Evaluation of Free Cooling Technique at the Telecom Cell Site in Ghana

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Abstract

Air Conditioning (AC) is the primary source of cooling in a typical Cell Site (CS) although it consumes a large quantity of electricity. Excessive energy consumption due to air conditioning increases the operational expenses of telecommunication companies. Therefore, network operators have attempted various techniques to reduce the exorbitant cost of a cell site's high-power consumption. A Free Cooling (FC) System is one such approach. This paper uses computer modeling to investigate how the FC System will function at a CS in Ghana for 12 hours (from 6 pm to 6 am). A shelter with dimensions of 3 m × 2.47 m × 2.45 m (L × B × H) is used in the study, with three window positioning scenarios (different window heights), namely: (a) an inlet window 0.5 m high, and the outlet window 1.5 m high, (b) an inlet window and outlet window both 1.0 m high and (c) an inlet window 1.5 m high, and the outlet window 0.5 m high. The analysis revealed that the shelter with inlet and outlet windows at the same height has the most efficient heat dissipation potential. Furthermore, at a set temperature threshold of 25 °C, the annual percentage share for the two operating modes is approximately 67% for AC and 33% for FC in 2020, 76% for AC and 24% for FC in 2021, and 61% for AC and 39% for FC in 2022. However, when the set temperature threshold is increased from 25 °C to 30 °C, the annual percentage share is approximately 0.01% for AC

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and 99.9% for FC in 2020, 0% for AC and 100% for FC in 2021, and 1% for AC and 99% for FC in 2022. Thus, the proportion of free cooling increases as the set temperature threshold is raised, indicating potential energy savings. It could be concluded that in Ghana, installing a cell site with an FC system and setting the temperature of its control system to 30 °C or higher will result in significant energy savings.

Keywords: Air Conditioning, Airflow Pattern, Cell Site, Cooling Load Factor, Cubic Feet Per Minute, Energy Savings, Free Cooling, Energy Savings, Free Cooling System, Indoor Set Temperature, Shelter Ambient Temperatures, Shelter Indoor Temperatures, Total Cooling Load

Introduction

Globally, the number of mobile phones and data usage has increased. According to Bhondge et al. (2016), there are approximately 12 billion cellular network subscribers across the world. In Ghana, as of January 2021, the total number of mobile connections had gotten to 41.69 million (Kemp, 2021). The increase in this sector has made mobile operators invest massively in their infrastructure for better service delivery. These infrastructures include the deployment of Cell Sites (CS) to ensure constant access to mobile networks and guaranteed Quality-of-Service (QoS) to network subscribers (Ayang et al., 2016). A Cell Site (CS) consists of the Baseband Unit (BBU), the Microwave Transmission (TXm) equipment, generators, masts, Backup Batteries (BB), shelters, the power conversion system, and other auxiliary electronic equipment.

The BBU, the TXm equipment, BB, and other electronic equipment generate large amounts of heat, so cooling systems are crucially needed to maintain the good performance of these units (Haghighi, 2016). The cooling systems help maintain a low-temperature range to deliver quality service. This equipment is either housed in outdoor cabinets or shelters. Outdoor cabinets employ fans to maintain the required temperature. Conversely, air conditioning (AC) systems are installed in shelters to keep them cool and maintain a high level of service quality.

In Ghana, major telecomunication backbone sites (the nerve centers of a high speed network) have their BBU, TXm units, and other auxiliary electronic equipment located in a shelter. These shelters are fitted with AC systems to dissipate the heat generated and maintain a constant temperature of about 25°C - 28°C.

Unfortunately, many electronic units found in the shelters are cooled unnecessarily as the AC systems run all year round and do not discriminate between the equipment that generates heat and those that do not. The impact of the AC systems running all year round on power consumption is so high

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that it negatively affects the operating cost of the network operators. To reduce this massive amount of high-power consumption, network operators have evaluated a variety of different techniques. The techniques include modifying building envelopes, upgrading AC systems, installing monitoring/control systems, improving indoor airflow delivery, Free Cooling (FC), utilising renewable energy, and enhancing energy efficiency (Haghighi, 2015).

This study examines the use of an FC technique as an alternative to an AC system for cooling equipment in a cell site shelter, then conducts a techno-economic analysis of the power consumption associated with employing the free cooling technique.

FC system is made up of an inlet window and outlet window in an enclosure, a Fan Group (FG) mounted on the windows, sensors, and a control unit. It involves cool ambient air being transported into the enclosure and the heat removed by an exhaust system. Compared with traditional coolers, this system can save energy. Unfortunately, active cooling is also needed in certain cases during times of extreme heat, as the fan group may not adequately cool the shelter. The simplest option will be to use a mixture of FC and AC units. It might be an expensive solution based on installation costs; however, it promises a high level of investment after the next few years of service by minimizing power prices. The intention is to operate an FC system as often as possible to the operation of the AC unit. This requires that the installed equipment operate at high temperatures (Ayang et al., 2016).

1.1 Review of Related Works

Many researchers have done valuable work to reduce the consumption of AC systems in CSs. Some of the work includes: Ayang et al. (2016) proposed a power usage model and conducted energy audits in selected telecom CSs where they categorized CSs based on their monthly power consumption in the Sahel area of Cameroon. The model savings were up to 17% for the Cameroon Radio Television (CRTV) cell site, about 24.4% for the Missinguileo cell site, and about 14.5% for the Maroua market cell site. Thermosyphon and its integrated system were analyzed by Zhang et al. (2018), who found loop thermosyphons more suitable for installation and suggested exploring the use of CO_2 as an alternative working fluid for experiment protection. In a study conducted by Haghighi (2016), free cooling was utilised in two distinct areas: dual-zone and single-zone. They observe that setting the internal temperature of the Free Cooling (FC) to 25°C can meet 21%-94% of the total cooling needs, depending on the region and methodology chosen. High indoor humidity can shorten the life cycle of IT/electronic devices in CS shelters, leading some operators to avoid using FC. Haghighi (2017b) proposed an analytical model to reduce humidity in outside air for FC. The model suggests that increasing the temperature of highly humid air can

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decrease humidity to 85% with low risk. Methods include mixing low-temperature outside air with warm shelter air, adjusting FC unit volume flow rate, and upgrading telecommunication equipment. In 2018, an air-cooled CS in Helsinki-Finland was transformed into a liquid-cooled telecommunication equipment, it resulted in 70% annual energy savings and an 80% reduction in CO_2 emissions compared to air cooling, with the potential to use 80% of total dissipated energy for heating (Huttunen et al., 2020). The study by Gözcü and Erden (2019), examines the energy consumption of data centres using free cooling systems like the direct air-side economizer , indirect air-side economizer , indirect evaporative cooler , indirect water-side economizer integrated with the existing cooling infrastructure of a typical 1 MW IT load centres. Results showed that indirect evaporative cooler IEC had the most energy-saving potential, reducing chiller hours by less than 10% across Turkey and by 1% in half of the cities studied. Zhou et al. (2013) developed an energy utilization model for indoor thermal building specifications based on a combined AC and thermosyphon heat exchanger device. Approximately 87% of Chinese cities are in cool and mild climates, making thermosyphon heat exchangers ideal for usage and saving more than 30% of energy annually.

A solar chimney with an earth-air heat exchanger is introduced in a paper by Dokkar et al. (2016), which suggested that rising inlet flow contributes greatly to the cooling change. Their findings showed a substantial decrease in energy usage due primarily to a decreased cooling energy. Venkatesan and Ramachandraiah (2016) modelled and simulated a CS shelter envelope with EnergyPlus for energy efficiency. In comparing the energy consumption during simulations, the proposed EnergyPlus model-based control had a saving of about 2.69% and 1.37%, respectively, for fixed and variable-capacity AC over the model. The overall energy saving was increased from 12.04% to 14.41% by using the EnergyPlus model-based control proposed. Petraglia et al. (2015) also investigated the energy consumption of a CS for mobile communication as well as conditioning functions. The investigation suggested annual energy savings between 10% and 30%.

Haghighi and Ghanbarpour (2016) proposed a hybrid cooling system that circulates indoor air through a closed loop with minimal interaction with outdoor air. The system can operate in three modes: AC, thermosiphon (TS), and dual (DU). The model was used to estimate the share of each operating mode for a typical base station in four locations with a set point temperature adjusted to 25 °C. Their results revealed that by increasing the set point temperature, the share of AC mode was reduced while the share of thermosiphon and the dual mode was increased. Silva et al. (2017) analyzed the thermal performance of an Outdoor Telecommunication Cabinet (OTC) using DesignBuilder. The simulation results showed that the model predicted air temperature closer to actual measurements, especially when weather data

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was similar. They observed that mechanical ventilation effectively extracted heat, but increased airflow rate did not significantly decrease temperature. Radiant properties and cabinet location also impacted performance.

1.2 Power Usage and Energy Conservation Strategies

According to Fabbri et al. (2011), the radio operators and AC are the primary energy consumers in a CS, so reducing their usage will reduce the CS's overall consumption. Reducing the amount of time AC is used for cooling is thus a potential method for reducing the power consumption of a CS. FG (FG)

1.3 Cooling Loads Calculation

The cooling and heating load calculations are normally made during Heating, Ventilating, and Air Conditioning (HVAC) system sizing. Figure 1 is a schematic diagram that expresses the necessary cooling load, Q_{COOL}, in a shelter. The cooling and heating load is expressed in Equation 1 (Haghighi, 2015) as:

$$Q_{COOL} = Q_{IT} + Q_{EVN} + Q_{SOL} + Q_{INF} \quad (1)$$

where, Q_{IT} = heat emission from indoor electrical appliances
Q_{EVN} = conduction and convection across the ceiling and walls of the shelter
Q_{SOL} = solar radiation absorption on the walls and roof of the shelter
Q_{INF} = infiltration of warm outdoor air through openings in a shelter

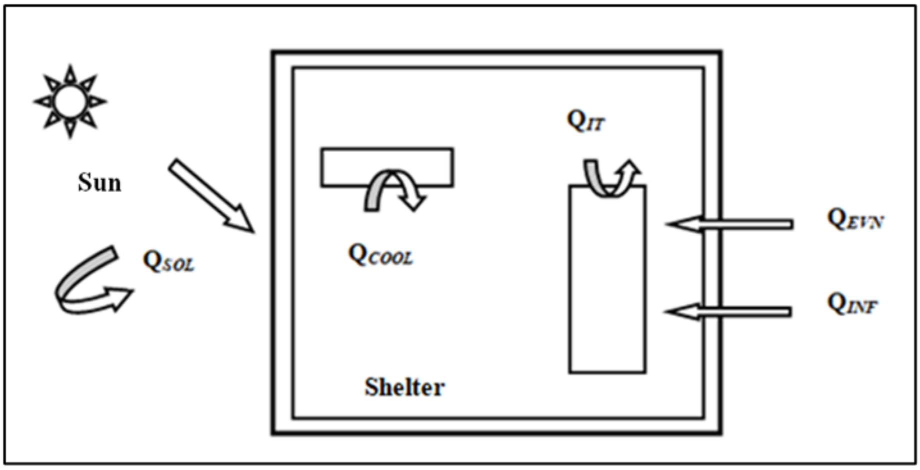

Figure 1: Key Thermal resources in a typical shelter of a CS

From Equation 1, the overall cooling load of a shelter can be split between an FC and an AC based on the following assumptions: if $T_{SET} \leq T_O$,

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the AC system works, and if $T_{SET} > T_O$, then the FC system takes over (Haghighi, 2017a). T_{SET} and T_O represent the indoor and outdoor set temperatures, respectively.

1.4 Energy Savings

The yearly Energy Savings (ES) can also be obtained by using Equation (2) (Zhou et al., 2013):

$$ES = C_1 - C_2 \quad (2)$$

where, ES = yearly savings on electricity (kWh/yr)
C_1 = yearly energy consumption with AC (kWh/yr)
C_2 = yearly energy consumption with the FG (kWh/yr)

1.5 Computer Simulations

Computer simulations are used to test the performance of proposed solutions before actual implementation. They are computer-based mathematical modelling programs that are used to predict physical system patterns. The veracity of a computer simulation result can be determined by comparing it to the actual results that it seeks to predict. It aids in experimenting without disrupting existing systems, testing concepts before installation, detecting unexpected problems or glitches in a system, and so on. Computer simulations were used to test the performance of the proposed FC system in this work.

1.6 Electronic Monitoring and Control

For the system to work an electronic monitoring and control system monitors the internal and external temperatures using two temperature probes then with a preset temperature range set in the control unit, switches the cooling of the shelter between the FC and the AC.

2. Methodology

An AC is typically used to dissipate the heat in a shelter in a CS. However, it is one of the major contributors to energy consumption. A combined AC and FC system is one feasible approach for reducing this high energy use. This goal can be achieved if the FC mode is employed as often as possible, decreasing active air conditioning time to the absolute minimum. For FC to be particularly effective, installed equipment must have a wide range of operating temperatures. Conversely, active regulation and active air cooling are required more frequently when the equipment's working temperature range is narrow. The success of the FC system depends on the direction of airflow through the shelter and the uniformity of air temperature in the shelter (Schmidt and Shaukatullah, 2002).

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2.1 Climate conditions of Ghana and location of adopted CS

Ghana has a tropical climate, with two seasons (the dry and rainy seasons). The rainy season lasts from May to September in the Northern part, from April to October in the Central part, and from April to November in the South. Ghana's average daily temperature range is between 25 ºC and 35 ºC. This study is conducted in Ejisu in the Ejisu-Juaben Municipal District in the Ashanti Region of Ghana. Ejisu has an average yearly temperature of 30 °C and receives about 608 mm of rain. With an average humidity of 80% and a UV index of 7, it is dry for 89 days a year. The highest average temperature is 31 °C, which occurs in March, and the lowest is 26 °C, which also occurs in August. Figure 2 is a monthly average climatic data graph for Ejisu obtained based on data collected over the last 30 years (Besttravelmonths.com - the Best Time to Visit Every Destination, 2023).

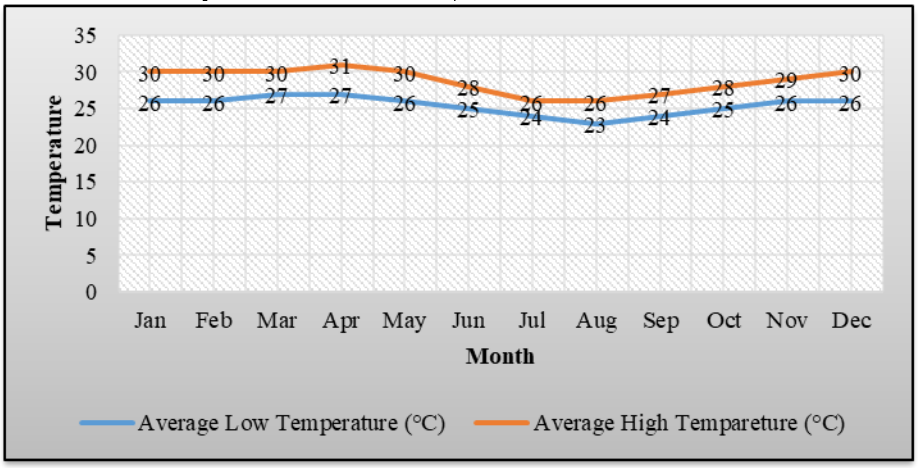

Figure 2: Monthly Average Temperature (°C) Graph for Ejisu

2.2 Adopted CS

Ejisu_1, an MTN cell site located in Ejisu, was chosen for the study. The dimension of the shelter is 3 m × 2.47 m × 2.45 m (L × B × H). The shelter is a movable sealed cabin consisting of sandwiched insulated panels between galvanised pre-coated steel sheets with polyurethane as a filling material. The floor is comprised of thick marine plywood with PVC antistatic flooring on top. A secondary slanting roof protects The primary roof from direct sunlight and moisture. Heavy-duty hinges hold the door in place. The shelter is mounted on a concrete pedestal and is supported by a galvanised I-beam base frame. The shelter has no windows; however, it does include a Roxtec access point for a cable. Two DC split air conditioners have been fitted for cooling. Figure 3 is a picture of the Ejisu_1 Cell Site Shelter.

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Figure 3: Shelter in Ejisu_1 Cell Site

2.3 Design Concept and Criteria

Figure 4 (Zhang et al., 2014) depicts a sketch of the proposed FC system in action in a typical shelter. The external walls are where the fans and filters are mounted. The control system controls the fans and air conditioners in two ways:: the air conditioners are turned on while the fans are turned off, or the air conditioners are shut off while the fans are turned on.

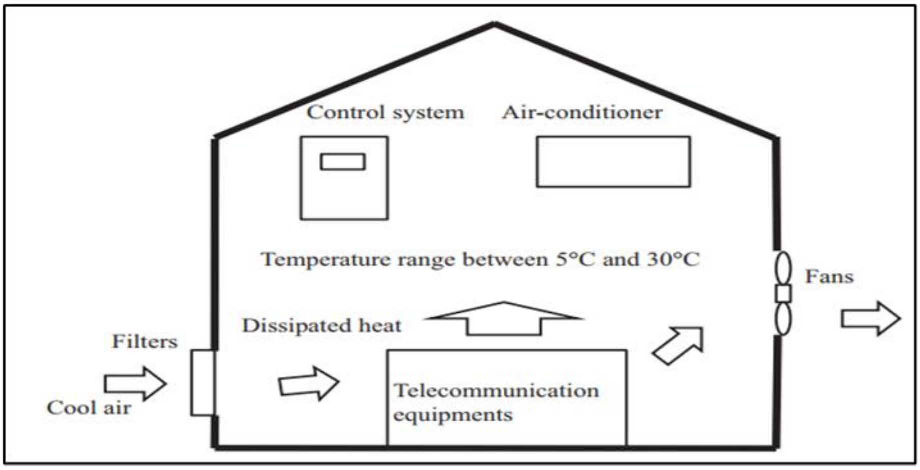

Figure 4: Sketch of the proposed AC and FC System

2.4 Creation of Shelter Geometry and Meshing

SOLIDWORKS 2017 Software was used to create the shelter (Figure 5). Then with ANSYS 19 workbench a mesh (Figure 6) is generated with 91922 nodes and 494779 elements. A set-up of the solver and physical models is done in the ANSYS 19 workbench to compute and monitor the solution after the meshing is finished.

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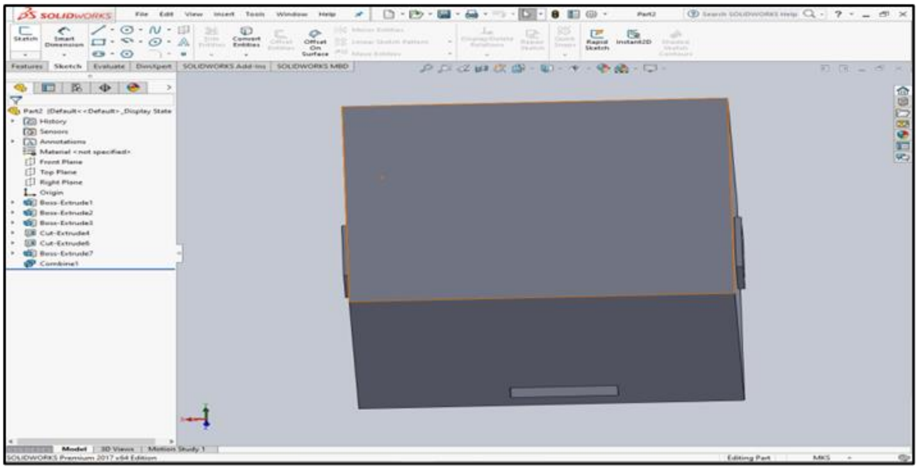

Figure 5: Geometry of the Shelter

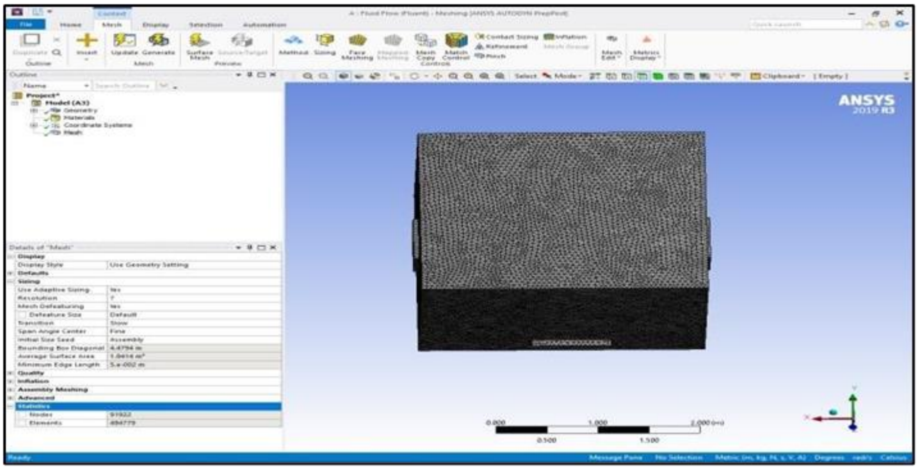

Figure 6: Generated Mesh

2.5 Positioning of the Inlet and Outlet Window

The location of the inlet and outlet window on the shelter plays a significant role in the efficiency of the dissipation of the heat generated by the installed equipment. Their location affects the air velocity distribution shelter's air velocity distribution (Chen et al., 2009). The positioning of the windows is analysed using a computational fluid dynamics simulation herein. With the shelter dimensions, three scenarios of different sets of window heights are examined, namely:

i. The inlet window is 0.5 m high, and the outlet window is 1.5 m high;
ii. The inlet window and outlet window are both 1.0 m high;
iii. The inlet window is 1.5 m high, and the outlet window is 0.5 m high.

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For the three aforementioned scenarios, the following assumptions were made to simulate the set of window heights where the best heat dissipation would be:

i. The shelters will have at least three Aviat transmission equipment, one Huawei BBU, and auxiliary equipment;
ii. There is no mixing of the hot air (generated in the shelter) with the cool air coming from outside into the shelter;
iii. The amount of heat generated by all auxiliary equipment is negligible;
iv. Temperature contours and Velocity contours for the shelter are simulated with velocity = 500 m/s; and
v. The temperature in the shelter is 50 °C (323.15 K).

2.6 Size of Inlet and Outlet Window

Heat dissipation in the shelter is greatly influenced by the size and design of the inlet and outlet windows. The shape can affect the effectiveness of the airflow. Long horizontal strip windows can help to ventilate a space evenly. Tall windows with top and bottom openings can employ convection and outside breezes to take the hot air out through the top of the room while giving cool air at the bottom. A smaller inlet can, however, be combined with a bigger exit opening to improve cooling efficiency. In this setup, the velocity of the input air can be increased. Because the same amount of air must flow through both the larger and smaller apertures in the same amount of time, the smaller opening must pass through faster (Sacht and Lukiantchuki, 2017).

2.7 Equipment Installed in the Shelter

Tables 1, 2, and 3 give the power consumption and operating temperature ranges of the installed Converged Transport Router (CTR), Extended Intelligent Node Unit (INUe), and Huawei BBU in the shelter.

Table 1: Power Consumption and Operating Temperature of the Installed Equipment

Equipment	Power Consumption Range (W)	Operating Temperature Range (°C)
CTR	30 - 200	-5 ° to +55

(Source: Aviat Networks, 2018)

Table 2: Power Consumption and Operating Temperature of the Installed Equipment

Equipment	Power Consumption Range (W)	Operating Temperature Range (°C)
INUe	15 - 54	-5 to +55

(Source: Aviat Networks, 2010)

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Table 3: Power Consumption and Operating Temperature of the Installed Equipment

Equipment	Power Consumption Range (W)	Operating Temperature Range (°C)
Huawei BBU3900	200 - 325	-20 to +55

(Source: Huawei Technologies, 2011)

2.8 Mathematical Modeling of Heat Generated

This study is conducted over 12 hours, from 6 pm to 6 am, using the day and night annualclimatic data obtained from AccuWeather Inc (Local, National, & Global Daily Weather Forecast | AccuWeather, n.d.).. This time was chosen because the outside temperature is at its lowest compared to the daytime and call traffic is at its lowest at night. With the 12 hours in mind, it is assumed that there will not be conduction and convection across the roof and walls of the shelter, thus, QEVN = 0, no solar radiation absorption on the walls and roof of the shelter, thus, QSOL = 0, and infiltration of warm outdoor air through openings in a shelter will not happen, thus, QINF = 0, rather heat will move out of the shelter through-hole and gaps in the shelter. Thus, Equation (1) can be simplified as Equation (3):

$$Q_{COOL} = Q_{IT} \tag{3}$$

2.8.1 Heat Gain from a Piece of Equipment

Also, the heat gain from a piece of equipment can be calculated using Equation (4) (Bhatia, 2001):

$$Q_E = Q_{in} \times F_u \times [CLF] \tag{4}$$

where, Q_E = heat gain from equipment
Q_{in} = 3.14× Power rating (Watts) of equipment
F_u = usage factor
CLF = cooling load factor

The rated energy input from appliances (Q_{in}) is obtained from the power rating (Watts) of the appliance provided on the nameplate. F_u can be obtained from the ASHRAE handbooks. CLF = 1.0 and latent load = 0, if a piece of equipment runs continuously for 24 hours (Bhatia, 2001).

2.8.2 Power Consumption of Fan and Air Conditioners

Equation (5) (Electricity Calculator: Power Consumption kWh Estimator, 2023) is used to compute the power consumption of an electrical appliance based on the capacity of the appliance and the number of hours and days it has been working.

$$W_{kh} = N_h \times N_d \times W_k \tag{5}$$

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where, W_{kh} = electrical appliance consumption (kWh)
N_h = number of hours used
N_d = number of days used
W_k = capacity of appliance (kW)

2.9 Energy Saving Analysis

The system's savings are calculated by calculating the percentage of time the AC is turned off and the FC is turned on during the year. Since it is assumed that the system operates for 12 hours, the AC consumption to be considered is half of the annual AC consumption; thus, $C_{12} = 0.5A_{AC}$, and the energy savings are calculated using Equation (6), Equation (7) and Equation (8).

$$P_{AC} = A_{PAC} \times C_{12} = A_{PAC} \times 0.5A_{AC} \quad (6)$$

$$P_{FC} = A_{PFC} \times A_{FG} \quad (7)$$

$$\text{Energy Savings} = C_{12} - (P_{AC} + P_{AC}) \quad (8)$$

where, A_{AC} = annual AC consumption
A_{FG} = annual FG consumption
C_{12} = consumption within 12 hours
P_{AC} = annual share of AC consumption
P_{FC} = annual share of FC consumption
A_{PAC} = annual percentage share of AC consumption
A_{PFC} = annual percentage share of FC consumption

2.10 Cooling Load Simulation

The cooling load for a shelter is calculated by obtaining the sum of the heat generated by the baseband unit, transmission equipment, and other electronic equipment installed in the shelter. The temperature in the shelter is obtained from the mathematical relation in Equation (9):

$$\Delta T = \frac{Q}{C \times m} \quad (9)$$

where, ΔT = resulting temperature change (°C or °K)
Q = quantity of heat transferred (kWh)
C = specific heat capacity of the material (kJ/kg/°K)
m = mass of the object (kg)

2.11 Heat Removal Method and Number of Fans for FG

The objective of the FCS is to keep the internal temperature of the shelter low for an extended period before an AC takes over. To achieve this objective, several airflows - Cubic Feet Per Minute (CFM) - must move through the shelter to ensure heat is adequately dissipated.. In general, airflow can be computed using Equation (10) (Kingenuity (2022).

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$$CFM = \frac{BTUH}{\Delta T \times 1.08} \tag{10}$$

where, CFM = a measure of airflow in Cubic Feet per Minute
BTUH = British Thermal Units per Hour
1.08 = convenience factor
ΔT = change in temperature (°F)

Once the CFM required to dissipate the quantity of heat in the shelter has been determined, it is compared to the CFM of a single fan to calculate the number of fans that can comprise the fan group using Equation (11).

$$N_f = \frac{CFM}{CFM_f} \tag{11}$$

where, CFM = a measure of airflow in Cubic Feet per Minute
N_f = number of fans required
CFM = stated CFM per fan

2.12 AC/FC Control System

MATLAB release 2015a simulates the control system for the switch between AC and FC. Two variable inputs, "shelter indoor temperature" and "shelter ambient temperature" and fuzzy controller output. A set of rules is chosen to relate the shelter temperature, ambient temperature, and fuzzy controller output. The combination of rule statements created is shown in Table 4.

Table 4: Set of Rules for the Created Fuzzy Controller

No.	Shelter Temperature	Ambient Temperature	Fuzzy Controller Output
1	Low	Low	FC
2	Low	Normal	FC
3	Low	Unfavorable	AC
4	Normal	Low	FC
5	Normal	Normal	FC
6	Normal	Unfavorable	AC
7	High	Low	FC
8	High	Normal	FC
9	High	Unfavorable	AC

3. Results

3.1 Inlet and Outlet Window Positioning

A plane is inserted into the meshed shelter geometry created to examine the velocity distribution of air in detail. The plane goes across the center of the shelter as seen in Figure 7.

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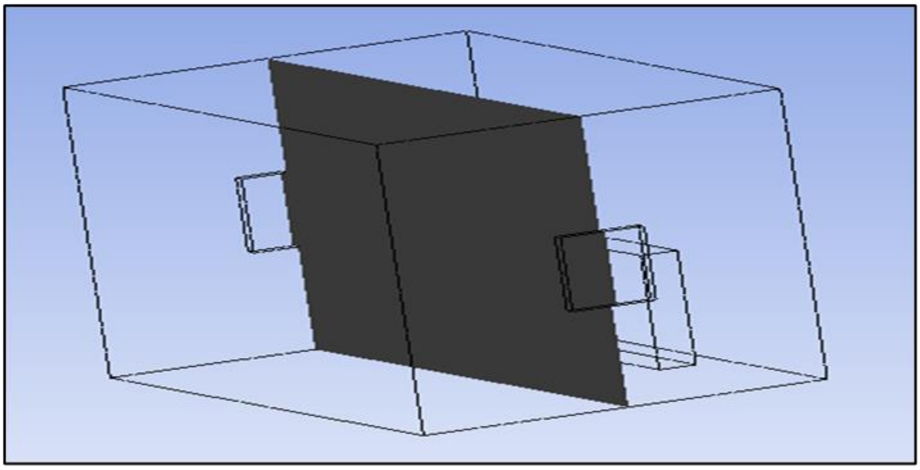
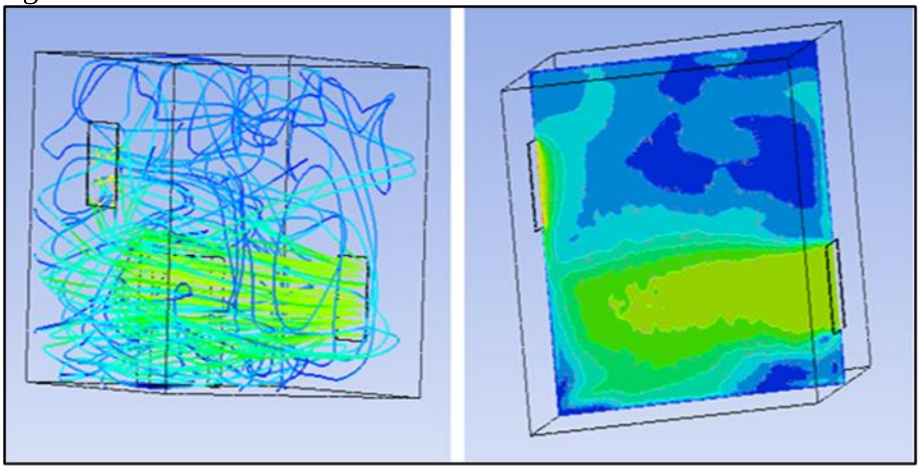


Figure 7: Plane in the Middle of the Geometry

3.1.1 Airflow Pattern

The airflow pattern, represented by Velocity Contours and Velocity Streams, through the input and output windows of the shelter, can be observed in Figure 8 for the inlet window at 0.5 m high and the outlet window at 1.5 m high, Figure 9 for the inlet window and outlet window are both 1.0 m high, and Figure 10 for the inlet window at 1.5 m high and the outlet window at 0.5 m high.



(a) (b)

Figure 8: Velocity Contours (a) and Velocity Streams (b)

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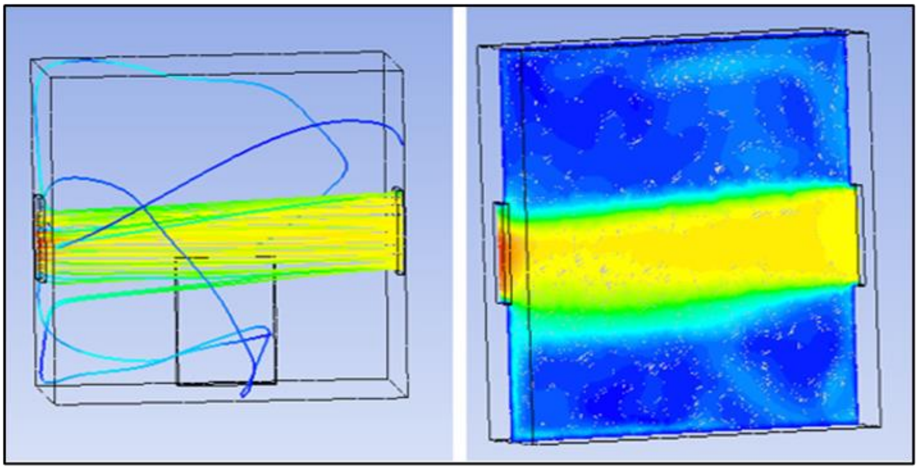
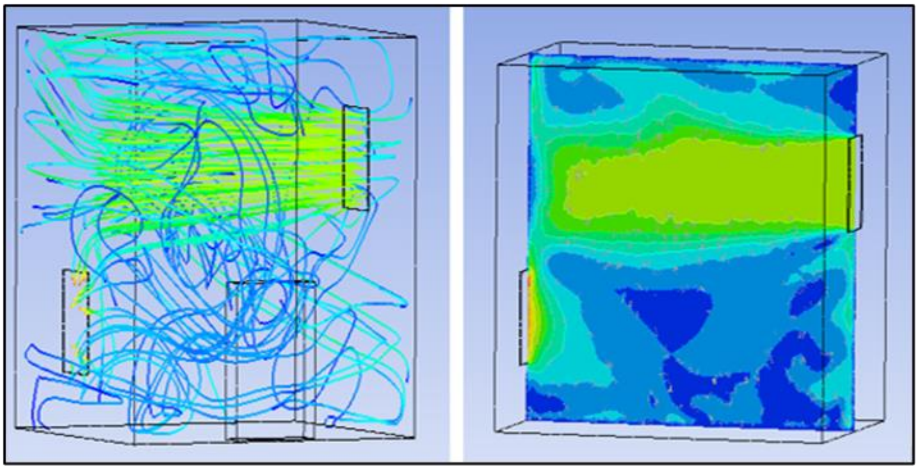


(a) (b)

Figure 9: Velocity Contours (a) and Velocity Streams (b)



(a) (b)

Figure 10: Velocity Contours (a) and Velocity Streams (b)

3.2 Heat Generated in the Shelter

The maximum power listed on the nameplate of installed equipment is used to calculate the heat generated when it is operating at full capacity. With Table 1, Table 2, and Table 3, the heat generated by Aviat CTR8540, Aviat INUe and Huawei BBU3900 is obtained as 628 W, 169.56 W and 1020.5 W, respectively.

3.3 Total Cooling Load (TCL)

The total quantity of heat generated in the shelter is given as the sum of heat generated by the total equipment installed in the shelter. This is obtained to be:

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$$TCL = (2 \times 628\ W) + 169.56\ W + 1020.5\ W = 2446.06\ W \approx 8346.30\ BTUH \quad (12)$$

3.4 Number of Fans Proposed for FG

The specifications for an EBM 6448 DC fan utilised in the analysis are shown in Table 5 below.

Table 5: Features of the EBM 6448 DC Fan

Features	Values
Air Flow [m³/h]	410
CFM	241
Nominal Voltage [V]	48
Voltage Range [V]	28…60
Noise [db]	57
Power Input [W]	17
Min. Temperature Range [°C]	-20
Max. Temperature Range [°C]	72

(Source: EBM Papst., 2019)

With Equation (10), Equation (11) and Table 5 the number of fans necessary for an FG is obtained as:

$$N_f = \frac{858.67}{241} = 3.56 \approx 4 \quad (13)$$

3.5 Annual AC Power Consumption (A_{AC}) and FG Power Consumption (A_{FC})

Table 6 summarises the yearly power consumption and energy savings based on the rated input power of the installed equipment (AC and FG), the number of hours they run per day, and the number of days in a year.

Table 6: Summary of power consumption

Item	Rated Input Power (W)	Number of Hours	Number of Days	Annual Power Consumption (kWh)
AC	1800	24	365	15768
FC	68	24	365	595.68

3.6 Operation of AC and FC Systems Using 1989-2019 Data

The average monthly climatic data for Ejisu collected over the last 30 years obtained from AccuWeather (Local, National, & Global Daily Weather Forecast | AccuWeather, n.d.), is analyzed to ascertain the share of AC and FC for a set temperature threshold of 25 °C in the shelter and it is presented in Figure 11 and Figure 12.

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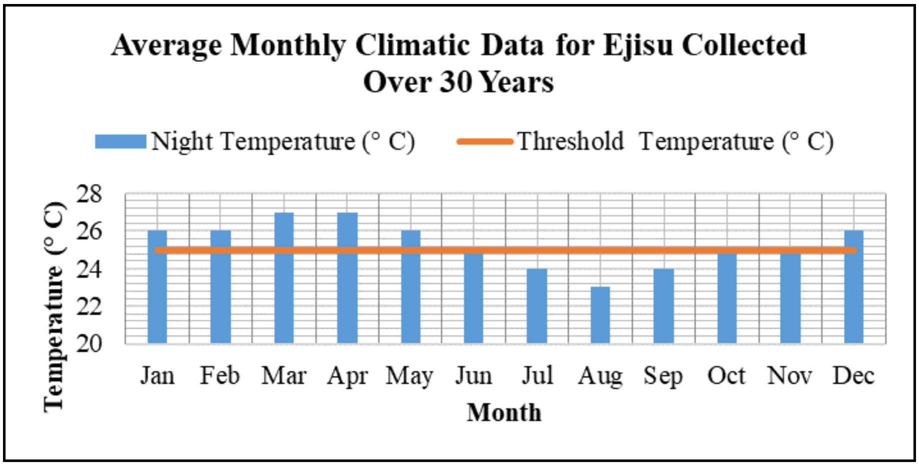

Figure 11: Graph of Average Temperature (°C) against Month

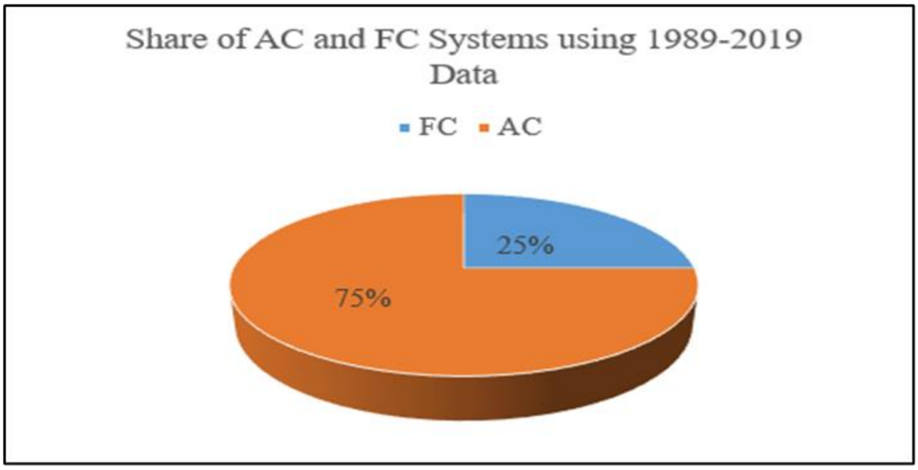

Figure 12: Share of AC and FC Systems using 1989-2019 Data

3.7 Operation of AC and FC Systems Using 2020, 2021 and 2022 Data

3.7.1 Share of AC and FC for 2020

Figure 13 displays the proportion of AC and FC at 25 °C and 30 °C in 2020, using weather data from AccuWeather.

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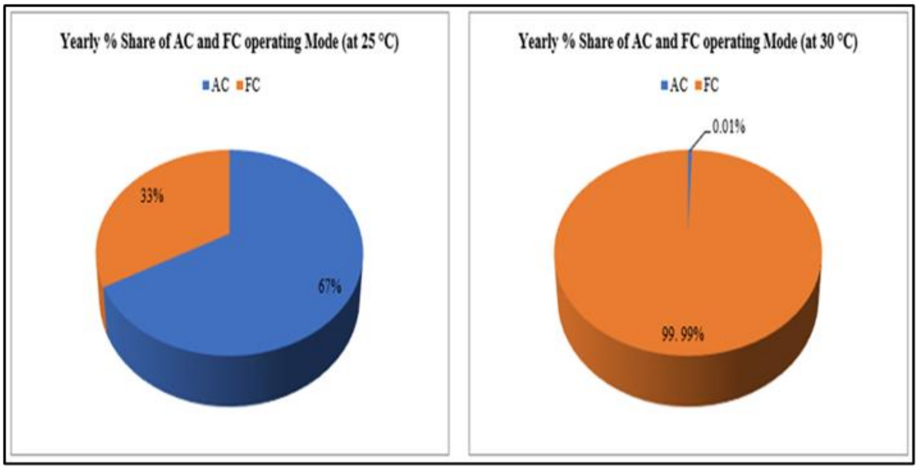
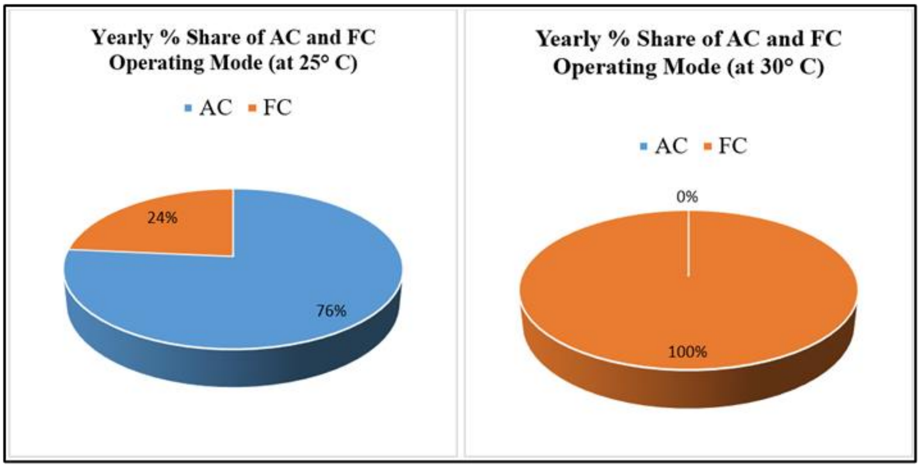


(a) (b)

Figure 13: Share of AC and FC (a) at 25 °C and (b) at 30 °C in 2020

3.7.2 Share of AC and FC for 2021

Figure 14 displays the proportion of air conditioning (AC) and fan cooling (FC) at 25 °C and 30 °C in 2021, using weather data obtained from AccuWeather.



(a) (b)

Figure 14: Share of AC and FC in 2021 (a) at 25 °C and (b) at 30 °C

3.7.3 Share of AC and FC for 2022

Figure 15 shows the percentage share of AC and FC at 25 °C and 30 °C in 2022 using weather information from AccuWeather.

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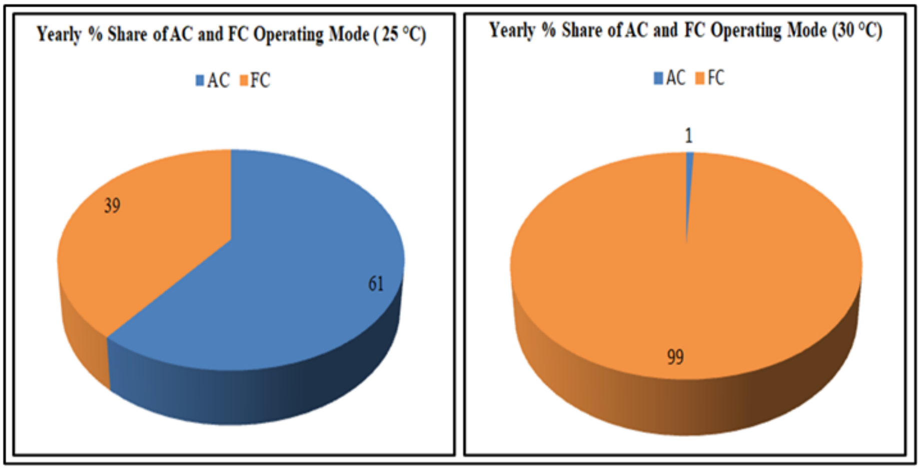

(a) (b)

Figure 15: Share of AC and FC in 2022 (a) at 25 °C and (b) at 30 °C

3.8 Calculation of Energy Consumption and Savings for 2020, 2021 and 2022

The energy consumption and savings for 2020, 2021, and 2022 are summarized in Table 7 below.

Table 7: Summary of Approximate Energy Consumption and Energy Savings

Year	Temperature	A_{PAC}	A_{PFC}	C_{12}	P_{AC}	P_{FC}	Approximate Energy Consumption	Approximate Energy Savings
2020	25 °C	67%	33%	7884 kWh	5282.28 kWh	196.57 kWh	5478.85 kWh	7287.59 kWh
	30 °C	0.01%	99.99 %	7884 kWh	0.79 kWh	595.62 kWh	596.41 kWh	7287.59 kWh
2021	25 °C	76%	24%	7884 kWh	5991.84 kWh	142.96kWh	6134.80 kWh	1749.20 kWh
	30 °C	0%	100 %	7884 kWh	00.00 kWh	595.68 kWh	595.68 kWh	7288.32 kWh
2022	25 °C	61%	39%	7884 kWh	4809.24 kWh	232.32kWh	5041.56 kWh	2842.44 kWh
	30 °C	1%	99%	7884 kWh	78.84 kWh	589.72 kWh	668.56 kWh	7215.44 kWh

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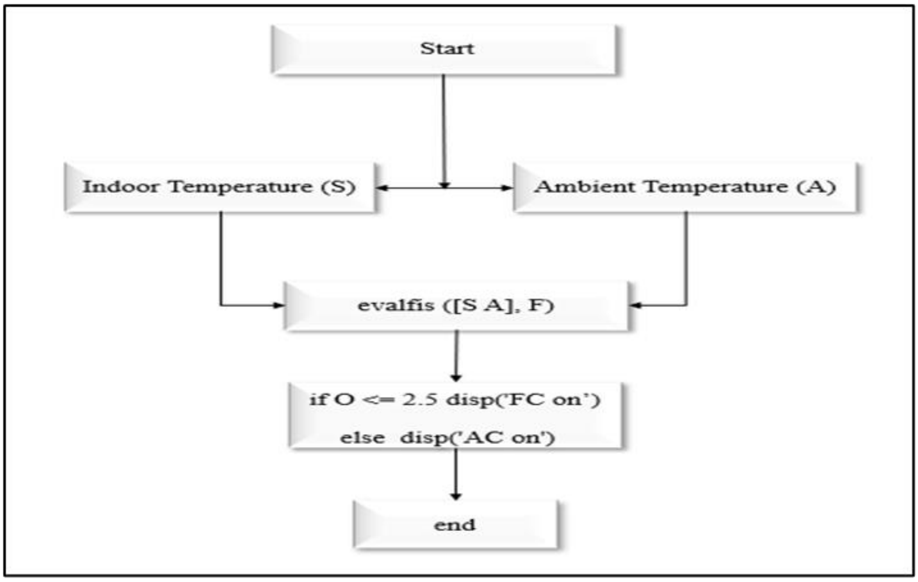

Figure 16: Flow Chart of Control Code

3.9 Control Strategy

Figure 16 above depicts the control code flowchart that compares the indoor and exterior shelter temperatures with the indoor set threshold temperature and sends a signal to activate or deactivate the AC/FC.

4. Discussion

4.1 Airflow Pattern Analyses

From section 3.1.1, the airflow pattern analysis is done. A jet-like flow of air is forced into the room by the inlet window. The airflow follows the path until it strikes the internal shelter wall surface, then bounces back into the shelter, as shown in Figures 3.3 and 3.5. It circulates for a short time throughout the space before exiting through the outlet window. Heat is recirculated in the shelter before some are transported out later. In Figure 3.4, the air flows into the shelter through the inlet window, then promptly moves out of the shelter and carries any heat on its passage through the outlet window. The shelter with an inlet window and an outlet window, both at 1.0 m high, has the most efficient heat dissipation potential compared to the shelter with an inlet window at 0.5 m high and an outlet window at 1.5 m high and the shelter with an inlet window 1.5 m high and an outlet window 0.5 m high.

4.2 Heat Generated in the Shelter

The heat produced when installed equipment runs at maximum capacity is determined using the maximum power indicated on the equipment nameplate. It is computed how much heat each unit produces. Following the

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calculation of the total amount of heat produced in the shelter using the combined output of two CTRs, one INUe, and one Huawei BBU. It comes out to be approximately 8346.30 BTUH.

4.3 Number of Fans

At least four fan units are computed to be a part of the proposed fan group. The fans are arranged in parallel in the same faction as in Figure 17 with dimensions of 344 mm × 300 mm × 51 mm (LWH). The fans are side-by-side to push air in the same direction so that their overall output increases the airflow volume.

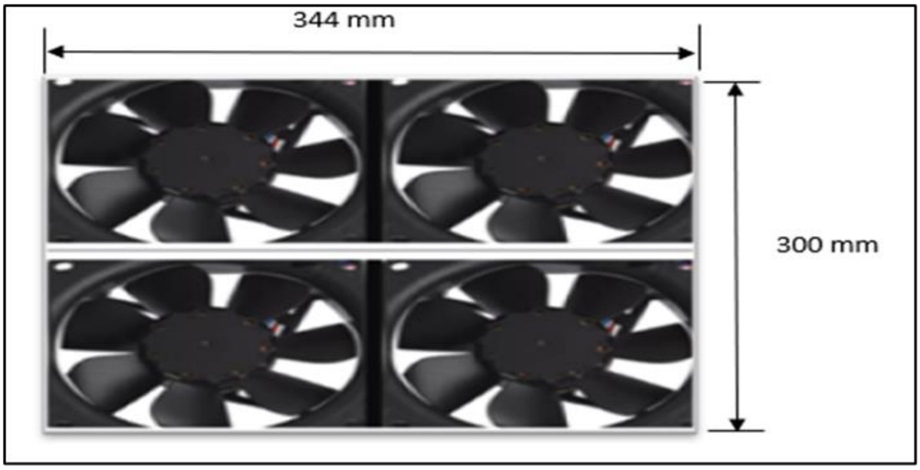

Figure 17: Proposed Fan Group

4.4 Annual Power Consumption

Annual AC power consumption is 15768 kWh, with the annual fan group consumption being 595.68 kWh. The AC consumes roughly 26 times the amount of energy the fan group uses.

4.5 Percentage Share of AC and FC Systems Using 1989-2019 Data

From section 3.7, It is observed from Figure 3.6 that FC operates in July, August, and September while AC operates for the remaining months. The percentage share of AC and FC operating modes is 75% and 25%, respectively, as shown in Figure 3.7. Thus, there will have been some savings in energy. At a set temperature threshold of 25 °C and the average monthly climatic data for Ejisu collected over the last 30 years, it is observed that FC is active only in July, August, and September, representing around 25% of the time, and AC runs about 75% of the time.

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4.5.1 Operation of AC and FC Systems Using 2020, 2021 and 2022 Data

The share of AC and FC operating modes is analyzed using the weather data obtained from AccuWeather in 2020, 2021, and 2022 (Local, National, & Global Daily Weather Forecast | AccuWeather, n.d.). The analysis herein is done between 6 pm and 6 am. Initially, it is done for 25 °C, then considering the operating temperature range (-5 °C to +55 °C) of the installed equipment, the indoor temperature threshold is increased from 25 °C to 30 °C to help examine the change in share of AC and FC operating modes.

Percentage Share of AC and FC for 2020

It can be seen in Figure 3.8 that for a temperature threshold of 25 °C, the annual percentage share for the two operating modes is approximately 67% and 33% for AC and FC, respectively. When the temperature threshold is increased from 25 °C to 30 °C, the percentage share is approximately 0.01% for AC and 99.99% for FC. The percentage share of FC increases when the indoor set temperature threshold is increased from 25 °C to 30 °C

Percentage Share of AC and FC for 2021

Figure 3.9 reveals that, at a temperature threshold of 25 °C, the yearly percentage share for AC and FC are approximately 76% and 24%, respectively. When the temperature threshold is adjusted from 25 °C to 30 °C, the percentage share of AC decreases to 0% and FC increases to 100%.

Percentage Share of AC and FC for 2022

For the weather data obtained in 2022, the share of AC and FC are shown in Figure 3.10. At an indoor set temperature threshold of 25 °C, the yearly percentage share for AC and FC are approximately 61% and 39%, respectively. When the indoor set temperature threshold is adjusted from 25 °C to 30 °C, the percentage share of AC decreases to 1% and FC increases to 99%.

4.6 Energy Savings

With the calculated yearly power consumption of the split AC being 15768 kWh and FG estimated to be 1191.36 kWh, the energy consumption and savings are calculated for 2020, 2021, and 2022 in section 3.9.1, section 3.9.2 and section 3.9.3 respectively. Below is a Table summarizing the year, temperature and the approximate energy savings obtained.

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Table 8: Summary of the Year, Temperature, and Approximate Energy Savings

Year	Temperature	Approximate Energy Savings
2020	25 °C	2405.15 kWh
	30 °C	7287.59 kWh
2021	25 °C	1749.20 kWh
	30 °C	7288.32 kWh
2022	25 °C	2842.44 kWh
	30 °C	7215.44 kWh

Conclusions

The shelter with the inlet and outlet windows at the same height has the most efficient heat dissipation potential. The air enters the shelter through the inlet window and exits through the outlet window without recirculating in the shelter.

The proportion of free cooling increases as the set temperature threshold is increased. As a result, operating telecom equipment at high temperatures while running FC can reduce a CS's energy consumption.

The proportion of free cooling increased during the cold months (June through to September) while decreasing during the warmer months.

Most CSs in Ghana will save significant energy when FC is run at a set temperature threshold of 30 °C or higher.

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Data Availability: All data are included in the content of the paper.

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