

Cool Materials and the Heat Island Effect: a bibliometric analysis

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ABSTRACT

A current problem triggered by anthropological factors that many cities in the world face is the increase in temperature in urban centres caused by urban heat islands. There is a constant proposal for measures to reduce these effects, which can be harmful to the health and well-being of the population. The purpose of this work is to carry out a bibliometric mapping to analyse the published documents on cool materials regarding the mitigation effects of heat islands and to understand their origin and possible reasons that led to the study of this theme. From the SCOPUS database, searching for “Cool Material AND (Albedo OR Reflectance) AND Heat Island”, the scientific documents (engineering area) published between 1995 and 2021 were selected and analysed: the types of documents, their origin, the year of publication, the main authors and the journals in which they were published. Energy and Buildings and Building and Environment were the two main journals on the subject. 1995 had the first article published and coincided with the year of the first Conference of the Parties (COP1), on climate change. Through a bibliometric survey, it is possible to understand the importance of the beginning of this line of research and that climatic events can trigger interest and bring the scientific view to a certain area. However, because it is a single-base study, the research, despite bringing good information, still needs constant updates.

KEYWORDS: cool materials, urban heat island, reflectance.

INTRODUCTION

In addition to climatic phenomena, human action is also largely responsible for climate change and this discussion has been gaining importance. According to the World Meteorological Organization, the decade between 2011 and 2020 was the warmest in the world, with 2016 being the hottest year, followed by 2020 and 2019 (ONU NEWS, 2020).

The lack of urban vegetation together with the large number of surfaces with low levels of albedo increases the temperature of cities in the summer, being one of the factors responsible for the occurrence of heat island effect in large urban centers. The reduction of albedo and the removal of vegetation, increases the surface heat gain, consequently increasing its surface temperature (ROSENFELD et al., 1995).

This rise in urban air temperature leads to greater consumption of electricity for cooling indoor environments, which also causes an increase in energy demand during peak hours. Another downside is the effect on air quality. The increase in energy demand contributes to the pollution rise in the energy production or the elevation in ambient temperature, which causes the smog effect (smoke plus fog). One of the measures to reduce or reverse this effect is to make cities wooded and to increase the albedo of surfaces (ROSENFELD et al., 1995).

A technology that has been widely used to reduce the effects of heat islands is the use of cool materials, which are materials with high solar reflectance and high emissivity in the infrared. The use of these materials contributes to increasing the albedo of cities and is considered one of the most promising methods to reduce the effects of heat islands in urban centers (SANTAMOURIS et al., 2011).

There are numerous articles about increasing the reflectance of urban surfaces, such as the use of cool materials in pavements and roofs, as they represent a large part of the surface of the cities. Akpınar e Sevin (2018) concluded that pavements made with asphalt have a higher surface temperature than concrete pavements. The study concluded that planting trees on the

sides of the pavements helps to minimize this surface temperature, consequently decreasing the radiation that is released by the pavement.

Regarding roof tiles, a study with 31 tiles with different colors and materials showed their different performance in terms of reflectance and surface temperature. These values ranged from 0.1 to 0.67 in reflectance and from 57.1 °C to 96.9 °C as equilibrium surface temperature (Ts). The roughness factor of the materials proved to be a variable that influences the reflectance (MUNIZ-GÄAL et al., 2018). Therefore, the choice of materials used on surfaces have a fundamental role in maintaining and mitigating the effects of urban heat islands.

This shows how the scientific contribution is essential for the standardization and knowledge dissemination that will be inserted into the construction market, bringing positive consequences for urban environmental quality.

OBJECTIVES

The objective of this article is to carry out a bibliometric analysis and investigate the documents published between 1995 and 2021 in the SCOPUS database, about the optical properties and thermal performance of cool materials, their implication in reducing the effect of urban heat islands and what may have started the interest in this topic.

METHODOLOGY

The methodology proposed by this work consisted of collecting data from the SCOPUS database on scientific documents. They were published between 1995 and 2021 on the study of cool materials - or cold materials -, which are materials with high solar reflectance and high infrared emittance, and its implications on the effect of heat islands.

The starting point was the choice of keywords. Aiming to seek the largest number of documents related to cold materials, but keeping reflectance as a desired subject, and its impact on mitigating the effects of heat islands, the set of words chosen was: "Cool Material AND (Albedo OR Reflectance) AND Heat Island".

This search resulted in a total of 152 scientific documents published in the SCOPUS database. By selecting only the documents from the engineering area, the result was reduced to 72 documents. The relevant indicators for this work were the type of documents, countries of origin, year of publication, authors and journals in which the articles were published.

Posteriorly, the article with the highest number of citations in the last 10 years was used on the website *Connectedpapers.com* to create a network of related articles and bring a visual tool to help in the perception of the main articles on the subject.

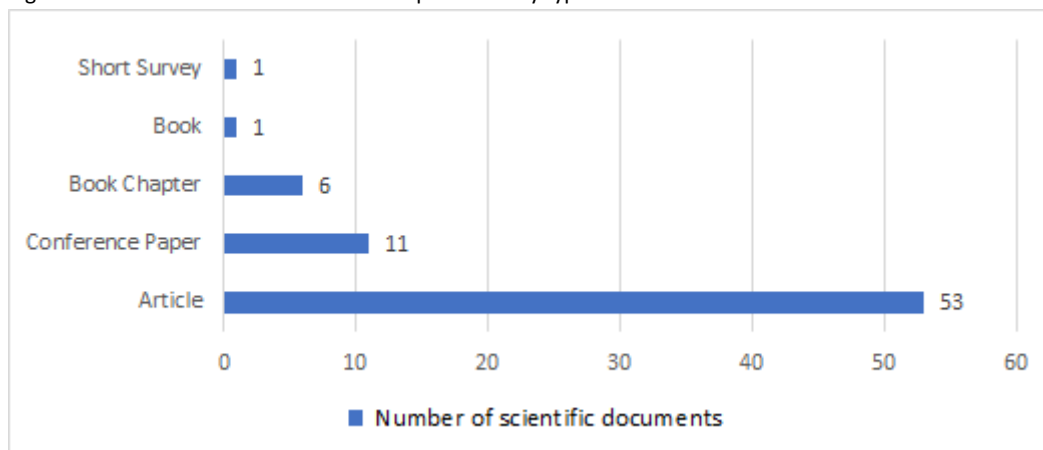
At last, a word cloud was made with the abstracts of 38% of the articles in the most recent journals through an online software called Word Clouds© to emphasize the most used words.

RESULTS

As can be seen in Figure 1, among the 72 documents published, 53 are journal articles, corresponding to 74% of all documents, followed by 11 conference papers (15%), 6 book chapters (8%), 1 book (1%) and 1 small survey (1%).

Each article brings a different perspective on the topic. In the last 5 years, studies have been found with different approaches to the application of these materials on different surfaces, such as pavements (HENDEL et al., 2018, ANTING et al., 2018 e 2017), roofs (FABIANI et al., 2019), the development of reflective pigments (ELAKKIYA e SUMATHI, 2020, ROSSO et al., 2020), and also simulations with the use of cold materials through the ENVI-Met software (ZHU et al., 2021, FAHED et al., 2020).

Figure 1: Number of scientific documents published by type



Source: Produced by the authors

Figures 2 to 4 were developed from the database generated from these 53 journal articles in the field of engineering on cold materials and their relationship with the heat island effect.

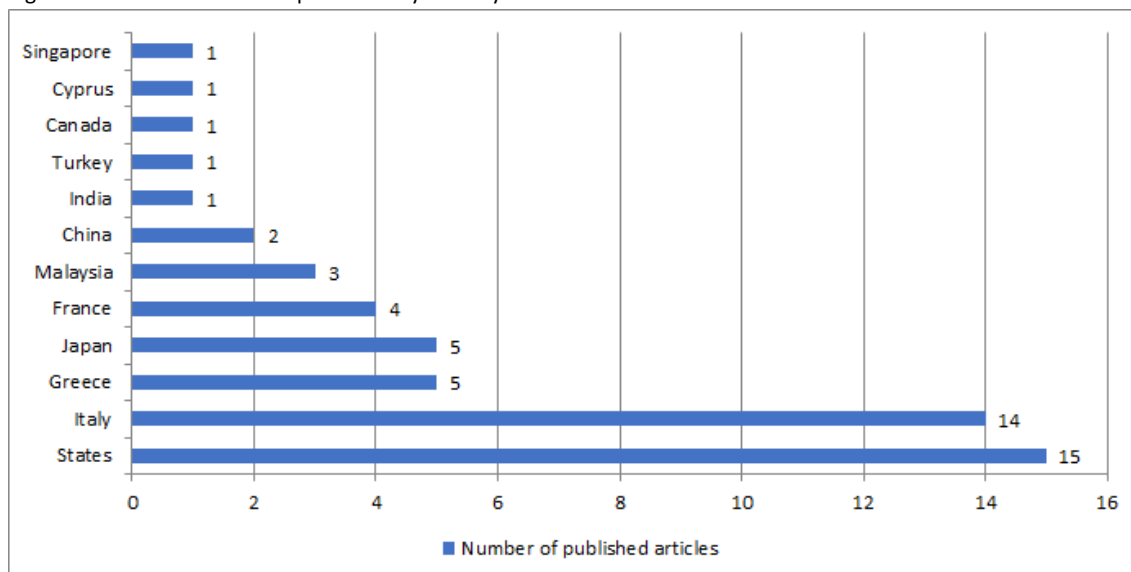
Figure 2 shows that although there are publications on the subject in 12 countries, the United States and Italy lead the ranking of countries that published the most, 15 and 14 articles, respectively. These two countries are responsible for 55% of publications on the subject. Followed by Greece and Japan with 5 articles each.

As can be seen in Figure 3, the first article was published in 1995. This article mentions that the research about mitigation measures for the heat island effect was a focus of attention in the Climate Change Action Plan of President Clinton in the United States (ROSENFELD et al., 1995). This evident concern on a president's agenda since 1995 may be one of the reasons that makes the United States the country with the largest number of published researches on the subject.

Of the 15 articles published by the United States over the years, the number of articles related to cool pavements represent 8 documents and corresponding to 53% of the total (ROSSO et al., 2017, SREEDHAR and BILIGIRI, 2016, LI et al., 2013, HASELBACH et al., 2011, WATHNE, 2010, TRAN et al., 2009, BORIBOONSOMSIN and REZA, 2007, GUI et al., 2007). Meanwhile, the priority of Italian publications are the retro-reflective materials and their different applications,

accounting for 6 of the 14 articles (CASTELLANI et al., 2020 and 2017, MORINI et al., 2018 and 2017, ROSSI et al., 2016 and 2014).

Figure 2 – Number of articles published by country

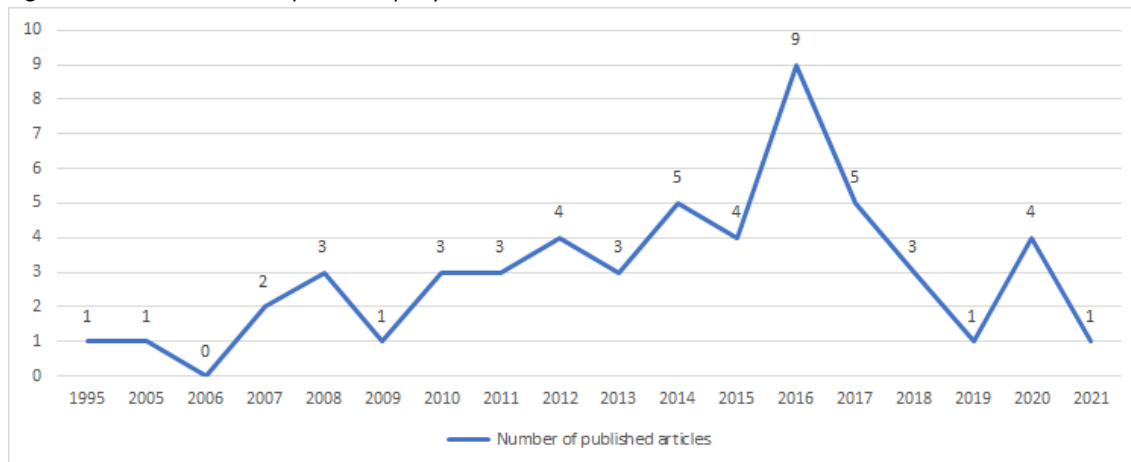


Source: Produced by the authors

Another highlight for 1995 was the first Conference of the Parties (COP 1). The conference, which took place in Berlin, was attended by 117 countries and had many hours of negotiation between all parties to reach the objective of the conference, the definition of commitments to mitigate the effects of global warming (CARPENTER et al., 1995). Thus, it is noted that the concern for climate change began to mark the agenda of several countries around the world and their representatives.

It is observed that the year 2016 leads with 9 articles published on the subject, with the use of cool materials on roofs being the most recurrent theme, with a total of 4 articles (ANTONAI et al., 2016, MASTRAPOSTOLI et al., 2016, PISELLO et al., 2016, ROMAN et al., 2016). This spike in publications can be explained by the fact that 2015-2016 was considered the hottest year in history. The 2015-2016 El Niño phenomenon was defined as one of the strongest since 1950, along with those that began to occur in 1997 and 1982, by the World Meteorological Organization (MARTINEZ et al., 2017). It drew attention and increased the interest for this line of research. The number of articles published remains constant because the subject has had a worldwide interest throughout the period, but it is clearly influenced by specific facts, referring to climate change, which concern and attract all the world's attention.

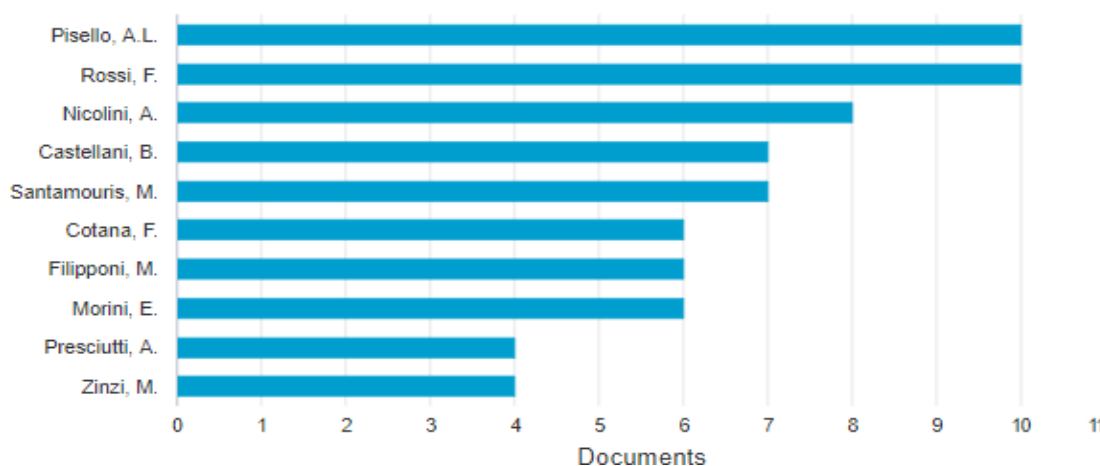
Figure 3 - Number of articles published per year



Source: Produced by the authors

It is possible to observe in Figure 4 the authors who publish the most on the SCOPUS platform on the researched topic. The top 5 is composed of Pisello, A. L. and Rossi, F. with 10 articles, Nicollini, A. with 8 articles, followed by Castellani, B. and Santamouris, M. with 7 articles each.

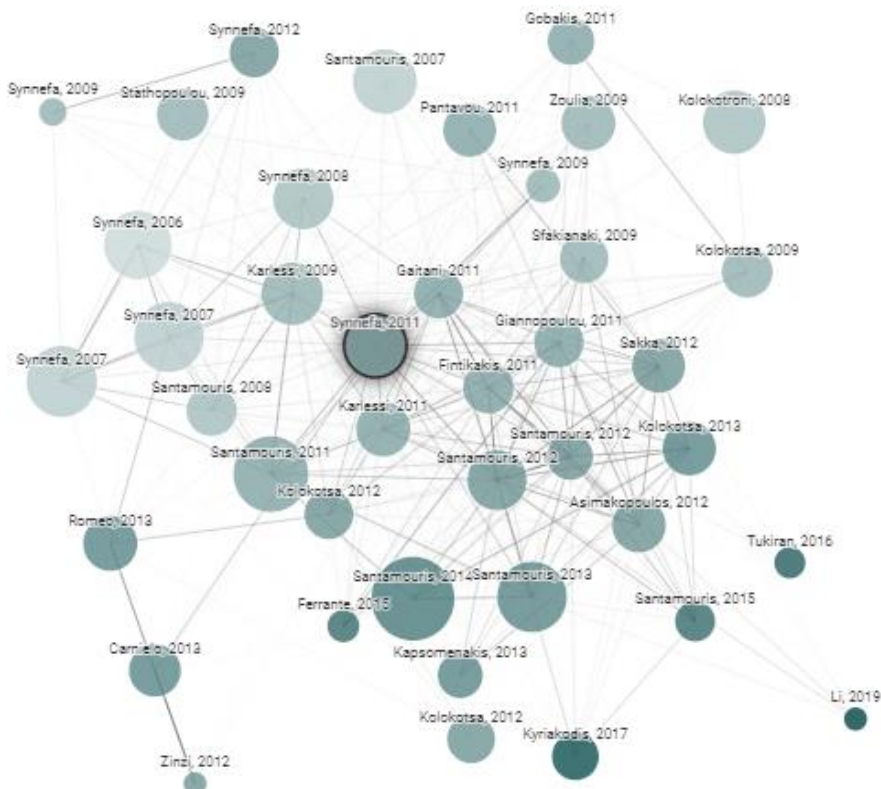
Figure 4 – Number of articles published per author



Source: SCOPUS, 2021

In addition, Synnefa et al. (2011) was the article with the highest number of citations in the last 10 years according to SCOPUS database. Through the Connectedpapers online tool (*CONNECTEDPAPERS, 2021*), it was possible to find the most connected researches with this article. In figure 5, the circles represent articles, their coloring is related to the year of their publication, the darker tones are the most recent ones. The size of the spheres is related to the number of times the article was cited by other scientific articles. Comparing figures 4 and 5, it can be seen that despite occupying the 5th place in the SCOPUS database, as the author with the most published articles, Santamouris, M. appears in a large number of articles in this connection network, among other names that are repeated.

Figure 5 – Articles with strong connections created through the Connectedpapers website

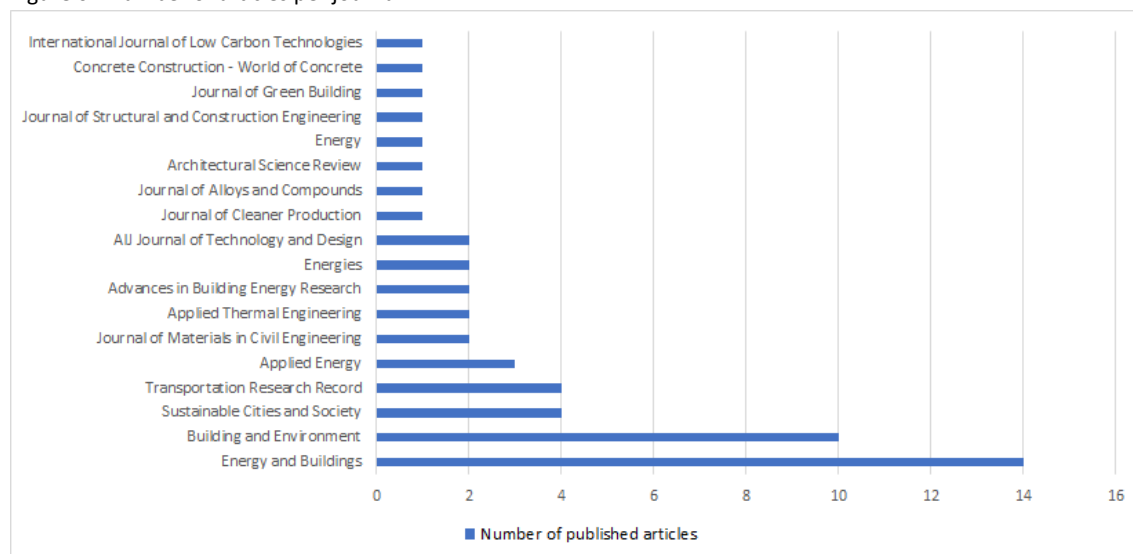


Source: Connectedpapers adapted, 2021

This tool has great functionality, as it brings us a visual way to understand the importance of certain articles in this line of research.

Observing figure 6, it is easy to identify the two most relevant journals in number of publications when the subject is cool materials and heat island: Energy and Buildings leading with 14 of the 53 articles analyzed and Building and Environment in second place, with 10 articles in your base. The two journals together represent more than 45% of the publications.

Figure 6 - Number of articles per journal



Source: Produced by the authors

Observing the word cloud formed by all the words in the abstracts of the last 20 selected articles, differentiating singular from plural, we see the main mentions in the articles (figure 7). Among the most mentioned words, “cool” (99 times), “materials” (98 times), “reflectance” (71 times), “Heat” (61 times) and “Island” (38 times) consist of the very words chosen for the search of articles and summarize the main idea of the subject. The word “urban” was the most mentioned word in the texts, 130 times, which brings us to the place where the heat island effect occurs, which is a problem in large urban centers. On the other hand, we find “surface” (66 times), “pavement” (59 times) and “roof” (57 times) being examples of studied surfaces. In addition, the use of cool materials and the reduction of energy consumption, surface temperature of cold materials, technologies applied to roofs and cold pavements are some of the most frequent topics in the articles.

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