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A theoretical study on a coupled effect of building envelope solar properties and thermal transmittance on the thermal response of an office cell

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ABSTRACT

In recent decades, high level of urbanization, air pollution and climate change have caused a frequent occurrence of urban heat islands, resulting in thermal discomfort and increased energy use of buildings. As a response, a lot of attention has been paid to building envelope characteristics, with an increasing number of studies investigating building envelope solar properties as one of the important factors affecting thermal performance. However, different climate characteristics are the reason why solar properties may have different efficiency at various locations, also because in cold or temperate climates building envelope has to be more thermally insulated, namely having lower thermal transmittance. Therefore, within this study, building energy use and indoor thermal conditions were analysed for an office cell using different types of solar absorptivity (e.g. white, dark grey, collector or cool coating) and thermal transmittance, on either external wall or roof. The analysis was conducted for hot-arid and temperate climate locations. The results showed that solar absorptivity can have a significant effect on total energy use, especially in cases with higher envelope thermal transmittance. It also showed that the application of cool coatings is more reasonable if the external building envelope is not intensively thermally insulated (e.g. in hot-arid climate). In general, the optimal total energy use in both analysed climates was always achieved by implementing cool coatings. Furthermore, the results showed that white and cool coatings have comparable external (20–30 K above T_{air} in summer) and internal surface temperature responses, while dark grey coatings cause the surface to heat up significantly (external surface 60 K above T_{air} in summer).

1. Introduction

The EU policy to reduce energy use and improve energy efficiency by 27% till 2030 (European Commission, 2014) has started to reflect through member state legislation and national plans for competitive, secure and sustainable energy use. Due to European climate conditions the majority of policy actions are directed towards the reduction of thermal losses, mainly by promoting and prescribing highly thermally insulated building envelopes. Nevertheless, today the consideration of building performance under non-stationary thermal conditions necessitates the application of holistic solutions, where optimal building thermal performance is achieved not only by the application of thermal insulation. It is crucial to realize that, similar to human body functions, all of the building elements must work in harmony. Only in such a manner, the optimal performance of a building will be guaranteed under dynamic environmental changes. However, most regulations regarding building envelope prescriptions do not go beyond the maximum allowed thermal transmittance (*U* value), despite the fact that the external surface spectral properties are also an important envelope characteristic. Spectral properties of external surfaces should also be considered when either designing new or renovating existing buildings (Rosso et al., 2017a), the envelope constructions of which usually have higher thermal transmittance.

The indoor living comfort and energy use of buildings are closely connected to various environmental as well as building characteristics, such as outdoor temperature, solar radiation, building envelope composition, human thermal comfort perception, etc. Furthermore, the aforementioned characteristics depend on physical laws of thermodynamics and materials' physical characteristics. For example, building envelope performance is, among several other factors, mainly determined by thermal transmittance, which influences the intensity of conductive heat flux. However, an important and often overlooked

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Abbreviations

ASHRAE	American Society of Heating, Refrigerating and A-C Engineers
EPS	expanded polystyrene
ETICS	external thermal insulation composite/compact system
FIR	far infrared (longwave) thermal radiation (5000–15,000 nm)
HVAC	heating, ventilation and air condition
NIR	near infrared (shortwave solar) thermal radiation (750–2800 nm)
OCF	the outside coating factor
PAT	parametric analysis tool
Q_c	annual energy use for cooling (GJ)
Q_h	annual energy use for heating (GJ)
Q_t	total annual energy use (GJ)
T_{air}	air temperature (°C, K)
U	thermal transmittance
VIS	visible (solar) radiation (350–750 nm)
α_S	surface solar absorptivity (280–2800 nm) (–)
ε_T	surface thermal emissivity (5000–15,000 nm) (–)
ρ	surface solar albedo (280–2800 nm) (–)

factor, which also affects thermal energy transfer through building envelope, is the externally received radiant heat flux, closely linked to the intensity of solar radiation and surface optical characteristics (Ascione et al., 2010). Both are discussed in the section below.

1.1. On solar radiation and surface optical characteristics

The building envelope external surface temperature is substantially influenced by the received solar radiant heat flux and surface solar absorptivity (α_S). In particular, the received solar radiation on the external opaque surface is partly absorbed and partly reflected, depending on the type and colour of the external surface, not only in the visible but also in the near infrared (NIR) wavelengths. The surface solar absorptivity defines the amount of solar radiation, which is absorbed on the surface. The remaining is reflected back to the external environment according to solar albedo (ρ). The solar albedo stands for the reflectance of solar electromagnetic radiation between 0.28 and 2.80 µm, including the ultraviolet, visible and NIR radiation intervals of the solar spectrum (Bretz and Akbari, 1997). The solar albedo more or less depends on the surface colour and structure, while in general, light colours have higher and dark colours have lower values of visible surface albedo. A related and equally important parameter is also the thermal emissivity (ε_T) (Ascione et al., 2010). "Real body" emissivity varies according to radiation wavelength, while "ideal black body" emissivity remains constant (Incropera et al., 2013). Further on, the Kirchhoff law describes the connection between emissivity and absorptivity, where both have equal values at specific wavelength. In the described context Santamouris (2014) noted that control over external surface albedo (ρ) and solar absorptivity (α_S) is necessary in order to control indoor environment through heat storage in the building envelope and external surface temperatures.

The solar characteristics of the building external surfaces can be controlled by the application of material having the desired optical properties, such as green vegetation surfaces, or by using spectrally modified coatings. The latter were developed in order to enable focused utilization of the coating optical characteristics. Such coatings have selective ratios of solar absorptivity and emissivity (Fig. 1). For instance, an example of such coating is "cool" coating with lower optical absorptivity and higher thermal emissivity values while preserving the optimal visual colour (Bretz and Akbari, 1997; Pisello, 2017). The non-white cool coatings absorb visual radiation but should be highly reflective in the NIR spectrum and have high thermal emissivity in long wave infrared (FIR) spectrum (Fig. 1). Such characteristics can be achieved by incorporating cool pigments (Synnefa et al., 2007b), giving the architect an opportunity to use darker colours instead of white (Revel et al., 2013; Synnefa et al., 2007b). With this in mind, Ascione et al. (2010) investigated the effect of building's surface coatings in Mediterranean climate, while they varied the solar albedo and FIR thermal emissivity. As a result, they highlighted the importance of decreasing the wall external surface temperatures in order to extend the lifetime of the building external surface coating. In addition, Bretz and Akbari (1997) emphasised that the characteristics of cool coating can deteriorate in time, depending on surface texture, dirt accumulation, etc.

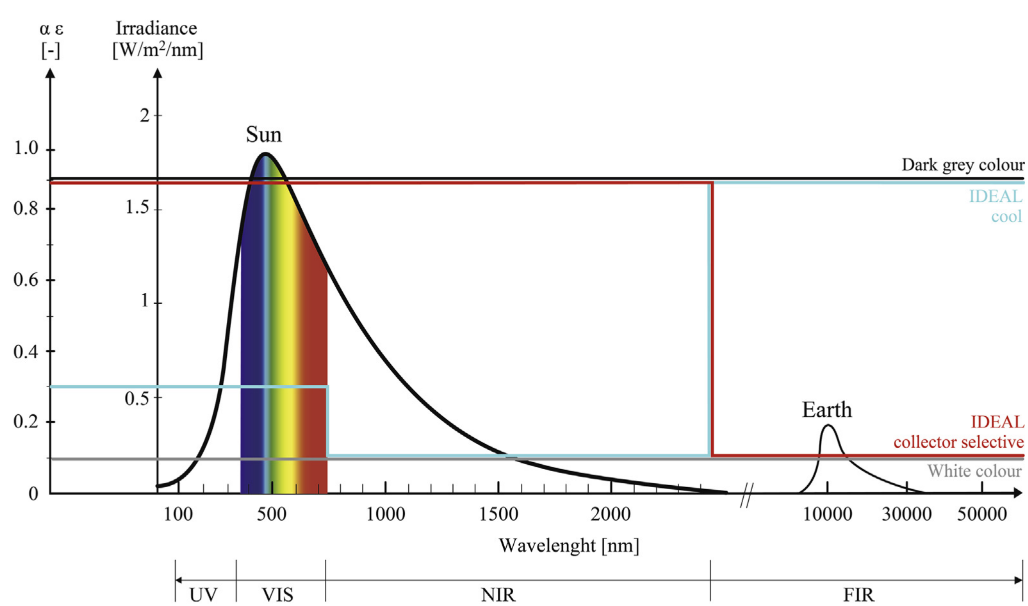

Fig. 1. Schematically represented solar spectra and corresponding performance of spectrally selective and spectrally non-selective coatings.