Cool roofs with high solar reflectance for the welfare of dairy farming animals

2017 J. Phys.: Conf. Ser. 796 012028

(http://iopscience.iop.org/1742-6596/796/1/012028)

Cool roofs with high solar reflectance for the welfare of dairy farming animals

G Santunione, A Libbra and A Muscio

Dipartimento di Ingegneria "Enzo Ferrari", Università di Modena e Reggio Emilia, Via Vivarelli 10, 41125 Modena, Italy

Corresponding author: alberto.muscio@unimore.it

Abstract. Ensuring livestock welfare in dairy farming promotes the production capacity of the animals in terms of both quantity and quality. In welfare conditions, the animals can produce at their full potential. For the dairy cattle the most debilitating period of the year is summer, when the stress arising from overheating induces physiological alterations that compromise the animals' productivity. In this study, the summer discomfort of dairy animals is primarily quantified and the production loss is quantified versus the Temperature Humidity Index (THI), which correlates the values of temperature and relative humidity to the thermal stress. In order to reduce or eliminate such thermal stress, it is then proposed to coat the roof of the stables with a paint having high solar reflectance and thermal emittance, that is a cool roof product. This type of roofing solution can considerably limit the overheating of stables caused by solar radiation, thus providing a positive impact on the animals' welfare and improving significantly their productivity in summer.

1. Introduction: thermal comfort of dairy farming animals

Milk production is a delicate process that strongly depends on the animal well-being, which in turn depends on several environmental, physiological and nutritional factors. If the environment provides a situation of comfort, the animals will be able to achieve the most of their productive potential, allowing the maximization of livestock economic results.

The main environmental parameters that determine the microclimate inside a stable are temperature (T) and relative humidity (RH). With regard to temperature, thermal comfort conditions for lactating dairy cows fall between 5°C and 25°C [1,2,3]. Within this range, the physiological rectal temperature is 38.5°C. If the ambient temperature does not fall in the range, the thermal stress increases proportionally to the deviation of temperature from the range limits. The process of temperature control that is put in place by the animals to compensate for the thermal stress is physiologically very fatiguing in terms of energy needs and it reflects directly on productivity. The lack of an ideal microclimate inside the shelter, and the consequent increase in body temperature, involve the activation of self-defense mechanisms such as the decrease in the amount of food ingested, metabolism, respiratory activity and, consequently, productivity. Hyperthermia also alters and worsens the reproductive functions of cells and tissues, constituting one of the main causes of the decrease in the conception rate in summer months [4].

1.1. Temperature Humidity Index (THI)

The importance of thermal comfort of farm animals and, in particular, of dairy cattle has necessitated the identification of conventional parameters of the microclimate inside the stables. The most used among conventional indicators is the Temperature Humidity Index (THI), developed by Thom and Bosen in 1959 [5] for humans, but later adapted for the welfare assessment of lactating cows. It is defined by the formula

$$THI = DBT + 0.36 \cdot DPT + 41.2 \quad (1)$$

where

DBT dry-bulb temperature (°C)
DPT dew point temperature (°C)

Another formula was developed from equation (1) to use ambient temperature and relative humidity instead of the wet bulb temperature [6]:

$$THI = (1.8 \cdot T + 32) - 0.55 \cdot (1 - RH/100) \cdot (1.8 \cdot T + 32 - 58) \quad (2)$$

where

T ambient temperature (°C)
RH relative humidity (%)

Wiersma [7] divided the THI values obtained from the aforementioned formula under heat stress intervals, ranking them according to their severity (Table 1, Table 2). The studies by Igono and Armstrong [8,9] recognized the value of 72 as the critical threshold of THI to which the beginning of the heat stress of dairy animals is associated and, with this, the decrease in milk production.

Table 1. Values of THI as a function of temperature T and relative humidity RH and progressive levels of stress in dairy animals

T		***RH***																				
°F	°C	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
75	23.9														72	72	73	73	74	74	75	75
80	26.7							72	72	73	73	74	74	75	76	76	77	78	78	79	79	80
85	29.4			72	72	73	74	75	75	76	77	78	78	79	80	81	81	82	83	84	84	85
90	32.2	72	73	74	75	76	77	78	79	79	80	81	82	83	84	85	86	86	87	88	89	90
95	35.0	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
100	37.8	77	78	79	80	82	83	84	85	86	87	88	90	91	92	93	94	95	97	98	99	
105	40.6	79	80	82	83	84	86	87	88	89	91	92	93	95	96	97						
110	43.3	81	83	84	86	87	89	90	91	93	95	96	97									
115	46.1	84	85	87	88	90	91	93	95	96	97											
120	48.9	86	88	89	91	93	94	96	98													

Table 2. THI values and stress level

THI values	***Stress level***
THI < 72	absent
72 ≤ THI < 79	mild
79 ≤ THI < 90	high
90 ≤ THI < 99	severe

In summer, the perceived temperature inside the stables turns out to be always higher than that outside due to heat radiated downwards in the far infrared by the roof, which heats up under the effect of solar radiation. This is more extensively explained in section 3. Moreover, the local relative humidity is drastically increased by evaporation of the liquid fraction of manure and the presence of many animals in constrained areas. It was calculated that the stables reach temperature values higher than the external one by at least 3-4°C, and relative humidity values greater than outside by 10%. Considering an average summer temperature of 28°C associated with a mean relative humidity value of 55-60%, as typically recorded by weather stations in the Po Valley, Northern Italy, the THI in the stables easily reaches values corresponding to high levels of stress (>80).

2. Production loss

During the summer period, many farms are affected by a significant decrease in milk production due to thermal stress of cows. Several authors have studied this phenomenon and most of them are concordant in reporting a decline of daily production quantifiable at around 2% for each point of increase above the critical threshold of THI = 72 [10]. Such decline increases in the case of highly productive animals. It was indeed observed that the genetic selection made in the last decades in order to obtain more and more productive animals has helped to make cows very sensitive to overheating since there was not a simultaneous improvement of body thermoregulatory capacity [11,12].

The drop of milk production versus temperature can be estimated by assuming a decline of 2% for each point of THI above 72, as reported in [10]. In this regard, the average value of relative humidity in Modena during summer is around 55% but, as already stated, it can increase by at least 10% inside a stable due to evaporation of the liquid fraction of manure and the respiration rate of animals. Therefore, the THI value and, from that, the drop of milk production, plotted in Figure 1, have been calculated all over the typical range of outside ambient temperature for 65% relative humidity. The outside ambient temperature was assumed to be close to the inside air temperature of the (open) stable and to the temperature perceived by the animals.

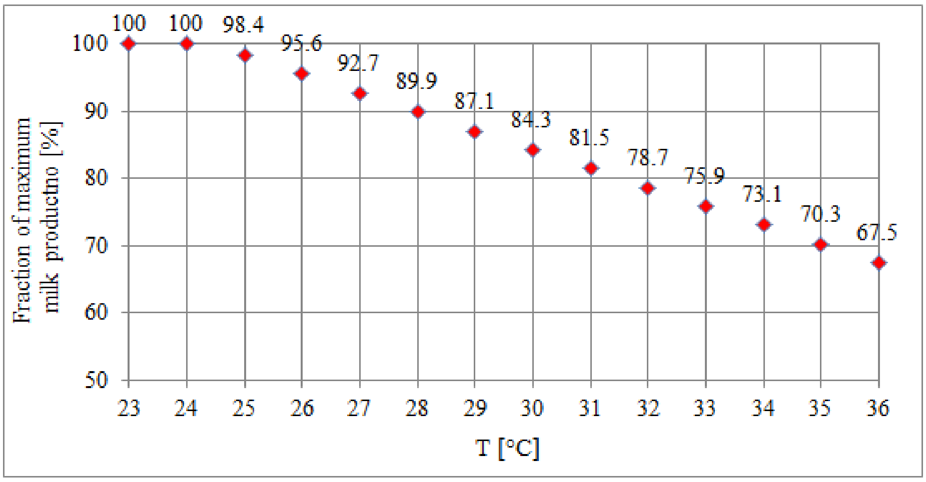

Figure 1. Fraction of potential milk productions vs. outside ambient temperature calculated for a stable located in the province of Modena, Po Valley (inner RH 65%).

The drop in conditions of thermal stress is a consequence of the numerous physiological alterations determined by hyperthermia of the cows. The more the perceived temperature moves away from the thermal comfort threshold (25°C), the more the rectal temperature rises above 38.5°C, compromising various aspects of metabolism and behavior pattern.

2.1. Decrease of food intake

The decrease in milk production due to hyperthermia is primarily related to the decrease in the intake of dry matter [13]. The body of dairy cows has two types of processes available to reject thermal energy: evaporative processes (sweating, tachypnea) and non-evaporative processes (thermal radiation, conduction and convection). Non-evaporative processes become less effective when the ambient temperature increases; on the other hand, evaporative processes are also compromised as a result of an increase in relative humidity. Therefore, during a summer period characterized by high humidity and high temperature, heat dissipation of cows is ineffective in preventing the increase of body temperature. For such reasons, in an attempt to protect themselves from thermal stress, cows enact behaviors to decrease the internal temperature or the heat input resulting from the metabolism, and this happens physiologically when the intake of food is reduced [14].

Kurihara and Shioya [15] reported that the consumption of daily dry matter amounts to an average of about 20 kg for an average daily production of 30 kg of milk, in the absence of stress conditions. This quantity begins to decrease above 25°C. Kurihara and Shioya also showed how food intake varies in relation to the increase in temperature and humidity. For example, if the temperature ranges from 24°C to 28°C, with humidity of 40% (THI 76), the drop in the daily intake of dry substance is about 13%. The problem is also documented by Wheelock et al. [16], which record intake drops of dry matter as high as 30%.

2.2. Alteration in milk composition

In addition to the quantitative decrease in milk production, hyperthermia of dairy cows leads to a qualitative deterioration of milk composition. The analyses performed by Sharma et al. on the milk produced by stressed Friesian cows [17] showed differences in the percentages of fat and protein with respect to milk produced in thermal comfort conditions. In particular, as shown in table 3, the fat decreases by more than 5%, and the proteins by almost 9%. Among the proteins involved in the percentage drop there are caseins, fundamental in the curdling process and therefore in production of cheese (especially Parmigiano Reggiano, the most important cheese product of Southern Po Valley). The decrease is also significant for total solids (over 14%) and non-fat solids (almost 7%), which are other indicators of the quality of milk.

Table 3. Percent decrease of components in milk produced by stressed cows

Component	Percent decrease
fats	5.05
proteins	8.91
non-fat solids	14.47
total solids	6.78

2.3. Fertility decrease

Thermal stress also contributes to the reduction of fertility typical of the summer period. This involves a considerable economic damage, affecting about 60% of cattle in the world [18]. The most important aspect of summer infertility is its multifactorial nature, since hyperthermia alters and directly worsens cellular functions of various parts and tissues of the reproductive system [19]. Overheating is responsible for the onset of both immediate and delayed effects on the reproductive system. In particular, the quality of the ovarian follicles is compromised and the duration of oestrus is reduced due to the production reduction of the luteinizing hormone (LH) and the secretion of estradiol during the thermal stress period [20]. The reduction of steroidogenic capacity comes from a malfunction of the theca and granulosa cells under stress.

The chronic exposure to heat causes a suppression of the production of progesterone, which leads to a series of negative effects before and after insemination. The low blood levels of this hormone in fact cause an abnormal oocyte maturation, or possibly an early death of the embryo. Moreover, the shortage of progesterone will have a negative impact on the development of the dominant follicle and corpus luteum that subsequently grow up, in addition to being responsible for the alteration of the morphology of the endometrium [21].

All these phenomena lead to a thinning of oestrus, to a decrease in conception rate and increased embryonic mortality. Jordan [22] showed many significant data concerning the effect of climatic factors on fertility: the conception rate falls from 62% to 45% when the rectal temperature rises by 1°C in the 12 hours after insemination; a rectal temperature of 40°C, resulting from an exposure to an external temperature of 32.2°C for 72 hours after insemination, has determined a zero conception rate. The infertility phenomenon due to thermal stress is especially noticeable in high yielding cows. Overheating also affects the bulls, whose sperm produced in stressful conditions is underperforming with respect to the cooler seasons.

2.4. Mortality increase
The mortality of animals is directly related with the THI. The study by Vitali et al. [23], which lasted six years, found that the highest number of deaths among animals occurs in summer. When thermal stress is severe, the loss of water through sweating and rapid breathing contributes to the onset of cardiovascular disorders. Moreover, there are modifications in the fatty acid and glucose metabolism associated with liver dysfunction and oxidative stress. All this increases the probability of death among cows stressed by the heat.

3. Improving thermal comfort of dairy cows
The trends described above, induced by high summer temperatures, have extremely negative repercussions on dairy farms, which would therefore benefit from technical solutions in favor of animal welfare. Typical remedies to lower the average temperature perceived by cattle such as using electric fans, water sprinklers or evaporative cooling systems cause a significant consumption of electricity and also water, moreover they seldom have a decisive effect because they do not intervene on the main cause of thermal discomfort, that is thermal radiation from the overheated ceiling. In fact, if the roof stable is overheated, the ambient temperature to be used for calculation of THI should not be that of the ambient air, but the operative temperature actually perceived inside the stable, about equal to the average of the air temperature and the mean radiant temperature of the building inner surfaces. An effective solution to lower the mean radiant temperature and, with this, the operative temperature is represented by coating the stable roof with solar-reflective products such as paints, membranes, sheaths, etc.

3.1. Cool roofs
Roofing products that contribute to the efficiency of civil engineering structures thanks to surface properties optimized for rejection of solar heat are identified with the technical name of cool roofs. They have been widely exploited in buildings for humans for decades in North America [24,25], more recently also in Europe [26,27] and are extensively considered in policies to counter overheating of both urban areas and dwellings [28,29]. They can of course be used to prevent overheating of roofs also in animal shelters, thus eliminating the infrared thermal radiation from the ceiling. In Figure 2, the thermographic image and the visible picture of the roof of a pig farm near Modena, Northern Italy, are shown. They were both taken in the late summer of 2013 and allow to check, on the right of the thermal image, the surface temperature of a piece of roof coated with solar reflective paint and, on the left, the surface temperature on an uncoated part of the roof. The image reveals how solar radiation heats the uncoated part up to 60°C and above, whereas the part with cool roof paint remains close to ambient temperature.

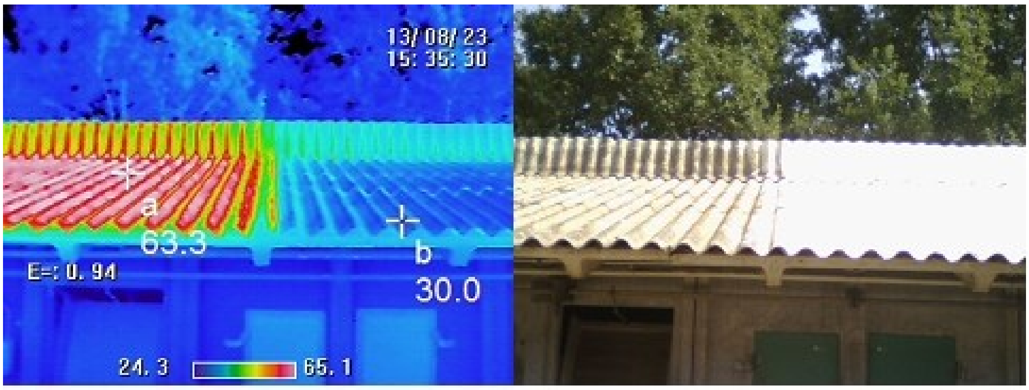

Figure 2. Thermal image (left) and visible picture (right) acquired in summer of 2013 on a pig shelter roof in the province of Modena, Northern Italy: the roof on the left side, uncoated, has surface temperature in excess of 60°C, while the roof right side, which was coated by a white cool roof paint, remains at a temperature around 30°C.

Below roofs subjected to solar radiation, especially poorly insulated ones, people and animals suffer the so-called "hot head" effect, the strong feeling of discomfort caused by radiation coming from the hot ceiling. Using a calculation model specifically constructed at the Laboratory for Energy Efficiency (EELab) of the University of Modena and Reggio Emilia to evaluate the effect of cool roof of building structures, it was possible to calculate the benefit provided a solar reflective coating (with solar reflectance as high as 85%) applied onto the roof of a typical stable covered with fiber cement panels (with solar reflectance before coating <40%). The calculation revealed that the operative temperature perceived by cows below the uncoated roof can be higher than that of the ambient by more than 3°C, whereas under the cool coated roof it becomes close to that of the ambient. In fact, cool roof products can prevent the onset of the "hot head" effect because they prevent roof overheating and thus thermal radiation from the ceiling.

3.2. Application example of a cool roof on a building

The use of cool coatings on opaque components of the building envelope can have a positive effect, if not decisive, on the problem of summer overheating of buildings and the resulting physical discomfort experienced by people (and animals) housed in them, as well as on the problem of energy and/or water consumption for cooling systems, where present. At the Department of Engineering “Enzo Ferrari” of the University of Modena Enzo Ferrari studies have been conducted on cool roofs for more than a decade [30-34].

A cool roof was installed in 2005 on a building of the Engineering Campus in Modena. This experiment, probably one among the very first cool roofs based on qualified solar-reflective products that have been installed in Italy, made it possible to prove the effectiveness of the technology. The building is a shed without air-conditioning and with relatively low thermal inertia, which always showed an intense overheating in summer and reached internal temperatures often in excess of 40°C. After application of a cool roofing product consisting of a white water-based liquid membrane with waterproofing capacity, a sharp drop of temperature was observed in all measured locations. Coincidentally, the two periods immediately before and after installation of the cool roof were characterized by similar conditions of solar radiation and ambient temperature, so it was possible to immediately verify the effect of the cool roof on the thermal behavior of the shed. In particular, the adoption of the cool roof allowed to reduce the temperature of the ceiling surface, which decreased by 3.7°C on average, as well as the temperature of the indoor air, which decreased by 3.0°C (Figure 3).

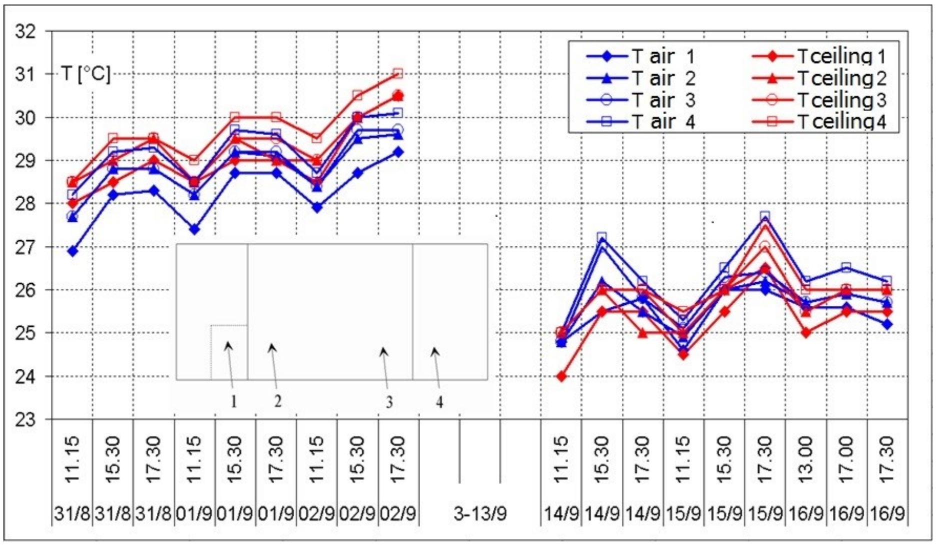

Figure 3. Measured air and ceiling temperatures in a laboratory building of the Engineering Campus in Modena before and after application of a cool roof: the temperature of the ceiling has fallen by 3.7°C on average, that of the air measured at ground level by 3.0°C

3.3. Example of use of a cool roof in farming

In the summer of 2014 a cool roofing product was applied onto the roof of a cattle farm in the province of Cremona, Po Valley, Northern Italy. It was applied on a summer day (July 31st, 2014) with average ambient temperature of 26°C, recorded by a local weather station, and 70% relative humidity measured inside the stable (slightly higher than that considered for Modena in section 2). As previously mentioned, radiative heating is released from the hot ceiling below a roof subjected to solar radiation, thus causing the discomfort of people or animals below. On the other hand, applying a high reflectance material onto the upper roof surface, a high fraction of solar radiation is reflected back to the sky and overheating of roof and ceiling is avoided. The thermographic images in Figure 4 explain the phenomenon.

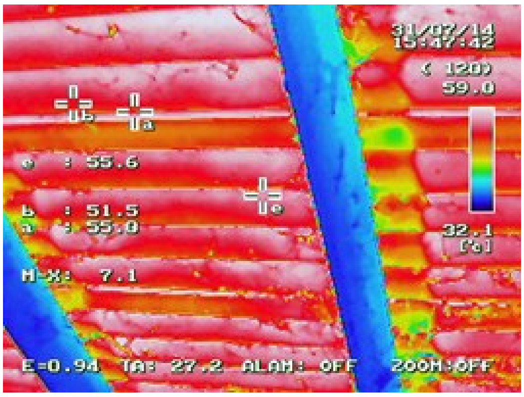

Figure 4a.

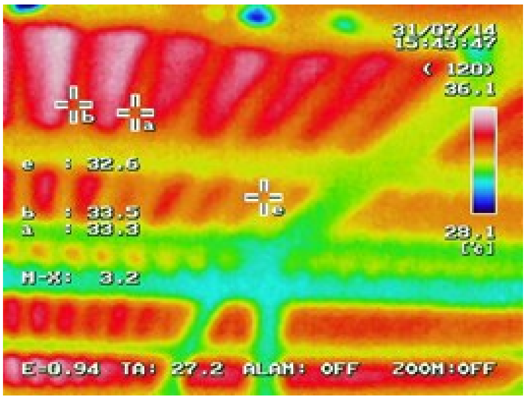

Figure 4b.

Figure 4: Underside roof temperature of a stable in the province of Cremona: a) uncoated roof (average ceiling temperature 55.6°C); b) cool roof (average ceiling temperature 32.6°C). The measurements have been made in the same stable, at the same time of the same day and in the same ambient conditions.

Entering into details, Figure 4a shows a part of the roof with upper surface not coated with solar reflective paint, which reached an average temperature of 55.6°C measured from below. Instead, Figure 4b shows a part with a cool roof coating applied onto the upper surface, with which the ceiling temperature remained at 32.6°C on average. The images were taken in the same stable, and at the same time of the same day, so they clearly show that the solar reflective paint was able to lower the average ceiling temperature by more than 20°C. This phenomenon has a consequence on the operative temperature, that is the temperature perceived by the animals that live below. Since past research has shown [30-34] an average difference of operative temperature between a standard and a cool roof around 3°C, the temperature perceived by the animals below the uncoated and overheated roof was assumed to be 3°C higher than that below the cool roof, which is instead close to the outside ambient temperature. The THI value was then evaluated below both the uncoated roof and the cool roof, considering the measured relative humidity value of 70%. For the ambient temperature in the day of the experiment, a THI value around 80 was calculated due to the increase of the perceived temperature below the uncoated roof, resulting in a potential drop of milk production as high as 16%. Thanks to the application of the cool roof, the perceived temperature was calculated to stay close to the ambient temperature, with a THI value around 75 and a potential production drop of 6%, much less than that in the previously considered condition.

The percentages of potential milk production achieved with and without cool roof were then compared for the considered stable all over the typical range of ambient temperature (Figure 5). Also in this case, the inside air temperature of the (open) stable was assumed to be close to the outside ambient temperature.The difference generally exceeds 10%.

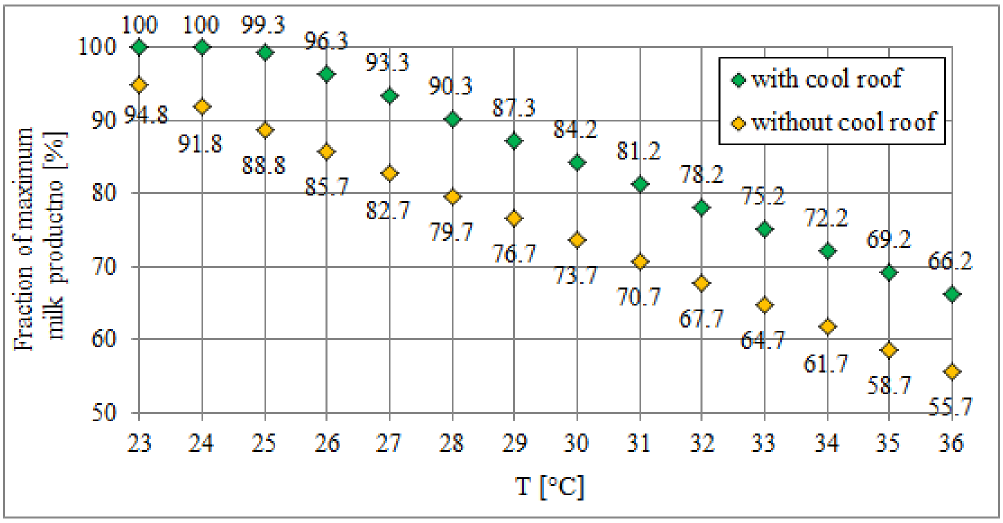

Figure 5. Fraction of potential milk productions vs. outside ambient temperature calculated for a stable in Cremona, Po Valley, considering the temperature perceived by the animals with and without cool roof (inner RH 70%).

3.4. Effects of cool roofs on the corporate balance sheet

The loss of milk production due to thermal stress results in a significant damage to the budget of farms during summer. Therefore, improving animal welfare by improving the microclimate conditions in the stables by means of the application of a cool roof allows to improve the corporate productivity.

In order to translate in economic terms the improvement of productive potential, one can consider the average daily production of a typical stable with about 200 Italian Friesian cows (about 30 kg of milk per cow). Referring to the price of milk for the production of Parmigiano Reggiano, it was calculated that the economic advantage resulting from higher milk production would correspond to about € 350 per day. Considering a surface to be treated of 3000 m^2 and a specific cost of the cool roof coating of 10 €/m^2, the investment could be recovered after 85 cumulative days with average temperature of 26°C or higher. This could amount to one or two calendar years. In such simple economic calculation other benefits from improved animal welfare such as an increased frequency of pregnancies and a reduction of summer mortality were not considered.

4. Concluding remarks

In temperate and hot climates, the microclimate inside animal shelters has an important role for dairy cows. More specifically, summer overheating becomes especially harmful because it is responsible for the onset of thermal stress in the animals. Thermal stress induces a number of physiological alterations that have as direct consequence the decrease of milk production. Indeed, there is a close interdependence between animal welfare and productive or reproductive factors, and the decline in production varies depending on the stress level.

The application of cool roofing materials with high solar reflectance on stable roofs can provide a solution to the problem of overheating of animal shelters in summer due to solar radiation. Such materials reduce the absorption of solar radiation and thus prevent the stable roof to overheat and, consequently, the temperature perceived below to increase, therefore they represent an effective mean to counter the thermal stress of dairy cattle and its negative consequences on the profitability of livestock production.

References

[1] Yeck R G and Stewart R E 1959 A ten-year summary of the psychroenergetic laboratory dairy cattle research at the University of Missouri *Trans. ASAE* **2** 71-77
[2] Ferrari P 2009 Il controllo ambientale nelle stalle *Atti 81[a] Fiera Agricola Zootecnica Italiana: Benessere animale: la vacca da latte "dalle parole ai fatti"* (Montichiari, Italy)
[3] Nardone A and Ronchi B. 1999 Lo stress da caldo nelle bovine da latte: benessere e aspetti produttivi *Atti Parliamo di… benessere e allevamento animale* (Fossano, Italy)
[4] Bernabucci U, Lacetera N, Baumgard L, Rhoads R, Ronchi B and Nardone A 2010 Metabolic and hormonal acclimatation to heat stress in domesticated ruminants *Animal* **4** 1167-1183
[5] Thom E C and Bosen J F 1959 The discomfort index *Weatherwise* **12** 57-60
[6] West J 1981 *Effect of Environment on Nutrient Requirements of Domestic Animals* (Washington DC: National Academy Press)
[7] Wiersma F 1990 *Temperature-humidity index table for dairy producer to estimate heat stress for dairy cows* (Tucson: Department of Agricultural Engineering, The University of Arizona)
[8] Igono M O, Bjotvedt G and Sanford-Crane H T 1992 Environmental profile and critical temperature effects on milk production of Holstein cows in desert climate *Int. J. Biometeorology* **36** 77-87
[9] Armstrong D V 1994 Heat stress interaction with shade and cooling *J. Dairy Science* **77** 2044-2050
[10] Bouraoui R, Lahmar M, Majdoub A, Djemali M and Belyea R 2002 The relationship of temperature-humidity index with milk production of dairy cows in a Mediterranean climate *Animal Research* **51** 479-491
[11] Erb H N, Martin S W, Ison N and Swaminathan S 1981 Interrelationship between production and reproduction diseases in Holstein cows. Conditional relationships between production and diseases *J. Dairy Science* **64** 272-281
[12] Nakao T, Moriyoshi M and Kawata K 1992 The effect of postpartum ovarian dysfunction and endometritis on subsequent reproductive performance in high and medium producing dairy cows *Theriogenology* **37** 341-349
[13] West J W 2003 Effects of heat-stress on production in dairy cattle *J. Dairy Science* **86** 2131-2144
[14] Righi F, Quarantelli A, Bonomi A and Renzi M 2004 L'assunzione di sostanza secca nella vacca da latte: parametri correlati, regolazione fisica e chimica *Annuario della Facoltà di Medicina Veterinaria di Parma* **XXIV** 299-315

[15] Kurihara M and Shioya S 2003 *Dairy cattle management in a hot environment* (Taipei: Food and Fertilizer Technology Center for the Asian and Pacific Region) Extension Bulletin 529
[16] Wheelock J B, Rhoads R P, VanBaale M J, Sanders S R and Baumgard L H 2010 Effects of heat stress on energetic metabolism in lactating Holstein cows *J. Dairy Science* **93** 644-655
[17] Sharma A K, Rodriguez L A, Mekonnen G, Wilcox C J, Bachman S K C and Collier R J 1983 Climatological and Genetic Effects on Milk Composition and Yield *J. Dairy Science* **66** 119-127
[18] Calamari L 2003 Condizioni di benessere: gestione degli animali e controllo del microclima *L'ipofertilità nella bovina da latte* (Brescia: Fondazione Iniziative Zooprofilattiche e Zootecniche)
[19] Wolfenson D 2009 Impact of Heat Stress on Production and Fertility of Dairy Cattlen *Proc. Tri-State Dairy Nutrition Conference* (Jerusalem: Department of Animal Sciences, Hebrew University)
[20] Wilson S J, Kirby C J, Koenigsfeld A T, Keisler D H and Lucy M C 1998 Effect of controlled heat stress on ovarian function of dairy cattle: 2. Heifers *J. Dairy Science* **71** 2132-2138
[21] Ahmad N, Schrick F N, Butcher R L and Inskeep E R 1995 Effect of persistent follicles on early embryonic losses in beef cows *Biology of Reproduction* **52** 1129-1135
[22] Jordan E R 2003 Effects of Heat Stress on Reproduction *J. Dairy Science* **86** (E Suppl) E104-E114
[23] Vitali A, Segalini M, Bertocchi U, Nardone A and Lacetera N 2009 Seasonal pattern of mortality and relationships between mortality and temperature-humidity index in dairy cows *Journal of Diary Science* **92** 3781-3790
[24] Taha H, Akbari H, Rosenfeld A and Huang J 1989 Residential cooling loads and the urban heat island-the effects of albedo *Building and Environment* **23** 271-283
[25] Akbari H, Konopacki S and Pomerantz M 1999 Cooling energy savings potential of reflective roofs for residential and commercial buildings in the United States *Energy* **24** 91-407
[26] Synnefa A, Santamouris M and Livada I 2006 A study of the thermal performance of reflective coatings for the urban environment *Solar Energy* **80** 968-981
[27] Santamouris M, Synnefa A, Kolokotsa D, Dimitriou V and Apostolakis K 2008 Passive cooling of the built environment – use of innovative reflective materials to fight heat island and decrease cooling needs *Int. J. Low Carbon Technologies* **3** 71-82
[28] Levinson R, Akbari H, Konopacki S and Bretz S 2005 Inclusion of cool roofs in nonresidential Title 24 prescriptive requirements *Energy Policy* **33** 151-170
[29] Akbari H, Cartalis C, Kolokotsa D, Muscio A, Pisello A L, Rossi F, Santamouris M, Synnefa A, Wong N H and Zinzi M 2016 Local climate change and urban heat island mitigation techniques – the state of the art *J. Civil Engineering and Management* **22** 1-16
[30] Libbra A, Tarozzi L, Muscio A and Corticelli M A 2011 Spectral response data for development of cool coloured tile coverings *Optics and Laser Technology* **43** 394-400
[31] Libbra A, Muscio A, Siligardi C and Tartarini P 2011 Assessment and improvement of the performance of antisolar surfaces and coatings *Progress in Organic Coatings* **72** 73-80
[32] Libbra A, Muscio A and Siligardi C 2013 Energy performance of opaque building elements in summer: Analysis of a simplified calculation method in force in Italy *Energy and Buildings* **64** 384-394
[33] Ferrari C, Gholizadeh Touchaei A, Sleiman M, Libbra A, Siligardi C and Akbari H 2014 Effect of aging processes on solar reflectivity of clay roof tiles *Advances in Building Energy Research* **8** 28-40
[34] Despini F, Ferrari C, Bigi A, Libbra A, Teggi S, Muscio A and Ghermandi G 2016 Correlation between remote sensing data and ground based measurements for solar reflectance retrieving *Energy and Buildings* **114** 227-233