Bibliometric Map of Academic Publications on Radiation and Building: VOSviewer Analysis

İlhami Ay[1*]
Hakkari University
Ilhamiay@hakkari.edu.tr
ORCID No: 0000-0002-3506-3234

Sema Bekler[2]
Munzur University
ksy.semabekler@gmail.com
ORCID No: 0009-0002-2152-2767

Barış Bekler[3]
Munzur University
ksy.barisbekler@gmail.com
ORCID No: 0009-0002-5908-6390

Murat Dal[4]
Munzur University
prof.dr.dal@gmail.com
ORCID No: 0000-0001-5330-1868

ABSTRACT

This study aims to analyse the academic literature on the use of radiation in building design and preservation through a bibliometric analysis of publications associated with the keywords "radiation" and "building$". By exploring the role of radiation in energy efficiency, material durability, and environmental impacts, the research employs VOSviewer software to map academic contributions. The study examines five key categories: academic language, keyword analysis, leading authors, prominent resources, and the most cited articles. The keyword analysis reveals emerging research trends and thematic areas, while the analysis of effective authors and resources highlights academic interactions and collaborations in this field. The findings provide valuable insights for researchers and policymakers investigating the effective use of radiation in building design.

KEYWORDS

Bibliometric analysis, building, radiation, VOSviewer, Scientific mapping

INTRODUCTION

Radiation and radioactivity have evolved from a phenomenon of interest in the laboratory to an indispensable part of modern science and technology. Today, radiation has a wide range of applications in many fields such as agriculture, health, science, manufacturing and energy production. In addition, research on the effects of radiation on materials such as concrete, bricks, tiles, clay, polymers, superconductors, and alloys is being carried out by different scientists (Agar et al., 2019; Akkurt & El-Khayatt, 2013; Akman et al., 2019; Dong et al., 2019; Kacal et al., 2019; Kuzmanovic et al., 2024; Sayyed I et al., 2019; Singh et al., 2018; Van Thuong et al., 2024).

The fact that the subject of radiation is a current issue and continues to be researched is the reason for the research of the study field. The addition of different study topics with radiation or different materials with radiation is the main theme of this study. The study analysed academic studies in which the keywords radiation and building were used together and the data obtained as a result of the examination were expressed numerically and verbally. The method of expression was used in the study

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[*] **Corresponding author.**

of bibliometric analysis method. The bibliometric analysis method is used to evaluate and reveal the research productivity, accuracy, and impact of a study through the quantitative analysis of publication data at the author, article, and journal levels. This method serves as a crucial tool for measuring research performance and assessing the impact of scientific contributions in the literature (Lawani, 1981).

The study aims of to is to provide a global overview of academic research on radiation and building issues between 1980-2024 (the study covers publications until 29-08-2024). It includes the languages of the publications containing the keywords specified in the study, keyword analysis, the most effective author, resource and article analysis.

Evaluating the validity and significance of academic studies is crucial; however, no such analysis has yet been conducted in the academic field concerning radiation and building materials. Based on this deficiency, this article provides important information about academic developments in publications containing the keywords radiation and building.

MATERIALS AND METHODS

Bibliometrics is an interdisciplinary science that evaluates published data by quantitatively analysing relevant survey data. Bibliometric analyses cover all factors such as number of publications, publication years, publication types, keywords. Thanks to this analysis, it is possible to get an idea about the research to be carried out and to make predictions about the future trends of the study (Girard-Perier et al., 2020; Mayr & Scharnhorst, 2015). It is very important to use appropriate and correct visualisation software in the analyses. There are CiteSpace, HistCite, Gephi, SciTool and VOSviewer programs for bibliometric analysis and visualisation. The VOSviewer program used for analysis and visualisation is particularly suitable for this study because of its ability to perform co-occurrence, self-occurrence and cluster analyses of scientific and technical data in specific fields of knowledge, to effectively highlight the relationships between research topics and to present them clearly (Chen, 2006; Chen, 2017). Therefore, in this study, VOSviewer software was used to visually analyse the collected literature.

Bibliographical reviews are important in the field of academic research as they enable the identification of dominant trends and focal points during the analysis of academic publications and establish relationships between various topics, keywords and authors (Ay et al., 2024; Ay & Dal, 2024a; Bekler et al., 2024; Burkut & Dal, 2023; Dal, 2024; Donthu et al., 2021). This analysis aims to identify keywords identified by the author and create a network linking these keywords (Tekin et al., 2024). Therefore, the resulting network visualisation can be used to visualise both a specific the frequency of the keyword and its relationship with other related keywords in the same articles (Ay & Dal, 2024b; Entezari et al., 2023). For a healthy bibliometric analysis, a number of stages are needed to be designed respectively and realised (Donthu et al., 2021) is as in Figure 1.
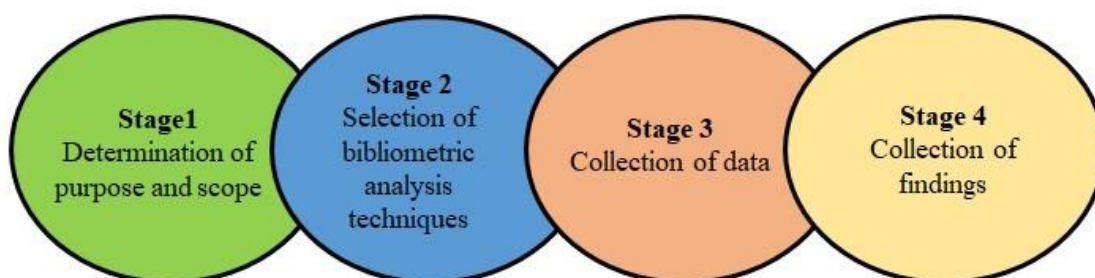
**Figure 1.** *Bibliometric analysis design process.*

In the first stage, the purpose and scope of the study were determined. The main purpose of this study is to determine bibliometric maps by analysing the researches related to 'RADIATION' and 'BUILDING$' within the scope of variables such as keywords, journals, publications, authors and collaborations of the field by using metadata. Accordingly, the following bibliometric indicators were analysed for performance analysis and science mapping purposes (Ay, 2024a; Özmen Halis et al., 2025). The data analysed are publication type distribution, publication language distribution, most effective journals, most influential articles, keyword analysis, most effective countries and institutions, most cited resources, journals and authors.

In the second stage, the analysis techniques to be applied in the bibliometric study are selected and designed. It is important to determine the techniques in a way to meet the study objectives specified in stage 1 (Ay, 2024b; Donthu et al., 2021). Table 1 shows the analysis methods selected for the questions and purpose of the study.

Table 1. *Selected analysis methods to be used in the study.*

Research Question	Analysis Unit	Data Requirements	Type of Analysis Used
Distribution of publication types	Document	Publication	Web of Science Database
Most active journals	Document	Journal	Resource Citation Analysis (VOSviewer)
Most active articles	Document	Publication	Citation Analysis (VOSviewer)
Keyword analysis	Word	Keyword	Common Word Analysis (VOSviewer)
Most active countries and organisations	Authors' Affiliated Organisations	Author's Organisation (institution-country)	Citation Analysis (VOSviewer)
Most co-cited resources, journals and authors	Author	Author	Joint Citation Analysis (VOSviewer)

In the third stage of the study, data sets were created using the Web of Science database to be analysed. In the creation of the data sets, four steps were followed: keyword detection and screening, sorting according to various parameters, examining whether the studies were suitable for the subject and exporting the obtained data. Figure 2 shows the preparation process of the data sets prepared in the Web of Science database. In the last stage, stage 4, the data obtained were analysed and visualised and the findings of the analysis were reported. VOSviewer analytical tool (version 1.6.20) was used to visualise and report the data.
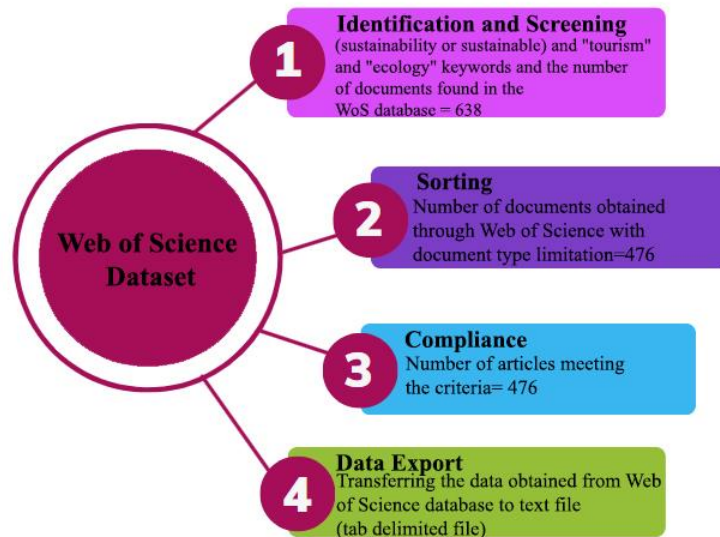
Figure 2. *Preparing a data set in Web of Science database.*

The circles obtained in the VOSviewer analysis programme represent entities such as literature, authors or keywords, and each circle corresponds to a separate element. The size of the circle indicates the importance of the entity within the network. The lines between these circles represent the relationships between entities and often indicate citation relationships, collaborative efforts or topic relevance in literature networks. The VOSviewer programme was chosen based on its ability to provide a more objective assessment and increase the scientific rigour of the research (van Eck & Waltman, 2010). Developed jointly by Dutch academics van Eck and Waltman, VOSviewer is an analysis tool designed to create maps based on network data and to facilitate the visualisation of these maps.

In the study, in order to identify and reveal the relationships between the concepts of radiation and building and to determine the trends that the field has evolved, the Topic tab was selected in the Advanced Search section of the Web of Science database on 29.08.2024 and the keywords 'RADIATION' and 'BUILDING$' were typed. In the Topic tab, a search including the title, abstract and keywords of the articles was made and 16052 documents, 12297 of which were articles, were reached. In this study, only articles were included and analyses were made on the basis of articles.

FINDINGS

In the advanced search section of the Web of Science (WoS) database on 29.08.2024, the keywords 'radiation' and 'building$' were entered in the topic tab where the title, abstract and keywords determined by the authors were scanned and online search was performed. As a result of the search, 16.052 studies containing the relevant keywords were reached and 12297 of these studies were found to be article studies. The 12297 articles obtained constituted the material of the study. The first article on the subject of the study indexed in the WoS database is Buffington and Skinner (1980) "Solar Radiation And Wind Effects As Functions of Building Orientation". It was determined that the year in which the articles on the relevant subject were published most intensively was 2022 with 1155 articles. It should be noted that the study data obtained from the WoS database was received on 29.08.2024, before the year 2024 was completed, and the number of studies in 2024 does not cover the year 2024. The number of articles by years is shown in Figure 3.
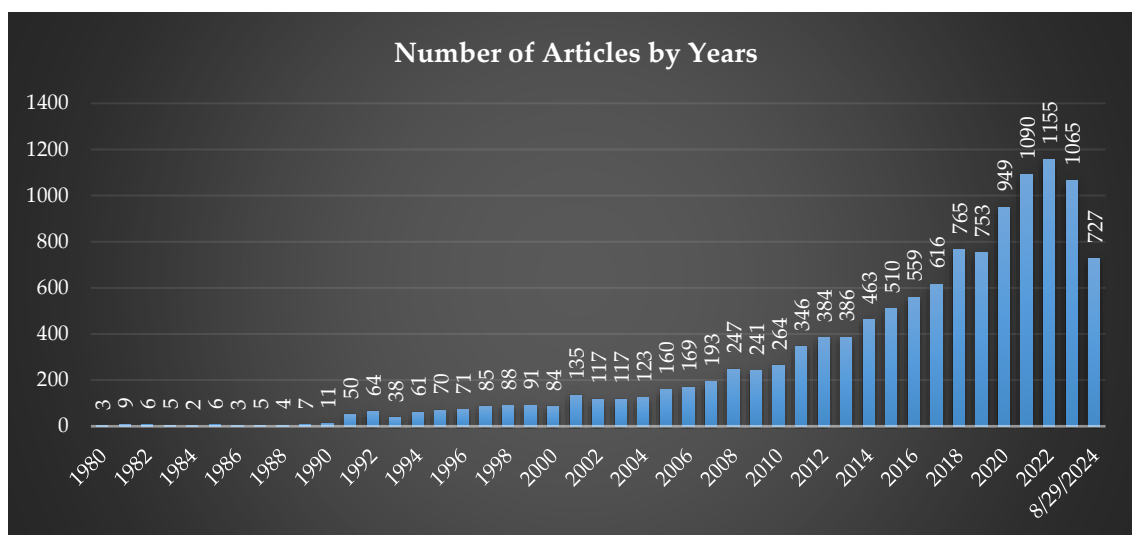
Figure 3. *Number of articles by years.*

According to the articles indexed on "radiation" and "building$" in the WoS database; It has been determined that articles on the subject began to be the subject of research in 1980, but the subject did not receive attention from researchers for 10 years. It was determined that studies began to be given importance between 1990 and 2007, but the number of articles indexed annually was less than 200 articles. It was found that a significant increase began to be seen in the number of articles indexed in 2008, and as of 2021, the number of articles exceeded 1000, and 2022 was the year in which the most articles were published, with 1155 articles.

ACADEMIC PUBLICATION LANGUAGE

When the publication language distribution of 12297 articles on 'radiation' and 'building$' indexed in the Web of Science database was analysed, it was seen that 12005 articles were written in English, 64 articles in German, 44 articles each in Chinese and Russian. In addition, there are articles in Spanish (33 articles), Korean (18 articles), Portuguese (15 articles) and Turkish (15 articles). Academic publication language distribution graph is shown in Figure 4.
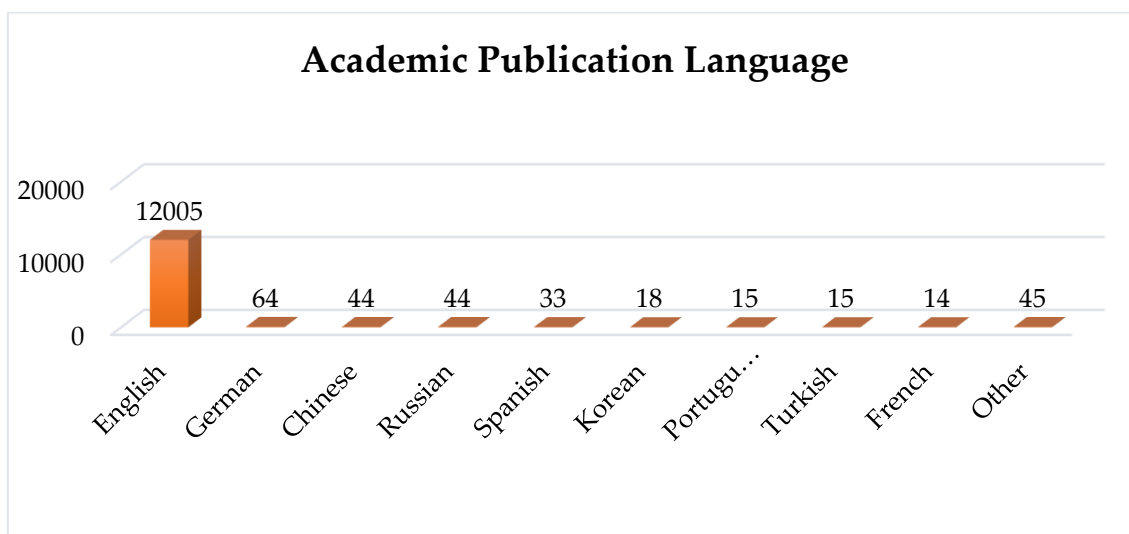
Figure 4. *Academic publication language graph.*

These results show that academic studies on 'radiation' and 'building$' are published in various languages besides English.

KEYWORDS ANALYSIS

By revealing the conceptual structure of the study subject "radiation" and "building$" in the WoS database, occurrence / author keywords were made to determine the most effective keywords of the field and to present to the reader the topics on which the field has evolved. Analysis; The keywords determined by the article authors in line with their own preferences were carried out with the occurrences link, which is formed by repeating at least two of the words in the article titles and article abstracts in different article studies. Within the scope of the analysis, it was seen that the same key concepts were written in different spellings and were combined under the same name by data cleaning. After data cleaning, it was determined that 27803 keywords were used in 12297 articles covered by the study, and with the condition that at least one word was used twice, the number of keywords was reduced to 5392 words, mapped and shown in Figure 5.
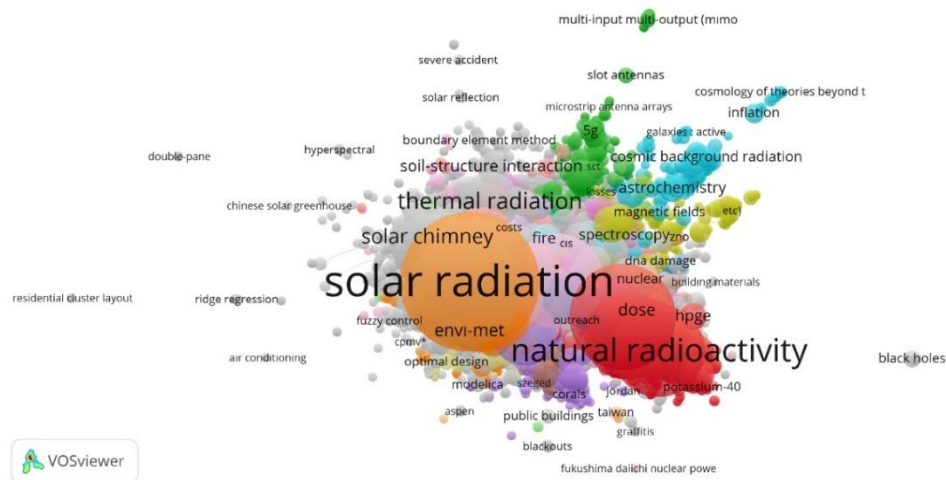

Figure 5. *Most effective key concept network visualization.*

In order to determine the relationships between key concepts, keywords with at least 50 occurrences links were mapped as 46 keywords and 5 clusters by the WOSviever analysis programme and shown in Figure 6.
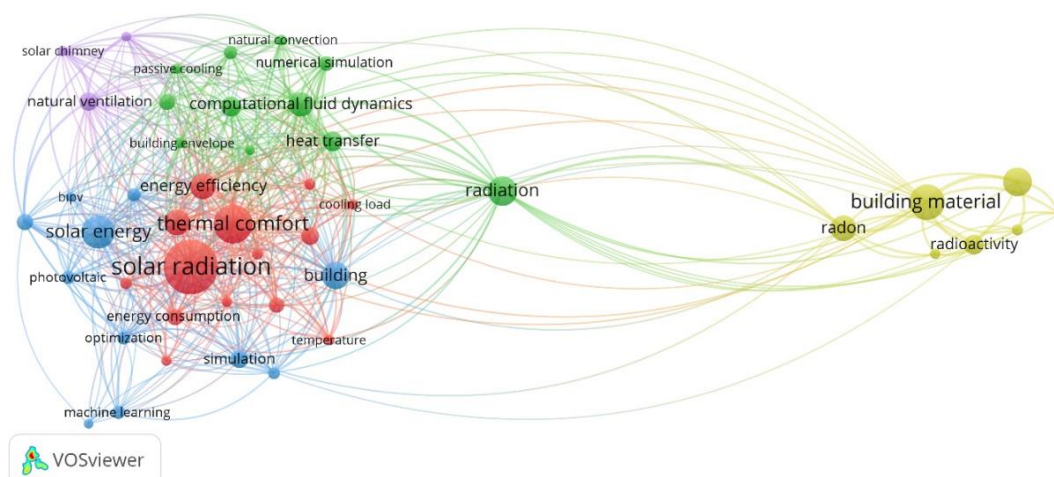

Figure 6. *The most effective interrelated key concept network visualization.*

Cluster 1 (red) was found to consist of the keywords building energy simulation, building simulation, climate change, cooling load, daylighting, energy consumption, energy efficiency, energy performance, energy saving, energyplus, solar radiation, temperature, thermal comfort, urban heat island. The most effective keyword in the cluster is solar radiation with 444 occurrences. Li, J., et al. (2024); "A New

Approach For Indoor Environment Design of Passive Solar Buildings in Plateau Areas" study was observed.

Cluster 2 (green); building envelope, computational fluid dynamics, heat transfer, natural convection, numerical simulation, passive cooling, radiation, radiative cooling, thermal insulation, thermal performance, thermal radiation key concepts and the most effective element of the cluster is radiation key concept with 205 occurrences link. Kafaei et al. (2024); "Transient Computational Fluid Dynamics Analysis of Passive Cooling in a Building with Diurnal Radiative Cooling Material Coated onto Its Rooftop".

Cluster 3 (blue); building-integrated photovoltaics, building, deep learning, optimisation, phace chance material, photovotaic, renewable energy, simulation, solar energy. It was determined that the prominent key concept in the cluster is the keyword 'solar energy' with 237 occurrence links. Yan, L., et al. (2023); "Estimation of Urban-Scale Photovoltaic Potential: A Deep Learning-Based Approach For Constructing Three-Dimensional Building Models From Optical Remote Sensing Imagery".

Cluster 4 (yellow) was found to contain the keywords annual effective dore, building material, gamma radiation, gamma spectrometry, natural radioactivity, radioactivitity, radon. The concept with the highest weight in the cluster was found to be building material with 259 occurrences. Papaefthymiou and Gouseti (2008), "Natural Radioactivity and Associated Radiation Hazards in Building Materials Used in Peloponnese, Greece".

The 5th cluster (purple) was found to contain the keywords natural ventilation, solar chimney, trombe wall and the most effective key concept in the cluster was natural ventilation. Ali et al. (2024) "Investigation of the Performance of a Newly Designed Solar Chimney for Enhancing Natural Ventilation and Mitigation of Summer Overheating."

The 10 keywords with the highest co-occurrence power are shown in Table 2.

Table 2. *Keyword co-occurrence table.*

Key Concept	Co-Occurrence	Total Link Power	Average Year of Publication	Average Citation Number
Solar radiation	444	276	2016.96	23.67
Thermal comfort	294	185	2017.72	23.06
Building material	259	175	2015.34	22.71
Solar energy	237	124	2017.84	30.41
Radiation	205	119	2015.57	16.63
Natural radioactivity	199	104	2016.14	17.97
Building	188	155	2016.87	22.13
Energy saving	177	114	2017.99	24.56
Radon	175	90	2012.83	14.55
Energy efficiency	172	107	2017.81	1983

When the co-occurrence ranking of the keywords of the field is analysed; it is determined that the keyword solar radiation ranks first. Solar radiation keyword is followed by Thermal comfort and Building material keywords.

MOST EFFICIENT AUTHORS ANALYSIS

In order to determine the most influential authors according to the number of citations by receiving the most citations on "Radiation" and "building$", citation/authors analysis was performed, limited to the bibliometric database obtained from WoS on 29.08.2024. In the analysis, each node represents an author and the size of the nodes varies according to the number of citations they receive. In the study, it was observed that some authors were written in different ways and data cleaning was performed. After data cleaning, it was seen that there were 43222 authors in 12297 articles constituting the sample of the study. The authors were reduced to 52 authors on the condition of publishing at least 10 documents and receiving 200 citations, and mapped as 40 authors and 6 clusters related to each other by the programme and shown in Figure 7.
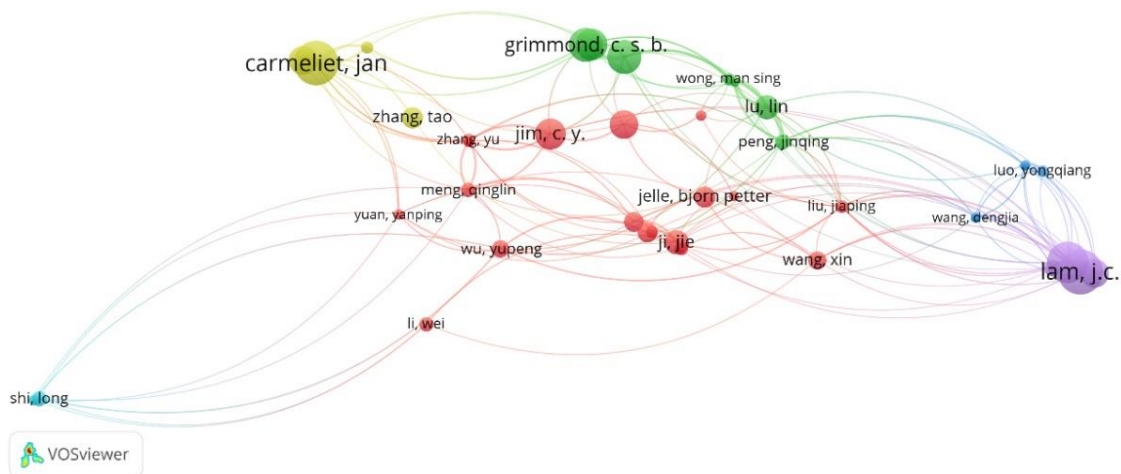
Figure 7. *Most active author network visualization.*

According to the most active author network visualisation, the most active author of the red coloured cluster 1 is Jim, C.Y. with 19 documents and 887 citations. The most active author of the 2nd cluster in green colour is Grimmond, C.S.B. with 12 documents and 1020 citations; the most active author of the 3rd cluster in blue colour is Luo, Y. with 14 documents and 269 citations. The most influential author of the yellow cluster 4 was Carmeliet, J. with 19 documents and 1406 citations; the most influential author of the purple cluster 5 was Lam, J.C. with 29 documents and 1430 citations and the most influential author of the turquoise cluster 6 was Shi, L. with 24 documents and 367 citations.

The 10 most effective authors of the study according to the citations they received are given in Table 3.

**Table 3.** *The 10 most influential authors according to the number of citations.*

Author Name	Citation Count	Average Citation Number	Average Year of Publication	Number of Documents	Total Link Power
Timmerman, R.	1628	325.60	2013.40	5	33
Lam, J.C.	1430	49.31	2006.17	29	295
Carmeliet, J.	1406	74.00	2014.16	19	238
Beckman. W.A.	1401	467.00	2003.33	3	6
Klein, S.A.	1380	690.00	2005.00	2	4
De Soto, W.	1329	1329.00	2006.00	1	3
Akbari, H.	1308	436.00	1999.33	3	105
Abdulrahman, R.	1281	640.50	2006.00	2	18
Li, D.H.W.	1273	37.44	2010.79	34	235
Lajeunesse, T.C.	1263	421.00	2012.67	3	80

The most cited authors on the research topic were Timmerman, R. (1628 citations), Lam, J.C. (1430 citations) and Carmeliet, J. (1406 citations).
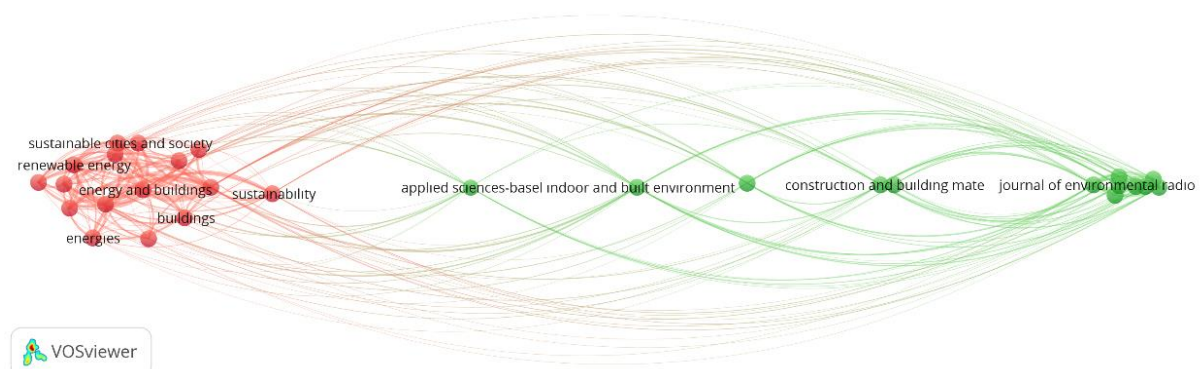
MOST EFFICIENT RESOURCES ANALYSIS

Citation/Resources analysis was performed through Vosviewer analysis software to identify the most effective resources of the articles on "radiation" and "building$" indexed in WoS according to the number of citations. In the visualisation, each resource is represented by a node and as the number of citations increases, the size of the nodes changes in proportion to the number of citations. Based on the data obtained from the Web of Science database, it was determined that there were 2521 resources on the subject, and 1084 related resources were visualised and shown in Figure 8.
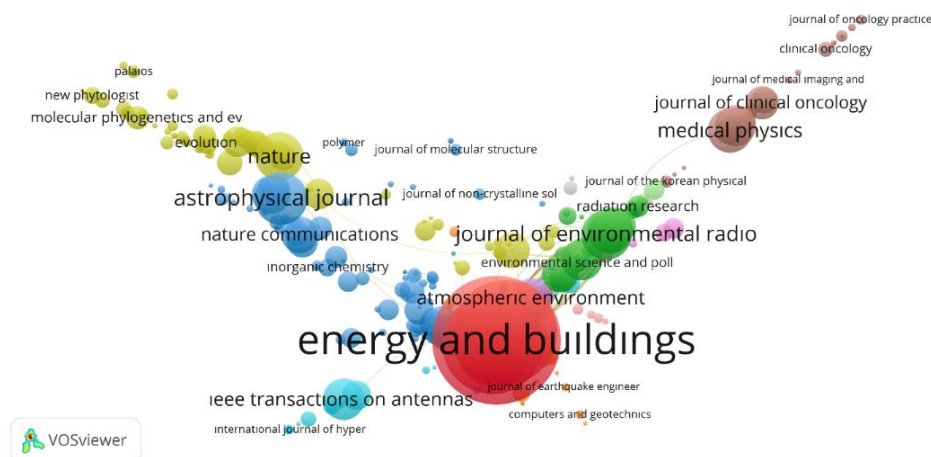
Figure 8. *Most efficient resource network visualization.*

In order to determine the most effectively used resources in article studies and to reveal the relationships between them, 29 resources and 2 clusters were visualised as 29 resources and 2 clusters with the conditions of publishing at least 55 documents and receiving 250 citations and shown in Figure 9.

Figure 9. *Most efficient resource network visualization.*

The most effective resource of the 1st cluster (red) is the Energy and Buildings journal with 683 documents and 26308 citations, while the most effective resource of the 2nd cluster (green) is the Journal of Environmental Radioactivity with 89 documents and 6319 citations.

When 2521 references in the bibliography of 12297 articles constituting the sample of the research are evaluated according to the number of citations; the 10 most cited references are given in Table 4.

Table 4. *The 10 most cited active resources.*

| Resource Name	Number of Documents	Citation Count	Total Link Power
Energy and Buildings	683	26308	3233
Building and Environment	431	16466	2166
Solar Energy	336	15193	2086
Applied Energy	164	8287	814
Renewable Energy	229	6787	929
Energy Conversion and Management	124	6338	386
Energy	163	5001	633
Boundary-Layer Meteorology	34	3821	509
Astrophysics journal	44	3537	11
Applied Thermal Engineering	116	3282	424

When the most effective resources are analysed according to the number of citations, Energy and Buildings journal ranks first, Building and Environment ranks second and Solar Energy ranks third.

MOST EFFICIENT ARTICLES ANALYSIS

A citation/documents analysis was performed to determine the effectiveness of the studies on "radiation" and "building$" indexed in the WoS database according to the citations they received and to visualise the relationships between them. In the analysis, each colour represents a cluster and each article is shown as a node. Through VOSviewer analysis programme, the visualisation of the 1000 most cited and interrelated articles among the 12297 articles constituting the sample of the study is presented to the reader in Figure 10.
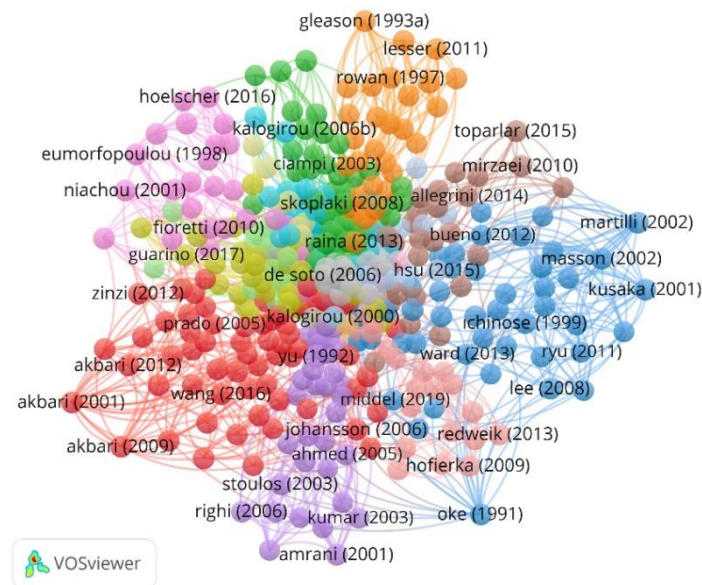
Figure 10. *Most influential articles analysis network map.*

In the VOSviewer analysis programme, in order to determine the most effective studies according to the number of citations of 12297 articles, which is the sample of the study, the number of articles was reduced to 86 articles with the restriction of at least 250 citations and 16 articles with a relationship between them were visualised as 3 clusters and shown in Figure 11.
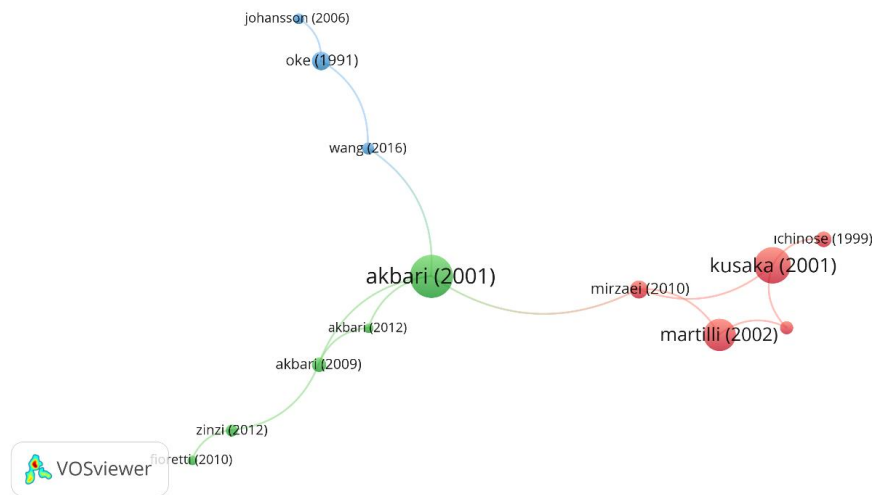
Figure 11. *Most effective article network map.*

In cluster 1; It was found to include the studies of Ichinose et al. (1999), Kusaka et al. (2001), Martilli et al. (2002), Mirzaei and Haghighat (2010), Salamanca et al. (2010). It was determined that the most effective article in the cluster was Kusaka et al.'s study "A Simple Single-Layer Urban Canopy Model for Atmospheric Models: Comparison With Multi-Layer And Slab Models", which received 944 citations.

In the 2nd cluster; It was observed that the article studies of Akbari et al. (2001), Akbari et al. (2009), Akbari and Matthews (2012), Fioretti et al. (2010), Zinzi and Agnoli (2012) were included. It was determined that the most cited article in the cluster was Akbari et al.'s study "Cool Surfaces and Shade Trees to Reduce Energy Use and Improve Air Quality in Urban Areas" with 1104 citations.

In the 3rd cluster, it was determined that there were studies by Johansson and Emmanuel (2006), Oke et al. (1991), Wang et al. (2016), and the most effective study of the cluster was "Simulation Of Surface Urban Heat Islands" by Oke et al., which received 475 citations. Under Ideal Conditions at Night 2. It was seen that there was a study called "Diagnosis of Causation".

The 5 most influential articles according to the number of citations of the 12297 articles subject to the study are shown in Table 5. Only the first authors of the studies are shown in the table.

Table 5. *The most effective articles.*

First Author Name	Article Name	Published Resource	Year of Publication	Number of Citations
De Soto, W.	*"Improvement and Validation of a Model for Photovoltaic Array Performance"*	Solar Energy	2006	1329
Akbari, H.	*"Cool Surfaces and Shade Trees to Reduce Energy Use And Improve Air Quality in Urban Areas"*	Solar Energy	2001	1104
Flanner, M. G.	*"Present-day Climate Forcing and Response From Black Carbon in Snow"*	Journal of Geophysical Research: Atmospheres	2007	946
Kusaka, H.,	*"A Simple Single-Layer Urban Canopy Model For Atmospheric Models: Comparison With Multi-Layer And Slab Models"*	Boundary-Layer Meteorology	2001	944
Martilli, A.	*"An Urban Surface Exchange Parameterisation for Mesoscale Models"*	Boundary-Layer Meteorology	2002	834

When the articles indexed in the Web of Science database were analysed, it was seen that the most cited article was De Soto, W. (2006) with 1329 citations. Akbari, H. (2001) with 1104 citations ranked second and Flanner, M. G. (2007) with 946 citations was found to be the third most effective article.

CONCLUSIONS

In this study, a bibliometric analysis of the literature associated with the keywords "radiation" and "building" in the Web of Science database was conducted. The aim of the study was to reveal the developments in the field of radiation and building over the years and to identify the trends that the field has evolved. VOSviewer version 1.6.20, a powerful bibliometric analysis tool, was used in the study. With VOSviewer analysis software, bibliometric maps were created to visualise the links between various research areas, authors and scientific publications using different match types such as journals, authors and keywords. This analysis helped to identify key research trends, influential authors and emerging areas of interest, facilitating a deeper understanding of the field and guiding future research directions. The results obtained from the study are as follows;

Distribution and Types of Publications: With the keyword search, 16052 academic studies were reached and it was observed that 12297 of them were articles. It was observed that there were review articles, early access, book chapters, editorial material, meeting abstract, letter and book review. It was determined that the first article on the research topic was addressed by Buffington and Skinner in 1980. In addition, it was observed that 2022 was the year with the most articles published with a total of 1155 articles published. The fact that there are different types of publications shows that the subject of radiation and building has attracted a wide interest in the academic field and that there is a significant accumulation of knowledge in this field.

Publication Language: According to the data obtained, it is seen that the subject of radiation and building has a global interest. Although the majority of the articles are written in English, the fact that there are publications in German, Chinese, Russian, Spanish, Korean, Portuguese, Turkish and French languages shows that the subject of radiation and building is not specific to a particular geographical region or language, on the contrary, it is a universal subject and constitutes a global research field.

Keywords: In this study, the most influential keywords in the field were identified by analysing the conceptual structure of academic publications dealing with "radiation" and "building$". Prominent keywords include solar radiation, thermal comfort, building material, solar energy and radiation. The word with the strongest co-occurrence was found to be solar radiation. In addition, key concepts such as energy efficiency, natural ventilation and gamma radiation stand out in different clusters. As a result of this analysis, it was seen that the leading research topics of the field are shaped around topics such as energy efficiency, solar energy, building materials and natural ventilation. The relationships between keywords show which concepts the field is centred on and how it has evolved.

Most Effective Authors: As a result of the author analysis, the authors who published the most documents and received the most citations were identified. Timmerman, Robert was identified as the most active author with 5 documents, 1628 citations and 33 total link strength. Timmerman is followed by Lam J. C. and Carmeliet J. respectively.

Most Active Resources: Among the most active resources, Energy and Buildings is the most cited journal with 638 documents and 26308 citations. Building and Environment and Solar Energy are ranked second and third.

Most Effective Articles: The most cited article among the articles on radiation and building is "Improvement and validation of a model for photovoltaic array performance" by De Soto et al (2006). This article was determined as the most influential article with 1329 citations. The articles written by Akbari et al. (2001) and Flanner et al. (2007) are ranked second and third, respectively.

Based on the findings of this study, it is recommended that future research should focus on more specific areas. In particular, more in-depth studies should be conducted to investigate the effects of prominent issues such as energy efficiency and solar energy on building design and performance. Furthermore, at the intersection of "radiation" and "building" the effects of climatic conditions in different geographical regions on radiation and building performance can be investigated. Improving data cleaning and analysis methods will also contribute to obtaining more accurate results. Finally, by encouraging interdisciplinary collaborations, new research directions can be established with a focus on building technologies and sustainability.

CONFLICT OF INTEREST

The Authors declare that there is not any conflict of interest about this paper.

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