

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/389030096>

Application of Thermochromic and Self-cleaning Materials in Buildings: A Bibliometric Analysis

Conference Paper · February 2025

DOI: 10.1007/978-981-97-8305-2_56

CITATIONS

0

READS

6

3 authors, including:



[Ana Carolina Hidalgo Araujo](#)
University of São Paulo

10 PUBLICATIONS 18 CITATIONS

SEE PROFILE



Application of Thermochromic and Self-cleaning Materials in Buildings: A Bibliometric Analysis

Ana Carolina Hidalgo-Araujo¹(✉) , Rafael Salomão² ,
and Kelen Almeida Dornelles¹ 

¹ Institute of Architecture and Urbanism, University of São Paulo (USP), São Carlos, Brazil
ana.hidalgo.araujo@usp.br

² São Carlos School of Engineering, Materials Engineering Department, USP, São Carlos, Brazil

Abstract. Climate change and global warming increasingly require artificial climate control to alleviate thermal discomfort in buildings. Reflective materials, while effective for passive cooling in hot climates, degrade over time due to particle deposition and microbial growth, and can be less effective in climates with wide temperature swings, resulting in a greater need for artificial cooling. Thermochromic and self-cleaning materials are promising alternatives. The former adjusts reflectance with temperature changes, whereas the latter provide superhydrophobic surfaces and can degrade organic compounds, potentially extending the life of the building envelope. This paper analyzed recent advances and shortcomings in the use of such materials in buildings. A bibliometric analysis of 123 articles showed that most were published in 2022 (24.39%), predominantly from China (52.99%). Although their focus was primarily on translucent building envelopes (85.33%), application to opaque surfaces such as roofs (9.33%) and walls (5.33%) remained limited. Despite the growing interest, there were significant research gaps in the application of these materials to opaque surfaces, particularly roofs, which contribute significantly to heat gain in low-rise buildings in hot climates and are more exposed to natural degradation than other building surfaces.

Keywords: Adaptative Building · Self-cleaning Materials · Energy saving

1 Introduction

Climate change and global warming have a direct impact on the energy consumption of buildings, especially in cities, leading to the formation of urban heat islands (UHI) [1]. Buildings account for about 40% of global energy consumption, with almost half of this energy being used for heating and/or cooling [2–4]. Therefore, it is critical to look for strategies to reduce the use of artificial climate control in buildings in order to mitigate the GEE emission, the formation of the UHI and global warming [5, 6].

Cool materials can effectively reduce heat gains by reflecting a large portion of incident solar radiation [7]. However, natural weathering can darken and roughen these materials, altering their optical properties and reducing thermal performance over time.

Additionally, cool materials may be less efficient in cold climates, increasing the need for heating in winter [8, 9]. As an adaptive alternative suitable for different climates and as an option to mechanical cleaning, recent studies have focused on materials that combine self-cleaning and thermo-chromic properties for building applications [10–14]. To fully understand their potential, it is crucial to analyze how these materials are applied. This bibliometric review of studies on the combined application of these materials on building envelopes represents a novel approach in the field. Given the experimental nature of the topic and the limited number of studies that have examined these materials together, this review is essential for uncovering trends, patterns, potentials, and gaps in existing research.

2 Bibliometric Analysis Methodology

Bibliometric analysis is the statistical analysis of written communication processes and the quantitative treatment of data [15]. It evaluates scientific work using statistical and computational methods to identify patterns, trends, gaps, and connections between studies [16, 17]. The following section outlines the steps for conducting this analysis.

2.1 Steps of the Bibliometric Analysis

The first step in this bibliometric analysis was the definition of the research question: “What are the gaps in the use of thermo-chromic and self-cleaning materials for buildings?” Then, keywords with the highest potential to address this question were selected [“thermo-chromic material” AND (“self-cleaning” OR “superhydrophobic”) AND “building”]. The analysis period was limited to the last 5 years, from 2019 to 2024. These criteria guided the initial search in three databases: Scopus, ScienceDirect, and Web of Science, conducted on March 11, 2024. Scopus yielded the most results (123 papers), followed by ScienceDirect (71 papers), with no results from Web of Science.

Two approaches were used in this study. The first involved the construction of a bibliometric network using VOSViewer software (.RIS), which visualizes correlations between words. The second strategy involved a bibliometric analysis using Excel (.CSV) to quantitatively analyze the database information through its range of statistical functions, charting capabilities, and tools for filtering and classifying information [18]. Both analyses were carried out using Scopus data due to its larger number of papers.

VOSViewer identifies themes and trends in the scientific literature by illustrating patterns and associations amongst terms, forming nodes, edges, and clusters. Nodes indicate the frequency of terms; edges connect co-occurring terms; and, clusters reflect common themes across articles [18]. In this study, two bibliometric networks were created: one for titles and abstracts (binary counting) and one for keywords (fractional counting). Binary counting is recommended for textual data because the frequency of a noun phrase in the title and abstract of a publication does not affect the construction of a co-occurrence network; a phrase occurring once is treated the same as one occurring ten times. Fractional counting is preferred for bibliometric analysis because it ensures that each cited reference has the same influence, providing an equal representation of publication content [18, 19]. Table 1 shows the input data for each network.

3.2 Bibliometric Analysis

The first bibliometric analysis concerned the number of publications per year from 2019 to March 2024 (Fig. 2a). There was a gradual increase in publications related to the research topic, peaking in 2022 (30 papers). In 2023, however, there was a decline, returning to the level of 2020. The data for 2024, show the potential to surpass 2023 and reach or exceed the level of 2022, with almost a third of the 2022 publications in the first quarter of the year. The second dataset concerned the countries in which the authors are affiliated. The articles found in Scopus were spread across 30 countries, but the graph only includes those with 3 or more studies, focusing on those with the highest recurrence rates (Fig. 2b). China stands out with 52.99% of the institutions in this bibliometric analysis. This is followed by Portugal (17), Hong Kong (14), Italy (13), the United States (11), Singapore (11), Australia (10), India (9), and South Korea (7). Overall, Asia is the leading producer of the papers analyzed in this study. Regarding the source of the articles, they were published in 90 journals, but for the same reasons as Fig. 2b, only those with 3 or more studies are included in the graph (Fig. 2c). The journals with the highest number of publications were Energy and Buildings (IF¹: 6.7) and Construction and Building Materials (IF: 7.4), with 5 articles each. Solar Energy Materials and Solar Cells (IF: 6.9) and ACS Applied Materials and Interfaces (IF: 9.5) followed with 4 articles each. Finally, Renewable Energy (IF: 8.7) and Journal of Materials Chemistry C (IF: 6.4) had 3 articles each. In particular, these journals are known for publishing significant work related to the thermal energy performance of buildings and the development of new materials, topics highly relevant to this analysis.

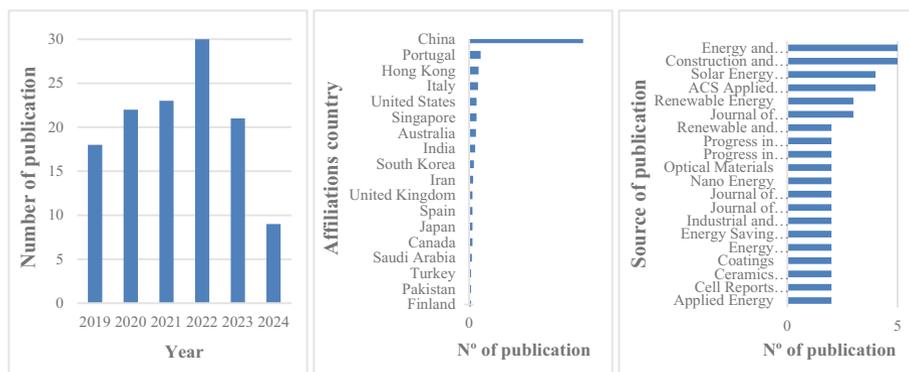


Fig. 2. a) Number of publications per year. b) Countries of publications. c) Places of publications.

A specific analysis of the building envelope was conducted by examining the prevalence of terms related to exterior surfaces in the keywords and abstracts of each article. Papers containing “window,” “roof,” and “wall” were selected separately (Fig. 3). In both keywords and abstracts, “window” was predominant, followed by “roof,” with “wall” being the least frequent and not present in any keyword.

¹ Each Impact Factor (IF) refers to March 2024 and was provided by each journal’s website.

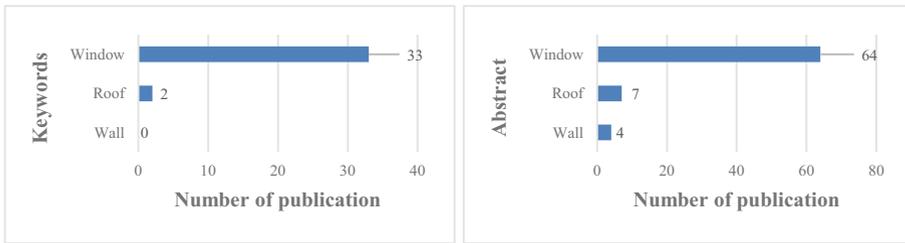


Fig. 3. Number of building envelope terms in a) keywords and b) abstract.

The predominance of “windows” was expected given the research on “smart windows” using inorganic thermochromic pigments such as VO_2 . To confirm this, we searched for “ VO_2 ” or “vanadium” in the abstracts of the articles found for each envelope element. Amongst the 64 papers containing “window”, 27 also mentioned “ VO_2 ” or “vanadium”. However, none of the papers that included “roof” or “wall” used these terms. Articles applying thermochromic pigments to opaque surfaces typically use dye-based thermochromics or organic thermochromic phase-change microcapsules, as opposed to those applied to translucent surfaces.

4 Conclusions

This BA showed a strong trend toward the use of thermochromic materials to improve energy efficiency in buildings, as demonstrated by the VOSViewer software. Despite a spike in publications in 2022, subsequent years did not show significant growth. It’s unclear if this reflects a trend, as 2024 articles could exceed the previous two years. China led with over 50% of the publications analyzed, while Portugal, Hong Kong, Italy, the United States, Singapore, Australia, and India had a balanced distribution of publications. The total production was spread over 90 different publication sources for 123 selected papers. Journals with three or more publications have impact factors above 6.4, which is considered favorable. In terms of application, over 85% of the studies focused on translucent building surfaces. Such results highlight the significant research gap for thermochromic and/or self-cleaning materials specifically designed for opaque surfaces. This study took a quantitative approach through bibliometric analysis. However, for a more detailed understanding, a systematic review of the literature would be necessary to conduct a qualitative analysis. This paper is part of a doctoral research project that, based on the data analyzed in this BA, aims to develop a multifunctional, thermochromic and self-cleaning film for application on ceramic and fiber cement tiles. This effort seeks to fill the identified gaps, such as the limited amount of research evaluating the application of these materials on opaque building surfaces.

Acknowledgments. The authors thank the Brazilian Research Foundation FAPESP (Grants 2022/14074-5 and 2022/03655-7) for supporting this work.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

References

1. Pisello, A.L., et al.: Innovative cool roofing membrane with integrated phase change materials: experimental characterization of morphological, thermal and optic-energy behavior. *Energ. Build.* **112**, 40–48 (2016)
2. Pacheco-Torgal, F.: Introduction to eco-efficient materials for reducing cooling needs in buildings and construction. *Eco-efficient Mater. Reducing Cooling Needs Build. Constr.* **1**, 1–11 (2020)
3. Hu, J., Yu, X.: Adaptive building roof by coupling thermochromic material and phase change material: Energy performance under different climate conditions. *Constr. Build. Mater.* **262** (2020)
4. Saber, H.: Experimental characterization of reflective coating material for cool roofs in hot, humid and dusty climate. *Energ. Build.* **242** (2021)
5. Zhao, Z.: Impacts of urbanization on climate change. In: 10,000 Scientific Difficult Problems Earth Science Committee (eds.) 10,000 Scientific Difficult Problems: Earth Science (in Chinese), pp. 843–846. Science Press (2011)
6. Huang, Q., Lu, Y.: The effect of urban heat island on climate warming in the Yangtze River delta urban agglomeration in China. *Int. J. Environ. Res. Public Health* **12**, 8773–8789 (2015)
7. Akbari, H., Menon, S., Rosenfeld, A.: Global cooling: increasing world-wide urban albedos to offset CO₂. *Clim. Change* **94**, 275–286 (2009)
8. Louzich, K., Callejas, I., Durante, L.E., Martins, A., Rosseti, K., Martins, W.: Absortância de telhas cerâmicas novas e deterioradas pela exposição às intempéries: impacto no desempenho térmico de edificações. In: ENTAC, São Paulo, p. 16 (2016)
9. Cheng, H., Wang, F., Liu, H., Ou, J., Li, W., Xue, R.: Fabrication and properties of thermochromic superhydrophobic coating. *Adv. Eng. Mater.* **24**, 1–13 (2022)
10. Hu, J., Yu, X.: Adaptive thermochromic roof system: assessment of performance under different climates. *Energ. Build.* **192**, 1–14 (2019)
11. Hu, J., Yu, X.: Design and characterization of energy efficient roofing system with innovative TiO₂ enhanced thermochromic films. *Constr. Build. Mater.* **223**, 1053–1062 (2019)
12. Liu, H., Jiang, T., Wang, F., Ou, J., Li, W.: Thermochromic superhydrophobic coatings for building energy conservation. *Energ. Build.* **251**, 1–13 (2021)
13. Sánchez, C.E., Vilà, M.D.: Thermochromic materials as passive roof technology: their impact on building energy performance. *Energies* **15**, 1–25 (2022)
14. Liu, S., Liu, Z., Wang, J., Ding, X., Meng, X.: Effect of the material color on optical properties of thermochromic coatings employed in buildings. *Therm. Eng.* **45**, 1–9 (2023)
15. Figueiredo, N.M.: Biblioteconomia e bibliometria. In: TÓPICOS MODERNOS EM BIBLIOTECONOMIA, pp. 17–25. ABDF, Brasília (1977)
16. Wang, B., Pan, S.-Y., Ke, R.-Y., Wang, K., Wei, Y.-M.: An overview of climate change vulnerability: a bibliometric analysis based on Web of Science database. *Nat. Hazards* **74**, 1649–1666 (2014)
17. Gall, M., Nguyen, K.H., Cutter, S.L.: Integrated research on disaster risk: is it really integrated? *Int. J. Disaster Risk Reduct.* **12**, 255–267 (2015)
18. Van Eck, N.J., Waltman, L.: Visualizing bibliometric networks. In: Ding, Y., Rousseau, R., Wolfram, D. (eds.) *Measuring Scholarly Impact: Methods and Practice*, pp. 285–320 (2014)
19. Perianes-Rodríguez, A., Waltman, L., Van Eck, N.J.: Constructing bibliometric networks: a comparison between full and fractional counting. *J. Informet. Informet.* **10**, 1178–1195 (2016)