Innovations in Eco-Friendly Materials and Sustainable Energy

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Technological Innovations Driving Sustainable Materials and Renewable Energy Solutions: Enhancing Guest Experience and Building Loyalty in Hospitality Industry.. 1
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Amrik Singh, Lovely Professional University, India

The growing urgency to mitigate climate change and resource depletion has accelerated research into sustainable materials and renewable energy technologies. This chapter examines the role of technological innovations in advancing eco-friendly materials and integrating renewable energy solutions for sustainable development. It explores the latest breakthroughs in material science, including bio-based composites, nanomaterials, and recyclable polymers, as well as advancements in energy technologies such as solar photovoltaics, wind systems, and energy storage. The discussion highlights the convergence of digital technologies—such as artificial intelligence, additive manufacturing, and the Internet of Things—in optimizing material efficiency and energy performance. Furthermore, the chapter addresses the implications of these innovations for industrial applications, life-cycle sustainability, and the circular economy.

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Bio-based and Biodegradable Nanocomposites for Clean Energy Applications 25
Pinar Bozbeyoglu, Biomedical Device Technology Program, Electronics and Automation Department, Gümüşhane University, Turkey
Elif Esra Altuner, Kocaeli Health and Tecnology University, Turkey

The growing global demand for energy and the environmental concerns associated with fossil fuels have accelerated the search for sustainable alternatives. Bio-based and biodegradable nanocomposites represent a new generation of materials that combine ecological compatibility with superior mechanical, thermal, and electrical properties. This chapter provides a comprehensive overview of bio-based polymer matrices (such as PLA, PHA, PBS, PEF, PVA, and natural polymers like cellulose, chitosan, and lignin) and their integration with nanofillers, including graphene, carbon nanotubes, TiO_2, ZnO, and nanoclay. The synergistic effects of these hybrid structures are discussed in the context of clean energy technologies, such as solar cells, fuel cells, batteries, supercapacitors, and piezoelectric nanogenerators. In addition, the chapter highlights green synthesis routes, characterization methods, life cycle assessment (LCA), and industrial perspectives, emphasizing how nanocomposite design bridges performance enhancement with environmental sustainability.

Chapter 3
Plant-Mediated Synthesis of Functional Nanocomposites for Clean Energy and Environmental Sustainability 69
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Elif Esra Altuner, Kocaeli Health and Tecnology University, Turkey

Plant-mediated synthesis has emerged as a sustainable method for producing functional nanocomposites with diverse applications, including clean energy, photocatalysis, electrochemical storage, and environmental cleanup. This approach differs from traditional chemical processes, which often require harsh conditions; instead, plant-derived systems combine reduction, nucleation, stabilization, and assembly in a single reaction environment. Phytochemicals such as polyphenols, flavonoids, and proteins act as both reducing agents and structure-directing agents, enabling the formation of various materials under gentle conditions

Chapter 4
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Zinc titanate ($ZnTiO_3$) has attracted considerable interest as a photocatalyst owing to its favorable optical characteristics, structural robustness, and eco-friendly nature. In this work, XRD patterns confirmed the dominant hexagonal phase of $ZnTiO_3$ with minor traces of secondary phases, and the crystallite size was found to be approximately 46 nm. The UV–Vis analysis indicated a noticeable red shift in light absorption, corresponding to a band gap of 3.6 eV, which enhances its photocatalytic utility. FESEM analysis revealed aggregated, porous nanostructures in the 20–50 nm range, contributing to a high surface area beneficial for photocatalysis. EDAX results confirmed the material's purity with only zinc, titanium, and oxygen elements detected. The photocatalytic performance was evaluated by degrading methylene blue dye under UV light at pH 6, achieving an efficiency of 86%. This high degradation rate is attributed to enhanced surface activity and the generation of reactive species under UV exposure.

Chapter 5
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Lalu Iqbal Aryadifta, University of Mataram, Indonesia
Sugiman Sugiman, University of Mataram, Indonesia
Agus Dwi Catur, University of Mataram, Indonesia

This research aims to study the effect of fiberglass layers of skin and core thickness of ethylene vinyl acetate (EVA) foam cored sandwich composites on its interlaminar shear strength. The sandwich composite consists of fiberglass woven roving reinforced unsaturated polyester resin skin and EVA foam core, where the skin serves to resist shear loads, and the core serves as a structural support and reduces the overall weight of the composite. This study varied the EVA foam core thickness to 5 mm, 8 mm, and 10 mm, and the number of fiberglass skin layers to 2, 4, and 6 layers. The tests were conducted with a 500 kN capacity Universal Testing Machine (UTM) in accordance with ASTM D2344 standard. The test results showed that the interlaminar strength increased significantly as the number of skin layers increased. However, an increase in core thickness leads to a decrease in interlaminar strength. The main failure mode observed was delamination within the fiberglass skin layers.

Chapter 6
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Hendry Sakke Tira, University of Mataram, Indonesia
Radiya Subagja, University of Mataram, Indonesia
Yesung Allo Padang, University of Mataram, Indonesia

This study investigates the reactivation of corn cob charcoal using NaOH solution to reduce exhaust emissions from dual-fuel LPG-pertalite two-wheeler. The research aims to evaluate the effectiveness of the adsorbent in lowering emissions emitted from two-wheeler. Experiments were conducted on a two-wheeler operating under various fuel conditions: pertalite alone (P), pertalite with adsorbent (PA), pertalite-LPG blend (PL), pertalite-LPG with adsorbent (PLA), and pertalite-LPG with adsorbent after first (PLRE1) and second reactivation (PLRE2). The results show that the use of LPG and adsorbent significantly reduced the two-wheeler emissions compared to the standard fuel. Moreover, the reactivated adsorbent (PLRE1) exhibited the highest reduction in emissions, demonstrating the potential of reactivated corn cob charcoal as an environmentally friendly solution for emission control. The study highlights the benefits of adsorbent reactivation in improving performance and sustainability.

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A Comprehensive Performance Analysis of Tin-Based Perovskite (CH3NH3SnI3) Solar Cells With Different Electron Transport Layers 163
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Nandita Pradhan, United College of Engineering and Research, Prayagraj, India
Satya Prakash Singh, United College of Engineering and Research, Prayagraj, India
Tushar, United College of Engineering and Research, Prayagraj, India

This study explores the performance of Tin-based Perovskite Solar Cells (TPSCs), focusing on $CH_3NH_3SnI_3$ as a non-toxic alternative to lead-based perovskites. Various organic and inorganic electron transport layers (ETLs) TiO_2, PCBM, WS_2, and ZnO were analyzed for their impact on key photovoltaic parameters: power conversion efficiency (PCE), open-circuit voltage (Voc), short-circuit current (Isc), and fill factor (FF). Simulations using SCAPS-1D software evaluated the influence of ETL thickness, doping concentration, temperature, and quantum efficiency across 300–900 nm wavelengths. Results identified optimal ETL configurations that enhance device performance, guiding the development of eco-friendly, high-efficiency perovskite solar cells for sustainable energy applications.

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Alihan Kumtepe, Kalyon PV, Turkey
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Çağdaş Eğin, Kalyon PV, Turkey
Ecem Tuğçe Özbek, Kalyon PV, Turkey
Özlem Coşkun, Kalyon PV, Turkey

Solar power has become a cornerstone of the clean-energy transition, valued for its scalability, declining costs, and contribution to energy security. Its deployment continues to expand across utility, commercial, and residential sectors, supported by strong policy frameworks and increasingly mature supply chains. Despite these advances, the thermal sensitivity of photovoltaic (PV) modules remains a key limitation. High operating temperatures can reduce voltage, lower maximum power output, and accelerate material degradation, particularly in hot and high-irradiance regions. This chapter reviews strategies to address these challenges through engineered cooling solutions. A comprehensive assessment is presented of passive methods such as natural ventilation, heat sinks, phase-change materials, radiative coatings, floating PV, liquid immersion, and heat pipes. Comparative evidence highlights practical approaches for stabilizing PV temperatures, mitigating efficiency losses, and supporting long-term system reliability and sustainability.

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Power Generate Forecast Using Gate Recurrent Unit-Neural Networks for Photovoltaic Plant System 221
Muhammad Rifqi Aulya, University of Mataram, Indonesia
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Mohan Vithalrao Aware, NIT Arunachal Pradesh, India

Indonesia is located on the earth's equator, where sunlight always exists yearly. Sunlight energy is converted to electrical directly through a photovoltaic power plant. This form of energy is free from nature, free from carbon emissions, and has a minimal negative impact on the environment. However, fluctuations in photovoltaic power plant production depend on the weather and exposure to sunlight. This situation creates a severe problem of managing the energy system. To overcome this problem, the artificial neural networks gated recurrent unit (GRU) model is proposed to predict the power production of photovoltaic power plants. Energy production historical data are from 1 August 2023 to 31 March 2024, 07.00-16.00; Lombok Island, Indonesia local time. These data are taken from supervisory control and data acquisition (SCADA) system of a 7-MWp photovoltaic power plant. The GRU model is able to predict 7-days loading pattern of the actual with error in tolerance value.

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R. Sowmiya, SASTRA (Deemed to be) University, India
M. Velavan, SASTRA (Deemed to be) University, India

This chapter examines the convergence of behavioral science and artificial intelligence (AI) in advancing demand-side energy efficiency (DSEE) within eco-friendly appliances. It highlights how socio-psychological drivers—such as attitudes, norms, and perceived behavioral control—influence consumer adoption of energy-efficient technologies. Simultaneously, AI models including Artificial Neural Networks (ANN), Long Short-Term Memory (LSTM), and hybrid forecasting systems enhance energy optimization, load prediction, and smart home automation. The chapter proposes an integrative framework linking behavioral insights with AI analytics to foster sustainable energy practices. Policy implications, including dynamic pricing, incentives, and ethical data governance, are explored alongside future directions such as edge computing, blockchain-enabled energy trading, and cross-cultural research. Together, these strategies support the Sustainable Development Goals (SDG 7 and SDG 12), offering a roadmap for intelligent, low-carbon, and consumer-centered energy ecosystems.

Chapter 11
Enhancing Climate and Weather Prediction With Machine Learning: A Support Vector Machine Approach 267
Binastya Anggara Sekti, Universitas Esa Unggul, Indonesia
Agung Mulyo Widodo, Universitas Esa Unggul, Indonesia

Climate change and extreme weather variability are major challenges of the 21st century affecting agriculture, health, energy, and infrastructure. Accurate weather forecasts are crucial to reducing risk and supporting adaptation strategies. This chapter discusses the application of machine learning, specifically Support Vector Machine, to improve the accuracy of climate and weather predictions. It begins with a review of the challenges of climate change and the limitations of traditional methods, then introduces the role of machine learning in meteorology. An in-depth explanation of SVM is presented by highlighting its ability to handle nonlinear and high-dimensional data. Using meteorological data from 2012–2015 (temperature, rainfall, humidity, wind, and weather conditions), pre-processing, model training, and evaluation were carried out. The results showed that SVM was superior to conventional statistical models, especially under conditions of high variability. It also explores applications in many sectors and future research directions towards sustainable climate resilience.

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Design of a Battery Energy Supply and Driving Range Estimation for a Prototype Vehicle 293
I. Ketut Wiryajati, Mataram University, Indonesia

This study designs and evaluates the battery energy supply system and driving range of an energy-efficient prototype vehicle as part of a project-based learning initiative within the MBKM framework. The methodology encompasses mathematical modeling of energy consumption (rolling resistance, aerodynamic drag, and inertia), CFD-based aerodynamic simulation, and the design and integration of the battery and Battery Management System (BMS), followed by track testing at constant speeds. The primary configuration—a 48 V 40 Ah $LiFePO_4$ battery (80% DoD)—yields a range of approximately 61 km at 45 km/h, with an energy consumption of around 25 Wh/km. Based on a 4,800 Wh capacity, the theoretical ideal range of 192 km drops to 163.2 km (85% efficiency) and further to 115.2 km when accounting for total resistance. Sensitivity analysis indicates that reducing the drag coefficient (Cd) to ≤0.20 increases the range by approximately 10%, a 50 kg mass reduction lowers consumption by 2 Wh/km, and the use of a 95%-efficient BLDC motor extends the range by about 20 km. Validation reveals a 3–5% variance, confirming the model's accuracy and highlighting the potential for efficiency improvements through the optimization of aerodynamics, mass, motor performance, and renewable energy integration.

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Optimization of Energy Consumption in Desantara Electric Vehicles Using Regression Models ... 325
I. Made Mara, University of Mataram, Indonesia
Fransiskus Yusdwi Benoit Toding, University of Mataram, Indonesia
I. Ketut Wiryajati, University of Mataram, Indonesia

This chapter analyzes the influence of vehicle speed and weight on energy consumption in electric vehicles, with a focus on the Desantara prototype. Using data from 23 driving tests across speed ranges of 22–47 km/h and weights of 123–141.45 kg, multiple linear regression was employed to examine the relationship between these factors and power consumption. Results indicate that energy use remains stable at 30–35 Wh for low speeds of 22–30 km/h, but rises sharply to 159 Wh at 47 km/h in heavier vehicles. The findings highlight that both speed and weight significantly affect energy demand, with heavier configurations consuming more energy, particularly at elevated speeds. Effective management of these variables is therefore critical for improving efficiency. This chapter concludes that lighter vehicles operated at moderate speeds can substantially reduce energy consumption, enhance performance, and extend driving range, offering practical insights for the design of more efficient electric vehicles.

Chapter 14
Design of a Clean Water Installation System of a 16-Story Hotel Building 345
Adam Bertrand, Universitas Tarumanagara, Indonesia
Steven Darmawan, Universitas Tarumanagara, Indonesia
Abrar Riza, Universitas Tarumanagara, Indonesia

Water is an essential resource, and clean water systems are critical in muti-story building design. This study is conducted at a hotel system that is supplied by the municipal network and held in a ground tank before being delivered to a roof tank using a centrifugal pump. Water from the roof tank is distributed to each floor via booster pumps in a parallel-alternate configuration. Random polypropylene (PPR) pipes were used in the design. The research assesses demand, head losses, pump capacity, and pipe sizing to ensure efficiency. Results show daily demand at 251 m^3, with municipal supply at 283 L/min, transfer pumps at 418 L/min, booster pumps at 750 L/min, and gravity pipelines at 1000 L/min. The selected pipe sizes are 73.6 mm (transfer), 130.8 mm (gravity), and 61.4 mm (municipal). These design results provide practical recommendations for designing dependable clean water systems in multi-story structures.

Chapter 15
Liquid Assets: Financing Clean Water and Sanitation for Sustainable Development 371
Mohammad Irfan, Chandigarh University, India
Paridhi Arora, Chandigarh University, India

Access to safe and sustainable water and sanitation continues to be a significant global concern. Many regions still struggle to provide reliable services because of limited financial resources, institutional

weaknesses, and growing climate pressures on water supplies. This paper examines how financing approaches, including blended finance, microcredit, and public–private partnerships, can be strengthened through the practical application of technology. Tools such as remote sensing improve understanding of water availability and quality, enabling more informed planning and allocation of resources. In addition, advanced data analysis supports better risk evaluation, operational efficiency, and long-term infrastructure management. The study concludes that when financial strategies are supported by accurate data and sound governance, they become more transparent, accountable, and capable of attracting sustainable investment. Such an integrated approach supports universal access to water and sanitation while promoting public health, social equity, and long-term economic resilience.

Chapter 16
Eco-Friendly Smart Grid Design Using IoT and Power-Efficient Multilevel Converters 389
M. Pavan Kumar, SR University, India
Durgam Rajababu, SR University, India
Ram Krishan, NIT Warangal, India

The increasing demand for Renewable Energy Sources and the need for efficient energy management have made the smart grid a significant area of the research. A truly intelligent and energy-efficient smart grid can be realized by integrating cloud-based Internet of Things technologies with the RES. This chapter proposes a novel approach for RES integration that leverages IoT and the multilevel converters to enhance energy efficiency, minimize power losses, and ensure reliable energy distribution. The proposed system utilizes IoT devices to collect the data, process, and analyze real-time data, thereby improving grid monitoring and optimizing the performance of renewable energy installations. A multilevel converter is employed to manage different voltage levels, to enhance power quality (PQ), and optimize power distribution, contributing to the stable and efficient operation of the grid. The effectiveness and practicality of the proposed methodology are validated through MATLAB/Simulink-based simulation models.

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Preface

The increasing urgency of environmental challenges, coupled with the growing demand for sustainable development, has accelerated the search for innovative solutions that can support a cleaner, more resilient future. As nations, industries, and communities work toward reducing environmental impacts and achieving long-term sustainability goals, advances in eco-friendly materials and sustainable energy technologies have emerged as critical drivers of transformation. It is within this context that we are pleased to present *Innovations in Eco-Friendly Materials and Sustainable Energy*, an edited volume that explores the latest developments, applications, and research directions shaping the future of sustainable technologies.

This book brings together contributions from researchers, engineers, scientists, and practitioners from diverse disciplines who share a common commitment to environmental stewardship and technological innovation. The chapters collectively examine emerging materials, renewable energy systems, optimization techniques, computational approaches, and practical implementations designed to address some of the most pressing global concerns, including climate change, resource depletion, waste management, energy security, and environmental degradation. By integrating theoretical foundations with real-world applications, the volume demonstrates how scientific innovation can contribute to sustainable economic growth while preserving ecological balance.

A distinguishing feature of this book is its interdisciplinary perspective. Sustainable development challenges rarely exist within the boundaries of a single discipline; rather, they require collaboration across materials science, engineering, environmental studies, energy systems, data analytics, policy development, and industrial practice. The contributions presented in this volume reflect this reality by offering diverse approaches to the design, development, and deployment of sustainable technologies. Readers will encounter research that spans bio-based and recyclable materials, renewable energy generation, energy efficiency enhancement, smart optimization methods, environmental monitoring, digital technologies for sustainability, and innovative solutions for resource management.

The primary objective of this book is to showcase cutting-edge research and technological advancements that support the transition toward environmentally responsible practices and sustainable energy utilization. The chapters highlight innovations that improve energy efficiency, enhance material performance and reusability, reduce environmental impacts, and promote safer and more sustainable industrial processes. In addition, the volume encourages cross-disciplinary collaboration by presenting methodologies and case studies that can be adapted and expanded across multiple sectors and application domains.

Beyond advancing academic discourse, this book seeks to bridge the gap between research and practice. The insights presented throughout the volume offer practical value for professionals and decision-makers who are responsible for implementing sustainable solutions in industry, government, and society. Through a combination of experimental investigations, computational modeling, optimization frameworks, and applied case studies, the contributors provide readers with actionable knowledge that can inform future innovations and policy development.

This volume has been developed with a broad audience in mind. Researchers and graduate students will find valuable perspectives on emerging trends and future research opportunities. Engineers and industry professionals will benefit from practical examples and technological applications that demonstrate how sustainability principles can be integrated into product development, manufacturing processes, and energy systems. Policymakers and sustainability consultants will gain insights into evidence-based strategies that support environmental objectives and sustainable growth. Innovators and entrepreneurs will discover new possibilities for developing environmentally conscious technologies and business solutions.

The themes explored throughout this book strongly align with global efforts to achieve the United Nations Sustainable Development Goals (SDGs), particularly those related to affordable and clean energy, industry innovation, responsible consumption and production, climate action, and sustainable communities. By highlighting advances that promote cleaner technologies, resource efficiency, and environmental responsibility, this volume contributes to the broader conversation surrounding sustainable development and the future of our planet.

As editor, I extend my sincere appreciation to all contributing authors for sharing their expertise, research findings, and innovative perspectives. I also thank the reviewers whose valuable feedback helped ensure the quality and rigor of the chapters included in this collection. Finally, I express my gratitude to the publishing team for their support throughout the development of this project.

I hope that *Innovations in Eco-Friendly Materials and Sustainable Energy* serves as a valuable resource for scholars, practitioners, policymakers, and innovators alike. More importantly, I hope it inspires continued research, collaboration, and action toward building a more sustainable, energy-efficient, and environmentally responsible future for generations to come.

ORGANIZATION OF THE BOOK

Chapter 1: Technological Innovations Driving Sustainable Materials and Renewable Energy Solutions

In Chapter 1, the authors provide a broad introduction to the transformative role of technological innovation in advancing sustainable materials and renewable energy systems. The chapter examines recent developments in bio-based composites, recyclable polymers, and nanomaterials alongside emerging renewable energy technologies, including solar, wind, and energy storage solutions. Particular attention is given to the integration of artificial intelligence, additive manufacturing, and Internet of Things technologies to improve material efficiency and energy performance. By connecting these advancements to industrial applications, life-cycle sustainability, and circular economy principles, this chapter establishes a strong foundation for understanding the interdisciplinary nature of sustainable innovation.

Chapter 2: Bio-Based and Biodegradable Nanocomposites for Clean Energy Applications

Chapter 2 explores the rapidly evolving field of bio-based and biodegradable nanocomposites and their growing significance in clean energy technologies. The authors present a comprehensive examination of sustainable polymer matrices and their integration with advanced nanofillers to create materials with enhanced mechanical, thermal, and electrical properties. The chapter highlights applications in solar cells, batteries, fuel cells, supercapacitors, and piezoelectric nanogenerators while also discussing green synthesis methods, characterization techniques, and life-cycle assessments. Through this analysis, readers gain valuable insight into how environmentally responsible material design can support next-generation energy systems.

Chapter 3: Plant-Mediated Synthesis of Functional Nanocomposites for Clean Energy and Environmental Sustainability

In this chapter, the authors introduce plant-mediated synthesis as an innovative and environmentally friendly approach to producing functional nanocomposites. Utilizing naturally occurring phytochemicals as reducing and stabilizing agents, this method offers a sustainable alternative to conventional chemical synthesis routes. The chapter discusses the production and application of nanocomposites for clean energy generation, electrochemical storage, photocatalysis, and environmental remediation. By demonstrating how biological resources can facilitate advanced material fabrication under mild conditions, the chapter highlights a promising pathway toward greener manufacturing practices and sustainable technological development.

Chapter 4: Zinc Titanate-Based Photocatalysts for Advanced Wastewater Treatment

Chapter 4 presents an in-depth investigation of zinc titanate as an effective photocatalyst for advanced wastewater treatment applications. The authors examine the material's structural, optical, and morphological characteristics using various analytical techniques and demonstrate its ability to achieve significant degradation of organic pollutants under ultraviolet irradiation. The findings reveal the importance of nanostructured photocatalysts in improving water quality while minimizing environmental impacts. This contribution underscores the growing role of advanced materials in addressing global water sustainability challenges.

Chapter 5: Effect of Fiberglass Layers in Skin and EVA Foam Core Thickness on the ILSS of Sandwich Composites

In Chapter 5, the authors investigate the mechanical performance of lightweight sandwich composites designed for structural applications. Through experimental evaluation of varying fiberglass skin layers and EVA foam core thicknesses, the study assesses their influence on interlaminar shear strength and failure behavior. The findings demonstrate the critical relationship between material configuration and structural performance, providing valuable guidance for the development of durable and efficient composite materials. This chapter contributes to sustainable engineering by supporting the design of lightweight structures that reduce material consumption while maintaining mechanical integrity.

Chapter 6: Optimizing Corn Cob Charcoal as an Adsorbent for Lowering Exhaust Emissions in LPG-Pertalite Dual-Fuel Engines

Chapter 6 explores the potential of agricultural waste valorization through the use of reactivated corn cob charcoal as an adsorbent for reducing vehicle exhaust emissions. The authors evaluate the effectiveness of chemically reactivated biomass-derived charcoal in dual-fuel engine systems and demonstrate its capacity to significantly decrease harmful emissions. The chapter highlights how renewable waste resources can be transformed into environmentally beneficial technologies, offering a practical approach to emission control while promoting circular economy principles and sustainable resource utilization.

Chapter 7: A Comprehensive Performance Analysis of Tin-Based Perovskite Solar Cells With Different Electron Transport Layers

In this chapter, the authors investigate tin-based perovskite solar cells as a promising non-toxic alternative to conventional lead-based photovoltaic technologies. Using simulation-based analyses, the study evaluates the impact of various electron transport layers on critical solar cell performance indicators, including power conversion efficiency, voltage, current, and fill factor. The chapter provides valuable insights into material selection and device optimization strategies that can accelerate the development of environmentally friendly, high-efficiency solar energy systems.

Chapter 8: A Proactive Approach to Design Integration of Cooling Technologies in PV Modules

Chapter 8 addresses one of the most significant challenges affecting photovoltaic performance: thermal management. The authors review a broad range of passive cooling strategies, including heat sinks, phase-change materials, radiative cooling coatings, floating photovoltaic systems, and heat pipe technologies. By examining the effectiveness of these approaches in reducing operating temperatures and enhancing long-term reliability, the chapter offers practical guidance for improving solar energy system efficiency and sustainability, particularly in regions with high solar irradiance.

Chapter 9: Power Generation Forecast Using Gate Recurrent Unit Neural Networks for Photovoltaic Plant Systems

In Chapter 9, the authors demonstrate the application of advanced machine learning techniques to improve renewable energy management. Using historical operational data from a large-scale photovoltaic power plant, the study develops a gated recurrent unit neural network model capable of accurately forecasting solar power generation. The chapter highlights the importance of predictive analytics in addressing the variability of renewable energy resources and supporting more efficient grid integration, energy planning, and system reliability.

Chapter 10: Behavioral and AI-Driven Approaches for Demand-Side Energy Efficiency in Eco-Friendly Appliances

Chapter 10 examines the intersection of behavioral science and artificial intelligence in promoting demand-side energy efficiency. The authors explore how consumer attitudes, social influences, and behavioral intentions affect the adoption of energy-efficient technologies while simultaneously demonstrating how AI-driven forecasting and optimization models can improve appliance performance and energy management. The chapter presents an integrated framework that combines human behavior and intelligent technologies, offering valuable perspectives for creating sustainable, consumer-centered energy ecosystems.

Chapter 11: Enhancing Climate and Weather Prediction With Machine Learning

In this chapter, the authors investigate the application of support vector machine algorithms to improve climate and weather forecasting accuracy. By analyzing meteorological data characterized by nonlinear and highly variable patterns, the study demonstrates the advantages of machine learning approaches over traditional statistical methods. The chapter highlights the growing role of artificial intelligence in climate resilience, emphasizing how improved forecasting capabilities can support decision-making across agriculture, energy, infrastructure, and disaster preparedness sectors.

Chapter 12: Design of a Battery Energy Supply and Driving Range Estimation for a Prototype Vehicle

Chapter 12 focuses on the design, modeling, and evaluation of an energy-efficient prototype vehicle powered by lithium iron phosphate battery technology. The authors integrate mathematical modeling, computational fluid dynamics simulations, battery management systems, and real-world testing to estimate driving range and optimize energy consumption. The findings illustrate the importance of aerodynamic performance, vehicle mass reduction, and motor efficiency in maximizing electric vehicle sustainability. This chapter offers practical insights into the development of next-generation transportation systems.

Chapter 13: Optimization of Energy Consumption in Desantara Electric Vehicles Using Regression Models

In Chapter 13, the authors examine the relationship between vehicle speed, weight, and energy consumption in electric vehicles using regression-based analytical methods. Through extensive testing of the Desantara prototype vehicle, the study demonstrates how operational conditions significantly influence energy demand and driving efficiency. The chapter provides actionable recommendations for vehicle design and operation, emphasizing the importance of lightweight construction and optimized speed management in extending vehicle range and reducing energy consumption.

Chapter 14: Design of Clean Water Installation System of a 16-Story Hotel Building

Chapter 14 presents a practical engineering approach to the design of clean water distribution systems in high-rise buildings. The authors analyze water demand, pumping requirements, pipeline sizing, and hydraulic performance within a multi-story hotel environment. By optimizing system efficiency and reliability, the chapter demonstrates how thoughtful infrastructure design can contribute to sustainable water resource management. The findings offer valuable guidance for engineers and planners involved in urban development and building services engineering.

Chapter 15: Liquid Assets: Financing Clean Water and Sanitation for Sustainable Development

In this chapter, the authors address the critical challenge of financing water and sanitation infrastructure in an era of increasing environmental and societal pressures. The discussion explores innovative financial mechanisms, including blended finance models, microcredit programs, and public-private partnerships, while highlighting the role of digital technologies, remote sensing, and advanced analytics in improving resource management and investment decisions. The chapter demonstrates how integrated financial and technological strategies can expand access to clean water and sanitation while supporting long-term sustainability and social equity.

Chapter 16: Eco-Friendly Smart Grid Design Using IoT and Power-Efficient Multilevel Converters

The final chapter examines the design of intelligent smart grid systems that integrate renewable energy resources through Internet of Things technologies and power-efficient multilevel converters. The authors present a framework for real-time monitoring, data-driven optimization, and enhanced power quality management within modern energy networks. Supported by simulation-based validation, the chapter demonstrates how advanced digital technologies can improve energy efficiency, reduce losses, and strengthen grid reliability. This contribution concludes the volume by illustrating the essential role of smart infrastructure in supporting a sustainable and resilient energy future.

CONCLUDING REMARKS

As the chapters in this volume collectively demonstrate, the pursuit of sustainability is no longer confined to a single discipline, industry, or technological domain. Rather, it has become a global imperative that requires the integration of innovative materials, renewable energy systems, intelligent technologies, sustainable infrastructure, and forward-thinking policy frameworks. The contributions presented in *Innovations in Eco-Friendly Materials and Sustainable Energy* highlight the remarkable progress being made across these interconnected fields and underscore the transformative potential of research-driven solutions in addressing some of the world's most pressing environmental and energy challenges.

Throughout this book, readers have explored advances in sustainable material development, nanotechnology, clean energy generation, photovoltaic optimization, smart grid systems, energy-efficient transportation, wastewater treatment, clean water management, and artificial intelligence-driven sustainability applications. Together, these chapters demonstrate that meaningful progress toward environmental stewardship depends not only on technological innovation but also on the effective integration of scientific knowledge, engineering expertise, data-driven decision-making, and responsible resource management.

A recurring theme across the volume is the importance of interdisciplinary collaboration. The challenges associated with climate change, resource scarcity, pollution, and energy security are complex and multifaceted. The research presented herein illustrates how collaborative efforts among scientists, engineers, policymakers, and industry professionals can generate practical solutions that are both environmentally responsible and economically viable. Equally important, many of the chapters emphasize the role of emerging digital technologies, including artificial intelligence, machine learning, the Internet of Things, and advanced modeling techniques, in accelerating the transition toward more sustainable and resilient systems.

As editor, I believe that the insights contained within this volume contribute meaningfully to ongoing global efforts to achieve a more sustainable future. The innovations discussed throughout these chapters align closely with international sustainability initiatives and the United Nations Sustainable Development Goals, particularly those related to affordable and clean energy, clean water and sanitation, sustainable industry and infrastructure, responsible consumption and production, and climate action. By advancing both theoretical understanding and practical implementation strategies, the contributors have provided a valuable foundation for future research and technological development.

I hope this book serves not only as a scholarly resource but also as a catalyst for continued innovation, collaboration, and action. Whether readers are researchers seeking new avenues of investigation, engineers developing next-generation technologies, policymakers shaping sustainability initiatives, or industry leaders implementing green solutions, I trust that the knowledge presented in this volume will inspire meaningful contributions toward a cleaner, more energy-efficient, and environmentally sustainable world.

Chapter 14

Design of a Clean Water Installation System of a 16-Story Hotel Building

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ABSTRACT

Water is an essential resource, and clean water systems are critical in muti-story building design. This study is conducted at a hotel system that is supplied by the municipal network and held in a ground tank before being delivered to a roof tank using a centrifugal pump. Water from the roof tank is distributed to each floor via booster pumps in a parallel-alternate configuration. Random polypropylene (PPR) pipes were used in the design. The research assesses demand, head losses, pump capacity, and pipe sizing to ensure efficiency. Results show daily demand at 251 m^3, with municipal supply at 283 L/min, transfer pumps at 418 L/min, booster pumps at 750 L/min, and gravity pipelines at 1000 L/min. The selected pipe sizes are 73.6 mm (transfer), 130.8 mm (gravity), and 61.4 mm (municipal). These design results provide practical recommendations for designing dependable clean water systems in multi-story structures.

I. INTRODUCTION

The design of potable water distribution systems in high-rise structures has garnered heightened focus owing to swift urbanization and the escalating demand for effective building services engineering. High-rise hospitality structures, such as hotels, necessitate dependable water supply systems that can sustain sufficient pressure, flow consistency, and operational efficacy under fluctuating demand scenarios. In the context of modern society, water is not only a biological necessity but also a critical

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component in urban development, infrastructure, and industry. As urban populations grow and building density increases, the provision of clean water in residential, commercial, and hospitality facilities has become an increasingly important engineering challenge. Drinking water system is even more crucial to be designed since it will relate to the safety and deterioration quality (Li et al., 2024).

Estimating water demand is a crucial phase in the design of building water supply systems. Conventional methods depend on actual consumption rates derived from building occupancy and functional utilization. Research by (Al-Jayyousi, 2003; House-Peters & Chang, 2011; Rafsanjani et al., 2021; Suárez-Varela, 2020) underscores the need of precise demand forecasting for maintaining system dependability and minimizing the oversizing of storage and plumbing infrastructure. In high-rise applications, demand variability can substantially impact system pressure stability and energy consumption.

The hydraulic design of water distribution systems in high-rise buildings entails intricate factors such as pressure zoning, pump selection, pipe sizing, and storage tank configuration. (Swamee & Sharma, 2008) asserts that vertical water distribution necessitates meticulous assessment of head losses and static pressure fluctuations across the height of the building. Insufficient pressure regulation may result in pipe leakage, fixture failure, or increased energy expenditure. Selection of ideal pipe diameter is also crucial for balancing installation costs and operational energy expenses.

Recent research has examined the amalgamation of plumbing systems with gravity-driven distribution methods to enhance energy efficiency. (Ramos et al., 2010) examined the benefits of hybrid water supply systems in diminishing peak pump operation and improving system resilience. Furthermore, (Menke et al., 2016) established that optimizing pump scheduling and analyzing demand patterns can markedly decrease energy usage in building water supply systems.

The planning and design of plumbing systems must be conducted in parallel with architectural and structural design processes. Integrating these systems early in the design stage ensures that space requirements, hydraulic performance, and system reliability are appropriately addressed. For high-rise buildings, this coordination is especially critical, as water distribution must overcome significant vertical distances, varying pressure requirements, and fluctuating daily needs according to the standard. Failure to properly plan a plumbing system can lead to operational inefficiencies, water shortages, excessive energy use, and costly retrofits. The challenge of clean water distribution becomes more pronounced in multi-story buildings, such as hotels, office towers, and apartment complexes. In such structures, water must be delivered evenly and consistently across multiple floors. Pressure levels at fixture units must remain within acceptable ranges to ensure usability while avoiding excessive forces that could damage fixtures or cause leaks. According to (Ir Sunarno, 2005), successful clean water installation requires attention to system components, transfer methods, and supply mechanisms in line with established plumbing standards. One of the fundamental design requirements is that the minimum pressure at the fixture outlet should be approximately 1 bar (1 kg/m^2), sufficient to allow proper water flow without user inconvenience. According to recent studies, visitor behavior and appliance type have a significant impact on hotel water consumption. In the Canary Islands, for instance, Ruiz-Rosa et al. (2023) discovered significant variance in consumption per guest-night among hotels.(Antonova et al., 2023).

In construction building, the plumbing system represents one of the most vital services. A plumbing system encompasses a network of pipes and associated components designed to deliver water and remove wastewater in a safe, efficient, and sustainable manner. Broadly, it includes several subsystems: clean water distribution, hot water supply, wastewater disposal, sanitation, and fire protection (Putu et al., 2023). Among these, the clean water installation system holds a central position, as it ensures that occupants receive adequate volumes of water for drinking, cooking, cleaning, bathing, and other daily activities since it will relate to pump selection, efficiency, and long-term operational and cost consideration (Jatmika et al., 2021), (Kondus et al., 2023). A well-designed plumbing system not only enhances comfort but also contributes to the overall safety and efficiency of a building, including water saving, the green building approach and sustainability (Thebuwena et al., 2024), (Cai et al., 2024).

As worldwide focus on sustainable infrastructure intensifies, the design of water distribution systems is increasingly assessed based on life-cycle performance and environmental effect. (Gleick, 2014) underscored the necessity for effective water and energy management in urban structures to facilitate sustainable development objectives. Energy consumption linked to water pumping systems is recognized as a significant operating cost factor, especially in high-rise buildings where substantial elevation heads are present.

Moreover, contemporary building services engineering methodologies promote integrated design frameworks that consider demand modeling, hydraulic efficiency, redundancy, and maintainability. (Walski et al., 2003) observed that effective engineering design must reconcile theoretical optimization with operational dependability and cost-effectiveness.

In addition to pressure considerations, the selection of piping materials and diameters plays a decisive role in system performance. Pipes with rough internal surfaces increase friction losses, thereby reducing effective pressure and flow. Inappropriate pipe sizing can lead to excessive velocities, which in turn generate noise, vibration, and accelerated wear in the system. Modern plumbing practice therefore emphasizes the importance of using smooth, durable pipe materials, such as polypropylene random (PPR) (Zgoul et al., 2008), and selecting diameters based on calculated flow rates and acceptable head losses.

To achieve reliable performance and compliance with safety regulations, plumbing systems must be designed in accordance with national and international standards. In Indonesia, the design of clean water installations is guided by Indonesian National Standard SNI 03-7065-2005 (Procedures for Planning Building Plumbing Systems) and SNI 8153:2015 (Plumbing Systems for Clean Water in Buildings) (Badan Standarisasi Nasional, 2005, 2015). These standards provide comprehensive criteria covering water needs estimation, pipe sizing, pump selection, storage requirements, and installation practices. By adhering to such standards, engineers can ensure that plumbing systems meet the dual objectives of technical reliability and regulatory compliance.

Notwithstanding the existence of basic design standards and hydraulic modeling studies, there persists a want for case-specific engineering evaluations that illustrate the implementation of integrated water supply system design in actual high-rise hospitality structures. Such studies can yield pragmatic insights into demand prediction techniques, hybrid distribution tactics, and system sizing considerations within the framework of local regulatory constraints.

This study seeks to enhance the current knowledge base by offering a detailed design framework for a clean water installation system in a multi-storey hotel, incorporating empirical demand estimation, hydraulic analysis, pump selection, and distribution system optimization with focusing on the plumbing design of a large-scale hotel and ballroom complex. The facility consists of three major functional zones:

1. Mall area: located from the basement up to the second floor, designed primarily for commercial and retail functions.
2. Hotel area: spanning from the third to the sixteenth floor, comprising guest rooms, service areas, and hospitality facilities.
3. Ballroom area: a separate structure intended for events, conferences, and large gatherings.

Among these, the hotel area presents the most complex challenge for clean water distribution due to its vertical span and high daily needs. The analysis in this research therefore concentrates on the hotel area, specifically from the third to the sixteenth floor. By narrowing the scope, the study provides a detailed investigation of design considerations most relevant to multi-story accommodation facilities.

Hotels are characterized by high variability in water usage, depending on occupancy rates, time of day, and types of activities. For example, peak needs often occur in the morning hours when guests shower and prepare for the day, or in the evening during dining and recreational activities. Designing a plumbing system that accommodates such fluctuating needs requires accurate estimation of daily consumption, realistic assumptions about usage periods, and appropriate storage and pumping solutions. In this research, the daily clean water requirement for the hotel area was calculated at 251 m^3/day, based on an assumption of average usage over 10 hours. The municipal waterworks system serving the building is capable of supplying approximately 283 L/min, a capacity considered adequate for meeting base needs. However, to ensure consistent distribution across all floors, additional systems such as transfer pumps, booster pumps, and gravity-fed storage are necessary. The study employs hydraulic calculations to determine pump capacities, required pipe diameters, and expected head losses. Specifically, the design process seeks to balance technical efficiency with economic feasibility by minimizing energy consumption, reducing unnecessary pipe oversizing, and selecting durable materials. By applying SNI 03-7065-2005 and SNI 8153:2015, the design adheres to nationally recognized best practices, thereby increasing reliability and safety in operation. The significance of this study lies in its practical contribution to building service engineering. First, it provides a systematic framework for designing clean water installations in high-rise hospitality facilities, integrating theoretical calculation methods with regulatory guidelines. Second, it presents a real-world case study, with quantitative results that include estimated water needs, pump capacities, pipe diameters, and material specifications. These results can serve as a reference for engineers, architects, and contractors engaged in similar projects.

Furthermore, the study emphasizes the importance of precision in system design. Overestimating water needs can lead to oversized pumps and pipes, resulting in unnecessary capital and operational costs. Conversely, underestimating needs may cause water shortages, inadequate pressure, and user dissatisfaction. By applying standardized methods and carefully analyzing needs, the research demonstrates how to achieve a balance between reliability, efficiency, and cost-effectiveness.

The remainder of this paper is structured as follows. Section 2 reviews relevant literature and previous studies on plumbing system design, with particular attention to high-rise applications. Section 3 outlines the methodology, including needs estimation procedures, pump sizing calculations, and pipe selection criteria. Section 4 presents the results of the design analysis for the hotel building, including calculated capacities, pipe lengths, and fitting requirements. Section 5 discusses the implications of these findings, and Section 6 concludes with recommendations for future applications and research.

II. RESEARCH METHOD

A 16-story hotel building's clean water consumption, storage tank capacity, pump performance, and pipe sizing were all meticulously calculated as part of this study's quantitative engineering methodology. The approach closely followed the Indonesian National Standards (SNI), namely SNI 03-7065-2005 and SNI 8153:2015 (Badan Standarisasi Nasional, 2005, 2015), which offer thorough instructions for plumbing system design and installation. Technical references like (Noerbambang & Morimura, 2005).

which highlight empirical and analytical techniques frequently used in plumbing design processes, significantly enhanced these standards. Credibility and reproducibility of the analytical procedure used in this study are guaranteed by the selected calculation framework's scientific backing and extensive validation in earlier research on water supply systems for high-rise buildings (SAYRIDDINOV, 2020), (Firdaus Namiroh et al., 2022).

The hotel portion of the building complex, which is separated into three primary functional areas—a shopping mall (basement–second level), the hotel tower (third–16th floors), and a ballroom housed in a separate structure—is the subject of the investigation. The subsequent design analysis and hydraulic modeling focused on the hotel tower, even though the initial water demand estimates were done for all three zones to estimate the complex's overall consumption. This choice was made because the hotel's water distribution system was more complicated, with more vertical head variances, fluctuating occupancy levels, and a variety of fixture types, including restrooms for guests, service areas, and cooking facilities.

The fixture-unit (UABP) method, which uses probabilistic demand modeling to translate individual fixture loads into equivalent flow rates, was used in the study to calculate water demand. This approach, which is also used in international standards like BS EN 806 and AS/NZS 3500, is still the most dependable for designing multi-story buildings since it can take fixture diversity and concurrent use variables into account (Müller et al., 2021), who examined the advantages and disadvantages of several water demand estimating techniques for high-rise applications, have also talked about the resilience of this approach.

The methodology of the design is divided into several main steps:

1. Calculation of clean water needs
2. Design of ground tank volume and pump room
3. Calculation of pump capacity, roof tank, and pipe sizing

This systematic framework ensures that each design stage—from estimating demand to determining equipment specifications—is interconnected, yielding a coherent and optimized clean water installation design aligned with both national standards and international best practices. Each stage is constructed as follows.

2.1. Calculation of clean water needs

This study begins with the calculation of daily clean water requirements for the entire building complex. Estimating water needs is a crucial step in the design of plumbing and water distribution systems. It establishes the necessary supply capacity from municipal waterworks, the volume of storage tanks, and the specifications for pumps and distribution pipelines. An accurate estimation of water demand ensures adequate supply during peak periods and prevents the oversizing of system components, thereby avoiding unnecessary construction and operational costs.

Clean water demand is estimated in accordance with SNI 03-7065-2005 and SNI 8153:2015, based on several key parameters such as building function, occupancy rate, and usage intensity. The standards establish a structured framework and per capita consumption data for various building types, including hotels, offices, and commercial centers, which serve as essential design references. To improve accuracy, the calculation method proposed by Noerbambang and Morimura (2005) was adopted, as it offers refined adjustment factors for specific facilities. Their method considers the distinct usage behavior in hotel operations, characterized by significant fluctuations in water consumption during morning and evening peaks, attributable to guest activities and service operations, in contrast to the more stable patterns observed in residential or office buildings.

In the hotel zone, daily water consumption was calculated by multiplying the total number of rooms by the assumed occupancy rate of two persons per room, and then by the standard consumption rate per person per day as outlined in the SNI guidelines. The total clean water requirement for the hotel area is calculated to be 251 m^3 per day, which is approximately 251,000 liters. It is acknowledged that average daily consumption is not uniformly distributed across a 24-hour cycle but rather concentrated within the standard 10-hour active period of guest and service operations. Consequently, this total was converted into an hourly design flow to reflect peak demand conditions. The resulting figure establishes the baseline for determining the sizes of transfer pumps, booster pumps, and pipe diameters utilized in both vertical and horizontal distribution systems.

The clean water requirement for the mall area was determined by calculating the gross floor area (GFA) of each level and multiplying it by the recommended water consumption per square meter as specified by SNI for commercial spaces. This method offers an accurate assessment of facilities characterized by high visitor turnover and transient occupancy. For the ballroom facility, water demand was calculated based on the maximum anticipated number of guests and staff during peak events, such as weddings or conferences, characterized by short-duration, high-intensity water use.

The calculations are essential for planning the overall water supply system of the complex; however, the detailed hydraulic and mechanical design primarily targets the hotel tower due to its significant engineering challenges. The demand in the hotel sector is characterized by increased dynamism and heightened complexity in vertical distribution, attributable to the building's height and the diverse range of services offered on each floor. The total clean water requirement for all functional zones, including the mall, hotel, and ballroom, is approximately 335 m^3 per day (335,000 liters). The hotel tower comprises 14 floors above the podium, featuring the following vertical configuration:

- 3rd floor: 5.0 m
- 4th floor: 6.5 m
- 5th–14th floors: 4.2 m each
- 15th floor: 5.0 m
- 16th floor: 6.0 m

The differing floor-to-floor heights are crucial in hydraulic calculations as they directly impact the static head that pump systems must overcome and influence pressure balancing throughout the distribution network. Thus, the following design steps—namely, determining pump head, pipe diameter, and tank elevation—are intricately connected to these geometric and functional characteristics.

The vertical distribution necessitates considerable static head requirements that must be meticulously considered in pump selection and pipe network design to maintain consistent water pressure at all outlets, including the highest service points. The differences in floor elevations, spanning from the podium to the 16th floor, result in a significant variation in hydraulic head, which directly influences the energy consumption of the pumping system and the pressure rating of the pipes. The design must include precise head-loss calculations that consider static head, frictional losses, minor losses from fittings and valves, and dynamic variations from simultaneous fixture usage. To address these challenges, the system may incorporate pressure zoning, booster pumps, or pressure-reducing valves (PRVs) at specific levels to ensure optimal operating conditions throughout the building.

The elevation differences directly affect the distribution efficiency and reliability of the clean water supply system. An unbalanced design may cause excessive pressure on lower floors and insufficient flow on upper floors, resulting in operational inefficiencies and possible pipe damage. Consequently, it is essential to assess static head and pressure variations alongside pump curve analysis and system curve development, ensuring that the chosen pumps function close to their best efficiency point (BEP). These considerations are crucial for attaining hydraulic stability and ensuring long-term energy efficiency.

The clean water requirements for the hotel, mall, and ballroom areas, as summarized in Tables 1, 2, and 3, provide essential data for the subsequent design stages, including the determination of tank volumes, pump capacities, and pipe diameters. The tabulated results illustrate the distribution of water demand across various functional zones and provide a framework for assessing the contribution of each subsystem to the total supply load of the complex. The incorporation of these quantitative results guarantees that the design methodology is both technically robust and consistent with established engineering standards for large-scale building water supply systems.

Table 1. The calculated of clean water needs for the hotel building area

Floor	Clean Water Needs (Liter)
3	13540
4	16990
5 - 14	202500
15	100
16	17230
Total	251000

Table 2. The calculated of clean water needs for the mall building area

Floor	Clean Water Needs (Liter)
Basement 1	3737
Ground Floor	7783
1	14465
2	15195
Total	42000

Table 3. The calculated of clean water needs for the ballroom building area

Floor	Clean Water Needs (Liter)
Basement 1	987
Ground Floor	2034
1	703

continued on following page

Table 3. Continued

Floor	Clean Water Needs (Liter)
Mezzanine	318
2	31478
3	6248
Total	42000

2.2. Design of ground tank volume and pump room

After determining the water demand, the next stage is the design of the groundwater storage tank, which is a critical component of the overall water supply system. This tank's main function is to provide a consistent and dependable water supply, especially during times when municipal water input may be temporarily disrupted, diminished, or subject to pressure variations. The ground tank serves as a buffer, enabling the system to function autonomously for a specified period without affecting service to the upper floors. Standard engineering practice and the provisions outlined in SNI 03-7065-2005 dictate that the tank must be designed to accommodate a minimum of one full day's water demand for the building, along with supplementary reserve capacity for firefighting, maintenance activities, and unexpected consumption increases. In high-rise applications, such as hotels, the safety margin is crucial due to occupancy variability and peak demand associated with guest usage during specific hours.

The calculated water requirements indicate that the proposed tank dimensions should be 12,200 mm × 8,570 mm × 4,500 mm, featuring an operational water depth of 3.2 meters. This configuration produces a volume that meets the daily consumption needs of the hotel tower while also offering a strategic buffer for operational stability. The chosen dimensions were refined to accommodate the constraints of the basement space, while facilitating construction and future maintenance accessibility. The tank's design incorporates structural load distribution, water turnover rate, and sediment control, which are essential for maintaining water quality and preventing stagnation.

The pump room is located immediately next to the ground tank to reduce suction losses and enhance system efficiency. This room houses the transfer pumps that facilitate the movement of water from the ground tank to the roof storage tank. The layout was developed to enhance efficient flow paths, reduce head losses, and provide convenient access for inspection and maintenance. Attention is focused on the configuration of the suction and discharge piping, ensuring sufficient submergence to prevent pump cavitation and that the valve arrangement facilitates smooth operation and isolation during maintenance. The incorporation of non-return valves, pressure gauges, and vibration dampers enhances system reliability and operational safety. These considerations collectively create a design that improves hydraulic performance and operational resilience, consistent with contemporary best practices in building water management systems.

2.3. Calculation of capacity, top water tank and pipe size

The hotel's clean water distribution system comprises two primary pumping stages and one gravity-fed section, engineered to ensure consistent water delivery throughout all floors while upholding operational efficiency and reliability. The system must address the cumulative impacts of static head, frictional losses, and minor losses in the piping network, while maintaining stable flow and sufficient pressure at all fixtures during peak demand conditions. The appropriate sizing of pumps, roof tanks, and pipes is essential for optimizing energy efficiency and ensuring system longevity.

2.3.1. Transfer Pumps

The transfer pumps function as the first stage of the vertical distribution system, responsible for lifting water from the ground storage tank to the roof water tank located at the top of the 16-story building. The design capacity of these pumps is derived from the peak demand of the hotel zone, adjusted to account for head losses along both the suction and discharge lines. These losses arise from pipe friction, bends, valves, and fittings that restrict flow. The calculation results indicate a required capacity of approximately 418 liters per minute (L/min) for the transfer pump, corresponding to the maximum anticipated consumption rate during high-demand periods.

2.3.2. Booster Pumps

The booster pump system, located near the roof tank, constitutes the second stage of water distribution. These pumps are responsible for supplying pressurized water to all fixtures, particularly on the upper floors (11th–16th), where gravitational pressure alone is insufficient. The pumps are installed in a parallel alternate configuration, allowing them to operate alternately during normal conditions to balance wear, or simultaneously during high-demand periods.

The calculated capacity for the booster system is 750 L/min, ensuring that each fixture receives adequate flow and pressure even during simultaneous usage. The pressure range is designed according to SNI 8153:2015, which recommends maintaining outlet pressure between 1–4 bar, depending on fixture type and floor elevation. The booster system also integrates automatic pressure sensors and control panels, enabling adaptive operation and preventing over-pressurization of lower floors. This design ensures operational flexibility, energy efficiency, and redundancy—a key factor in maintaining uninterrupted water service for hospitality buildings where reliability is critical.

2.3.3. Gravity System

In addition to the pump-driven sections, a portion of the distribution network operates through a gravity feed system, particularly for the lower floors (3rd–10th). Water flows from the roof tank under the influence of gravitational potential energy, minimizing the need for mechanical pumping and reducing operational costs. The flow capacity through the gravity pipeline is estimated at 1,000 L/min, depending on the available static head, pipe diameter, and flow resistance within the network.

The design of the gravity system must balance pressure and flow to prevent excessive pressure buildup at lower levels, which could damage fittings or cause noise and vibration. Therefore, pressure-reducing valves (PRVs) may be installed on selected floors to stabilize the system. Using gravity-fed distribution also enhances energy efficiency, as it allows partial reliance on natural head pressure during off-peak periods when booster pumps can remain idle.Overall, the calculation of pump capacities, roof tank volume, and pipe sizing aims to achieve an effective, efficient, and sustainable water supply design. The equations and design principles are adapted from the literature study by Noerbambang and Morimura (2005), which provide validated analytical methods for determining head loss, pump performance, and optimal pipe diameters. These principles ensure that the resulting system not only meets functional requirements but also adheres to recognized engineering standards for reliability, safety, and energy efficiency in modern high-rise building plumbing systems.

- Average hourly water requirement

$$Q_h = \frac{Q_d}{t}$$

With:
Q_h: average water consumption (m^3/h)
Q_d: water consumption per day (m^3/h)
t: duration of usage (hours)

- Water usage during peak hours

$$Q_{h-max} = C_1 \times Q_h$$

With:
Q_{h-max}: water consumption at peak hours (m^3/h)
C_1: constant for building type use (2.0 for hotel building)
Q_h: average water consumption (m^3/h)

- Peak water usage at peak minutes

$$Q_{m-max} = \frac{(C_2 \times Q_h)}{60}$$

With:
Q_{m-max}: water consumption at peak hours (m^3/min)
C_1: constant for building type use (4.0 for hotel building)
Q_h: average water consumption (m^3/h)

- Transfer pump capacity

$$Q_h = \frac{Q_d}{t}$$

- Booster pump capacity

The capacity of the booster pump is obtained by calculating the number of units of plumbing equipment load based on the SNI standard (SNI 8153:2015)

- Supply capacity of municipal waterworks pipes

$$Q_s = \frac{2}{3} \times Q_h$$

- Top water tank

$$V_E = \left[\left(Q_p - Q_{h-maks} \right) T_p - \left(Q_u \times T_{pu} \right) \right]$$

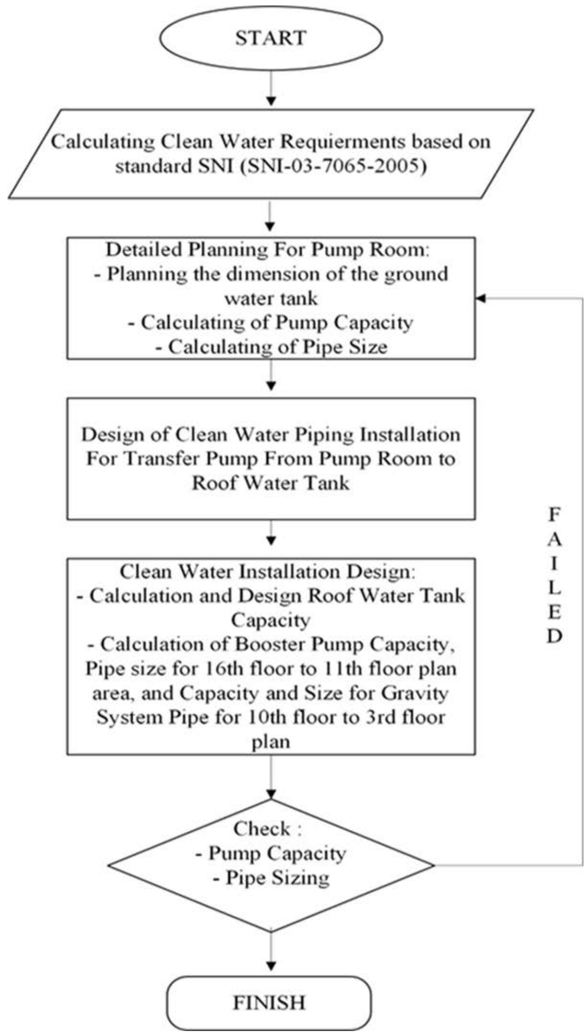
With:
Q_{h-max}: water consumption at peak hours (m^3/h)
V_E: effective capacity of the roof tank (m^3)
Q_P: peak requirement (m^3/min)
Q_{PU}: capacity of the filling pump (m^3/min)
T_P: peak requirement duration (min)
T_{PU}: filling pump working time (min)

- Pipe size

$$D = \sqrt{\frac{4Q}{v \times \pi}}$$

The research procedure for designing a clean water installation system in the hotel building can be seen in Figure 1:

Figure 1. Design flow diagram



III. RESULTS AND DISCUSSION

The design of the clean water installation system for the 16-storey hotel exemplifies the practical application of standardized hydraulic calculations combined with engineering decision-making. The results yield quantifiable metrics for water consumption, pump capacity, and pipe dimensions; nevertheless, a more profound analysis is required to assess system performance, efficiency, and relevance to comparable high-rise structures.

3.1. Clean Water Demand Characteristics and System Implication

The evaluation of clean water demand is fundamental to all subsequent design phases, as it directly impacts the capacity of storage tanks, specifications of pumps, and sizing of pipes within the system. An accurate assessment of this demand guarantees that the entire installation functions efficiently, avoiding the overdesign of components that may result in increased capital and energy expenditures. The design framework outlined in SNI 03-7065-2005 and SNI 8153:2015, indicates that the daily potable water requirement for the hotel area is 251 m^3, based on an average usage period of 10 hours per day. The value indicates an average hourly consumption rate of approximately 25.1 m^3/hour, which serves as the baseline for assessing the hydraulic load on the pumps and distribution network.

Adjustment coefficients from established literature were applied to model peak demand scenarios, ensuring the system's responsiveness to operational fluctuations. During periods of high usage, such as morning guest activity or evening service operations, the instantaneous water requirement was observed to nearly double the average hourly rate, with peak-minute demands potentially reaching four times the average. These conditions underscore the variable characteristics of hotel water consumption, characterized by swift fluctuations in flow rate over brief periods. The findings highlight the necessity of developing a system that incorporates sufficient surge capacity and pressure stability, thereby guaranteeing user comfort and uninterrupted service without notable pressure fluctuations or flow irregularities.

Parallel assessments were conducted for the retail and ballroom areas, each contributing an additional 42 m^3/day to the total daily water demand of the building complex. While these areas constitute minor segments of the overall consumption profile, they nonetheless impact the dimensions of shared infrastructure, including the groundwater tank and transfer pump capacity. This study primarily examines the hotel tower, specifically the 3rd to 16th floors, as this segment demonstrates significant variations in water demand and distribution challenges due to its vertical height and diverse service functions.

The hotel's vertical layout, which includes guest rooms, service corridors, kitchens, and housekeeping facilities, results in a non-uniform distribution of water demand among the floors. Guestroom floors exhibit synchronized peaks during morning and evening hours, whereas back-of-house and service floors demonstrate a moderate yet continuous flow. The identified usage patterns underscore the importance of implementing zonal pressure management and dual pumping stages (transfer and booster systems) to ensure consistent flow conditions across the building. The incorporation of booster pumps for upper floors alongside gravity-fed systems for lower levels exemplifies an effective hybrid strategy that optimizes energy performance and hydraulic reliability.

The results of the water demand calculation establish a quantitative foundation for subsequent design steps and highlight the interdependence between water consumption patterns and mechanical system design. Comprehending these relationships is essential for enhancing infrastructure performance and user satisfaction, especially in high-rise hospitality establishments where comfort, continuity, and reliability are critical.

- Average clean water needs per hour (hotel building area)

$$Q_h = \frac{251\, m^3}{10\, hours} = 25.1\, \frac{m^3}{h}$$

- Water usage during peak hours

Based on (Noerbambang & Morimura, 2005), the need for clean water for the hotel building area is assumed to be an average of 10 hours.

$$Q_{h-max} = C_1 \times Q_h$$

$$Q_{h-max} = 25.1\frac{m^3}{h} \times 2 \; = \; 50.2\frac{m^3}{h} \; = \; 0.83\,\frac{m^3}{min}$$

- Water usage at peak minutes

$$Q_{m-max} \; = \; \frac{\left(C_2 \times Q_h\right)}{60}$$

$$Q_{m-max} \; = \; \frac{(4 \times 25.1\ {}^{m^3}\!/_{h})}{60} \; = \; 1.67\,\frac{m^3}{min}$$

- Municipal waterworks supply pipe capacity for hotel building area

$$Q_s \; = \; \frac{2}{3} \times Q_h$$

$$Q_s \; = \; \frac{2}{3} \times 25.1\,\frac{m^3}{h} \; = \; 17\frac{m^3}{h}$$

The calculated daily water demand of 251 m^3/day for the hotel area reflects a typical consumption pattern for high-rise hospitality facilities, where demand is highly concentrated within limited operational hours. The assumption of a 10-hour usage period leads to significantly higher peak demand, which directly influences pump sizing and storage requirements. This concentration of demand highlights a key design challenge in high-rise systems specifically balancing average demand with peak demand conditions to avoid excessive capital cost and inefficient pump operation at partial loads. Moreover, this balanced condition can reduce the risk of pressure instability. Therefore, the selected design approach, which incorporates both storage tanks and staged pumping, represents a compromise between reliability and efficiency.

3.2. Hybrid Distribution Strategy with Gravity and Booster System

One of the most important design decisions in this study is the use of a hybrid distribution system, where:

- Lower floors (3rd–10th) are supplied using gravity flow
- Upper floors (11th–16th) are supplied using booster pumps

A groundwater tank with dimensions of 12,200 × 8,570 × 4,500 mm was developed based on the assessed needs, operated at a water depth of 3.2 m. This offers adequate storage to provide a minimum of one day's needs for the hotel tower, along with supplementary reserve capacity for safety and firefighting purposes.

The roof tank serves a similarly vital function. Situated at its highest point of the structure, it facilitates water distribution via gravity to the lower floors and provides the suction side for booster pumps servicing the top levels. This dual purpose underscores the significance of precise sizing: undersizing sufficient risk during peak times, whilst oversizing incurs superfluous construction and maintenance expenses. Capacity of the roof tank, the upper tank calculated using followed equation:

$$V_E = \left[(Q_p - Q_{h-maks})\, T_p - (Q_u \times T_{pu}) \right]$$

$$V_E = \left[\left(1.67\,\frac{m^3}{min} - 0.83\,\frac{m^3}{min} \right) 30min - \left(1.67\,\frac{m^3}{min} \times 15min \right) \right] = 50.25\, m^3$$

This configuration offers engineering advantages in energy efficiency since gravity distribution reduces reliance on continuous pumping and lowering energy consumption. The pressure rise also can be controlled more effectively and reduce the possibility of pipe leakage and fitting failure since water pressure naturally decreases with elevation when using gravity distribution. Another advantage is that the combination of roof tank, gravity distribution and booster pump can contribute to a more reliable system.

3.3. Pump Capacity and Operational Consideration

The needs estimates indicated that the necessary transfer pump and booster pump capacity is 418 L/min and 750 L/min respectively which reflect the peak demand conditions derived from UABP analysis.

3.3.1. Transfer pump capacity

The transfer pump transports water from the underground tank to the rooftop tank. The needs estimates indicated that the necessary transfer pump capacity is 418 L/min. A centrifugal pump was chosen because to its suitability for continuous operation and efficiency in handling the moderate heads necessary for vertical transfer. The capacity guarantees that the roof tank can be filled within reasonable timescales, even during peak consumption, and facilitates reserve replacement during interruptions in municipal supplies. The capacity of the transfer pump can be determined by calculating the need for clean water per min:

$$Q_h = \frac{251\, m^3}{10\, hours} = 25.1\,\frac{m^3}{h} = 418\; L/min$$

3.3.2. Booster pump and gravity pipe capacity

Booster pumps are used to increase fluid pressure and ensure acceptable pressure and flow at fixture outlets located at higher elevations. In practice, booster systems for high-rise buildings are commonly configured with two or more pumps arranged to operate in parallel and alternately; this provides both operational flexibility (automatic staging) and redundancy for maintenance or pump failure.

In this project the booster system is dedicated to serving the upper hotel floors where static head requirements are highest. The booster pumps are designed to supply the 11th–14th floors (guest rooms) and the 16th floor (kitchen and sanitary facilities). The load served by the boosters is therefore the aggregated needs of:

- Four guest floors (11th–14th) with 144 rooms total
- Service rooms on the 16th floor (1 kitchen and 2 bathrooms).

Floors 3 through 10 are served by a gravity distribution system fed from the roof tank; these floors rely primarily on available static head and appropriately sized gravity mains.

Capacity for both the booster pumps and the gravity distribution pipes was determined by the standard fixture-unit method (UABP unit) as specified in the applicable SNI standards. The procedure used is as follows:

1. Inventory fixtures / plumbing tools on the floors served by the booster system (showers, toilets, faucets, kitchen fixtures, etc.) and assign each a UABP value per SNI tables.
2. Sum the UABP for all fixtures served by the booster
3. Convert the sum of UABP to a design flow (L/min) using the SNI conversion table or formula that maps total UABP to an equivalent flow rate (this conversion reflects probabilistic simultaneity factors and peak needs behaviour).
4. Apply operating-time and safety factors where appropriate. Capacity for booster pumps and gravity system pipes is obtained by calculating the unit load of plumbing tool (UABP) value against the number of plumbing tools available and converting it into liters per minute.

The plumbing equipment load unit (UABP) for 1 room consists of:

- Closet (gravity tank > 6 L per flush (LPF)): 1 unit x 3 UABP = 3 UABP
- Shower: 1 unit x 2 UABP = 2 UABP
- Lavatory: 1 unit x 1 UABP = 1 UABP
- Total 1 room = 6 UABP
- Total UABP from 11th to 14th floor: 6 UABP x 144 rooms = 864 UABP

The 15th floor load unit consists of:

- Hosebib: 3 unit x 2,5 UABP = 7,5 UABP

The 16th floor load unit (restaurant area) consists of:

- Closet (gravity tank > 6 LPF): 5 units x 5.5 UABP = 27.5 UABP
- Urinal (flushing tank): 3 units x 2 UABP = 6 UABP
- Lavatory: 5 unit x 1 UABP = 5 UABP
- Hose bib (kran): 1 unit x 2,5 UABP = 2,5 UABP
- Kitchen Sink: 20 unit x 2 UABP = 40 UABP
- Total UABP on the 16th floor: 68.5 UABP
- Total UABP score on the 11th – 16th floor = 952.5 UABP or 953 UABP

The design of booster pumps and gravity pipes necessitates an accurate assessment of needs, determined by the quantity and kind of plumbing fixtures present in the structure. The technique outlined by the Indonesian National Standard (SNI 03-7065-2005 and SNI

8153:2015) was utilized, employing the idea of *Unit Beban Alat Plambing* (UABP) or plumbing fixture unit load. Each fixture is allocated a UABP coefficient that indicates its likelihood of concurrent usage and flow needs. The overall building needs is calculated by combining the UABP values for all fixtures and then converting the total UABP into flow rate (L/min) utilizing SNI conversion tables.

a. Load Unit per Hotel Room

For the standard hotel guest room, the plumbing fixtures consist of a water closet (gravity tank type, > 6 LPF), one shower, and one lavatory. According to SNI tables, these correspond to unit loads of 3 UABP, 2 UABP, and 1 UABP respectively. Thus, the total for one room is:

UABProom=3+2+1=6UABP_{room} = 3 + 2 + 1 = 6 UABP room=3+2+1=6

This value was applied consistently across all typical guest rooms in the building.

b. Floors Served by Gravity System

The lower guestroom floors (10th to 5th) are supplied by the gravity system. In total, 216 rooms are distributed across these levels. Multiplying by the load per room gives:

UABP10−5=6×216=1296UABP_{10-5} = 6 \times 216 = 1296UABP10−5=6×216=1296

On the 4th floor, the primary load comes from 20 kitchen sinks, each assigned a coefficient of 2 UABP. This results in:

UABP4=20×2=40UABP_{4} = 20 \times 2 = 40UABP4=20×2=40

On the 3rd floor, which contains a variety of public and service facilities, the loads are more diverse. The calculation is as follows:

- Water closet (10 units × 3 UABP) = 30
- Urinal stall (6 units × 2 UABP) = 12
- Lavatory (9 units × 1 UABP) = 9
- Hose bib (5 units × 2.5 UABP) = 12.5
- Shower (8 units × 2 UABP) = 16

Summing these gives a total of 79.5 UABP for the 3rd floor.

The overall UABP for floors 10 through 3 is therefore:

UABPgravity=1296+40+79.5=1415.5≈1406UABP_{gravity} = 1296 + 40 + 79.5 = 1415.5 \approx 1406UABPgravity=1296+40+79.5=1415.5≈1406

This value represents the effective fixture unit load to be supplied by the gravity piping network.

c. Conversion to Flow Rate

After determining the total UABP, the subsequent step involves converting this value into an equivalent design flow rate. The SNI indicates that the relationship between UABP and flow is non-linear and includes a probabilistic simultaneity factor. In cases of larger totals, the peak flow is lower than the sum of individual flows, since not all fixtures operate concurrently. According to the SNI conversion chart, a load of approximately 1406 UABP correlates with a flow needs between 950 and 1050 L/min. The design flow for the gravity-fed system was established at an upper limit of 1000 L/min to ensure safety and facilitate design considerations.

The flow value was utilized to ascertain pipe sizing, ensuring that velocities are maintained within the recommended range (typically 1.0–2.0 m/s for distribution mains) and that head losses do not jeopardize minimum pressure at the fixtures.

d. Booster Pump Loads

The calculation method previously described for the gravity-fed system was similarly utilized in the design of the booster pump system, as both depend on the conversion of total fixture-unit loads (UABP) into flow rates according to SNI standards. The booster system is essential as the static head of the top levels surpasses the gravity distribution system's ability to provide sufficient pressure. This hotel project includes booster pumps intended to service the 11th to 14th floor, comprising 144 guest rooms (36 rooms per floor), and the 16th floor, which contains a service kitchen and two restrooms. The top floors are the most hydraulically needsing regions of the building because of their height, necessitating pressurization that exceeds the capacity of the roof tank alone. Calculated number of tools and UABP values in the hotel building area provided in Tabel 4.

In the gravity system calculation, each guest room was allocated a load of 6 UABP, which includes a water closet, a shower, and a lavatory. The multiplication of 144 rooms results in 864 UABP. The additional requirement for the 16th floor includes a kitchen sink and sanitary fittings. The 16th level adds roughly 40–50 UABP, resulting in a cumulative total of around 915 UABP. According to the SNI conversion table, this corresponds to a design flow of about 750 L/min, indicating the highest probable simultaneous needs for the booster-served floors.

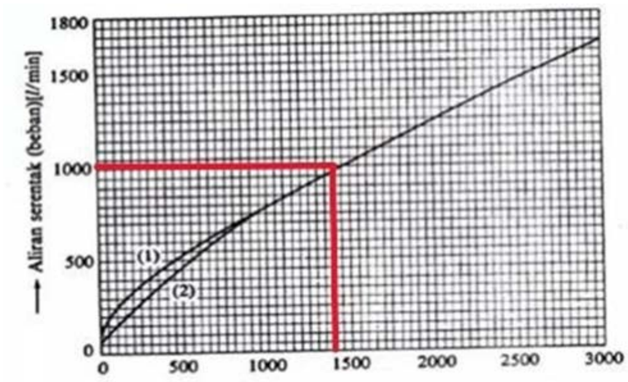
The booster system was developed with two identical centrifugal pumps configured in a parallel arrangement to enhance reliability and operating flexibility. Each pump is designed to provide a minimum of 50–60% of the total design flow, indicating that often only one pump is necessary for regular operation, although both can function concurrently during high needs periods. This configuration offers redundancy; if one pump malfunctions or necessitates maintenance, the second may still fulfill a significant percentage of the needs, preventing service disruption for hotel guests.

Table 4. Calculated number of tools and UABP values in the hotel building area

Floor	Types of plumbing tools	Number of tools	Plumbing equipment load unit (UABP)	Total
14 - 11	Closet	144	3	432
	Shower	144	2	288
	Lavatory	144	1	144
15 - 16	Urinal	3	5,5	16,5
	Kitchen Sink	20	2	40
10 - 5	Closet	216	3	648
	Shower	216	2	432
	Lavatory	216	1	216
4	Kitchen Sink	20	2	20
3	Hose Bib	5	2,5	12,5
	Urinal	6	2	12
	Shower	8	2	16
	Lavatory	9	1	9
	Closet	10	5,5	55

Therefore, from the UABP value data obtained converted into pump capacity in liters per minute (lpm), the capacity of the *booster* pump was obtained at 750 lpm. This conversion provided at Figure 2.

Figure 2. Conversion of UABP values of booster pumps to liters per minute



For clean water pipes using a gravity system using the same principle for the booster pump system by calculating the unit load of plumbing tool (UABP) value for each floor:

Load unit for 1 room consists of:

- Closet (gravity tank > 6 LPF): 1 unit x 3 UABP = 3 UABP
- Shower: 1 unit x 2 UABP = 2 UABP
- Lavatory: 1 unit x 1 UABP = 1 UABP
- Total 1 room: 6 UABP
- Total UABP from 10th to 5th floor: 6 UABP x 216 rooms = 1296 UABP

The 4th floor load unit consists of:

- Kitchen Sink: 20 unit x 2 UABP = 40 UABP
- Total UABP on the 16th floor: 40 UABP

The 3rd floor load unit consists of:

- Closet (gravity tank > 6 LPF): 10 units x 5.5 UABP = 30 UABP
- Urinal Stall (flushing tank): 6 units x 2 UABP = 12 UABP
- Lavatory: 9 unit x 1 UABP = 9 UABP
- Hose bib: 5 unit x 2,5 UABP = 12,5 UABP
- Shower: 8 unit x 2 UABP = 16 UABP
- Total UABP from 10th to 3rd floor: 1405.5 ≈ 1406 UABP

Therefore, from the unit load of plumbing tool (UABP) value data obtained converted into pump capacity in liters per minute (lpm), the gravity pipe capacity is obtained at 1000 lpm. This can be seen in Figure 3 and calculated UABP provided in Table 5.

Figure 3. Conversion of UABP value of gravity pipe to liters per minute

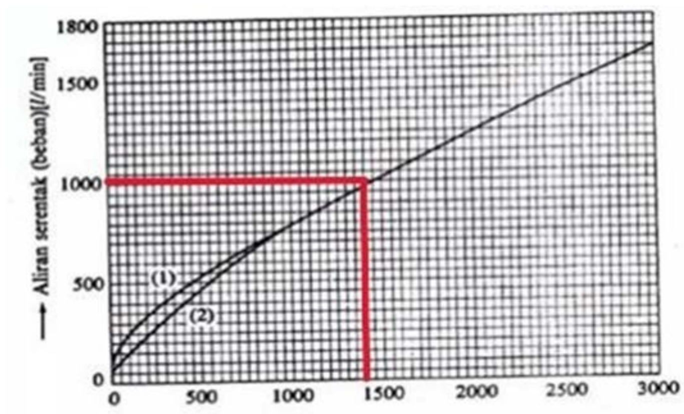


Table 5. UABP table based on standard SNI 03-7065-2005

No	Type of plumbing tools	Personal (UABP)	General (UABP)
1	Bathtub	2	4
2	Bedpan Washer	-	10
3	Combined sink and washing tray	3	-
4	Dental unit or spitting	-	1
5	Hand washing basin for dentist	1	1
6	Kitchen sink	2	2
7	Laundry tub	2	4
8	Service sink	2	4
9	Pedestal filtration	-	10
10	Urinal stall (wall lip model)	-	5
11	Urinal stall (flushing tank model)	-	3
12	Wash Basin	-	2
13	Closet with flush valve	6	10
14	Closet with flush tank	3	5
15	Drinking water jets	1	2

Pump load efficiency due to energy consumption and parallel pump configuration in this study is therefore appropriate, as it follows staged operation and improved efficiency under varying demand. However, the use of Variabel Speed Drive pump is also potential for future implementation.

3.4. Pipe Sizing and Hydraulic Performance

The size of the pipe in this study was calculated by the capacity of each pump that had been obtained. Based on the SNI 03-7065-2005 standard, the maximum water velocity is 2 m/s. In this study, PPR-PN.10 type pipe is used (Zgoul et al., 2008).

- Pipe size for transfer pump

$$D = \sqrt{\frac{4Q}{v \times \pi}}$$

$$D = \sqrt{\frac{4 \times 0.0069\, {}^{m^3}\!/_{s}}{2\, {}^{m}\!/_{s} \times \pi}} = 0.66294\ m \approx\ 73.6\ mm$$

- Municipal waterworks supply pipe size

$$D = \sqrt{\frac{4Q}{v \times \pi}}$$

$$D = \sqrt{\frac{4 \times 0.0047\, {}^{m^3}\!/_{s}}{2\, {}^{m}\!/_{s} \times \pi}} = 0.0547\ m \approx\ 61.4mm$$

- Booster pump pipe size

$$D = \sqrt{\frac{4Q}{v \times \pi}}$$

$$D = \sqrt{\frac{4 \times 0.0125\, {}^{m^3}\!/_{s}}{2\, {}^{m}\!/_{s} \times \pi}} = 0.089229\ m \approx\ 90\ mm$$

- Gravity pipe size

$$D = \sqrt{\frac{4Q}{v \times \pi}}$$

$$D = \sqrt{\frac{4 \times 0.01666\, {}^{m^3}\!/_{s}}{2\, {}^{m}\!/_{s} \times \pi}} = 0.1030\ m \approx\ 103\ mm$$

The pipeline is planned to use PPR-PN.10 material. Based on the availability of PPR-PN.10 pipes, PPR-PN.10 pipes with an inner diameter of 130.8 mm and an outer diameter of 160 mm were chosen, but in order for the capacity of the transfer pump to have the same value as the gravity pipe, the size of the gravity pipe has the same diameter as the transfer pump pipe. The length of each is obtained based on the design drawing of the building's clean water installation, so the length of pipes and fittings is needed as shown in Table 6.

Table 6. Table of size, length, and number of fittings of pipe

Function of the Pipe	Pipe Diameter (mm)	Pipe Length (m)	Number of *fittings*
Municipal waterworks supply pipe	61,4	200	6
Transfer Pump Pipe	73,6	133	12
Booster Pump Pipe	90	370	40
Gravity Pipe	73,6	186	22

IV. CONCLUSION

This study outlines the planning and design of a clean water installation system for a 16-story hotel structure, utilizing the Indonesian National Standards SNI 03-7065-2005 and SNI 8153:2015 as primary design references. The fixture unit approach (UABP) was employed to accurately and efficiently ascertain daily needs, pump capacity, and pipe dimensions.

The main conclusions are as follows:

1. The needs for clean water in the hotel area was determined to be 251 m^3 per day, based on an average operational duration of 10 hours. This value serves as the foundation for calculating tank capacities, pump dimensions, and pipe diameters.
2. The groundwater tank was engineered with a enough capacity (about 12200 × 8570 × 4500 mm with a water depth of 3.2 m) to meet daily requirements while preserving operational reserves. The roof tank functions as the principal distribution source, providing gravity-fed supplies to the lower levels and suction feed to the booster pumps.
3. The transfer pump capacity was established at 418 L/min, guaranteeing dependable water transport from the ground tank to the roof tank.
4. For the upper floors (11th–16th), the booster pumps were calibrated to provide approximately 750 L/min, predicated on a total load of roughly 920–950 UABP. Two identical pumps functioning in a parallel-alternate configuration were proposed to ensure redundancy, operational flexibility, and energy savings.
5. The gravity system for the 3rd to 10th floors necessitated a flow rate of around 1000 L/min, based on a fixture load of approximately 1400 UABP. Pipes were dimensioned to sustain velocities within prescribed limits, thereby reducing head losses, noise, and erosion.
6. The length of the pipe required for the clean water transfer process is 133 meters, for the municipal waterworks pipe is 200 meters, for the booster pump pipe is 370 meters, and the gravity pipe is 186 meters.
7. The number of fittings required for transfer pumps is 12 pieces, for municipal waterworks pipes as many as 6, for booster pump pipes as many as 40 pieces, and gravity pipes as many as 22 pieces.
8. The selection of PPR-PN.10 pipe material guarantees durability, minimal frictional resistance, and compliance to pressure ratings, with diameters varying from 61.4 mm to 130.8 mm based on the application (municipal supply, transfer, booster, or gravity).

The findings indicate that using UABP-based needs analysis in compliance with SNI requirements results in a dependable and effective design of clean water installation systems in high-rise structures. The integration of gravity distribution for lower levels and booster pumps for upper levels constitutes a cost-efficient and technically robust approach. Further studies may enhance this study by integrating seasonal needs fluctuations, pump energy performance, and intelligent monitoring systems to optimize operational efficiency and sustainability.

The selected diameters ensure controlled flow, reduced friction losses and minimized noise and vibration. However, the capital cost, head loss, and energy consumption as trade-off between smaller pipe size and larger pipe size is considered to contribute the robustness in this study and engineering design as the design use dual booster pump configuration, hybrid distribution ground tank and roof tank storage, separated gravity and pressurized zones. This results is expected to gain lower energy consumption, controlled water pressure with simpler operational complexity. Variable speed pump, Smart water monitoring system and demand-based pump controlled may contribute as future improvement.

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