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Renewable-Powered HVAC and Smart Ventilation Systems for Sustainable Hospital Environments

Ch. Venkateswara Rao, V M Periyasamy
UNIVERSITY OF TECHNOLOGY AND APPLIED SCIENCES,
SONA COLLEGE OF TECHNOLOGY

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[1]Ch. Venkateswara Rao, Senior Lecturer, Engineering Department, Electrical and Electronics Unit, University of Technology and Applied Sciences, Salalah, Dofar, Sultanate of Oman, chvr5816@gmail.com

[2]V M Periyasamy, Assistant Professor, Department of EEE, Sona College of Technology, Salem, Tamilnadu.swamymp@gmail.com

Abstract

The transition toward sustainable healthcare infrastructure necessitates the integration of renewable energy technologies within critical hospital systems, particularly Heating, Ventilation, and Air Conditioning (HVAC) units. This chapter investigates the design, control, and optimization of renewable-powered HVAC systems and smart ventilation strategies tailored for healthcare environments. Emphasis is placed on hybrid architectures that incorporate solar, wind, and geothermal sources to ensure continuous thermal regulation while significantly reducing carbon emissions. Advanced energy management systems (EMS) and adaptive control mechanisms, including logic-based automation and real-time energy source allocation, are examined for their role in maintaining indoor environmental quality under dynamic clinical and energy conditions. The interplay between renewable energy variability and HVAC load profiles is analyzed through simulation-based performance evaluations and lifecycle cost assessments, structural, acoustic, and regulatory considerations for deploying renewable systems in urban hospital settings are addressed to ensure feasibility and compliance with international health and energy standards. By synthesizing multidisciplinary insights, this chapter provides a comprehensive framework for designing resilient, energy-efficient, and patient-centered HVAC solutions powered by renewables. The content serves as a foundational reference for healthcare planners, engineers, and sustainability policymakers seeking to align medical infrastructure with global decarbonization goals.

Keywords: Renewable HVAC, Energy Management Systems, Smart Ventilation, Hospital Infrastructure, Hybrid Energy Systems, Thermal Regulation.

Introduction

The global healthcare sector is under mounting pressure to reduce its environmental footprint while maintaining uninterrupted and high-quality service delivery [1]. Hospitals, as critical infrastructure, operate continuously and consume a substantial share of energy for functions such as heating, ventilation, air conditioning (HVAC), sterilization, and lighting [2]. Among these, HVAC systems account for a significant proportion of energy demand due to the need to ensure precise indoor climate control, filtration, and air quality in diverse functional zones including operating theatres, intensive care units, and isolation rooms [3]. Traditional HVAC systems, largely powered by grid electricity derived from non-renewable sources, contribute significantly to greenhouse gas (GHG) emissions [4]. This reality underscores the need for transitioning towards more sustainable HVAC models powered by renewable energy [5].

As the decarbonization of energy systems becomes a strategic global objective, renewable-powered HVAC technologies are gaining increasing relevance in hospital infrastructure design [6]. Solar photovoltaics, geothermal heat pumps, and wind energy systems are among the most commonly explored renewable sources for integration with hospital HVAC loads [7]. These energy sources can be used either independently or in hybrid configurations, offering flexibility and resilience in meeting fluctuating energy demands [8]. Unlike conventional systems that operate in a static manner, renewable-powered HVAC systems must be dynamically managed to align energy generation with variable loads, weather conditions, and clinical priorities [9]. This necessitates the deployment of advanced energy management systems (EMS) that can process real-time data, optimize source allocation, and support intelligent control of HVAC subsystems to ensure thermal comfort and patient safety [10].