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Reflective thermal insulation systems in building: A review on radiant barrier and reflective insulation

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A B S T R A C T

The concerns over depletion of fossil fuel resources and negative environmental impact arising from energy generation have prompted increasing attention on the use of thermal insulation in building energy conservation. This article strives to make an overall review of reflective thermal insulation system which focuses on radiant barrier and reflective insulation. The main parameters in evaluating the performance of radiant barrier system are reduction of heat flux, thermal load and attic air temperature. Based on studies, radiant barrier is effective in reducing heat flux, thermal load and attic air temperature during summer and to a lesser extent during winter. Researchers found that on average radiant barrier installed on attic space could reduce heat flux by 26% to 50% and cooling load by 6% to 16% during cooling seasons. Fundamentally, reflective insulation system works under enclosed reflective airspace(s) and thus its key thermal performance is usually measured by level of thermal resistance produced by the enclosed air cavity. Although many research works have been conducted on reflective insulation, there are still many uncertainties exist in predicting the correct resistance value. The most commonly used method to measure the resistance value is guarded hot box which can simulate large-scale assemblies that are closer to real conditions. Heat flow meter was used to test smaller specimen. Calculation using theoretical approach provides a more simplified method to predict the resistance value. However, this method may tend to over predict the value given the limitations from which its basis was formed. It was discovered that emittance of upward facing reflective foil used in both radiant barrier and reflective insulation system are also susceptible to degradation due to dust accumulation, moisture condensation and corrosion. Hence, it is imperative to ensure a low-emittance surface for a sustainable performance of both insulation systems in the long run.

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1. Introduction

The 1970s energy crisis which heavily affected major developed countries like the United States, the United Kingdom, Germany, Japan, Australia and New Zealand had sent an alarming signal to the world that conserving energy is of paramount importance as energy was no longer cheap and production of petroleum had reached its peak. In the United States, although the oil price shocks during 1970s and 1980s had led to a shift away from petroleum based power generation, both coal and natural gas have made a recent come back [1]. Coal and natural gas are the two predominant fossil fuels used in electricity generation in most countries which are also depletable resources. While efforts to explore and use renewable sources such as hydropower, wind and solar [2] are being undertaken, energy conservation should remain as the priority measure to prevent the depletion of scarce fuel for a sustainable future.

The greenhouse gases from combustion of fuel to generate electricity are one of the major causes of climate change. According to the Synthesis Report of the Intergovernmental Panel on Climate Change (IPCC) [3], cumulative carbon dioxide (CO_2) emissions from fossil fuel combustion, cement production and flaring have tripled from 1970 to 2010. Fossil fuel combustion and industrial processes made up about 78% to the total greenhouse gases emission increase during the same period. From this report it is evident that human activities are the main culprit in changing the global climate system. It is therefore human being plays an important role in mitigating if not stopping the climate change.

The urgent needs in preserving the non-renewable fuels and growing concern on the climate change from its use make it increasingly important to implement energy saving measures and passive heating and cooling strategies in building especially. This is because the International Energy Agency (IEA) reported that buildings represent 32% of the total energy consumption in the World [4]. In a research done by Perez-Lombard et al. [5], it was found that percentage of energy consumed in heating, ventilation and air conditioning (HVAC) in office was 48% in the United States, 55% in the United Kingdom and 52% in Spain. While in the residential sector, space conditioning consists of 53%, 62% and 42% of the total energy consumption in residential in the three respective countries. In view of the high usage of energy in HVAC, Ibrahim [6] and Dylewski and Adamczyk [7] both in their research stated that thermal insulation is one of the most effective measures in conserving energy used for heating and cooling buildings. Thermal insulation in building is essential to reduce excess heat loss or heat gain which leads to decrease of energy consumption in heating and cooling systems. In hot climates, thermal insulation can slow or reduce the heat gain from solar radiation into building. On the contrary, it serves to reduce heat loss from building in cold climates.

Generally thermal insulation technologies can be classified into four main categories namely bulk, reflective, vacuum and nanotechnology as shown in Fig. 1.

Thermal insulation using bulk technology make use of bulk or fibrous material such as fiberglass, mineral wool, expanded polystyrene (EPS), extruded polystyrene (XPS), etc to block or trap the transfer of heat via conduction and convection. Its ability to resist heat depends on thermal conductivity and density or thickness of the material used. Bulk insulation may not be the most effective material in resisting radiative heat transfer. On the other hand, thermal insulation that adopts reflective technology such as radiant barrier and reflective insulation uses very thin layer of low-emittance aluminium foil is more effective in preventing the transfer of radiative heat. These two categories of reflective technology are the focus of this paper. Combined with airspace adjacent to the low-emittance surface, this technology can resist conductive and convective heat transfer as well. Thermal insulation using interior radiation control coatings (IRCCs) and the latest innovation, gas-filled panels (GFPs) also incorporate the reflective technology. The evolution of nanotechnology has enabled the development of another type of thermal insulation for building i.e. aerogel which is made of nanostructured material and very lightweight. Its porous structure and up to 99% airspace make it very good thermal insulation. Another advance in thermal insulation applying vacuum technology is vacuum insulated panels (VIPs). This thermal insulation is able to resist heat transfer with its air tight enclosure surrounding a panel.

The objective of this paper is to review studies done on radiant barrier and reflective insulation system in order to provide an insight to reader on these two technologies.

2. History of reflective thermal insulation

The discovery of the principle in reflective thermal insulation can be traced back to the middle of 19th century when a French physicist Jean Claude Eugene Peclet carried out experiments with multiple layers of tin-coated steel (reflective surface) facing various thickness of the airspace between the reflecting surfaces. Peclet discovered the excellent insulating property with reflective surface in reducing the transfer of heat. However, the widely use of this type of insulation commercially was only started in 1925 when two German businessmen Schmidt and Dykerhoff filed patents on reflective surfaces for use as insulation. They experimented with very thin aluminium foil with less than 0.0005 in. (0.0127 mm) thick which had very low-emittance surface. With this, they further improved and developed an effective and inexpensive form of insulation which is commercially viable. This is a paradigm shift in the insulation industry as the thin aluminium is very lightweight and more affordable as compared to conventional insulation materials like rock wool. Within the next 15 years millions of square feet of radiant barrier were applied in the United States alone [8].