Comparison of Energy Efficiency Ratio and Indoor Environmental Quality Factors of a Window-Type and Portable-Type Air Conditioners

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Abstract

An air conditioning unit is a machine that is designed to provide comfort cooling to its users. One of these types is the window-type air conditioning unit (ACU) which is most common in the Philippine market. The portable-type ACU is another type but it's not as popular as the other. Since data on the portable-type ACU is scarce, the window-type ACU is the more suggested type used. The study aims to compare the Energy Efficiency Ratio (EER), temperature uniformity, and the Indoor Environmental Quality (IEQ) such as carbon dioxide concentration and noise levels of these two types of air conditioning units. In the Energy Efficiency Ratio and temperature uniformity test results, the window-type ACU yielded a better EER and has a more uniform cooling than the portable-type ACU. In the CO_2 concentration tests, the CO_2 concentration of the room using the portable-type ACU was lower than when using the window-type ACU. From the tests conducted, the CO_2 concentrations were a factor of the air changes per hour of both ACUs and the breathing activity of the occupants as well. Lastly, the noise level results for both ACUs showed that neither was within the standards for the maximum noise level produced in a room.

Keywords
energy efficiency ratio, indoor environmental quality factors, window-type ACU, portable-type ACU

1. Introduction

Air conditioners are machines used to provide comfort cooling for a specific space. Different types of air conditioning units can be selected based on different room designs, the heat generated inside the room, and the size of the room to be cooled. In the Philippines, the window-type ACUs were significantly more popular. The demand for window-type ACUs in the Philippines in 2015 was recorded at 425,000 versus the 226,000 recorded demand by the split- type ACU. In 2017, the window-type ACU recorded demand of 503,000 while the split-type ACU recorded demand of 290,000. The window-type ACU's popularity in the Philippine market can be attributed to it being easy to install, attractive to retrofits, and inexpensive when compared to central air conditioning units (Sanchez, 2019). Like the window-type ACU, the portable-type ACU also provides comfort cooling in the room. However, it does not require major changes or modifications of the room for its installation procedures, such as a hole on the wall of the room for the installation of a window-type ACU. The portable-type ACU usually takes a space inside a room, which means that the unit utilizes indoor air for its intake. The portable ACUs are mobile, lightweight, and easy to use, all of which are key selling points for buyers who desire the comfort of the window-type ACU but need to maximize space.

Data in the public is not sufficient enough to determine how efficient a portable air conditioning unit is because it is not popular in the Philippine market. That being the case, people still choose to depend on the more popular air conditioning unit which is the window-type air conditioning unit as it has already proven its effectiveness, especially in-home use. This comparative study can address this issue by investigating the Energy Efficiency Ratio and indoor environmental quality factors, specifically the temperature uniformity, carbon dioxide (CO_2) concentration, and the noise levels, of these two types of air conditioning units (CDC, 2013).

2. Methodology

The process flowchart shown in Figure 1 presents the sequence of the events done by the researchers to achieve the objectives of the study.

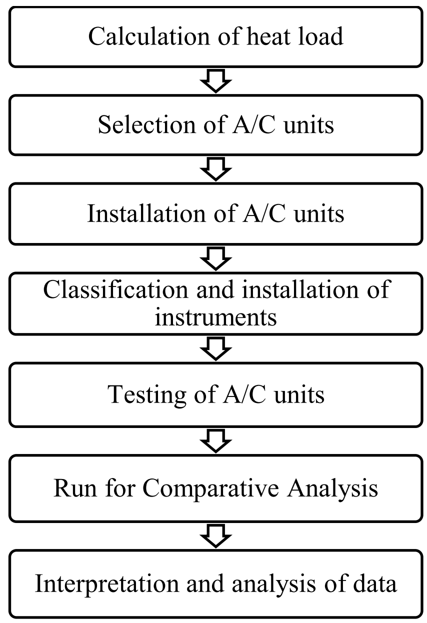

Figure 1. Process Flowchart

2.1. Calculation of Heat Load

The factors that were considered in the computation were the following: the volume of the room, the total number of occupants in the room, the orientation of the room along with its windows, the lights in the room and the partitions beside the room that contributes to the total heat load of the room. The heat load calculation was done using a heat load form by Carrier (CACC, 1966).

Two separate heat loads were created for the study, one for the morning tests and another for the afternoon tests. The outdoor air conditions such as the temperature and the humidity used for the heat load calculation were measured using a thermos-hygrometer.

2.2. Selection of Air Conditioning Units

In selecting the air conditioners used for testing, the researchers considered the price, the brand, the refrigerant, and the cooling capacity of both air conditioners. A brand new 1 HP window-type ACU from the parents of one of the researchers was used for the testing; the brand of the air conditioner was Everest and was priced at 11,500.00 Php. This heavily influenced the decision of the researchers in deciding what portable-type ACU was to be procured. Since the researchers wanted to maintain uniformity in the brand of the air conditioners used, the researchers decided to purchase a 1 HP portable-type ACU from the brand Everest. Both air conditioning units were purchased brand new with warranty and had the same refrigerant, R410a, and cooling capacities at 9500 kj/hr.

2.3. Installation of Air Conditioning Units

The air conditioning units were installed in room N100 in Mapúa University. N100 is the Heating, Ventilation, and Air conditioning and Refrigeration (HVAC&R) room of Mapúa University. Here within, is a room 8.882 square meters in floor area. This room was previously used as a thesis study for a centralized air conditioning unit. Proper installation coming from the manufacturer's manual were followed for both air conditioning units. The researchers examined the room for holes in the ceiling and the walls and covered them in duct tape to minimize leakage.

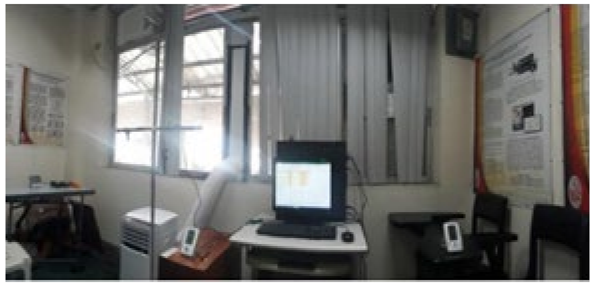

Figure 2. Set-up of the Testing room inside N100 of Mapúa University

The window-type air conditioner was installed as per the manufacturer's procedures in the allocated hole in the wall inside the room. The hole was located in the top left corner of the room as shown in figure 2. Since the hole was bigger than the air conditioner bought, the researchers filled in the spaces with Styrofoam and sealed with duct tape. The portable-type air conditioner was installed in the middle of the room. Since the portable ACU needs exhaust air through ducting, a portable exhaust hose was installed to a window using a window slide connector provided by the manufacturer.

2.4. Installation of Instruments

These are the different measuring equipment and tools that were used in this comparative study.

Clamp Meter
The clamp meter was used in determining the current drawn by the air conditioning unit. The average current of the two wires was used for the calculation of the Energy Efficiency Ratio. The researchers used a calibrated Fluke clamp meter.

Thermistor Thermometer
The temperatures of the air through the return air grille and the supply air grille were recorded using a thermistor thermometer. In recording the suction temperature of the air conditioner, the thermistor thermometer was placed at the center of the return air grille of the ACU. In determining the temperature of the cooled discharged air, the thermistor was set over the center of the supply air grille. The temperatures were allowed to stabilize before they were recorded and used in the calculation of the EER.

Digital Thermo-hygrometer
Three digital thermos-hygrometers were used for this study as shown in figure 3. Each one was situated in a specific location within the room: the center, center-left, and the center-right. All of these sensors are equidistant to each other and were positioned 0.8 meters above the ground and were used to determine the temperatures at these three locations. Figure 3 shows the exact location of the thermos-hygrometers used in testing.

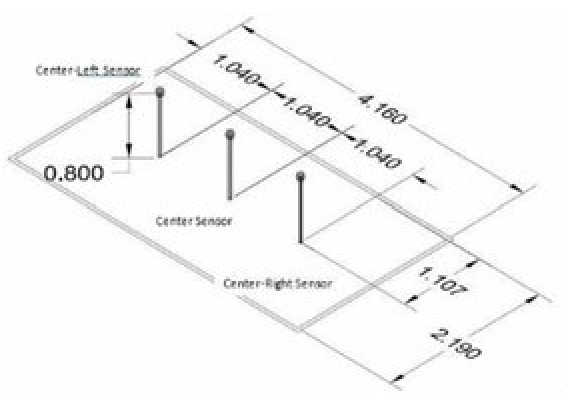

Figure 3. Schematic Illustration of Set-up of Digital Thermo-hygrometer

Carbon Dioxide Sensor
A Vernier Carbon Dioxide Gas Sensor was used to measure the carbon dioxide concentration of the testing room. It also displayed real-time ventilation rates through an Android application using Bluetooth connectivity. The carbon dioxide sensor was positioned 1.1 meters above the ground in the center of the room.

Sound Level Meter
The Extech sound level meter was used for determining the noise level produced by the air conditioning unit. The unit used for this measurement is the A-weighted decibel or dBA. This pertains to the relative "loudness" as perceived by the human ear. In testing the sound level, the sound level meter was positioned at the center of the room at a height of 1.1 meters from the ground.

2.5. Testing of Air Conditioning Units
These are the testing procedures and IEQ factors tests that were to be considered in this comparative study. This specifically includes the following: EER determination, carbon dioxide concentration testing, temperature uniformity test, and noise level test.

Energy Efficiency Ratio (ERR) Test
EER was measured in a one-hour interval in a span of three-hour test. Half thermostat setting and maximum thermostat setting EERs were measured and computed for the study. The factors needed to calculate the EER using air enthalpy method were the area of the return air grille, air velocity through the return air grille, return air temperature, supply air temperature, air density, relative humidity, and current supplied to the air conditioner. The density of air used was 1.225 kg/m3 based on the International Standard Atmosphere at 15 degrees C at sea level. The area of the return air grille was measured using a ruler. The air velocity through the return air grille was also measured using an Anemometer. The Anemometer was situated at the center of the return air grille where the speed is at its maximum. The temperatures and relative humidity were measured using the thermistor thermometer and thermos-hygrometer every hour for three hours while the instantaneous current supplied to the unit was measured using the clamp meter. All of these parameters were used to calculate the Energy Efficiency Ratio of the air conditioning unit. The formula used is given in equation 1.

$$COPdyn = \frac{\rho Av(\Delta H)}{Electrical\ Power\ (V*I)} \tag{1}$$

Temperature Uniformity Test
The temperature uniformity of the room was tested using three thermos-hygrometers situated in three locations within the testing room. The temperatures were recorded every ten minutes until the temperature read by the thermos-hygrometers stabilized. The final temperature reading of each of the sensors used in testing both ACUs was used for comparison. Half thermostat tests and maximum thermostat tests for both ACUs were also followed.

Carbon Dioxide Test
Carbon dioxide concentrations were measured and recorded every ten minutes throughout the study. The Vernier carbon dioxide sensor was used to measure the carbon dioxide concentrations inside the testing room. The sensor was operated and installed in the center of the room at 1.1 meters above the ground. This is the approximated breathing level of a person. The data for concentrations found were used to determine whether the room meets the desired safety limits set by the OSHA. The air changes per hour (ACH) was also computed for both the thermostat setting, this relates to how many times the volume of air inside the room is replaced with fresh air (400 ppm CO_2 concentration). Using the concept of mass balance, the researchers created a formula for ACH that relates to the CO_2 concentration of the room. The formula used is given in equation 2:

$$ACH = \frac{Q(3600)}{(CO2ave - CO2ambient)(Volume\ of\ the\ room)} \tag{2}$$

Noise Level Test
A sound level meter was positioned at the center of the room at a height of 1.1 meters above the ground. This was used in recording the sound produced by the air conditioning units. The researchers recorded the noise level in ten-

minute intervals throughout the 2-hour tests. This was done for four days and the data gathered was then compared to a standard of acoustics for classrooms, ANSI S12.60-2002.

2.6. Statistical Analysis

The data collected and calculated were analyzed using a two-sample t-test. However, the normality assumption was violated, a non-parametric test (Mann-Whitney Test) was used for the data set. Three data sets in this study used statistical analysis and they were performed using Minitab version 17 for Windows and IBM Statistical Product and Service Solution for Windows. For EER tests, an independent t-test was used to determine if there is a significant difference between the values of energy efficiency ratio data of the window-type ACU and the portable-type ACU. The second t-test was performed on the noise level data of both ACUs to determine whether there is a significant difference between the two. The last set of statistical tests was used to determine if there is a significant difference between the carbon dioxide concentration between the portable-type ACU and window-type ACU operation. Both the two-sample t-test used an alpha level or a level of significance of 0.05. If the p-value from the tests is lower than the level of significance, the null hypothesis (H0) is rejected.

3. Results and Discussion

3.1. Energy Efficiency Ratio

The energy efficiency ratios of both window-type and portable-type air conditioners, at a certain time, were calculated using the air-enthalpy method. Temperatures and relative humidity of suction and discharge air of both air conditioners were measured. These parameters were used to identify the enthalpies generated by the air conditioners. Several constant parameters were also used for the calculation of the energy efficiency ratios. The calculated energy efficiency ratios are shown in Tables 6 and 7. Based on the data, the majority of the generated energy efficiency ratios of the window-type air conditioner were relatively higher than that of the portable-type air conditioner.

Table 6. Energy Efficiency Ratio at Half Thermostat Setting

DAY	TRIAL	TIME	WINDOW-TYPE	DAY	TRIAL	TIME	PORTABLE-TYPE
1	1	9:30	12.6949	**5**	1	9:30	12.8642
	2	10:30	11.3649		2	10:30	10.8793
	3	11:30	10.5208		3	11:30	10.4461
2	4	9:30	13.6411	**6**	4	9:30	11.1851
	5	10:30	13.2233		5	10:30	9.4185
	6	11:30	12.9795		6	11:30	9.6479
3	7	9:30	12.0384	**7**	7	9:30	10.2407
	8	10:30	11.3987		8	10:30	10.812
	9	11:30	10.3808		9	11:30	9.6278
4	10	9:30	12.8164	**8**	10	9:30	10.0311
	11	10:30	11.5313		11	10:30	11.0223
	12	11:30	11.1977		12	11:30	7.5424

Table 7. Energy Efficiency Ratio at Max. Thermostat Setting

DAY	TRIAL	TIME	WINDOW-TYPE	DAY	TRIAL	TIME	PORTABLE-TYPE
1	1	12:30	13.7787	**5**	1	12:30	10.1052
	2	13:30	11.0991		2	13:30	11.8661
	3	14:30	11.0039		3	14:30	12.9863
2	4	12:30	14.158	**6**	4	12:30	9.5586
	5	13:30	10.4375		5	13:30	11.7526
	6	14:30	11.3637		6	14:30	9.4287
3	7	12:30	11.1179	**7**	7	12:30	11.0569
	8	13:30	10.4886		8	13:30	10.3094
	9	14:30	9.4339		9	14:30	9.3062
4	10	12:30	11.1975	**8**	10	12:30	10.206
	11	13:30	10.9846		11	13:30	11.5887
	12	14:30	10.4932		12	14:30	9.5369

Statistical Analysis of Energy Efficiency Ratio

For further analysis of the calculated energy efficiency ratios, the independent sample t-test was conducted, and the data calculated showed a p-value of 0.002, a lesser value than the α-value of 0.05. This would suggest a statistically significant difference between the data sets. It can also be noted that the mean value of the Energy Efficiency Ratios of the window-type air conditioning units is higher than the portable-type air conditioning units. This would suggest a higher Energy Efficiency Ratio for the window-type ACU over the portable-type ACU. The results of the statistical analysis are shown in Table 8-9.

Table 8. Descriptive Analysis of Energy Efficiency Ratio

ACU Type	N	Mean	Std. Deviation
Window-type	24	11.639	1.246
Portable-type	24	10.476	1.216

Table 9. Independent Sample T-test of Energy Efficiency Ratio

	LEVENE'S TEST FOR EQUALITY OF VARIANCES	TEST FOR EQUALITY OF MEANS		
	Sig.	Sig. (2-tailed)	Mean Diff.	Std. Error Diff
Equal Variance Assumed	0.701	0.002	1.164	0.355
Equal Variance Not Assumed		0.002	1.164	0.355

3.2. Temperature Uniformity

The final temperatures at different locations in the room are shown in Tables 10-11. The data was taken from three sensors after the temperatures in the room had stabilized. The standard deviation of the temperature readings was taken to determine how far the values were from each other. From the data gathered, the window-type ACU recorded a lower standard deviation value against the portable-type ACU. This would suggest that the window-type ACU more uniformly cooled the room.

Table 10. Final Temperature at Half Thermostat Setting

LOCATION	TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4	
	Window	Portable	Window	Portable	Window	Portable	Window	Portable
Center-Left	24.2	25	24.5	26.7	23	24.6	24.1	25
Center	24.8	26.8	25.4	28.1	24.1	25.8	24.9	26.1
Center-Right	22.7	24	22.7	25.1	22.9	22.7	22.9	22.9

Table 11. Final Temperature at Max Thermostat Setting

LOCATION	TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4	
	Window	Portable	Window	Portable	Window	Portable	Window	Portable
Center-Left	24	25.9	23.5	26.8	23.6	24.3	22.3	26.3
Center	25	26.9	24.8	27.3	24.6	26.3	23.1	28
Center-Right	24.1	25.3	22.9	25.1	22.9	22.9	20.6	23.8

3.3. Carbon Dioxide Concentration

For the study, the Carbon Dioxide concentrations of a window-type and a portable-type air conditioning unit was tested within a room. The air conditioners were tested under half and maximum thermostat conditions, each for 2 hours a day for 4 days. Figures 4-7 show the dataset concerning the time of the Carbon Dioxide concentrations within the room at their respective thermostat settings.

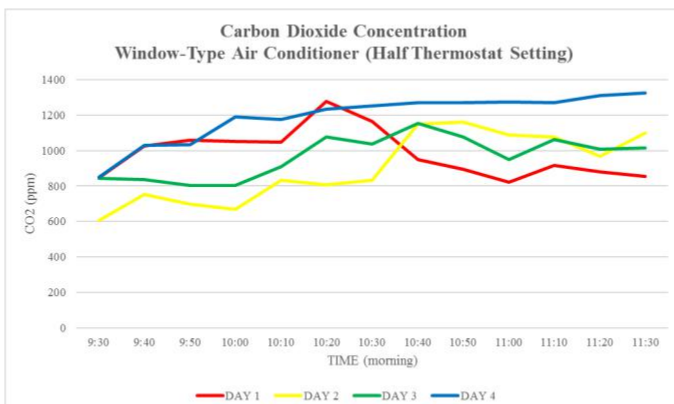

Figure 4. CO_2 Concentrations of Window-type Air Conditioner at Half Thermostat Setting

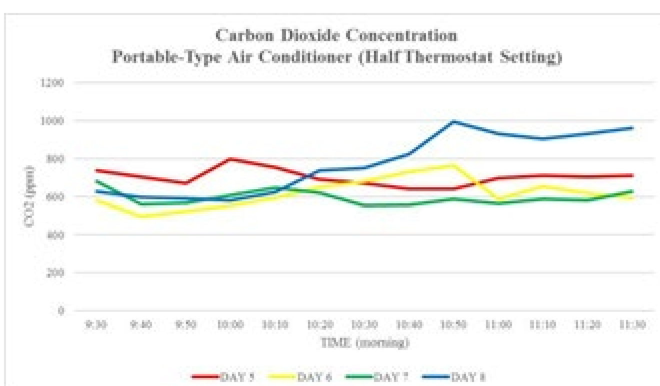

Figure 5. CO_2 Concentrations of Portable-type Air Conditioner at Half Thermostat Setting

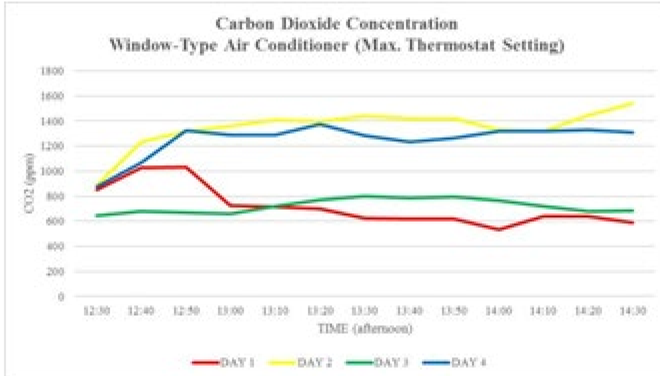

Figure 6. CO_2 Concentrations of Window-type Air Conditioner at Max. Thermostat Setting

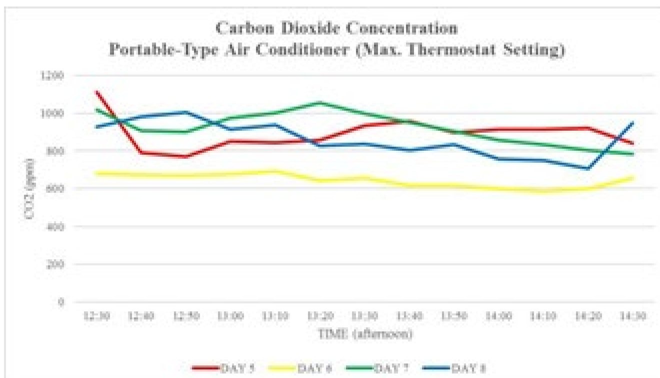

Figure 7. CO_2 Concentrations of Portable-type Air Conditioner at Max. Thermostat Setting

The data sets were subjected to a Shapiro-Wilks test for normality to determine which statistical procedure best fits the given data. From the test, it was determined that a Mann-Whitney U-test would best interpret the dataset gathered.

Statistical Analysis of Carbon Dioxide Concentration

Using the program, IBM SPSS Statistics 24, the Mann-Whitney U-test was performed and from this, the mean ranks, and the p-value were recorded. From the data gathered, the p-value and the α- value of 0.05 were compared to determine whether the data collected was significantly different from each other. The data can be seen in Table 8. The calculated p-value of the Carbon Dioxide concentrations of the room using the window-type air conditioner and the portable-type air conditioner tested at half their thermostat settings was recorded at less than 0.0001, lower than the α-value of 0.05. This would suggest that the dataset of the window-type ACU was significantly different from the dataset of the portable-type ACU. Also, from the data, the mean rank of the window-type air conditioning unit was higher than the portable-type air conditioning unit. This would suggest that the Carbon Dioxide concentrations of the room using the window-type air conditioner was higher than the portable-type air conditioner. Under maximum thermostat settings, the p-value recorded for both air conditioning units was 0.035, still lower than the α-value of 0.05. This would once again suggest that the datasets of both air conditioning units were significantly different from each other. The results of statistical analysis are shown in Tables 12-13.

Table 12. Descriptive Statistics of CO_2 Concentrations

SETTING	ACU TYPE	N	MEAN	STD. DEVIATION
Half Thermostat	Window-type	52	1011.17	181.83
	Portable-type	52	671.81	115.14
Max. Thermostat	Window-type	52	1008.88	322.37
	Portable-type	52	830.15	135.31

Table 13. Mann-Whitney U-test of CO_2 Concentrations

Statistics	Half Thermostat	Max. Thermostat
Mann-Whitney U	164.000	1028.000
Wilcoxon W	1542.000	2406.000
Z	-7.724	-2.106
Asymp Sig. (2-Tailed)	0.000	0.035

3.4. Noise Level

The noise levels generated by both window-type and portable-type air conditioners are shown in Table 14. Based on the measured data, the window-type air conditioner was able to generate lower noise levels, measure in dBA, compared to that of the portable-type air conditioner.

Table 14. Measured Noise Levels of Air Conditioners

TIME	TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4	
	Window	Portable	Window	Portable	Window	Portable	Window	Portable
0	51.3	58.1	52.4	56.2	51.2	55.7	52.5	54.1
10	50.3	57.4	50.7	58.1	54.9	57.3	56.4	55.9
20	50.3	57.5	54.9	57.8	54.9	57.9	56.1	57.4
30	51.1	57.6	54.7	59.3	53.7	58.6	55.3	58
40	50.7	57	55.3	57.3	51	59	52	54.2
50	51.7	56.8	52.8	57.3	50.7	59.4	53.8	54.8
60	50.7	57.3	50.7	59.6	52.3	56.3	55.9	59.5
70	53.6	57.1	54.1	58.7	56.4	55.8	54.8	58.7
80	56.4	58.7	56.7	56.3	55.9	57.3	56.7	56.3
90	52.8	57.9	55	57.7	52.9	58.1	53.1	55.1
100	50.7	57.5	53.4	58.5	53.6	59	52	56.9
110	51.3	58.2	53.1	56	51.3	56.1	52.8	55
120	51.8	58.5	51.7	56.2	50.7	55.9	51.8	54.6

Statistical Analysis of Noise Level

For further analysis of the noise levels, an independent samples t-test was conducted. From the data gathered, the p-value and the α-value of 0.05 were compared to determine whether the data collected was significantly different from each other. The calculated p-value of the noise levels of the window-type air conditioner and the portable-type air conditioner was less than 0.001, lower than the α-value of 0.05. This indicates that there is a significant difference between the noise levels of the window-type air conditioner and portable-type air conditioner. The results of the statistical analysis are shown in Table 15-16.

Table 15. Descriptive Statistics of Noise Levels

ACU Type	N	Mean	Std. Deviation
Window-type	24	11.639	1.246
Portable-type	24	10.476	1.216

Table 16. Independent Sample T-test of Energy Efficiency Ratio

	LEVENE'S TEST FOR EQUALITY OF VARIANCES	TEST FOR EQUALITY OF MEANS		
	Sig.	Sig. (2-tailed)	Mean Diff.	Std. Error Diff
Equal Variance Assumed	0.002	0.000	-4.127	0.338
Equal Variance Not Assumed		0.000	-4.127	0.338

4. Conclusion

For this study, the researchers were able to develop a comparative study on the Energy Efficiency Ratios and indoor environmental quality factors of a window-type and a portable-type air conditioning unit. To assess the effectiveness of both air conditioning units, the Energy Efficiency Ratios, Temperature Uniformity, Carbon Dioxide Concentrations, and noise levels of the room were recorded. Based on the independent samples t-test conducted on the Energy Efficiency Ratios, there was shown a statistically significant difference between the data Energy Efficiency Ratios of the window-type and the portable-type air conditioning unit. The data gathered showed that the difference in the datasets was caused by the temperature uniformity and cooling losses. Since the mean values of the Energy Efficiency Ratios of the window-type ACU were higher than the portable-type ACU's, the window-type incurred a better Energy Efficiency Ratio in the tests. Other factors such as temperature uniformity, Carbon Dioxide, and noise levels were also tested and compared. For the temperature uniformity, the standard deviation of the sensors was recorded at the time the temperatures had stabilized. From the data gathered, the window-type air conditioner exhibited lower standard deviation values compared to the portable-type air conditioner suggesting a more uniform cool in the room. In the comparison of datasets for the Carbon Dioxide concentrations within the room, the Mann-Whitney U-test was conducted. A p-value of less than 0.0001 was recorded for the air conditioners under the half thermostat. A p-value of 0.035 was also recorded for the air conditioners under the maximum thermostat. These p-values were both lower than the α-value of 0.05, leading the researchers to conclude that there was a statistically significant difference between the datasets of both air conditioning units at both thermostat settings. Factors that affected these changes were the air changes per hour, where the portable-type ACU exhibited higher values. This would suggest that the air in the room was replaced more times in an hour as against the window-type ACU during both thermostat settings. Another factor that may have affected the values of the Carbon Dioxide concentrations in the breathing activity of the occupants. Both air conditioning units were within the standard set by the Occupational Safety and Health Administration at 5000 ppm. The noise levels were then subjected to an independent samples t-test and comparing the calculated p-value to the α-value of 0.05, the researchers determined that the p-value of the datasets was less than 0.001. This would suggest a statistically significant difference between the noise levels produced by both ACUs. This difference was caused by the assembly of both air conditioners since the window-type air conditioner had its compressor situated outside the room, the noise levels heard by the occupants was lesser than that of the portable-type air conditioner whose compressor was situated within the room. Regardless, neither noise level produced by either air conditioner was within the standard set by the American National Standard Institute on acoustics at 35 dBa.

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