Energy and Buildings 124 (2016) 88–98

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

# Energy performance analysis of variable reflectivity envelope systems for commercial buildings

Benjamin Park, Moncef Krarti*

*Department of Civil, Environmental, and Architectural Engineering, University of Colorado Boulder, ECOT 441 UCB 428, Boulder, CO 80309-0428, USA*

ARTICLE INFO

*Article history:*
Received 27 February 2016
Received in revised form 26 April 2016
Accepted 26 April 2016
Available online 27 April 2016

*Keywords:*
Commercial buildings
Cool roofs
Energy savings
Variable reflectivity

ABSTRACT

This paper evaluates potential energy savings associated with variable reflectivity envelope systems (VRCs) including cool roofs associated the application of coatings that can change their reflective properties over time depending on outdoor conditions and desired controlled strategies. It is well known that static cool roofs can save energy use during cooling periods but may increase energy consumption during swing or heating seasons due to lower beneficial heat gains. In the analysis, a two-step control strategy is considered to modify the properties of the cool roof coatings based on the temperature difference between internal and external roof surfaces. Using a simulation environment capable of modeling variable properties of outer surface of building envelope, a comparative analysis is carried out to evaluate the impact of VRCs on the heating and cooling energy end-uses for commercial buildings in four US climates. It is observed that VRCs can save heating energy use compared to static cool roofs for all four US climates for both commercial buildings. In particular, it is found that VRCs have the potential to reduce annual energy use in commercial buildings up to 11% compared to the static cool roofs.

© 2016 Elsevier B.V. All rights reserved.

## 1. Introduction

Building heating and cooling energy use accounts for up to 40% of the total energy consumption in developed countries [1]. Heat losses and gains through the building envelope greatly contribute to build thermal heating and cooling loads [2,3]. In particular, solar radiation incident on the outer surfaces of building envelope considerably affect both heating and cooling loads. Cool roofs have been utilized as one of the passive cooling techniques to reduce cooling energy demand for buildings. Using highly reflective coatings, cool roofs reduce solar heat gains during the summer and can keep exterior roofs cooler compared to roofs with standard reflectivity properties [4].

Impact of cool roofs on the reduction of building energy consumption has been widely investigated in various climate conditions and building operations [5]. Specifically, it has been shown that cool roofs, with high reflectivity coating materials, are effective in reducing solar heat gains through building shell [6,7]. The benefits of cool roofs to reduce cooling energy use for air conditioning buildings during the summer and improve thermal comfort for non-air conditioning buildings have been evaluated and tested for several building types and regions around the world [6–9]. In the US and based on an electricity price of \$0.10/kWh, the economical value of cooling energy savings has been estimated to range from \$0.25 to 1.00/year/m$^2$ of roof area for most buildings located in cooling dominated climates [10]. In India, it has been found that cool roofs can achieve up to 20% in cooling energy use savings for commercial buildings [11].

Currently, several US building codes and standards have prescribed and provide energy efficiency credits for utilizing cool materials and high solar reflective roofs for buildings [4]. A detailed study to assess the impact of cool roofs on air conditioning needs for a prototypical house located in cooling dominated sites has found annual cooling energy use is reduced by 170 kWh/year for mild climates and 700 kWh/year for very hot climates [12]. Similar study for a prototypical office building indicate cooling energy use savings ranging from 500 kWh/year for mild climates to 1000 kWh/year for hot climates [13].

However, cool roofs have been found to be not necessarily beneficial during winter seasons when buildings are required to be heated. In fact, several studies have noted that cool roofs actually increase building heating loads by reducing the amount of solar heat gains. In particular, the heating penalty associated with cool roofs for cold climates was estimated to be 2.3 GJ/100 m$^2$ of roof area for a retail store in Anchorage, AL [14]. This penalty was reduced when accounting for snow on the roof due to its insulating

* Corresponding author.
*E-mail address:* moncef.krarti@colorado.edu (M. Krarti).

http://dx.doi.org/10.1016/j.enbuild.2016.04.070
0378-7788/© 2016 Elsevier B.V. All rights reserved.

effects. In Italy, an experimental study found an increase of 5% in heating energy use associated with the installation of an innovative cool fluorocarbon coating on the roof of an industrial facility [15].

To compensate for the increase in heating load by using cool roofs, variable roof reflectivity control strategy is introduced in the analysis presented in this paper. Specifically, the main purpose of the study summarized in this paper is to investigate and quantify the potential energy savings of VRCs for US commercial buildings. In particular, the total energy savings associated with VRCs are estimated and compared for a benchmark office building located in four US climates.

Materials and coatings with variable or switchable optical properties have been available commercially and have been applied for several building applications including smart glazing. These switchable coatings can change optical properties based on changing outdoor conditions such as temperature and heat or control parameters such electrical current [16–21]. Indeed, there are several types of swichable materials including electrochromic, liquid crystal, suspended particle device, and thermochromic [22]. While, for smart glazing applications, electrochromic materials have been widely used and tested, there is recently a growing interest in exploring thermochromic thin-films for switchable glazing and other building applications due to their lower costs [23].

Thermochromic materials change structure from monoclinic (cold) to rutile (hot) state when their temperature increases. In the rutile state, the thermochromic materials act like semi-metals and reflect significant amount of solar radiation. Through doping techniques, the transition temperature of the thermochromic materials can be changed to be suitable for building applications. Reported testing analyses of thermochromic materials have shown solar reflectance that ranges from 10 to 25% in the cold state to 30–43% in the hot state [23]. The cold and hot temperatures for the tested thermochromic coatings have been in the range of respectively 20–25 °C and 40 °C–100 °C. While the transition temperatures seem appropriate, additional research is underway to reach ideal optical properties of 70–80% solar reflectance at the hot state for thermochromic coatings to be suitable for building applications [23]. Most of the research studies used the vanadium dioxide ($VO_2$) as the thermochromic material for switchable window glazing with several doping options including fluorine, Tungsten, and gold nanoparticles [24].

Few cool materials including thermochromic coatings with high and potentially variable solar reflectance properties have been developed and applied to building envelopes to mitigate urban heat island effects and reduce air conditioning loads. In particular, Karlessi et al. [25] have developed and tested thermal and optical performance of 11 thermochromic coatings for buildings and urban structures. They found that the solar reflectance can be increased from the colored to colorless phase of the coatings by up to 43%. The best result was achieved by a green thermochromic coating sample made with titanium dioxide ($TiO_2$) with a solar reflectivity that can change from 0.51 to 0.73. In addition, Ferrari et al. [26] has tested the application of inexpensive pigments commonly used in the ceramic industry to develop high reflective englobe. They also tested the impact of the application of three types of glaze coating to improve the resistance to mechanical stress and weathering of the englobe. They found that white gloss glaze has the best performance and maintain the high solar reflectance of the pigmented englobe at about 0.86 paving the way to produce ceramic tiles that can be utilized as cool roof surfaces. More recently, Rossi et al. [27] have evaluated the benefits of the application of retroreflective (RR) materials on building envelopes in urban canyons. RR materials have high reflectivity values and can reflect the incoming solar radiation backward to the same direction of incidence. Most diffuse white surfaces typically reflect solar radiation in all directions. Using a small-scale testing facility for canyons, the performance of RR and diffuse white materials has been compared to assess their potential in reducing the canyon temperatures. The results indicated that despite having lower solar reflectance (0.628 vs. 0.865), RR materials provide cooler temperatures in the pavements and canyons than the diffuse white materials achieving temperature decreases of up to 22% during 10 summer days of testing. Using modeling analysis, Akbari and Touchai [28] has evaluated the performance of directional reflective materials (DRMs) as cool roof coatings. DRMs reflect solar radiation during the summer when the sun is high in the sky and absorb solar radiation during the winter when the sun angle is low. The modeled DRMs consist of tilted corrugations with reflective sides and absorptive sides. The modeling analysis results have indicated that one average annual reflectivity value cannot be used to approximate the performance of DRMs over one year. At least two reflectivity values: one for the summer and one for the winter should be used to estimate the thermal performance of DRMs applied on the roofs of buildings.

In this paper, the results of a simulation analysis are discussed to identify the potential application of variable solar reflectivity coatings such as those obtained by thermochromic materials when applied to commercial building opaque envelope surfaces including roofs and walls. The analysis considers both heating and cooling energy consumption associated to a prototypical commercial building located in four US climates. First the simulation analysis is briefly presented including a description of the energy model for the commercial building. Then, the results of the simulation analysis are outlined to determine the potential of variable reflectivity coatings to reduce energy consumption for air conditioned buildings in various US climates. In particular, the analysis compares the performance of the variable reflectivity roofs, referred to in this paper as dynamic cool roofs, to the static conventional cool roofs in order to assess the potential benefits of developing optically active coatings suitable for opaque building envelope systems.

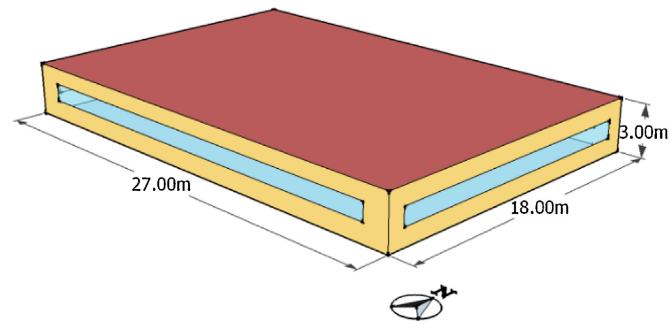


**Fig. 1.** Isometric view of the building model.

**Table 1**
Thermal characteristics of building envelope constructions.

| Construction name | U-value [W/m²-K] | Capacitance [kJ/m²-K] |
|---|---|---|
| Roof | 0.19 | 445 |
| Floor | 0.55 | 377 |
| Exterior wall | 0.49 | 266 |

## 2. Description of the building model

The top story of a prototypical office building Fig. 1 is considered in this study with a total conditioned floor area of 486 $m^2$. The height of the floor is 3 m resulting in total conditioned volume of 1458 $m^3$. The building window-to-wall ratio is 15% for all orientations.

Table 1 shows the thermal characteristics of the exterior roof, floor, and walls for the office building. The total thermal mass is estimated to be approximately 567 $kg/m^2$ of conditioned floor area.

Download English Version:

https://daneshyari.com/en/article/262091

Download Persian Version:

https://daneshyari.com/article/262091

Daneshyari.com