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Feasibility of intelligent logistics management for operational efficiency in smart hospitals: a case study

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It is imperative to enhance the scientific management of logistics through the creation and advancement of an Intelligent Logistics Management in Smart Hospitals. This paper presents a preliminary introduction to an intelligent logistics management system. The subsequent section offers a comprehensive overview of the diverse platforms that constitute the intelligent logistics management system. These include the energy management platform, intelligent lighting control platform, one-stop service platform, power operation and maintenance monitoring platform, and the BIM O&M platform, the latter of which is visualised. Furthermore, it provides a comprehensive account of the construction, architectural design, and the functions and responsibilities of the constituent sub-platforms. Furthermore, a thorough examination is conducted to ascertain the substantial efficacy and energy-saving impact of implementing an intelligent logistics management system within the context of a hospital project in Shenzhen, China. The findings indicate a substantial reduction in the energy consumption of the entire building structure, with the maximum total energy consumption reduced by 402 MWh, signifying an 18.5% decline. The system has been demonstrated to reduce operational costs and facilitate environmentally conscious operations, which represents a core objective. The construction of the logistics operation and maintenance platform serves to enhance the efficiency of integrated logistics management, as well as the degree of management refinement. The management system, which employs information technology, is an effective tool for the oversight and enhancement of logistics management. Furthermore, the system provides logistical support for the construction of an environmentally sustainable hospital.

Keywords Smart hospital, Logistics management, Technical framework, Energy saving, Green operation

In recent years, the rapid growth of the economy has resulted in a concomitant increase in energy demand[1,2]which has, in turn, given rise to a number of environmental problems[3]. Figure 1 presents a list of countries that are expected to experience the highest rates of resource demand in 2040[4]. Figure 2 illustrates the proportion of consumption attributable to the current major consumers. It is noteworthy that hospitals, which play an indispensable role in the healthcare sector, have gradually become significant consumers of energy. It is imperative to optimize and transform the existing energy framework in a rational and efficient manner.

The concept of the smart hospital entails the integration of contemporary technological advancements, including artificial intelligence and the internet, into the domain of medicine[5]. Rajaei et al.[6] explore the attributes of a smart hospital and use them to propose a definition that considers both academic and industry perspectives. This integration enhances the overall intelligence of the hospital environment, facilitating more efficient and effective healthcare delivery. The National Health Commission of the People's Republic of China was the first to issue the "Hospital Intelligent Service Graded Evaluation Criteria System (for Trial Implementation)"[7], which explicitly sets out the objective of promoting the construction of smart hospitals and improving medical services. Yu et al.[8] conducted an analysis of the factors contributing to the high energy consumption observed in existing hospital buildings. They subsequently proposed an upgrade of the existing systems with the objective of generating photovoltaic power for these buildings. The influence of disparate smart systems on the development

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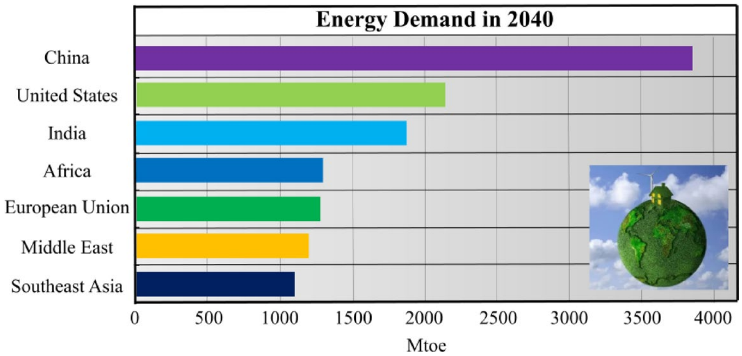

Fig. 1. Energy demand in 2040.

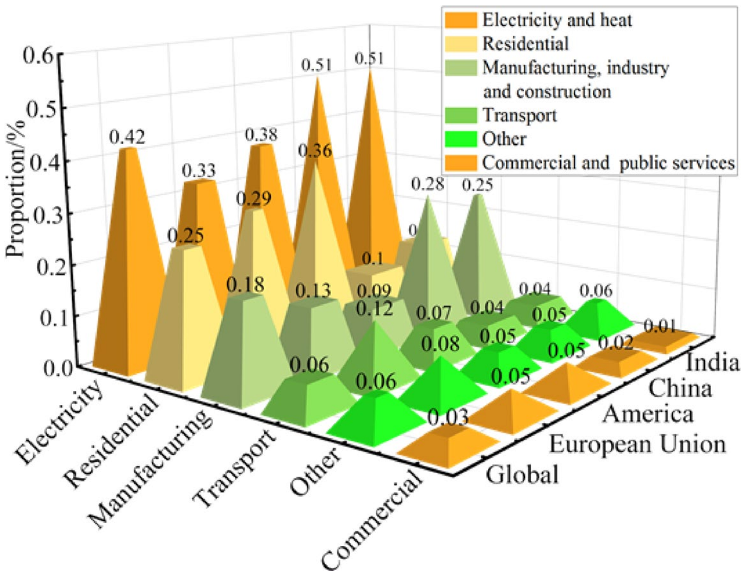

Fig. 2. Consumption share of current major consuming countries.

of smart hospitals has also been the focus of independent research by several scholars[9]. A substantial body of research has been conducted by various scholars. Lu et al.[10] investigated the potential of intelligent intrusion detection technology in the public cloud to enhance the security of medical logistics management applications, while also assessing its impact on cost. Cheng et al.[11] proposed the concept of intelligent hospital twins, which would facilitate comprehensive situational awareness and enhance the operational efficiency of the hospital. Mi et al.[12] developed an intelligent hospital management mode that is specifically tailored to the needs of patients with the novel coronavirus (2019-nCoV) infection. Zhou et al.[13] provided a qualitative insight into the implementation of an intelligent Fangcang shelter hospital system. In light of the theoretical research on machine learning in the context of big data, Liu and Pu[14] designed the JZ intelligent medical disease diagnosis and classification products. In a further contribution to this field of research, Yu et al.[15] proposed a methodology for modelling and verifying hospital intelligent diagnosis and treatment services within an Internet of Things (IoT) environment. The objective of this methodology is to enhance the system's stability and reliability in order to guarantee its accuracy. Huang et al.[16] attempted to integrate blockchain, homomorphic encryption and zero-knowledge proof technology to investigate the security architecture and privacy protection of intelligent hospitals. Subsequent research has extended to areas such as hospital storage and logistics. It can be reasonably assumed that the introduction of smart hospitals will be straightforward for residents to use, which will in turn lead to an improvement in people's sense of well-being and experience.

In order to better address the practical needs of new logistics management strategies in hospitals, Su[17]conducted a study of the logistics innovation process and its impact on the organization in focus as well as on the supply chain, especially suppliers. Building upon extant research on digital twin technology, which facilitates real-time feedback from physical entities, Han et al.[18] proposed a digital twin conceptual framework for smart hospitals and specified information requirements and enabling technologies. A pilot platform has been developed and tested in Shanghai Municipal Hospital. Mahendrawathi's et al.[19]analysis revealed a conspicuous absence of attention in the extant literature on the role of logistics in ensuring the delivery of high-quality and responsive health services. To address this gap, the study proposes a preliminary research initiative, namely the development of a dashboard prototype for XYZ logistics management in hospitals. Guo[20] constructed an intelligent logistics management system with the objective of improving the management level. Chen et al.[21] established a hospital logistics information SPD system, which enabled the realisation of the entire process of implanting interventional and high-value consumables into three codes. Hu et al.[22] constructed a global medical device product space and evaluated the innovation potential and opportunities of potential medical device products in major Asian countries. Liu et al.[23] introduced technological mechanisms designed to reduce miners' storage costs and discussed future challenges and open problems in this field. Luo et al.[24] investigated the impact of the financial status of the hospital, perceived usefulness and perceived ease of use on the adoption of health information systems through a questionnaire survey. Xu and Wei[25] proposed an enhanced heuristic algorithm to improve the quality of solutions. The initial solution generated by the Clarke-Wright (CW) saving algorithm is incorporated into Adaptive Large Neighbourhood Search (ALNS), and Q-learning is employed to adjust the operator weights in order to enhance the efficiency of the solution process. As can be observed, the majority of extant studies concentrate on the influence of medical devices, medical resources and medical information systems utilised in hospitals on the functionality of hospital operations. Nevertheless, the development and implementation of intelligent logistics management systems are still in their infancy, and there is a paucity of analytical studies and conclusive findings on the impact of such systems on energy conservation and emission reduction in hospitals, given their distinctive structural characteristics. Despite the strides made in various components of smart hospitals, three fundamental challenges persist. These challenges include single-domain optimization, information silos resulting from disparate data standards across sub-systems, and the reliance on manual adjustment of traditional energy management, which underscores significant research gaps concerning the in-depth synergy between smart management and energy optimization. In this paper, we methodically examine the limitations of the extant literature. We then propose a novel system, which we refer to as "deep optimization of energy consumption by intelligent management system." This system incorporates a theoretical framework, technological path, and practical benefits of previous research. The integration of multidimensional real-time data and a dynamic decision-making mechanism is a key feature of the system. This integration enables the system to address the challenge of smart management-energy fragmentation. Additionally, it establishes a novel framework for precise monitoring and prediction of hospital carbon footprints.

In light of the inherent constraints associated with the concept of smart hospitals, as elucidated in the aforementioned study, and in view of a more nuanced understanding of the principles of carbon neutral emission reduction, this paper presents a comprehensive and detailed account of the construction and architectural design of an intelligent system for smart logistics management. Additionally, it provides a thorough examination of the system's sub-platforms and business systems. The document meticulously delineates the specific tasks and functions of each module and sub-platform. Additionally, it provides a critical evaluation of the system's practicality and benefits. Consequently, a comprehensive evaluation of the system's practical performance benefits is imperative. Finally, the energy consumption data before and after the deployment of the system are quantitatively compared and analyzed with a tertiary hospital as a full-scale test site to prove its energy-saving benefits. The objective of this study is to furnish a technical framework and practical reference for analogous hospital logistics intelligence upgrading projects.

Intelligent logistics management intelligent system architecture design

The intelligent hospital logistics management system is comprised of five distinct platforms: an energy management platform, an intelligent lighting control platform, a one-stop service platform, a power operation and maintenance monitoring platform, and a visualization platform for the BIM O&M platform. The platform exhibits substantial expandability and forward-thinking characteristics, ensuring its adaptability to novel business models over time while concurrently reducing logistics input costs. The Internet of Things (IoT) and intelligent logistics management systems represent two pivotal areas of interest within the domain of healthcare. The integration of the Internet of Things (IoT) and High-Integrity Logistics Management (HILIMP) through the utilization of state-of-the-art information technology (IT) applications, including cloud computing, big data, and spatial geographic information, has the potential to transform the manner in which hospitals oversee their logistics operations. The sharing of information resources and the optimisation of their allocation can facilitate the streamlining of hospital operations, the improvement of efficiency, and the realisation of lean and efficient management. The integrated management platform for hospital intelligent logistics, which incorporates the Internet of Things, comprises a business module that encompasses a multitude of terminals, including web, mobile, handheld, and large-screen devices. The aforementioned terminals facilitate access to a diverse array of applications, which are currently constrained by their limited accessibility.

An intelligent logistics management system has been developed to enhance energy efficiency in hospitals through five core mechanisms. The first mechanism is territorial monitoring, which involves the deployment of multi-mode sensors in high energy-consuming equipment to collect real-time data. These sensors are designed to identify anomalies with an energy efficiency deviation greater than 20%. The first method is based on the dynamic energy consumption baseline, and it involves the realization of second-level interception (e.g., charging the pile at full power during non-working hours) through the LSTM anomaly detection model. The second method is prediction-driven dynamic tuning, which integrates outpatient volume and environmental data to predict regional load demand (e.g., The operating room air conditioning system is preheated to achieve on-demand regulation of HVAC and self-adaptation of logistics equipment. The pneumatic pipeline air pressure is dynamically adjusted according to the transport load. The third component is equipment health—energy-efficiency linkage. This is achieved through analysis of over 200 dimensional characteristics of early warning of energy-efficiency deterioration equipment, priority maintenance of high-energy-consumption failure points, and reduction of sudden energy consumption loss by 67%. The fourth component is process re-engineering—

system synergy. Intelligent path planning has been demonstrated to reduce handling mileage by 22%. Batch removal of medical waste has been shown to reduce cold chain energy consumption by 19%. Furthermore, cross-system energy savings can be achieved through fresh air, air-conditioning residual cooling recovery, lighting, and logistics linkage. The fifth component is the digital twin, which is continuously optimized. The establishment of a three-dimensional baseline, encompassing the interrelationships among buildings, equipment, and temporal periods, is imperative. This baseline should be subject to automatic refinement, informed by historical data. A case in point is the adjustment of the air-conditioning set temperature by 0.5 °C in a given season, a strategy that is dynamically adapted through the analysis of past data. The technological closed loop (data collection → AI diagnosis → demand prediction → automatic execution → system synergy) has been demonstrated to reduce the ineffective energy consumption of equipment by 42%, the air conditioning power by 35%, and the overall energy consumption of the hospital by 25–32%. Furthermore, it has been shown to promote the transformation of energy management from experience-driven to AI-driven.

System components

In order to circumvent the inherent limitations of the Internet + Hospital Intelligent Logistics Comprehensive Management Platform and give full play to its potential, the Internet + Hospital Intelligent Logistics Comprehensive Management Platform is constructed using the microservice architecture, as shown in Fig. 3. The characteristics of the hospital intelligent logistics platform with multi-terminal access (Web/mobile/handheld devices/large screen), multi-business modules (equipment monitoring/materials scheduling/energy management), and large fluctuations in the amount of access are addressed by this system, which adopts Spring Cloud microservices architecture (Spring Boot 3.0 + Nacos 2.2 Service Governance + Sentinel 1.8 Fusion Limit Flow). Achieving technical decoupling is contingent upon the following core value: The first component of interest is the medical-level high availability, which is characterized by the independent deployment of microservices and rolling upgrades. This ensures that the core business of power equipment monitoring and other 7 × 24 h of uninterrupted operation is supported. The K8s elastic scalability is also of note, as it can support emergency scheduling emergencies (> 500 QPS). The second component of interest is the non-functional depth of the adaptation. Redis caching through the Redis + library table is employed to ensure that the response time to the application of the hospital district is less than 200 milliseconds. The integration of Spring Security OAuth2 + State Secrets SM4 and GitLab CI/CD is achieved to facilitate a single-service upgrade with zero interruption. The architecture design primarily emphasizes non-functional requirements, encompassing performance, security, usability, ease of use, and maintainability. The overarching design concept constitutes the platform that provides support for the system. The overarching design concept underpinning the development of this system is the establishment of a unified platform capable of supporting all applications. The overarching design concept entails the establishment of a cohesive platform capable of supporting all applications. The architectural design features of this product are enumerated below:

(1) The microservice architectural style is readily adaptable to accommodate growth and expansion. The partitioning of services into discrete units, or microservices, represents a means of reducing the overall size of a service while increasing its precision. This approach entails concentrating on a relatively autonomous domain with the objective of mitigating risk and facilitating the reuse of combinations. Furthermore, it enables the expansion of the service, which is frequently a constraint. In contrast to the necessity of simultaneous upgrades for all services, optimisation and expansion can be achieved in an incremental manner. The pro-

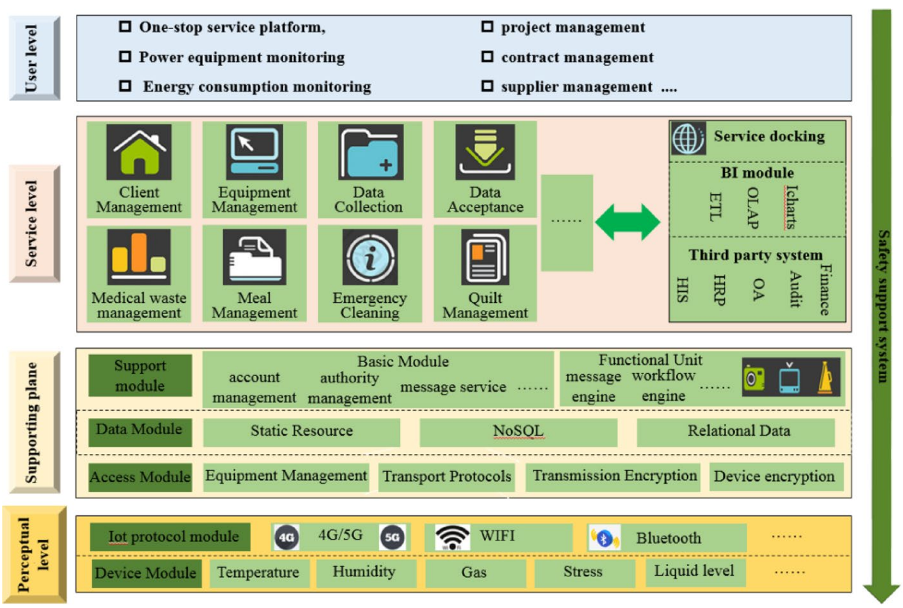

Fig. 3. System components.

cess of data slicing may be conducted by user organisations, data centres and service area clusters according to geographic location, with each entity having the capacity to perform this process independently.

(2) Protocol adaptation represents a more flexible approach. The adaptation of communication protocols is achieved through the protocol adapter of the device management module, which is capable of supporting a variety of communication protocols, including MQTT, ModbusTCP, OPC UA, and BACnet, among others.

(3) The provision of an open interface allows for seamless integration. The platform offers an open application programming interface (API) based on Hypertext Transfer Protocol (HTTP) or Hypertext Transfer Protocol Secure (HTTPS), which permits third-party applications to access the data.

(4) The implementation of encryption ensures an elevated level of security. The application layer is secured through the utilisation of the HTTPS protocol in conjunction with digital certificates, thereby preventing any potential data tampering or denial of information interaction. The application layer's sensitive data is encrypted through the utilisation of symmetric encryption algorithms, thereby ensuring the confidentiality and integrity of the data. The server-side interface processing serves to prevent both SQL injection attacks and cross-site XSS attacks.

Function introduction

Figure 4 illustrates the system function diagram. The IoT + Hospital Intelligent Logistics Comprehensive Management Platform's product system represents a business architecture of $N+1+5$, comprising N applications, one center, and five centers. The system can be described as an $N+1+5$ business architecture, consisting of N applications, one center, and five centers. The N applications encompass four business sections: a one-stop service; safety, operations, and maintenance; energy consumption management; and BIM + FM visualization and big data DSS. The one-stop service section incorporates various business subsystems, including a unified scheduling desk, maintenance and repair reports, medical waste management, meal ordering systems, inspection management tools, warehouse management platforms, satisfaction surveys, and more. This section is made up of several business subsystems, including a unified dispatching desk, maintenance and repair, medical waste management, food ordering, inspection management, warehouse management, vehicle management, and satisfaction surveys. The Safety Operations and Maintenance and Energy Consumption Management section is responsible for monitoring safety operations, issuing alerts in the event of malfunctions, administering operations and maintenance, and compiling statistical analyses related to water, electricity, gas, and specialized equipment consumption in the context of hospital logistics.

One centre makes reference to the Internet of Things (IoT) + hospital intelligent logistics centre, which is capable of carrying out a multitude of applications. Such applications include unified user management, unified resource management, unified process management, unified payment management, unified report management, and open unified login and access interfaces. The open and unified login and access interface serves to dismantle information silos, integrate third-party applications, and provide a unified management portal. This has the effect of further improving the efficiency of management and business flow, while also facilitating a deeper exploration of the potential value of data to support logistics management decisions. The aforementioned five centres are the process centre, the report centre, the user centre, the resource centre, and the payment centre.

The Internet of Things (IoT) has become the cornerstone of the perception layer of the smart hospital logistics system, stemming from the rigid needs of medical scenarios. The necessity of full-domain perception is paramount in hospitals, where equipment status must be monitored in real time. The magnetic resonance imaging (MRI) temperature rise of ± 0.5 °C, the direction of energy flow (sub-metering), and the traditional supervisory control and data acquisition (SCADA) system's support for point collection are limitations that the Internet of Things (IoT) distributed sensing network (temperature/vibration/current sensors) overcomes by meeting the needs of hospitals simultaneously. The IoT distributed sensing network can provide a building's

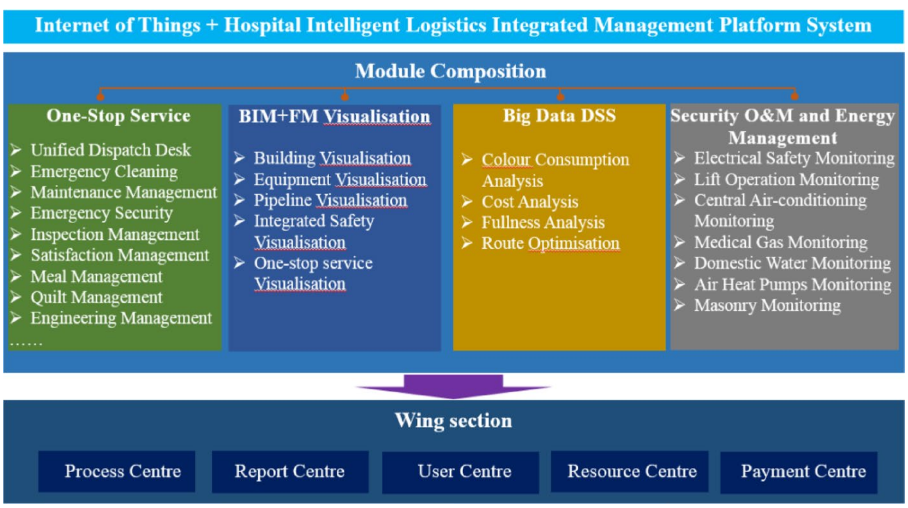

Fig. 4. System function diagram.

whole chain of dynamic sensing. The present study explores the phenomenon of real-time control dependency. The deployment of IoT actuators, such as smart valves and inverters, has been shown to be 60% more cost-effective than traditional PLC systems. These actuators facilitate wireless remote regulation, a feature that enhances their functionality and versatility. The following essay will explore the core benefits and synergistic value of big data technology.

The utilization of big data technology has become an inevitable choice due to the inherent characteristics of medical data, which can be defined by three key elements: volume, speed, and variety. The first element, volume, refers to the substantial quantity of data generated on a daily basis, which can exceed 50 gigabytes. The second element, speed, refers to the rapid rate at which updates to the second-level data are executed, typically within a span of less than one second. The third element, variety, refers to the diverse range of data types and formats that are present. The utilization of BIM (Building Information Modeling) models and video streaming in this context underscores the necessity of meticulous analysis for intelligent decision-making. Predictive maintenance, in particular, necessitates the integration of vibration spectra (time series data), maintenance records (text), and infrared images (unstructured). The utilization of infrared images (unstructured) necessitates the implementation of Hadoop + MLlib and other big data platforms to facilitate multimodal analysis. The process of energy consumption optimization entails the extraction of data spanning a decade, incorporating historical meteorological information and outpatient visit records. Conventional relational databases, such as Oracle, are susceptible to failure during petabyte-scale data processing operations. The integration of technological systems fosters the creation of exclusive value in the medical field. The Internet of Things (IoT) has been demonstrated to collect current harmonics and large volumes of data, thereby warning of bearing wear and reducing the need for excessive maintenance. The integration of IoT with big data has been shown to reduce operational and maintenance (O&M) costs and energy expenditure, thus establishing itself as the optimal solution for the digital transformation of medical logistics.

Security system

Data security system

In the context of hospital logistics management systems, data security emerges as a paramount concern. The implementation of a robust data security framework entails the integration of three core components: storage encryption, local disaster recovery, and off-site disaster recovery. This triad of mechanisms constitutes the foundation of a comprehensive data security system.

The storage layer employs a hierarchical encryption strategy, utilizing AES-256 for database field encryption to defend against drag database attacks, BitLocker full disk encryption to prevent physical theft, eDrive protocol to block the loss of mobile media hardware-level encryption leakage, and a unified key management platform to ensure that even if the data is misdirected, it remains unreadable ciphertext.

The local disaster recovery system is predicated on the zero-trust principle, which is to say that it is based on continuous data protection (CDP) technology. This system generates anti-pollution snapshots at 15-minute intervals. Furthermore, it utilizes write-once-read-many (WORM) locks to operate logs, thereby preventing tampering. In addition, all transmission channels are encrypted by TLS 1.3 + SM4 to meet the relevant audit requirements.

Thirdly, off-site disaster recovery employs blockchain-verified replicas in at least 200 km geographically isolated nodes (RPO < 5 min) and facilitates 10-second fusion switching (RTO < 30 s). These mechanisms ensure the comprehensive and traceable management of first aid material dispatch records during extreme disasters. The system has passed the Equal Protection Level 3 certification (GB/T 22239 – 2019), thereby achieving military-grade protection for the entire life cycle of core data. The system has been designed to ensure that backup points are independently backed up, with multiple backups stored in different locations. This enhances the system's disaster-tolerance capability and ensures the integrity of data.

Network security system

The network security system is founded upon four fundamental principles.

<u>Physical isolation</u> It is of paramount importance to implement external network switches in order to guarantee the segregation of data flows between the local area network (LAN), intranet and Internet. This approach permits the segregation of data flows pertaining to internal and external networks, thereby enhancing the security of network-borne information.

<u>Firewall technology</u> The network system utilises high-performance and high-security firewalls, which provide comprehensive protection at both the network and application levels. It is of the utmost importance that the router is configured in a manner that enables comprehensive monitoring of all communications by the firewall. The monitoring and filtering capabilities of the firewall permit the authentication and authorisation of trusted users or information, thereby enabling them to log in to external servers or exchange information.

<u>Access control</u> It is recommended that an external network switch be implemented to segregate the data flow between the internal and external networks. This approach permits the sharing of data traffic while maintaining the security of network information. Computers with internet access and data ports are connected to the external network switch in order to prevent the incursion of viruses into the internal network system and to safeguard the security of related data.

<u>Intrusion monitoring and network audit</u> A system for monitoring and auditing network operations is selected for deployment on the external and internal networks of the system. This system is responsible for monitoring

and recording all types of network activity. The system is capable of analysing a range of security events, external events (such as external intrusion) and internal events (such as file copying, information access, information release, resource change by internal personnel, and so forth) that occur within the network in real time. Subsequently, the system assesses the violations in accordance with the established criteria and documents them, along with any associated alarms and blocks.

System advantages

Multi-system interaction

The integration, expansion and interconnection of digital systems have historically constituted the primary challenges to the digital development of hospitals. The lack of compatibility between products from different vendors has further complicated the process of overall hospital informatisation. The IoT + Hospital Intelligent Logistics Comprehensive Management Platform offers comprehensive system integration specifications that encompass all aspects of hospital logistics, thereby providing a unified and standardised platform for data exchange and workflow collaboration. The system enables interaction between disparate business segments (e.g. maintenance and warehouse) and systems (e.g. equipment O&M and BIM visualisation) within the system. Furthermore, it enables the integration of data with external systems, including HRP, HIS, and other hospital systems.

The IoT + Hospital Intelligent Logistics Integrated Management Platform employs a layered decoupling architecture, a strategy that aims to address the systemic barriers impeding digital development in healthcare settings. The core of the system is comprised of four layers. The data layer is transmitted through the unified data exchange platform, thereby providing a standardized interface that supports JSON, XML, and HL7. This facilitates heterogeneous system data conversion, thereby breaking down the barriers to compatibility with external systems, such as HRP, HIS, and others. The service layer is responsible for the deployment of the workflow collaboration engine, which is integrated vertically through various business modules, including maintenance, warehousing, and other relevant systems. One notable feature is the automatic triggering of MRI failure by spare parts requisition, which exemplifies the system's intelligent design. Additionally, the application layer integrates business modules such as BIM visualisation, equipment operation and maintenance, and energy consumption analysis, establishing a unified operation interface for logistics business. The interaction layer utilizes API gateway and message middleware, with Kafka ensuring latency below 200 milliseconds, to facilitate horizontal cross-system synergy, such as fire alarm linkage and video monitoring.

Multi-service integration

The IoT + Hospital Intelligent Logistics Comprehensive Management Platform has the potential to integrate a number of different hospital logistics business sections, including BIM visualisation, a one-stop service, equipment operation and maintenance, energy consumption statistics and analysis, video monitoring, fire and safety monitoring, and more. Such integration could facilitate the optimisation of hospital logistics operations, enabling the streamlining of processes and the real-time monitoring of key performance indicators. The creation of a unified logistics platform that incorporates all of the aforementioned logistics business sections has the potential to improve logistics efficiency and facilitate the development of an information management model.

Business sub-platforms and applications

It is imperative that the system's construction utilizes existing software systems and hardware equipment. This approach is crucial to avoid replicating construction processes and minimizing resource wastage. The utilization of existing systems and equipment enables the circumvention of superfluous replication and the conservation of resources. The implementation of existing systems and equipment facilitates the circumvention of superfluous replication and the conservation of resources. The intelligent logistics informatization platform has been designed with the objective of facilitating the centralized management of hospital intelligent subsystems with varying functions and related equipment. This objective has been accomplished by establishing a comprehensive management platform that encompasses the collection of information, interconnection, and optimized management. The platform provides hospital logistics personnel with the necessary tools to effectively manage the medical environment, thereby ensuring a safe and comfortable setting that meets the needs of patients and medical staff, while also supporting the smooth functioning of the hospital.

The proposal entails the construction and development of an intelligent logistics management system, with a foundation in Internet and Internet of Things technology. The proposed platform would be constructed using both personal computers and mobile terminals with the objective of providing a comprehensive, integrated logistics service. This would encompass a range of functions, including daily repair, equipment management, electromechanical operation, and monitoring. The energy consumption of hospitals and other logistics services will be reduced, and the means of informatization will be fully utilized to enhance the acquisition, calibration, and control of the logistics management and service process. This will facilitate the control of nodes and processes in logistics services, thereby promoting the standardization of management levels and service quality. The implementation of information technology facilitates the acquisition, verification, and control of data throughout the logistics management and service process, thereby enabling node control and process control in the logistics service process. This, in turn, facilitates the standardization of logistics management processes and enhances the quality of logistics management. The intelligent logistics management system is predicated on the business processes of the various departments within the logistics sector. The system has been designed with the objective of diagnosing, analyzing, and optimizing existing manual reporting business processes. The development of this system is predicated on the principle of cost control and is structured around a three-layer client/server (B/S) architectural model. The following elements constitute the primary construction elements:

Energy management platform for full cost control management of energy consumption

The construction of the energy consumption management platform will make use of the Internet, computers, big data analysis and other cutting-edge technologies with the objective of achieving comprehensive monitoring of the energy consumption process from the point of energy generation to the various stages of consumption, as shown in Fig. 5. This will facilitate the introduction of a novel model of scientific monitoring and management. The generation of statistics and analysis reports on the consumption of various types of energy enables managers to identify irregularities in energy consumption in a timely manner, thus facilitating prompt action to address any issues that may arise. This allows for the investigation of potential avenues for energy savings, the identification of the most effective direction for energy savings, a reduction in energy consumption and operating costs, and the promotion of the hospital's continuous integration and innovation in the utilisation of resources. This approach facilitates comprehensive enhancements in energy efficiency and the optimization of the economic benefits of the hospital. Furthermore, it establishes a framework for periodic energy audits of the hospital. The term "infrastructure layer" is employed to describe the hardware configuration of systems, including metering and collection equipment, various functional servers, storage and backup equipment, and information security equipment.

Intelligent lighting control platform based on digital control technology

An intelligent lighting control system is defined as a system that integrates the knowledge of automatic control, network communication, field bus, embedded software, lighting technology, and other related fields (as illustrated in Fig. 6). It considers the overall structure, main performance and key technology of the intelligent lighting system in a systematic manner, with the intelligent control module serving as the core of the hardware. The corresponding central control software is employed for the purposes of comprehensive management and monitoring. The hardware module is constituted of three discrete types of modules: input units, output units, and system units. The primary mode of communication between the modules is 485 bus communication, which is combined with TCP/IP network communication in order to facilitate system networking.

The intelligent control system employs 485 bus technology, integrating network technology and power monitoring technology, and offers a range of functions, including online monitoring, intelligent alarm, multi-party linkage, and remote control. The integration of network technology and power monitoring technology facilitates real-time network activity monitoring and the identification of potential issues. It also enables the implementation of intelligent alarms and multi-party linkage. The latter facilitates coordination and communication among the system's multiple parties, while remote control enables management and operation of the system from a distance. This facilitates the expeditious identification of defective circuits and the underlying causes of such faults, thereby addressing the intrinsic safety concerns associated with conventional lighting circuits and control methodologies. The system is controlled via the aforementioned control panel, control screen, tablet PC, mobile phone, and computer, and incorporates both local and remote control functionality.

One-stop service platform for full-process node control

The hospital's logistics department is responsible for the repair and maintenance of essential utilities, including water, electricity, gas, and energy supply, as well as the maintenance of medical equipment and other hospital infrastructure. In order to facilitate a rapid, responsive and accurate service, a one-stop logistics service

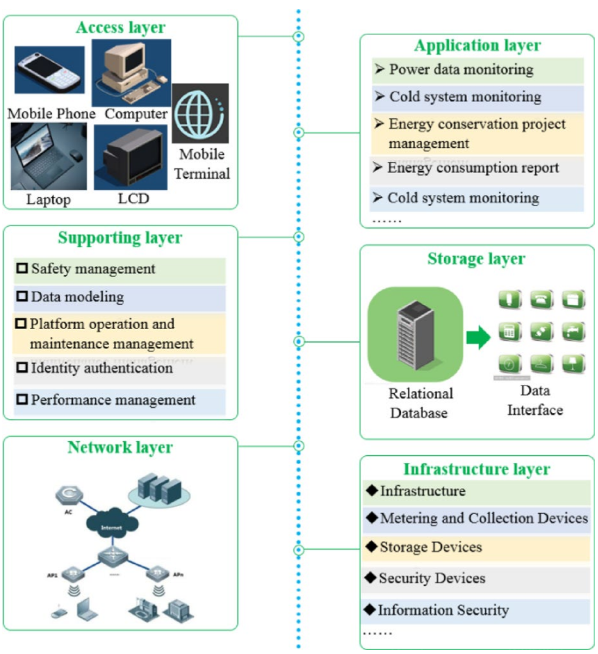

Fig. 5. Schematic diagram of energy management platform.

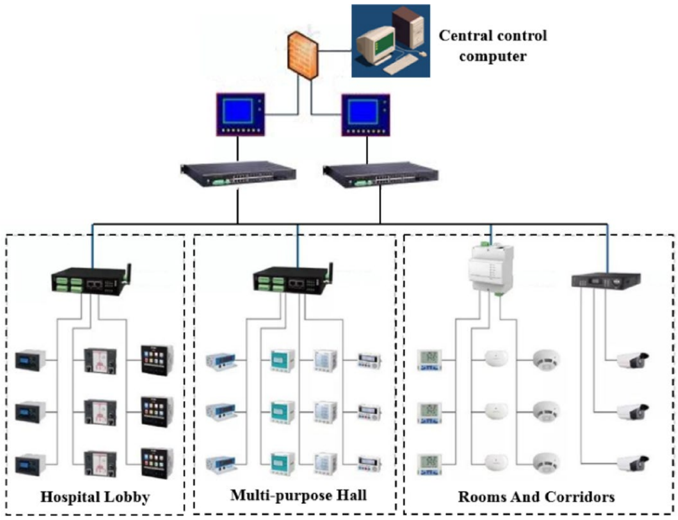

Fig. 6. Intelligent lighting control platform.

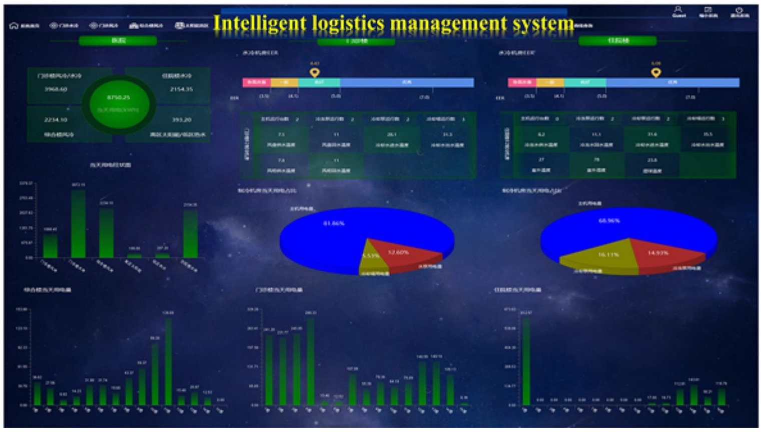

Fig. 7. One-stop service platform.

centre will be established. The establishment of a one-stop logistics service center is imperative to ensure the provision of a rapid, responsive, and accurate service. The objective will be achieved through the construction of information technology, the design and development of a web interface and a logistics application, and the utilization of personal computers and smartphones as the tools for the electronic flow of logistics work orders. Figure 7 illustrates the proposed one-stop service platform, which will entail the implementation of a unified scheduling platform, repair report management, inspection management and maintenance management. A web interface and logistics application will be designed and developed, and personal computers and smartphones will be employed as tools for the electronic flow of logistics work orders, including a unified scheduling platform, maintenance report management, inspection management and maintenance management.

Power operation and maintenance monitoring platform based on centralised control system

As illustrated in Fig. 8, the power equipment operation and maintenance monitoring platform enables the interconnection of all equipment information, leveraging the Internet to facilitate remote supervision and accelerate the collection and transmission of data. Furthermore, the incorporation of extensive data from the hospital's centralized power control system allows for comprehensive and effective analysis of the hospital, thereby facilitating improvements in operational efficiency, cost reduction, and a significant contribution to the advancement of quality management and information technology in logistics. The personnel on duty are able to monitor the operational status of the equipment in real time via the PC mainframe, thereby ensuring that the system maintains a stable operational status at all times.

The system construction methodology ensures the optimal utilisation of existing hardware resources, thereby avoiding the replication of construction and the waste of resources. Moreover, supplementary hardware monitoring apparatus is integrated when the existing equipment is unable to fulfil the requisite criteria for information technology integration. Such equipment includes pressure transmitters, temperature and humidity transmitters, liquid level transmitters, video monitoring, and other devices. The system is thus capable of

Fig. 8. Power operation and maintenance monitoring platform.

performing a number of functions, including basic management, alarm management, report management, management monitoring, data management, remote access and remote control.

Visualisation of the BIM O&M platform

The BIM visual hospital integrated safety management system is based on a unified data dictionary of the hospital, with the spatial and equipment information of the hospital BIM serving as its foundation. The system has been developed to promote the concepts of visualization, intelligence, networking, and integration. The system integrates the existing equipment safety operation management system, thereby transforming the traditional central monitoring center into an all-in-one integrated safety monitoring and emergency command center. Additionally, the system integrates equipment safety monitoring into the central monitoring system in a novel manner. The system signifies a pioneering integration of equipment safety monitoring into the central monitoring system. The system integrates BIM visualization technology with data integration and intelligent analysis technology to establish a comprehensive safety management system for large hospitals. The system facilitates the incremental visualization of the park, the building itself, the interior spaces, and the equipment within the building. The system places particular emphasis on the intelligent monitoring of the building, encompassing intelligent power supply, intelligent lift, intelligent water supply, and other management systems. The result of this process is the creation of a three-dimensional visualization platform that integrates monitoring, early warning, diagnosis, and analysis of the building management system.

The fundamental components of the BIM visual hospital integrated safety management system can be broadly categorised as follows: the visualisation of the central monitoring and alarm system; the visualisation of equipment operation safety monitoring; and the real-time linkage of on-site videos (power supply and distribution, lifts, boilers, air conditioning, etc.). In light of the accelerated advancement of BIM technology in recent years, the BIM visualisation technology, as a foundation, has been integrated with the Internet of Things, big data and agile interactive technology with the objective of achieving a comprehensive operational and management mode for large hospitals. This mode is characterized by the principles of "visualization, integration, and intelligence" and represents a transition from a "global vision" and "precise" approach to a "global vision" and "precise" one. This comprehensive operational and management model for large hospitals oversees the building space, mechanical, electrical, and plumbing (MEP), and comprehensive security of such institutions from a "global vision" and "precise insight" perspective, yielding noteworthy outcomes.

Discussion of application value and prospects

In order to enhance the functionality of the smart hospital, the paper proposes the utilisation of Internet and Internet of Things technology for the construction and development of an intelligent logistics management system, which will be accessible from both personal computers and mobile devices. This will facilitate the provision of comprehensive logistics services, encompassing daily repairs, equipment management, electromechanical operation and monitoring, hospital energy consumption and other logistical services. The implementation of information technology should be utilized to enhance the acquisition, verification, and control of information throughout the logistics management and service processes. This will optimize the quality of the available information. This will facilitate the implementation of node control and process control within the logistics service framework, thereby advancing the standardization of logistics management processes and enhancing the management level and service quality of logistics.

Optimising the energy consumption framework

The system relies on the hospital's existing IT infrastructure to connect the various business functions of the logistics systems and aggregate their data. This allows hospital managers to efficiently and accurately monitor the hospital's logistics through digital interfaces, such as the web, mobile applications, WeChat, and SMS. To enhance energy utilization and management efficiency, monitoring points should be established in energy-consuming areas to facilitate monitoring of energy consumption. These monitoring points will enable the online monitoring, control, and regulation of water, electricity, and natural gas consumption in each hospital building, facilitating item-by-item and sector-by-sector metering and real-time monitoring of the hospital's building energy-saving monitoring data center. The data collected by the monitoring platform can be used for various purposes, including generating statistics related to energy consumption, analyzing such consumption, diagnosing potential issues, planning energy-saving transformations, and managing energy resources.

Enhancement of service quality

The one-stop service platform employs process node control to facilitate the provision of controllable logistics services throughout the entire process, thereby markedly enhancing clinical satisfaction with logistics services. The implementation of the platform has resulted in a notable reduction in the number of facility and equipment defects, service complaints, and unexpected safety incidents. Moreover, a substantial enhancement in patient and clinic satisfaction has been observed. The functional application and technical architecture of the platform exhibit sufficient versatility to accommodate the diverse logistics requirements of the hospital and to align with the needs of medical, nursing, and patient user groups in relation to logistics.

Increased efficiency of equipment management operations and maintenance

It is imperative to ensure the optimal functionality of the equipment, to proactively anticipate and address potential issues and risks, to establish a robust power operation and maintenance monitoring platform, and to utilize communication interfaces, sensor data collection, and other techniques to integrate the status, alerts, flow rate, pressure, and other operational parameters of the hospital's power conversion and distribution systems. The aforementioned facilities and equipment systems, including central air-conditioning, domestic water, sewage treatment, boiler, medical gases, lift, and other systems, are to be integrated into a unified management platform. The integration of these systems will facilitate centralized monitoring and enable the utilization of comprehensive data, cross-system linkage, and information sharing among sub-systems. The system is designed to facilitate comprehensive data utilization, establish cross-system connections, and enable information exchange among subsystems.

Enhancement of overall management

The objective is to provide unified service standards and process construction functions, thereby ensuring the implementation of processes and service standards for logistics service providers and management teams. The objective is to alleviate the workload of logistics service personnel through the implementation of technical solutions, thereby enhancing the efficiency of logistics services. The information-based management system ensures that logistics operations are conducted in accordance with a systematic process, thereby enhancing the precision and reliability of logistics services while reducing the probability of errors.

Case studies

Overview of the project

The Shenzhen Hospital of Guangzhou University of Traditional Chinese Medicine (GZUTM) was previously designated as the Futian District Hospital of Traditional Chinese Medicine (Fig. 9). The establishment of the hospital was approved on 26 October 1992, and it was designated as a comprehensive Grade 3 A hospital specialising in traditional Chinese medicine. This integration encompasses the functions of medical treatment, scientific research, teaching, prevention, healthcare and rehabilitation. On 8 July 2015, the Futian District People's Government and Guangzhou University of Traditional Chinese Medicine (GZUTM) entered into a cooperative agreement to construct the Shenzhen Hospital of GZUTM on the site of the former Futian District Hospital of Traditional Chinese Medicine.

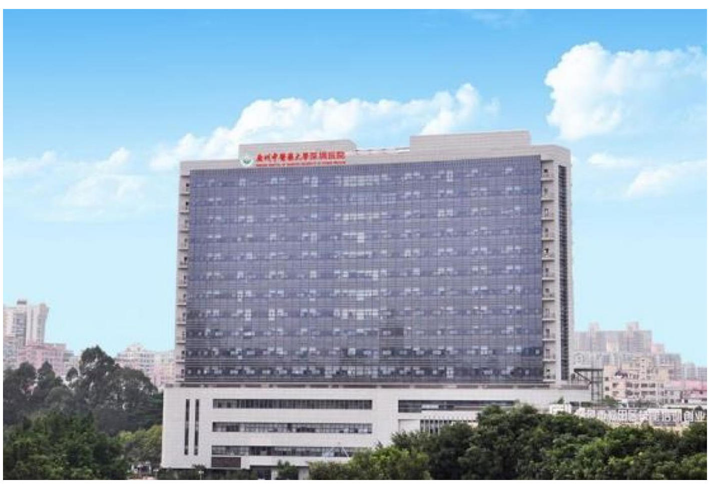

Fig. 9. Topographical map of the hospital.

The hospital is currently affiliated with Guangzhou University of Chinese Medicine, which is the sixth clinical medical school of Guangzhou University of Chinese Medicine and the first five-star Chinese medicine hospital in China. The hospital serves as a synergistic base for the national standardised training base. It is a Chinese medicine residency training facility, an AAA-grade social insurance designated medical institution in Shenzhen, and an award-winning unit of the national standardised Metabolic Disease Management Centre (MMC) and the Department of Respiratory and Critical Care Medicine (PCCM). The hospital has a total building area of approximately 111,586 m^2, comprising outpatient, inpatient, scientific and educational, comprehensive, and other main buildings.

Analysis of results

The energy management system of the Shenzhen Hospital of Guangzhou University of Chinese Medicine must be installed on each floor of the hospital to ensure precise measurement of electrical energy consumption. Subsequently, these statistics should be mapped to provide a comprehensive picture of the hospital's electricity consumption patterns over the course of a month. The system utilizes an industrial-grade ring network architecture and edge computing nodes to achieve high-precision data collection and analysis. The analysis yielded findings that indicate a clear seasonal fluctuation pattern in the distribution of power consumption on a monthly basis, as illustrated in Fig. 10. The period from January to April is characterized by a low level of power consumption, with a proportion of less than 8% of the total annual consumption occurring during this interval. Conversely, the months from May to September represent a period of heightened power consumption, with a total annual consumption reaching 31,223 MWh, accounting for 58.56% of the yearly total. The maximum power consumption per unit share is observed in July, with a recorded value of 6,598 MWh. It is noteworthy that the power consumption in October and November reached 4,576 MWh and 4,039 MWh, respectively, accounting for 11.5% and 8.6% of the total power consumption. This fluctuation was attributable to Shenzhen's distinctive hot and humid climate, characterized by elevated temperatures and humidity during the summer months. This led to hospitals' reliance on energy-consuming refrigeration equipment, such as air conditioners, resulting in a significant increase in electricity consumption.

In order to accurately assess the energy-saving effectiveness of the intelligent logistics management platform, this study employs a systematic approach by selecting the Inpatient Building and the Complex Building as typical cases. A comparative and analytical examination of the energy consumption data of these two core buildings is conducted before and after the deployment of the platform, as illustrated in the Figs. 11 and 12. A thorough examination has been conducted, and the findings indicate a substantial reduction in energy consumption. The analysis reveals a significant decrease in the total annual power consumption of the two buildings, from 18,948 megawatt-hours (MWh) prior to the implementation of the new system to 16,477 MWh post-implementation. This reduction in energy usage translates to an absolute energy saving of up to 2,471 MWh. The following investigation will address the question of how to optimize energy savings during the summer months. The most pronounced decline in energy consumption occurs during the summer months, which extend from June to September. The platform demonstrated its capacity to manage high loads, as evidenced by the following monthly savings: 261 MWh in June, 302 MWh in July, 402 MWh in August (the largest reduction in a single month), and 259 MWh in September.

In-depth analyses of individual buildings validate universality: Complex Building: During the period of non-deployment, spanning from May to November, the platform's monthly power consumption consistently exceeded 1,000 megawatt-hours (MWh). Subsequent to the implementation of the platform, a substantial decrease in energy consumption was observed, with the most significant single-month reduction reaching 230 MWh. This reduction effectively mitigated the building's role as a substantial energy consumer. Inpatient Building: Concurrently, from May to November, the monthly power consumption of the platform alone exceeded 490 MWh. Subsequent to the deployment, a substantial reduction in energy consumption was observed. In July, the month with the highest load, for example, power consumption was optimized from 725 MWh before deployment to 652 MWh, demonstrating the platform's ability to regulate power consumption at critical times.

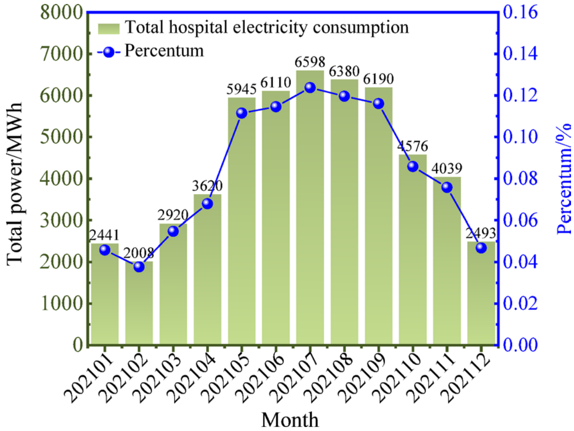

Fig. 10. Map of energy consumption data for 2021.

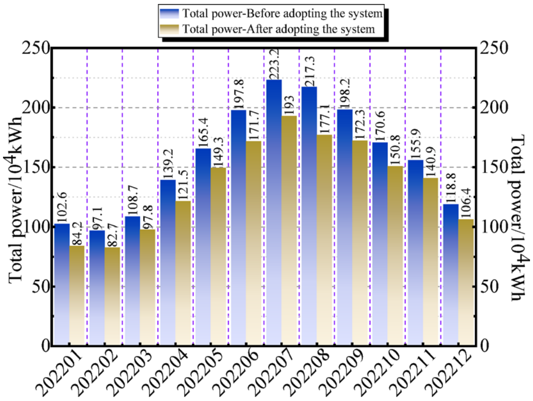

Fig. 11. Total energy consumption of buildings before and after the adoption of the smart platform.

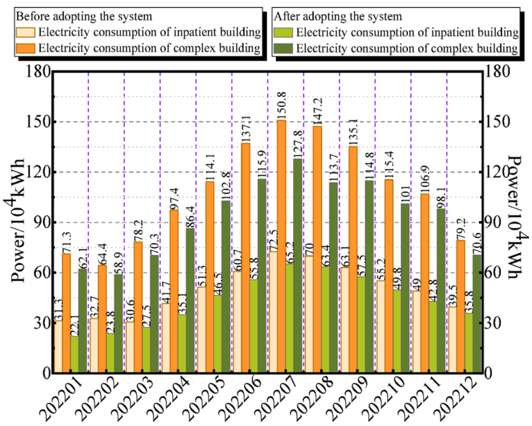

Fig. 12. Energy consumption of buildings before and after the adoption of the smart platform.

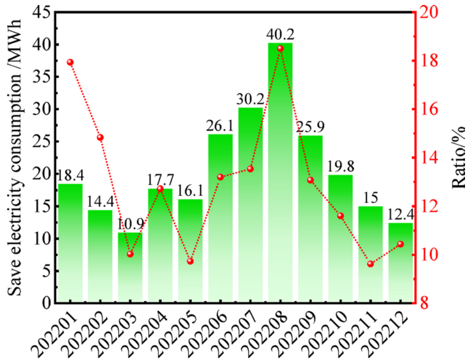

Fig. 13. Percentage reduction in total building energy consumption.

Through the empirical analysis of the inpatient and comprehensive buildings, it has been demonstrated that the intelligent logistics management platform is highly effective in optimizing the energy consumption structure and load distribution of hospital buildings. The platform demonstrated a substantial decrease in overall energy consumption throughout the year, with annual savings amounting to 2,471 MWh. Additionally, it exhibited notable energy-saving potential during the summer peak and in individual buildings with high energy consumption. For instance, a maximum reduction of 230 MWh was observed in the Complex Building, and an optimization of 73 MWh was achieved in the Inpatient Building in July. This finding substantiates the efficacy of the platform in enhancing energy efficiency and facilitating refined energy management in hospital buildings.

As demonstrated in Fig. 13, a comparative analysis of the energy consumption data of hospital buildings before and after the implementation of the smart platform reveals significant power savings on a monthly basis. It is particularly salient that the energy-saving effect is most pronounced during the summer peak period from June to September, as illustrated below: June: 26.1 megawatt-hours (MWh), constituting 13.20% of the annual total; July: 30.2 MWh, constituting 13.53% of the annual total; August: The total energy consumption in September was 40.2 MWh, which constituted 18.50% of the annual maximum. This is equivalent to 25.9 MWh, which is equivalent to 18.50% of the annual maximum, and so on. August: Specifically, the total energy consumption in September was 25.9 MWh, constituting 13.07% of the annual savings, while in August it was 40.2 MWh, representing 18.50% of the yearly savings (the annual peak). The magnitude of the savings accumulated over the course of these four months is substantial. Furthermore, the proportion of the total annual savings represented by these savings is relatively high, at 58.3%. This is indicative of the efficacy of the smart platform in managing periods of high demand. Conversely, the range of savings from January to May and from October to December was from 10.9 MWh to 19.8 MWh. Despite exhibiting lower absolute values compared to the summer peak months and accounting for a marginally smaller percentage of the total, the consistent performance of these months (with a combined percentage of approximately 41.7%) unequivocally substantiates the general applicability and effectiveness of the smart platform throughout the year.

Discussion

Effectiveness of the implementation of the smart platform

The findings of this study demonstrate that the implementation of a smart energy management platform in hospital infrastructure has yielded substantial positive outcomes, with the primary value manifesting in considerable power savings and fundamental alterations in the management paradigm.

This approach has been demonstrated to result in substantial power savings. The platform exhibited considerable peak shaving potential during periods of high demand, such as August, reducing consumption by 40.2 MWh within a single month and thereby alleviating pressure on the grid. The savings demonstrated stability throughout the year, with a range of 10.9 to 19 MWh per month on average. This consistency in savings provided stable support for the optimization of a sustainable energy mix.

A paradigm shift in management mode has occurred. The platform effectively promoted the transition of hospital energy management from a passive response model to an active intelligent control framework. The system employs real-time data collection and artificial intelligence analysis to dynamically optimize the operation strategies of air conditioning, lighting, and other key loads. This approach effectively overcomes the rigidity of the traditional energy consumption model.

The enhancement of fine control capability is imperative. The platform offers a comprehensive, building-by-building, time-by-time perspective on energy consumption, facilitating a transition from a rudimentary management approach to a precise operational model. This sophisticated energy consumption monitoring and analysis capability is instrumental in facilitating precise decision-making, facilitating the identification of inefficiencies, and achieving substantial reductions in energy loss. A thorough examination of the available data reveals that during the summer months, from June to September, the reduction of ineffective losses plays a pivotal role in achieving substantial power savings. This reduction contributes to an impressive 58.3% of the total power savings, thereby significantly enhancing the operational efficiency of the hospital's energy system and fortifying its resilience against extreme weather conditions and energy shortages.

In summary, the intelligent platform is not only an efficient energy-saving tool, but also a key technical support for reconstructing the hospital's energy management system. Its implementation has verified its core value in optimizing the overall energy consumption structure, reducing operating costs, and improving comprehensive energy efficiency. The impact of this initiative has exceeded the significance of simple energy saving and has profoundly influenced the evolution of the hospital energy management paradigm.

Implementation limitations and rollout challenges

The following section will address the limitations in the implementation process and the challenges encountered during the rollout.

Despite the platform's validation in tertiary hospitals, significant challenges emerge when attempting to implement it in small healthcare organizations, such as community hospitals with <200 beds, which often possess underdeveloped IT infrastructures.

Technical Adaptation Barriers: The construction of a complete logistics digital twin necessitates the deployment of a substantial number (50+) of sensors at the edge. However, small hospitals often have inadequate network infrastructure (e.g., an average of only 8 POE switch ports) to support reliable backhauling of substantial real-time data. The issue is further compounded by the limited network infrastructure in small hospitals, which typically have an average of only 8 POE switch ports, making it challenging to support reliable backhaul of substantial real-time data.

The following are the economic viability challenges: The substantial financial demands of full implementation and ongoing maintenance of the platform stand in stark contrast to the modest average annual budgets of community hospitals. The substantial initial investment and recurrent operation and maintenance expenses (including hardware and software updates, cloud service fees, etc.) pose a significant economic challenge.

A discernible expertise gap exists concerning the effective operation and maintenance of the system. The successful execution of these processes is contingent upon the presence of professional engineers who possess a comprehensive understanding of containerization technologies, such as Kubernetes (K8s). It is often the case that smaller hospitals lack such highly skilled IT operations personnel. The cost and feasibility of recruiting additional personnel is another barrier to be considered.

The confluence of technical, economic, and human resource constraints acts as a bottleneck to the widespread deployment of smart energy management platforms within primary care systems.

Conclusion

(1) The objective of this section is to provide a systematic introduction to the construction and architectural design of the intelligent logistics management system. The subsequent sections offer a comprehensive overview of the energy management platform, intelligent lighting control platform, one-stop service platform, power operation and maintenance monitoring platform, and visualization of the BIM O&M platform. Additionally, it meticulously delineates the distinct responsibilities and capabilities of each module and sub-platform.

(2) The intelligent logistics management system, when utilized in conjunction with a series of professional sub-platforms, facilitates the deployment of information technology application systems. It enables the refinement and intelligence of logistics management and optimizes logistics services and energy use.

(3) The intelligent logistics management system has the effect of reducing the operating costs associated with energy consumption in the hospital. This is evidenced by a reduction in the energy consumption of the overall building structure of the hospital, with a total reduction of 402 MWh, representing a maximum reduction of 18.5 per cent. This finding underscores the potential of implementing an intelligent logistics management system to enhance energy efficiency and reduce costs.

(4) The construction and design of the intelligent logistics management system facilitates improvements in the efficiency of integrated logistics management and the degree of management refinement. In order to facilitate the comprehensive construction of green hospitals, it is essential to provide targeted logistics capacity support, ensure the effective utilisation of data and information, and furnish data that can inform management decision-making processes.

The potential for energy savings and the range of possible applications of the smart platform in hospitals are not yet fully realized. There is considerable opportunity to expand the platform by integrating energy consumption data with medical business flows (e.g., surgical scheduling, bed usage) to identify previously unrecognized opportunities for energy savings. Additionally, the platform could be extended to include smart operation and maintenance areas such as environmental monitoring and preventive maintenance of equipment. This would contribute to achieving a comprehensive upgrade in the "energy saving-safety-efficiency" triad. The smart platform is not merely a tool for cost reduction and efficiency; it is also an indispensable core infrastructure for the development of zero-carbon, resilient, and efficient smart hospitals in the future. Its continuous evolution will strongly support the sustainable development of healthcare organizations and the enhancement of operational resilience.

Data availability

The data used to support the findings of this study available from the corresponding author upon reasonable request.

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References

1. Shimoda, Y. et al. Energy demand science for a decarbonized society in the context of the residential sector. *Renew. Sustain. Energy Rev.* **132**, (2020).
2. Keiner, D., Gulagi, A. & Breyer, C. Energy demand Estimation using a pre-processing macro-economic modelling tool for 21st century transition analyses. *Energy* **272**, 127199 (2023).
3. Zhang, X., Luo, G., Liu, S. & Zhang, J. Benefit evaluation of energy substitute terminal energy project. *IOP Conf. Ser. Earth Environ. Sci.* **252**, 032066 (2019).
4. Ghasemian, S. et al. An overview of global energy scenarios by 2040: identifying the driving forces using cross-impact analysis method. *Int. J. Environ. Sci. Technol.* **21**, 7749–7772 (2024).
5. Zhang, G. W., Gong, M., Li, H. J., Wang, S. & Gong, D. X. The trinity smart hospital construction policy promotes the development of hospitals and health management in China. *Front. Public Health* **11**, (2023).
6. Rajaei, O., Khayami, S. R. & Rezaei, M. S. Smart hospital definition: academic and industrial perspective. *Int. J. Med. Inform.* **182**, (2024).
7. National Health Commission of. the People's Republic of China. *Hospital Intelligent Service Graded Evaluation Criteria System*.
8. Yu, D. et al. Energy saving and carbon reduction schemes for hospital with photovoltaic power generation and system upgrading technology. *Heliyon* **9**, (2023).
9. Xia, X., Ma, Y., Luo, Y. & Lu, J. Artificial intelligent Human-Computer dialogue support platform for hospitals. *Int. J. Pattern Recognit. Artif. Intell.* https://doi.org/10.1142/S021800142359019X (2024).
10. Lu, W. Application cost of intelligent intrusion detection in medical logistics management under public cloud environment. *Comput. Electr. Eng.* **112**, (2023).
11. Cheng, W., Lian, W. & Tian, J. Building the hospital intelligent twins for all-scenario intelligence health care. *Digit. Health* **8**, (2022).
12. Mi, D. et al. Exploring intelligent hospital management mode based on artificial intelligence. *Front. Public Health* **11**, (2023).
13. Zhou, Y., Wang, L., Xu, Y., Ding, L. & Tang, Z. Intelligent Fangcang shelter hospital systems for major public health emergencies: the case of the optics Valley Fangcang shelter hospital. *J. Manag. Eng.* **38**, (2022).
14. Liu, Z. & Pu, J. Analysis and research on intelligent manufacturing medical product design and intelligent hospital system dynamics based on machine learning under big data. *Enterp. Inf. Syst.* **16**, 193–207 (2022).
15. Yu, L. et al. Modeling and verification of hospital intelligent diagnosis and treatment service based on timed automata in internet of things. *Proc. 2020 6th Int. Conf. Big Data Comput. Commun. BigCom 2020*. **168-179** https://doi.org/10.1109/BigCom51056.2020.00031 (2020).
16. Huang, Q., Chen, S., Zhao, H. & Wen, J. Blockchain-based intelligent hospital security and data privacy construction. *J. Phys. Conf. Ser.* **1187**, (2019).
17. Su, S. I. I., Gammelgaard, B. & Yang, S. L. Logistics innovation process revisited: insights from a hospital case study. *Int. J. Phys. Distrib. Logist Manag.* **41**, 577–600 (2011).

18. Han, Y., Li, Y., Li, Y., Yang, B. & Cao, L. Digital twinning for smart hospital operations: framework and proof of concept. *Technol. Soc.* **74**, (2023).
19. Mahendrawathi, E., Pranantha, D. & Utomo, J. D. Development of dashboard for hospital logistics management. *ICOS –2010 IEEE Conf. Open Syst.* 86–90. https://doi.org/10.1109/ICOS.2010.5720069 (2010).
20. Guo, X. Application of intelligent logistics system based on AGV robot in medical consumables management. *Zhongguo Yi Liao Qi Xie Za Zhi.* **48**, 108–110 (2024).
21. Chen, Y., Zhan, F., Wang, K., Feng, X. & Cheng, J. Accurate management practice of medical consumables in the whole process based on SPD supply chain. *Zhongguo Yi Liao Qi Xie Za Zhi.* **46**, 696–700 (2022).
22. Hu, F., Qiu, L. & Zhou, H. Medical device product innovation choices in Asia: an empirical analysis based on product space. *Front. Public Health* **10**, (2022).
23. Liu, Y., Fang, Z., Cheung, M. H., Cai, W. & Huang, J. Mechanism design for blockchain storage sustainability. *IEEE Commun. Mag.* **61**, 102–107 (2023).
24. Luo, J. et al. Role of perceived ease of use, usefulness, and financial strength on the adoption of health information systems: the moderating role of hospital size. *Humanit. Soc. Sci. Commun.* **11**, 516 (2024).
25. Xu, X. & Wei, Z. Dynamic pickup and delivery problem with transshipments and LIFO constraints. *Comput. Ind. Eng.* **175**, 108835 (2023).

Author contributions

Dongchao Yu: writing–review and editing, and investigation. Hanli Lin: writing – review & editing. Xu Tan: Writing—review &editing, Visualization. Jinle Zhang: Visualization, Data curation. Zehui Liu: Data curation. Dongliang Li: Data curation. Zhigang Wang: Writing—review & editing, and conceptualization. Figs. 1, 2, 3 were produced by Dongchao Yu and Xu Tan. Figures 4, 5, 6 were created by Jinle Zhang, Zehui Liu, and Dongliang Li, respectively. As indicated in the figure captions, Figs. 7, 8 and 9 were taken by Dongchao Yu and Hanli Lin. As demonstrated in Figs. 10, 11, 12 and 13, the illustrations were created using the Origin software by Zhigang Wang.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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