Energy Efficiency Techno-Economic Analysis on Cooling Equipment

DISCLAIMER

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This content solely demonstrates my technical expertise in energy efficiency, energy analysis and monitoring and does not represent nor is considered as an official report or representation of any past employer or client. This report only warrants for reading purposes.

Tables of Contents

List of Figures

List of Tables

Acronyms/Abbreviation

Variable Frequency Drives	**VFD**
Carbon Dioxide	**CO_2**
Watt	**W**
Kilowatt	**kW**
Air Conditioner	**AC**
Tonnage	**Tons**
Degrees Celsius	**^0C**
Kilowatt hour	**kWh**
Kenya Shilling	**Ksh**

EXECUTIVE SUMMARY

In the rising need for clean energy access across Africa and globally, energy efficiency is a key factor. Efficient appliances are a necessity and improve energy efficiency at high percentage. This applies across all energy consumers, from small house-hold to large industrial consumers. Energy-efficient appliances can be incorporated in our day to day lives.

Key Findings

- Energy-efficient practices range from behavioral factors (no-cost) to advanced cost intensive measures.
- To attain the clean energy access goal in Africa incorporation of energy-efficient cooling appliances ought to be available in the market.
- Energy-efficient measures play a huge role in CO_2 reduction.
- Data collection, analysis offers a proper economic analysis offering better stakeholder engagement and decision making.

Recommendations

- Regular preventive maintenance of cooling equipment should be implemented across.
- Incorporation of free cooling within high cooling-energy consumers in regions experiencing low ambient temperatures.
- Encourage the use of modern technology like Variable Frequency Drives (VFD) to drive cooling efficiency.

This analysis shows that with proper data allocation, there is not only an environmental impact but an economical one as well. Even as the drive for renewable energy hikes on, energy-efficiency will be incorporated seamlessly

1.Energy Efficiency – Cooling Equipment Maintenance

At Facility A, a high mission critical facility, requires constant cooling so as to maintain optimal operating conditions for its equipment. The cooling system should be well maintained and in full operation to avoid downtime and malfunctioning of the critical equipment

Facility's Current Situation

Cooling of outdoor unit with water flowing over it

During the facility assessment it was observed that figure outdoor AC unit was constantly cooled using running water. This method has several repercussions as follows:

a) Overtime the condenser coils could corrode.
b) The facility water is being utilized wrongly. This results to high water and electricity bills. The water pumps will have to supplement the water used to cool the AC outdoor unit

Figure 1: Outdoor AC unit cooled with running water

2. Energy Efficiency – Use of advanced modern Technology (VFD)

Variable Frequency Drives is a technology used in modern energy management and motor control. The VFDs enable the precise control of motor speed and torque by varying the frequency and voltage of the electrical supply.

Benefits of VFDs are:

1. Reduce energy consumption by operating compressors at tailored speed rather than at a full continuous capacity.
2. Improves process control by adjusting motor speeds to match process requirements

Facility B's Current Situation

Facility B has a total of three cooling units. The units operate **24 hours** every day, maintaining room temperatures between **25^{0}C - 26^{0}C.**

Figure 2: Facility B AC unit

Field Data Analysis

From figure 3 and 4, it can be observed that the cooling load trends are consistent for both facilities. Therefore, a VFD will regulate the cooling load profile. See tables at Annex 2.

Facility B

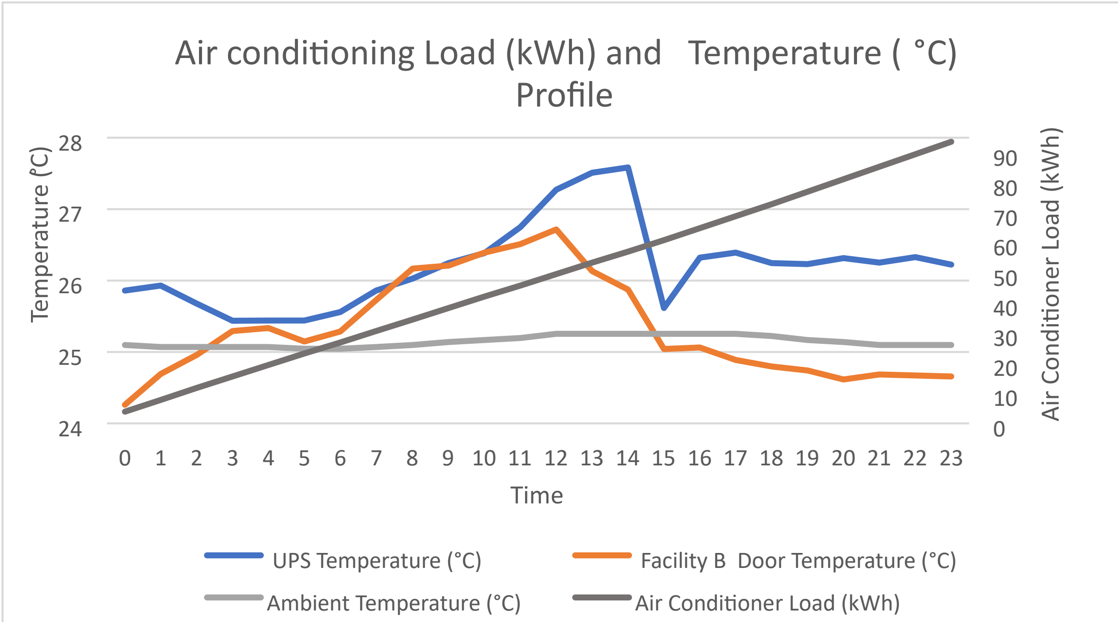

Figure 3:Temperature and AC Load Profile for Facility B

Facility C

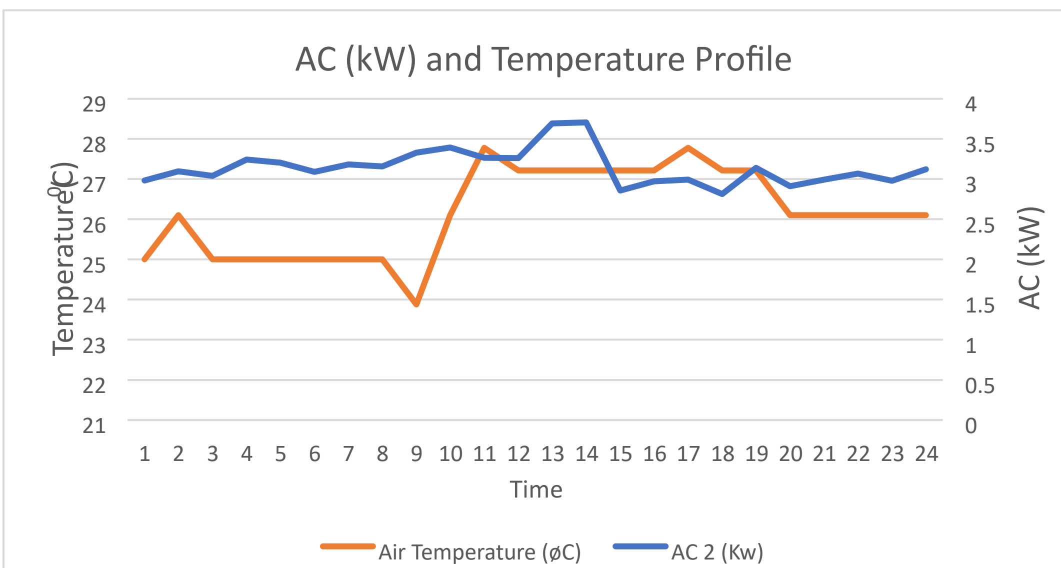

Figure 4:Facility C Temperature and cooling load profile

Energy, CO_2 and Economic Analysis

Facility B's Energy and CO_2 Savings

Using a VFD savings estimator calculator, VFD for the two AC units of 4,980 W split AC units will save 52,580.3 kWh and 17.35 tons of CO_2 annually.

Calculations are on Annex 2

Facility B's Economic Analysis

Figure 5, below, shows the break-even analysis for VFD for Facility B's Room Air conditioner unit

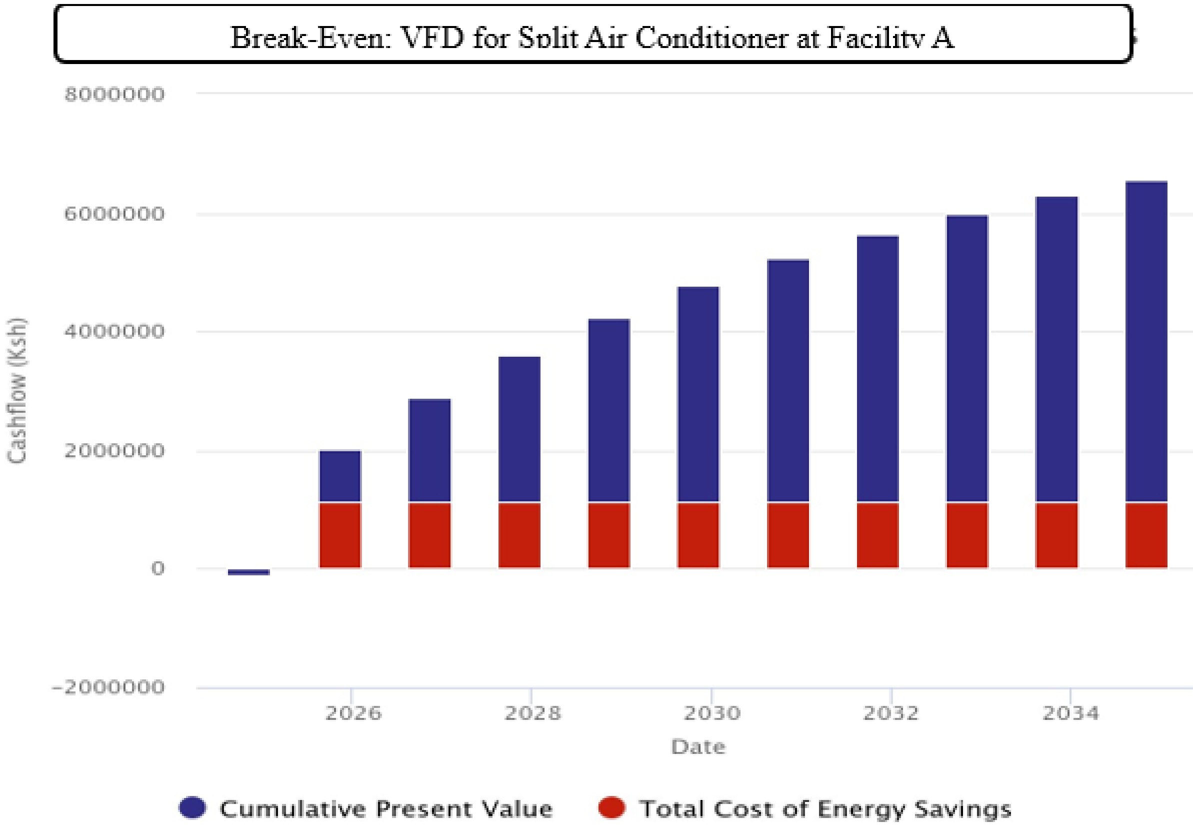

Figure 5:Facility B's VFD Cash Flow Analysis

Facility C's Current Situation

Facility B has a total of 10 split AC units at **6300 W**: 8 Type Y units serve the data rooms while 2 Type Z units serve the office space. The units operate **24 hours** every day, maintaining the facility's temperatures between **20^{0}C - 25^{0}C**

Figure 6: Some AC units at Facility C

Table 1:Facility B's VFD Economic Analysis

Investment Analysis	
Purchase of Equipment	Ksh 100,000.00
Total	Ksh 100,000.00
Savings Summary	
Annual CO_2 Emission Reduction	17.35 Tons
Annual Energy Saving (kWh)	52,580.30 kWh
Annual Cost of Savings (Ksh) at 20 Ksh/kWh	Ksh 1,051,606
Simple Payback Period (Years)	0.09 Years
Financial Summary	
Discounting Factor	16.00 %
Energy Savings Reduction	0.01 %
Net Present Value (10 Years, 16.00 % interest)	Ksh 5,419,759.003
Profitability Index	55.198

Facility C's Energy and CO_2 Savings

Using a VFD savings estimator calculator, VFD for the 10, 63000W split AC units will save 15,774 kWh and 5.21 tons of CO_2 annually. Calculations are on Annex 2.

Facility Cs Economic Analysis

Figure 5, below, shows the break-even analysis for VFD for Facility C's Room Air conditioner unit.

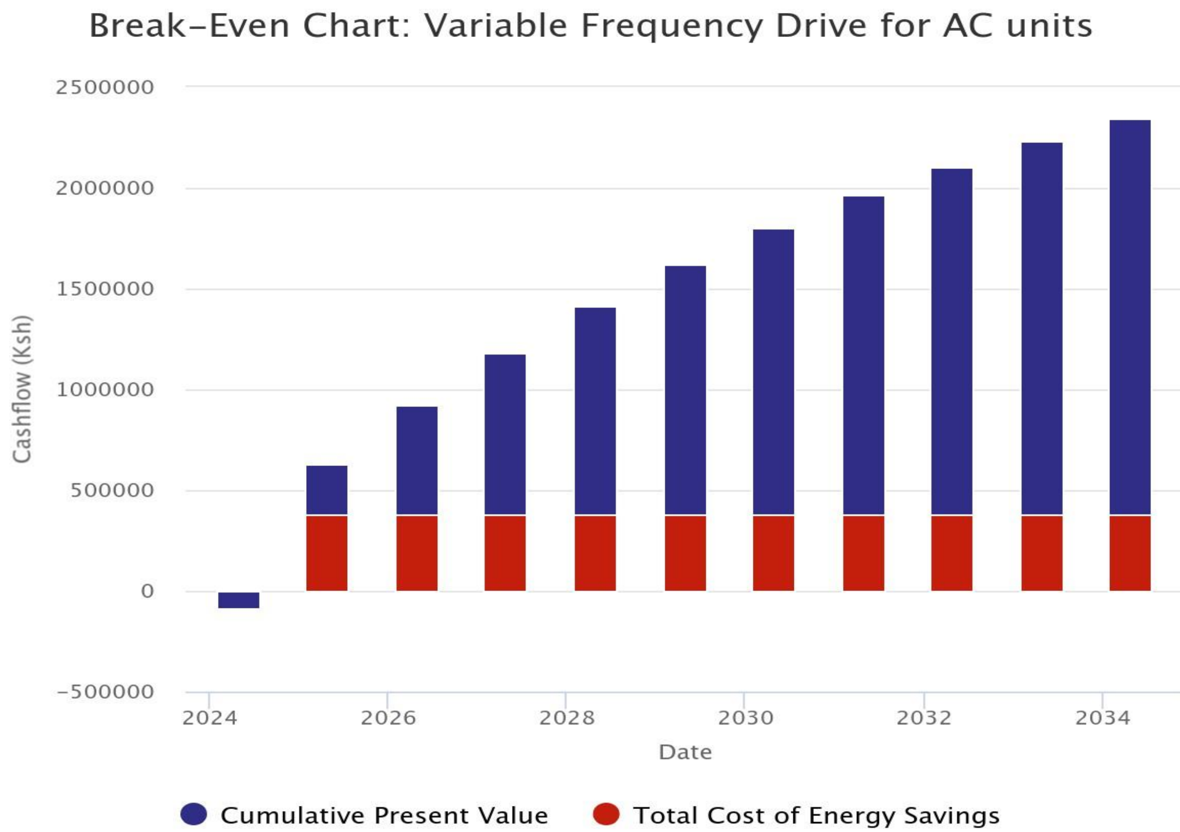

Figure 7:Facility C's VFD Cash Flow Analysis

Table 2: Facility C's Economic, Energy CO_2 and Economic

Investment Analysis	
Purchase of Equipment	Ksh 77,760.00
Installation and Commissioning	Ksh 7,776.00
Total	Ksh 85,536.00
Savings Summary	
Annual CO_2 Emission Reduction	5.21 Tons
Annual Energy Saving (kWh)	15,744.00 kWh
Annual Cost of Savings (Ksh) at 20 Ksh/kWh	Ksh 314,880
Simple Payback Period (Years)	0.23 Years
Financial Summary	
Discounting Factor	13.00%
Energy Savings Reduction	1.26 %
Net Present Value (10 Years, 16.00 % interest)	Ksh 1,965,285.00
Profitability Index	23.98

3. Energy Efficiency – Use of Direct Free Cooling

Air conditioning typically accounts for approximately 40% of total electricity consumption in data centers around the world [1]. This assertion draws form the crucial nature of climate control for data centers to ensure proper operation and long life for the relevant equipment.

However, cases exist where outside temperatures are low enough to provide proper cooling for these devices with lower electrical energy consumption. Experts call these approaches free cooling techniques [2]. A few approaches exist under the umbrella of free cooling. These include:

- Direct fresh air cooling which has the highest potential for free cooling
- Rotating wheel heat exchanger which can provide indirect free cooling
- Heat pipe integration with server tack backplates
- Water-based free cooling with an integrated chiller.

Facility's Current Situation

Current Situation at Facility D

The average demand trend for the cooling units stands at 22 kW with a peak demand of 24 kW.

Figure 8: AC Demand Trend at Facility D

The set temperature for facility D is between 20^0C - 25^0C. It is recommended that the facility performs free cooling as expounded in the filed data analysis section.

The cooling units used at Facility D are 6 closed control brand A units, 3 brand B closed control units and 7 split brand C AC units.

Figure 9:Cooling Unit at Facility D

Current Situation at Facility E

Facility E has a total of 19 split Air conditioning units installed around. Figure 10 shows one of the split units on site.

Figure 10:Cooling Unit at Facility C

The demand trend for the cooling units analyzed during the audit period, is as shown in Figure 12.

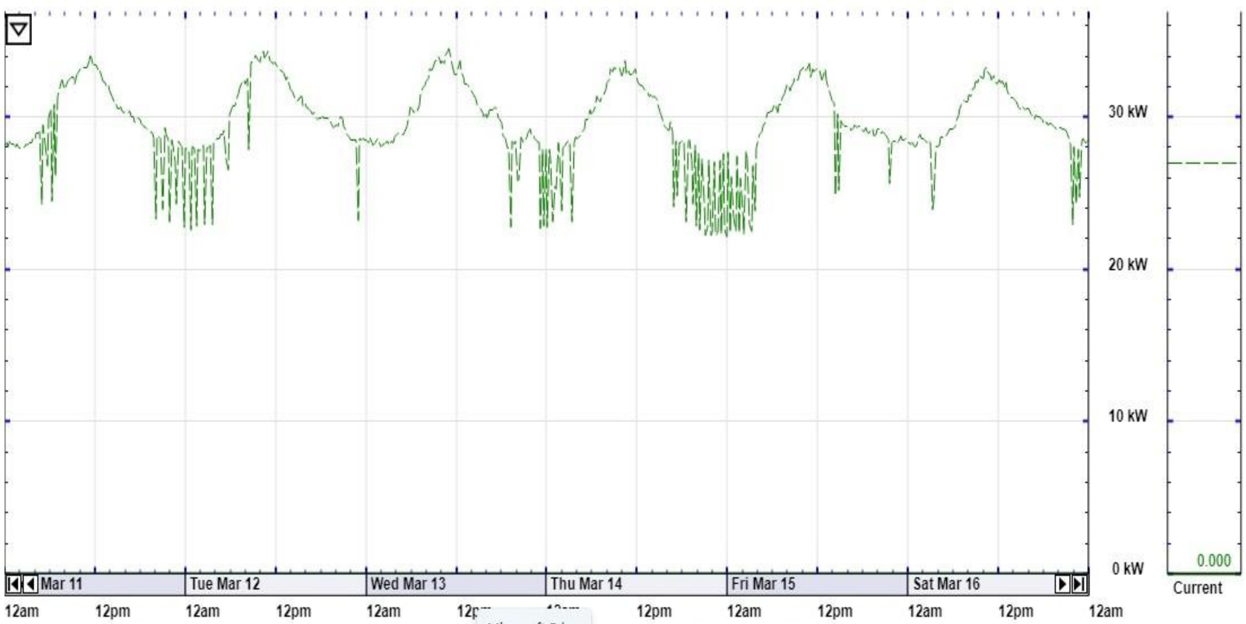

Figure 11:AC Demand Trend at Facility E

The average demand trend for the cooling units stands at 44 kW with a peak demand of 52 kW.

The set temperature for facility E is between 20^0C - 25^0C. It is recommended that the facility performs free cooling as expounded in the filed data analysis section.

Annex 2 provides data indicating monthly Facility D's region temperature profile of two years. The average temperature is 16 ^{0}C, maximum temperature 17.78 ^{0}C and minimum temperature 14.3^{0}C.

The data in Table 2, indicates that out of 168 hours in the 1 week, 105 hours qualifies for the condition of being below 20 ^{0}C. During this period, the free cooling can be used.

Table 3:Facility D's region Geographical Analysis

Ambient Temperature for 1 week	**Hours**
20 ^{0}C and below	105
Above 20 ^{0}C	63

The graph below shows the temperature profile at Facility D.

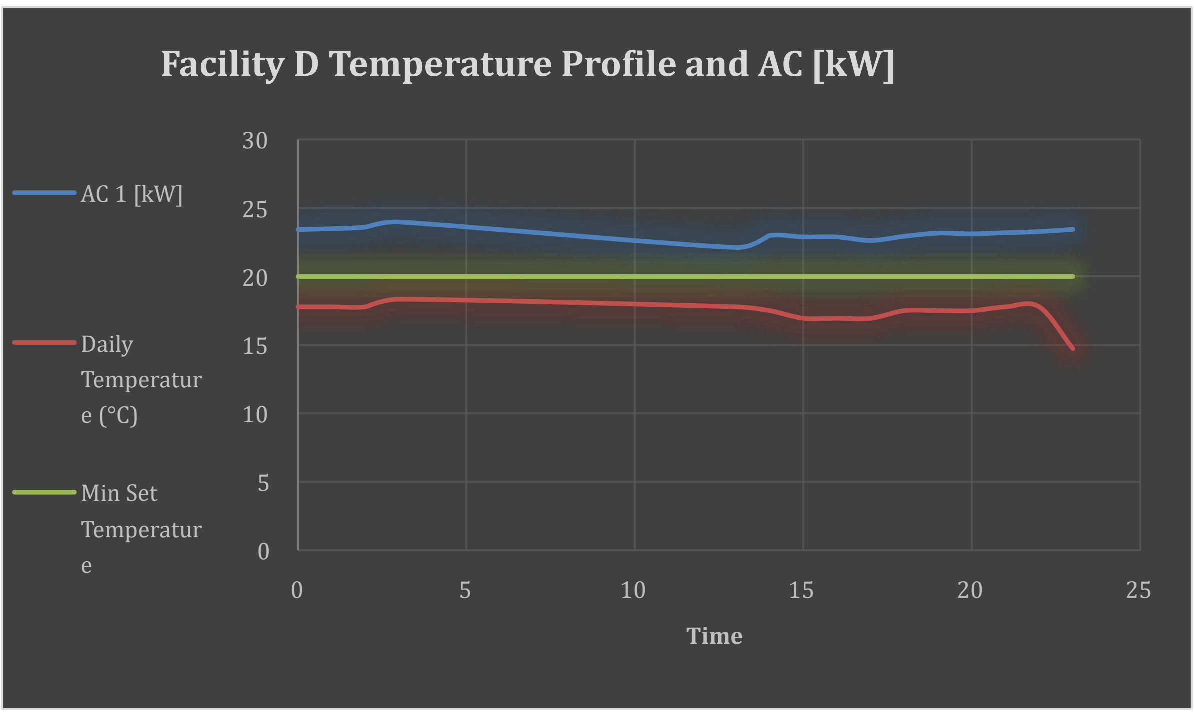

Figure 12: Geographical Temperature vs Desired facility D's ambient temperature

Annex 2, provides the calculations for the field analysis. As seen below, it can be observed that in a day the hours in which cooling demand is high is approximately 9 hours. Concluding the facility can utilize free cooling.

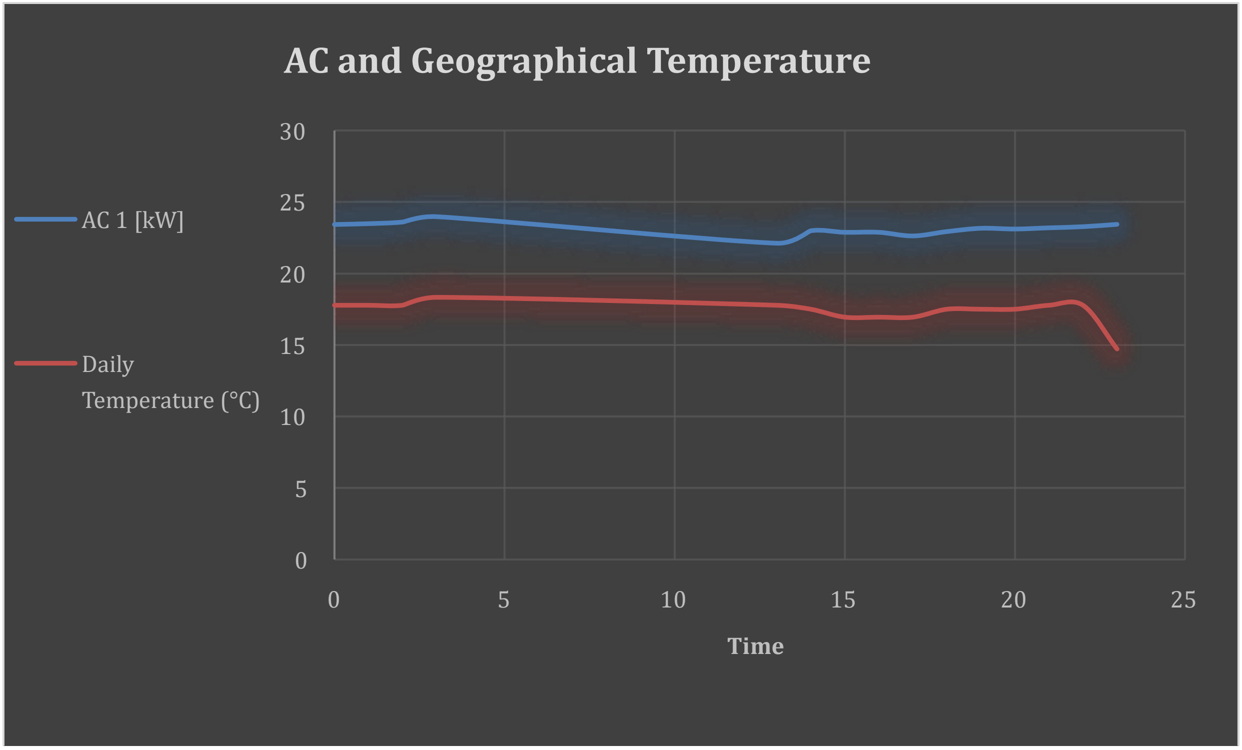

Figure 13:Facility D's AC cooling Demand and Hourly Geographical Temperature

Facility E

Annex 2 provides data indicating monthly facility E's region temperature profile of two years. The average temperature is 20^0 C, maximum temperature 18^0 C and minimum 22^0 C.

The data in table 4 indicates that out of 168 hours in the 1 week, 91 hours qualifies for the condition of being below 20 ^{0}C. During this period, the free cooling can be used

Table 4: Facility E's region Geographical Analysis

Ambient Temperature for 1 week	**Hours**
20 ^{0}C and below	91
Above 20 ^{0}C	77

The graph below shows the temperature profile at Facility E.

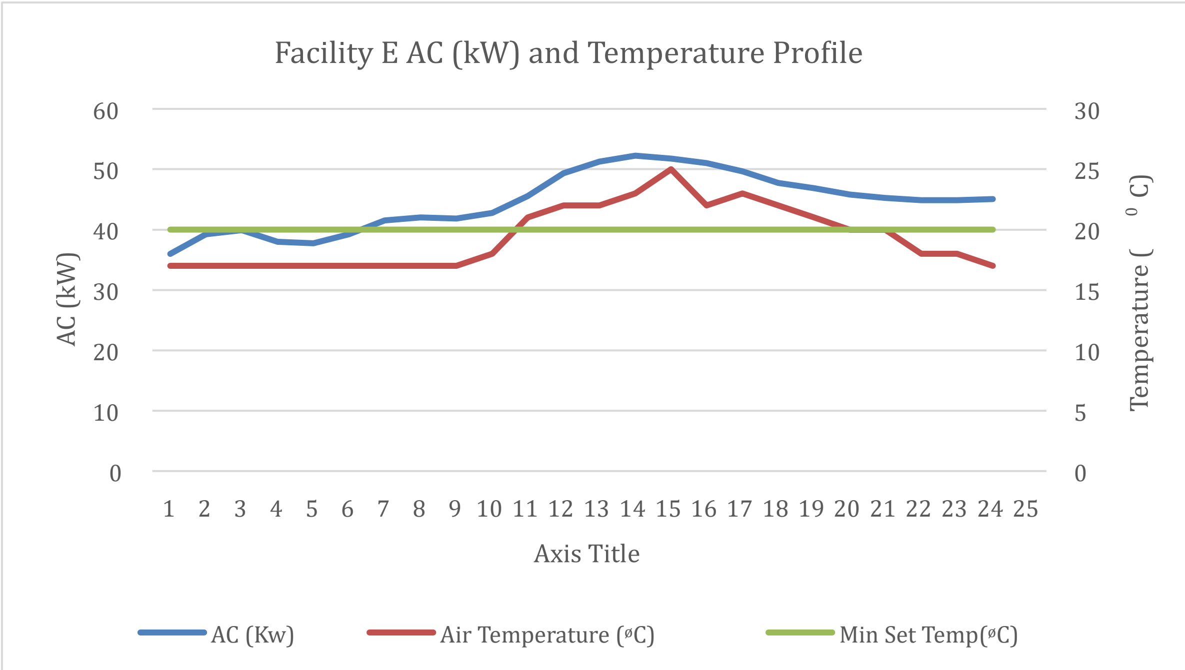

Figure 14: Facility E's Geographical Temperature vs Desired facility ambient temperature

Facility E can utilize free cooling units as replacements of the 19 split units. This will switch off or slow down the cooling units. Particularly at night and during the day when the temperature is below 20 ^{0}C.

Annex 2 provides the calculations for the field analysis

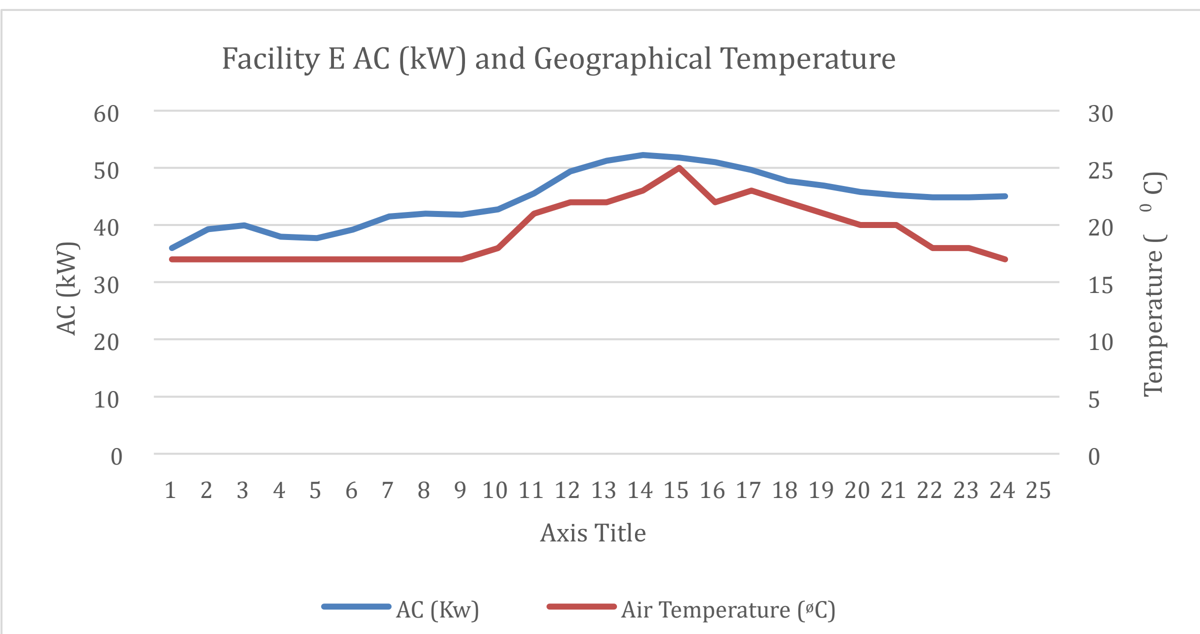

Figure 15: Facility E's AC cooling Demand and Hourly Geographical Temperature

In the figure below, it can be observed that in a day the hours in which cooling demand is high is approximately 13 hours. Therefore, the facility can utilize free cooling.

Energy, CO_2 and Economic Impact Analysis

Facility D

From the logged data, the current total energy consumed for cooling is as follows in Table 5.

Table 5:Facility D's Current Energy Cost and Demand

Period	**Cooling Demand (kWh)**	**Cost at 20.00 (Ksh/kWh)**
Daily	538	Ksh 10,760.00
Monthly	16,140	Ksh 322,800.00
Annually	196,370	Ksh 3,927,400.00

From Table 3, 105 hours in a week the temperature is below 20 ^{0}C. If the facility utilizes free cooling. The savings will be as follows:

Table 6: Facility D Free Cooling Energy and Cost Savings

Period	**Energy Saved (kWh)**	**Cost at 20.00 (Ksh/kWh)**
Daily	336.25	Ksh 6,725.00
Monthly	10,088	Ksh 201,760.00
Annually	122,731	Ksh 2,454,620

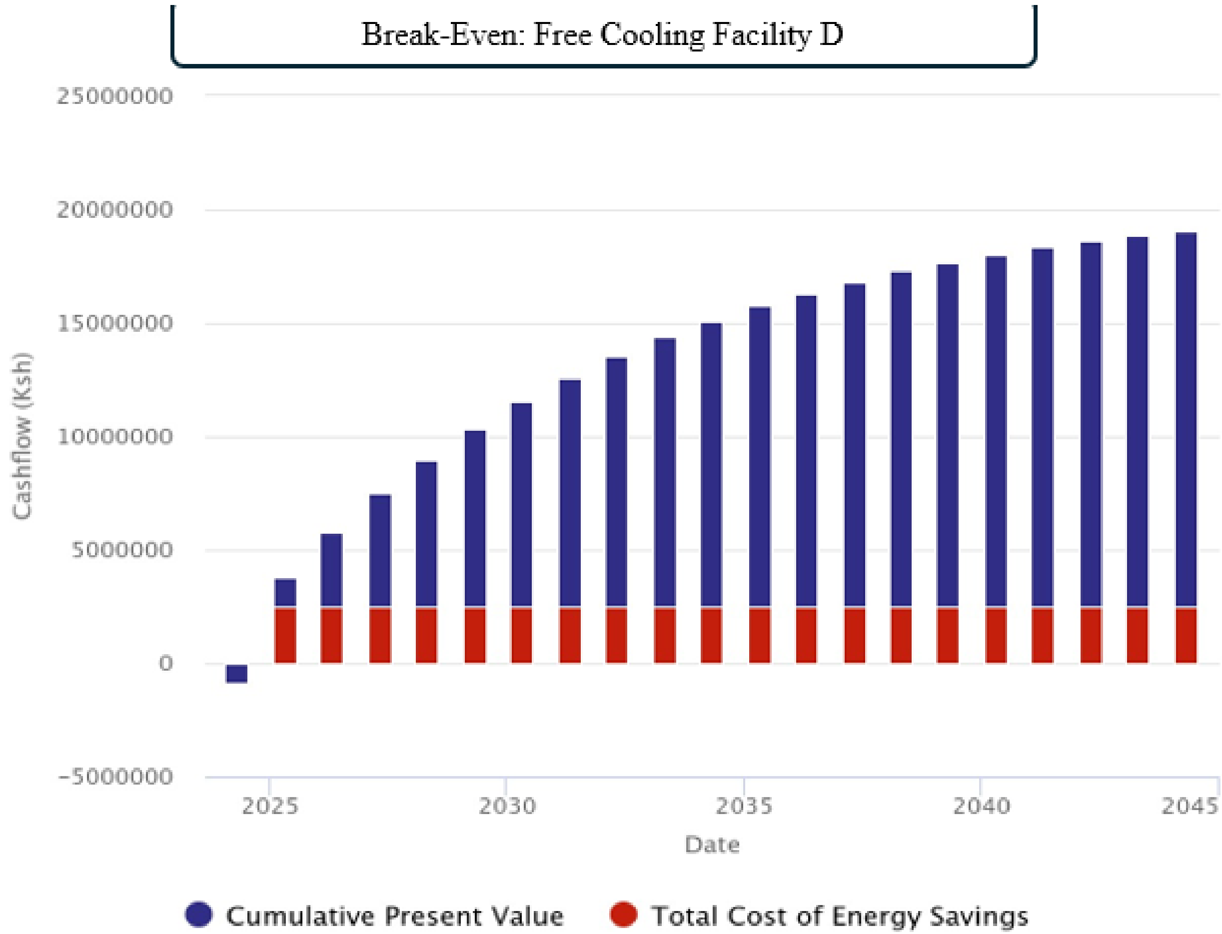

Figure 16: Facility D's Cash Flow Analysis

Table 7: Facility D Economic, Energy and CO_2 Analysis

Investment Analysis	
Purchase of Equipment	Ksh 807,000.00
Installation and Commissioning	Ksh 80,700.00
Total	Ksh 887,700.00
Savings Summary	
Annual CO_2 Emission Reduction	40.50 Tons
Annual Energy Saving (kWh)	122,731.00 kWh
Annual Cost of Savings (Ksh) at 20.00 Ksh/kWh	Ksh 2,454,620.00
Simple Payback Period (Years)	0.36 Years
Financial Summary	
Discounting Factor	13.00%
Energy Savings Reduction	6.02%
Net Present Value (10 Years, 16.00 % interest)	Ksh 16,596,799.059
Profitability Index	19.696

Facility E

From the logged data, the current total energy consumed for cooling is as follows in Table 8. Calculations are at Annex 2.

Table 8: Facility E's Current Energy Cost and Demand

Period	Cooling Demand (kWh)	Cost at 20.00 (Ksh/kWh)
Daily	1028.9	Ksh 20,578.00
Monthly	30,867	Ksh 617,340
Annually	375,549	Ksh 7,510,980

From Table 4, 91 hours in a week the temperature is below 20 ^{0}C. If the facility utilizes free cooling. The savings will be as follows:

Table 9: Facility E's Free Cooling Energy and Cost Savings

Period	Energy Saved (kWh)	Cost at 20.00 (Ksh/kWh)
Daily	557.32	Ksh 11,146.40
Monthly	16,719.6	Ksh 334,392.00
Annually	203,422	Ksh 4,068,440.00

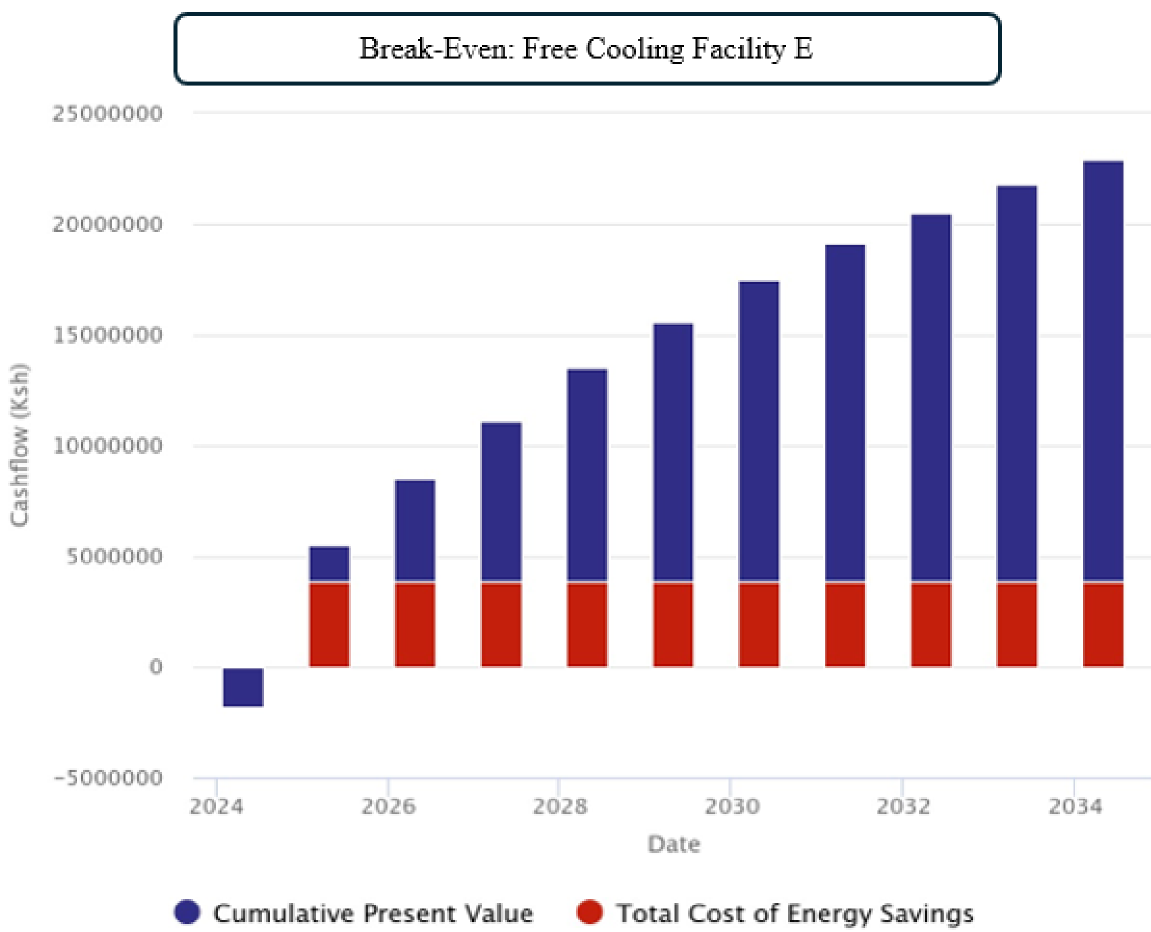

Figure 17: Facility E's Cash Flow Analysis

The analysis shows that the simple payback period will be 0.46 years.

Table 10: Facility E Economic, Energy and CO_2 Analysis

Investment Analysis	
Purchase of Equipment	Ksh 1,614,000.00
Installation and Commissioning	Ksh 161,400.00
Total	Ksh 1,775,400.00
Savings Summary	
Annual CO_2 Emission Reduction	67.13 Tons
Annual Energy Saving (kWh)	203,422.00 kWh
Annual Cost of Savings (Ksh) at 20.00 Ksh/kWh	Ksh 4,068,440
Simple Payback Period (Years)	0.46 Years
Financial Summary	
Discounting Factor	13.00%
Energy Savings Reduction	0.52 %
Net Present Value (10 Years, 16.00 % interest)	Ksh 19,108,823.323
Profitability Index	11.763

ANNEX 1 – Methodology and Data Collection Tools

To identify energy-efficient measures for HVAC equipment, an accurate analysis of the individual performance and effectiveness of the equipment was paramount.
The following tools and technology were used in conjunction to software systems and applications for both data collection and analysis.

1. Power Energy Logger (PEL 103)

Used to log the actual load at distribution boards.
The PEL 103 software was used to perform a load profile analysis.

2. Real time energy meter

Used to log loads and obtain the power consumption at distribution boards
The internal software was used to perform load profile analysis.

3. HOBO

The device was used to measure room temperature and humidity level.
The HOBO software was used to operate the HOBO device, develop load profiles and collect data.

4. Clamp meter

Used to confirm accuracy of data logged.

The data was collected for an entire week to obtain an entire profile of weekdays to weekends.

ANNEX 2 – Data Analysis

Variable Frequency Drive Analysis

Table 11: Facility B VFD Savings Calculation

Step 1	Converting motor Horsepower to Kw							
	13.41	HP x .746 =	10.00386	Kw_A				
Step 2	Multiply the Adjustable Frequency Drive Power Ratio (from table below) times Kw_A from Step 1.							
	0.28	Ratio x	10.00386	Kw_A =	2.801081	Kw_B (using VFD)		
	0.28							
Step 3	Multiply the Power Ratio of the presently employed control (see below) times Kw_A from Step 1.							
	0.88	Ratio x	10.00386	Kw_A =	8.803397	Kw_C (method now employed)		
Step 4	Subtract Step 2 Kw_B from Step 3 Kw_C.							
	8.803397	Kw_C -	2.801081	Kw_B =	6.002316	Kw_D (savings using VFD)		
Step 5	Multiply Step 4 KW_D savings, times hours per year of operation, times cost of electricity per KwH.							
	6.002316	Kw_D x	8760	Hrs x K	21.72	Ksh/KwH =	1142044	VFD Annual Calculated Savings

Table 12: Facility B VFD Savings Calculation

Converting motor Horsepower to Kw							
4.023	HP x .746 =	3.0012	Kw_A				
Multiply the Adjustable Frequency Drive Power Ratio (from table below) times Kw_A from Step 1.							
0.28	Ratio x	3.0012	Kw_A =	0.8403	Kw_B (using VFD)		
0.28							
Multiply the Power Ratio of the presently employed control (see below) times Kw_A from Step 1.							
0.88	Ratio x	3.0012	Kw_A =	2.641	Kw_C (method now employed)		
Subtract Step 2 Kw_B from Step 3 Kw_C.							
2.641	Kw_C -	0.8403	Kw_B =	1.8007	Kw_D (savings using VFD)		
Multiply Step 4 KW_D savings, times hours per year of operation, times cost of electricity per KwH.							
1.8007	Kw_D x	8760	Hrs x Ksl	23.96	Ksh/KwH = Ksh	377945	VFD Annual Calculated Saving

Table 13:Control Systems method

Fans at 60% of maximum flow	
Ratio	**Flow Control Method**
0.28	Variable Frequency Drive
0.62	Inlet Guide Vane
0.88	Outlet Damper
0.88	Fan Curve
1.00	Bypass Damper

Free Cooling Analysis

Facility D monthly temperature profile

Table 14 shows the monthly temperature profile: Average temperature is 16^0 C, maximum temperature 17.78^0 C and minimum 14.3^0 C.

Table 14: Facility D's region monthly temperature profile

Month	Air temperature - average (°C)
Jun-21	15.10
Jul-21	14.30
Aug-21	15.20
Sep-21	16.37
Oct-21	17.04
Nov-21	17.05
Dec-21	15.87
Jan-22	16.15
Feb-22	17.58
Mar-22	17.78
Apr-22	17.23
May-22	16.60
Jun-22	15.28
Jul-22	14.64
Aug-22	14.80

Sep-22	15.19
Oct-22	15.83
Nov-22	15.77
Dec-22	15.74
Jan-23	15.53
Feb-23	17.20
Mar-23	17.30
Apr-23	16.38
May-23	16.08
Jun-23	15.49

Facility D Calculation, hourly AC Demand and temperature profile

Table 15, shows the calculations for obtaining current energy consumed and energy saved when temperature is below 20^0 C through the use of free cooling.

Table 15: Facility D's Temperature and AC cooling load hourly data

Time	AC 1 [kW]	Air Temperature (ᶲC)	Min Set Temperature
0	23.42899	18	20
1	23.48726	18	20
2	23.60048	18	20
3	23.97493	18	20
4	23.8915	19	20
5	23.78193	19	20
6	24.19434	20	20
7	24.72393	19	20
8	24.57286	19	20
9	22.52924	19	20
10	24.3415	19	20

11	24.05339	19	20
12	23.22801	19	20
13	22.11773	18	20
14	22.98947	18	20
15	22.88266	17	20
16	22.88372	17	20
17	22.62736	17	20
18	22.93417	18	20
19	23.16401	18	20
20	23.11185	18	20
21	23.19607	18	20
22	23.27483	18	20
23	23.43919	15	20

Using the trapezoidal formula:

$$\int_{T0}^{T24} ACdT = \frac{1}{2} \times h\ ((2(a+b) + (a+b))$$

Where:

$$h = \frac{T24 - T0}{24}$$

Calculation:

$$h = \frac{24 - 0}{24} = 1$$

$$Energy = \frac{1}{2} \times 1\{(2(515.561) + (23.42899 + 23.43919)\}$$

Energy Used = 538 kWh per day

Monthly Energy = 538 × 30 = 16,140 kWh

Monthly Energy = 538 × 365 = 196,370 kWh

Calculation of hours where temperature is below 20 ^{0}C. From Table 7.2, temperature below 20 ^{0}C is 15 hours in a day out of 24 hours.

$$15hrs \times 7 = 105$$

$$24 - 15 = 9$$

$$9 \times 7 = 63$$

Total Hours = 105+63 = 168 hours

Energy saved when temperature is below 20 ^{0}C:

$$\frac{105}{168} \times 538 = 336.25\ kWh$$

Monthly Energy Saved = 336.25 × 30 = 10,088 kWh

Annual Energy Saved = 336.25 × 365 = 122,731 kWh

Facility E Region monthly temperature profile

Table 16, shows the monthly temperature profile: Average temperature is 20^0 C, maximum temperature 18^0 C and minimum 22^0 C.

Table 16: Facility E monthly temperature profile

Month	Air temperature - average (°C)
Jun-21	19.09
Jul-21	18.87
Aug-21	18.28
Sep-21	19.42
Oct-21	20.56

Nov-21	21.64
Dec-21	21.47
Jan-22	19.64
Feb-22	20.15
Mar-22	21.70
Apr-22	22.84
May-22	21.36
Jun-22	20.52
Jul-22	19.27
Aug-22	18.45
Sep-22	18.79
Oct-22	19.50
Nov-22	21.12
Dec-22	20.17
Jan-23	20.32
Feb-23	20.63
Mar-23	22.49
Apr-23	21.83
May-23	20.04
Jun-23	20.10

Facility E Calculation, hourly AC Demand and temperature profile

Table 17, shows the calculations for obtaining current energy consumed and energy saved when temperature is below 20^0 C through the use of free cooling.

Table 17:Facility E Temperature and AC cooling load hourly data

Time	AC (Kw)	Air Temperature (ºC)	Min Set Temp(ºC)
0	35.97726	17	20
1	39.25264	17	20
2	39.92976	17	20
3	37.98843	17	20
4	37.72976	17	20
5	39.21488	17	20
6	41.50796	17	20
7	41.99532	17	20
8	41.80225	17	20
9	42.7527	18	20
10	45.5287	21	20
11	49.35688	22	20
12	51.23682	22	20
13	52.24452	23	20
14	51.785	25	20
15	51.02252	22	20
16	49.63076	23	20
17	47.70885	22	20
18	46.86791	21	20
19	45.80002	20	20
20	45.22886	20	20

21	**44.86894**	**18**	**20**
22	**44.86103**	**18**	**20**
23	**45.03103**	**17**	**20**

Using the trapezoidal formula:

$$\int_{T0}^{T24} ACdT = \frac{1}{2} \times h\ ((2(a + b) + (a + b))$$

Where:

$$h = \frac{T24 - T0}{24}$$

Calculation:

$$h = \frac{24 - 0}{24} = 1$$

$$Energy = \frac{1}{2} \times 1\{(2(988.3145) + (35.97726 + 45.03103)\}$$

Energy Used = 1028.9 kWh per day

Monthly Energy = 1028.9 × 30 = 30,867kWh

Monthly Energy = 1028.9 × 365 = 375,549

Calculation of hours where temperature is below 20 ^{0}C. From Table 7.2, temperature below 20 ^{0}C is 13 hours in a day out of 24 hours.

$$13hrs \times 7 = 91$$
$$24 - 13 = 11$$
$$11 \times 7 = 77$$

Total Hours = 91+ 77 = 168 hours

Energy saved when temperature is below 20 ^{0}C:

$$\frac{91}{168} \times 1028.9 = 557.32\ kWh$$

Monthly Energy Saved = 557.32 × 30 = 16,719.6

Annual Energy Saved = 557.32 × 365 = 203,422kW.

Bibliography

[1] Z. W. a. M. Y. Zhang, Free cooling technologies for data centers: Energy Saving Mechanism and Applicatons, Energy Procedia, 2017.

[2] B. W. a. O. Y.Yang, Air Conditoning System Design using Free Cooling Technology and Running Mode of a Data Center in Jinan, Procedia Engineering, 2017.