Air Conditioning Energy Efficiency and Thermal Comfort in Hotel Buildings in Hot and Humid Tropical Climates

The Case Study of Makassar City Coastal Area Hotel, South Sulawesi, Indonesia

Nasrullah Nasrullah
Department of Architecture, Faculty of Engineering, Bosowa University, Makassar, Indonesia
nasrullah@universitasbosowa.ac.id (corresponding author)

Muhammad Awaluddin Hamdy
Department of Architecture, Faculty of Engineering, Bosowa University, Makassar, Indonesia
awaluddin.hamdy@universitasbosowa.ac.id

Received: 22 July 2024 | Revised: 2 September 2024 | Accepted: 8 September 2024

 DOI: https://doi.org/10.48084/etasr.8463

ABSTRACT

The objective of this research is to examine energy consumption efficiency strategies with respect to the type of dwelling unit, cooling load, and thermal comfort. This can be evaluated through the study of the hotel building air system, with the aim of ensuring the thermal comfort of its occupants. This research employs a quantitative methodology, using observation, measurement, and experimental techniques. The case study is situated within the context of hotels in Makassar City, South Sulawesi Province, Indonesia. The subject of this study is the Swissbel Hotel building, located in the coastal area of Makassar City. The data are analyzed in order to determine the Energy Consumption Intensity (ECI), Room Energy Intensity (REI), and occupancy rate based on the heat load inside and outside the building. The data are then processed using a parametric statistical approach. Subsequently, the building envelope is analyzed through the calculation of the Overall Thermal Transfer Value (OTTV) in accordance with the standards set out in SNI 6390: 2011. The cooling load and a thermal comfort assessment, in line with the Predicted Mean Vote (PMV) index, Predicted Percentage of Dissatisfaction (PPD) index, and effective temperature according to the ASHRAE 55-2022 standard, are then calculated, and a simulation is performed to determine the most efficient strategy for the use of air conditioning energy. The findings indicated that alterations in the dimensions of the facade (sun shading) resulted in a 16% reduction in the cooling load, with the incorporation of horizontal and vertical shading sizes of 4 m × 2.5 m, square glass openings, and 8 mm heat-absorbing glass. This led to a PMV value of 0.40, a PPD of 8%, and an effective temperature value of 26.8°C. The modification resulted in a percentage gain of 20.08%, at 10-60% occupancy load with a cooling load reduction rate of 1,912.07 kW and a thermal comfort index within the comfortable range.

Keywords-energy efficiency; air conditioning; thermal comfort; residential building; humid hot tropics; Makassar city

I. INTRODUCTION

Buildings represent one of the world's most significant energy consumers. The energy consumption of buildings can be reduced by employing development concepts that are adaptable to the surrounding environment and economical in energy use while still maintaining a comfortable environment for building occupants. It is important to note that the concept of thermal comfort in a given space should not be determined by the presence or absence of temperature indicators, as this approach may not fully capture the varying perceptions of comfort within a given environment [1]. The implementation of energy-saving architectural designs could lead to significant reductions in electricity consumption, including air conditioning, artificial lighting, and operation of electrical equipment within buildings [2-4]. Energy conservation has emerged as a pivotal objective in the global response to climate change and the reduction of the environmental impact of energy consumption. It is evident that buildings, including hotels, play a significant role in global energy consumption. In the context of energy conservation, air conditioning systems in hotel buildings represent a significant area of focus, as they have the potential to contribute substantially to the overall energy use [5-8]. Owing to its geographical location, Indonesia has a humid tropical climate, which is/makes it thermally uncomfortable. To address the issue of thermal discomfort, an air conditioning machine is employed to maintain a comfortable room temperature in accordance with the body's thermal comfort requirements. While the use of air conditioning does provide numerous advantages, it also has a significant drawback in the form of wasteful energy consumption [9].

The design of comfortable space conditions requires consideration of multiple factors, including microclimate conditions, such as humidity, air temperature, air movement, and human physiological aspects within the room, namely activities performed and clothing worn. Authors in [10, 11] indicate that the indoor thermal environment is significantly influenced by the local climate, as well as air movement through buildings. This is particularly relevant in hot and humid tropical climates, where indoor discomfort due to overheating can be reduced through the implementation of effective air movement strategies. The indoor environment is subject to the influence of external conditions, and therefore factors affecting the indoor thermal environment are of significant importance in the creation of a comfortable and healthy environment in residential buildings [12-15]. Hotel management must implement practical energy conservation practices in order to reduce greenhouse gas emissions. This involves providing hoteliers with implications for developing and diversifying energy management practices so that energy conservation for hotel buildings can be efficiently measured [16-18]. In the context of the hospitality industry, the implementation of these measures can assist hotels in achieving enhanced energy efficiency, reducing operating costs, and fostering an awareness of the significance of energy conservation [19, 20]. Authors in [21] investigated electrical energy conservation in Santika Palu Hotel, and found that replacing the lamp power in each room, which was used beyond the standard limit of lighting levels according to the function of the room, led to a reduction in electrical ECI.

As observed by authors in [22], the implementation of energy conservation measures in hotels presents a unique set of challenges due to the inherent characteristics of these facilities, including their size and fluctuating occupancy rates. The incorporation of specific measures within the air conditioning systems, such as zoning, presence sensors, the selection of efficient equipment, and the provision of education for both employees and guests, can prove effective in reducing energy consumption and positively impacting the environment. The hospitality industry is becoming increasingly aware of the importance of energy conservation and the reduction of environmental impacts. These measures can be beneficial for hotels and may appeal to guests who are concerned about sustainability [23]. Furthermore, a comparison of energy conservation in hotel air conditioning systems highlights the difficulties associated with managing large building sizes and fluctuations in occupancy rates, which directly impact HVAC settings. Furthermore, the challenge of balancing guest satisfaction with energy conservation remains a significant hurdle in the implementation of energy-efficient measures [24]. The distribution of energy use in a hotel can be observed, and it is evident that the largest component of energy use is the cooling system. In fact, air conditioning/fan reaches 50%-70% of all electrical energy used, while lighting accounts for only 10%-25%, and elevators represent a mere 2%-10% [25-28]. Authors in [29, 30] reviewed the research having been conducted on the energy conservation of building envelopes and air conditioning systems in relation to thermal comfort. Given the advancement of the field of architecture, particularly in the context of physical building design, the objective is to achieve energy savings and ensure thermal comfort in high-rise buildings.

The conservation of energy in hotel building air conditioning systems plays an important role in reducing energy consumption and maintaining environmental sustainability [31]. By selecting efficient equipment, using the latest technology, and implementing educational programs for employees and guests, hotels can achieve a balance between energy efficiency and guest comfort while positively impacting the environment. These endeavors are becoming increasingly pertinent in the hospitality industry, which is highly cognizant of the significance of energy conservation and sustainability [18]. The initiative to develop an energy-saving program in hotels represents the primary step in the establishment of an Energy Management System (EMS) that enables hotel management to regulate energy usage in a rational manner, thereby enhancing the efficiency of energy usage without compromising the quality and quantity of services. The presence of hotels in Makassar is significantly shaped by the city's climatic conditions, being characterized by a hot and humid tropical climate, with temperatures reaching 35 °C-39 °C and humidity levels that can exceed 90%. Additionally, wind speed conditions are highly variable. The research object, a hotel building located in the coastal area of Makassar City, has a building orientation facing east-west, as shown in Figure 1. This orientation results in significant exposure to solar radiation and hot air, which can influence the thermal comfort of occupants. Additionally, the building includes entirely glass building elements, which can contribute to a solar heat gain.

Fig. 1. Location of the research object.

The objective of this research is to examine energy consumption efficiency strategies with respect to the type of dwelling unit, cooling load, and thermal comfort. This is to be achieved through an analytical study of the hotel building air system, with the aim of ensuring the thermal comfort of its occupants. It is expected that this research will provide a more profound comprehension of energy efficiency strategies in relation to the thermal comfort of building occupants in coastal areas with a hot and humid tropical climate, as observed in Makassar City.

II. MATERIALS AND METHOD

This research employs a quantitative methodology, incorporating observational, measurement, and experimental techniques. It deploys a case study approach, focusing on the energy performance of hotel buildings situated within the Makassar City area of South Sulawesi Province. The data collection, observation, and objective measurements include energy consumption and efficiency, cooling load, occupancy rate, and thermal comfort. These are measured based on environmental parameter data such as air temperature, relative air humidity, and solar radiation. The observations and measurements were carried out in June and December 2023. The research instruments used include the HOBO UX100-023A External Temp/RH data logger, the Hobo MX2302 series data logger, and the RC-5 temperature data logger, which were employed to measure temperature, radiant temperature, relative air humidity, and room area, respectively, as depicted in Figure 2.

Fig. 2. Objective research instruments and positioning of measuring instruments.

A total of six units of bedroom type were selected for objective measurement within the building and hotel rooms. The measuring instrument was positioned, as evidenced in Figure 2, at a height of one meter above the floor surface, in accordance with the methodology outlined in [22, 32]. The data analysis performed in this study comprises the calculation of ECI and REI for the purpose of assessing the energy consumption of hotel buildings. Additionally, the building envelope is analyzed through the calculation of OTTV in accordance with the methodology proposed in [33]. Furthermore, the cooling load analysis, occupancy level, and thermal comfort index are evaluated in order to ascertain the comfort limit of the hotel building conditions, as defined by the standard in [34], with a view to assessing the scale of Predicted Mean Vote (PMV), Predicted Percentage of Dissatisfied (PPD), and Effective Temperature (TE). The subsequent phase of the study is based on the research objectives, namely the formulation of an energy efficiency strategy for the research object, which is based on the following research flow.

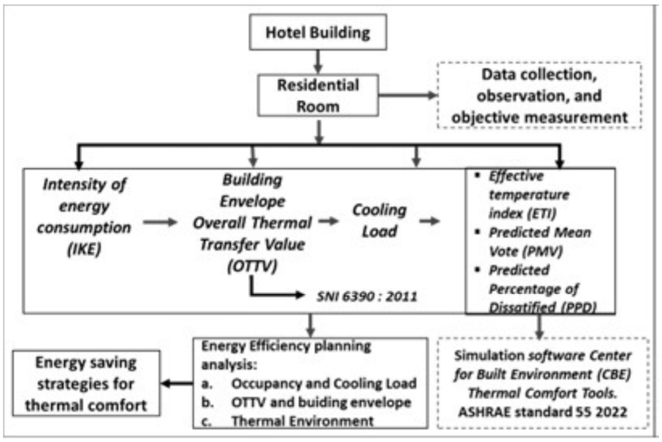

Fig. 3. Research flowchart.

III. RESULTS

The case study, was focused on a business hotel located in the waterfront area of the city. The majority of guests staying at the hotel were business professionals engaged in business activities within the city of Makassar. The review of hotel cases observed in this study is contingent upon three considerations: the physical condition of the building, the condition of the air outside the building, and the condition of the air system in the building. The physical condition of the building is observed to be at least 1,000 m² per floor, classified as a star hotel building. The upper structure comprises reinforced concrete construction and a concrete plate roof, while the lower structure is supported by a pile foundation. Figure 4 presents the building plan of the research object. The Swissbell Hotel is located at the west of the Makassar City administration building. It is a 5-star hotel comprising 19 floors and 296 rooms, offering eight different room types. The building's north-south orientation is aligned with the position of the beach, which is located directly in front of the structure. The air conditioning system comprises 25% central air conditioning, 75% split air conditioning, 10 PK stand floor/dak air conditioning, a minimum temperature of 25 °C, a maximum temperature of 33.5 °C, and an average temperature of 29.5 °C. The outdoor temperature was 36 °C, while the indoor temperature was 29.5 °C. The room temperature was 29 °C with humidity ranging from 50% to 75%. The radiation was 1,667.16 kWh/m², and the thermal comfort ranged from +1 to +3. The energy consumption was 55%.

The air conditioning system used in the hotel's residential rooms is designed to align with the specific cooling load requirements. The cooling load of a hotel building must be conditioned in accordance with the internal and external load requirements of the hotel [35, 36]. The internal load is defined as the energy consumption generated by the hotel, including the use of lighting, occupants, and other equipment that produces heat. External loads from the hotel include heat entering the building due to solar radiation and conduction through the building envelope. To address the challenges associated with hotel buildings, particularly with regard to external loads, it is essential to have a robust building envelope. The roof plane is a crucial element of the building envelope that must be considered in energy usage. The function of the external building envelope is to determine the energy conservation criteria that are taken into consideration in the design process of a hotel building, particularly concerning the design of the building's external appearance. In establishing the design criteria for the building envelope, the Indonesian National Standard Agency has set an OTTV requirement of less than 45 W/m². The existing building envelope and building materials in the research object are presented in Table I.

Fig. 4. Typical floor plan of the Swissbell Hotel.

TABLE I. BUILDING ENVELOPES AND MATERIALS OF THE RESEARCH OBJECTS

Data on building	% Building envelope area	Materials
Swissbell Hotel Losari Address: Jl. Ujung Pandang No. 8 Makassar, 90111 Number of floors:22	North 14.64%	Dark blue stop-sol glass
	South 14.64%	Dark blue stop-sol glass
	West 36.04%	Dark blue stop-sol glass
	East 34.71%	Dark blue stop-sol glass
	Building Area: 18,456 m^2 Building envelope area: 11,427 m^2 Conditioned Floor Area 21,451 m^2	

The Swissbell Hotel has a total building envelope area of 11,427 m² and a conditioned floor area of 21,451 m². The building is positioned in the east and west, which aligns with the trajectory of the sun. The building envelope area is 34.71% (east), 36.04% (west), 14.64% (north), and 14.64% (south), respectively. The material used is stop sol classic dark blue glass, which constitutes 100% of the total envelope.

A. Analysis of Electrical ECI and REI

The analysis of the energy consumption of the air conditioning system in the object of research is based on the calculation of the energy use of the air conditioning system, which is expressed in terms of the energy consumption of the hotel building. This is calculated using the price per kWh and the quantity of electricity consumed. The ECI or Energy Use Intensity (EUI) is a numerical value representing the amount of energy consumed in kWh for each square meter of conditioned building area per year. Table II presents the results of the calculation of electrical energy consumption as observed from the ECI on the object.

TABLE II. ENERGY CONSUMPTION INTENSITY CALCULATION OF THE RESEARCH OBJECT

Conditioned floor area	Electricity consumption (kWh)	Average	
		Consumption Electricity/room (kWh/m^2)	Occupancy level (%)
21,451 m^2	2,889,868	2,940	57.47

Table II portrays the electrical energy consumption of the research object in 2023, comprising 296 residential units and a conditioned floor area of 975 m². Based on an occupancy rate of 57.47%, the electricity consumption rate is 2,940 kWh/m²/month. The ECI value established by SNI 6390: 2011 for conditioned spaces is 8.5 kWh/m²/month–14 kWh/m²/month. This description demonstrates that the consumption of electricity in hotel buildings, the consumption of electricity per room, and the occupancy rate are directly or indirectly influenced by the characteristics of the building in question, including the number of floors, the number of residential rooms on each floor, the total floor area, the conditioned floor area, the conditioned area per floor, and the number of residential rooms that use electrical devices. In light of the data presented, the electrical energy consumption for each hotel room category can be calculated based on the REI, as presented in Table III. The Superior Room exhibits the highest percentage of occupancy, with an Energy Consumption Index (ECI) of 103,161 kWh and an ECR of 3,684 kWh/m². This is due to the numerous electrical appliances utilized in the room, including AC, televisions, refrigerators, lighting, hot water usage for bathrooms, cellphone and laptop charging, and hair dryer operation.

TABLE III. ENERGY CONSUMPTION BY ROOM TYPE

Room Type and Size (m^2)	Room Size m^2	Occupancy level 1 year (%)	REI (kWh)	kWh/m^2
Superior Room	28	82.20	103,161	3,684
Deluxe Room	30	78.91	99,427	3,314
Grand Deluxe	42	75.61	148,574	3,537
Business Suite	60	65.75	165,296	2,755
Executive	80	59.18	161,857	2,023
President Room	116	16.44	78,008	672

B. Analysis of Building Envelope

In order to ascertain the building envelope wall area and thermal transfer, an analysis is required. This analysis will calculate the OTTV, which is an overall thermal transfer value that determines the amount of heat load entering a building through its surface construction. In this case, the walls and roof of the building are of particular interest, especially in residential rooms that use AC. The OTTV analysis is founded upon the internal and external loads of the building. The OTTV value is calculated based on the external load, which is the heat entering the building caused by solar radiation, conduction, and ventilation/infiltration through the building envelope. In accordance with the standards set forth in SNI 03 6389: 2011, the OTTV value must be less than 35 W/m² in order to meet the requisite design criteria. The OTTV value of the research object is presented in Table IV. The calculation results for air conditioning system energy efficiency based on room type at Swissbell Hotel indicate that five rooms exhibit the highest thermal transfer value: the Superior Room, Deluxe Room, Grand Deluxe, Business Suite, and President Room, with values of 94.95 W for each.

TABLE IV. OTTV VALUES BY ROOM TYPE AND AREA

Room Type and Size	Room Size (m^2)	OTTV (W)
Superior Room	28	94.95
Deluxe Room	30	94.95
Grand Deluxe	42	94.95
Business Suite	60	94.95
Exekutive	80	61.78
President Room	116	94.95

The OTTV value of the star hotel building is calculated to be 29.45 W/m², which remains below the SNI OTTV standard value of 35 W/m². This can be attributed to the fact that the entirety of the structure is equipped with window film and shading elements, which collectively serve to impede the influx of solar radiation. The usage of window film and shading is intended to diminish the influx of solar heat into the room while maintaining the level of natural light. The existing vegetation system is also sufficient to maintain an OTTV value that remains below the SNI standard. The vegetation system plays a significant role in reducing the temperature of the surrounding air. The vegetation system may be implemented through the introduction of flora and/or the construction of water ponds in the vicinity of the edifice.

C. Analysis of Cooling Load

In this context, air dispersion can be defined as the process of cooling the air to achieve the desired temperature and humidity levels in each room of the hotel building. This research is concerned with calculating the efficiency level of energy-saving conservation control of air conditioning systems in the design of hotel buildings, employing the calculation of external and internal heat loads. The external heat load is determined by calculating the Room Sensible Heat Gain (RSHG), which is based on the surface area of the roof, walls, and glass partitions, as well as the ceiling and floor and glass. The internal heat load is based on the Room Latent Heat Gain (RLHG) from occupants, the RSHG from occupants, lighting, and electrical equipment. The resulting calculations will yield the cooling capacity, in Tons of Refrigeration (TR), used in each observed hotel room. One TR is equivalent to 12,000 British Thermal Units (BTU) per hour. The cooling load, which is based on the external and internal heat loads, determines the cooling capacity, as shown in Table V.

Tables V and VI present the results of the cooling load analysis based on external and internal RSHG and RLHG from room occupants within the subject of the investigation. The external heat load is calculated based on the RSHG roof, walls, and glass. The Executive room type exhibits the highest external heat load, which is 3,000.70 Btu/h. The President Room type demonstrates the second-highest external heat load, which is 3,885.46 Btu/h. Notably, the President Room type also exhibits the highest internal heat load, which is 21,921.94 Btu/h. With regard to the internal heat load based on occupant RLHG, lamp RSHG, and equipment RSHG, the President Suite room type demonstrates the highest values for all four categories. The RLHG value is 930 Btu/h, while the occupant RSHG, lamp RSHG, and equipment RSHG values are 1,470 Btu/h, 511.80 Btu/h, and 4,620 Btu/h, respectively. The highest value of tons of refrigeration is obtained for the President Suite room type, with a total of 3.02 TR. The displayed data indicate that the air conditioning system in the hotel building requires an upgrade to meet the energy demands of the President's room type, which is a suite with a range of premium amenities. The objective of air conditioning is to achieve the desired temperature, humidity, and air distribution in hotel rooms, thereby ensuring the comfort of each hotel guest. The fundamental principle of air conditioning is to manage the external and internal heat loads of energy-consuming residential spaces.

TABLE V. COOLING LOAD BASED ON RSHG EXTERNAL ROOM TYPE OF THE RESEARCH TTV VALUES BY ROOM TYPE AND AREA

Room Type	External heat loads		
	RSHG		
	Roof, walls, glass	Partition, ceiling, floor	Glass
Superior Room	710.78	1,364.67	1,376.92
Deluxe Room	761.90	1,415.72	1,582.09
Grand Deluxe	1,066.53	1,765.76	3,100.04
Business Suite	1,523.11	2,281.32	6,322.53
Executive	3,000.70	2,766.32	14,731.44
President Room	2,836.13	3,885.46	21,921.94

TABLE VI. COOLING LOAD BASED ON INTERNAL RSHG OF ROOM TYPE OF THE RESEARCH

RLGH occupants	Internal heat load			TR
	RSHG			
	Occupants	Lamps	Equipment	
310	490	225.19	1,200	0.47
310	490	245.66	1,200	0.50
465	735	266.14	1,900	0.77
620	980	343.93	2,430	1.21
775	1,225	429.91	2,630	2.13
930	1,470	511.80	4,620	3.02

D. Analysis of Thermal Comfort

The process of measuring the temperature, humidity, and radiation temperature of the research object is extracted from the instrument and subsequently subjected to statistical analysis, thereby facilitating the acquisition of the average measurement results. The thermal comfort data for the research object are based on the temperature and humidity of each room type, calculated by the CBE thermal comfort tool, as observed in Figure 5. The average results of psychometric charts according to the thermal comfort index ASHRAE 55-2022 standard in the building unit type rooms Swissbell Hotel are not accepted and visitors feel less comfortable (+1 - +2). The ASHRAE 55-2022 PMV value index is based on conditions that can be accepted as comfortable, namely PMV values between -0.5 and +0.5.

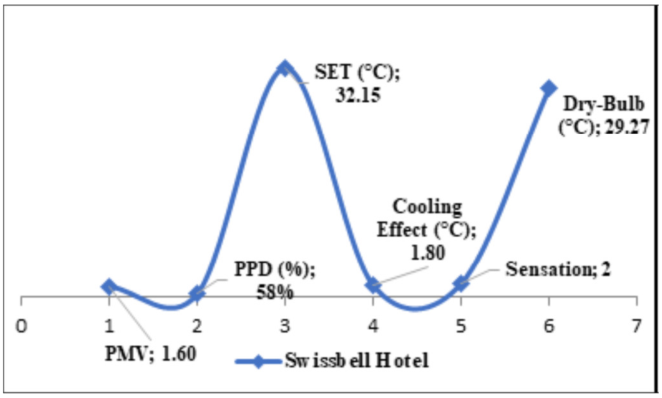

Fig. 5. Thermal environment graph of Swissbell Hotel's residential room units.

Table VII presents the data analysis of the thermal environment measurement results based on room type in Swiss- Bell Hotel. There are 7 types of rooms, showing that the temperature index of each room varies between 29.96 °C and 32.34 °C, with humidity ranging between 69% - 74%, so the average result of air temperature is 31.06 °C, suggesting that the air temperature is at a warm level with a humidity threshold of 71%. Thermal comfort is predicted using the PMV and PPD models by entering the influencing factors: thermal environmental factors, temperature, humidity, wind speed, radiation temperature, and human thermal comfort factors, type of clothing and activity. PMV is an index that indicates the sensation of cold and warmth felt by humans on a scale from +3 to -3. Furthermore, the comparison of thermal comfort according to the ASHRAE 55 2022 standard in both buildings simulated with CBE software can be seen in Tables VIII and IX.

TABLE VII. THERMAL ENVIRONMENT MEASUREMENT RESULTS OF RESIDENTIAL ROOM

Room Type	**Thermal Environment**			
	Temp Indoor	Temp Outdoor	Humidity	Wind Speed
	(°C)	(°C)	(%)	m/s
Superior Room	30.22	34.6	71.00	0.32
Deluxe Room	29.96	34.6	69.00	0.30
Grand Deluxe	31.67	34.6	70.40	0.33
Business Suite	30.54	34.6	70.00	0.36
Executive	31.62	34.6	74.90	0.36
President Room	32.34	34.6	70.00	0.20
Average	31.06	34.6	70.88	0.31

TABLE VIII. PMV, PPD, AND SET VALUES AT EACH MEASURING TIME BASED ON CBE

Room Type	**PMV**	**PPD**	**SET**
	(°C)	(%)	(°C)
Superior Room	1.24	37.00	30.60
Deluxe Room	1.01	41.00	29.30
Grand Deluxe	1.83	69.00	32.60
Business Suite	1.31	41.00	30.90
Executive	1.87	70.00	34.00
President Room	2.35	90.00	35.50
Average	1.6	58.00	32.15

Table VIII demonstrates that the values of PMV, PPD and SET in the residential unit of the research object indicate that the thermal sensation of the grand deluxe room type, executive, and president room is in a hot position (warm). Hence, the average value of PMV is 1.6, PPD is 58, and SET is 32.15 ˚C. Based on the thermal comfort index ASHRAE 55-2022 standard in the building unit type rooms of the Swissbell Hotel is not accepted and visitors feel less comfortable, while PMV index is between +1 - +2.35. Table IX lists the thermal comfort calculations, using CBE Thermal Comfort Tool.

TABLE IX. COOLONG, DRY-BULB VALUES BASED ON CBE

Cooling Effect (°C)	**Sensation**	**Dry-Bulb (°C)**
2.00	Warm	28.20
1.70	Warm	27.50
1.60	Heat	30.00
2.00	Warm	28.50
1.80	Heat	29.80
1.70	Heat	31.60
1.80	Heat	29.27

Source: comfort.cbe.berkeley.edu/en-16798

IV. DISCUSSION

A. Energy Efficiency Planning Based on Variations in Sun Shading Dimensions

The design of the building envelope is based on an analysis of the orientation of the building in relation to the dimensions of the room, ceiling height, windows, outdoor temperature, and indoor humidity. The simulated envelope treatment for energy efficiency is divided into three orientations based on the shape of the window surface area, sun shading, and window glass. The predominant use of windows based on shape and surface area refers to rectangular windows, the efficient use of sun shading to box-shaped, and the most widely used window glass is double glass. These envelope treatments for efficiency are then combined into one based on the room conditions at each hotel, as shown in Figure 6. The building envelope treatment of the 25 m² room, which features a ceiling height of 2.9 m and a window area of 10.15 m². The energy use efficiency system is based on the cooling load, with variations in sun shading dimensions, with the objective of achieving a target cooling load of 25 °C and humidity of 60%. Table X displays the impact of window variations, sun shading, and window glazing on the building envelope of the 25 m^2, 2.9 m high Hotel Swissbel room with 10.15 m^2 of windows. The windows are single glass, tinted, reflective glass 8 mm thick at an outdoor temperature of 34 °C, indoor temperature of 29 °C, and indoor humidity of 70% with blinds in use. The data indicate that the highest existing sun shading dimension of room 2 is 13,607 W, which corresponds to a high cooling load, while room 1 has the lowest value at 5,824 W, corresponding to a low cooling load. The results of the planning simulation, which considered various facade size variations, indicate that the cooling load can be reduced by up to 16% if the building is equipped with horizontal and vertical sun shading measuring 4×2.5 m, square glass openings, and 8 mm heat-absorbing glass.

The sequence of the rooms in accordance with the cooling load is:

- Room 2 (southwest-northeast orientation) = 13,607 W

- Room 5 (northeast-southwest orientation) = 13,107 W
- Room 3 (northeast-southwest orientation) = 9,113 W
- Room 4 (northeast-southwest orientation) = 5,881 W
- Room 1 (west-east orientation) = 5,824 W

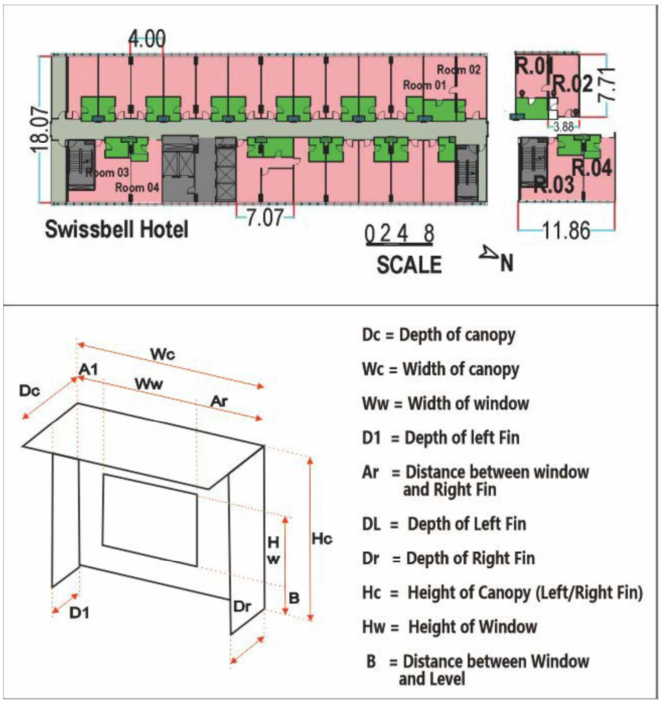

Fig. 6. Building envelope treatment for each room.

B. Energy Efficiency Planning Based on Occupancy and Cooling Load

The planning of energy use efficiency is based on the percentage of occupancy and the cooling load (in kW) of the object of research. As depicted in Figure 7, the highest percentage gain based on occupancy is 20.08%, which was observed at a load from 10% to 50% occupancy. In contrast, the lowest percentage gain is 5.38%, which was noted at a load of 90% occupancy. Additionally, as evidenced in Table XI, the use of building cooling load before modification was 2,173.92 kW and after modification decreased to 1,912.07 kW.

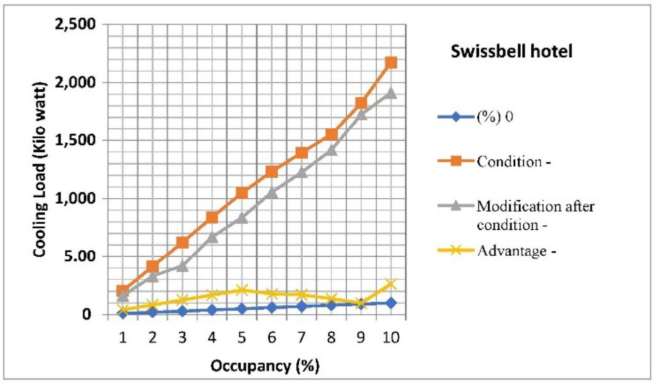

Fig. 7. Cooling Load Data Graph Variation of occupancy.

TABLE X. COOLING LOAD WITH VARIOUS TREATMENTS ON THE BUILDING FACADE

Swisebell hotel	Cooling Load (Target 25 °C temperature and 60% humidity)						
	Existing condition 4×2.5 m single glass 8 mm window	Sun shading horizontal window 4×2.5 m tinted reflective glass 8 mm		Sun shading horizontal sun shading vertical window 4×2.5 m		Sun shading horizontal sun shading vertical window 4×2.5 m	
				Tinted reflective glass 8 mm		Heat absorbing glass 8 mm	
	(W)	(W)	(%)	(W)	(%)	(W)	(%)
Room 5	1,3107	12,016	-8%	11,804	-10%	11,155	-15%
Room 4	5,881	5,504	-6%	5,292	-10%	5,087	-14%
Room 3	9,113	8,339	-8%	8,127	-11%	7,676	-16%
Room 2	13,607	13,280	-2%	13,131	-3%	12,761	-6%
Room 1	5,824	5,714	-2%	5,514	-5%	5,329	-8%

TABLE XI. COOLING LOAD OF SWISSBELL HOTEL

Cooling Load (kW)				
Occupancy (%)	Existing Condition	Modification after condition	Advantage	%
0	-	-	-	0.00
10	203.85	162.91	40.94	20.08
20	413.53	330.48	83.05	20.08
30	623.20	420.04	125.16	20.08
40	838.71	670.27	168.44	20.08
50	1,048.38	837.84	210.55	20.08
60	1,232.05	1,055.90	176.15	14.30
70	1,394.09	1,225.36	168.73	12.10
80	1,553.33	1,416.57	136.76	8.80
90	1,824.17	1,725.94	98.23	5.38
100	2,173.92	1,912.07	261.85	12.05

As a result of modifying the cooling load, the highest percentage gain is 20.08%, from 10% to 50% occupancy load, with a decrease in cooling load of 1,912.07 kW from the cooling load of 2,173.923 kW. The equation for 100% occupancy can be written as:

Occupancy = Before Modification - After Modification

Occupancy = 2,173.92 - 1,912.07 = 261,852

Occupancy (%) = 12.05% Energy Efficiency Planning Based on Thermal Comfort Level

A hotel guest who selects a room based on the building's energy-saving strategies and thermal comfort standards desires conditions with an Effective Temperature Index (ETI) between

22.8 °C and 26.8 °C and a humidity level of 70%. These conditions are determined by PMV, which indicates the level of cold and warmth that a person would find comfortable. The level of satisfaction is determined by PPD, which takes into account various factors influencing thermal comfort. These include the activity level, the condition of outside activities, body surface ratio, surface temperature of clothing, radiation temperature, convective heat transfer, air humidity, and the insulation value of clothing and airflow velocity. An optimal ventilation strategy for a room is one that allows for the alternating entry and exit of air, ensuring a uniform distribution of air throughout the space. It is widely acknowledged that the provision of AC is a necessity in every residential room within a hotel building. However, in order to achieve the optimal energy efficiency of an AC system, the usage of ventilation is essential. This can effectively reduce the reliance on cooling machines, such as air conditioners and fans, which consume a considerable amount of energy. Without the need for cooling through the use of ventilation, the air within the room will be perceived as healthy. It is possible to install artificial airflow systems in a number of different spaces, including hallways and corridors between hotel rooms. This is because such spaces often have very small openings, which require an automated air conditioning system to maintain a comfortable temperature. Table XII presents the PMV values and PPD based on the findings of the planning variations of building facades for thermal comfort. The results of the average value of PMV, PPD, and SET after simulating the modification of the building envelope indicate that the PMV index is 0.40 with 8% PPD, thereby establishing an effective temperature range from 26.2 °C to 26.8 °C for the building in question. The results are then entered into the CBE thermal comfort tool software, and it is confirmed that they meet the ASHRAE 55-2022 standard in the comfort category index.

TABLE XII. AVERAGE VALUES OF PMV, PPD, AND SET BASED ON BUILDING ENVELOPE MODIFICATION RESULTS

Data	PMV	PPD (%)	SET (°C)	Cooling Effect (°C)	Thermal sensation
Planning Condition	0.40	8%	26.2	1.5	Comfortable

C. Energy Efficiency Strategy

In this study, the term "energy efficiency in hotel buildings" is understood in accordance with the provisions set forth in the regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia Number 14 of 2012 concerning energy management. This regulation is further explained in the Government Regulation of the Republic of Indonesia Number 70 concerning Energy Conservation. Air conditioning system energy management is an integrated activity that controls energy consumption with the objective of creating effective and efficient energy usage, thereby producing maximum output through technical actions in a structured and economical manner. In order to achieve energy efficiency and thermal comfort, a series of simulations were conducted to evaluate the impact of various building envelope modifications, including alterations to sun shading dimensions and occupancy levels, as well as cooling loads. The application of energy efficiency strategies is: Swissbell has 22 floors, 19 of which are residential rooms. The conditioned building area is 24,775 m², with conditioned floor areas of 21,451 m² and 975 m², for a total of 296 residential rooms. The strategies that were adopted include the use of Multy V non-central AC units with a supply per floor for residential rooms, a central control system, and the setting of room AC units to be on/off at 29 °C in the control room when it is empty in order to maintain the duration of room cooling before the arrival of guests. Split Dac AC units with a capacity of 10 PK, used 14 units for public areas, with a block save per floor, a reduction in the use of AC units in public areas between the hours of 23:00 and 05:00 with manual settings, and a subsequent setting of the thermostat at 22 °C for public areas. The efficiency of electrical equipment at peak load hours, 17:00-23:00, was enhanced through the implementation of an energy efficiency control system with a periodic system, coupled with the usage of an artificial airflow system for space conditioning.

Based on the preceding description, it was determined that the implementation of energy-efficient management of air conditioning systems in Swissbell hotel buildings can be explained by three main propositions. These present findings that elucidate the interrelated relationships between the various factors involved. The three propositions were: energy conservation is oriented towards reducing the heat transfer of the hotel building, energy-saving strategies are focused on reducing the cooling load and achieving thermal comfort in the hotel's residential rooms, and air system management is aimed at planning the operation and supervision of the hotel building. The evaluation and subsequent application were/considered the following facts:

- In the case of buildings that employ AC, it is recommended to use energy-efficient AC units (inverter technology) with power output proportional to the size of the room, utilizing hydrocarbon-type refrigerants, positioning the AC compressor in a location shielded from direct sunlight, and deactivating the AC when the room is unoccupied. The installation of a room thermometer allows the monitoring of temperature. According to the Indonesian National Standard (SNI), the temperature and relative humidity should be adjusted accordingly. The use of central air conditioning is recommended, and it is essential to ensure that no outside air enters the air-conditioned room, which would otherwise result in a reduced cooling effect. Regular maintenance, as outlined by the manufacturer's guidelines, is also a crucial aspect of maintaining optimal air conditioning performance.
- The use of specific types of glass can facilitate the reduction of solar heat entering the room while maintaining natural lighting. One such example is a 8 mm heat-absorbing glass.
- The use of sun shading is an effective method of anticipating direct solar radiation.
- The temperature of the air within or in the vicinity of the construction may be reduced by the cultivation of flora and/or water installations.

V. CONCLUSIONS

The results of the calculation of the use of Air Conditioning (AC) energy systems in the hotel rooms of the research objects, based on the International Energy Conservation (IEC) code, yielded a total of 2,940 kWh/m². The results of the calculations based on the Room Energy Intensity (REI) ranged from 672 kWh/m² (in the president's room) to 3,684 kWh/m² (in the superior room). Additionally, the results of the calculations based on the Outdoor Transmission and Distribution Voltage (OTTV) standards ranged from 61.78 W to 94.95 W. The five rooms in question exhibit the same OTTV value of 94.95 W, and thus fail to meet the SNI standards. The results of the energy-saving analysis of the air conditioning system in the hotel rooms observed are based on the calculation of external and internal cooling load, which yielded Tons of Refrigeration (TR) of 3.012. Additionally, the planning of thermal comfort level was based on Effective Temperature Index (ETI), with a range from 22.8 °C to 26.8 °C. The results of the Predicted Mean Vote (PMV) calculation were 0.40, while the results of the Predicted Percentage of Dissatisfaction (PPD) calculation ranged from 8.0% to 90%. This indicates that the hotel, based on the results of the simulation planning of the building envelope with a neutral thermal sensation (comfortable), meets the standards set by ASHRAE 55 2022. The analysis of the optimal AC strategy for the building was conducted based on the simulation results at the target cooling load of 25 °C and humidity of 60%. The existing conditions of windows, glass, and sun shading differed according to the building's orientation. The cooling load can be reduced by modifying the dimensions of horizontal and vertical sun shading, glass openings extending from top to bottom, and the use of double glass. The simulation results indicate a decrease in the research object, specifically a 16% reduction in cooling load due to the addition of 240 cm (-27.7%) and a percentage of occupancy energy gain of 20.08% at 60% occupancy load.

This research makes a significant contribution to the field of architecture, particularly in the area of physical building design. It demonstrates how energy-saving and thermal comfort can be achieved in high-rise buildings, as well as how the design of this hotel building can be assessed for energy efficiency based on the use of OTTV, which involves evaluation of the building wall area and thermal transfer.

REFERENCES

[1] N. V. Ayuningtyas, J. A. Suryabrata, A. Sarwadi, "Effect of Window To Wall Ratio (WWR) for Thermal Comfort in Energy Efficient Office Buildings Based on Jakarta Climate Data," in *SAKAPARI 2019*, pp. 158-168, 2019.

[2] R. Vale and B. Vale, *Green Architecture: Design for a Sustainable Future*. London, UK: Thames & Hudson, 1991.

[3] E. Elsarrag and Y. Alhorr, "Using Dynamic Facade for Indoor Air Quality, Thermal Comfort and Energy Efficient Air Conditioning," *University of Khartoum Engineering Journal*, vol. 1, no. 2, pp. 63–66, Oct. 2011.

[4] N. H. Phuong, L. D. L. Nguyen, V. H. M. Nguyen, V. V. Cuong, T. M. Tuan, and P. A. Tuan, "A New Approach in Daylighting Design for Buildings," *Engineering, Technology & Applied Science Research*, vol. 13, no. 4, pp. 11344–11354, Aug. 2023, https://doi.org/10.48084/etasr.5798.

[5] R. Losung and I. Makainas, "Energy Conservation in Architecture," *Journal of Media Matrasain (JMM)*, vol. 8, no. 3, pp. 108–120, Nov. 2011, https://doi.org/10.35793/matrasain.v8i3.339.

[6] R. Rahim, B. Hamzah, R. Mulyadi, and Nasrullah, "Energy conservation of the air-conditioning system of hotel building in Makassar City," *International Journal of Civil Engineering and Technology (IJCIET)*, vol. 10, no. 10, pp. 115–123, Oct. 2019.

[7] A. Marjianto and D. Mangindaan, "Air Conditioning System Design from Energy and Cost Aspects in Hotel Building in Semarang," *Engineering, MAthematics and Computer Science Journal (EMACS)*, vol. 2, no. 3, pp. 97–106, Sep. 2020, https://doi.org/10.21512/emacsjournal.v2i3.6594.

[8] Y. Sheng, Z. Miao, J. Zhang, X. Lin, and H. Ma, "Energy consumption model and energy benchmarks of five-star hotels in China," *Energy and Buildings*, vol. 165, pp. 286–292, Apr. 2018, https://doi.org/10.1016/j.enbuild.2018.01.031.

[9] P. Satwiko, *Definition of comfort in a building*. Yogyakarta, Indonesia, 2009.

[10] N. L. Latifah, H. Perdana, A. Prasetya, and O. P. M. Siahaan, "Thermal Comfort Study on Student Centre Building Itenas Bandung," *Reka Karsa: Jurnal Arsitektur*, vol. 1, no. 1, 2013, https://doi.org/10.26760/rekakarsa.v1i1.43.

[11] M. A. Hamdy, B. Hamzah, R. Wikantari, and R. Mulyadi, "Analysis of Thermal Environmental in Buildings with Water and Landscape Elements as Microclimate Modifiers in Hot and Humid Tropical Climates," *IOP Conference Series: Earth and Environmental Science*, vol. 1157, no. 1, Apr. 2023, Art. no. 012008, https://doi.org/10.1088/1755-1315/1157/1/012008.

[12] I. Rajapaksha, H. Nagai, and M. Okumiya, "Indoor Thermal Modification of a Ventilated Courtyard House in the Tropics," *Journal of Asian Architecture and Building Engineering*, vol. 1, no. 1, pp. 87–94, Mar. 2002, https://doi.org/10.3130/jaabe.1.87.

[13] N. Jamaludin, M. F. Khamidi, S. N. A. Wahab, and M. M. A. Klufallah, "Indoor Thermal Environment in Tropical Climate Residential Building," *E3S Web of Conferences*, vol. 3, 2014, Art. no. 01026, https://doi.org/10.1051/e3sconf/20140301026.

[14] F. A. AlFaraidy and S. Azzam, "Residential Buildings Thermal Performance to Comply With the Energy Conservation Code of Saudi Arabia," *Engineering, Technology & Applied Science Research*, vol. 9, no. 2, pp. 3949–3954, Apr. 2019, https://doi.org/10.48084/etasr.2536.

[15] Sangkertadi, *Thermal Comfort in a Humid Tropical Climate Outdoor Space*. Bandung, Indonesia: Alfabeta, 2013.

[16] R. Sucheran, "Energy Conservation Measures in the Hotel Sector in Kwa-Zulu Natal South Africa," *African Journal of Hospitality, Tourism and Leisure*, vol. 4, no. 2, 2015.

[17] Nasrullah, R. Rahim, B. Hamzah, and R. Mulyadi, "Energy Conservation of Hotel Building Air Conditioning System Based on Makassar City Microclimate Condition," *Plano Madani, Journal of Urban and Regional Planning*, vol. 8, no. 1, pp. 100–113, Apr. 2019, https://doi.org/10.24252/jpm.v8i1.9279.

[18] D. F. Satriopratomo, Y. P. Devia, and L. Susanti, "Energy use Efficiency on High Rise Hotel Building to Reduce Carbon Emission Using Sefaira," *Astonjadro*, vol. 13, no. 1, pp. 212–224, Jan. 2024, https://doi.org/10.32832/astonjadro.v13i1.14591.

[19] M. Tang, "Evaluating green hotels in Taiwan from the consumer's perspective," *International Journal of Management Research and Business Strategy*, vol. 4, no. 1, pp. 1–15, 2015.

[20] J. C. Wang, "A study on the energy performance of hotel buildings in Taiwan," *Energy and Buildings*, vol. 49, pp. 268–275, Jun. 2012, https://doi.org/10.1016/j.enbuild.2012.02.016.

[21] A. Tanod, H. Tumaliang, and L. Patras, "Electrical Energy Conservation at Santika Hotel Palu," *Journal Teknik Elektro dan Komputer*, vol. 4, no. 4, pp. 46–56, 2015.

[22] L. M. Dibene-Arriola, F. M. Carrillo-González, S. Quijas, and M. C. Rodríguez-Uribe, "Energy Efficiency Indicators for Hotel Buildings," *Sustainability*, vol. 13, no. 4, Jan. 2021, Art. no. 1754, https://doi.org/10.3390/su13041754.

[23] H. Nauwir, K. Kusmanurwira, and M. A. Firdaus, "Evaluation of Electric Energy Utilisation System at Grand Clarion Hotel Makassar," *Jurnal Teknik Mesin Sinergi*, vol. 16, no. 2, pp. 181–189, 2018, https://doi.org/10.31963/sinergi.v16i2.1513.

[24] Y. Lavafpour, "Towards new approaches for integrating principles of precedent architecture into energy efficient buildings in hot-dry climate," *Serbian Architectural Journal*, vol. 4, no. 3, pp. 240–253, Jan. 2012, https://doi.org/10.5937/SAJ1203240L.

[25] "Program Quarter 4 Progress Report," United States Agency for International Development, Jakarta, Indonesia, 2017.

[26] D. Ariestadi, I. Alfianto, and M. Sulton, "Energy Performance Criteria for Thermal Comfort in Higher Education Facility Buildings in Indonesia, Analysed by Important Performance Analysis Method," *Review of Urbanism and Architectural Studies*, vol. 12, no. 1, pp. 31–41, Jul. 2014, https://doi.org/10.21776/ub.ruas.2014.012.01.4.

[27] H. Abdurrachman, M. Sibarani, and J. V. Tuapetel, "Design of Central Air Conditioning (AC) in Building G of the Indonesian Institute of Technology," *Journal of Mechanical Engineering-ITI*, vol. 2, no. 2, pp. 35–41, 2018.

[28] S. Lehmann, "Energy-Efficient Building Design: Towards Climate-Responsive Architecture," *Encyclopedia of Life Support Systems*. EOLSS, Paris, France, 2011.

[29] T. Hendarto, M. Rachman, O. Sulastio, and D. Afrinaldi, "Study of Space Proportion in the New Building of Concordia Hotel Bandung," *Reka Karsa, Journal of National Institute of Technology, Department of Architecture*, vol. 1, no. 1, Jul. 2012.

[30] R. Gendo, J. Priatman, and S. Loekito, "Energy Conservation Analysis of Building Envelope Based on SNI 03-6389-2011, Case Study: Building P1 and P2 of Petra Christian University Surabaya," *Dimensi Utama Teknik Sipil*, vol. 2, no. 1, pp. 1–7, Apr. 2015, https://doi.org/10.9744/duts.2.1.1-7.

[31] C. Mediastika, Energy Efficient and Environmentally Sustainable Through Buildings. Yogyakarta, Indonesia: Andi Publishing, 2013.

[32] N. H. Wong and S. S. Khoo, "Thermal comfort in classrooms in the tropics," *Energy and Buildings*, vol. 35, no. 4, pp. 337–351, May 2003, https://doi.org/10.1016/S0378-7788(02)00109-3.

[33] *SNI 6390:2011, Energy Conservation of Building Envelope in Building*. Jakarta, Indonesia: National Standardization Agency, 2011.

[34] *ANSI/ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy*. Atlanta, USA: ASHRAE, 2020.

[35] N. Nasrullah, M. Hamdy, M. Mustamin, and A. Faharuddin, "Energy Management Model for Air Conditioning Energy Conservation in Hotel Buildings of Makassar City, Indonesia," *Civil Engineering and Architecture*, vol. 12, no. 4, pp. 2755–2771, Jul. 2024, https://doi.org/10.13189/cea.2024.120419.

[36] R. Govindarajan, S. Meikandasivam, and D. Vijayakumar, "Performance Analysis of Smart Energy Monitoring Systems in Real-time," *Engineering, Technology & Applied Science Research*, vol. 10, no. 3, pp. 5808–5813, Jun. 2020, https://doi.org/10.48084/etasr.3566.