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Research Paper

Evaluation of the radiometric properties of roofing materials for livestock buildings and their effect on the surface temperature

Giuliano Vox [a], *Angela Maneta* [b,1], *Evelia Schettini* [a,*]

[a] *Department of Agricultural and Environmental Science (DiSAAT), University of Bari, via Amendola 165/A, 70126 Bari, Italy*

[b] *University of Patras, Patra 26504, Greece*

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Passive systems, such as high solar reflective roofing materials, protective facades, vegetative green walls and roofs, can be used in order to control solar heat gain in buildings. These sustainable technologies can reduce the temperature of the external surface of the building envelope, so reducing the energy consumption for cooling in summer. The radiometric properties of metallic roofing materials and their effects on the surface temperature were evaluated. Nine smooth metallic materials used for livestock buildings were tested; 4 were made of aluminium and the other 5 of steel and they were characterised by different colours. Solar reflectivity and long wave infrared emissivity were evaluated by means of laboratory tests; the influence of the radiometric properties on the surface temperature was evaluated in the field by using an experimental structure in Summer. The solar reflectivity coefficient ranged from 7.1% for the brown aluminium to 40.1% for the red steel; significant differences of the temperatures were recorded when the solar radiation hitting the metallic surface was higher than 600 W m^{-2}. A difference of 13.4% of the solar reflectivity coefficient resulted in a difference of the surface temperature of up to 8 °C. Variation of the slope from 15° to 40° resulted in an increase of the surface temperature of more than 8 °C. The value of the convection coefficient was calculated by means of the data measured in the field, and the mean value was equal to 12.2 W m^{-2} K^{-1}.

1. Introduction

The indoor microclimate of livestock buildings plays an important role in animal comfort, health, welfare, growth and productivity (Caroprese, 2008; Jeppsson & Gustafsson, 2001). The indoor air temperature depends on a combination of several different parameters related to the climate of the region, the building itself and its use, and also to the animals. The main parameters influencing the microclimate are; external air

* *Corresponding author*. Tel.: +39 080 5443060; fax: +39 080 5442977.
E-mail address: evelia.schettini@uniba.it (E. Schettini).

[1] Student of the University of Patras (Greece) hosted by the University of Bari for placement within the framework of Lifelong Learning Programme-Erasmus.

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Nomenclature

A	slope of the regression equation (°C)
B	Y intercept of the regression equation (°C)
F	view factor
h_c	convection heat transfer coefficient (W m^{-2} K^{-1})
LWIR	Long wave infrared
R	solar radiation (W m^{-2})
r	Pearson product moment correlation coefficient
S_λ	weighting function (nm^{-1})
T	Temperature (K)
Δλ	wavelength interval (nm)
ε	emissivity (%)
λ	wavelength (m)
ρ	reflectivity (%)
σ	Stefan–Boltzmann's constant = 5.6697×10^{-8} (W m^{-2} K^{-4})

Subscripts

a	air
c	convection
s	surface

temperature and relative humidity, incident solar radiation, long wave radiation exchange between the structure and its surroundings, incidence and speed of the wind, air exchanges, the physical and thermal properties of the building's exterior materials, design variables such as building dimensions and orientation, presence of artificial light, electrical equipment and also heat produced by the animals (Jo, Carlson, Golden, & Bryan, 2010; Simpson & McPherson, 1997).

In the Mediterranean region the main problem is to control solar heat gain penetrating through the building's surfaces during the hot season from June to September. Solar heat is transferred to the internal air through the envelope by the heat transfer mechanisms of conduction, convection and radiation. Indoor air temperature is influenced by the solar radiation incident on the external surfaces of the buildings and also by the heat exchange processes between the building and the external environment. Solar radiation incident on the outer surface of the building is either reflected to the environment, absorbed by the surface then transferred into the building envelope by conduction, convected or re-radiated. The part that is conducted into the building is characterised by a damped and phase shifted thermal wave; i.e. this energy is transferred by convection with delay from the internal surface of the building into the internal air. The external building surface exchanges energy by convection with the external air, by conduction with the internal layers of the surface, and by radiation through the daytime absorption of solar radiation. The external surface also exchanges energy by radiation in the long wave infrared range through the absorption of the radiation coming from the atmosphere and through the absorption and emission of radiation with the surrounding buildings and infrastructures connected with the surface temperature (Cooper, Parsons, & Demmers, 1998; Jeppsson & Gustafsson, 2001).

The external surface temperature of the building is a key parameter that is influenced by the physical properties of the surface, such as the solar reflectance or albedo (the ability of a surface material to reflect the incident solar radiation), infrared emittance (the ability of a surface to release the absorbed heat by radiation) and the convection coefficient (Berdahl & Bretz, 1997; Gentle, Aguilar, & Smith, 2011; Joudi, Svedung, Cehlin, & Rönnelid, 2013; Karlessi et al., 2011; Synnefa, Santamouris, & Livada, 2006; Zinzi, Carnielo, & Agnoli, 2012). The convection coefficient can be modified by architectural features, such as screens, that can influence air flow near the roof surface. Materials with high albedo and high infrared emissivity are known as cool materials and they can be used on external surfaces of the livestock buildings to keep them cooler under day-time solar radiation and to dissipate the stored heat by radiation during night-time. Moreover, low-emissivity materials applied to the internal surface of a building can decrease the amount of long wave thermal energy radiating into the interior (Bretz, Akbari, & Rosenfels, 1998; Uemoto, Sato, & John, 2010).

Lower surface temperatures reduce building heat gain, in the case of air conditioning decrease the cooling load, or create more comfortable thermal conditions inside non air-conditioned buildings (Berdahl & Bretz, 1997; Bretz & Akbari, 1997; Bretz et al., 1998; Gentle et al., 2011). Improvements that limit solar heat gain result in energy cost savings, reducing the overall environmental impact of buildings and improving the overall sustainability of production in agriculture (Bretz et al., 1998; Briassoulis et al., 2013; Castellano, Candura, & Scarascia Mugnozza, 2008; Jo et al., 2010; Picuno, 2014; Picuno, Sica, Laviano, Dimitrijević, & Scarascia Mugnozza, 2012).

Commercially available cool materials to be used for roofs and walls include cool roof coatings (elastomeric, acrylic, etc.), cool single-ply membranes, reflective tiles and metal roofs (Synnefa et al., 2006). Non-metallic inorganic materials such as fibre cement tiles are highly emissive (Uemoto et al., 2010). Low-emissivity materials include many aluminium coatings and unpainted metal shingles or panels (Bretz et al., 1998).

The external surface temperature of a building's envelope is also affected by the convection heat transfer coefficient (h_c) of the surface; the higher h_c, the lower the surface temperature. The convection heat transfer coefficient depends on wind velocity, surface orientation and roughness, and the temperature difference between the surface and air temperature. Convection coefficients have, over many years, been the focus of a large body of research (Defraeye, Blocken, & Carmeliet, 2011; Hagishima & Tanimoto, 2003; Jayamaha, Wijeysundera, & Chou, 1996; Kindelan, 1980; Liu & Harris, 2007; Loveday & Taki, 1996; Zhang, Zhang, Zhao, & Chen, 2004).

Solar radiation that reaches the earth's surface is an electromagnetic radiation in the wavelength range from 280 to 2500 nm. Thus, the capacity of a construction material to reflect solar radiation is defined by its capacity to reflect in this range of wavelengths (Duffie & Beckman, 1991; Prado & Ferreira, 2005). The ability of a surface to reflect and, afterwards, to absorb the solar radiation is evaluated by means of a coefficient of reflectivity that is obtained as the weighted