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Article

Enhancing hotel efficiency and environmental health with biosensors and big data analytics

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Abstract: The hospitality industry embraces digital technologies to enhance efficiency, guest satisfaction, and environmental sustainability. Integrating biosensors and big data analytics allows hotels to monitor operational processes while maintaining high ecological health standards. However, the impact on environmental health is not fully understood, leading to suboptimal decisions and missed opportunities. This research proposes a novel Tabu Search Drove-Extended Multi-Layer Perceptron (TSD-EMLP) to evaluate the effectiveness of digital operations in hotels through the use of biosensors and big data for predicting hotel environmental conditions. Initially, smart biosensors are deployed in key areas and heating, ventilation, and air conditioning denoted as HVAC systems in the hotel, then the water quality data, noise levels, lighting quality, waste management data, operational data, financial and operational effectiveness data are collected and transmitted to the Internet of Things (IoT) cloud for further process. Interquartile Range (IQR) utilizes the IoT cloud data to remove sensor errors and anomalous events to frame outlier data for the Wavelet Packet Transform (WPT) feature extraction process to decompose sensor data into detailed frequency bands, allowing for precise analysis of complex environmental signals, TSD-EMLP model predicts the environmental health in hotels using the decomposed data. The results demonstrate reducing energy consumption, ventilation systems, indoor environment control, and guest satisfaction, improving air quality, and adjusting environmental settings based on real-time environmental conditions through TSD-EMLP optimized settings. TSD-EMLP classification model achieved high accuracy in predicting hotel environmental health, with a low improvement in guest satisfaction metrics.

Keywords: environmental monitoring; hotel evaluation; environmental health; big data; biosensors data; Tabu Search Drove-Extended Multi-Layer Perceptron (TSD-EMLP); hospitality

1. Introduction

In the digital world, hotels are progressively relying on digital tools and platforms to streamline their operations. Digital operation effectiveness encompasses various features including visitor experience optimization, effective productivity, and energy management [1]. Hotels that effectively utilize digital technologies could deliver continuous services, enhance customer engagement and achieve cost abilities [2]. Evaluating digital operations is important because of the growing requirement for sustainable practices and personalized experiences. Hotels could gain insights into guest behavior, preferences, and operational performance by using digital technologies to accumulate and analyze enormous amounts of data [3]. Hotels could boost overall profitability, customize guest experiences, and enhance efficiency by utilizing such knowledge to inform data-driven choices. The capacity to analyze data from many sources like biosensors and an extensive understanding of hotel performance essentially determine the effectiveness of the digital services [4]. The hotel sector depends significantly on environmental health, maintaining a secure and appealing environment requires several factors, including pollution levels, water quality, and indoor air quality [5]. An essential part of environmental health in hotels is indoor air quality. The comfort, well-being, and general pleasure of guests could be adversely affected by low-quality air. Many elements, including humidity, carbon dioxide, and allergens, affect the quality of the air, and pollution levels. Environmental contaminants and allergens in biosensors can track the amount of particulate matter, and other airborne contaminants [6]. Allergies, discomfort, and respiratory problems could be spurred by high amounts of such chemicals. To maintain environmental health in hotels, water quality, and utilization are crucial, sustainability is enhanced by effective water management, while clean and safe water is necessary for visitor happiness and safety [7]. The quality of water could be determined by using biosensors to identify infections, contaminants, and chemical pollutants. Maintaining visitors' confidence in the hotel's services and preventing health risks are two benefits of maintaining excellent water quality through continual surveillance [8]. Hotels maintain a calm and comfortable atmosphere by using noise-reduction techniques, such as modifying HVAC systems, by evaluating the data [9]. Through the application of biosensors that provide precise, moment monitoring of such variables, hotels could ensure a high level of environmental health and quickly solve potential issues. Maintaining ideal environmental conditions is essential for a hotel's performance and reputation, with the growing emphasis on sustainability and eco-friendly activities [10].

Importance of evaluating digital operation effectiveness

Assessing digital operation effectiveness is crucial for hotels to optimize performance and stay competitive in the industry. It involves assessing booking platforms, guest management systems, and automation technologies [11]. Hotels have to examine the efficacy of their digital operations to maximize productivity while maintaining their edge in the market. By incorporating intelligent biosensors into strategic locations and utilizing big data analytics, hotels could effectively monitor and improve their operating procedures [12]. The environmental health regulations are upheld while efficiency is also increased, then sustainability by using data to inform decision-making areas for the development of the hospitality sector. It is made possible by evaluating the efficiency of the digital activities [13]. The hotel managers and guests are becoming increasingly concerned about environmental health. Hotels continuously monitor air quality, water usage, and other environmental factors by incorporating biosensors into their operations [14]. The biosensors identify variations in the quality of indoor air, such as elevated carbon dioxide or volatile organic compound (VOC) levels, and instantly activate ventilation systems to rectify the problem. Real-time water usage monitoring using sensors enables hotels to spot leaks or excessive usage, which is to save waste and uphold sustainability objectives. **Figure 1** shows the hotel's efficiency with maintenance.

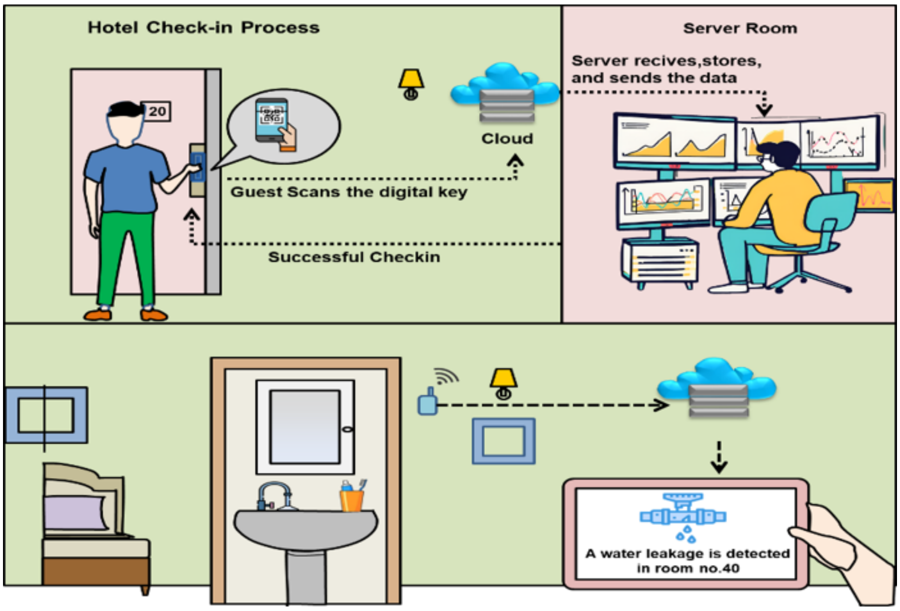

Figure 1. Hotel efficiency with maintenance framework.

A safe and healthy work environment for guests is mostly dependent on the hotels by maintaining the environmental health standards evaluation that enhances guest experiences, improves operational efficiency, and helps identify cost-saving opportunities [15]. The objective of this study is to evaluate hotel digital operation efficiency and environmental health by integrating biosensor data with big data analysis. To enhance operational effectiveness, optimize guest experiences, and ensure sustainable practices by monitoring environmental factors and customer responses in real time.

Key contribution

The main contributions are as follows:

- The integration of biosensors and big data analytics allows hotels to monitor operational processes while maintaining high environmental health standards. Initially, smart biosensors are deployed in key areas and heating, air, and ventilation conditioning (HVAC) systems in the hotel, and then environmental data are collected and transmitted to the IoT cloud.
- Interquartile Range (IQR) utilizes the IoT cloud data to remove sensor errors and anomalous events to frame outlier data for wavelet packet transform (WPT) feature extraction process to decompose sensor data into detailed frequency bands, allowing for precise analysis of complex environmental signals, Tabu Search Drove-Extended Multi-Layer Perceptron (TSD-EMLP) model predicts the environmental health in hotels using the decomposed data.
- The results demonstrate reducing energy consumption, ventilation systems, indoor environment control, and guest satisfaction, improving air quality, and adjusting environmental settings based on real-time environmental conditions through TSD-EMLP optimized settings.

Organization of the study

The study is organized into the following sections: Section II briefly describes related work, section III demonstrates methods, section IV evaluates the result, section V describes discussion, and section VI concludes the study.

2. Related work

This section examines a collection of research related to the topic, using big data analysis, biosensor integration, and research that assesses hotel digital operations and environmental health. Optimizing hotel performance and environmental practices is made possible by examining the operational effectiveness, guest satisfaction, and sustainability criteria.

Nguyen et al. [16] discussed wearable biosensors have completely changed the way healthcare was monitored by offering ongoing, non-invasive screening. The study examined the novel advancements and uses of wearable FET-based biosensors, including as ion-sensitive membrane sensors, enzymes, antibodies, nanobodies, and aptamer detectors, for healthcare surveillance. The use of Field-Effect Transistor denoted as FET-based biosensors to the way biomarkers in biological fluids such as sweating, tears, saliva, and fluids found in the outer layer of skin was also explored in the study. It highlighted how wearable biosensors based on FET technology have the potential to revolutionize individualized medical care and bio-sensing technologies. Kadian et al. [17] explained the noninvasive portable and wearable biosensors were enhanced by integrating ML to improve clinical decision-making. ML algorithms for data processing, various biosensor applications in healthcare, and the impact of ML on sensor performance, accuracy, and scalable production were highlighted, with the technologies.

Li et al. [18] explained versatile textile-based biosensors that could be worn had emerged as an effect of advancements in wearable devices and biosensors. These biosensors, which offered reliable health feedback and real-time physiologic indications, were essential for medical oversight, detecting movement, and health maintenance. The materials, production techniques, and sensing principles of biosensors that were worn based on fabric were examined in the assessment of current research. It also exposed how they might be used to detect bodily fluids and monitor vital signs.

Lawal and Rafsanjani [19] described Internet of Things (IoT) applications in residential and commercial buildings, categorized residential into home automation, energy management, and healthcare, while commercial covered office, healthcare, educational, and retail facilities. Integration of IoT technology, effective data storage management, and robust risk evaluation reduction strategies for ensuring privacy and security. It highlighted the superior outcomes of building directions for IoT developers and researchers. Zhao et al. [20] described the possibility of biosensors that could be worn in individualized illness diagnosis and real-time monitoring attracts attention. They might be applied to noninvasive physiological wellness assessments, converting physiological data into understandable information for medical personnel. The research discussed the most recent advancements in flexible and ubiquitous gauges with an emphasis on electrical sensing and technology. The process, system architecture, common applications, present difficulties, and prospective advancements in biosensor technology were also covered.

Zhang et al. [21] developed an effective methodology for predicting energy usage in hotel structures by analyzing 78 architectural drawings to create six typical models across two standard floor layouts and three public area levels. Using Energy Plus for sensitivity analysis and R to generate a 5000-sample database, quadratic polynomial regression emerged as the most accurate and stable prediction model for Guangzhou hotels.

Li et al. [22] classified the three varieties of sky gardens plaza-park, rest-stay, and move-pass according to five indications that correspond to the features of the high-rise structures where they were situated. For the next experiment, representative sky gardens of each kind were chosen. The research showed notable variations in sky gardens, especially in their spatial features. In terms of visual-physiological, emotional valence, interest, and coherence, plaza-park gardens had superior healing results. Rajesh et al. [23] explored the impact of digital social networking and IoT on the hotel industry, emphasizing deep learning (DL) for marketing strategies and customer preference estimation. Support vector machine (SVM)--based DL was utilized to predict key hotel ratings. Results demonstrated the DL's superior classification efficiency and highlighted the untapped potential of IoT in enhancing hotel operations and customer experience. Zare-Shehneh et al. [24] explained that electrochemical biosensors had been pivotal in addressing environmental pollution by detecting pollutants like heavy metals, pesticides, and toxic gases. The use of carbon-based nano-materials in these sensors, focusing on their sensing performance metrics, such as limit of detection, and linear range, developments were crucial for effective environmental monitoring and management. Dutta et al. [25] examined how IoT technology affects relative humidity monitoring and control in smart cities, with an emphasis on how it might improve people's quality of life. Big data analytics, wireless communication, and IoT-based humidity sensors with an emphasis on applications in healthcare in better sensors and blockchain technology, challenges include data security and device compatibility**.**

3. Methodology

This work aims to evaluate the effectiveness of digital operations in hotels by leveraging biosensors and big data analytics to predict and enhance environmental conditions and improve operational efficiency and guest satisfaction through optimized HVAC systems and real-time environmental adjustments. Initially, smart biosensors are deployed in HVAC systems in the hotel, then the water quality, noise levels, lighting quality, waste management data, and operational, financial, and operational effectiveness data are collected and transmitted to the IoT cloud. IQR utilizes the IoT cloud data to remove sensor errors and anomalous events to frame outlier data for WPT is a feature extraction process to decompose sensor data into detailed frequency bands, allowing for precise analysis of complex environmental signals, TSD-EMLP model predicts the environmental health in hotels using the decomposed data. **Figure 2** shows the proposed framework.

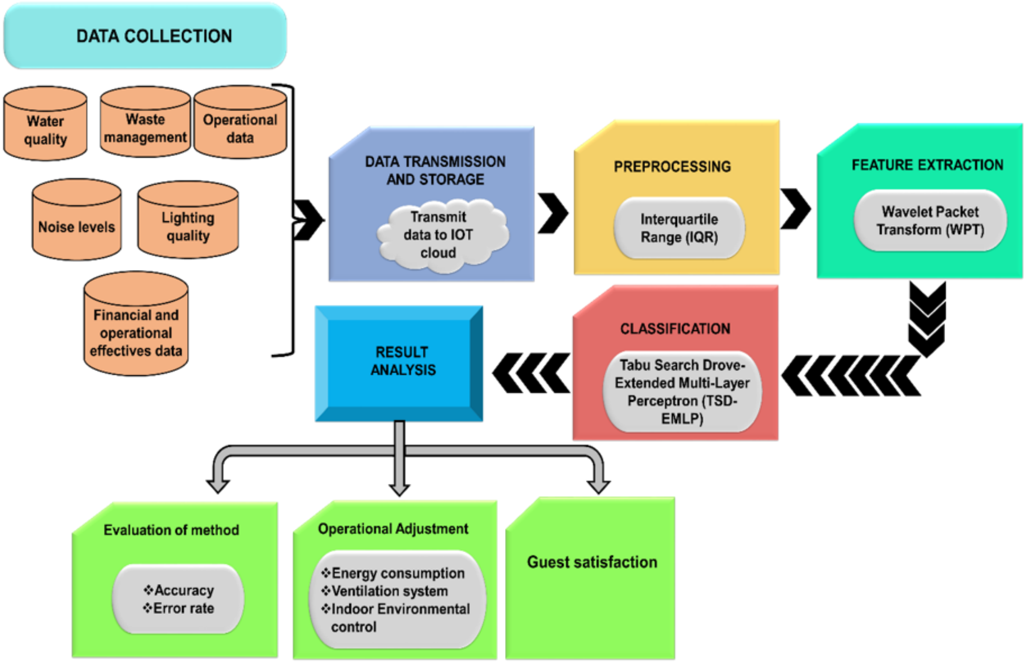

Figure 2. Flow for proposed method.

3.1. Dataset

The purpose of the data gathering is to use biosensors to obtain environmental and operational data. Data collected by the biosensors is transmitted to cloud-based storage systems. Cloud storage solutions offer scalable and flexible data storage options, allowing for the accumulation of amounts of environmental data. The data collection includes water quality, noise levels, lighting quality, and waste management, operational, financial, and operational effectiveness data. **Table 1** shows the data description.

Table 1. Environmental data.

Data's	**Description**
Water quality	Ensures cleanliness and safety of water sources
Noise levels	Monitors noise pollution and its impact on guest satisfaction
Lighting quality	Assesses the adequacy of lighting in different areas.
Waste management	Tracks waste generation and disposal efficiency
Operational data	Includes data on hotel operations such as energy consumption and system performance.
Financial and operational effectiveness data	Measures financial performance and operational costs.

Biosensors substantially enhance the environmental health of hotels by way of providing real-time, unique information on various environmental parameters inclusive of air first-rate, noise ranges, water safety, and lighting situations. By continuously monitoring those elements, biosensors allow accommodations to directly deal with issues like negative poor air quality or excessive noise, leading to advanced visitor consolation and satisfaction. They additionally facilitate powerful waste management and green power use by detecting anomalies and inefficiencies in operational structures. This proactive technique permits resorts to make knowledgeable changes to their surroundings, reducing operational costs and promoting a healthier, more pleasant environment for visitors and staff. Overall, biosensors assist in a dynamic and responsive control method that complements both operational effectiveness and environmental well-being.

3.2. Data transmission and storage

Ascertain the secure storage and analytical accessibility of the accumulated data. To successfully manage and utilize sensor data, it is essential to transmit the amassed statistics to a centralized IoT cloud platform. This platform gives scalable storage solutions, ensuring that big volumes of statistics may be stored successfully. It facilitates real-time statistics processing, permitting for immediate analysis and actionable insights. By leveraging the IoT cloud, customers advantage more advantageous accessibility to their records from any vicinity, promoting better decision-making and enabling timely responses to changing conditions or anomalies detected with the aid of the sensors. The setup helps robust information control and operational flexibility.

3.3. Data preprocessing using IQR

The pre-processing technique IQR is employed to identify and remove sensor errors from IoT cloud data. Air quality examines the distribution of readings from air quality index readings routinely IQR, which could be a sign of possible problems. Environmental levels are within safe and healthy bounds by analyzing IQRs. To evaluate the variability and identify results, compute the IQR for each environmental metric. The definition of IQR is the constant distribution of measured environmental data using Equation (1).

$$IQR = Q_3 - Q_1 \tag{1}$$

where $Q_3 - Q_1$ are discovered by resolving the subsequent integral is represented in Equation (2). The indoor air quality calculates the 25th percentile and 75th percentile of air quality index readings.

$$25 = \int_{-\infty}^{Q_3} e(w)cw + 75 = \int_{-\infty}^{Q_1} e(w)cw \tag{2}$$

The integrals are used to find the value of Q_3 and Q_1 represents the thresholds. Equation (3) specifies conditions for $e(w)$, which is a probability density function (PDF), where $e(w) \geq 0$. The PDF should be non-negative. $\int_{-\infty}^{\infty} e(w)cw = 1$ Denotes that PDF is considered accurate, provided the integral over all possible values is equal to 1.

$$(i): e(w) \geq 0 \; and \; (ii): \int_{-\infty}^{\infty} e(w)cw = 1 \tag{3}$$

The formulas to calculate the quartile positions in an analysis of a given size are found in Equations (4) and (5). It gives the position of first quartile Q_1 in the ordered data, and third quartile Q_3 in the ordered data.

$$R_1 = \frac{m+1}{4} \tag{4}$$

$$R_3 = \frac{3(m+1)}{4} \tag{5}$$

Preprocessing makes sure the data is clear and ready for reliable analysis by removing such outliers, therefore raising the caliber of the insights derived from the data.

3.4. Feature extraction using WPT

To extract preprocessed environmental data, utilize the feature extraction technique WPT method to decompose sensor data into detailed frequency bands, allowing for precise analysis of complex environmental signals. Biosensors and big data analysis combined offer an effective method to assess hotel digital operations and environmental health. Real-time environmental parameter monitoring is possible with biosensors, including temperature, humidity, and air quality. Orthogonal scale function $\varphi(w)$ as well as the corresponding smaller wave function of $\psi(w)$ are calculated using Equation (6).

$$\begin{cases} \varphi(w) = \sqrt{2}\sum_{l \in Y} r_l \varphi\,(2w - l) \\ \psi(w) = \sqrt{2}\sum_{l \in Y} r_l \varphi\,(2w - l) \end{cases} \tag{6}$$

Here r_l is the low pass filter coefficient and $\mu_0 = \varphi(w), \mu_1 = \psi(w)$ is the high pass filter coefficient, Equation (7).

$$\begin{cases} \mu_{2m}(w) = \sqrt{2}\sum_{l \in Y} r_l \mu_m\,(2w - l) \\ \mu_{2m+1}(w) = \sqrt{2}\sum_{l \in Y} h_l \mu_m\,(2w - l) \end{cases} \tag{7}$$

Among the m wave function when the decomposition i scale and, U_i^m is closure space function of $\mu_m(w)$ then it could be decomposed as $\mu_{2m+1}(w)$, which is represented in Equation (8).

$$U_i^m = U_i^{2m} + U_i^{2m+1} \tag{8}$$

The coefficients of signal's wave packet $O_l^{i+1,2m}$ output level of $i + m$, WPT is a potent signal processing method for feature extraction. It provides a multi-resolution analysis that catches both high-frequency $\sum_k h_{2k-l}\, o_k^{i,m}$ low-frequency $\sum_k g_{2k-l}\, o_k^{i,m}$ components by breaking down signals into different frequency sub-bands using Equation (9).

$$\begin{cases} O_l^{i+1,2m} = \sum_k g_{2k-l}\, o_k^{i,m} \\ O_l^{i+1,2m+1} = \sum_k h_{2k-l}\, o_k^{i,m} \end{cases} \tag{9}$$

When combined with big data analytics, $F_{ji} = \int \left|T_{j,i}(s)\right|^2 dt$ is a measure of the energy integral function of total data $\sum_{l=1}^{n} \left|w_{j,i}(l)\right|^2$ that makes it possible to evaluate environmental factors and operational effectiveness. The patterns that can be used to improve guest satisfaction, resource efficiency, and identification of areas for improvement are represented in Equation (10).

$$F_{ji} = \int \left|T_{j,i}(s)\right|^2 dt = \sum_{l=1}^{n} \left|w_{j,i}(l)\right|^2 \tag{10}$$

WPT makes it possible to extract important features that raise the accuracy and performance of the model by determining pertinent sub-bands, the signal's valuable data also disappears of high decomposition level of signal noise, and reduction of noise. The sensors produce signal noise and selecting the proper wavelet breakdown level is a crucial step in the signal produced by the light ionization sensor. The ability to recognize complex patterns and features in the data is an improved method. **Figure 3** displays the total number of decomposition layers.

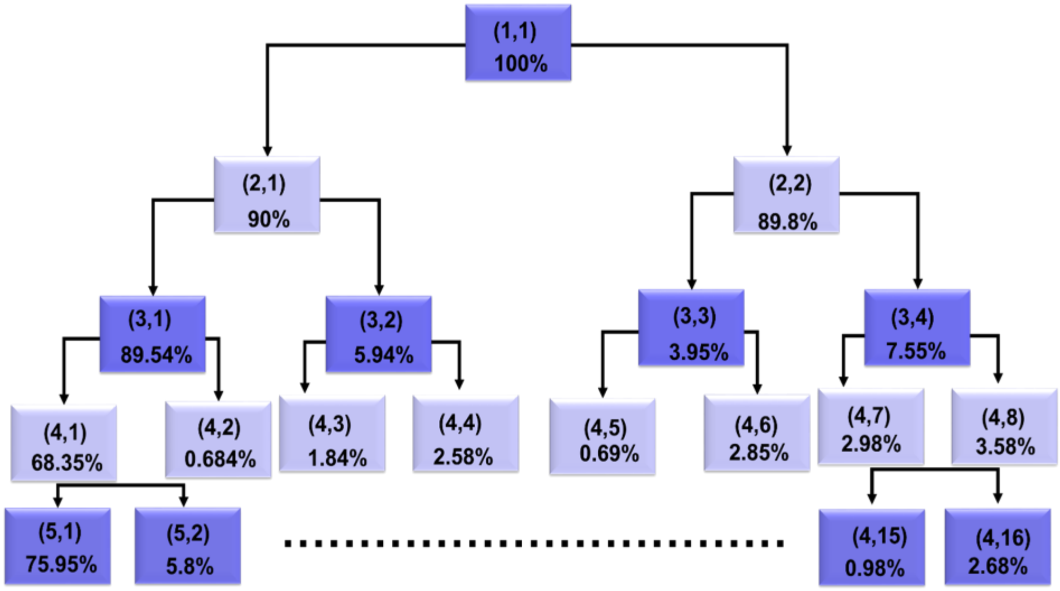

Figure 3. Node and energy of WPT decomposition diagram.

The amount of signal in each node WPT is referred to as energy in the context of WPT and it provides the amount of the signal's information that is present in each frequency band and resolution level. By isolating important frequency components, WPT enhances feature extraction with noise reduction, allowing WPT to monitor environmental conditions accurately, which improves decision-making and insights.

3.5. To predict hotel environmental conditions using Tabu Search Drove-Extended Multi-Layer Perceptron (TSD-EMLP)

After extracting the environmental data, TSD-EMLP improves the prediction of hotel environment conditions and offers innovative optimization approaches with the integration of big data analytics in biosensor data. It's the ability to assess digital operations in hotels and informed ranges that maximize guest satisfaction and operational efficiency.

Extended Multi-Layer Perceptron (EMLP)

The EMLP is a useful tool for assessing digital operations in hotels using biosensors and big data since it improves on neural network models by layers or mechanisms to evaluate complex data more effectively. Environmental conditions change the situations that the EMLP could train to forecast by gathering and analyzing real-time environmental data from sensors. Hotels can improve visitor comfort, and operational efficiency, and make proactive system adjustments. The hidden layers are positioned in between the input and output layers. EMLPs could represent intricate relationships within data in their architecture. Similar to a feed-forward network topology, data moves forward through an EMLP's network as neurons often referred to as perceptron's are trained using the back propagation process.

ω_j, denotes the weights data index, particular elements are represented by element m, and the function of J is an exponential function to calculate performance or prediction using Equation (11).

$$J = \sum_{w=1}^{m} \omega_j jow \tag{11}$$

In Equation (12), $P_w(n)$ denotes the activation values and then $\sum_{g=1}^{n} \omega_g^2 e$ represents the weight of hidden layers.

$$P_w(n) = \sum_{g=1}^{n} \omega_g^2 e \left(\sum \omega_{jg}^1 h_j(n) + S_g\right) \tag{12}$$

where (η)denotes the sigmoid function's input, which is usually the weighted sum of its inputs, and $e(\eta)$ represents the output of the sigmoid function using Equation (13).

$$e(\eta) = \frac{1}{1 + f^{-\eta}} \tag{13}$$

The transformation of the output network is T_g and the biases function is $\omega_{gi} \times P_w(n) + a_{gi}$ using Equation (14).

$$T_g = \sum_{i=1}^{n} \omega_{gi} \times P_w(n) + a_{gi} \tag{14}$$

This is the logistic sigmoid function, which neural networks frequently use as an activation function as represented in Equation (15).

$$T_g = \sum_{i=1}^{n} \omega_{gi} \times P_w(n) + a_{gi} \tag{15}$$

The function receives the input feature vector as an input layer such as $\{im_1, im_2 \ldots\ldots, im_n\}$ and output layers are $\{op_1, op_2\}$. **Figure 4** shows the structure of EMLP.

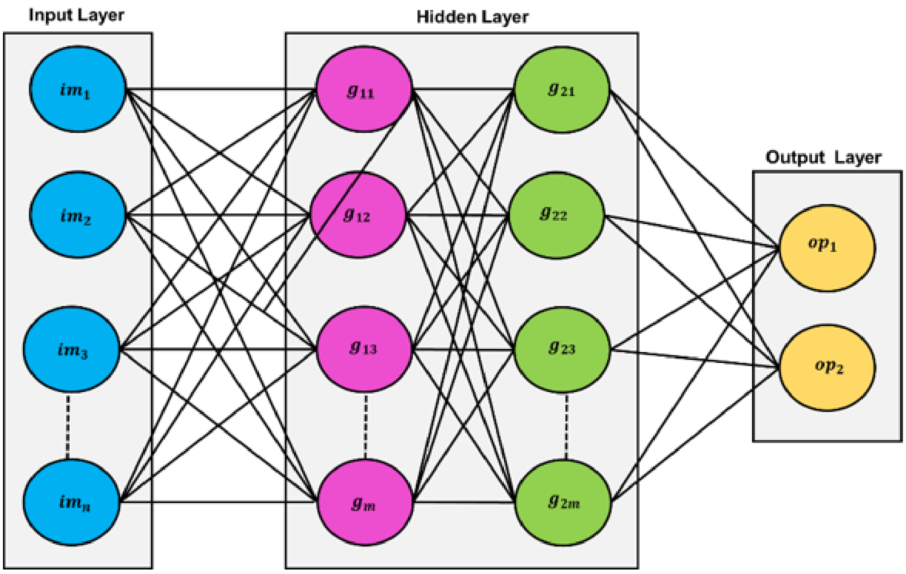

Figure 4. Structure of EMLP.

EMLP significantly improves digital operations in hotels by enhancing environmental conditions, increasing guest satisfaction, and boosting operational effectiveness.

Tabu Search Drove (TSD)

TSD is a comprehensive optimization method that combines different solutions searching the space concurrently to enhance conventional TSD and applies this cooperative method to forecast hotel environmental conditions to maximize forecasts for variables that are environmental conditions. In TSD architecture, each agent experiments with various prediction algorithms and adapts in response to input; in the meantime, a Tabu list eliminates duplicates. Combine the agents exchange ideas and improve their tactics, producing predictions that are increasingly precise and effective. The method uses a variety of search channels in addition to avoiding local ideals to increase overall forecast accuracy and operational effectiveness. Dynamic properties study is crucial for solving the adaptive management of memory in Tabu Waves, there are optimization difficulties with finite resolutions. Repetitive solutions are not included since they entail non-replicable tasks. The forbidding strategy, the liberating strategy system, and the short-term strategy called as STS are the three variants of TSD. To keep the FS called forbidding strategy and the freeing strategy method or FSS connected, the STS approximates solutions. After optimization, FSS handles residual data, FS selects which data enters the operating zone. Based on neighborhood layouts, using Equation (16) memory dependence, and nonlinearity, **Figure 5** depicts TSD neighborhood solutions new solution.

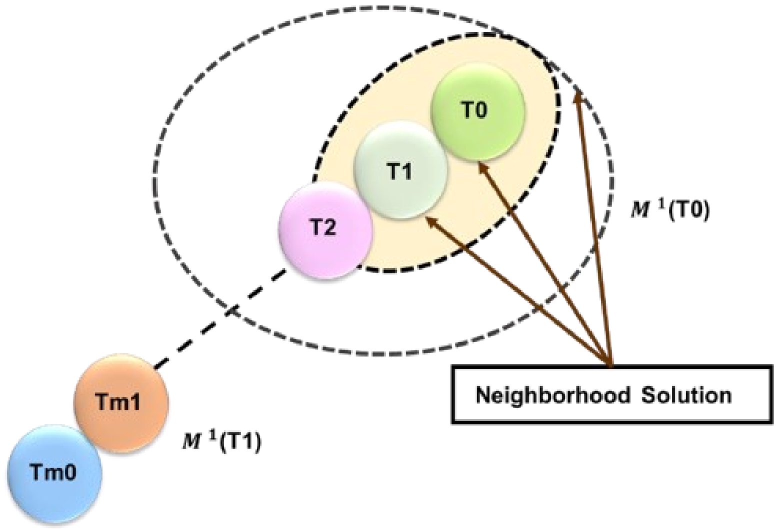

Figure 5. TSD neighborhood solutions new solution.

$$M' \in T(m) = \{T(m) - M(S) + T(s) \quad (16)$$

An optimal collection of parameters at each iteration represents the present solutions, crucial for generating neighbor trial solutions. Moves are actions that generate trial solutions pertaining to a group of potential motions, including possible trial solutions that can be infinite in continuous optimization; hence, a limited subset is often used. Tabu restrictions prevent certain moves to avoid cycling back to the local optimum, aspiration criterion allows a forbidden move that leads to a better solution. The stopping criteria include: (a) exceeding the quantity of iterations from the most recent optimal solution, (b) reaching the maximum iterations, or (c) the objective function value reaching zero. By evaluating solutions from several approaches, the TSD framework includes goal programming. **Figure 6** shows the step-by-step process used by the TSD framework in optimizing complex decision-making scenarios. It also visually represents the detailed structure of this evaluation process.

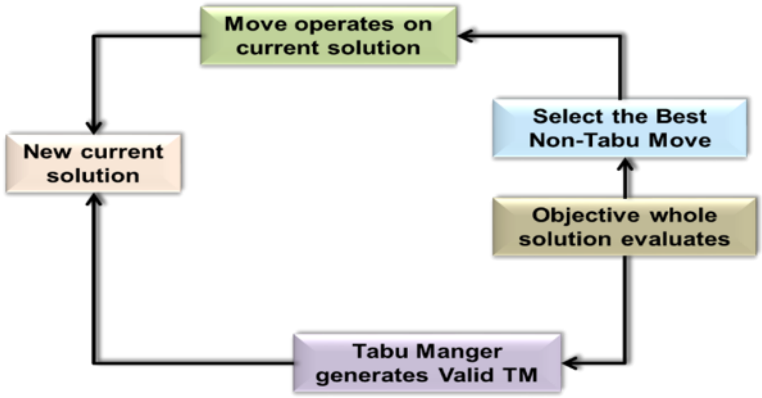

Figure 6. TSD Framework for optimal solution.

In the hotel environmental conditions, TSD improves efficiency to accurate efficient control of environmental levels resulting from cooperative advancements and dynamic adaptation. Algorithm 1 shows the Tabu Search Drove-Extended Multi-Layer Perceptron (TSD-EMLP).

Algorithm 1 Tabu Search Drove-Extended Multi-Layer Perceptron (TSD-EMLP)	
1:	Step 1. Initialize parameters
2:	Step 2. Initialize the EMLP model
3:	Step 3. Initialize the Tabu Search
4:	Step 4. For iteration = 1 to MaxIter
5:	Step 5. Output the best solution found
6:	Step 6. Train the final EMLP model with the best solution

The TSD-EMLP method combines TSD with an enhanced EMLP architecture, optimizing performance by avoiding local minima and improving convergence speed. In hotel digital operations and environmental health assessments, TSD-EMLP leverages biosensor data and big data analysis to provide more accurate and comprehensive evaluations, leading to better decision-making and operational efficiency in a complex and dynamic environment.

4. Result analysis

The research evaluates the effectiveness of digital operations in hotels by using biosensors and big data to predict environmental conditions and improve guest experiences and operational efficiency through analytics and real-time monitoring. The necessary protocols were created in a Python 3.11.4 environment. To duplicate the analysis of the recommended optimization choices, a Windows 11 laptop equipped with an Intel i5 11th Gen CPU and 32 GB of RAM was used. To enhance guest satisfaction, operational adjustments focus on optimizing energy consumption, improving ventilation systems, and maintaining a favorable air quality index.

4.1. Evaluation methods

Evaluation methods using accuracy measure the percentage of accurate forecasts among all predictions, while error rate calculates the proportion of incorrect predictions. These metrics provide insights into model performance but from different perspectives of accuracy emphasizing correct predictions, while the error rate highlights inaccuracies.

Accuracy: The percentage of accurately predicted outcomes out of all the predictions a model produces is called its accuracy. Divided by the total number of instances, the ratio of true positives to true negatives is calculated, high accuracy in the context of the TSD-EMLP classification model means that the model closely matches real conditions and could be relied on to predict the environmental health status of hotels.

Precision: The precision metric quantifies the percentage of true positive forecasts among all positive predictions generated by the model. With a 93% accuracy rate, this indicates that the environmental health problems the model diagnosed had been efficaciously categorized as true positives, reflecting its effectiveness in minimizing false positives and ensuring that when it predicts a difficulty, it's far more likely accurate. High precision is crucial for reducing the risk of false alarms that could lead to useless interventions.

Recall: Recall assesses the proportion of actual positive instances that have been efficiently recognized by way of the model. A recall of 92% way that the version effectively detected of all real environmental health issues present in the statistics, showcasing its potential to capture most of the true positives while lowering the range of missed instances.

F1-Score: The F1-Score provides a fair assessment of the model's effectiveness by taking the harmonic average of accuracy and recall. An F1-score of ninety 92% reflects the version's basic effectiveness in identifying environmental health elements, integrating the precision of its high-quality predictions and the recall of its true positives to offer a comprehensive assessment of its predictive accuracy. **Figure 7** shows the result of outcomes.

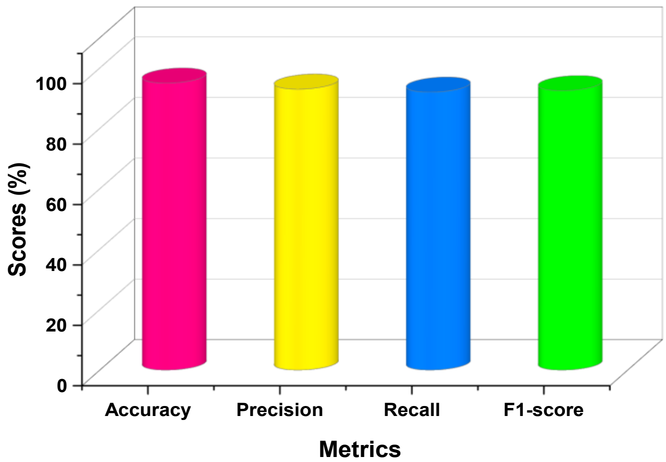

Figure 7. Outcome of accuracy, precision, recall and f1-score.

Error rate

The proportion of erroneous data units relative to the total data units is called error rate. It provides a measure of overall predictive performance by separating the amount of error from the total amount of observations, which quantifies the accuracy of the model. In the simulated outcomes, with 10 iterations, the highest error rate is 1.00 observed in iteration 7. Other notable error rates include 0.50, which occurs in iterations 4, 5, and 10. **Figure 8** shows the error rate.

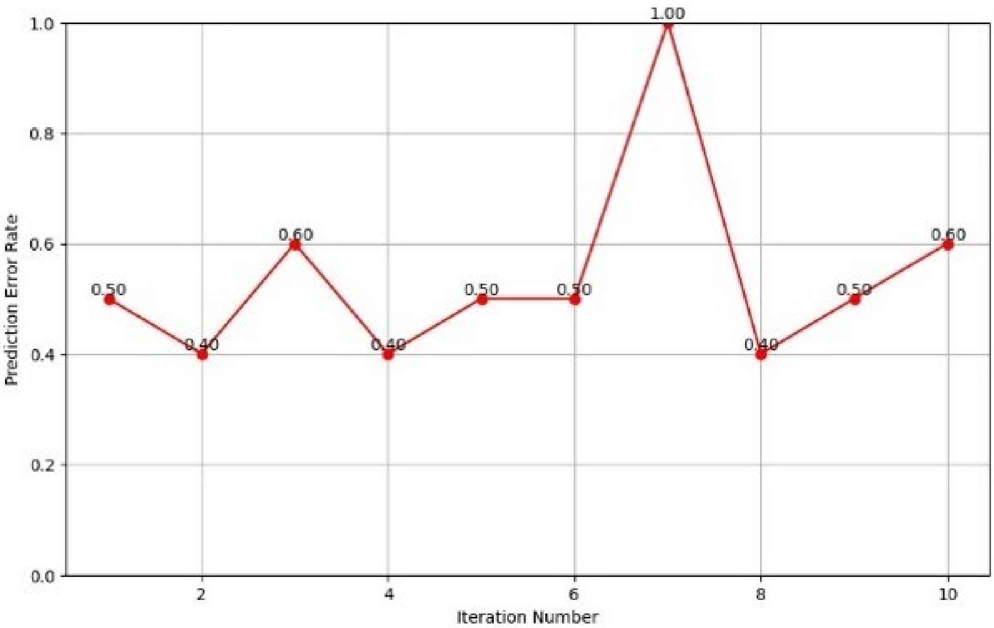

Figure 8. Result of error rate.

4.2. Operational adjustment

The manual adjustment of environmental settings by predetermined timetables resulted in energy inefficiency, substandard air quality, and inconsistent visitor comfort. By synchronizing modifications with actual conditions, this strategy considerably lowered energy usage, improved air quality, and increased visitor satisfaction. Adjust lighting levels and settings according to the model's recommendations to ensure adequate light while conserving energy. For example, adjust lighting intensity in rooms and common areas according to occupancy and natural light conditions. Smart controls are automated lighting systems that adjust based on real-time data, such as dimming lights when natural light is sufficient or turning off lights in unoccupied areas.

Energy consumption

The term energy consumption describes how much energy is utilized during an amount of time through systems. It measures energy use in forms including fuels, heat, and electricity and evaluates its effectiveness, affordability, and environmental impact. Before, inefficient systems and a lack of real-time modifications resulted in significant energy use in hotel surroundings. After optimizing operational settings, including automated controls and energy-efficient technologies, energy consumption was significantly reduced. Adjustments such as improved ventilation and real-time environmental controls led to lower energy usage, enhancing sustainability and reducing operational costs while maintaining guest comfort. This facilitates the identification of energy usage reductions. The energy consumption before operational adjustments was 500 kWh per day, while after operational adjustments, it decreased to 400 kWh per day. Energy consumption should decrease to enhance operational performance, reduce prices, and minimize environmental impact. Lower energy use suggests that the implementation of computerized controls and strength-green technologies is efficiently optimizing lodge structures, main to fee savings and reduced carbon footprint. Additionally, reduced energy consumption helps sustainability goals and ensures that sources are used more efficiently, contributing to an extra environmentally friendly and economically feasible operation at the same time as nevertheless preserving guest comfort. **Figure 9** illustrates the result of energy consumption.

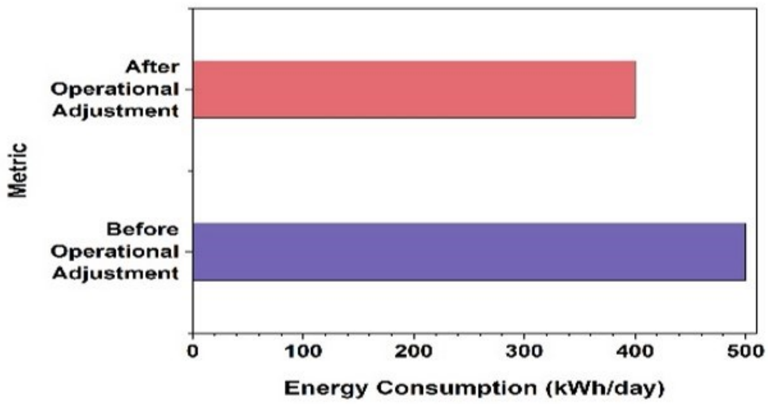

Figure 9. Result of energy consumption.

The energy consumption decreases from 500 kWh/day to 400 kWh/day after the operational adjustment, indicating a 20% reduction in energy use. This improvement reflects the effectiveness of the changes implemented, resulting in significant energy savings and potentially lowering operational costs and environmental impact.

Ventilation systems

Ventilation systems are designed to control and exchange indoor air, ensuring a continuous supply of fresh air while removing stale or contaminated air. The systems enhance indoor air quality, regulate temperature, and reduce humidity by employing mechanical or natural methods to improve comfort and health. Adjust HVAC system controls the temperature and humidity based on the model's predictions to maintain optimal indoor climate. For instance, if the model predicts higher levels of indoor pollutants, enhance ventilation in operational adjustment to reduce contaminants. **Figure 10** demonstrates the result of ventilation system efficiency.

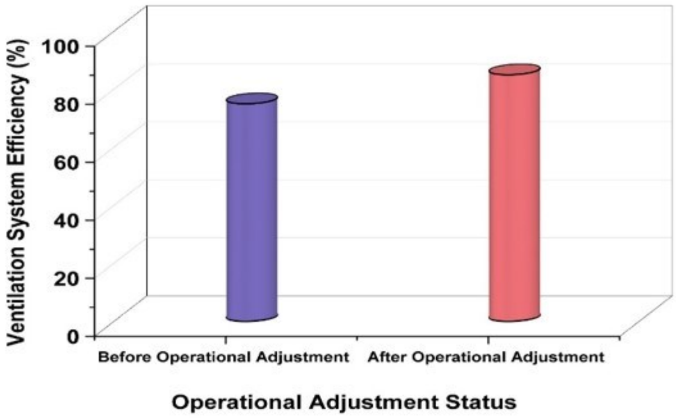

Figure 10. Result of ventilation systems efficiency.

Before the operational adjustment, the ventilation system efficiency is 75%. While after adjustment, efficiency improved to 85%. This increase indicates that the operational changes enhanced the system's performance, leading to more effective air circulation and better overall functionality. The adjustment likely optimized system components or settings.

Air quality index

The Air Quality Index assesses the improvements in air quality by comparing before and after adjustment data on pollutants, particulate matter, and ventilation effectiveness. Evaluate changes in environmental levels to ensure they meet comfort standards maintained within optimal ranges. Lighting quality is improved in lighting conditions, including illumination levels and energy efficiency of lighting systems. **Figure 11** shows the result of indoor environment control.

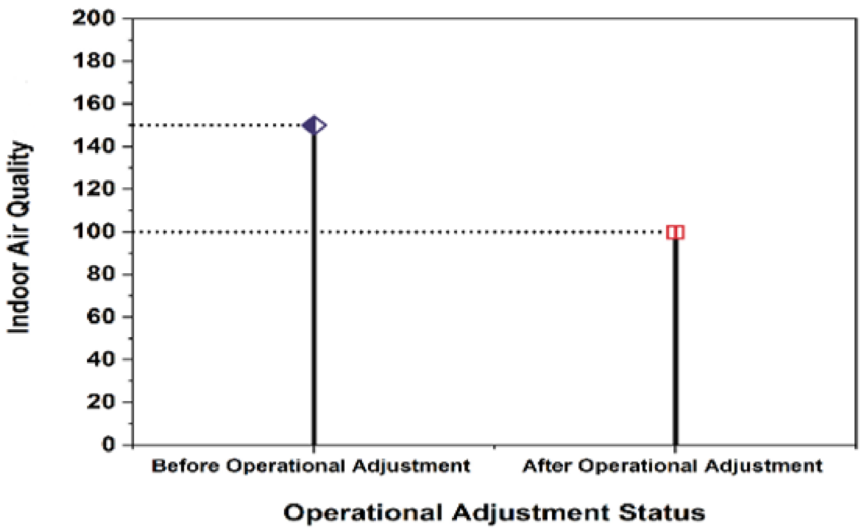

Figure 11. Result of air quality index.

Before the operational adjustment, the air quality index was at 150, indicating poor air quality. After the adjustment, the indoor air quality improved to 100, reflecting a significant enhancement in air quality. Air quality has declined, as shown by the shift from 100 moderate to 150 unhealthy. This reduction suggests that the operational changes were effective in reducing air pollutants and improving indoor air conditions.

4.3. Guest satisfaction

Satisfaction metrics analyze changes in guest satisfaction scores related to comfort, air quality, lighting, and noise levels. As a result of operational changes, the guest satisfaction score raised from 4.2 to 4.5, indicating improved guest experiences. This rise indicates that the improvements were beneficial in addressing the difficulties, which had before occurred and raising overall guest satisfaction. Service quality and operational effectiveness were improved by the changes. **Figure 12** illustrates the result of the guest satisfaction score.

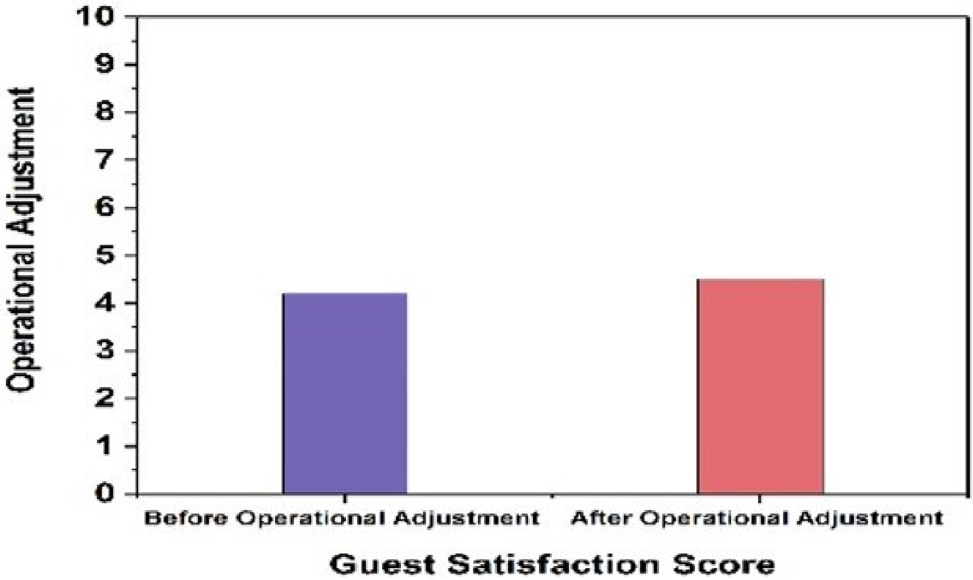

Figure 12. Result of guest satisfaction score.

5. Discussion

The study demonstrates substantial enhancements in hotel operations, especially in ventilation, energy efficiency, and guest satisfaction, through the implementation of the TSD-EMLP model. By leveraging real-time information from biosensors, the model allows particular modifications to environmental settings, leading to reduced energy consumption and improved air quality. With an accuracy rate of 95%, the TSD-EMLP model proves particularly powerful in predicting and optimizing environmental situations, significantly minimizing error rates. This capability underscores the model's ability to remodel automated control practices using integrating computerized controls and actual-time analytics, fostering both operational efficiency and advanced guest experiences. Real-time data-driven optimizations, such as smart lighting and improved ventilation, not only lower operational charges but also elevate air quality standards, similarly validating the version's effectiveness in preserving sustainable and guest-friendly surroundings. The TSD-EMLP version's sturdy overall performance highlights its rate as a critical device for dynamic and responsive manipulate, making sure non-prevent improvements in each environmental sustainability and standard provider great.

6. Conclusion

The study concludes the utility of digital technology in the hotel quarter, focused on the usage of biosensors and big data analytics to enhance operational performance and environmental health. The effectiveness of digital operations in accommodations turned into evaluated by leveraging the TSD-EMLP method. It highlighted the effectiveness of integrating digital technologies for real-time environmental monitoring and operational enhancements in the hospitality enterprise. By combining big data analytics with biosensor data, the TSD-EMLP concept considerably complements hotel operations. It expanded the guest satisfaction and running efficiency by using optimizing strength consumption, improving air quality, and making real-time environmental modifications. In digital operations and environmental health assessment, TSD-EMLP has demonstrated to be beneficial in predicting and dealing with motel environmental conditions, with a 95% accuracy rate. The limitations include potential sensor calibration troubles and the want for greater diverse information assets. Future work will explore incorporating additional environmental variables and enhancing sensor accuracy. Expanding the version to distinctive forms of accommodations and geographic places will offer greater comprehensive insights and further beautify the predictive skills of the brand new models.

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