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Energy Consumption Analysis Using Weighted Energy Index and Energy Modeling for a Hotel Building

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Abstract: Energy consumption is an essential and vital issue for commercial hotel buildings. Regulations and codes are commonly used to regulate the energy usage of the building. However, the energy index used to evaluate energy performance does not include the usage of hotel buildings for different service purposes. This study utilizes a comprehensive approach involving data collection, field measurement, regression analysis, and building energy modeling to investigate the energy performance in hotel buildings. The study finds that ambient temperature and occupancy rate are key factors in energy consumption, resulting in a weighted energy index for public areas and guest rooms with an R-square of 0.8314 and 0.9184, respectively. The measurement data are also used to perform the energy modeling, and the data are validated. Studies on different regions, occupancy, orientation, window-to-wall ratios, and U-values are evaluated and simulated to determine the energy consumption, which might be useful for the hotel building design phase. In addition, it also evaluates the energy-saving potential, including chilled and condenser water temperature, COP, and indoor temperature settings. The study finds that implementing various studies could result in significant energy consumption and savings, with higher chilled water and lower condenser water temperature having a particularly prominent impact. The study concludes that energy modeling approaches can be useful tools for identifying and implementing energy-saving strategies.

Keywords: field measurement; regression analysis; EnergyPlus; energy saving

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1. Introduction

The advancement of the technology sector has raised people's living standards. Cities have a variety of buildings, including homes, offices, and other constructions. Nonetheless, the topic of energy misuse and ways to save energy has emerged as one of the issues addressed the most frequently worldwide [1]. The reference electricity index for building users was issued to assist various buildings' energy-saving diagnosis and improvement [2]. The energy consumption of buildings varies according to the usage situation and continuously formulated regulations to regulate buildings' energy consumption standards [3]. Moreover, buildings have various functions and energy needs, such as schools, restaurants, hotels, hospitals, museums, and others, including lighting, heating, ventilation, air conditioning (HVAC), domestic hot water (DHW), refrigeration, food preparation, etc. The demand for services in healthcare, education, culture, hospitality, etc., increases along with the population and economy, which also increases energy consumption [4]. Many studies have been dedicated to the problem of hotels' excessive energy consumption and potential solutions, such as using renewable energy sources and monitoring equipment. An on-grid, small wind turbine is the most practical among the potential energy sources for a small hotel's load demand [5]. Non-residential buildings, such as hotel buildings, currently consume more energy because they have a higher number of EUI. In comparison with other commercial industries, such as schools and hospitals, the hotel sector consumes a lot of energy [6].

Energy use in hotels is rising, similar to other types of buildings. The rising operating costs due to the energy demand are related. The main goal is to reduce air pollution in addition to the potential financial savings that can be made by lowering the energy demand [7]. The hotel industry emits 1% of the world's carbon, and this percentage is expected to increase. Similar to other industries, hospitality must reduce its environmental impact [8]. A commercial hotel was analyzed for energy savings and consumption. The envelope design scenario shows that changing the envelope design standards could reduce energy consumption by 7.5%, with wood for walls, IEAD for roofs, and fixed windows for glazing being the best materials. In addition, three energy conservation alternatives were modeled by changing the hotel residents and workers' behavior to reduce energy consumption by 5–25% [9]. Furthermore, several effective energy-saving technologies have been carried out for energy-saving renovation and actual verification in a practical case, taking into account the characteristics of building energy-saving in hotels [10]. A building utilizing a heat pump was researched to discover the possibilities of efficient energy [11]. The heat pump has become a leading technology in the building energy sector. The use of the air source heat pump (ASHP) in energy installations in so-called nZEB low-consumption buildings is currently on the rise [12]. However, a systematic approach for integrating the optimum heat pump system in buildings in order to meet the space heating/cooling and DHW loads is still missing [13].

Energy performance criteria and metrics can inform management regarding the energy value chain, processes, and components. The EUI of a building is calculated by dividing its annual energy use by its built-up area in kWh/m^2/year or MJ/m^2/year. It answers the question of energy efficiency, but the measurement level is too high to identify specific regions, procedures, or pieces of equipment where energy management opportunities exist [14]. Several investigations have investigated the cause of the EUI baseline standard for hotel buildings. Sustainable hotel development requires objective energy benchmarking. It identifies the major and minor streams of hotel energy benchmarking and has found that floor-level normalized energy use intensity (EUI) is the most popular method. In order to ensure the sustainable growth of the hotel industry, it is important to conduct energy benchmarking in a way that is both effective and objective for hotels [15]. NIST has conducted HVAC EUI studies for commercial buildings [16]. NIST correlations have been used to develop coefficients for eleven prototype buildings, eight cities, and two levels of building envelope airtightness, resulting in HVAC-EUI savings of 6%. Infiltration's effects on HVAC energy use are important and should be better accounted for in whole-building energy modeling. Moreover, the energy consumption of guests from different regions in Taiwan hotels has been widely investigated, with a total of 73 hotels investigated. The results show that the average EUI is 968 MJ/m^2 per year (268 kWh/m^2/year) [17]. Nateghi et al. [18] researched reducing energy costs by decreasing the energy consumption of a hotel building. EnergyPlus is used in energy simulations to determine the schedule, number of people, electrical equipment, zones, lighting, building location, weather, etc. It is also used to assess energy performance to find the best way to improve it [19–21].

Regression analysis has been used to simulate energy usage in construction-related elements. Building construction sectors may benefit from the findings on energy optimization [22]. Research using a linear regression model was conducted to approach the energy performance of the building [23]. The linear regression method developed some simple relationships to determine the building's thermal heating or cooling energy demand [24]. Tahmasebinia et al. [25] also conducted an energy simulation using the same software to predict precise energy consumption. The regression model was validated by case study and simulation results, with most deviations under 5% in 35 validation runs. The results demonstrate linear regression model limitations; more HVAC prediction detail aids source-side energy supply strategies [26]. Furthermore, Building Energy Management Systems

(BEMS) are the most pressing issue, and they provide reliable and helpful resources and monitoring data for building owners and managers [27]. BEMS is a technique used for monitoring and controlling the power consumption of buildings, such as electric chillers, pumps, fans, and other electrical devices, which can significantly control the energy in a building with proper management and control. Overall, using a BEMS will probably result in greater energy savings than not using one, because it offers the simple access and control required to operate more affordably [28].

Although various studies have been conducted on reducing energy consumption in hotels, this study discusses the importance of energy consumption in commercial hotel buildings through field measurement, BEMS system, regression analysis, and energy modeling. However, the current energy index used to evaluate energy performance does not include the usage of hotel buildings for different service purposes. Therefore, there is a research gap in understanding how different service purposes impact energy consumption in hotel buildings, and how the energy index used for evaluation can be improved to consider these factors. The study utilizes a comprehensive approach to investigate the energy performance in hotel buildings and identifies ambient temperature and occupancy rate as key factors in energy consumption. The study also analyzes and simulates various scenarios to evaluate the energy-saving potential, and energy modeling approaches can be useful tools for identifying and implementing energy-saving strategies.

2. System Description

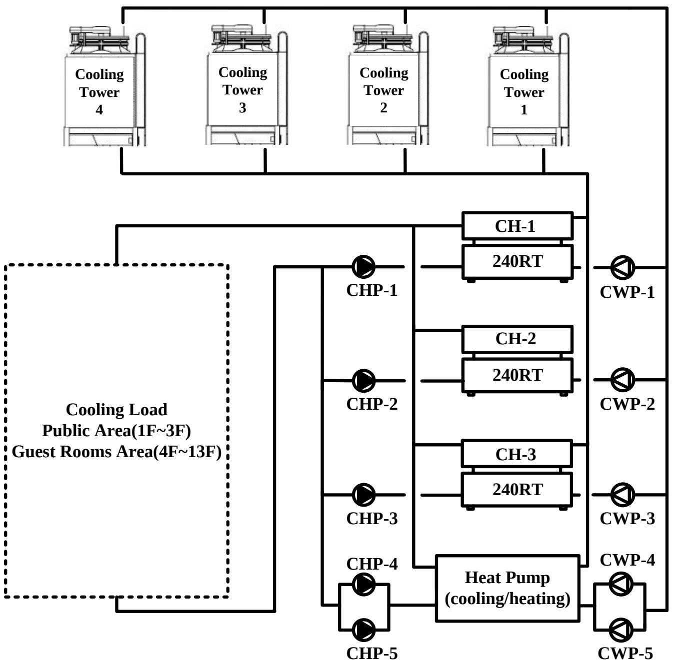
The investigated hotel building, as shown in Figure 1a, is located in central Taiwan, with subtropical weather conditions. The location faces south, and the building has 13 floors and 2 floors in the basement. The building has a total floor area of about 23,021 m^2 and is 52 m in height. The elevation view of the hotel building is shown in Figure 1b. The hotel is divided into the public space and the guest/hotel room section. Parking is available in B1 and B2. The main hall and cafeteria are on 1F, the office and staff restaurant are on 2F, the restaurant is on 3F, and the hotel guest rooms are on 4F to 13F. In addition, the machinery, such as the cooling tower, is located on the roof floor.

(**a**) (**b**)

Figure 1. The investigated hotel building: (**a**) façade of the existing building and (**b**) area and elevation.

Central HVAC systems are installed throughout the building. The schematic diagram for a water-based chiller as the cooling system is depicted in Figure 2a—a total of three sets of 240 RT (840 kW) chillers. At the same time, the water-cooled chiller is divided into two fixed frequency types and one variable frequency type. One fixed frequency type is for backup, and each main chiller is equipped with a 40 HP (29.8 kW) condenser water pump and a 25 HP (18.6 kW) cooling water pump to supply the chilled water system. For the heating system in Figure 2b, a heat pump with a heating capacity of 132 RT (465 kW) and a cooling capacity of 100 RT (350 kW) is provided for the cooling and heat water system.

A heat pump uses two 25 HP (18.6 kW) water pumps to provide chilled water in parallel and two 15 HP (11.2 kW) water pumps to supply water in parallel. A 725,000 BTU/hour (212.5 kW) boiler provides the hot water. Two 15 HP (11.2 kW) hot water pumps are sent to the four water tanks, which can store a total of 60,000 L. The hot water pump (HWP) has a capacity of 5 HP (3.7 kW) to supply the water to the plate heat exchanger.



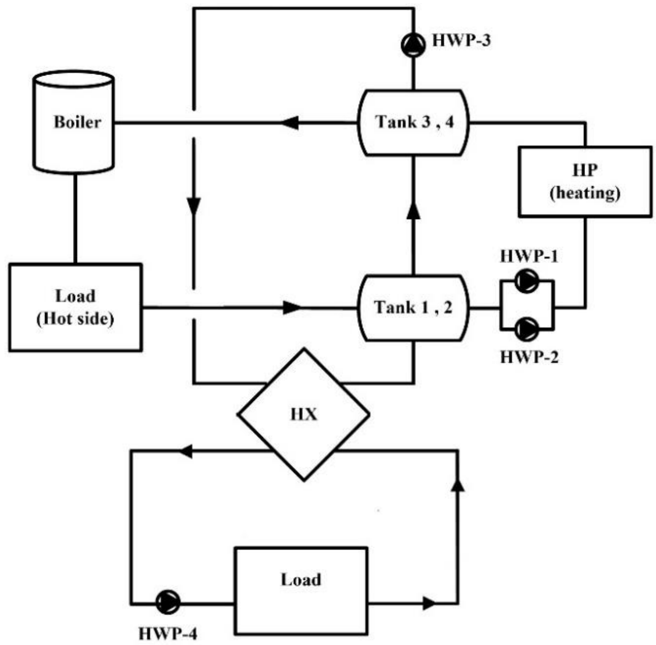


Figure 2. The investigated hotel building: (**a**) HVAC system and (**b**) hot water system.

According to the ventilation system, the air-conditioning equipment supplied differs due to the floor space used. The hotel space can be divided into public and guest room areas. The lobby and restaurant from 1F to 3F of the public space use four air handling units (AHU) and several fan coil units (FCU). In addition, the basement also uses FCU, then the guest rooms from 4F to 13F also use FCU. Moreover, four primary air handling units (PAH) are placed on the roof floor to introduce fresh air in order to maintain indoor air quality (IAQ) in the hotel building. Table 1 lists the specifications for the air conditioning ventilation system.

Table 1. Specifications for the air conditioning ventilation systems.

Equipment	Capacity (kW)	Airflow Rate (CFM)	Static Pressure (Pa)	Water Flow (LPM)	Quantity
AHU–1 and 2	106	9000	700	300	2
AHU–3 and 4	85	8000	600	240	2
PAH–1 and 2	155	6500	650	440	2
PAH–3 and 4	70	2500	600	200	2
FCU–1	3.5	400	50	9.1	40
FCU–2	5.3	600	50	14	243
FCU–3	7	800	50	18.2	69
FCU–4	8.8	1000	50	22.7	31
FCU–5	10.6	1200	50	27.3	6

3. Data Collection and Field Measurement

A thorough field assessment, comprising measurements of water temperature, energy consumption, temperature, humidity, and airflow rate supply, needed to be performed with HVAC system testing, adjusting, and balancing (TAB) in order to assess the building's energy performance. Field measurement tests were carried out to provide a reliable baseline for comparison, validate the simulation results for improved performance, and identify opportunities for the building's energy efficiency. The apparatus for field measurements are listed in Table 2.

Table 2. Apparatus for field measurements.

Apparatus Model	Parameter	Operative Range	Accuracy	Period
TSI-9565-P	Temperature Relative humidity Pressure	−10–60 °C 0–95% −3735–3735 Pa	±3% °C ±3% RH ±1 Pa	1 point for 1 min 3 times measurement
TSI-8380	Airflow rate (Air hood capture)	0.125–12.5 m/s	±3%	1 point for 1 min 3 times measurement
HIOKI-3169-20/21	Power meter	0–600 Vrms 0.5–5000 A	±0.20%	1 panel unit 3 times measurement

As shown in Figure 3, an advanced building energy management system (BEMS) was used to conduct extensive data acquisition for energy usage at the hotel building in order to obtain reliable measurement data. The BEMS data show how much energy the HVAC system used to operate, as well as for lighting and plugs. Specifically, through on-site real-time measurement in the rooms on each floor, the sum of chillers and pumps totaled the total energy consumption of the HVAC and air handling systems. Using extensive data collection from BEMS, the energy usage trend was displayed over hours, days, weeks, months, and years. Complex calibration procedures were carried out and kept up to date in comparison with data from the BEMS's on-site monitoring, increasing the simulation results' accuracy.

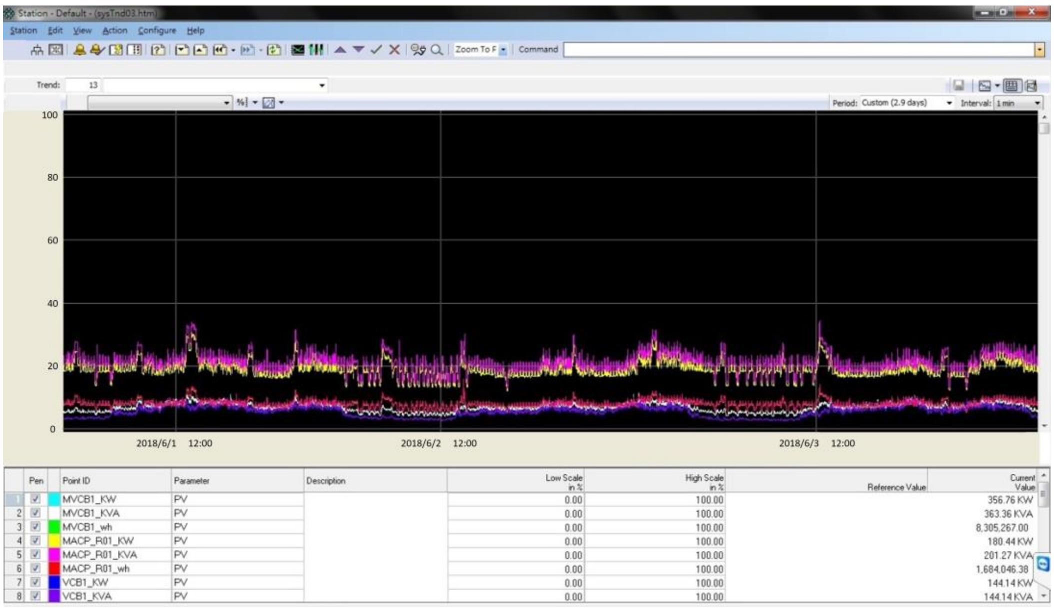


Figure 3. Data collection by the building management system.

As the outside air temperature changed, the energy consumption of the building also varied. Figure 4 shows an analysis of hotel building energy consumption and outside air temperature from January 2018 to December 2019. A temperature difference was found between day and night in some parts of the winter. The temperature varied greatly during the day. The temperature could reach a high temperature of about 27 °C to 30 °C during the day, but dropped to about 9 °C at night. The temperature change in summer was small, but the average temperature was relatively higher than in winter. Therefore, it is found that energy consumption in summer was high. Still, in winter, due to the high temperature during the day, some air conditioners in the public area operated, and the guest room area varied according to the occupants' usage.

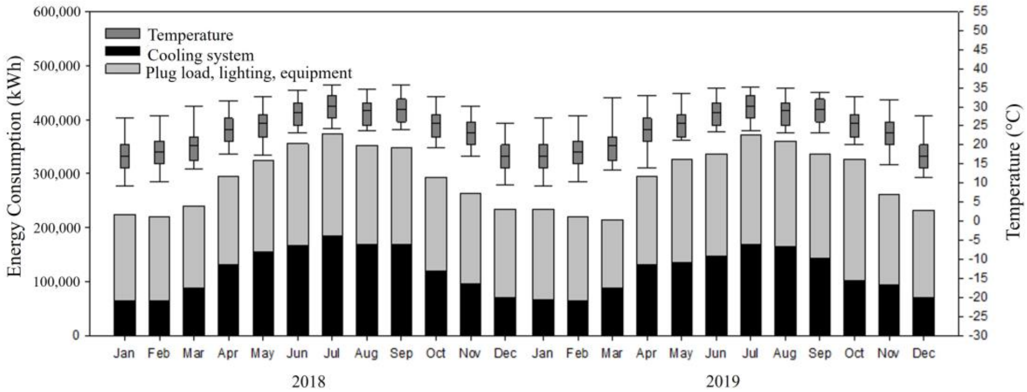


Figure 4. The effect of outside air temperature on energy consumption.

The energy consumption of hotel buildings is not only related to the outside air temperature, but also has a relative relationship with the occupancy rate. The energy monitoring system of the hotel building not only records the system's energy consumption, but also records the daily occupancy rate of the guest rooms. Figure 5 shows the relationship between the hotel building energy consumption and occupancy rate from January 2018 to December 2019. It can be found that the monthly energy consumption trend and occupancy rate did not have the same relativity. Still, in the winter and summer months, the energy consumption change had a relative trend with the occupancy rate. In addition, from the summer months, the energy consumption of the hotel buildings increased significantly, and the occupancy rate in the hotel was not much higher than in winter. The main reason is that the weather in the summer months is relatively hot, so there is also a significant increase in the energy consumption of air conditioners, increasing the total energy consumption. In addition, from the comparison of the air-conditioning energy consumption and total energy consumption, the energy consumption trends of the two were similar. Therefore, the total energy consumption was related to the AC system, and the total energy consumption changed with the use of the air-conditioning system with different temperatures in winter and summer.

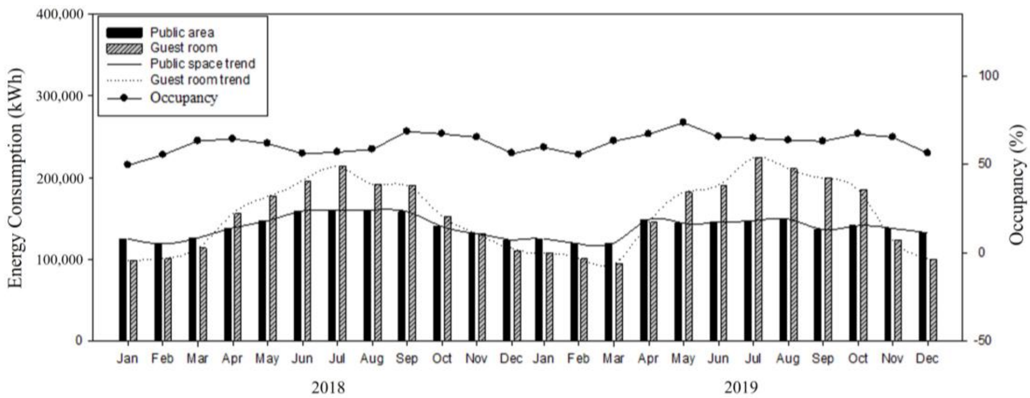


Figure 5. Energy consumption in different areas and occupancies.

4. Regression Analysis

4.1. Single Regression

The energy consumption model was predicted using regression analysis, and data from 24 consecutive months of on-site monitoring were used as the input. Thus, it is not fair to compare the various types of floors based on their energy usage based on floor area per unit. This research distinguishes between the different kinds of area use and used the hotel building case to investigate the factors of varying area use conditions to compare the weights of EUI and general EUI calculations in an effort to make the EUI standard more reasonable and the energy consumption index fairer.

Simple regression analysis depends on the Y variable as the EUI value of the area of use, which is the key to hotel energy consumption. The relationship between the values is the most significant, and the independent X variable is the outside air temperature (T_A) and the occupancy rate (O_R). We applied regression analysis to determine the relationship between the significant factor of the outside air temperature and the occupancy rate in each building area. The optimal regression equation for each floor was determined by determining which factor influenced the EUI value through regression analysis. The results of the regression analysis are shown in Table 3.

Table 3. Regression analysis results.

Regression Analysis	R-Squared	Source	DF	SS	MS	F Value	p
$EUI_{total} = 1.684 + 0.622T_A$	0.914	Model	1	134.86	134.86	236.04	0.00
		Residual	22	12.56	0.57		
		Total	23	147.43	–		
$EUI_{total} = 2.857 + 0.220O_R$	0.15	Model	1	22.11	22.11	3.88	0.06
		Residual	22	125.31	5.69		
		Total	23	147.43	–		
$EUI_{public} = 13.235 + 0.405T_A$	0.782	Model	1	88.59	88.59	78.96	0.00
		Residual	22	24.68	1.12		
		Total	23	113.28	–		
$EUI_{guest} = 4.326 + 0.735T_A$	0.895	Model	1	290.79	290.79	187.93	0.00
		Residual	22	34.042	1.54		
		Total	23	324.84	–		
$EUI_{public} = 15.149 + 0.125O_R$	0.097	Model	1	11.02	11.02	2.372	0.13
		Residual	22	102.25	4.64		
		Total	23	113.28	–		
$EUI_{guest} = 3.539 + 0.270O_R$	0.157	Model	1	51.28	51.28	4.12	0.04
		Residual	22	273.55	12.43		
		Total	23	324.84	–		

The EUI_{total} to T_A is shown in Figure 6a. After evaluating the coefficient, the model F value was 236.04, the significant level value was a = 0.05, and the p value was 0.00. As the p value was <0.05, it was determined that the total energy consumption had a significant relationship with the outside air temperature, and the R-squared value was 0.914. Then, the regression model could explain 91.4% of the total variation. The EUI_{total} to O_R is shown in Figure 6b. Suppose the occupancy rate accounted for 15% of the total variation in energy consumption. The EUI_{public} to T_A is shown in Figure 6c. It can be concluded that the public space did, in fact, have a statistically significant relationship with the average outdoor temperature. The regression model thus accounted for 78.2% of the total variance. The EUI_{Guest} to T_A is shown in Figure 6d. It was determined that there was a substantial relationship between the guest room area and the outside air temperature, and the R-squared value was 0.895. After that, the regression model could account for 89.5% of the total variance. The EUI_{public} to O_R is shown in Figure 6e. The R-squared value of 0.097 indicated that there was not a significant relationship between the public space and the housing rate. Consequently, the regression model accounted for 9.7% of the total variation, revealing that the housing rate was significantly correlated with the public area regression model. The EUI_{Guest} to O_R is shown in Figure 6f. Therefore, it can be found that the occupancy rate had a certain influence on the regression model of the guest room area. A regression model was able to explain 15.7% of the total variance (R-squared = 0.157).

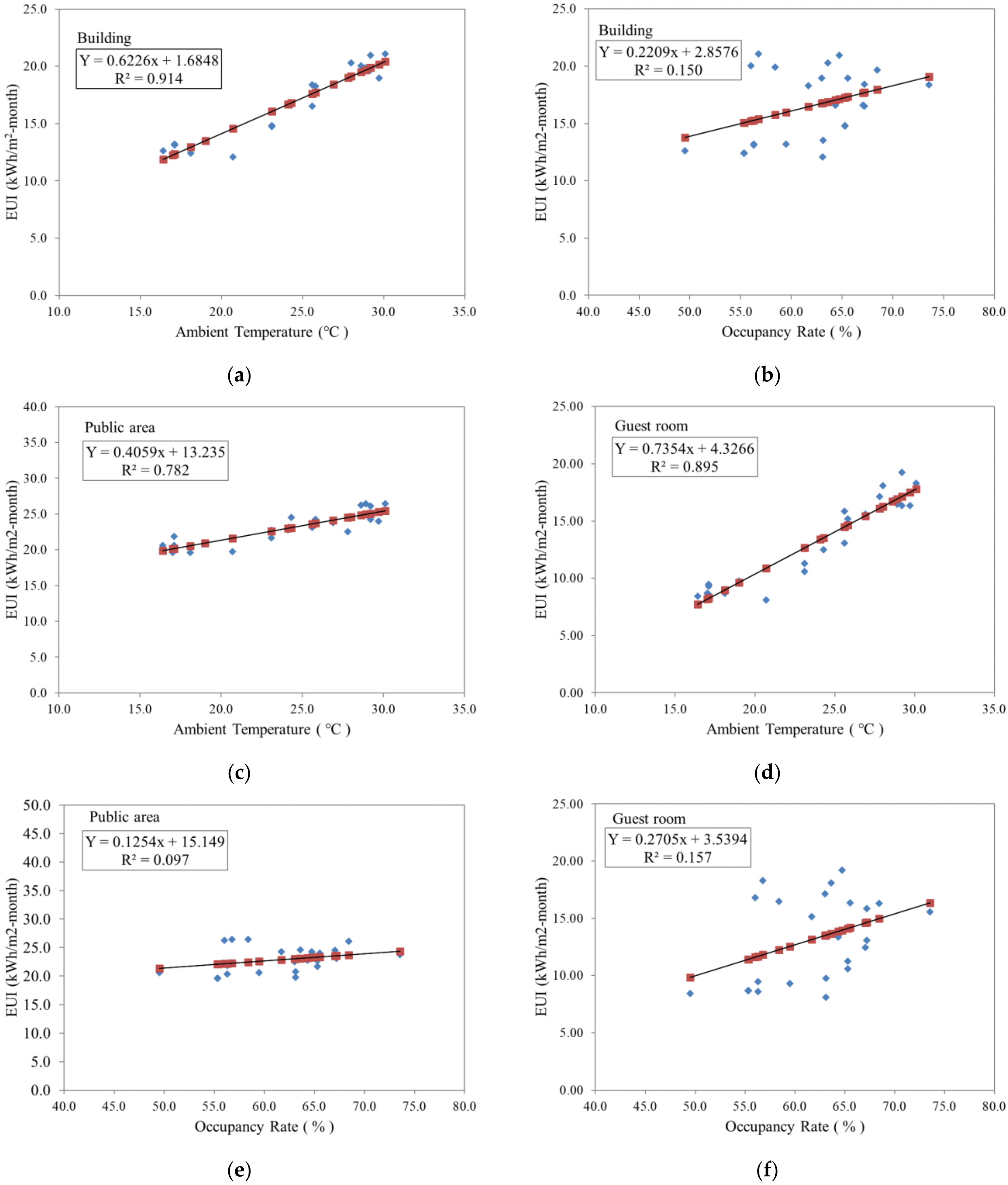


Figure 6. Regression analysis in different conditions. (**a**) EUI total to T_A. (**b**) EUI total to O_R. (**c**) EUI Public to T_A. (**d**) EUI Guest Room to T_A. (**e**) EUI Public to O_R. (**f**) EUI Guest Room to O_R.

As a result, it is clear that the ambient air temperature greatly affected energy use. In contrast, the occupancy rate had a smaller impact on the common areas because the public areas' energy consumption was driven by the provision of air conditioning and restaurants in the hall, power use, and accommodation staff. In this study, even if it is known that ambient air temperature affected energy use, regression analysis helped us quantify the magnitude of this effect and to determine the statistical significance of the relationship. Furthermore, regression analysis helped us make predictions about energy use based on ambient air temperature, which could be useful for decision-making and resource allocation. In summary, while regression analysis may not always be necessary, it can provide valuable insights and information, even when the underlying mathematical model is known.

4.2. Multiple Regression

There is a disparity in energy consumption between buildings because their functions vary across floor plans. Because of the differences in energy consumption and floor count, the resulting regression model based on the characteristics of each area also needed to adapt. This research assessed the common areas and guest rooms and arrived at the same conclusion regarding the EUI value. The sample data were derived from monthly monitoring data collected in 2018 and 2019. A simple regression analysis determined that the outdoor temperature and the building's occupancy rate were the two most significant determinants of the energy used by each room. Therefore, multiple regression techniques were employed in this study for the supplementary analysis. Then, a multiple regression bivariate process was established to determine the optimal equation for common areas and guest rooms. Equation (1) displays the EUI energy baseline equation, which is weighted to reflect the EUI.

$$\mathrm{EUI} = a_0 + a_1 T_A + a_2 {T_A}^2 + a_3 O_R + a_4 {O_R}^2 + a_5 T_A O_R \tag{1}$$

where, $a_{0\sim}a_5$ is the coefficient value. T_A is the outside/ambient air temperature (°C). O_R is the occupancy rate (%). The dependent variable is $\mathrm{EUI}_{\mathrm{Public}}$, and the double variables are the outside air temperature T_A and the occupancy rate. The model F value is 17.7, the significant level value a = 0.05, and the *p* value is 0. *p* value < 0.05 indicates the test is important, and the R-squared is 0.8314. This multiple regression model can explain 83.14% of the total variance, so the null hypothesis is that the entire multiple regression model has no explanatory power and can be excluded. The multiple regression equation is shown in Equation (2). Figure 7a compares the theoretical and EUI values of the regression in the public area.

$$\mathrm{EUI}_{\mathrm{Public}} = 38.281 + 1.046 T_A + 0.013 {T_A}^2 - 1.028 O_R + 0.011 {O_R}^2 - 0.020 T_A O_R \tag{2}$$

The dependent variable is $\mathrm{EUI}_{\mathrm{Guest}}$, and the double variables are the outside air temperature TA and the occupancy rate. The model F value is 40.48, the significant level value a = 0.05, and the *p* value is 0. For a *p* value < 0.05, the test is considered to have a substantial relationship. So, the null hypothesis that the entire multiple regression model had no explanatory power can be excluded, and the R-squared is 0.9183. This multiple regression model accounted for 91.8% of the observed variance given sufficient data. Equation (3) displays the numerous correlation equations. Figure 7b compares the theoretical and EUI values of the regression in the guest area.

$$\mathrm{EUI}_{\mathrm{Guest}} = 7.670 - 1.077 T_A + 0.022 {T_A}^2 + 0.293 O_R - 0.005 {O_R}^2 + 0.013 T_A O_R \tag{3}$$

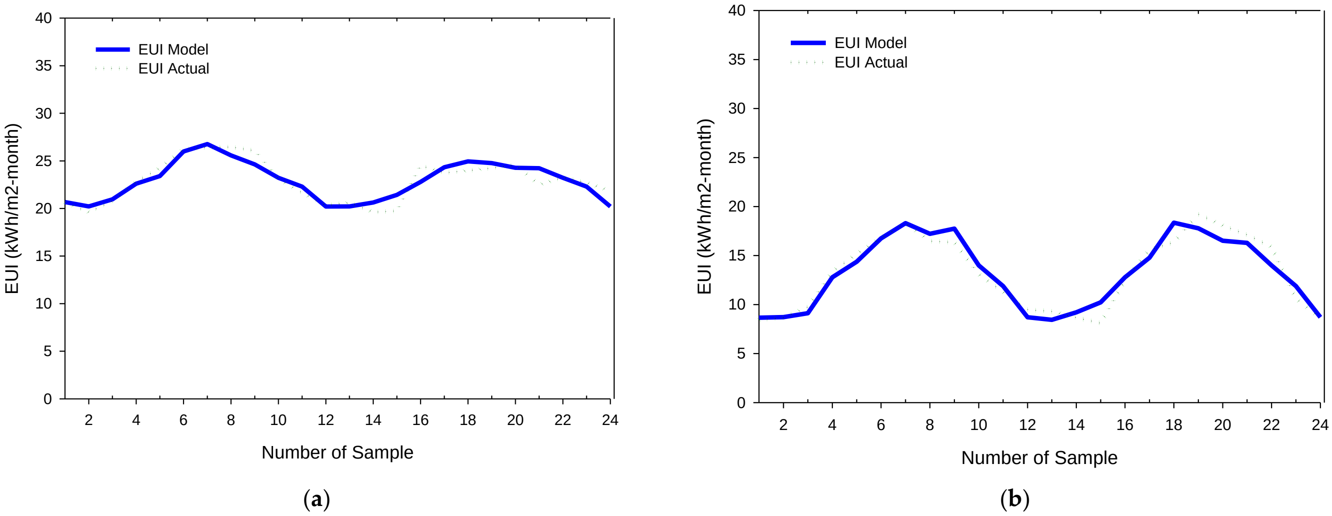


Figure 7. Comparison of EUI baseline model and actual: (**a**) public area and (**b**) guest area.

5. Energy Modeling

5.1. Geometry Model and Parameter Setup

In this study, EnergyPlus building energy simulation software version 9.2.0 was used to construct and simulate the energy consumption of the hotel building. As shown in Figure 8, the geometry model of the building was established based on actual conditions. The establishment of the geometry model of the building based on the existing conditions is a critical step for ensuring the accuracy of the simulation results. Accurate geometry models ensure that the simulation considers the building's shape, orientation, and surface area, which can significantly impact its energy consumption. Therefore, ensuring that the geometry model is as accurate as possible is essential.

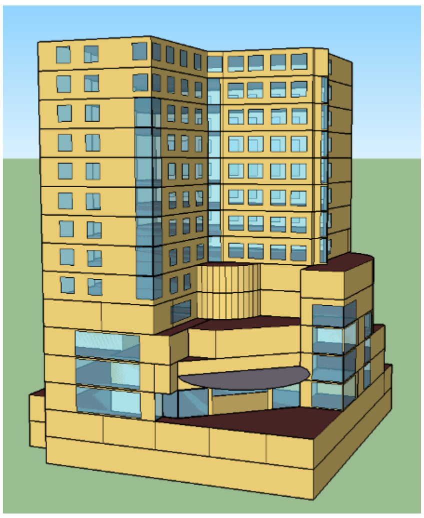


Figure 8. The geometry model of the investigated hotel building.

Weather data are important in building energy modeling because it greatly impacts a building's energy consumption. EnergyPlus is a popular building energy modeling software that allows users to import weather data files from various sources, including meteorological agencies and weather stations. The weather data file in this case was obtained from Taiwan's Central Weather Bureau [29], which provides reliable and accurate weather data for the region. Temperature, humidity, air velocity, and solar irradiation were all included in the weather data file. These parameters are critical for accurately simulating the building's thermal performance and energy consumption. The weather data file obtained from Taiwan's Central Weather Bureau, which includes temperature, humidity, air velocity, and solar irradiation, is critical for accurately simulating the building's thermal performance. EnergyPlus software used this data to identify energy-saving opportunities and optimize the building's design and operation in order to reduce energy consumption.

The building material properties are important for conducting energy modeling in EnergyPlus because they determine how the building envelope interacts with the external environment and how it retains or loses heat. For example, the thermal conductivity of the building materials determines how easily heat flows through them, which affects the heat transfer rate between the inside and outside of the building. This parameter is essential for accurately modeling the building's heat transfer and energy consumption. The building material properties for this investigated hotel building are listed in Table 4.

Table 4. Building material properties.

Category	Analytic Construction	U Value (W/m^{2}K)
Roof	15 cm RC + 5 cm PS board lightweight concrete	0.572
Exterior Wall	10 cm ALC Panel	0.650
Interior Wall	Frame partition with 3/4 in gypsum board	1.473
Ceiling	Rock wool ceiling	0.140
Floor	Passive floor, no insulation, tile, or vinyl	2.958
Door	Metal	3.702
Window	Large single-glazed windows	5.7

The input parameters for conducting building energy modeling are listed in Table 5, and they were also obtained based on the existing measurement data. They provide insight into the data used for building energy modeling. It is crucial to use reliable and accurate data for building energy modeling, as it can significantly impact simulation results. In addition, obtaining input based on existing measurement data is an excellent approach for ensuring the accuracy of the simulation results.

Table 5. Input parameters for energy modeling.

Parameters	Description	
	Baseline	Case Study
Building Type	Hotel	-
Floor area (m^2)	23,021	-
Total height (m)	52 m	-
Total Floors	13 Floors and 2 Floors of Basement	-
Zones	2 (public and guest rooms)	-
Sensible heat gain (w/person)	73.27	-
Latent heat gain (w/person)	58.67	-
Electric plug density (W/m^2)	20	-
Lightings density (W/m^2)	15	-
Infiltration Rate (ACH)	0.3	-
Window to Wall Ration (WWR)	25%	15% and 35%
Coefficient of Performance (COP)	4.953	3.953 and 5.953
Chilled Water Temperature	7.2 °C	6.2 °C and 8.2 °C
Condenser Water Temperature	29.4 °C	27.4 °C and 31.4 °C
Indoor Setting Temperature	25 °C	24 °C and 26 °C
Occupancy (persons)	600	420 and 780
Orientation	South	North, East, West
Location	Taichung, Taiwan	Taipei, Taitung, Kaohsiung

The schedule operation time is also important for conducting energy modeling in EnergyPlus because it determines when and for how long various building systems and components operate during a typical day, week, month, or year. For example, the operation schedule of lighting systems affects the amount of electricity used for lighting, while the operation schedule of HVAC systems affects the amount of energy used for heating and cooling. Similarly, the operation schedule of hot water systems affects the amount of energy used for water heating, and the operation schedule of appliances and equipment affects the building's internal heat gains and plug loads. The building schedule and operation time used in this study are listed in Table 6.

Table 6. Building schedule and operation time.

Time	AM													PM											
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Occupancy	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5
Lightings	0.6	0.4	0.4	0.2	0.2	0.4	0.6	0.6	0.8	0.8	1	1	1	1	1	1	1	1	1	1	1	0.8	0.8	0.6	0.6
Equipment	0.8	0.6	0.6	0.4	0.4	0.4	0.6	0.8	1	1	0.8	0.8	0.8	0.8	0.8	0.8	1	1	1	1	1	1	1	0.8	0.8
HVAC	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0

5.2. Validation

In order to validate a model, one must compare its predicted outcomes to the observed data. Data cleansing is the first step in the data validation process, which checks to see if the cleaned data are accurate and useful. Uncertainty is needed in both the modeling and measurement sides for validation, and error estimation is a prerequisite for this. We did not claim that the experimental measurements were more accurate than the modeling results for validation purposes, but rather that they were the most accurate representations of reality. The error rate can be calculated with Equation (4).

$$ErrorRate(\%) = \left| \frac{Measurement - Simulation}{Measurement} \right| \times 100\% \tag{4}$$

The accuracy of the simulation models was checked against data collected on site. As a result, we used information from customers' monthly electricity bills to test the model. A comparison with the observed data was used to evaluate the model's precision. The BEMS-gathered power consumption data were compared to the building's energy model results. Figure 9 shows that this occurred frequently. The error rates in field measurements and energy modeling were verified to be under 10%. When the energy model was validated against the field measurements and the error rate was low, indicating its accuracy and that it could be applied to a wide range of scenarios.

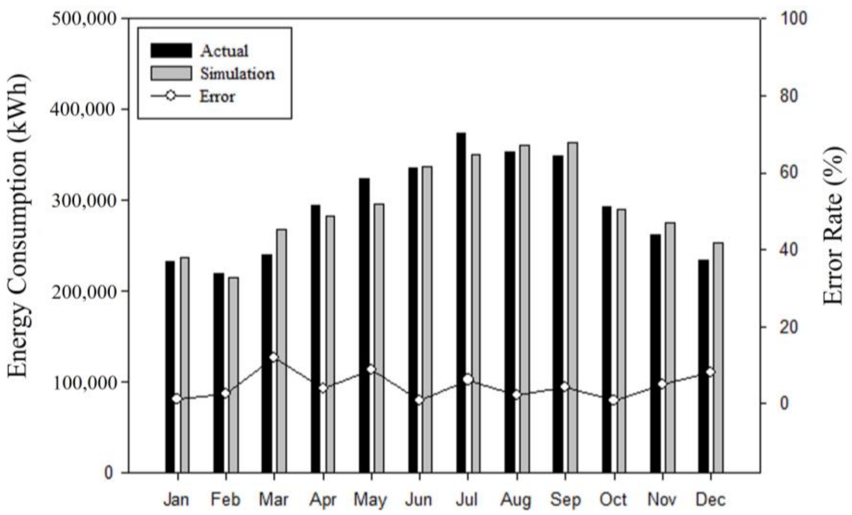


Figure 9. The comparison of energy consumption between the measurement and simulation.

5.3. Energy Modeling Results

Figure 10 shows the analysis of energy consumption saving based on different studies. The building's location implied different climate conditions, which significantly impacted its energy consumption. Climate factors, such as solar radiation, air temperature, airflow, and humidity, greatly influence energy costs. In Taiwan, the weather conditions vary significantly between different regions of the country. Taipei, located in the northern part of Taiwan, has a subtropical climate with mild winters and hot and humid summers. Taitung, located on the eastern coast, has a tropical monsoon climate, which means it has high humidity and heavy rainfall all year round. Kaohsiung, located in the southern part of the island, has a tropical savanna climate with hot and humid summers and mild winters. The average energy consumption in Kaohsiung is lower than in Taipei and Taitung due to the weather conditions in the region. The hot and humid summers in Kaohsiung mean that air conditioning is necessary for most of the year. However, the winters are mild, and heating is not required, resulting in a lower energy consumption overall. Additionally, the tropical savanna climate in Kaohsiung has lower humidity levels than Taipei and Taitung, reducing the amount of energy needed for dehumidification. In addition, changing the orientation of the building has the lowest impact on energy consumption, which is only 0.2%. The possible reason is that the difference in the design of the building shell and the simulation error is very small. However, it is still found that the orientation of the building facing west causes energy consumption. The increase is because, under the climate conditions of Taiwan, the orientation of the building faced the west, which resulted in more sunlight than any other orientation.

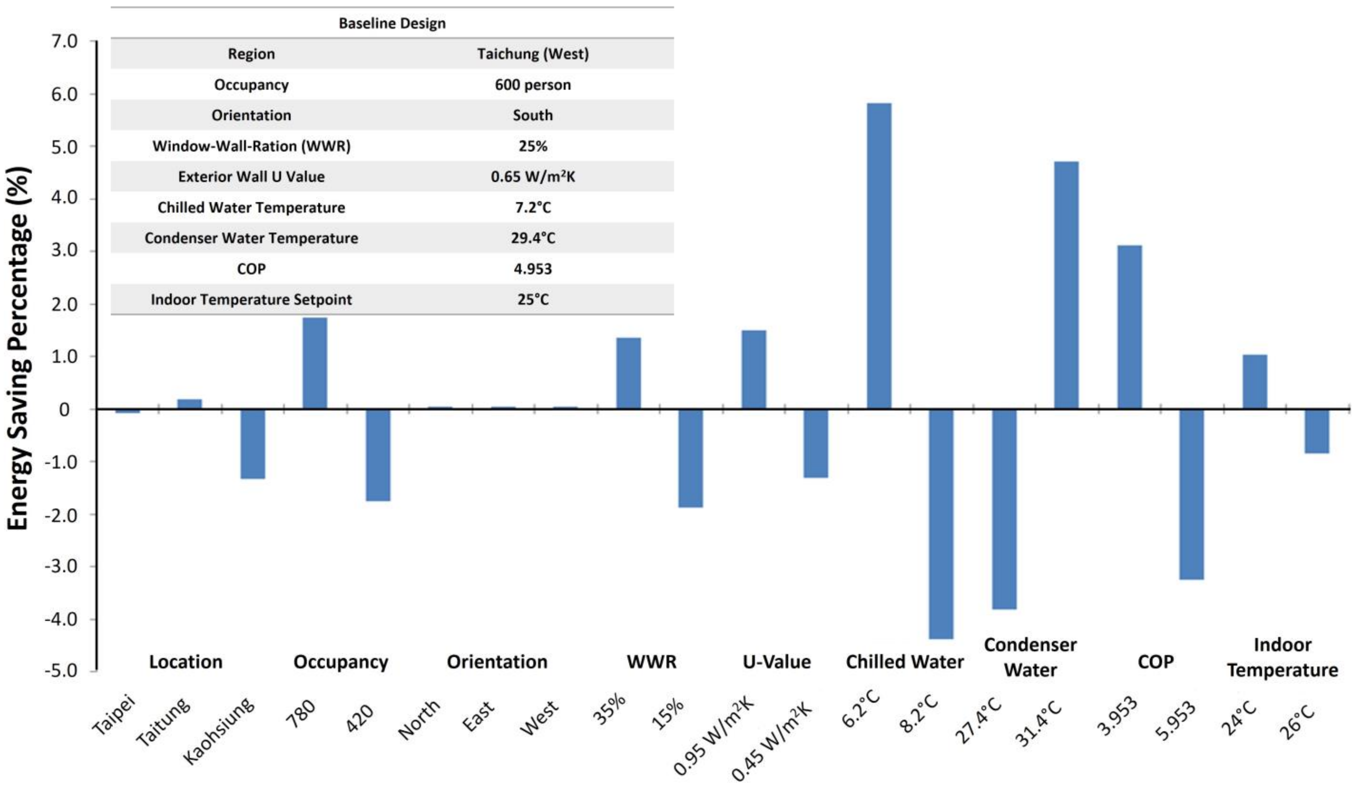


Figure 10. Energy saving percentage based on different studies.

Other factors that can affect a building's energy consumption include its orientation, insulation, and shading. Buildings that are well insulated and have proper shading can reduce the amount of energy needed for heating and cooling, regardless of their location. The window-to-wall ratio (WWR) indicates the proportion of a building's window area to its total exterior wall area. The most energy-efficient window-to-wall ratios are around

20% window-to-wall area. The U value of a wall is the measure of its insulating capacity. This indicates the rate at which heat from hot air (as opposed to direct sunlight) will pass through the wall. The better the insulation, the lower the U value. Other results revealed that the occupancy rate change increased significantly. The increase in personnel caused the demand for equipment to increase, thus increasing energy consumption. At the same time, it is known that the occupancy rate was one of the important factors in the energy consumption of hotel buildings, so through the simulation analysis, it was confirmed that the occupancy rate influenced energy consumption.

The simulated change in the main part of the chilled water in the AC system resulted in the largest energy-saving shift. Changing the set temperature of the chilled water could save 4% of the air conditioner's energy consumption, while changing the set temperature of the condenser water would save 3.5% of the air conditioner's energy consumption. Then, changing the COP would save the air conditioner's energy consumption by 3%. The change was quite huge because the air conditioning system accounted for 40% of the total energy consumption of the building. The chilled water supply is an important core of the air conditioning system. Improving the performance of the ice water host will help improve energy consumption. Because of the high energy consumption of building air conditioning systems, numerous techniques and technologies have been developed to enhance their efficiency. In an air-conditioned space, one method of temperature regulation is to consider the thermal comfort of the occupants. Here, the energy consumption of the air conditioning system decreased as the room temperature increased. We adjusted the room temperature in this study between 24 and 26 °C with a 1 °C increment. This reveals that resetting the thermostat's temperature contributed to the energy-saving concern.

6. Conclusions

In conclusion, this study has demonstrated the importance of evaluating a building's energy consumption using on-site monitoring, regression analysis, and simulation data. First, using measurement data, regression analysis can help us make predictions about energy use based on ambient air temperature and occupancy, which can be useful for decision-making and resource allocation. It can also help us control for other factors that may influence energy use, such as time of day, day of the week, or seasonality. Even if it is known that ambient air temperature and occupancy affect energy use, regression analysis can help us quantify the magnitude of this effect and determine the statistical significance of the relationship.

By modeling and simulating different scenarios, designers can gain insight into the energy performance of a building under different conditions and make informed decisions about how to optimize energy efficiency. However, it is also important to note that energy savings are relative and depend on the baseline level of energy consumption. For example, a building in a warm climate with a high cooling demand may have a greater potential for energy savings through passive cooling strategies than a building in a cooler climate with a lower cooling demand. Similarly, a building with poor insulation and high energy consumption may have a greater potential for energy savings through retrofits and efficiency improvements than a building with an already high energy efficiency. In conclusion, it is important to consider a range of factors when evaluating energy savings in building design, and to contextualize these savings in relation to the baseline level of energy consumption. By doing so, designers can make informed decisions about how to optimize energy efficiency and reduce energy consumption in a way that is appropriate for a given project and location. The energy modeling approach could be a useful and satisfying method for identifying energy savings opportunities.

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