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ENERGY AND COST SAVING OF AIR CONDITIONING SYSTEM USING MAGNETIC BEARING CHILLER FOR HOTEL A IN JAKARTA

A. Marjianto[1], Haftirman[2], and P. S. Darmanto[3]*

[1] Mechanical Engineering Master Program, Universitas Mercu Buana
[2] Lecturer of Department of Mechanical Engineering, Faculty of Engineering, Universitas Mercu Buana
[3] Lecturer of Department of Mechanical Engineering, Faculty of Mechanical and Aerospace Engineering, ITB

Abstract

The use of magnetic bearing chillers in hotel air conditioning systems is an opportunity for energy or cost savings. This study will compare the electrical energy consumption and cost analysis of the centralized air conditioning system using magnetic bearing chiller that uses variable flow to another air conditioning system such as the centralized air conditioning using constant flow chiller and the VRF (Variable Refrigerant Flow) split air conditioning system at Hotel A in Jakarta. The calculation of energy consumption for each air conditioning system is carried out for a year. Meanwhile, the cost analysis will be carried out using the life cycle cost method for 20 years. The air conditioning system which has the least energy consumption and has the lowest life cycle cost is the best air conditioning system for this hotel building. The maximum cooling load that occurs in Hotel A is 3,281 kW. From the results of energy calculations and cost analysis, a centralized air conditioning system with magnetic bearing chiller with variable flow is the best choice to Hotel A or similar building to Hotel A, with IKE (*Intensitas Konsumsi Energi*) value of 84 kWh/(m2.year), and a total cost of 78,873,678,478.00 IDR for a period of 20 years.

Keywords: Cooling Load; Hotel; Energy; Magnetic Bearing Chiller

*Corresponding author: Tel. +62 8121052170
E-mail address: gusmarjianto@gmail.com

1. Introduction

The selection of the air conditioning system in hotel buildings is very important in terms of energy and cost aspects because the air conditioning system requires the largest consumption of electrical energy compared to other systems in hotel buildings. Choosing an energy-efficient air conditioning system will reduce operational costs, which in turn will benefit building owners from a business perspective.

To get an air conditioning system that has a high efficiency in a hotel building, a magnetic bearing chiller is chosen as one of the alternative refrigeration machine. The compressor of this chiller consists of a stator, a rotor, sensors, and magnetic bearings. The magnetic force generated by magnetic bearings on the compressor will maintain the position of the rotor shaft so that it is not in contact with the bearings and the motor. Because there is no contact between the stator and the rotor, there is no heat due to friction between them. Therefore, this chiller does not require oil as coolant. Without the use of oil, it will increase the efficiency of heat transfer because no oil enters the evaporator and condenser. Oil in the evaporator fills 7%-8% of the volume of the evaporator. It can reduce the performance of the chiller by around 13%-15%[1]. The VSD (Variable Speed Drive) used on the motor allows the compressor to work more efficiently at partial load. This type of chiller is able to adjust the cooling load of buildings to a minimum load of up to 10% of the cooling capacity (Smardt, 2020), so that the use of electrical energy will be more efficient.

Another alternative air conditioning system that is often used in hotel buildings is to use a chiller with a centrifugal or screw type compressor with a constant flow rate. The characteristic of hotel cooling load is that it fluctuates every week where there is a difference between the peak cooling load and the minimum cooling load that occurs very wide. To cope with a wide fluctuating load, this chiller is not suitable because the compressor motor rotation will always be constant even though the cooling load varies. The electrical energy released will be proportional to the rotation of the compressor motor. This causes a chiller with a constant flow rate to be less efficient than a chiller that uses a variable flow rate of energy for use in hotel buildings. Although this type of chiller can pass a part load to the cooling load, it is a minimum of 40% of the total cooling load. Oil is needed as a coolant in the compressor due to the friction that occurs between the rotor and the stator. The heat that

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occurs due to friction will reduce the efficiency of the chiller. In addition, the alternative air conditioning system that is often used for hotel buildings is a separate VRF (Variable Refrigerant Flow) air conditioning system with a compressor equipped with a VSD. Even though the compressor is equipped with VSD, the energy efficiency is still relatively high because the condenser cooler uses air. If there is a leak in the installation pipe in a VRF air conditioning system, it will be difficult to detect where the leak is. So it will cause air pollution due to leaking refrigerant gas and possibly poison the occupants in the room where the gas leak occurs.

The research on electrical energy consumption for hotel buildings can be seen in several previous journals. The electricity consumption of hotels in Yogyakarta shown that the air conditioning system is 44.76%, the lighting system is around 54.96% and other electrical equipment is around 10.2% of the total electrical energy consumption of 434 kWh/(m^2.year)[2]. Hotel in Kupang has an annual electrical consumption for the air conditioning system of 206.33 kWh/(m^2.year)[3]. A study in Singapore described the annual consumption of electrical energy of 468 kWh/(m^2.year) for the average of 29 hotel buildings[4]. The annual energy consumption for Hellenic Hotels in Crete is 273 kWh/(m^2.year)[5]. Meanwhile, a study of 19 hotels in Hainan, China, shown that the annual consumption of electrical energy is at the range of 45 to 211 kWh/(m^2.year)[6]. In Taiwan, a study on the annual consumption of electrical energy for 200 hotels has also been carried out. Taiwanese international tourist hotels reported an annual electrical energy consumption of 280 kWh/(m^2.year). Meanwhile the standard tourist hotels limit the value of 238 kWh/(m^2.year), 187 kWh/(m^2.year) for hotel enterprises, and 144 kWh/(m^2.year) for bed and breakfast facilities consumption[7]. In Lijiang, China, study has been carried out on the electrical energy consumption of 24 hotels from which consists of 4-star, 3-star, 2-star, and 1-star hotels. The study showed that the IKE value of each type of hotel is at 180.8, 113.3, 74.2, 70.2 kWh/(m^2.year), respectively[8]. In 2009, a study was also conducted in Singapore on 29 hotels showing the average IKE value for hotels at 427 kWh/(m^2.year)[9]. And a study at the *Majapahit* Hotel in Surabaya reported the IKE value of 347.6 kWh/(m^2.year)[10].

The building's electrical energy consumption can be expressed in terms of the IKE (*Intensitas Konsumsi Energi*) value. The DKI Jakarta Governor Regulation "*Peraturan Gubernur DKI Jakarta Nomor 38 Tahun 2012 tentang Bangunan Gedung Hijau*" regarding green building states that IKE value for hotel buildings is 350 kWh/(m^2.year)[11]. The book has published by DKI Jakarta Government, "Air Conditioning & Ventilation System, Jakarta Green Building User Guide" shown that the energy consumption of an air conditioning system is around 65% of the total electrical energy consumed by hotel buildings[12].

Furthermore, in this study the air conditioning system that uses a magnetic bearing chiller will compared to other air conditioning systems those commonly used in hotel buildings, which are centralized air conditioning system with constant flow chiller and VRF split air conditioning system. All air conditioning systems will be analyzed based on energy efficiency and costs. The calculation of the energy consumption of all components of each air conditioning system will be calculated for one year. While the cost analysis for each air conditioning system uses the life cycle cost analysis over a period of 20 years. Based on these comparisons of these air conditioning systems will determine the air conditioning system that has high energy efficiency and low cost as the best air conditioning system in hotel buildings.

2. Experimental and Procedures

2.1 Materials

The Hotel A building that is being studied in this research is located in Jakarta, and it is geographically located on $6^0$19'00" South Latitude and $106^0$43'00" East Longitude. Based on SNI 03-6390-2011, the outdoor temperature design has an average maximum dry bulb temperature of 33^0C and an average maximum wet bulb temperature of 27^0C. The hotel consists of 18 floors with 3 basements with an area will be air conditioned of 27,535 m^2 and total building area of 50,255 m^2.

Coefficient value of heat transfer depends on a few parameters such as thickness of the building material and the characteristics of the material. A few of U values that are used in this building are as follows:

- U-value of the wall : 1.673 W/m^2 K
- U-value of partition : 2.497 W/m^2 K
- U-value of the roof : 0.497 W/m^2 K
- U-value of floor : 1.111 W/m^2 K
- U-value of window : 2.960 W/m^2 K
- SC value of window : 0.64

Heat is coming from many sources internally and externally has a pre-determined value based on the standard from *Badan Standarisasi Nasional*. The standard that is used to determine ventilation requirement for each room as well as sensible and latent heat is of the occupants is SNI 03-6372-

2001[13]. In addition, to find out the occupant density refers to the international standard ASHRAE Standard 62.1-2007[14]. The schedule room is divided into three types, which are lamps usage, electronic equipment, and occupant density. In this hotel building, the schedule will affect the cooling load curve for each times. Based on SNI 03-6372-2001, room design temperature is $25^0C \pm 1^0C$ and room design relative humidity is 55%±10%[13]. Based on SNI 03-6197-2011, the estimated lamp load is determined based on the function of the room while electrical equipment is estimated based on position of equipment in the interior drawing[15].

2.2 Experiment

In this research, Hotel A building's data received from architects included floor area, rooms function, and building envelope type. Furthermore, calculating the cooling load of the Hotel A building using Trace 700 software based on design parameters that comply with standards including room temperature and relative humidity. The cooling load calculating using CLTD (Cooling Load Temperature Difference) method. Based on the results of the cooling load calculation, an air conditioning system that has the potential to save energy and costs in Hotel A by choosing a centralized air conditioning system using a magnetic bearing chiller as the refrigeration machine.

In order to obtain a comprehensive study on the energy and cost saving potential of Hotel A, it is necessary to compare it with other air conditioning systems commonly used in hotel buildings. The air conditioning system chosen as a comparison to the central air conditioning system using a magnetic bearing chiller is are the centralized air conditioning system using a constant flow chiller and VRF split air conditioning. In addition, the energy calculation results are also compared with DKI Jakarta Governor Regulation Number 38 of 2012. Energy analysis is done by calculating the electrical energy consumption for each air conditioning system alternatives for one year period.

The energy consumption of air conditioning system is calculated based on the consumption of all air conditioning system equipment for a year. While the cost analysis in this study used life cycle cost analysis limited to design, investment, operational and maintenance costs, excluding disposal costs. When analyzing the life cycle cost, all these costs have to be equalized to the present value (PV). PV is defined as the present value of money for the amount of money in the future. The equalization of the amount of money is caused by the depreciation of currency due to inflation as time goes by. Life cycle cost calculation is done by adding all the present value from all cost such as costs of design, investment, operation, and maintenance. The present value of operational costs can be calculation using equations (1) and (2).

$$PV = A_0 \times UPV \quad (1)$$

$$UPV = \frac{(1+e)}{(1+d)}\left[1 - \left(\frac{1+e}{1+d}\right)^n\right] \quad (2)$$

UPV is the unit present value factor, A_0 is the annual operating cost, e is the increase in operating costs per year, d is the interest rate value, and n is the time period in years.

Life cycle cost method is used to do the cost analysis. The life cycle cost analysis method is based on the calculation all costs incurred for each system for one life cycle. In this study, a life cycle cost analysis is limited to the design, investment, operation and maintenance phases, excluding disposal costs. In this research, life cycle cost analysis was done using life cycle of 20 years.

From the result of electrical energy calculation and life cycle cost analysis, the air conditioning system will selected which has the least energy consumption and has the lowest life cycle cost for Hotel A or similar hotel building to Hotel A.

3. Results and Discussion

3.1 Cooling Load

The Hotel A consists of 18 floors with 3 basements with an area will be air conditioned of 27,535 m^2 and total building area of 50,255 m^2. The cooling load calculation is based on the building envelope material data of Hotel A, the design of the dry bulb temperature is 25^0C, the outside air condition is 33^0C the dry bulb temperature and 27^0C the wet bulb temperature, and the total internal load includes occupant loads, lamp loads, and electrical equipment loads. The cooling load calculation for this research is done using the CLTD method at *Trace 700* software and the results can be seen in Table 1 and Table 2. From the conditioned area data to the peak cooling load, it shows that the hotel cooling load per unit area is 0.12 kW/m^2. Based on the ASHRAE Pocket Guide Handbook, 2013, Table 12.1 "Cooling Load Check Figures" state that the estimated hotel cooling load ranges from 0.11 kW/m^2 to 0.17 kW/m^2. So the results of calculating the cooling load using the *Trace 700* software still meet the standards based on the ASHRAE Pocket Guide Handbook. Furthermore, the cooling results of the cooling load calculation can be used to analyze electrical energy for the air

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conditioning system that will be used in the Hotel A. Due to the number of occupants between weekends and weekdays, the calculation will be divided into weekends cooling loads profile and weekdays cooling loads profile. The number of hotel occupants on weekdays is approximately 40% of the number of residents on weekends (BPS, 2020). The maximum cooling load occurs on weekends in November and the lowest load occurs on weekdays in August. The maximum cooling load that occurs is 3,281 kW for one hour, starting at 15:00 and the minimum load occurs is 303 kW. Electrical energy consumption per year will be determined by calculating the energy for as long as 12 months, both weekends and weekdays. Weekend consists of 2 days and weekday consists of 5 days operation period.

3.2 Air Conditioning System Selection

The results of the cooling load calculation of Hotel A shows that there is some cooling load fluctuations every hour which is presented through a maximum cooling load of 3,281 kW and a minimum load of 303 kW. Based on the results of the cooling load estimation, a few air conditioning systems alternatives are used in Hotel A buildings will be chosen such as:

1. Centralized air conditioning system using magnetic bearing chiller, hereinafter referred to as variable flow chiller, is referred to as Alternative 1 as shown in Figure 3.
2. Centralized air conditioning system, which consist constant flow chiller, is referred to as Alternative 2 as shown in Figure 4.
3. Split air conditioning system with VRF, referred to as Alternative 3 as shown in Figure 5.

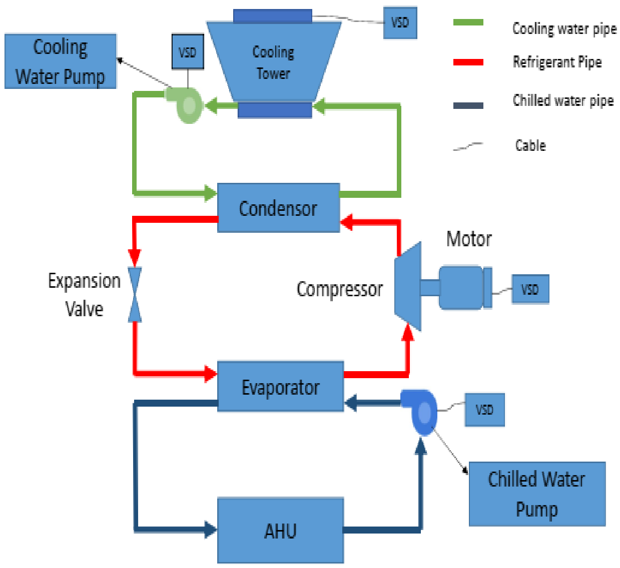

Figure 3. Alternative 1 Air Conditioning System

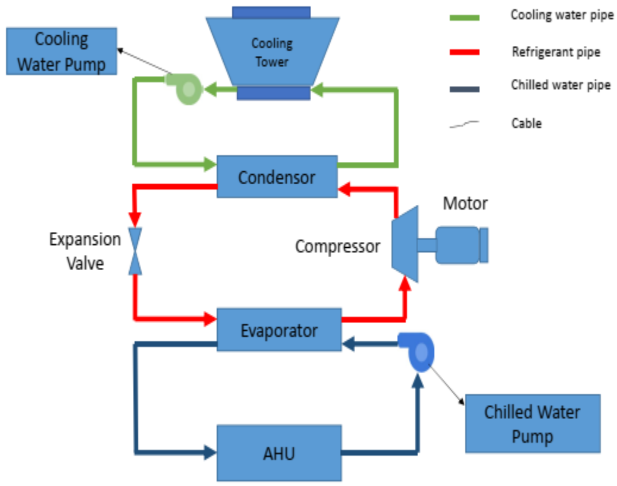

Figure 4. Alternative 2 Air Conditioning System

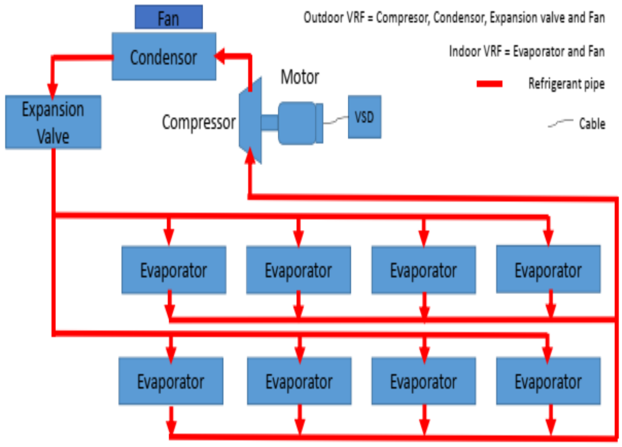

Figure 5. Alternative 3 Air Conditioning System

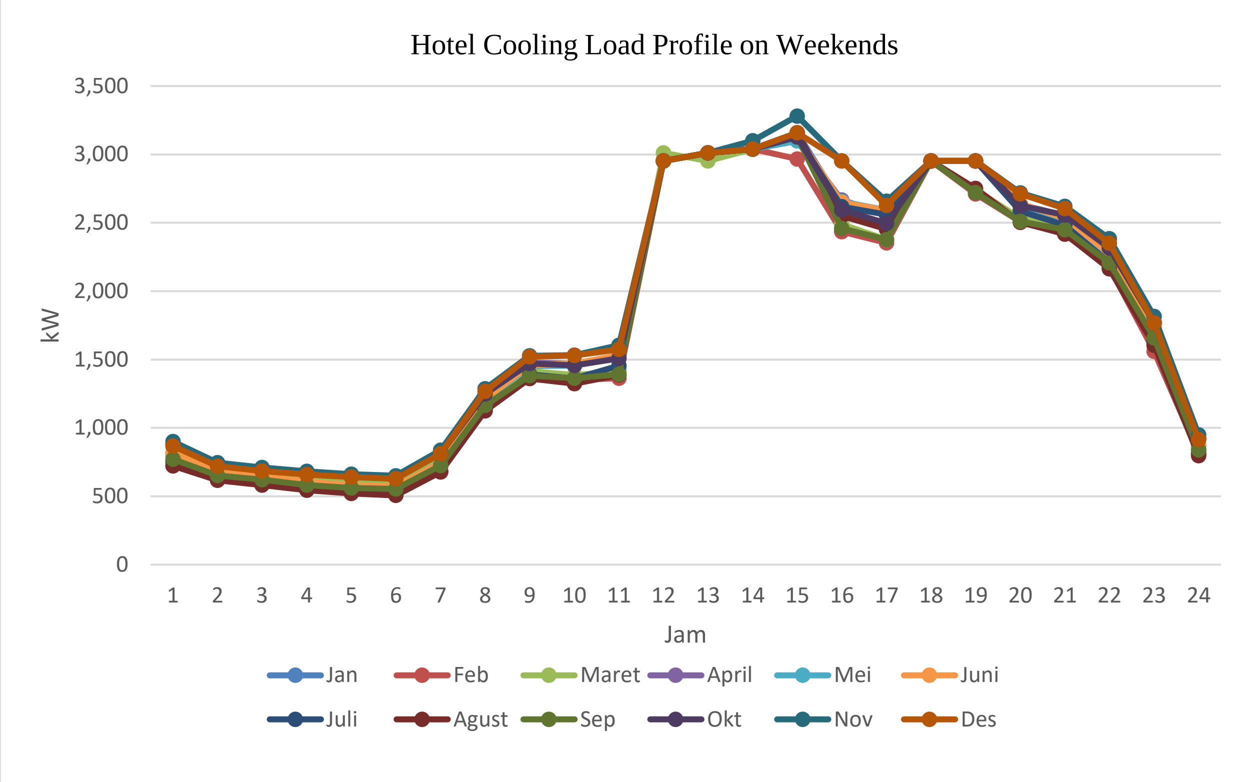

Figure 1. Cooling load profile on weekends

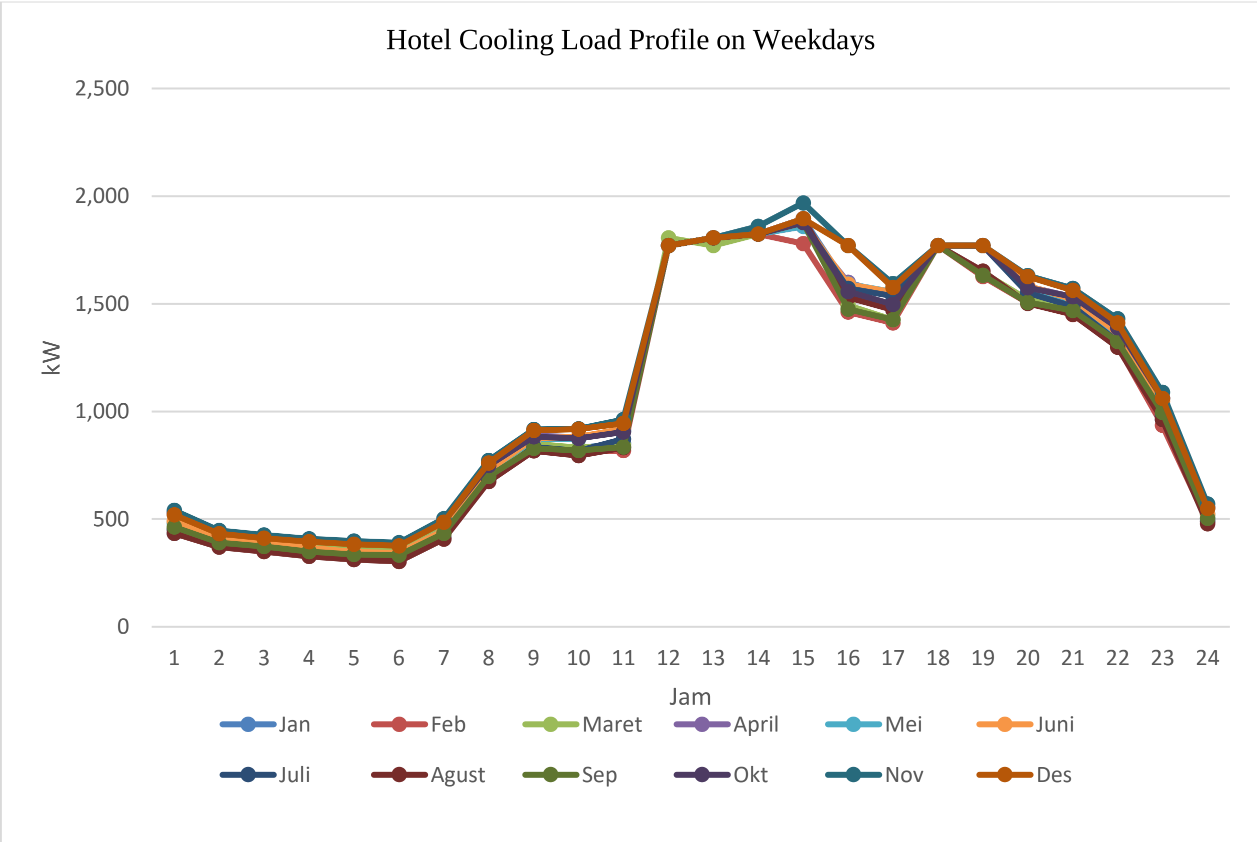

Figure 2. Cooling load profile on weekdays

Table 1. Cooling load profile on weekends

	Cooling Load Profile on Weekends (kW)											
Hour	**Jan**	**Feb**	**Mar**	**April**	**Mey**	**June**	**July**	**Agst**	**Sep**	**Okt**	**Nov**	**Des**
1	724	750	813	871	800	818	754	722	772	887	901	866
2	660	641	685	729	681	685	634	618	652	722	745	720
3	622	607	654	698	640	647	596	581	620	693	711	685
4	602	586	636	671	598	610	556	544	581	666	681	658
5	583	569	616	651	577	579	535	521	560	649	662	639
6	573	561	611	642	568	571	522	506	553	638	650	627
7	737	715	761	807	747	745	686	678	723	811	837	810
8	1,164	1,151	1,193	1,247	1,207	1,211	1,144	1,125	1,163	1,248	1,287	1,268
9	1,410	1,382	1,415	1,477	1,451	1,459	1,390	1,360	1,382	1,470	1,527	1,520
10	1,383	1,352	1,387	1,468	1,455	1,470	1,361	1,325	1,364	1,457	1,532	1,529
11	1,420	1,364	1,409	1,520	1,517	1,532	1,454	1,387	1,390	1,509	1,605	1,574
12	2,951	2,951	3,010	2,951	2,951	2,951	2,951	2,951	2,951	2,951	2,951	2,951
13	3,010	3,010	2,951	3,010	3,010	3,010	3,010	3,010	3,010	3,010	3,010	3,010
14	3,040	3,040	3,040	3,040	3,040	3,040	3,040	3,040	3,040	3,040	3,099	3,040
15	3,158	2,967	3,129	3,099	3,099	3,129	3,129	3,158	3,129	3,129	3,281	3,158
16	2,632	2,436	2,489	2,666	2,655	2,651	2,619	2,550	2,459	2,594	2,951	2,951
17	2,453	2,353	2,376	2,561	2,591	2,589	2,560	2,454	2,378	2,495	2,657	2,626
18	2,951	2,951	2,951	2,951	2,951	2,951	2,951	2,951	2,951	2,951	2,951	2,951
19	2,951	2,711	2,743	2,951	2,951	2,951	2,951	2,752	2,722	2,951	2,951	2,951
20	2,595	2,507	2,532	2,634	2,621	2,639	2,585	2,504	2,510	2,624	2,718	2,711
21	2,505	2,416	2,473	2,553	2,520	2,535	2,481	2,419	2,448	2,556	2,620	2,603
22	2,236	2,174	2,238	2,314	2,261	2,274	2,209	2,164	2,208	2,315	2,384	2,351
23	1,604	1,559	1,681	1,772	1,724	1,746	1,635	1,604	1,658	1,768	1,815	1,768
24	838	813	865	923	871	872	817	798	838	921	950	915

Table 2. Cooling load profile on weekdays

	Cooling Load Profile on Weekday (kW)											
Hour	**Jan**	**Feb**	**Mar**	**April**	**Mey**	**June**	**July**	**Agst**	**Sep**	**Okt**	**Nov**	**Des**
1	434	450	488	522	480	491	453	433	463	532	540	520
2	396	385	411	438	408	411	380	371	391	433	447	432
3	373	364	393	419	384	388	358	349	372	416	426	411
4	361	352	382	402	359	366	334	326	349	399	409	395
5	350	342	369	391	346	348	321	312	336	389	397	383
6	344	337	367	385	341	343	313	303	332	383	390	376
7	442	429	457	484	448	447	411	407	434	486	502	486
8	698	691	716	748	724	727	687	675	698	749	772	761
9	846	829	849	886	871	875	834	816	829	882	916	912
10	830	811	832	881	873	882	816	795	818	874	919	918
11	852	818	845	912	910	919	873	832	834	905	963	944
12	1,771	1,771	1,806	1,771	1,771	1,771	1,771	1,771	1,771	1,771	1,771	1,771
13	1,806	1,806	1,771	1,806	1,806	1,806	1,806	1,806	1,806	1,806	1,806	1,806
14	1,824	1,824	1,824	1,824	1,824	1,824	1,824	1,824	1,824	1,824	1,859	1,824
15	1,895	1,780	1,877	1,859	1,859	1,877	1,877	1,895	1,877	1,877	1,969	1,895
16	1,579	1,462	1,493	1,600	1,593	1,591	1,571	1,530	1,476	1,557	1,771	1,771
17	1,472	1,412	1,425	1,536	1,555	1,553	1,536	1,472	1,427	1,497	1,594	1,576
18	1,771	1,771	1,771	1,771	1,771	1,771	1,771	1,771	1,771	1,771	1,771	1,771
19	1,771	1,627	1,646	1,771	1,771	1,771	1,771	1,651	1,633	1,771	1,771	1,771
20	1,557	1,504	1,519	1,580	1,573	1,583	1,551	1,502	1,506	1,574	1,631	1,627
21	1,503	1,449	1,484	1,532	1,512	1,521	1,489	1,451	1,469	1,534	1,572	1,562
22	1,342	1,305	1,343	1,388	1,357	1,365	1,325	1,298	1,325	1,389	1,430	1,411
23	962	936	1,009	1,063	1,034	1,048	981	962	995	1,061	1,089	1,061
24	503	488	519	554	523	523	490	479	503	552	570	549

The chiller commonly used in the refrigeration process is a vapor compression chiller because it has better efficiency than other types of chiller, such as the absorption type chiller. While the vapour compression chiller based on the cooling method on the condenser is divided into two, namely using air and using water. The energy consumption between water cooled chiller is better than air cooled chiller, so in this study a water cooled chiller is used to get hotel buildings that have good energy efficiency. Based on the maximum cooling load of 3,281 kW and a minimum cooling load of 303 kW, a selection of the chiller that will be used in this study can be selected. It is planned that the number of chiller machines is 3 units with each capacity of 1,100 kW. Selected a small chiller engine capacity so that at low cooling load, only 1 chiller unit is run to overcome the cooling load. The following is the 1,100 kW chiller characteristic curve shown in Figure 6 for constant flow chiller and Figure 7 for magnetic bearing chiller.

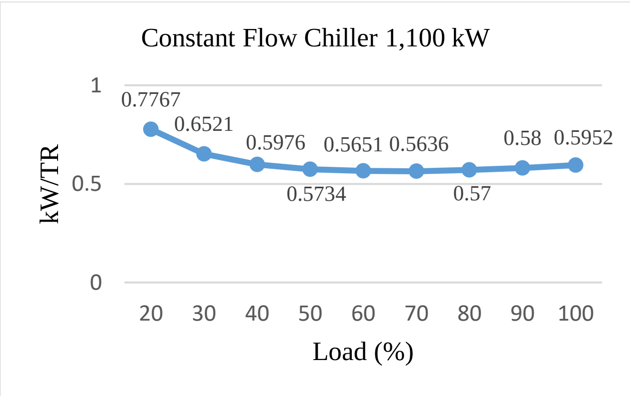

Figure 6. Constant flow chiller curve characteristic

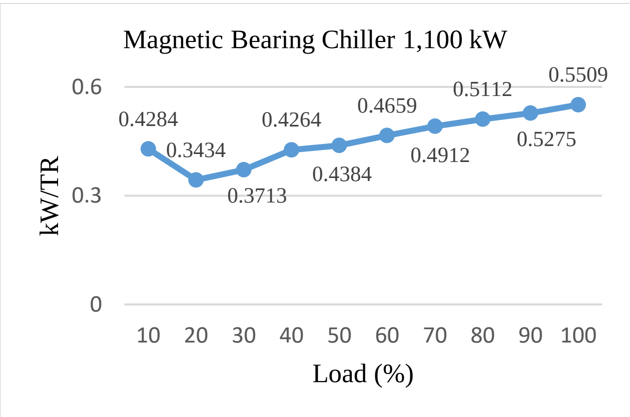

Figure 7. Magnetic bearing chiller curve characteristic

Meanwhile, the selection of outdoor units of VRF air conditioning system will be divided by floor. The number of outdoor units per floor varies from one unit to eight units, depending on the maximum cooling load on each floor. The location of the outdoor unit in this design is on the roof floor, because only on the roof floor it is possible to put the outdoor unit. This is possible because one of the advantages of the VRF system is that the distance between the indoor unit and the outdoor unit can be up to 100 m vertically. The following is the 28 kW VRF characteristic curve shown in Figure 8 which is one of the units used in the VRF air conditioning system.

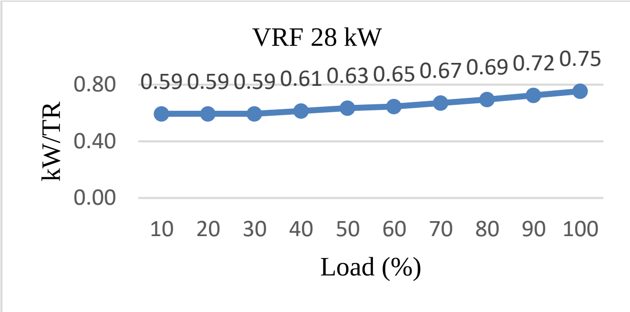

Figure 8. VRF curve characteristic

Based on the chiller efficiency curve and VRF to the percentage of cooling load, it can be seen that the magnetic bearing chiller is very suitable for the cooling load characteristics of the hotel, where at low cooling load the chiller energy efficiency is very good.

The required cooling tower capacity is influenced by the value of the condenser cooling water discharge, the temperature of the condenser cooling water in and out, and the temperature of the wet bulb outside the air. The amount of condenser cooling water required for one chiller is 213.11 m^3/hour. The temperature of the condenser cooling water in and out of the cooling tower is set at 35.5^{0}C and 30^{0}C, respectively. While the temperature of the wet bulb outside air is determined to be 27^{0}C. Based on the above, the cooling tower capacity for Alternative 1 and Alternative 2 is the same as 1364.2 kW. Alternative 3 does not require a cooling tower because the condenser cooling uses air.

The design of main equipment of each alternative air conditioning system is shown in Table 3 including pumps for chilled water and condenser water.

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Table 3. Main equipment of air conditioning system

Description	Variable flow chiller	Constant flow chiller	VRF
Type	Water Cooled Chiller (VSD)	Water Cooled Chiller	Variable Refrigerant Flow
	Centrifugal magnetic bearing	Screw	Scroll
Capacity	1100 kW	1100 kW	28 kW up to 146 kW
Number of unit	3	3	31
Refrigerant	HFC-134a	HFC-134a	R 410A
Input power	180 kW	180 kW	952 kW (Total)
Efficiency	0.5952 kW/TR	0.5952 kW/TR	0.8968 kW/TR
Description	**Variable flow cooling tower**	**Constant flow cooling tower**	
Type	Cross-flow	Cross-flow	-
Capacity	1364.2 kW	1364.2 kW	-
Number of unit	3	3	-
	VSD	Without VSD	-
Input power	7.5 kW/unit	7.5 kW/unit	-
Description	**Variable flow chiller water pump**	**Constant flow chilled water pump**	
Flow	170.34 m^3/hour	170.34 m^3/hour	-
Input power	15.4 kW	15.4 kW	-
Head	25 m.H_20	25 m.H_20	-
	VSD	Without VSD	-
Number of unit	3	3	-
Description	**Variable flow cooling water pump**	**Constant flow cooling water pump**	
Flow	213.11 m^3/hour	213,11 m^3/hour	-
Input power	12.42 kW	12.42 kW	-
Head	15 m.H_20	15 m.H_20	-
	VSD	Without VSD	-
Number of unit	3	3	-

3.3 Energy Analysis of Air Conditioning Systems

Electrical energy consumption is calculated for one year for each air conditioning system including chiller, cooling tower, pump, air treatment unit, outdoor VRF unit, and indoor VRF unit. This energy consumption calculation is based on the estimated cooling load of the *Trace 700* software.

1. Alternative 1

Table 4. Energy consumption of Alternative 1

Description	kWh/year
Chiller	1,604,311
Chiller Pump	101,669
Cooling Tower	97,519
Cooling Tower Pump	87,622
AHU	425,307
Total	**2,316,428**

2. Alternative 2

Table 5. Energy consumption of Alternative 2

Description	kWh/year
Chiller	2,021,260
Chiller Pump	232,213
Cooling Tower	213,155
Cooling Tower Pump	187,529
AHU	425,307
Total	**3,079,463**

3. Alternative 3

Table 6. Energy consumption of Alternative 3

Description	kWh/year
VRF	3,333,095
Total	**3,333,095**

Based on energy consumption calculations above, the comparison can be seen in Table 7.

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Table 7. Air conditioning energy consumption

Description	kWh/year
Alternative 1	2,316,428
Alternative 2	3,079,463
Alternative 3	3,333,095

Based on the calculation of the energy consumption of each air conditioning system, the central air conditioning system with a magnetic bearing chiller is the best choice of several alternative air conditioning systems commonly used in Hotel A. Centralized air conditioning system with variable flow chiller has the lowest electrical energy consumption, which is 2,316,428 kWh/year.

Table 8. IKE of air conditioning system

Description	kWh/(m² .year)
Alternative 1	84
Alternative 2	112
Alternative 3	121

From Table 8, the IKE of Alternative 1, Alternative 2, and Alternative 3 are still considered efficient due to their value are lower than IKE standard of 227.5 kWh/(m^2.year)[11][16]. Alternative 1 has the most efficient compared to other alternatives with IKE is 84 kWh/(m^2.year)

3.4 Water Evaporation of Cooling Tower

Centralized air conditioning system of Alternative 1 and Alternative 2 uses water to cool down the refrigerant in coil of condenser. Water losses during the process is shown in Table 9.

Table 9. Cooling tower water consumption

Description	Water consumption (m^3/year)
Alternative 1	18,548
Alternative 2	18,548
Alternative 3	0

3.5 Life Cycle Cost Analysis

After deciding the most efficient system regarding the energy aspect, the cost calculation is then done to analyze the cost. Cost analysis that is used in this design is the life cycle cost analysis. This method is based on calculating all costs of a product or system starting from design, investment, operation, maintenance and disposal. However, in this study, only a partial analysis of life cycle costs is done to the costs of design, investment, operation and maintenance. In addition, this analysis method is adjusted to the life span of a product. In this research, life cycle cost analysis is done for a 20 years period.

a) Design Cost

The design cost is based on INKINDO DKI Jakarta [17]. The estimated cost obtained for the three air conditioning systems for three alternatives is the same, which is Rp. 819,500,000.00.

b) Investment Cost

Investment cost is the cost incurred by the developer during initially during the purchase of product that fits the air conditioning system according to the design. Investment costs of air conditioning system can be seen in Table 10.

Table 10. Air conditioning investment cost

Description	Cost (IDR)
Alternative 1	31,584,635,750.00
Alternative 2	29,368,290,000.00
Alternative 3	37,311,696,000.00

c) Operational cost for electricity and water

Operational cost of the air conditioning system consists of electricity operating cost and replacement water usage cost to replace water lost in cooling tower. Based on the basic electricity tariff reference issued by PLN, this hotel building has electricity requirement above 200 kVA and is included in the large business group (B-3). Furthermore, to calculate the loss of water due to the process in cooling tower. Water usage cost that is used is based on the basic rate issued by PAM DKI is used. The operational costs of this hotel building can be seen in Table 11.

Table 11. Electrical and water operational cost

Description	Cost (IDR)
Alternative 1	2,814,992,627.00
Alternative 2	3,665,579,449.00
Alternative 3	4,087,087,244.00

d) Maintenance Cost

Maintenance costs is a cost incurred so the machine is still in a good condition, and therefore it can be continuously operated. Maintenance cost is generally spent periodically to prevent product failure. It consists of spare part replacement for the component that make up the air conditioning system. Operational costs for maintenance is shown in Table 12.

Table 12. Air conditioning maintenance cost

Description	Cost (IDR)
Alternative 1	255,150,000.00
Alternative 2	255,150,000.00
Alternative 3	1,042,000,000.00*
	187,560,000.00

* Compressor replacement cost after 10 years

Life cycle cost calculation is the final step that need to be done after all basic rate obtained. Design, investment, operation, and maintenance costs of the three system alternatives are added for their life cycle of 20 years. There are few assumptions used in calculating the life cycle cost analysis, such as:

- Life cycle cost analysis is limited to investment cost, design cost, operational cost, and maintenance cost.
- An increase in electricity and water usage costs, which is 5% per year.
- Increase in maintenance cost by 2% per year.
- Constant interest rate of 7.5%.
- Analyzes were performed for cycle times of 20 years.
- Constant rupiah exchange rate of IDR 15,000.00/USD

After calculating using equation (2), a different UPV factor is obtained for operational cost of 15.77 and for maintenance cost of 12.06. Both of this values are UPV value used in life cycle cost analysis for 20 years ahead. UPV value is then multiplied by the operational cost and maintenance fee to get the present value if the product is still being operated for the span of 20 years. Detail cost for all three alternatives is as shown in Table 13.

Table 13. Life cycle cost for 20 years period

Description	Cost (IDR)
Alternative 1	78,873,678,478.00
Alternative 2	91,089,086,911.00
Alternative 3	105,888,534,438.00

4. Conclusions

Based on the design results and analysis done, it can be concluded that the Alternative 1 air conditioning system, centralized air conditioning system with variable flow chiller is the best air conditioning system for Hotel A, with an IKE value of 84 kWh/(m^2.year) and life cycle cost for a period of 20 years amounting to 78,873,678,478.00 IDR.

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