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ENERGY AND COSTS SAVING AIR CONDITIONING SYSTEM OF SHOPPING MALL BUILDINGS: A CASE STUDY IN JAKARTA

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Abstract

The air conditioning system for the Mall A building in Jakarta uses a constant flow chiller with TES (Thermal Energy Storage). This system will be verified by measuring data regarding the cooling load of the Mall A. The peak cooling load measurement results is 12,299 kW with a cooling energy of 45,733,180 kWh for 1 year. Based on *Trace 700* software calculation, the peak cooling load is 12,594 kW with a total cooling energy of 44,617,405 kWh. The air conditioning system in Mall A, it will be compared with a central air conditioning system with a magnetic bearing chiller to find out how well its energy performance and costs are for a mall building similar to Mall A, as a potential for energy and cost savings. The results of energy calculations and cost analysis, the central air conditioning system with the magnetic bearing chiller is 99 kWh/(m^2.year) and the life cycle costs for 20 years, 30 years, and 50 years are 339,828,248,242 IDR, 415,994,136,400 IDR, 521,915,598,761 IDR. While the results of energy calculations and cost analysis, the TES combination constant flow chiller central air conditioning system is 141 kWh/(m^2.year) and the life cycle costs for 20 years, 30 years, and 50 years are 435,150,140,059 IDR, 541,700,386,487 IDR, 690,535,151,478 IDR. Based on the foregoing, the central air conditioning system with variable flow magnetic bearing chiller is a better system than the central air conditioning system with TES combination constant flow chiller for shopping mall buildings similar to Mall A.

Keywords: Cooling load, Chiller, Cost, Energy, Shopping Mall

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1. Introduction

Inappropriate selection of air conditioning systems in shopping mall buildings will result in high operational costs which as a whole will affect the shopping mall business scheme. The amount of energy consumption and the cost of the shopping mall building air conditioning system must be an important consideration in determining the air conditioning system that will be used in shopping mall buildings. The Mall A building in Jakarta uses a central air conditioning system using TES (Thermal energy Storage) in combination with a constant flow chiller. The TES system is a method of storing energy in tanks in the form of ice. Furthermore, the energy in the tank will be used to cool the mall building during peak cooling loads. To keep the freezing point of water below 0°C, 25% ethylene glycol is added to the chilled water. In addition to the air conditioning system used in Mall A, several air conditioning systems commonly used in shopping mall buildings include a central air conditioning system using a constant flow chiller, a central air conditioning system using a magnetic bearing chiller and a splitduct air conditioning system. Some of these systems have advantages and disadvantages in terms of energy consumption and costs. In this study, the existing air conditioning system at Mall A is compared to the central air conditioning system using a magnetic bearing chiller equipped with VSD (Variable Speed Drive) in terms of energy consumption and cost aspects.

The central air conditioning system using magnetic bearing chiller is an alternative solution to save electrical energy consumption in mall buildings. This magnetic bearing chiller is equipped with VSD to regulate the rotation speed of the compressor. The central air conditioning system using a magnetic bearing chiller is very suitable for shopping mall buildings because the distribution of cooling loads fluctuates every hour. The advantage of magnetic bearing chiller compared to constant flow chiller is that magnetic bearing chiller has higher efficiency at low cooling load. In addition, the magnetic bearing chiller compressor does not occur between the rotor and the stator so that no heat loss occurs. There is no need for oil as a coolant in a compressor such as a brine chiller, so the weight and size are lighter and smaller. 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 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[2], so that the use of electrical energy will be more efficient.

In Joseph C. Lam's research in Hong Kong in 2002 on the electrical energy consumption of mall buildings with a case study at 4 different malls, it was stated that the average EUI (Energy Use Intensity) value was 430 kWh/(m^2.year) with a percentage of electrical energy air conditioning system at Mall 1 by 52%, Mall 2 by 47%, Mall 3 by 48%, and Mall 4 by 52%[3]. The consumption of electrical energy in the USA for mall buildings is 233 kWh/(m^2.year) with the percentage of electricity consumption in the air conditioning system of 42%[4]. The consumption of electrical energy for food stores is 346 kWh/(m^2.year) to 700 kWh/(m^2.year), while for non-food stores it is 146 kWh/(m^2.year) up to 293 kWh/(m^2.year)[5]. The consumption of electrical energy for commercial buildings which have a large area of 200 kWh/(m^2.year) to 400 kWh/(m^2.year)[6]. In Saudi Arabia, the electricity consumption for mall buildings is 250 kWh/(m^2.year) to 275 kWh/(m^2.year)[7]. Meanwhile, based on the electrical energy audit at *Matahari* shopping center in Pontianak, the consumption of electrical energy for the building is 331.48 kWh/(m^2.year) with a percentage of electricity consumption in the air conditioning system of 75%[8]. The consumption of electrical energy for the Gresmall Surabaya building is 332.86 kWh/(m^2.year)[9].

Based on the Regulation of the Governor of DKI Jakarta Number 38 of 2012 regarding "*Bangunan Gedung Hijau*", the EUI value for mall buildings is 450 kWh/(m^2.year)[10]. Meanwhile, in the book issued by the DKI Jakarta Government "Air Conditioning & Ventilation System", the Jakarta Green Building User Guide states that electricity consumption for mall buildings is 57% of the total electricity consumption[11].

In this study, the actual cooling load that occurs during 1 year will be verified compared to the calculation with the *Trace 700* software. In addition, it will also calculate the consumption of electrical energy from the Mall A air conditioning system. To find out whether the air conditioning system used by Mall A is optimal in terms of energy consumption and costs, it will be compared to a central air conditioning system using a magnetic bearing chiller equipped with VSD. The calculation of energy consumption and cost of the central air conditioning system using a magnetic bearing chiller will use the measurement data. The results of the cost energy analysis between the two systems can be taken into account in the selection of air conditioning systems in shopping mall buildings that are similar to Mall A buildings.

2. Experimental and Procedures

2.1 Data

The Shopping Mall A building which will be analyzed in this study is located in Jakarta. Based on SNI 03-6390-2011 regarding energy conservation of building air conditioning systems (BSNI, 2011: 3), the outdoor air condition of the design in the area has a maximum average dry bulb temperature of 33°C and a maximum average wet bulb temperature of 27°C[12].

The Shopping Mall A building consists of 4 floors with 2 basements with a conditioned total area of 118,000 m^2 and a building area of 141,600 m^2. The function of this mall is for shops, restaurants, and parking.

The overall heat transfer coefficient value depends on several parameters, such as the thickness of the building material and the characteristics of the building material itself. Based on glass technical specification from the architectural data, the shading coefficient value of glass that used in this mall is 0.66[13]. While some U values used in this building are shown in Table 1.

Table 1. U Value of Mall A Building Material

Description	U-Value (W/m^2 K)
ACP Wall	1.421
Plaster Walls	1.536
Partition	2.378
Roof	0.501
Floor	1.089
Glass	2.298

Heat load come from various sources, both external and internal, the values have been determined in accordance with the standards issued by the National Standardization Agency of Indonesia (*Badan Standardisasi Nasional*-BSN). The standard used in determining the ventilation requirements of each room and the sensible and latent loads of the occupants is SNI 03-6572-2001[14]. Meanwhile, to find out the need for occupant density refers to the international standard ASHRAE Standard 62.1-2007. Based on SNI 03-6572-2001, the design conditions

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for indoor air temperature 25°C ± 1°C and relative humidity 55% ± 10% were selected[14].

The cooling load of the Mall A building is influenced by the number of people, lights, and electrical equipment contained in Mall A. The amount varies every hour from the mall building open to closing expressed in the form of a percentage of the maximum amount of each of these loads. References to the number of mall visitors in Jakarta are obtained from Central Park and Grand Indonesia Shopping Mall[15]. Table 2 describes the schedule of the number of people, lights and electrical equipment per hour.

Table 2. Schedule of people, lightings and equipment

Description	Hour	Percentage (%)
People	00:00-09:00	0
	09:00-10:00	10
	10:00-11:00	40
	11:00-13:00	60
	13.00-15:00	80
	15:00-17:00	100
	17:00-20:00	80
	20:00-22:00	30
	22:00-00:00	0
Lights	00:00-09:00	0
	09:00-10:00	50
	10:00-21:00	100
	21:00-22:00	20
	22:00-00:00	0
Equipment	00:00-09:00	0
	09:00-10:00	10
	10:00-11:00	40
	11:00-16:00	100
	16:00-21:00	60
	21:00-22:00	10
	22:00-00:00	0

2.2 Procedures

In this study, data were collected regarding cooling loads and electrical energy consumption in the Mall A building air conditioning system. The air conditioning system is equipped with a computerized data storage system, so that data will be stored automatically while the air conditioning system operates. The data used in this study are data for 1 year, in 2019. Measurement data taken include data on chilled water temperature, cooling water temperature, chiller pump pressure, chiller water flow pump, cooling tower flow pumps and other data related to the cooling load and energy consumption of the air conditioning system.

The measurement data will be verified with calculations using *Trace 700* software regarding the cooling load of the Shopping Mall A building. Shopping Mall A building data is obtained from the architect including the building area and its designation as well as the building's wall and glass materials. The parameters used in calculating the cooling load must follow applicable standards and regulations including temperature and relative humidity. The building cooling load calculation uses the CLTD (Cooling Load Temperature Difference) method, which is one of the methods recommended by ASHRAE. If the difference between the measurement data and the calculation result is less than 5%, the measurement data can be used for energy and cost analysis calculations.

To determine the energy performance of the air conditioning system used by the Shopping Mall A building, the central air conditioning system using a TES combination constant flow chiller, it will be compared with the another air conditioning systems and applicable standards. The another air conditioning system chosen is a central air conditioning system using a magnetic bearing chiller equipped with a VSD. The design of central air conditioning system with the magnetic bearing chiller includes the selection of a chiller, cooling tower, chilled water pump, cooling water pump, air ducts, piping, and control systems. Energy analysis is carried out by calculating the consumption of electrical energy for each air conditioning system, both the central air conditioning system using a brine chiller with constant flow combined with TES and a central air conditioning system using a magnetic bearing chiller with VSD. The calculation of electrical energy consumption is calculated for 1 year. The calculation of energy consumption per unit area m^2 each year is expressed by the value of EUI. The results of the calculation of the EUI value for each air conditioning system will be compared with the EUI value determined by DKI Jakarta Governor Regulation Number 38 of 2012 and a book issued by the DKI Jakarta Government entitled "Jakarta Green Building Guide, Air Conditioning & Ventilation System".

The cost analysis in this study used a life cycle cost analysis limited to planning, investment, operational and maintenance costs, not including disposal costs. In calculating the life cycle cost analysis, all these costs must be equalized to a value that is equivalent to or equivalent to the current conditions, both investment costs and annual operating costs during the specified period. The equivalent value is represented as the present value (PV). PV value is defined as the present value of money for an amount of money in the future. This currency equalization is caused by a decrease in the value of the currency due to inflation over time in the future. The calculation of the value of life cycle costs is done by adding up all the PV values from the costs of planning, investment, operation, and maintenance. The present value of operational costs can be determined through equations (1) to (2).

$$PV = A_0 \, x \, UPV \tag{1}$$

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

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.

Cost analysis is done by comparing the cost aspects of the two air systems. The method for conducting cost analysis uses the method of life cycle cost analysis. The life cycle cost analysis method is based on the calculation of all costs incurred in a product or system during one life cycle. The life cycle of the product or system starts from the design, investment, operation, maintenance and disposal stages. However, in this study, only a limited life cycle cost analysis was carried out at the planning, investment, operation and maintenance stages. In addition, this analysis method is adjusted based on the life span of a product. In this study, analysis was carried out with a period of 20 years, 30 years and 50 years.

3. Results and Discussion

3.1 Cooling load

The Shopping Mall A consists of 4 floors with 2 basements with an area will be air conditioned of 118,000 m^2 and total building area of 141,600 m^2.

The cooling load calculation is based on the building envelope material data of Shopping Mall A, the design of the dry bulb temperature is 25°C, the outside air condition is 33°C the dry bulb temperature and 27°C the wet bulb temperature, and the total internal load includes people loads, lights 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 4 and Table 5. While the cooling load based on actual measurements can be seen in Tables 6 and Table 7. From the conditioned area data to the peak cooling load, it shows that the shopping mall cooling load per unit area is 0.109 kW/m^2 for actual measurement and 0.112 kW/m^2 for calculation by *Trace 700*. Based on the ASHRAE Pocket Guide Handbook, 2013, Table 12.1 "Cooling Load Check Figures" state that the estimated shopping mall cooling load ranges from 0.108 kW/m^2 to 0.252 kW/m^2[16]. So the results of calculating the cooling load using the *Trace 700* software and the actual measurement data still meet the standards based on the ASHRAE Pocket Guide Handbook.

Due to the number of people between weekends and weekdays, the calculation will be divided into weekends cooling loads profile and weekdays cooling loads profile. The number of mall occupants on weekdays is approximately 80% of the number of residents on weekends[17]. The maximum cooling load occurs on weekends is 12,299 kW for actual measurement data and 12,594 kW for *Trace 700* software calculation. 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. The cooling load profile curve for Mall A at weekends can be seen at Figure 1 dan Figure 2. Based on the results of the cooling load calculation using the *Trace 700* software, the cooling load distribution is grouped based on the cooling load component as shown in Table 3.

Table 3. Cooling load component of the Mall A

Description	**Percentage (%)**
Envelope building	19
Occupant	22
Lights	26
Equipment	6
Ventilation	27

Table 3 shows the most influential heat gain from ventilation, lighting and the number of people. This is due to the very high number of occupant densities for mall buildings ranging from 2.5 m^2/person[18], thus requiring a large amount of fresh air to keep the amount of oxygen fulfilled for mall residents. While the building envelope affects the heat gain by 19% to the cooling load of Mall A. Because the building envelope of Mall A mostly uses walls covered with aluminum panels, while the glass walls are only located on the ground floor of Mall A. The total window wall ratio (WWR) of this building is 0.25. Figure 1 shows the peak cooling load occurs at 15:00 for 1 hour, this is proportional to number of people, lights and building envelope loads in Mall A which are maximum at 15:00 to 16:00. While the heat gain at the beginning of the opening of the mall is higher than the next 1 hour because the cooling energy produced by the chiller is absorbed first by the building envelope which during the night until the morning dissipates cooling energy. So the cooling load at the first time the chiller is turned on is not only absorbed by the building envelope but also cools the

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room. Furthermore, based on the number of people and the load on the building envelope, the cooling load profile will increase until the cooling load peaks at 15:00 and will decrease again because the load on the number of people and the building envelope load will also decrease.

Table 4. Cooling load profile (kW) Shopping Mall A at weekend based on Trace 700

Hour	Jan	Feb	March	April	May	June	July	Agst	Sept	Oct	Nov	Dec
9	7,997	8,024	8,173	8,273	8,129	8,073	7,883	7,945	8,201	8,334	8,304	8,173
10	6,965	7,099	7,633	7,740	6,761	6,529	6,107	6,299	7,166	8,026	7,981	7,649
11	6,730	6,792	7,454	7,682	7,124	6,962	6,602	6,677	7,215	7,858	7,827	7,375
12	9,640	9,669	10,240	10,710	10,432	10,321	9,854	9,829	10,400	10,679	10,750	10,296
13	10,600	10,579	11,114	11,582	11,412	11,332	10,970	10,901	11,316	11,566	11,651	11,192
14	11,030	10,962	11,475	11,890	11,785	11,722	11,402	11,265	11,692	12,008	12,080	11,658
15	11,157	11,059	11,494	11,863	11,709	11,633	11,319	11,563	12,065	12,388	12,594	11,760
16	11,307	11,218	11,655	11,931	11,605	11,524	11,247	11,301	11,905	12,008	12,323	11,838
17	9,756	9,713	10,037	10,193	9,774	9,675	9,414	9,488	10,146	10,583	10,679	9,943
18	7,176	7,140	7,230	7,180	6,837	6,782	6,683	6,726	7,127	7,449	7,606	7,410
19	6,751	6,736	6,926	6,947	6,626	6,575	6,462	6,485	6,824	7,126	7,212	7,040
20	6,381	6,344	6,515	6,576	6,304	6,272	6,121	6,133	6,443	6,733	6,830	6,653
21	6,044	5,999	6,192	6,283	6,042	6,018	5,849	5,840	6,131	6,371	6,460	6,321

Table 5. Cooling load profile (kW) Shopping Mall A at weekday based on Trace 700

Hour	Jan	Feb	March	April	May	June	July	Augst	Sept	Oct	Nov	Dec
9	7,970	8,824	8,162	8,271	8,138	8,079	7,894	7,943	8,193	8,330	8,301	8,179
10	6,573	6,737	7,199	7,286	6,399	6,139	5,772	5,947	6,732	7,541	7,527	7,258
11	5,927	6,006	6,568	6,742	6,227	6,058	5,783	5,851	6,284	6,892	6,885	6,529
12	8,654	8,691	9,175	9,615	9,343	9,229	8,834	8,795	9,284	9,571	9,648	9,248
13	9,591	9,583	10,049	10,503	10,337	10,251	9,907	9,860	10,217	10,472	10,556	10,137
14	10,016	9,959	10,403	10,839	10,736	10,654	10,337	10,211	10,620	10,927	11,043	10,613
15	10,122	10,029	10,424	10,802	10,653	10,576	10,265	10,195	10,668	11,053	11,193	10,734
16	10,334	10,248	10,594	10,861	10,568	10,467	10,202	10,249	10,840	11,188	11,283	10,850
17	8,795	8,771	8,983	9,049	8,658	8,552	8,377	8,456	9,019	9,411	9,523	9,212
18	7,265	7,241	7,323	7,262	6,935	6,874	6,795	6,838	7,216	7,518	7,688	7,504
19	6,866	6,864	7,030	7,044	6,755	6,698	6,582	6,611	6,941	7,221	7,317	7,147
20	6,493	6,467	6,646	6,695	6,429	6,389	6,257	6,262	6,557	6,832	6,937	6,791
21	6,159	6,125	6,312	6,402	6,170	6,139	5,980	5,970	6,250	6,505	6,602	6,446

Table 6. Cooling load profile (kW) Shopping Mall A weekend based on actual measurement

Hour	Jan	Feb	March	April	May	June	July	Agst	Sept	Oct	Nov	Dec
9	9,373	9,481	9,697	7,176	9,980	9,346	8,277	9,352	9,412	9,827	9,553	9,741
10	8,836	8,981	9,389	9,077	9,485	8,971	9,801	8,527	8,803	9,640	9,353	9,427
11	8,714	8,815	9,286	10,195	10,695	10,258	10,270	8,717	8,832	9,537	9,258	9,262
12	10,229	10,372	10,879	10,841	11,407	11,098	10,720	10,296	10,706	11,257	11,064	11,014
13	10,729	10,865	11,379	11,428	11,846	11,532	10,999	10,833	11,245	11,798	11,621	11,552
14	10,952	11,072	11,585	11,093	11,715	11,746	10,846	11,016	11,466	12,068	11,885	11,831
15	11,019	11,125	11,596	11,289	12,210	12,055	11,532	11,165	11,685	12,299	12,203	11,893
16	11,096	11,211	11,688	12,154	10,220	9,947	9,512	11,034	11,592	12,068	12,035	11,939
17	10,289	10,396	10,763	11,121	9,106	9,484	8,729	10,125	10,556	11,199	11,020	10,803
18	8,946	9,003	9,158	9,845	9,419	8,953	8,044	8,741	8,781	9,288	9,122	9,283
19	8,725	8,784	8,985	8,883	8,384	8,498	7,751	8,621	8,602	9,091	8,878	9,061
20	8,532	8,572	8,750	8,430	7,822	8,002	7,770	8,444	8,378	8,851	8,642	8,829
21	8,357	8,385	8,565	7,309	6,596	7,226	7,037	8,297	8,194	8,630	8,414	8,630

Table 7. Cooling load profile (kW) Shopping Mall A at weekday based on actual measurement

Hour	Jan	Feb	March	April	May	June	July	Agst	Sept	Oct	Nov	Dec
9	9,359	9,914	9,691	6,821	9,485	8,883	7,867	9,351	9,407	9,825	9,551	9,745
10	8,632	8,784	9,141	8,627	9,014	8,524	9,314	8,351	8,548	9,344	9,073	9,192
11	8,296	8,389	8,780	9,689	10,165	9,749	9,761	8,303	8,284	8,948	8,676	8,755
12	9,715	9,843	10,270	10,303	10,841	10,548	10,188	9,778	10,050	10,581	10,383	10,386
13	10,203	10,326	10,769	10,862	11,258	10,960	10,453	10,312	10,598	11,131	10,944	10,919
14	10,425	10,530	10,972	10,543	11,134	11,163	10,308	10,487	10,835	11,409	11,245	11,205
15	10,480	10,567	10,984	10,729	11,605	11,457	10,960	10,480	10,864	11,485	11,338	11,277
16	10,590	10,686	11,081	11,552	9,713	9,454	9,040	10,507	10,965	11,568	11,393	11,347
17	9,789	9,886	10,160	10,570	8,654	9,014	8,296	9,608	9,894	10,484	10,306	10,364
18	8,992	9,058	9,212	9,356	8,952	8,509	7,645	8,797	8,833	9,330	9,172	9,340
19	8,785	8,854	9,044	8,442	7,968	8,077	7,367	8,684	8,671	9,148	8,943	9,125
20	8,590	8,639	8,824	8,011	7,435	7,606	7,384	8,509	8,445	8,911	8,708	8,912
21	8,417	8,453	8,634	6,947	6,269	6,867	6,688	8,362	8,264	8,712	8,501	8,705

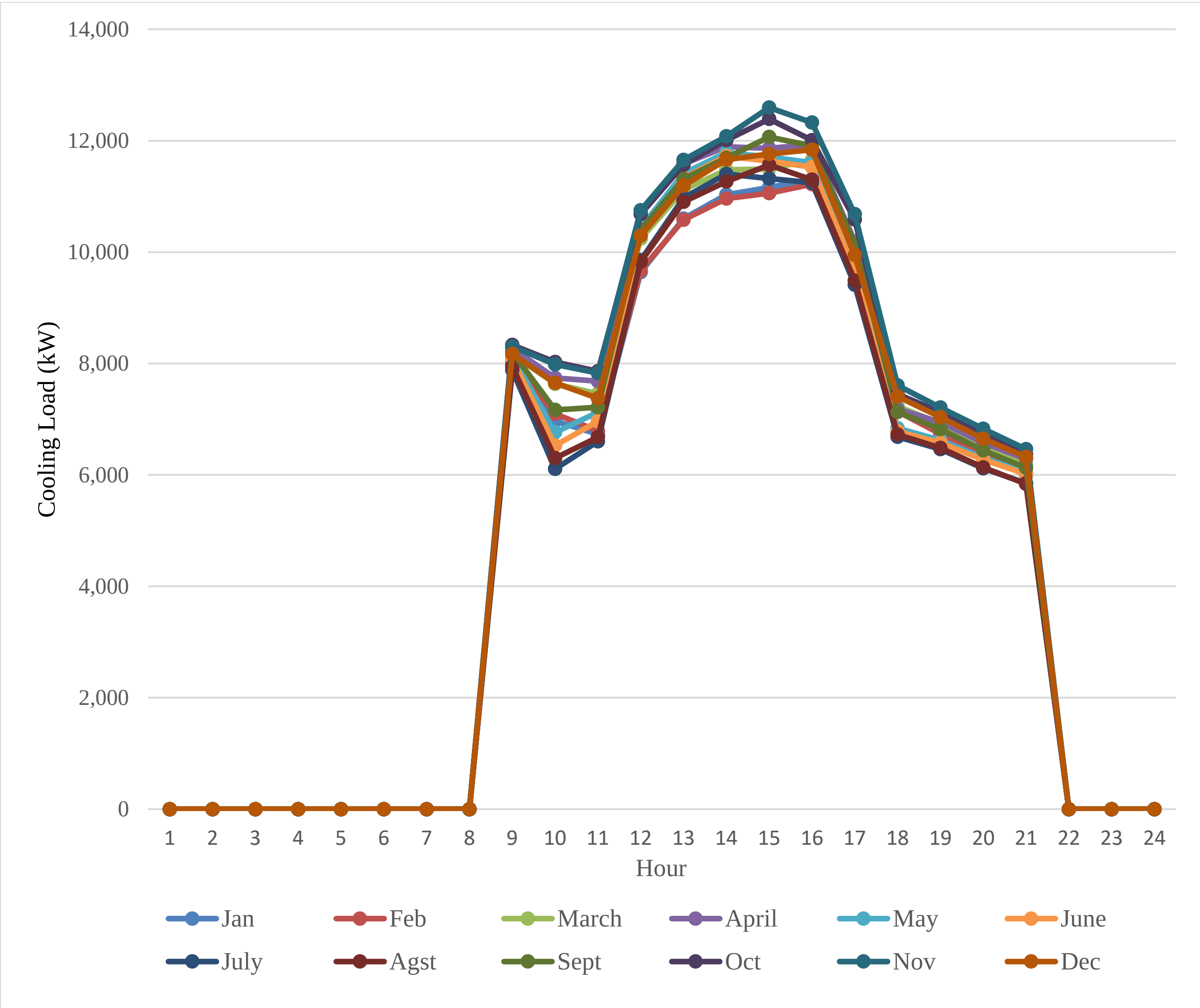

Figure 1. Cooling Load Profile of Mall A at Weekends by Trace 700 Software

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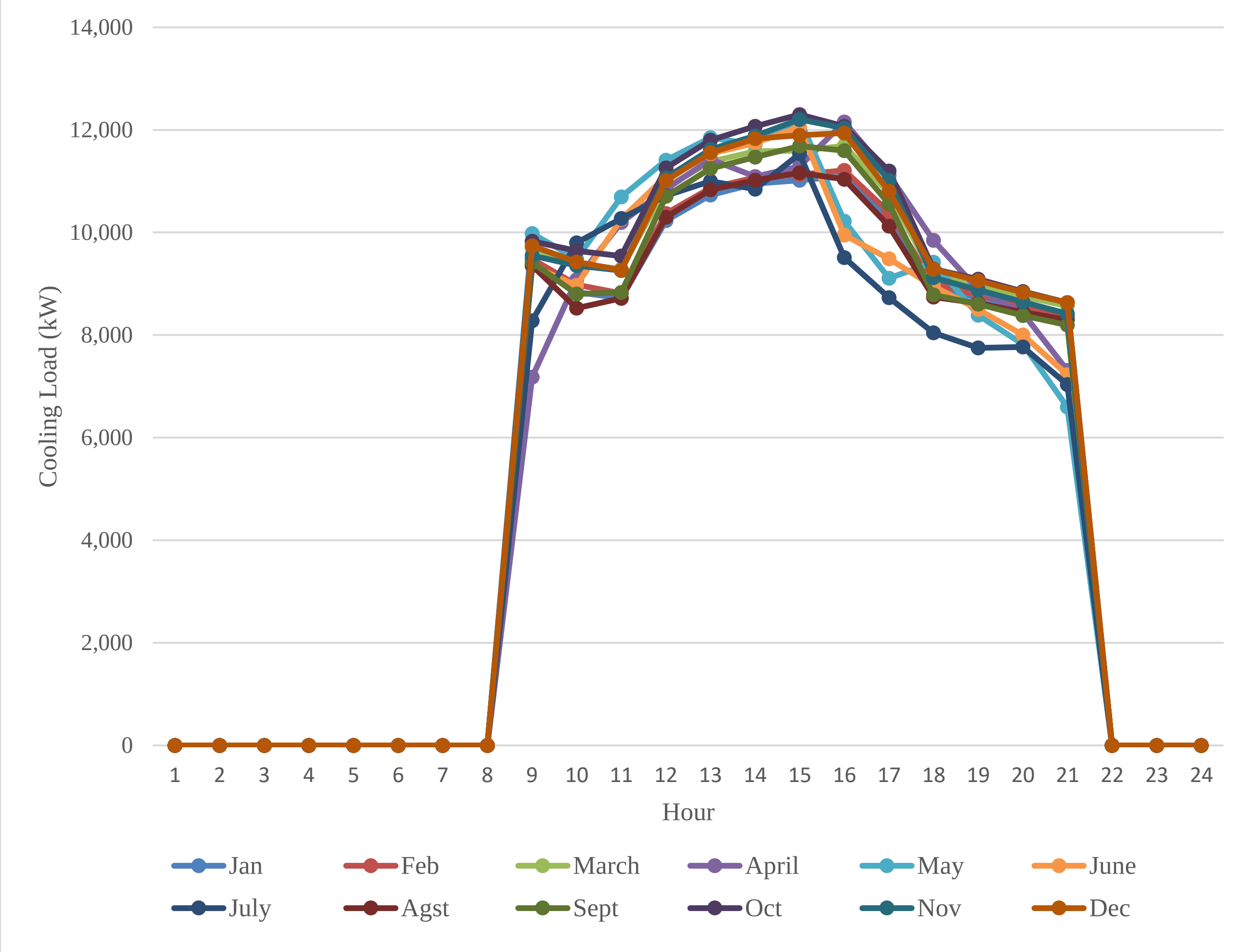

Figure 2. Cooling Load Profile of Mall A at Weekends by Actual Measurement

Based on the calculation of *Trace 700* and measurements, the difference in cooling energy is shown in Table 8.

Table 8. Cooling Energy (kWh) Shopping Mall A

	Calculation	Measurement	Difference	(%)
Jan	3,668,692	3,818,650	149,958	3.9%
Feb	3,335,084	3,495,041	159,957	4.6%
Mar	3,814,485	3,987,703	173,218	4.3%
April	3,778,838	3,724,663	-54,175	1.5%
May	3,761,422	3,848,413	86,991	2.3%
June	3,601,836	3,674,737	72,901	2.0%
July	3,608,806	3,621,544	12,738	0.4%
Agst	3,618,842	3,796,466	177,624	4.7%
Sep	3.696.754	3,746,518	49,764	1.3%
Oct	3,976,237	4,094,600	118,363	2.9%
Nov	3,886,038	3,885,498	-540	0.0%
Dec	3,870,371	4,039,347	168,976	4.2%
Total	**44,617,405**	**45,733,180**	**1,115,775**	**2.4%**

The difference in average cooling energy of the Shopping Mall A building between calculations and measurements is 2.4%. Because the difference in the value is still within the tolerance value, below 5%, the cooling load from the *Trace 700* calculation and measurement results can be said to be acceptable. Due to the total cooling load for 1 year the measurement results are greater than the calculated results, the measured cooling load will be used for further analysis, either the analysis of the energy aspect or the cost aspect.

3.2 TES Combined Constant Flow Chiller System

This air conditioning system is used in Shopping Mall A. The main equipment of this system consists of a constant flow chiller, cooling tower, pump, AHU and TES. A list of the main equipment for this air conditioning system can be seen in Table 9, and the schematic of the TES combination constant flow chiller central air conditioning system can be seen in Figure 3. While the operating schedule of the chiller and TES can be shown in Figure 4.

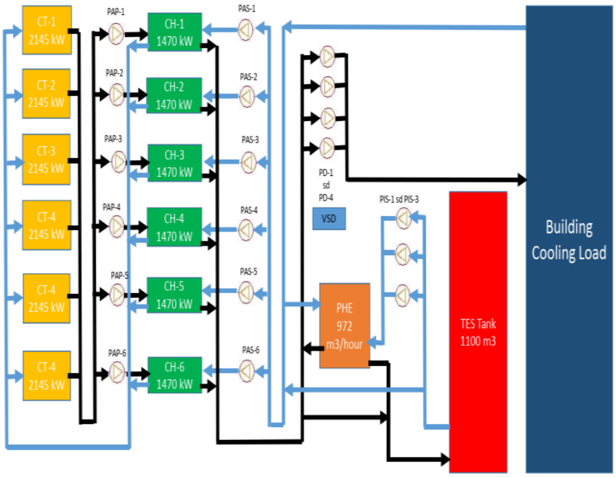

Figure 3. Schematic of chiller and TES system

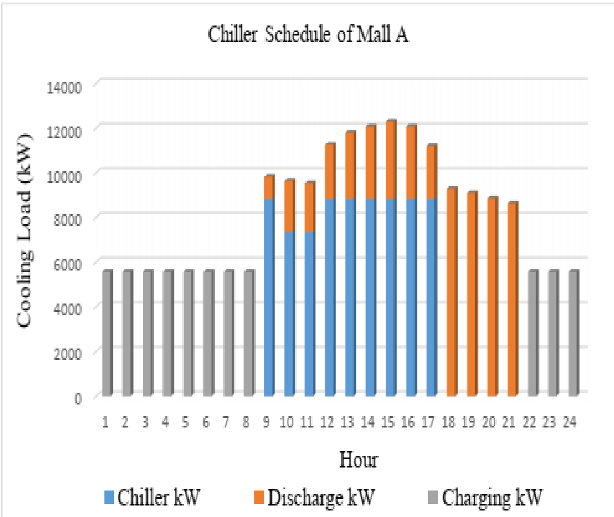

Figure 4. Chiller Schedule of Mall A

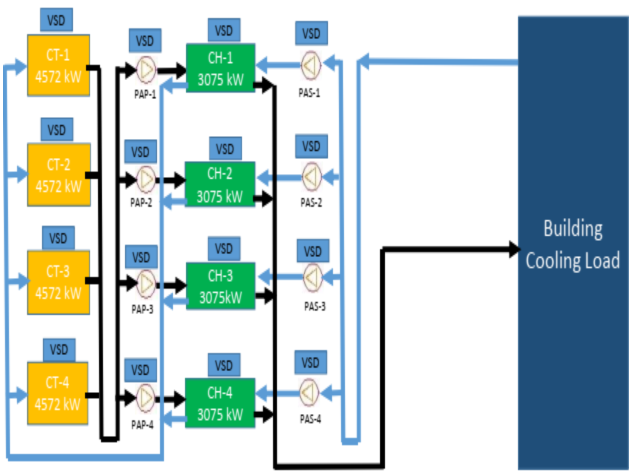

Figure 5. Schematic of variable flow chiller system

Table 9. Air conditioning main equipment

Description	**Chiller and TES**
Type	Water Cooled Chiller
Compressor	Screw
Capacity	1,470 kW
Number	6
Refrigerant	HFC-134a
Power	246.7 kW
kW/TR	0.59
Description	**Cooling Tower**
Type	Cross-flow
Capacity	2,145 kW
Number	6
	Without VSD
Power	30 kW/unit
Description	**Chilled Water Pump**
Flow	245 m^3/hour
Power	30 kW
Head	24 m.H_20
	Without VSD
Number	6
Description	**Cooling Water Pump**
Flow	306 m^3/hour
Power	30 kW
Head	20 m.H_20
	Without VSD
Number	6
Description	**TES Pump**
Flow	324 m^3/hour
Power	37 kW
Head	28 m.H_20
	Without VSD
Number	3
Description	**Distribution Pump**
Flow	433 m^3/hour
Power	90 kW
Head	42 m.H_20
	VSD
Number	4
Description	**PHE**
Flow	433 m^3/hour
Number	4
Description	**Ice Storage**
Capacity	1,100 m^3
Number	1

3.3 Variable Flow With Magnetic Bearing Chiller

The variable flow chiller central air conditioning system used as an alternative to the existing system consists of a chiller, cooling tower, AHU and pump. A list of the main equipment in this system can be seen in Table 10. While the scheme of the central air conditioning system for the variable flow chiller can be shown in Figure 5.

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Table 10. Air conditioning main equipment

Description	**Variable Flow Chiller**
Type	Water Cooled Chiller (VSD)
Compressor	Centrifugal magnetic bearing
Capacity	3,075 kW
Number	4
Refrigerant	HFC-134a
Power	488 kW
kW/TR	0.541
Description	**Cooling Tower**
Type	Cross-flow
Capacity	4,572 kW
Number	4
	VSD
Power	45 kW/unit
Description	**Chilled Water Pump**
Flowrate	491 m^3/hour
Power	75 kW
Head	42 m.$H_2$0
	VSD
Number	4
Description	**Cooling Water Pump**
Flowrate	613 m^3/hour
Power	55 kW
Head	23 m.$H_2$0
	VSD
Number	4

3.4 *Energy Analysis*

The energy aspects of the two air conditioning systems will be analyzed to determine the best choice of air conditioning systems for Shopping Mall A building by comparing the energy consumption of each of these systems. The air conditioning system is said to be energy efficient if the electrical energy consumption is lowest. The efficiency of a building in consuming electrical energy can be shown by a value known as the EUI value of a building, especially in relation to the air conditioning system. The energy consumption of each air conditioning system and the EUI value can be seen in Table 11 and Table 12.

Table 11. Air conditioning energy consumption (kWh)

Description	**TES and Chiller**	**Magnetic Bearing Chiller**
Chiller	10,139,936	8,625,495
Cooling tower	617,805	166,513
Chilled water pump	1,235,610	291,119
Cooling water pump	1,235,610	246.625
TES Pump	337,070	0
Distribution Pump	742,153	0
AHU	1,935,508	1,935,508
Fan	365,000	365,000
Total	**16,608,692**	**11,630,261**

Table 12. Air conditioning EUI value (kWh/(m^2.year))

Description	**Area (m^2)**	**Calculation**	**Standard**
Existing	118,000	141	256.5
Alternative	118,000	99	256.5

From Table 12, the EUI value of the existing air conditioning system at Shopping Mall A and the alternative air conditioning system still meets the efficiency limit as a green building, where the EUI value of the air conditioning system is below the standard EUI value of 256.5 kWh/(m^2.year)[10][11]. The air conditioning system using a chiller and TES in the Mall A building is a fairly good air conditioning system with energy efficiency because this air system uses a chiller that has an efficiency of 0.59 kW/TR. This is shown by the EUI value of this air conditioning system at 141 kWh/(m^2.year), is still below the standard passed for mall buildings, which is 256.5 kWh/(m^2.year). This chiller is combined with TES to produce ice when the mall is not operating which will be used during peak cooling loads. However, the drawback of this existing air conditioning system is that when the chiller produces ice, the efficiency of the chiller will decrease to 0.78 kW/TR, so that the consumption of electrical energy will be greater than when the chiller produces chilled water. In addition, the drawback of the chiller and TES systems is that the electricity tariff between on-peak and off-peak is the same or the difference is too small. The current electricity tariff in Indonesia is the same for the building category for business[18]. The air conditioning system using a magnetic bearing chiller as an alternative solution in a building similar to a Mall A building produces an EUI value of 99 kWh/(m^2.year) smaller than the chiller and TES air conditioning system as well as the standards used in mall buildings. Because at magnetic bearing chiller heat does not occur due to friction, oil is not needed as engine coolant. Without the use of oil, it will increase the efficiency of heat transfer because no oil enters the evaporator and condenser. The VSD in the motor allows the compressor to work more efficiently at partial load than a typical compressor. These two things make the performance of magnetic bearings chiller better, so that the magnetic bearing chiller uses less energy than chillers that are currently widely used.

3.5 *Life Cycle Cost Analysis*

The cost analysis used in this design uses the method of life cycle cost analysis. This life cycle cost method is based on the calculation of all costs on a product or system during one life cycle. The product or system life cycle starts from design, investment, operation, maintenance and disposal. The life cycle cost method is one of the comprehensive cost methods of a product in analyzing costs during the life cycle of a product so that it is more accurate in analyzing these costs. However, in this design only part of the life cycle cost analysis is limited to the costs of design, investment, operation, and maintenance. In addition, this analysis method is adjusted based on the life span of a product. In this design study, a life cycle cost analysis was carried out with a period of 20 years, 30 years, and 50 years. This is done to see how much the difference in costs between the two air conditioning systems. The amount of costs between the existing and alternative air conditioning systems in the first year can be seen in Table 13 and Table 14.

Table 13. Existing air conditioning system cost

Description	Cost (IDR)
Design	819,500,000
Investment	122,138,000,000
Operational	18,050,969,896
Maintenance	1,498,080,000

Table 14. Alternative air conditioning system cost

Description	Cost (IDR)
Design	819,500,000
Investment	114,173,000,000
Operational	13,152,096,756
Maintenance	1,445,040,000

The design, investment, operation and maintenance costs of the two systems are totaled over their entire life cycle of 20 years, 30 years, and 50 years. In calculating the life cycle cost analysis, all of these costs must be equalized to a value that is equivalent or equivalent to the current conditions, both investment costs and annual operating costs during the specified period. The equivalent value is represented as the present value (PV). PV value is defined as the present value of money for an amount of money in the future. This currency equalization is caused by a decrease in the value of the currency due to inflation over time into the future. There are several assumptions used in calculating the life cycle cost analysis, namely:

- Life cycle cost analysis is limited to design, investment, operational, and maintenance costs.
- An increase in electricity and water costs, which is 5% per year.
- Increase maintenance costs by 2% per year.
- Constant interest rate of 7.5%
- Analyzes were performed for cycle times of 20 years, 30 years, and 50 years.
- Constant rupiah exchange rate of IDR 15,000.00/USD

After being calculated using equation (2), different UPV factors are obtained for operational costs and maintenance costs. Obtained the UPV value for operational costs of 15.77 and for maintenance costs of 12.06 for a period of 20 years. Meanwhile, for a period of 30 years, the operational UPV value was 21.27 and the maintenance UPV was 14.71. For a period of 50 years, the operational UPV value was 29.05 and the maintenance UPV was 17.20. This value is the value of the UPV used in the analysis of life cycle costs with a period of 20 years, 30 years and 50 years. The UPV value is then multiplied by operational costs and maintenance costs to get the present value if the product is still operating for 20 years, 30 years, and 50 years. The breakdown of costs for the two air conditioning system can be seen in Table 15.

Table 15. Air conditioning life cycle costs

Description	Costs (IDR)
20 years period	
TES and Constant Flow Chiller	435,150,140,059
Magnetic Bearing Chiller and VSD	339,828,248,242
30 years period	
Tes and Constant Flow Chiller	541,700,386,487
Magnetic Bearing Chiller and VSD	415,995,136,400
50 years period	
TES and Constant Flow Chiller	690,535,151,478
Magnetic earing Chiller and VSD	521,915,598,761

4. Conclusions

The results of the calculation of *Trace 700* cooling load that occur in 1 year, the peak load that occurs is 12,594 kW with a total cooling energy of 44,617,405 kWh. While the peak load measurement results amounted to 12,299 kW with a total cooling energy of 45,733,180 kWh. The difference in the total cooling load between the calculated and measured results is 2.4%.

Based on the energy analysis and the cost of the central air conditioning system that uses a variable flow chiller, this is the best air conditioning system for Shopping Mall A buildings with an EUI value of 99 kWh/(m^2.year) and from a cost aspect, according to the life cycle cost analysis for a period of 20 years requires a total cost of 399,828,248,242 IDR, 415,994,136,400 IDR for a period of 30 years, and 521,915,598,761 IDR for a period of 50 years. The chiller used is a chiller that uses a magnetic bearing compressor equipped with a VSD. The number of chillers used is 4 units with a cooling capacity of 3,075 kW.

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