature range for higher egg production is that of 13 °C to 24 °C, with an excellent temperature of 24 °C.

2.6.2 Ambient humidity in poultry houses

The relative humidity for laying hens should not fall below 40%, because it favors the creation of dust in their environment, which causes irritation to the mucous membranes and predisposes the respiratory tract to microbial infections. Below favorable ambient temperatures, the relevant humidity is recommended: (a) 75–80% for floor rearing, (b) 80% for cage rearing.

3. Results and Discussion

The environmental control systems during the housing of productive animals, which require meticulously thoughts and investigation as they affect the study of the construction of this standard livestock-desalination greenhouse type unit with the desalination system on the roof, are the ventilation system and the cooling system. This of course provided that this standard unit includes thermal insulation (passive system) which is necessary anyway at least on the roof for the process of solar desalination. The heating system as well as the lighting system can be installed in addition to the original construction depending on the ‘optimum’ temperature requirements, and light intensity for the photoperiod of the productive animals. In case, of course, in which parts of the heating and lighting system are heavy and must be mounted on the frame of this standard unit, these extra permanent loads should be taken into account in structural analysis by solving the statics of the construction frame.

In case of need of an artificial heating system, its power is calculated according to its thermal efficiency and the equation of thermal balance (energy balance) given below [11]:

$$q_{AH} + q_{an} = q_{LB} + q_V$$

where:
q_{an}: heat produced by housed farm animals
q_{AH}: heat added by the artificial heating system
q_{LB}: heat losses from the livestock building to the outdoor environment
q_V: heat losses by ventilation

Nonetheless, the required environmental control systems (heating, cooling, ventilation) and the proposed design techniques and modifications of a livestock building in general may also differ depending on the world’s climatic zones and the climatic variations caused by local conditions. Consequently, in case such a structure to be applied in different places around the world it should be modified accordingly (percentage of ventilation openings for natural ventilation, number of fans for artificial ventilation, cooling pads *etc.*) by taking into account the external climatic conditions and the climatic zoning of land area.

3.1 Cattle, pig and sheep greenhouse type houses with the solar desalination system on the roof

In cattle, pig and sheep houses the natural ventilation is adequate, except for the pig houses located in areas with high temperatures where in some cases artificial-mechanical ventilation is required. The natural ventilation is carried out with side windows and for the greenhouse type constructions, obligatorily with a roof opening, at least 30 cm wide (Figure 7). In all cases the percentage of ventilation openings (Figure 7) must be greater than 25% of the floor area of the livestock-desalination greenhouse type installation. During the summer to reduce the temperature in the sheep houses, the air should be changed about 4 times an hour.

Figure 7 Side openings and ventilation roof opening in greenhouse type livestock construction [16].

In cases where natural ventilation offers the ideal conditions for housing sheep, cattle and pigs, the greenhouse-type structure with the solar desalination system on the roof, must adapt and accept design modifications for the proper side and roof openings (Figure 8).

In the case of pig farms where artificial-mechanical ventilation is required. This can be achieved either by the traditional method of ventilation, *i.e.*, by chimney openings with ventilator and simultaneous air intake from side openings in the walls or by other alternative ventilation systems, such as: (a) air extraction from the outer wall of the runway-corridor, (b) air extraction from the sewage disposal system (Figure 9), (c) ventilation with overpressure system and (d) ventilation system with air recirculation (Figure 10). In natural ventilation the exhaust surface must be 70 mm^2 for each kg of live weight, while in artificial ventilation the maximum ventilation value is 0.9–1.9 m^3h^{-1} kg^{-1}. The air inlet surface is about three times the outlet surface to avoid creating currents.

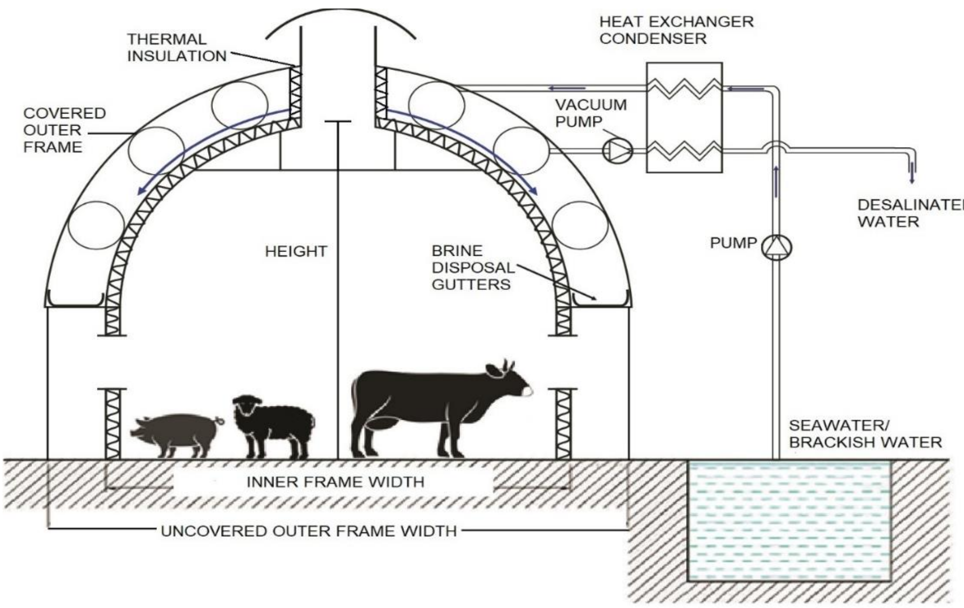

Figure 8 Livestock construction of greenhouse type with natural ventilation and the integrated solar desalination system on the roof.

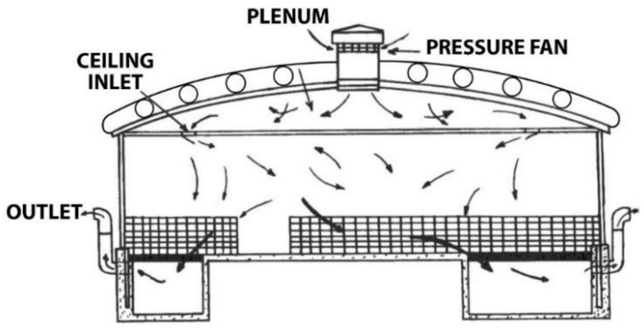

Figure 9 Ventilation system with air exits through the sewage disposal system (as modified by the authors from Hellickson *et al*. Used with permission [17]).

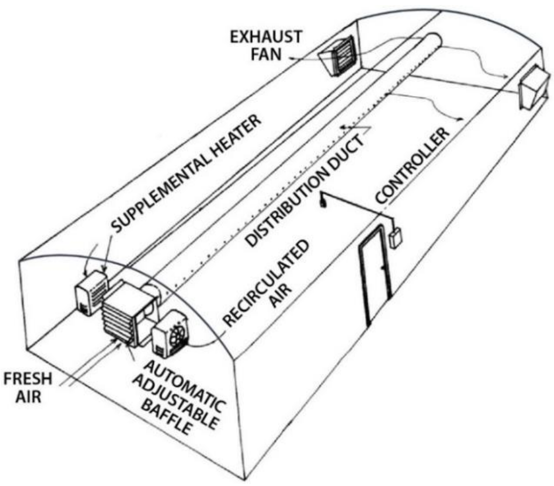

Figure 10 Ventilation system with air recycling (as modified by the authors from Nikita-Martzopoulou C. and Hellickson *et al*. Used with permission [11,17]).

3.2 Poultry greenhouse type houses with the solar desalination system on the roof

Ventilation of poultry farms and in particular mechanic ventilation is necessary because chickens by breathing and by the decomposition of their manure enrich the air with harmful gases such as CO_2, NH_3 and H_2S and reduce the O_2 content. Of the above gases, ammonia is mainly of interest, which should not exceed 40 ppm, although from 20 ppm the respiratory organs are irritated.

Ventilation seeks to keep the air in its natural composition while at the same time it is controlling the temperature and humidity. Dynamic ventilation in poultry farms should be combined with cooling pads (cooling panels) (Figure 11). Indicatively, the maximum ventilation needs per bird are for pullet from 0.110–0.170 m^3/min and for hens from 0.90 kg to 3.60 kg the corresponding values are from 0.170 to 0.225 m^3/min.

Figure 11 Fans and cooling pads on poultry houses [16].

Ventilation is kept to a minimum when outside temperatures are low. The permissible air speeds are [18]:

a. At floor height or between cages

For day-old chicks at room temperature of 32 °C	Vmax = 12 m/min
For mature chickens at 7 °C	Vmax = 12 m/min
For mature chickens at 13 °C	Vmax = 18 m/min
For mature chickens at 18 °C	Vmax = 36 m/min
For mature chickens at 24 °C	Vmax = 60 m/min

b. At the air inlets into the space

For young birds	Vmax = 60 m/min

Light Intensity: Intensity of light is usually expressed in Lux and has an effect on both the development of birds and the production of eggs. Specifically, the following intensities are given:

Pullet:	10 Lux in the first days and 1-2 Lux afterwards
Hens in production age:	10−25 Lux at floor height or in front of the cages

The photoperiodism of poultry can be divided into those where the duration of light is constant at 24 hours base and those that change over the period of egg production. Thus, two categories of photoperiodism can be distinguished. Photoperiodism with constant light duration and photoperiodism with variable light duration. In terms of reproduction, the problem is more complicated. There are also areas for growing and producing eggs without windows (complete lighting control and corresponding areas with windows).

Figure 12 shows the design modifications of the solar desalination greenhouse structure required to achieve optimum conditions to house poultry. Design modifications are needed to install properly cooling pads on the sides of the structure and mechanical ventilation with exhaust fans on the back side. Consequently, fans and cooling pads can be installed without modifying the solar desalination system on the roof provided that the in-between thermal insulation on the inner frame is adequate for non or insignificant thermal loss from the solar desalination system to the inside space

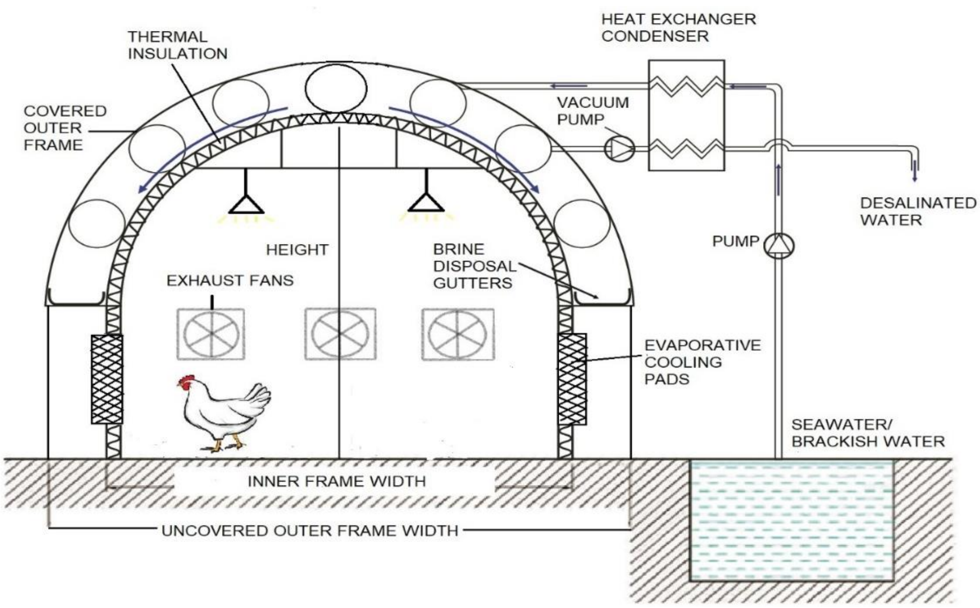

Figure 12 Greenhouse type poultry house with mechanical ventilation, cooling pads and the integrated solar desalination system on the roof.

4. Conclusions

(a) Desalination plants have proven to be particularly energy-intensive with increased operating costs. Solar desalination is a significantly good alternative technology, especially in terms of water production for use in the agricultural sector (irrigation). The integration of a solar desalination system in a greenhouse type construction also offers the possibility for combined use of the space for housing productive animals or cultivation or storage.

(b) The operation of such an innovative greenhouse system for combined agricultural use and irrigation water production through solar desalination creates the opportunity for local communities to benefit from the increase of locally produced products at lower prices, and from the upgrading and utilization of arid areas that previously had no other use. The combined use of the space of such structures are also in favor of sustainable land use planning and multiple land uses, increasing the regional productivity and enhancing the local economy.

(c) The greenhouse-type structure with the solar desalination system should be adapted accordingly due to the special conditions required for the proper growth of the productive animals. This is possible by taking into account the ideal – optimum climatic conditions for the welfare of the productive animals housed in this structure. Each type of productive animal needs different environmental conditions which also depend on their age.

(d) The environmental control systems that affect the initial study and design of the construction are mainly those of ventilation and cooling, while the heating and lighting systems may be installed in addition to the existing construction.

(e) Cattle, pigs and sheep: In cases where natural ventilation offers the ideal conditions for housing sheep, cattle and pigs, the greenhouse - type structure with the solar desalination system on the roof, must adapt and accept design modifications for the proper side and roof openings. There are cases of pig farms though, where artificial-mechanical ventilation is required and therefore fans and ventilators must be adapted in the initial design accordingly and in consistent with the method of ventilation (traditional and alternative dynamic ventilation systems).

(f) Poultry: Mechanic ventilation is necessary in poultry farms and it should be combined with evaporative cooling pads. Fans and cooling pads can be installed on the sides of the structure without modifying the solar desalination system on the roof provided that the in-between insulation on the inner frame is adequate for non or little thermal loss from the solar desalination system to the inside space.

(g) The required environmental control systems (heating, cooling, ventilation) and the proposed design techniques and modifications of a livestock building in general may also differ depending on the world's climatic zones and the climatic variations caused by local conditions. Therefore, in case such a structure to be applied in different places around the world it should be modified accordingly (percentage of ventilation openings for natural ventilation, number of fans for artificial ventilation, cooling pads *etc*.).

Ethics Statement

Not applicable.

Consent for Publication

Not applicable.

Availability of Data and Material

Not applicable.

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Competing Interests

The authors have declared that no competing interests exist.

Author Contributions

Anastasia Martzopoulou: Initial writing, Research contribution, Design of the original article, Figure creation.
Vasileios Firfiris: Initial concept, Editing, Research investigation-contribution.
Thomas Kotsopoulos: Initial concept, Editing, Research investigation-contribution.

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References

1. FAO. The state of the world's Land and Water Resources for Food and Agriculture (SOLAW) – Managing systems at risk. Food and Agriculture Organization of the United Nations, Rome and Earthscan, London [Internet]. 2011. [cited 2021 Feb 20] Available from: https://www.fao.org/3/i1688e/i1688e.pdf.

2. Fischer G, Hizsnyik E, Prieler S, Wiberg D. Scarcity and abundance of land resources: competing uses and the shrinking land resource base [Internet]. 2010. [cited 2021 Jan 15] Available from: http://www.fao.org/nr/solaw/.
3. FAO. Planning for sustainable use of land resources. Towards a new approach [Internet]. 1995. [cited 2020 Nov 10] Available from: https://www.fao.org/3/v8047e/v8047e00.htm.
4. Dinesh H, Pearce JM. The potential of agrivoltaic systems. Renew Sust Energ Rev. 2016;54:299-308.
5. Pascaris AS, Schelly C, Burnham L, Pearce JM. Integrating solar energy with agriculture: Industry perspectives on the market, community, and socio-political dimensions of Agrivoltaics. Energy Res Soc Sci. 2021:75. DOI
6. EEA (European Environment Agency). Towards efficient use of water resources in Europe. EEA Report. Report No.: 1/2012. 2012
7. WWAP (United Nations World Water Assessment Programme). The United Nations World Water Development Report 2014: Water and Energy. Paris:UNESCO; 2014.
8. Scott NR, DeShazer JA. Roller WL. Chapter 7: Effects of the thermal and gaseous environment on livestock. In: Hellickson M, Walker J. editors. Ventilation of Agricultural Structures, ASAE Monograph No. 6. St. Joseph, Mich.: ASAE; 1983. pp. 121-165.
9. Martzopoulou A, Firfiris V, Kotsopoulos T. Application of urban passive cooling systems and design techniques in livestock buildings. IOP Conf Ser Earth Environ Sci. 2020;410(1):012029. DOI
10. Mount LE. The concept of thermal neutrality. In: Montieth JL, Mount LE, editors. Heat loss from animals and man. London: Butterworths. 1974; pp. 426–439.
11. Nikita-Martzopoulou C. Livestock Buildings. Thessaloniki, Greece: Yahoudis Publications. 2006.
12. Institution of Heating and Ventilating Engineers. I.H.V.E. Guide 1965, sect. 4. London: The Institution of Heating and Ventilating Engineers. 1965; pp. 111-126.
13. Sainsbury D, Sainsbury P. Livestock Health and Housing. London: Baillière Tindall. 1979.
14. Yeck RG, Stewart RE. A ten-year summary of the psychroenergetic laboratory dairy cattle research at the University of Missouri. Trans. Am. Soc. Agric. Eng. 1959:2(1):71-77. DOI
15. Morrison SR, Bond TE, Heitman H. Effect of humidity on swine at high temperature. Trans. Am. Soc. Agric. Eng. 1968:11(4):526-528. DOI
16. Geothermiki SA. Greenhouse type livestock building (tunnel) [Internet]. [cited 2020 Nov 20] Available from: www.geotherm.gr/thermokipiakoy-typoy-toynel-2. (in Greek).

17. Hellickson MA, Driggers LB, Muehling AJ. Chapter 9: Ventilation systems for livestock structures. In: Hellickson M, Walker J, editors. Ventilation of Agricultural Structures, ASAE Monograph No. 6. St. Joseph, Mich.: ASAE. 1983; pp. 193-214.
18. Kyritsis, S. Poultry Houses-Agricultural building construction. Athens, Greece: Stamoulis Publications. 1986.

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