JOURNAL OF MECHANICAL, INDUSTRIAL,

ORIGINALITY REPORT

3%

SIMILARITY INDEX

PRIMARY SOURCES

1	https://jscires.org/10.5530/jscires.20250738	Internet	49 words - 30%
2	https://ejournal.uin-suska.ac.id/index.php/juring/arti...	Internet	31 words - 19%
3	https://www.waterless.com/blog/how-2025-plumbin...	Internet	30 words - 19%
4	https://www.sas.usace.army.mil/Portals/61/docs/S...	Internet	27 words - 17%
5	https://pdhonline.com/courses/m126/m126content....	Internet	25 words - 15%

Include Quotes : OFF
Include Bibliography : OFF

JOURNAL OF MECHANICAL, INDUSTRIAL, ELECTRICAL, AND CIVIL ENGINEERING

CONFIGURATIONS AND EFFICIENCY OF PLUMBING SYSTEMS IN HIGH-RISE BUILDINGS: A SYSTEMATIC LITERATURE REVIEW AND SCOPUS-BASED PUBLICATION TRENDS (2000–2025)

Zufri Hasrudy Siregar[1*], Arif Fadillah Nasution[2], Yuri Dwi Lianto[3], Refiza[4]

[1,2] Mechanical Engineering, Faculty of Engineering, Universitas Al Azhar Medan, Jl. Pintu Air IV No.214, Kwala Bekala, Kec. Medan Johor, Medan City, North Sumatra 20143

[3] Civil Engineering, Faculty of Engineering, Universitas Al Azhar Medan, Jl. Pintu Air IV No.214, Kwala Bekala, Kec. Medan Johor, Medan City, North Sumatra 20143

[4] Industrial Engineering, Faculty of Engineering, Universitas Al Azhar Medan, Jl. Pintu Air IV No.214, Kwala Bekala, Kec. Medan Johor, Medan City, North Sumatra 20143

Email: * rudysiregar7@gmail.com

Info Article

Historical Articles:
Received: March 16, 2026
Accept and revise: March 25, 2026
Approved: March 28, 2026

Keywords: Plumbing systems; High-rise buildings; Smart water management

Abstract

High-rise building plumbing systems face increasing challenges related to hydraulic efficiency, energy consumption, and sustainable water management. This study aims to analyze the evolution of plumbing system configurations, efficiency strategies, and emerging research trends through a Systematic Literature Review and bibliometric analysis of Scopus-indexed publications from 2000–2025. The novelty of this research lies in integrating hydraulic engineering, smart building technology, IoT, and AI within a unified analytical framework focused on tropical high-rise buildings. PRISMA methodology, Bibliometrix-R, and VOSviewer were employed to evaluate 751 documents. The results reveal rapid growth in smart plumbing research, emphasizing energy optimization, digital monitoring, and AI-based water management systems.

Abstrak

Sistem plumbing pada gedung bertingkat tinggi menghadapi tantangan yang semakin kompleks terkait efisiensi hidrolik, konsumsi energi, dan pengelolaan air berkelanjutan. Penelitian ini bertujuan untuk menganalisis evolusi konfigurasi sistem plumbing, strategi efisiensi, serta tren penelitian terkini melalui

Keywords: *Sistem plumbing; Gedung bertingkat tinggi; Manajemen air cerdas*

pendekatan Systematic Literature Review (SLR) dan analisis bibliometrik terhadap publikasi terindeks Scopus periode 2000–2025. Keterbaruan penelitian ini terletak pada integrasi rekayasa hidrolik, teknologi bangunan pintar, Internet of Things (IoT), dan Artificial Intelligence (AI) dalam satu kerangka analisis terpadu yang berfokus pada gedung bertingkat tinggi di wilayah tropis. Metodologi PRISMA, Bibliometrix-R, dan VOSviewer digunakan untuk mengevaluasi 751 dokumen. Hasil penelitian menunjukkan pertumbuhan pesat riset smart plumbing yang menekankan optimasi energi, pemantauan digital, dan sistem manajemen air berbasis AI.

INTRODUCTION

The construction of high-rise buildings has become the primary solution for addressing increasingly severe urban land scarcity as a result of global urbanization[1], [2], [3]. These buildings feature complex structures that require specialized design approaches for internal engineering systems, including plumbing systems covering cold and hot water supply, drainage, and sanitation. High hydrostatic pressure in vertical buildings is a key factor determining the design principles for cold and hot water supply systems, drainage, and waste disposal [1], [4]. Plumbing systems in high-rise buildings must be designed to ensure that overpressure or negative pressure does not cause water to be extracted from water traps, which could result in unpleasant odors and health risks within the building [5], [6]. The energy efficiency of water supply systems in high-rise residential buildings has become a significant concern in sustainable development today [4], [7]. Studies show that the energy efficiency of water supply systems in high-rise buildings is below 25%, with over 75% of energy input "lost," and about half of this energy loss is due to water pumps operating at low efficiency [8], [9]. On the other hand, accurate estimation of peak water demand is a fundamental parameter in the design phase to ensure proper dimensioning of the building's water systems [10], [11]. However, for years, overestimation has persisted as a problem in studies of Simultaneous Peak Water Flow (SPWF), leading to inefficiencies in energy and water use [12], [13].

The urgency of this research is becoming increasingly pressing given that globally used peak water demand estimation methods are still based on the probabilistic "fixture unit" approach developed by Hunter in 1940 [10], [14]. This approach is now widely recognized as outdated because water consumption patterns have changed significantly with the widespread adoption of water-saving devices[15], [16].

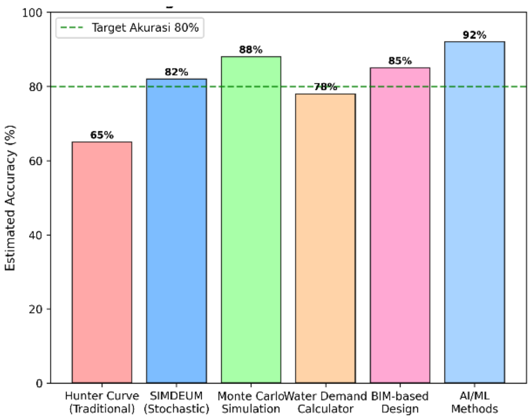


Figure 1. comparison of peak discharge estimation method accuracy

The planning of plumbing systems in high-rise buildings in Indonesia still relies on the Hunter Curves, which are more than eight decades old, and this technique is not aligned with modern, more efficient water usage trends[16], [17]. As a result, pipe designs tend to be oversized, leading to energy waste, increased construction costs, and potential health risks from water stagnation in pipes that enables microbial growth[18].

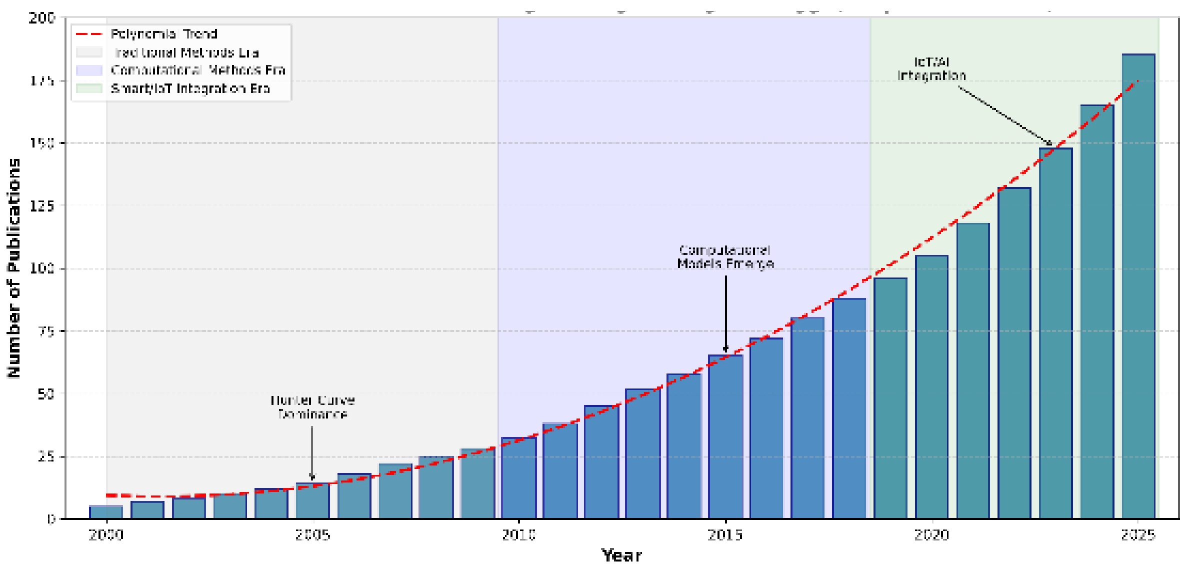


Figure 2. trends in high-rise building plumbing system publications

This study aims to conduct a Systematic Literature Review (SLR) of the configuration and efficiency of plumbing systems in high-rise buildings, with a particular focus on identifying research gaps and analyzing publication trends in the Scopus database for the period 2000–2025. Specifically, this study seeks to: (1) identify the evolution of plumbing system design methodologies from the traditional Hunter Curve approach to data-driven and artificial intelligence-based models; (2) analyze developments in peak water demand estimation technologies including the Modified Wistort Method, Water Demand Calculator (WDC), and Loading Unit Normalisation Assessment (LUNA) [19], [20]; (3) evaluate the effectiveness of vertical pressure zoning systems and pump efficiency optimization in high-rise buildings [21]; (4) examine the integration of Internet of Things (IoT) and Artificial Intelligence (AI) technologies for smart water management in modern building infrastructure [3]; and (5) identify research gaps that may serve as the basis for future studies, particularly in the context of tropical buildings in Indonesia.

This study also aims to analyze how current national design guidelines—which are largely based on research from the 1940s to the 1970s—have significant limitations when applied to modern buildings exceeding 30 floors[22]. The findings from this study are expected to provide a reference framework for the development of plumbing design standards that are more adaptive and based on local empirical evidence.

Research Questions

To achieve this objective, this study is designed to address the following research question:

1. RQ1. What plumbing system configurations and design strategies have been reported for high-rise buildings in the Scopus-indexed literature from 2000–2025 (e.g., pressure zoning, booster pump configuration, PRV/break tank, riser design, hot water systems, and drainage/ventilation systems)?
2. RQ2. How is the efficiency/performance of plumbing systems in high-rise buildings defined and measured in the literature, and which metrics/indicators are most commonly used (pumping energy, system efficiency, water consumption intensity, water loss/NRW, reliability, life cycle cost, and water quality/stagnation issues)?
3. RQ3. What research methods are most predominantly used (for example, field measurement, experimental studies, simulation/modeling, optimization, as well as IoT/AI-based approaches), and how are validation practices (benchmarking, sensitivity analysis, field validation) reported?
4. RQ4. What research gaps most consistently emerge, particularly regarding SPWF estimation, vertical stress management, two-phase flow drainage performance, and their implications for energy efficiency, water consumption, and building health risks?
5. RQ5. How have publication trends in Scopus evolved over 2000–2025 (annual growth, dominant sources/journals, geographical distribution, and emerging keyword themes), and what research agenda can be derived including its relevance for the context of tropical buildings such as Indonesia?

State Of The Art

The evolution of building water management systems has shifted from conventional approaches to systems based on the Internet of Things (IoT) and Artificial Intelligence (AI) to enhance the efficiency and accuracy of water management [23]. The Hunter method, which has been used since 1940, has proven to be less accurate

p-ISSN :2746-9778
Website: http://jurnal.alazhar-university.ac.id/index.php/vorteks e-ISSN: 2746-976X
DOI: 10.54123/vorteks.v7i1.533

in predicting peak water demand due to changes in consumption patterns and user probability factors, often resulting in oversized system designs that increase energy consumption, carbon footprint, and the risk of water stagnation [24], [25]. Various modern computational models such as the Modified Wistort Method (MWM), Exhaustive Enumeration Method (EEM), Water Demand Calculator (WDC), and SIMDEUM have been developed to produce more realistic and adaptive estimates of water demand in modern buildings.

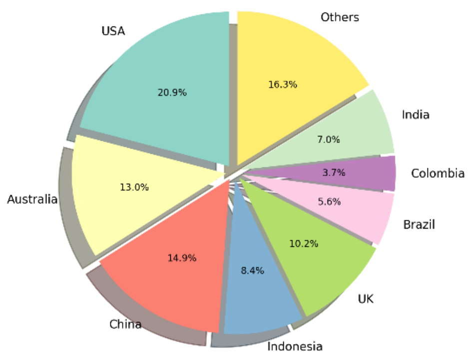


Figure 3. geographic distribution of researchers

A new methodology for determining the diameter of vertical drainage pipes and vent pipes has been proposed based on analogy with other multiphase flow transport systems [26]. Current national design guidelines only cover buildings up to 30 stories, while modern high-rise buildings often exceed 100 stories, surpassing the predictive capabilities of existing codes regarding operating conditions [27].

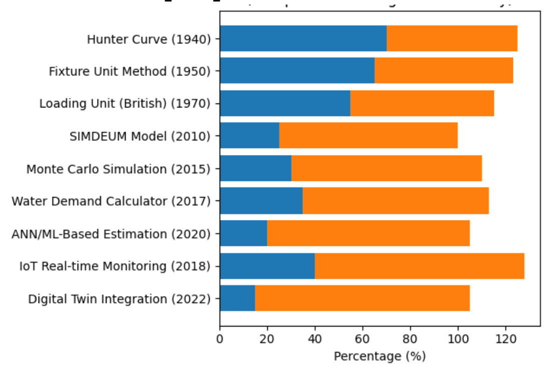


Figure 4. State of the Art - Evolution of Building Water Demand Estimation Methods (Comparison of Use and Accuracy)

Tabel 1. state of the art

Researcher/ Project	Year	Technology	Research Focus	Main Findings
IBM Smarter Water Project (Dubuque, USA)	2012	Smart meters, Analytics dashboards	Consumer awareness, Behavior change	15% reduction in household water consumption
Singapore PUB Smart Water Grid	2015	Pressure/flow sensors, AI analytics	Nationwide water grid, Demand forecasting	100% treated water reuse, Global leader

Jurnal VORTEKS, Vol. 07 No. 01, April 2026
p-ISSN :2746-9778
Website: http://jurnal.alazhar-university.ac.id/index.php/vorteks e-ISSN: 2746-976X
DOI: 10.54123/vorteks.v7i1.533

Smart Water Watch (SWMT) - Springer	2022	Arduino, ESP32, MQTT, MongoDB	Five-layer IoT monitoring	18% water wastage reduction, 12% energy savings
Indian Smart Cities Mission	2020	IoT sensors, Automated billing	Real-time leak detection	Pilot success, scalability challenges
London IoT Sensor Network	2018	City-wide IoT sensors	Leak detection and repair	25% NRW reduction
Nugroho & Iriawan (Malang, Indonesia)	2019	GWR model, Spatial Point Process	Leakage pattern analysis	Inhomogeneous leakage pattern, 1.97-2.02 days recovery
Singh & Kumar	2025	IoT + AI integration	Urban water infrastructure	35% water loss reduction, 60% faster leak detection
Fulawade et al.	2025	Arduino UNO, Flow sensors	Pipeline leakage detection	Real-time alerts, cost savings in maintenance

Research Gap

Despite significant advances in Smart Water Management Systems, several barriers still hinder large-scale implementation, particularly in developing countries. Major challenges include costly infrastructure retrofitting, data security and privacy concerns, lack of standardized regulations, ineffective Non-Revenue Water management, inadequate distribution networks, and limited technical and technological capabilities in water utility operations.

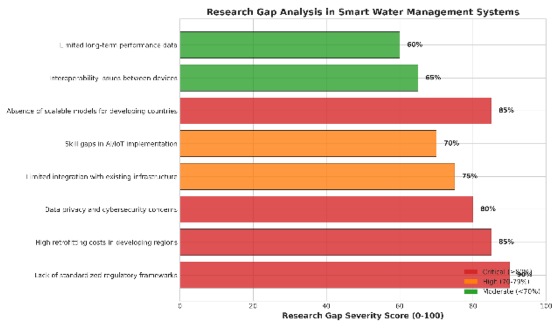


Figure 5. research gap analysis

The implementation of Smart Water Management Systems faces several critical challenges, including infrastructure incompatibility, high initial investment costs for IoT sensors and AI platforms, data privacy and cybersecurity concerns, and the absence of standardized regulatory frameworks. Furthermore, although advanced countries have applied Artificial Neural Network (ANN)-based approaches for water loss analysis,

p-ISSN :2746-9778
Website: http://jurnal.alazhar-university.ac.id/index.php/vorteks e-ISSN: 2746-976X
DOI: 10.54123/vorteks.v7i1.533

similar implementations remain limited in developing countries such as Indonesia due to differing urban infrastructure characteristics and technological capacities.

Research Novelty

The novelty of this research lies in several fundamental aspects. First, this SLR constitutes the first comprehensive effort to synthesize the literature on the configuration and efficiency of plumbing systems in high-rise buildings, with a particular focus on identifying research gaps and publication trends in Scopus over a 25-year period (2000-2025). Second, this study integrates a multi-domain analysis encompassing hydraulic engineering (water demand estimation, pipe design, pump efficiency), building services engineering (drainage systems, ventilation), and smart building technology (IoT, AI, Digital Twin) within a single coherent analytical framework [28]. Third, this study provides an evidence-based research roadmap for developing adaptive plumbing design standards for tropical building contexts, particularly in Indonesia, where similar research remains very limited. The conceptual framework developed in this SLR is expected to serve as a foundation for developing alternative models for more accurate water demand estimation suited to local characteristics, as well as driving innovation in the integration of smart technologies for sustainable building water management.

RESEARCH METHODS

This study employs a Systematic Literature Review (SLR) approach combined with bibliometric analysis to evaluate the development of research related to piping system configuration and efficiency in high-rise buildings during the period 2000–2025 [29], [30]. This approach was chosen because it enables systematic, objective, and measurable scientific synthesis of global publication trends based on Scopus-indexed scientific data. Data were collected from the Scopus database. Inclusion criteria comprised journal articles and reviews discussing piping systems, water distribution, energy efficiency, and configuration in high-rise buildings. Non-English articles, conference papers, and editorial documents were excluded from the analysis. The search was conducted using a combination of keywords: "water supply systems," "high-rise buildings," "pipe configuration," and "energy efficiency" with Boolean operators. Search results were sorted by relevance and publication year for easier initial selection.

Tabel 2. Search Strategy

TITLE-ABS-KEY (("plumbing system" OR "water supply system" OR "sanitary system") AND ("high-rise building" OR "multi-storey building" OR "tall building" OR "skyscraper") OR (configuration OR design OR layout OR efficiency OR performance))	7,948
TITLE-ABS-KEY (("plumbing system" OR "water supply system" OR	751

Jurnal VORTEKS, Vol. 07 No. 01, April 2026
p-ISSN :2746-9778
Website: http://jurnal.alazhar-university.ac.id/index.php/vorteks e-ISSN: 2746-976X
DOI: 10.54123/vorteks.v7i1.533

"sanitary system") AND ("high-rise building" OR "multi-storey building" OR "tall building" OR "skyscraper") OR (configuration OR design OR layout OR efficiency OR performance)) AND (LIMIT-TO (SUBJAREA , "ENGI")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (OA , "all"))

Article selection was carried out in three stages: (1) removal of duplicates, (2) screening of titles and abstracts to assess relevance to the research focus, and (3) full-text review to ensure content suitability with the research topic. The PRISMA flow diagram can be used to visualize the selection process and the number of publications passing each stage. Bibliometric analysis was conducted using VOSviewer version 1.6.19 and R-Studio.

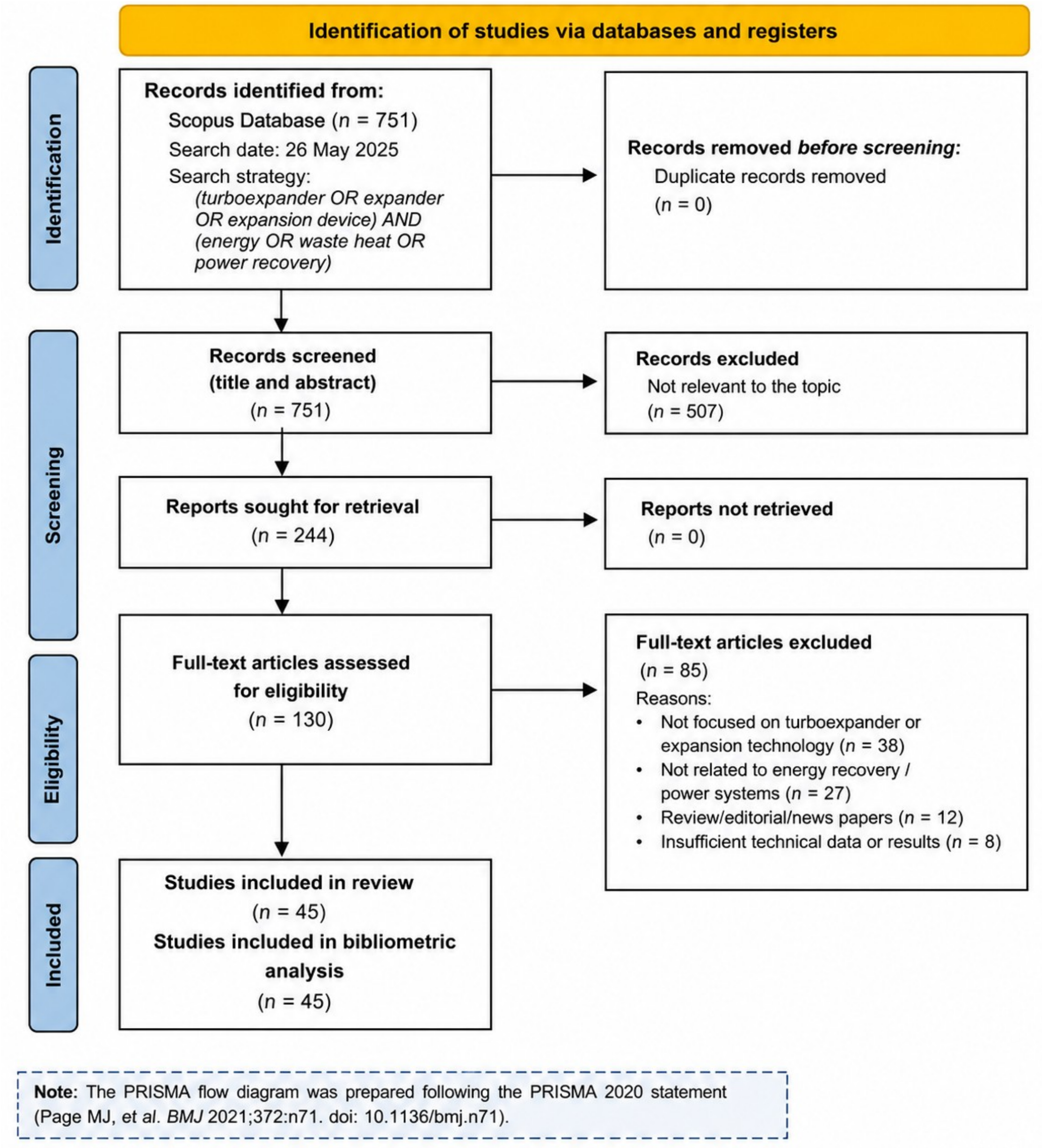


Figure 6. PRISMA Study table

The analysis includes visualization of the keyword network, identification of research clusters, and temporal trends in publication. Clustering parameters are set to obtain a comprehensive overview of research focus and topic evolution from 2000 to 2025. The results of the keyword network analysis and publication trends are interpreted to identify dominant topics, relationships between studies, and shifts in research focus. This information is used to compile a systematic literature review and provide recommendations for future research.

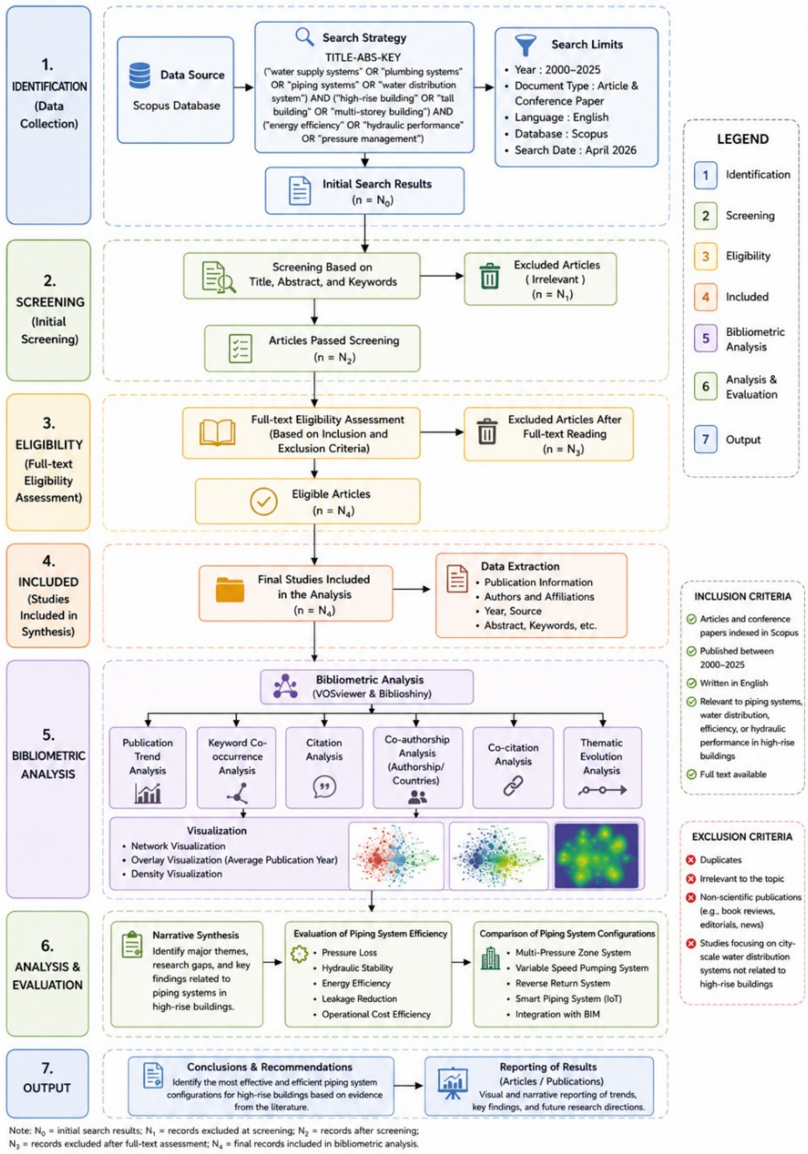


Figure 7. research flowchart

Tools and Methods of Bibliometric Analysis

Bibliometric analysis was conducted using three platforms: (1) the Bibliometrix R package (Aria & Cuccurullo, 2017) for descriptive statistical analysis, Bradford's law, Lotka's law, keyword trend analysis, and thematic mapping; (2) VOSviewer v1.6.19 (van Eck & Waltman, 2014) for co-word network visualization and temporal overlay mapping; and (3) Python 3.11 with

Jurnal VORTEKS, Vol. 07 No. 01, April 2026
p-ISSN :2746-9778
Website: http://jurnal.alazhar-university.ac.id/index.php/vorteks e-ISSN: 2746-976X
DOI: 10.54123/vorteks.v7i1.533

the matplotlib, numpy, and pandas libraries for additional data visualization.

Table *1*: bibliometric analysis tools and methods

Analysis Method	Objective	Software
Descriptive Bibliometric Analysis	Annual trends, source distribution, author/country productivity	Bibliometrix-R
Hukum Bradford	Identification of core journals	Bibliometrix-R
Hukum Lotka	Author productivity distribution	Bibliometrix-R
Co-Word Analysis (Co-word)	Theme clusters and inter-concept relationships	VOSviewer
Thematic Map	Theme classification: motor, niche, emerging, declining	Bibliometrix-R
Topic Trend Analysis	Temporal evolution of dominant keywords	Bibliometrix-R
Peta Overlay Temporal	Average age of keywords in the network	VOSviewer

ANALYSIS AND EVALUATION

Of the 751 documents included in the analysis, an overview is presented in Table 4, covering publications from 237 different sources (journals and proceedings), involving 2,248 unique authors from at least 65 countries, with a total of 9,847 citations. The average number of citations per document is 13.1, with the most cited document reaching 377 citations.

Table *2.* Scopus document analysis

Indicator	Value
Publication period	1980–2026 (analysis focus: 2000–2025)
Total documents analyzed	751
Total sources (journals + proceedings)	237
Total authors	2.248
Single-author article	1.906 (84,8%)
Total global citations	9.847
Average citations per document	13,1
Most cited document	Cimellaro et al., 2016 (377 sitasi)
Document with full keyword	87.7% (659 documents)
h-index corpus (average)	~35
Highest country of origin	China (183), Italia (134), USA (124)
Most productive institution	Universitat Politècnica de València (20 artikel)

The distribution of documents by type shows the dominance of conference papers published through Procedia Engineering (163 articles, 21.7% of the total), reflecting the significant role of international conferences such as the International Conference on Hydroinformatics and WDSA (Water Distribution Systems Analysis) in the development of this field. Peer-reviewed research articles in international Q1 journals dominate in terms of citation impact..

Annual Publication Trend Analysis (2000–2025)

Figure 7 shows a growth pattern that can clearly be divided into three phases: the Incubation Phase (2000–2013), the Acceleration Phase (2014–2019), and the Consolidation Phase (2020–2025). In the Incubation Phase, the publication volume was very low (1–13 articles per year), reflecting that this topic was still a niche research area that had not yet developed. An extraordinary surge occurred in 2014, recording 102 articles, most of which were published in Procedia Engineering through various international conference series accommodating papers from the fields of water distribution systems and hydroinformatics. The Acceleration Phase (2014–2019) was characterized by an average annual growth rate of 12.5%, driven by increasing global awareness of the water-energy nexus, the development of increasingly affordable IoT sensor technology, and green building and net-zero energy policies in various countries. Quantitative peaks were reached in 2017 (78 articles) and 2023 (63 articles), while the Consolidation Phase shows volume stabilization at around 43–54 articles per year,

Jurnal VORTEKS, Vol. 07 No. 01, April 2026
p-ISSN :2746-9778
Website: http://jurnal.alazhar-university.ac.id/index.php/vorteks e-ISSN: 2746-976X
DOI: 10.54123/vorteks.v7i1.533

indicating that this field has reached a certain level of maturity but is still actively developing.

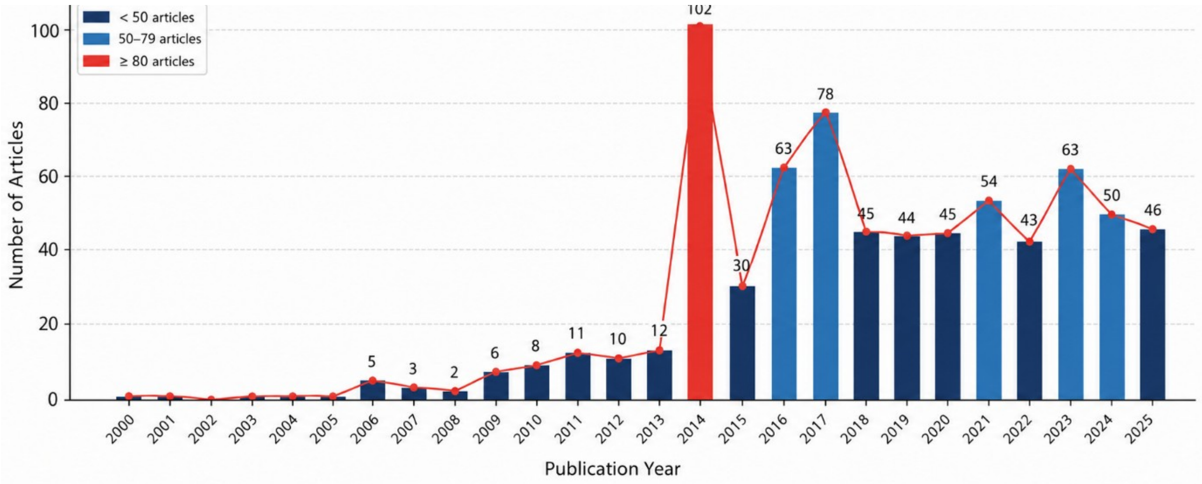


Figure 8. publication trends from year to year (Scopus, 2000-2025)

Analysis of Publication Sources and Bradford's Law

The Bradford analysis identified the distribution of publication sources into three zones. Zone 1 (Core Zone) consists of 4 sources containing one third of all articles, with Procedia Engineering (163 articles) as the dominant source far surpassing the others. Journal of Water Resources Planning and Management (43 articles), IOP Conference Series: MSE (32 articles), and Water Resources Management (26 articles) complete the Bradford core.

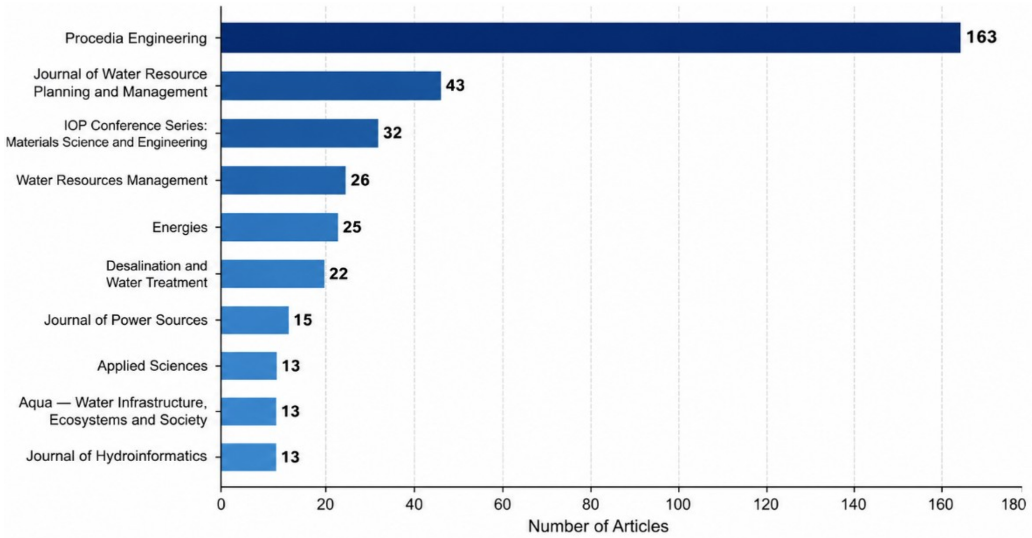


Figure 9. Ten Most Relevant Journal and Proceedings Sources (Scopus, 2000–2025; N = 751 documents)

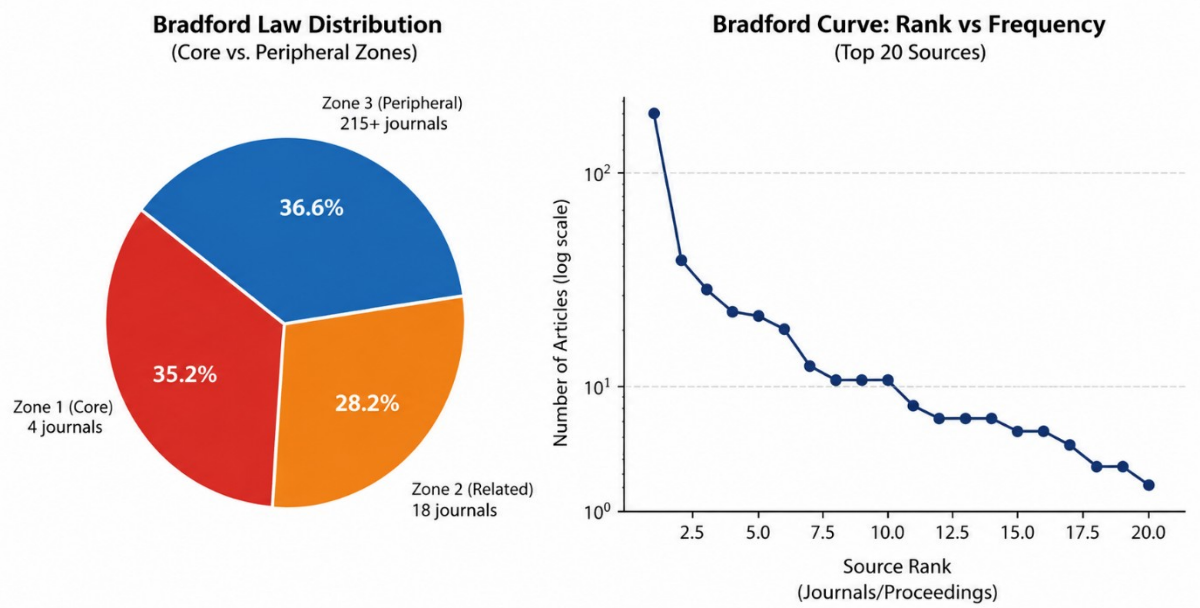


Figure 10. Bradford Law Distribution: Core Zone Division and Rank-Frequency Distribution (N = 237 sources, from 751 documents, Scopus 2000–2025)

The significance of the Journal of Water Resources Planning and Management (ASCE, SJR Q1) and Water Resources Management (Springer, SJR Q1) in Zone 1 confirms that high-rise building piping issues are inseparable from the broader context of urban water resources management. Meanwhile, Building Services Engineering Research and Technology (BSER&T, CIBSE) in Zone 2 is the only journal that specifically focuses on building MEP systems, indicating that there remains substantial room for publication in journals that are more oriented toward building engineering.

Tabel 3. Zona Bradford

Zona Bradford	Number of Sources	Number of Articles	% of Total	Interpretation
Zone 1 (Core)	4 sources	264 articles	35,2%	Most relevant journal/proceedings
Zone 2 (Related)	18 sources	212 article	28,2%	Active supporting journal
Zone 3 (Peripheral)	18 sources	275 article	36,6%	Peripheral and specialist sources

Analysis of Author Productivity and Lotka's Law

Table 4 presents the 10 most productive authors based on the number of articles. Izquierdo J. (Universitat Politècnica de València) leads with 11 articles focusing on water distribution network optimization and hydroinformatics. Giustolisi O. (Technical University of Bari), Kapelan Z. (University of Exeter), and Ramos HM (Universidade de Lisboa) each contributed 10 articles.

Table 4. Ten most productive authors

Ranking	Author	Affiliation	Article	Fractional Article	Main Research Focus
1	IZQUIERDO J	Univ. Politècnica de València, ES	11	2,29	Network optimization, DMA design
2	GIUSTOLISI O	Technical Univ. of Bari, IT	10	3,29	GIS-based network analysis
3	KAPELAN Z	University of Exeter, UK	10	3,10	Multi-objective optimization
4	RAMOS HM	Universidade de Lisboa, PT	10	2,43	Energy & hydraulics, PAT
5	BERARDI L	Technical Univ. of Bari, IT	8	1,74	Network modeling
6	ZHANG J	Hohai University, CN	8	1,29	Water quality management
7	ZIMOCH I	Silesian Univ. of Technology, PL	8	3,25	System reliability
8	SAVIĆ D	University of Exeter, UK	7	2,17	Machine learning, EPANET
9	TANYIMBOH TT	Univ. of the Witwatersrand, ZA	7	3,58	Network design, entropy
10	LIU J	Zhejiang University, CN	7	1,67	Sensor & monitoring

Jurnal VORTEKS, Vol. 07 No. 01, April 2026
p-ISSN :2746-9778
Website: http://jurnal.alazhar-university.ac.id/index.php/vorteks e-ISSN: 2746-976X
DOI: 10.54123/vorteks.v7i1.533

Lotka's Law analysis shows a highly skewed distribution typical of academic research: 84.8% of 2,248 authors (1,906 individuals) published only one article on this topic, while only 2.4% of authors published 5 or more articles. The obtained Lotka coefficient (n ≈ 2.4) approaches the theoretical value n = 2 of the classic Lotka's Law, indicating a distribution consistent with established patterns in scientific literature.

Analysis of National Productivity

China leads in the absolute number of articles (183), but its average citations per article (6.1) are lower compared to the United States (10.6), Spain (13.7), and the United Kingdom (10.8). This indicates that although China is highly productive in terms of quantity, the scientific impact per article is still below that of Western European countries. An interesting fact is that Denmark, despite publishing only a few articles, has the highest average citations (57/article), indicating exceptionally high research quality in specific sub-niches. Indonesia ranks 20th with 20 articles, a fairly good regional position considering the availability of research infrastructure. However, in the context of being a developing country with the largest urban population in ASEAN and rapid high-rise building growth, Indonesia's research contribution in this topic is still far below its potential and represents an area that urgently needs to be improved..

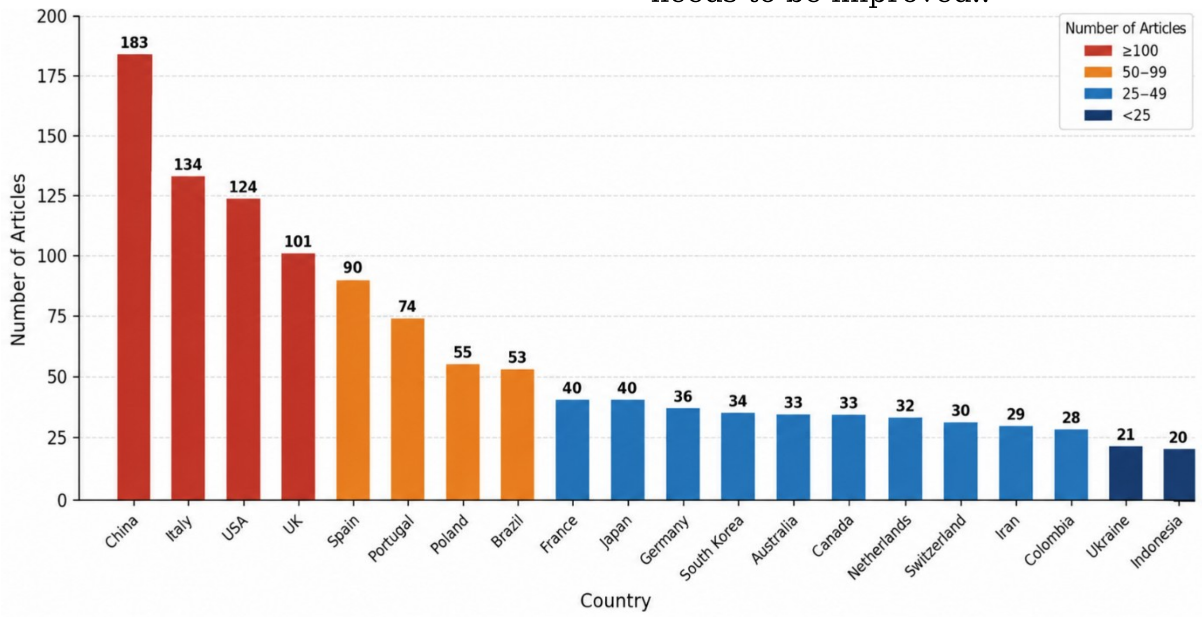


Figure 11. top 20 Countries by publication output (Scopus, 2000-2025)

Table 5. Country rankings based on publications

Ranking	Country	Article	Total Sitasi	Rata-rata Sitasi/Artikel	Kolaborasi Utama
1	China	183	1.116	6,1	USA, Australia
2	Italia	134	1.211	9,0	UK, Spanyol

JOURNAL OF MECHANICAL, INDUSTRIAL, ELECTRICAL, AND CIVIL ENGINEERING

3	USA	124	1.309	10,6	UK, China
4	UK	101	1.094	10,8	Portugis, Spanyol
5	Spanyol	90	1.234	13,7	Italia, Portugal
6	Portugal	74	394	5,3	Spanyol, UK
7	Polandia	55	164	3,0	Jerman, Ceko
8	Brasil	53	326	6,2	Kolombia, Portugal
9	Prancis	40	369	9,2	Belgia, Swiss
10	Jepang	40	271	6,8	China, Korea
20	Indonesia	20	N/A	N/A	Malaysia, Australia

Co-Word and Thematic Cluster Analysis (VOSviewer)

Co-word analysis using VOSviewer produced a network map showing five main thematic clusters based on the co-occurrence of author keywords and keywords plus (Figures 12 and 13). Each cluster represents a research community with different research agendas, but interconnected through bridging topics.

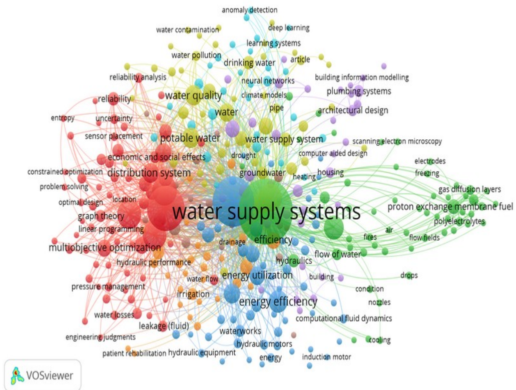


Figure 12. VOSviewer Co-Word Network Map: Thematic Clusters (Density/Cluster View) N = 751 documents, Scopus 2000–2025; Minimum co-occurrence = 5; Visualization: VOSviewer v1.6.19

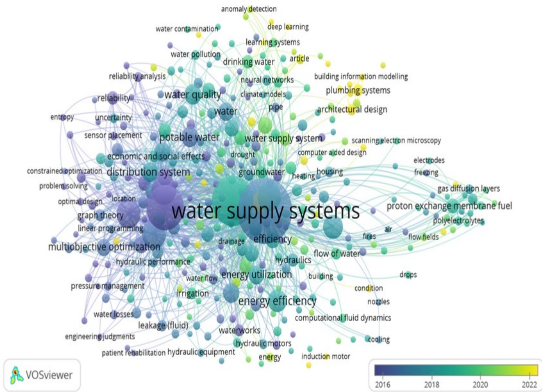


Figure13. VOSviewer Co-Word Network Map: Temporal Overlay (2016–2022) Yellow = newer keywords (2020–2022); Dark blue = older keywords (2016–2018)

Table 6. Dominant keyword cluster network

Cluster	Color (VOSviewer)	Dominant Keywords	Thematic Interpretation	Number of Nodes
1	Red	Water supply systems, distribution system, potable water, reliability, multiobjective optimization	Optimization of water distribution networks & reliability	~45
2	Blue	Energy efficiency, energy utilization, hydraulic motors, hydraulics, waterworks	Energy efficiency & pumping systems	~30
3	Green	Plumbing systems,	MEP system design &	~25

Jurnal VORTEKS, Vol. 07 No. 01, April 2026
p-ISSN :2746-9778
Website: http://jurnal.alazhar-university.ac.id/index.php/vorteks e-ISSN: 2746-976X
DOI: 10.54123/vorteks.v7i1.533

		architectural design, BIM, housing, heating, computer aided design	BIM integration	
4	Yellow	Water quality, drinking water, water pollution, pipe, climate models	Water quality & climate modeling	~30
5	Cyan/ Purple	Deep learning, IoT, anomaly detection, neural networks, sensor placement	Smart technology & monitoring	~20

Cluster 1 (red) dominates the network and centers on "water supply systems" as the largest node, reflecting a strong research orientation toward urban water infrastructure optimization. Cluster 3 (green), centered on "plumbing systems" and "architectural design," is the cluster most relevant to the focus of this study—high-rise building piping systems yet its size is relatively small compared to the other clusters, confirming that this subtopic remains underrepresented in the literature. The temporal overlay map (Figure 7) reveals that the newest keywords (colored yellow, 2020–2022) are dominated by: "building information modelling," "plumbing systems," "deep learning," "anomaly detection," and "internet of things." This confirms the current research trend toward the integration of digital technology with building piping systems.

Analysis of Most Frequently Occurring Keywords

"Water supply systems" dominated with 509 occurrences (67.8% of all documents), followed by "water supply" (305) and "water distribution systems" (248). The occurrences of "energy efficiency" (61 times) and "optimization" (95 times) reflect two of the strongest research agendas in this field. The keyword "plumbing systems" itself appeared 30 times, indicating that much of the research uses broader terminology (water supply systems, water distribution) rather than terminology specific to buildings.

Jurnal VORTEKS, Vol. 07 No. 01, April 2026
p-ISSN :2746-9778
Website: http://jurnal.alazhar-university.ac.id/index.php/vorteks e-ISSN: 2746-976X
DOI: 10.54123/vorteks.v7i1.533

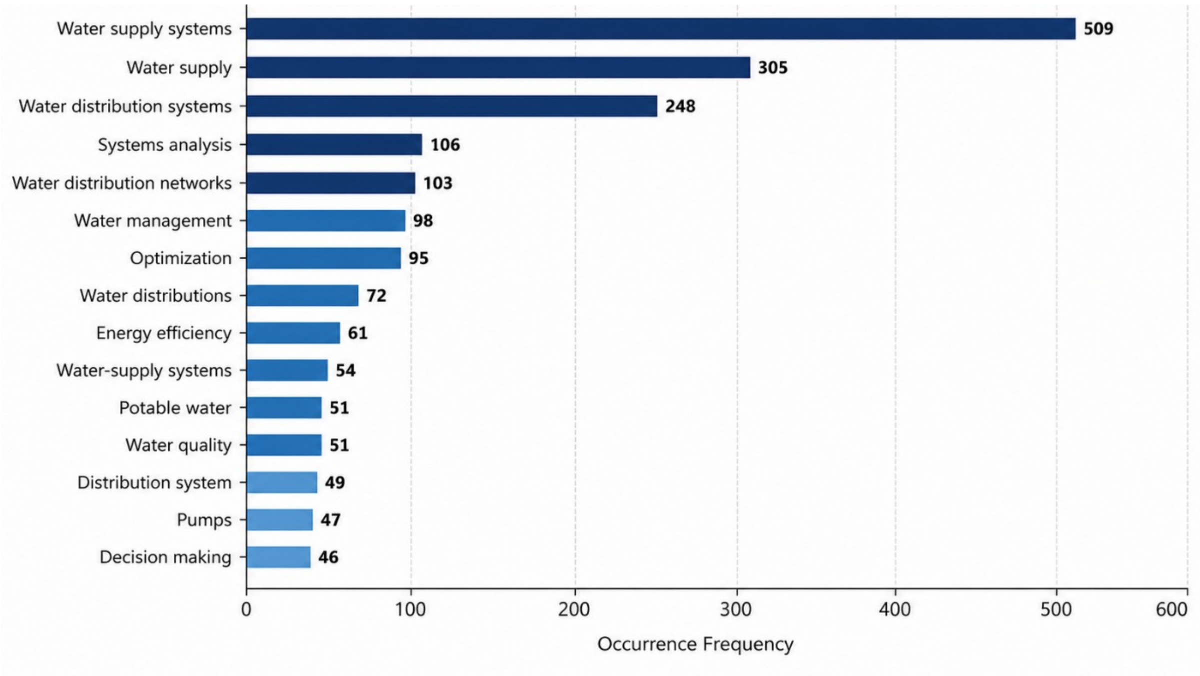
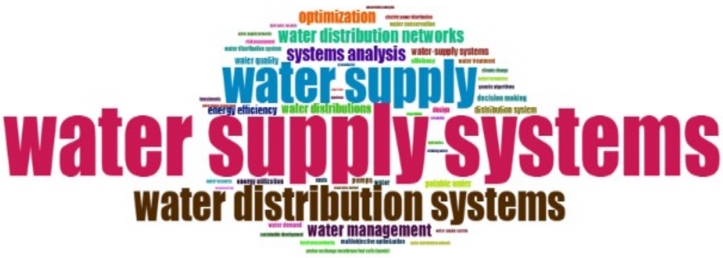


Figure 14. most frequently occurring keywords



Temporal Topic Trend Analysis

Table 8 summarizes the results of the topic trend analysis based on the median year of keyword appearance, showing the temporal evolution of the research agenda from traditional topics to emerging topics.

Table 7. trend analysis of topics based on the median year of keyword appearance

Topic/Keyword	Frequency	Median Year	Trend Interpretation	Relevance of High-Rise Building Plumbing
Mathematical models	8	2008	Mature Topic	Low general methodology
Systems analysis	106	2014	Growing Rapidly	Medium network analysis
Water distribution systems	248	2016	Highly Active	High core topic

p-ISSN :2746-9778
Website: http://jurnal.alazhar-university.ac.id/index.php/vorteks e-ISSN: 2746-976X
DOI: 10.54123/vorteks.v7i1.533

Energy efficiency	61	2017	Active and Relevant	Very High
Water supply systems	509	2017	Stable Dominant	Very High core topic
Water conservation	36	2018	Emerging	High sustainability
Water management	98	2019	Active	Medium
Building information modelling	~10	2021	Newly Emerging	Very High research gap
Internet of Things	11	2021	Newly Emerging	Very High smart building
Deep learning / AI	~8	2022	Frontier Topic	High prediction and detection

Data on topic trends confirm a gradual transition from conventional engineering approaches (mathematical optimization, hydraulic analysis) towards approaches integrated with digital technology. Topics with a median year of 2020 or later (BIM, IoT, deep learning) represent the most active and promising research frontiers for subsequent studies.

Most Influential Documents

Table 8 presents the 10 documents with the highest global citations in the corpus. These documents represent the bedrock literature that every researcher entering this field must understand..

Table 8. Ten documents with the highest global citations

Rank	Authors, Year	Short Title	Journal	Total Citations	TC/Year
1	Cimellaro et al., 2016	Resilience of interconnected systems (J. Struct. Eng.-a)	J. Struct. Eng.	377	34,3
2	Fraga-Lamas et al., 2021	IoT for water management (Sensors)	Sensors	364	60,7
3	Villarreal & Bengtsson, 2005	Infiltration & stormwater management	Build. Environ.	248	11,3
4	Wang et al., 2015	Contamination source identification in WDS	J. Water Resour. Plan.	198	16,5
5	Cimellaro et al., 2016	Earthquake-resilient buildings (J. Struct. Eng.)	J. Struct. Eng.	177	16,1
6	Carravetta et al., 2013	Pump as Turbine in WDS	Energies	161	11,5
7	Niblett et al., 2020	PEM fuel cell two-phase flow	J. Power Sources	134	19,1
8	Fecarotta et al., 2015	PAT design optimization	Water Resour. Manage.	118	9,8

9	Goulet & Smith, 2013	Structural monitoring & diagnostics	Adv. Eng. Inf.	117	8,4
10	Du et al., 2017	Energy recovery in water supply	Energy	109	10,9

Interestingly, several of the highest-cited documents (Niblett et al., 2020; rank 7) are related to proton exchange membrane fuel cells (PEMFC), which apparently entered the corpus due to terminological similarities in fluid flow management. This reflects the inherent challenges in broad bibliometric searches that use generic keyword-based queries. These studies, although not directly related to high-rise building plumbing, offer methodological insights that can be adopted.

Identification of Research Gaps and Future Research Agenda

Based on a comprehensive synthesis of the results from bibliometric analysis, co-word analysis, thematic mapping, and topic trends, seven main research gaps have been identified at the intersection of high-rise building piping systems and emerging technologies. These gaps are organized according to their level of urgency and potential research impact.

Table 9. Identification of Research Gaps

#	Identified Research Gap	Basis of Identification	Urgency	Potential Impact
G1	Integration of BIM with high-rise building plumbing system design and operation	BIM emerged in a new cluster (2021) but with very low frequency (n < 15)	Very High	Very High
G2	Digital Twin for predictive maintenance of plumbing systems	Digital Twin did not appear among dominant keywords; IoT exists but is not linked to DT	Very High	Very High
G3	Plumbing system configurations for tropical climates (Southeast Asia, Africa)	Research is dominated by temperate climate regions (Europe, USA); Indonesia contributed only 20 articles	High	High
G4	AI/Machine Learning-based pressure zoning system optimization	AI/ML emerged as an emerging topic (2022), but its application in pressure zoning remains limited	High	Very High
G5	Integrated Life Cycle Assessment (LCA) for high-rise plumbing systems	Sustainability emerged, but plumbing-specific LCA studies were not identified	High	High
G6	Evidence-based plumbing standards and regulations for	Most studies focus on buildings <100 m; very limited studies on supertall	Medium	High

Jurnal VORTEKS, Vol. 07 No. 01, April 2026
p-ISSN :2746-9778
Website: http://jurnal.alazhar-university.ac.id/index.php/vorteks e-ISSN: 2746-976X
DOI: 10.54123/vorteks.v7i1.533

	buildings >200 m	buildings		
G 7	Integrated greywater recycling systems in tropical high-rise buildings	Water conservation emerged (2018), but few studies specifically address greywater recycling	Medium	High

Gap G1 (BIM Integration) and G2 (Digital Twin) are the most critical gaps, as both are positioned at the intersection between the practical needs of the construction industry and current research limitations. Although BIM has become the de facto standard in the global construction industry, its adoption in the operational and maintenance phases of MEP systems—including plumbing—is still very limited. Research that integrates BIM Level of Detail (LOD) 400+ with real-time hydraulic simulation for high-rise building piping systems represents a highly promising area. Gap G3 (Tropical Climate) has particular urgency for Indonesia and the Southeast Asia region. Piping system design parameters such as bacterial growth factors, pipe material degradation due to high temperatures, domestic water consumption patterns, and source water quality differ significantly between tropical and temperate climate zones. The majority of international piping standards (ASHRAE, CIBSE, ASPE) have been developed based on temperate climate conditions, so their direct application in Indonesia may result in suboptimal designs.

Research Question Findings

1. RQ1. What plumbing system configurations and design strategies are most commonly reported in high-rise buildings?

The reviewed literature demonstrates that the most frequently reported plumbing configurations in high-rise buildings include pressure zoning systems, booster pump arrangements, pressure reducing valves (PRV), break tank systems, riser-based vertical distribution, and separated hot-water circulation systems. Studies published between 2014–2025 increasingly emphasize optimized pressure zoning to reduce hydraulic losses and improve energy efficiency in tall buildings exceeding 30 floors. In addition, modern drainage systems increasingly adopt two-phase flow analysis and advanced venting strategies to minimize pressure fluctuation and trap seal failure. The findings indicate a gradual transition from conventional empirical plumbing layouts toward data-driven and simulation-based hydraulic configurations.

2. RQ2. How is plumbing system efficiency defined and measured in the literature?

The literature defines plumbing system efficiency using several dominant indicators, including pumping energy consumption, hydraulic efficiency, water consumption intensity, leakage reduction, pressure stability, lifecycle cost, and water quality performance. Energy efficiency and optimization emerged as the most

Jurnal VORTEKS, Vol. 07 No. 01, April 2026
p-ISSN :2746-9778
Website: http://jurnal.alazhar-university.ac.id/index.php/vorteks e-ISSN: 2746-976X
DOI: 10.54123/vorteks.v7i1.533

frequently discussed themes, particularly in relation to pump operation and water distribution systems. Recent studies also integrate sustainability indicators such as water conservation and carbon reduction. Furthermore, research trends after 2020 increasingly evaluate system efficiency through smart monitoring approaches using IoT-based sensors and AI-assisted predictive analytics.

3. RQ3. What research methods are predominantly used in the field?

Simulation and computational modeling represent the dominant research approaches identified in the Scopus corpus. Frequently used methods include EPANET-based hydraulic modeling, optimization algorithms, Monte Carlo simulation, BIM-assisted design analysis, and machine learning approaches. Experimental studies and field measurements are still limited compared to simulation-based studies. Validation approaches commonly include benchmarking against existing standards, sensitivity analysis, and limited field validation. Emerging studies integrate IoT sensors, digital twins, and AI-based anomaly detection to improve real-time system analysis and predictive maintenance.

4. RQ4. What are the major research gaps identified in the literature?

The most critical research gaps identified include the lack of integration between BIM and plumbing operation systems, limited application of Digital Twin technology, insufficient research on tropical high-rise plumbing systems, and the absence of adaptive standards for supertall buildings exceeding 200 meters. Furthermore, the traditional Hunter curve and fixture-unit approaches are increasingly considered inaccurate for modern low-flow buildings, resulting in oversized pipe systems and inefficient energy consumption. Research related to AI-based pressure zoning optimization, greywater recycling integration, and tropical climate-specific plumbing design remains limited, particularly in developing countries such as Indonesia.

5. RQ5. RQ5 : :How have publication trends evolved from 2000 to 2025?

The bibliometric analysis reveals a substantial increase in publication activity after 2014, driven by global concerns regarding water-energy efficiency, sustainable buildings, and smart infrastructure technologies. China, Italy, the United States, and the United Kingdom dominate global publication productivity, whereas Indonesia remains underrepresented despite rapid urban growth. Thematic evolution analysis shows a transition from traditional hydraulic analysis toward emerging topics such as BIM, IoT, deep learning, anomaly detection, and digital water management systems. These trends suggest that future research will increasingly focus on intelligent plumbing infrastructure, predictive maintenance, and sustainable water management in smart buildings.

EVALUATION

Interpretation of Trends and Implications for Indonesian Research

Jurnal VORTEKS, Vol. 07 No. 01, April 2026
p-ISSN :2746-9778
Website: http://jurnal.alazhar-university.ac.id/index.php/vorteks e-ISSN: 2746-976X
DOI: 10.54123/vorteks.v7i1.533

The rapid growth in publications since 2014 reflects the convergence of several global factors: (1) increasing urbanization and the need for sustainable buildings driving attention to the efficiency of MEP systems; (2) increasingly affordable Internet of Things (IoT) sensor technology, enabling monitoring and empirical research that were previously not feasible; (3) tightening regulations on water and energy efficiency in various countries, particularly the European Union (EU) Energy Performance of Buildings Directive (EPBD); and (4) the availability of open-source network analysis tools such as EPANET and WNTR, which have lowered the barriers to research in this field. For the Indonesian research community, these findings have significant strategic implications. First, Indonesia's position as the 20th most productive country (20 articles), despite a growing population and an increasing number of high-rise buildings, represents a gap that must be addressed. Leading Indonesian technical universities need to develop a long-term research roadmap for high-rise building MEP systems that are contextualized to tropical conditions, seismicity, and local urbanization patterns. Second, international collaboration is a proven strategy for increasing research impact. Data show that countries with the highest average citations per article (Spain, Denmark, and the United States) possess strong cross-country collaboration networks. Researcher exchange and joint publication programs between Indonesian institutions and partners in Europe or East Asia could catalyze this acceleration. Study limitations

This study has several limitations that should be acknowledged transparently. First, although Scopus is a comprehensive database, some high-quality publications in non-English languages or those not indexed by Scopus are not included in this analysis. Second, the open access filter applied may cause selection bias toward certain types of institutions and countries that are more active in open access publishing. Third, thematic cluster interpretation from the co-word map has a subjective element in the naming and categorization of clusters. Fourth, several documents in the corpus relate to fuel cell technology (PEMFC) that were included because of terminological overlap in fluid flow management, which slightly affected the composition of certain clusters.

CONCLUSION

This study successfully presents a comprehensive systematic literature review and bibliometric analysis of plumbing system configurations and efficiency in high-rise buildings based on 751 Scopus-indexed publications from 2000 to 2025. The findings demonstrate that research trends have evolved significantly from conventional hydraulic design approaches to intelligent, data-driven, and sustainability-oriented plumbing systems. Pressure zoning, booster pump optimization, water distribution efficiency, and drainage performance remain dominant engineering concerns, while recent studies increasingly focus on IoT integration, artificial intelligence,

Jurnal VORTEKS, Vol. 07 No. 01, April 2026
p-ISSN :2746-9778
Website: http://jurnal.alazhar-university.ac.id/index.php/vorteks e-ISSN: 2746-976X
DOI: 10.54123/vorteks.v7i1.533

BIM, and Digital Twin technologies for predictive monitoring and smart water management.

The bibliometric results reveal that publication growth accelerated rapidly after 2014, driven by global urbanization, green building policies, and advances in sensor technologies. China, Italy, the United States, and the United Kingdom dominate scientific productivity, whereas Indonesia still contributes relatively limited research despite its rapidly expanding high-rise building sector. Bradford and co-word analyses further confirm that "water supply systems," "energy efficiency," and "optimization" are the most influential research themes, whereas emerging topics include BIM integration, anomaly detection, and AI-based water management.

REFERENCE

[1] S. D. Astarini and C. Utomo, "Performance-based building design of high-rise residential buildings in Indonesia," *Sustain.*, vol. 12, no. 17, p. 7103, 2020, doi: 10.3390/su12177103.

[2] S. P. D and G. P. Ramesh, "Smart IoT-enabled Water Quality Management using Generative AI and Super-Resolution GAN for Enhanced Monitoring and Prediction," in *2025 3rd International Conference on Integrated Circuits and Communication Systems (ICICACS)*, Raichur, India: IEEE, 2025, pp. 1–7. doi: 10.1109/ICICACS65178.2025.10968178.

[3] N. Geetha, S. Midharshana, R. K. S, R. J. R, and S. Swetha, "Survey on Smart Water Management System," *Int. J. Sci. Res.*, vol. 17, no. October, pp. 314–318, 2025, doi: 10.30574/ijsra.2025.17.1.2720.

[4] J. Y. R. Liew and Y. S. Chua, "Innovative modular systems for high-rise buildings," *Eng. Struct.*, vol. 323, no. PA, p. 119270, 2025, doi: 10.1016/j.engstruct.2024.119270.

[5] W. Nugroho and N. Iriawan, "Effect of the leakage location pattern on the speed of recovery in water supply networks," *J. Phys. Conf. Ser.*, vol. 1402, no. 2, p. 1402, 2019, doi: 10.1088/1742-6596/1402/2/022023.

[6] K. Rambabu, S. Dubey, K. N. Srinivas, D. N. Reddy, and C. Rohith, "Smart Water Flow and Pipeline Leakage Detection Using IoT and Arduino UNO," *2nd Int. Conf. Intell. Data Commun. Technol. Internet Things, IDCIoT 2024*, vol. 12, no. 1, pp. 174–180, 2024, doi: 10.1109/IDCIoT59759.2024.10467990.

[7] Z. Liu, X. Zhu, J. Liu, M. K. Kim, and W. Jiang, "A Numerical Investigation of the Influence of Diffuser Vane Height on Hydraulic Loss in the Volute for a Centrifugal Water Supply Pump," *Buildings*, vol. 14, no. 8, p. 2296, 2024, doi: 10.3390/buildings14082296.

[8] H. Yang, W. Zhang, G. Lin, and H. Li, "Annual Operation

Jurnal VORTEKS, Vol. 07 No. 01, April 2026
p-ISSN :2746-9778
Website: http://jurnal.alazhar-university.ac.id/index.php/vorteks e-ISSN: 2746-976X
DOI: 10.54123/vorteks.v7i1.533

Energy Efficiency Benchmarking of Chilled Water Plants: A Systematic Review of Global Cases (2014–2025),” *Buildings*, vol. 16, no. 4, pp. 1–29, 2026, doi: 10.3390/buildings16040756.

[9] Z. H. Siregar, A. F. Nasution, and Refiza, “Deconstructing the Empirical Fixture Unit Method : a Monte Carlo – Based Paradigm for Water-Efficient Wastewater Piping Design,” *J. Vor.*, vol. 06, no. 02, pp. 544–556, 2025, doi: 10.54123/vorteks.v6i2.480.

[10] C. Mera-parra and H. M. Benavides-muñoz, “Empirical Recalibration of Hunter ’ s Method for Peak Flow Estimation in Institutional Buildings : A Pilot Study in Data-Scarce Contexts,” *Water*, vol. 17, no. 22, pp. 1–18, 2025, doi: 10.3390/w17223233.

[11] I. Askarin, S. Sutikno, and A. Naibaho, “Perencanaan Jaringan Pipa Air Bersih Dan Air Kotor Pembangunan Gedung Guest House Exindo Grup,” *J. JOS-MRK*, vol. 2, no. 3, pp. 287–291, 2021, doi: 10.55404/jos-mrk.2021.02.03.287-291.

[12] K. H. Mendonça, H. P. Gomes, J. M. M. Villanueva, and S. T. M. Bezerra, “Performance of Oversixed Pumps controlled by variable frequency drivers in water supply system,” *J. Urban Environ. Eng.*, vol. 16, no. 2, pp. 186–192, 2022, doi: 10.4090/juee.2022.v16n2.186192.

[13] M. Lazova, H. Huisseune, A. Kaya, S. Lecompte, G. Kosmadakis, and M. De Paepe, “Performance evaluation of a helical coil heat exchanger working under supercritical conditions in a solar organic rankine cycle installation,” *Energies*, vol. 9, no. 6, 2016, doi: 10.3390/en9060432.

[14] A. Stelzl, M. Pointl, and D. Fuchs-Hanusch, “Estimating future peak water demand with a regression model considering climate indices,” *Water (Switzerland)*, vol. 13, no. 14, p. 1912, 2021, doi: 10.3390/w13141912.

[15] Z. H. Siregar, A. F. Nasution, and Refiza, “Efisiensi dan kesesuaian kapasitas sistem Plumbing pada bangunan tinggi berdasarkan beban air hunian dan fasilitas pendukung,” *J. Mekanova Mek. Inov. dan Teknol.*, vol. 12, no. 1, pp. 69–75, 2026, doi: 10.35308/jmkn.v12i1.15105.

[16] Z. H. Siregar, A. F. Nasution, Mawardi, Refiza, and Suherman, “Evaluasi Kritis dan Model Alternatif Hunter Curves untuk Sistem Plumbing Gedung Bertingkat di Medan,” *J. Mekanova Mek. Inov. dan Teknol.*, vol. 11, no. 2, pp. 205–217, 2025, doi: 10.35308/jmkn.v11i2.13638.

[17] R. M. Kaustav, D. Subhasish, and M. Asis, “Standardization of Fixture Units for Modern Flush Valves by Optimizing Water Demand Using Modified Hunter’s Curve,” *J. Pipeline Syst. Eng. Pract.*, vol. 12, no. 3,

p. 4021022, Aug. 2021, doi: 10.1061/(ASCE)PS.1949-1204.0000558.

[18] P. Cortez-Lara, E. S. Hernández Gress, R. Ballinas-Gonzalez, and B. Sanchez, "A methodology to simulate peak water demand for water supply systems using semi-direct methods: A case study for a residential building in Mexico," *Heliyon*, vol. 10, no. 3, p. e25104, 2024, doi: 10.1016/j.heliyon.2024.e25104.

[19] M. Scanlan and Y. R. Filion, "Influence of Topography, Peak Demand, and Topology on Energy Use Patterns in four Small to Medium-Sized Systems in Ontario, Canada," *Water Resour. Manag.*, vol. 31, no. 4, pp. 1361–1379, 2017, doi: 10.1007/s11269-017-1582-0.

[20] I. Vlăducă *et al.*, "Compressed air energy storage facility with water tank for thermal recovery," in *E3S Web of Conferences*, G. Negreanu, V. Vladut, and M. Tazerout, Eds., EDP Sciences, 2020. doi: 10.1051/e3sconf/202018002002.

[21] R. Effendi, A. Rijal Siswanto, M. Qadri, F. Hendra, and A. Yunus Nasution, "Power Optimisation of Centrifugal Pumps in a 4-Storey Building," *Dinamis*, vol. 13, no. 1, pp. 1–7, 2025, doi: 10.32734/dinamis.v13i1.18837.

[22] M. Gormley, D. Kelly, D. Campbell, Y. Xue, and C. Stewart, "Building drainage system design for tall buildings: Current limitations and public health implications," *Buildings*, vol. 11, no. 2, pp. 1–17, 2021, doi: 10.3390/buildings11020070.

[23] K. N. Singh and C. Kumar, "Smart Water Management Systems: Integration of IoT Sensors and AI for Sustainable Urban Water Infrastructure," *Int. J. Sci. Res. Eng. Manag.*, vol. 09, no. 05, pp. 1–9, 2025, doi: 10.55041/ijsrem47819.

[24] F. J. Chang, L. C. Chang, and J. F. Chen, "Artificial Intelligence Techniques in Hydrology and Water Resources Management," *Water (Switzerland)*, vol. 15, no. 10, pp. 1–6, 2023, doi: 10.3390/w15101846.

[25] Tiago de V G Ferreira and Orestes M Goncalves, "Stochastic simulation model of water demand in residential buildings," *Build. Serv. Eng. Res. Technol.*, vol. 41, no. 5, pp. 544–560, Dec. 2019, doi: 10.1177/0143624419896248.

[26] M. Zaresefat and R. Derakhshani, "Revolutionizing Groundwater Management with Hybrid AI Models: A Practical Review," *Water (Switzerland)*, vol. 15, no. 9, p. 1750, 2023, doi: 10.3390/w15091750.

[27] G. Kantayeva, J. Lima, and A. I. Pereira, "Application of machine learning in dementia diagnosis: A systematic literature review," *Heliyon*, vol.

9, no. 11, p. e21626, 2023, doi: 10.1016/j.heliyon.2023.e21626.

[28] Atheer Zaki Al-Qaisi, "Smart Water Systems: The Role of Technology and Engineering in Optimizing Urban Water Resources," *J. Inf. Syst. Eng. Manag.*, vol. 10, no. 21s, pp. 833–846, 2025, doi: 10.52783/jisem.v10i21s.3445.

[29] D. Kim, Y. Yoon, J. Lee, P. J. Mago, K. Lee, and H. Cho, "Design and Implementation of Smart Buildings: A Review of Current Research Trend," *Energies*, vol. 15, no. 12, pp. 1–17, 2022, doi: 10.3390/en15124278.

[30] A. Batwara, V. Sharma, M. Makkar, and A. Giallanza, "Towards smart sustainable development through value stream mapping – a systematic literature review," *Heliyon*, vol. 9, no. 5, p. e15852, 2023, doi: 10.1016/j.heliyon.2023.e15852.