Quantitative Assessment of the Impact of Retrofitting an Electric Boiler with an Air Source Heat Pump Unit at University Campus Students Residence

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***Abstract* - The study focused on comparing the electrical energy and the volume of hot water consumed using the inefficient 18 kW, 1600 L electric boiler and an efficient and renewable air source heat pump (ASHP) unit with an input power of 6.0 kW, as retrofit to the electric boiler, for sanitary hot water production. A data acquisition system was built and deployed, to monitor the baseline while the electric boiler was in used and the performance assessment were the ASHP water heater was in operation. The results showed that the annual energy saving and the load factor reduction, due to the retrofitting of the electric boiler with the ASHP unit, was 52117.630 kWh and 0.092. One-way ANOVA test depicted that the p-value of the average month-day electrical energies consumed by the electric boiler and the ASHP water heater during the entire monitoring period was 1.09 x 10-22. A very small p-value confirmed a significant difference existed in at least one of the among four groups of the average month-day electrical energies consumed and the heating season. The implementation of ASHP water heater for sanitary water heating at the residence on University's campus served as sustainable energy technology.**

Keywords - Air source heat pump, Electric boiler, One-way ANOVA test, significant difference and p-value, energy saving, load factor

I. INTRODUCTION

An electric boiler is an inefficient sanitary hot water device, with a storage capacity greater than or equal to 500 L and the hot water heating is primarily achieved by resistive element [1]. The energy factor of an electric boiler is around 0.92 due to standing losses [2]. South Africa electricity supply utility (Eskom) is the supplier of electricity in South Africa with over 90% of its generation derived from coal. The utilization of coal as base load for electricity generation in the thermal power plant is linked with greenhouse gas emissions and global warming potential [3]. The global warming potential associated with greenhouse gases (primarily carbon dioxide) is 510 million tons, of which 45% is originated from the generation of electricity from coal [4]. Sanitary hot water production optimal threshold temperature can be set at 55 °C to prevent the growth of the bacteria (Legionella) [5]. Sanitary water heating in South Africa is the largest electrical energy consuming devices with an average of between 40 and 50% of the monthly electrical cost, associated to domestic water heating [1]. The conventional heater (electric geysers) makes up the bulk of the hot water heating devices with an average energy factor of 0.92 [6]. The type of hot water storage tank in ASHP water heater is a real challenge to the hot water temperature inside the tank. Heated water in identical volume of a storage tank by the ASHP unit, is at a much higher temperature in a dual tank than in a single tank system, but the thermal energy losses are lower for the latter [7].

The thermo-physical properties of the refrigerant are of priority in ASHP. Extensive research has exploited eco-friendly fluid, as emerging replacement of R22 (dichlorodifluoromethane) and R12 (chlorodifluoromethane) because of their high ozone depletion potential [8]. It is of almost importance to emphasized that series of researchers have effectively evaluated heat pump water heater performance. In addition, a dynamic model of an ASHP water heater was designed to achieve optimal energy management in a test room [9]. The residential ASHP water heater rebate programme was implemented as a strategic energy management intervention to avoid constraint on the national grid during peak hours, with Eskom intended to roll out 65,580 ASHP systems [10]. Tangwe et al. (2014) conducted an experimental study to show that the residential split type ASHP water heater is an energy efficient technology for sanitary hot water production [11].

Sanitary hot water production in the university's residence may achieve more energy savings, by retrofitting the existing electric boiler with a commercial ASHP unit [12]. The ASHP water heater is capable of utilizing one unit of input electrical energy and provide two to four units of useful output thermal energy during the vapour compression refrigeration cycle [13, 14]. The COP of an ASHP water heater, is governed by the design of the components that make up the close loop circuit of the heat pump unit, the thermo-physical properties of the refrigerant utilized in the heat pump and the ambient conditions [15]. The performance of an ASHP water heater depends strongly on the ambient temperature, as opposed to other weather parameters (relative humidity, wind speed) and the COP is higher in summer than in winter season [16]. The energy saving, due to retrofitting of the electric boiler with an ASHP unit, depends on the volume of hot water consumption. Therefore, the energy saving in the winter months are usually higher than the corresponding saving in the summer months, as hot water demand is more during the winter period [17]. It is imperative to mention that unlike the solar water heater, the ASHP water heaters may operate throughout the year, with an annual COP greater than 2, in any region of South Africa [18].

The commercial ASHP water heaters possess better COP than the residential ASHP water heaters, due to the type of compressor and expansion valve used. Experimental research conducted in South Africa demonstrated that both the split and integrated types of residential ASHP water heaters are viable technologies for sanitary hot water heating, with a significant energy saving [19]. The rebate programme of the residential ASHP water heaters was discontinued at the end of 2015 due to the lack of funding to sustain the scheme, although, the technology demonstrated an excellent operational performance [20].

The study focused on comparing the energy consumed and the volume of hot water heated and used with an 18 kW, 1600 L electric boiler and a split type 6 kW, 1600 L ASHP water heater, installed in a postgraduate female residence (Manheim ladies). The student residence was accommodating 80 students and is at the Central University of Technology, Bloemfontein campus, Free State Province, South Africa. In addition, an in-depth statistical tests was conducted, on the average month-day electrical energy and the volume of hot water consumed during winter and summer seasons, by the electric boiler and the ASHP water heater, to test, if any significant difference existed in the consumption.

Objectives: To execute the study, the following specific objectives were investigated:

i. To analyze the average month electrical power and energy consumed as well as the load factor for the electric boiler and the ASHP water heater over a year.

ii. To employed both a one-way ANOVA and a multiple comparison tests to demonstrate if any significant difference exist among the derived group means, of the average month-day electrical energy consumed and the volume of the hot water consumed using the electric boiler and the ASHP water heater.

II. STATISTICAL INFERENCES

The one-way ANOVA and a multiple comparison tests are the two statistical tests employed in the comparison of the electrical energy consumed and the volume of hot water consumption, when both the electric boiler and the ASHP water heater were used in the production of the hot water.

A. One-way ANOVA Test

ANOVA techniques test whether a set of group means are equal or not. Rejection of the null hypothesis leads to the conclusion that not all group means are same. This result, however, does not provide further information on which group means are different. The ANOVA test is characterised with a p-value. The p-value is the probability that the F-statistic can take a value larger than the computed test-statistic value [21]. If the p-value is less than 0.05, among group means, it imply that, at least a significant difference exist among the group means at 95% confidence level.

B. Multiple Comparison Test

The multiple comparison test is capable to perform pairwise comparison among the group means using the information contained in the statistics structure. It can also displays an interactive graph of the estimates (difference in group means in a pairwise matrix comparison) and comparison intervals (pairwise comparison of the upper and lower confidence intervals among the group means) [22]. Each group mean is represented by a symbol (circle) and the interval is represented by a line extending out from the symbol (circle). Two group means are significantly different, if their intervals are disjoint. They are not significantly different, if their intervals overlap. Alternatively, if the confidence interval in a pairwise group means does not contain 0, the difference is significant at the 5% significance level.

C. Mathematical Detail of ANOVA among Group Means

ANOVA test for the difference in the group means by partitioning the total variation in the data into two components [23]. These are:

- Variation of group means from the overall mean, given as $\bar{y}_j - \bar{y}$ (variation between groups), where $\bar{y}_j$ is the sample mean of group j, and $\bar{y}$ is the overall sample mean.
- Variation of observations in each group from their group estimates, $y_{ij} - \bar{y}_j$ (variation within group).

D. ANOVA Table

The ANOVA table captures the variability of the model by source, the F-statistic for testing the significance of this variability and the p-value for deciding on the significance of this variability [24]. The p-value is correct, only if, the distribution is independent, normally distributed and have a constant variance [25]. The standard ANOVA table has the form given in Table I.

TABLE I. STANDARD FORM OF AN ANOVA TABLE

Source	Sum square SS	Degree of freedom df	Mean square MS	F-statistic	p-value (prob > F)
Group (between)	SSR	k-1	MSR=SSR/k-1	MSR/MSE	$P(F_{k-1,N-k}) > F$
Error (within)	SSE	N-k	MSE = SSE/N-k		
Total	SST	N-1			

III. THEORY AND CALCULATIONS

Electrical energy consumed by the electric boiler or the ASHP water heater, is the product of the electrical power consumed and the time taken during the heating cycle, given in Equation 1:

$$E = Pt \quad (1)$$

Thermal energy gained by the stored water in the storage tank of the ASHP water heater, is the product of the mass of the water heated, the specific heat capacity of water and the temperature difference between the temperature of the water at the outlet and the inlet of the ASHP unit, during the heating cycle, given in Equation 2:

$$Q = mc(T2 - T1) \quad (2)$$

COP of the ASHP water heater is the ratio of the useful output thermal energy to the input electrical energy consumed during the vapour compression refrigeration cycle, given in Equation 3:

$$COP = \frac{Q}{E} \quad (3)$$

Load factor of the hot water heating devices, is the ratio of the energy consumed over a 24 h period and the product of the maximum power and period (24 h), given in Equation 4:

$$\mathrm{LF} = \frac{\mathrm{E\ over\ 24h}}{\mathrm{P_{max}\times 24h}} \quad (4)$$

The electrical energy saving achieved is based on a conservative perspective, and is the difference between the electrical energy consumed by the electric boiler and the electrical energy consumed by the ASHP water heater, on identical months. Since, it was determined that the volume of the average daily hot water consumed by the students showed negligible variation, with a percentage difference of 0.01.

ANOVA partitions the total sum of squares (SST) into sum of squares due to between-groups effect (SSR) and sum of squared errors (SSE), given in Equation 5:

$$\sum_i \sum_j \left(\bar{y}_{ij} - \bar{y}\right)^2 = \sum_j n_j \left(\bar{y}_j - \bar{y}\right)^2 + \sum_i \sum_j \left(y_{ij} - y_j\right)^2 \quad (5)$$

Where;

SST = $\sum_i \sum_j \left(\bar{y}_{ij} - \bar{y}\right)^2$

SSR = $\sum_j n_j \left(\bar{y}_j - \bar{y}\right)^2$

SSE = $\sum_i \sum_j \left(y_{ij} - y_j\right)^2$

n_j = Sample size for the group size for the jth

$j = 1,2, \ldots \ldots \ldots \ldots \ldots . . k$

The ANOVA compares the variation between group means to the variation within group means. If the ratio of within group means variation to between group means variation is significantly high, then the group means are significantly difference from each other. This can be measure using a test statistic that has an F-distribution with (k-1, N-k) degree of freedom, given in Equation 6:

$$F = \frac{SSR/k-1}{SSE/N-k} = \frac{MSR}{MSE} \cong F_{k-1,N-k} \quad (6)$$

Where;

MSR = mean squared treatment

MSE = mean squared error

k = number of groups

N = total number of observations

If the p-value for the F-statistic is smaller than the significance level, the test reject the null hypothesis that all group means are equal and concludes that at least one of the group means is different from the others [26].

IV. MATERIALS AND METHODS

The list of hot water devices, sensors and transducers used in the study, is shown in Table II.

TABLE II. HOT WATER DEVICES, SENSORS AND TRANSDUCERS USED IN THE EXPERIMENT

Materials	Quantity
Power meter	1
Flow meters	2
Temperature sensors	5
Ambient temperature and relative humidity sensor	1
1600 L, 18 kW, 3 phase electric boiler	1
6.0 kW, 3 phase, 50 Hz, ASHP unit	1
Water filter	1
Data logger	1
Waterproof enclosure	1

Figure 1 shows the electric boiler (comprised of an 18 kW resistive element contained in a 1600 L storage tank) and a 6 kW input power ASHP unit. Figure II, shows the schematic diagram of the ASHP unit retrofitting the electric boiler. The electric boiler was retrofitted with the ASHP unit and the sensors were installed at various locations of the hot water heating devices. A temperature sensor was installed at the inlet of the cold water pipe of the boiler, which feeds the main cold water into the storage tank.

This temperature sensor measured the temperature of the main cold water. A temperature sensor was installed via a hole drilled at the outlet pipe of the hot water storage tank and measured the temperature of the hot water supplied to the residence. A temperature sensor was installed via a hole drilled at the inlet of the ASHP unit, on the copper pipe feeding the condenser of the ASHP unit with water from the storage tank which was intended to undergo heating to the set point temperature.

A temperature sensor was installed via a hole drilled at the outlet of the ASHP unit, on the copper pipe allowing the heated water to exit from the outlet of the ASHP unit to the storage tank. A flow meter was installed on the pipe that led to the inlet of the ASHP unit and measured the volume of hot water heated by the ASHP unit, during the vapour compression refrigeration cycles.

A second flow meter was installed on the inlet pipe that was supplying the main cold water into the storage tank and measured the volume of hot water consumed by the students in the residence. A power meter was installed on the electrical supply line, powering either the 3 phase, 18 kW resistive element (electric boiler) or the 3 phase, 6.0 kW input power ASHP unit. The power meter measured the power consumed by either the electric boiler or the ASHP unit. An ambient temperature and relative humidity sensor was installed in the vicinity of the hot water devices and measured the ambient temperature and relative humidity. All the sensors and transducers were connected to a data logger, which was configured to log in 5 minute intervals throughout the monitoring period during the baseline (where the electric boiler was utilisation) and the performance assessment (where the ASHP water heater in used) periods. The methodology of the study is divided into two:

-i. Comparison of the energy and volume of hot water consumed as well as the load factors of both the electric boiler and ASHP water heater, for the entire monitoring period.

-ii. Performance of the statistical tests to verify if there exists any significant difference in both the electrical energy and the volume of hot water consumed while the electric boiler and ASHP water heater are in operation.

Figure 1. Installed ASHP and retrofitted electric boiler used in the study

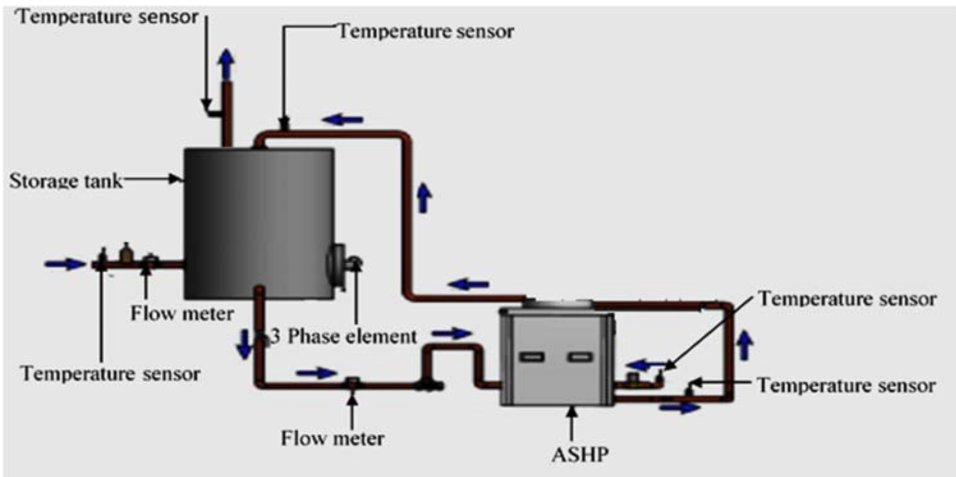

Figure 2. Schematic diagram of the electric boiler retrofitted with an ASHP unit.

V. RESULTS AND DISCUSSION

A. Average Month-Day Electrical Energy Consumed and the Volume of Hot Water Consumption

The average month-day electrical energy consumed and the volume of hot water consumed while using the electric boiler and the ASHP water heater over the entire monitoring period are presented in Figure III. The average month-day of the electrical energy and the volume of hot water consumed are shown in the subplots of the bar charts represented in Figure III. Figure III, showed that the mean of the average month-day electrical energy consumed and the volume of hot water consumed, for the electric boiler was 193.36 kWh and 1959 L over the monitored periods (January 2017 – December 2017). In addition, the mean of the average month-day electrical energy and the volume of hot water consumed over the monitored periods (January 2018 – December 2018) for the ASHP water heater was 50.62 kWh and 1940 L. The difference in the mean of the average month-day electrical energy consumed by the electric boiler (193.36 kWh) and the ASHP water heater (50.62 kWh), throughout the monitored period was 142.72 kWh. The electrical saving due to retrofitting of the electric boiler by the ASHP unit can be attributed to the characteristics of the ASHP water heater as an energy efficiency and renewable energy technology. The difference in the mean of the average month-day volume of hot water consumption was negligible (19.0 L) when compared to the average month-day consumption from the both hot water heating devices.

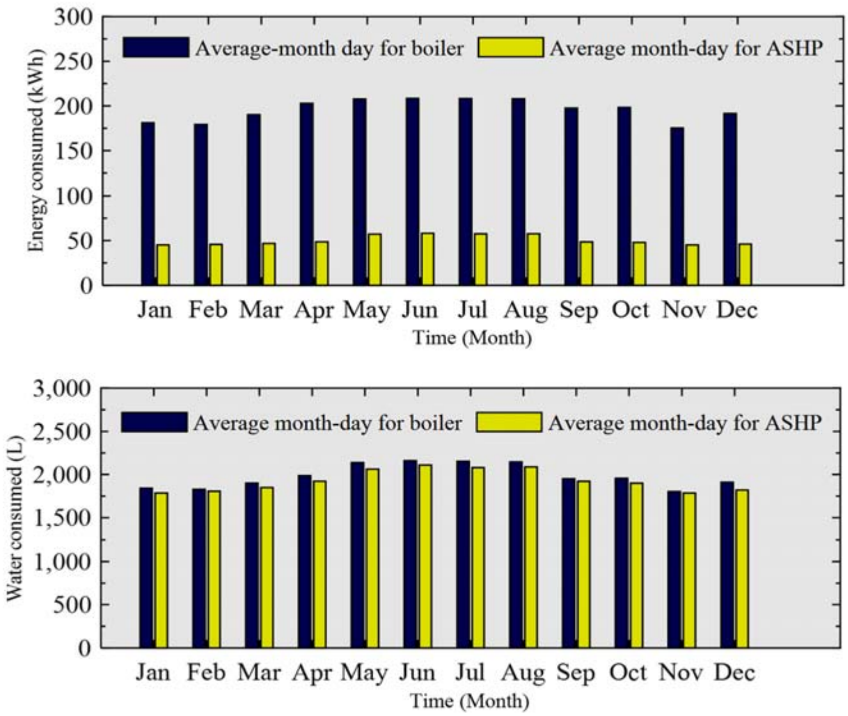

Figure 3. Systems average month-day electrical energy and volume of hot water consumed

B. Average Month Performance of the Electric Boiler and the ASHP Water Heater

Table III presents the average month performance of the electric boiler and the ASHP water heater. The electrical parameters of the electric boiler and the ASHP water heater that were used to compare the operating performance of both hot water devices for each of the months in the respective year include: the electrical energy consumed, the load factor and the average power consumed. The mean of the average months power and the energy consumed by the electric boiler was 18.38 kW and 5884.07 kWh while for the ASHP water heater was 6.55 kW and 1540.93 kWh, respectively. The difference in the mean of the average months for both the electrical power and the electrical energy consumed by the electric boiler and the ASHP water heater was 11.83 kW and 4343.136 kWh. The difference in the mean of the average months load factor of the electric boiler (0.462) and the ASHP water heater (0.369) was 0.093. The average monthly COP of the ASHP water heater was 3.18.

TABLE III, AVERAGE MONTH PERFORMANCE OF THE ELECTRIC BOILER AND THE ASHP WATER HEATER

Month	systems	p/kW	E/kWh	LF	COP
January	Electric boiler	18.08	5616.61	0.454	
	ASHP	6.60	1401.91	0.372	3.40
February	Electric boiler	18.33	5021.01	0.451	
	ASHP	6.49	1279.92	0.364	3.52
March	Electric boiler	18.16	5634.34	0.455	
	ASHP	6.61	1448.56	0.367	3.46
April	Electric boiler	18.16	6048.90	0.459	
	ASHP	6.51	1523.41	0.370	3.00
May	Electric boiler	18.55	6437.60	0.457	
	ASHP	6.58	1773.06	0.382	2.85
June	Electric boiler	18.77	6255.67	0.468	
	ASHP	6.24	1742.79	0.354	2.88
July	Electric boiler	18.57	6455.77	0.466	
	ASHP	6.57	1783.70	0.372	2.97
August	Electric boiler	18.63	6376.87	0.464	
	ASHP	6.46	1808.66	0.370	2.90
September	Electric boiler	18.45	5928.78	0.457	
	ASHP	6.63	1457.28	0.372	3.12
October	Electric boiler	18.28	6148.57	0.478	
	ASHP	6.6	1489.48	0.364	3.14
November	Electric boiler	18.33	5258.68	0.466	
	ASHP	6.64	1355.90	0.372	3.48
December	Electric boiler	18.34	5425.99	0.464	
	ASHP	6.66	1426.47	0.370	3.39

C. One-way ANOVA Test among the Derived Groups Means

The group's means was classified into four groups with each group composed of the average month-day electrical energies consumed by the hot water devices and the heating seasons. The four group means include; the average month-day electrical energies consumed by electric boiler during the summer season (E_{bs}), the average month-day electrical energies consumed by ASHP water heater during the summer season (E_{as}), the average month-day electrical energies consumed by electric boiler during the winter season (E_{bw}) and the average month-day electrical energies consumed by ASHP water heater during the winter season (E_{aw}). Similarly, four groups means of the average month-day volumes of hot water consumed from the hot water heating devices and the seasons were also derived. These included the average month-day volumes of hot water consumed from electric boiler during the summer season (V_{bs}), the average month-day volumes of hot water consumed from ASHP water heater during the summer season (V_{as}), the average month-day volumes of hot water consumed from electric boiler during the winter season (V_{bw}) and the average month-day volumes of hot water consumed from ASHP water heater during the winter season (V_{aw}). One-way ANOVA test were conducted on the derived group means of electrical energies and volumes of hot water consumed. It is critical to emphasized that the summer months were January, February, March, April, September, October, November and December while the winter months were May, June, July and August in a year.

C1. One-Way ANOVA Test among the Derived Groups Means of Electrical Energies Consumed

Table IV shows that the sum of the squared for the between group means was 127979.4 while that of the within group means was 718.7. The total sum of squared for the group means was the sum for the between group means and the within group means and was 128698.1. The degree of freedom for the between group means and the within group means was 3 and 20. The total degree of freedom was 23. The mean squared between the group means was 42659.8 while the mean squared within the group means was 35.9. The F-statistic of the group means of the average month-day electrical energy consumed was 1187.06. The large value of the F-statistic revealed that the ratio of the mean squared of the between group means and the within group means for the distribution was very large and resulted in a very small p-value of 1.09×10^{-22}. The very small p-value, justified that at least there exist a significant difference at a 5% significance level between the groups pairs, among the four group means (consisting of the average month-day electrical energies consumed).

TABLE IV. ONE-WAY ANOVA TABLE OF THE AVERAGE MONTH-DAY ELECTRICAL ENERGY CONSUMED

Source	Sum Square SS	Degree Of Freedom Df	Mean Square MS	F-Statistic	P-Value (Prob > F)
Group (between)	127979.4	3	42659.8	1187.06	1.09×10^{-22}
Error (within)	718.7	20	35.9		
Total	128698.1	23			

C2. Multiple Comparison Test among the Derived Group Means of Electrical Energies Consumed

The multiple comparison test is an advanced ANOVA test used to show if there exist any significant difference between the group pairs at 5% significance level among the four group means of electrical energies consumed (E_{bs}, E_{as}, E_{bw} and E_{aw}). Table V shows the multiple comparison matrix among the group means of the average month-day electrical energies consumed. The lower confidence interval for a group pair is the mean of the true difference between the 95% lower confidence levels of the two group means. The upper confidence interval for a group pair is the mean of the true difference between the 95% upper confidence levels of the two group means. The confidence interval is the range between the lower confidence interval and the upper confidence interval for a pair of group means. The estimate is the difference in the means of a group pair contain in a given group means. The estimate for the pair of group means of E_{as} and E_{aw} was -10.86 and the 95% confidence interval for the true difference of the means is [138.61 162.34]. The confidence interval does not contain 0, so the difference is significant at 5% significance level. Therefore, the p-value for the corresponding hypothesis test that the difference of the means of the groups E_{as} and E_{aw} is significantly different from 0 is 0.035. Since, the p-value of 0.035 is less than the 0.05 significance level, there exist a significant different between the group means of E_{as} and E_{aw}. Furthermore, based on similar interpretation of the rest of the five group pairs (E_{bs} and E_{as}; E_{bs} and E_{aw}; E_{bs} and E_{aw}; E_{as} and E_{bw}; E_{bw} and E_{aw}), it can be illustrated that all the corresponding confidence intervals do not include 0 and their p-values were very smaller than the 5% significance level. We can conclude that all the six between group pairs from the four among group means of average month-day electrical energies consumed are significantly different.

TABLE V. MULTIPLE COMPARISON OF THE AVERAGE MONTH-DAY ELECTRICAL ENERGIES CONSUMED

Group	Group	Lower Confidence Interval	Estimate	Upper Confidence Interval	P-Value
E_{bs}	E_{as}	134.38	142.77	151.16	3.81×10^{-9}
E_{bs}	E_{bw}	-28.84	-18.56	-8.29	3.25×10^{-4}
E_{bs}	E_{aw}	121.63	131.91	142.18	3.81×10^{-9}
E_{as}	E_{bw}	-171.61	-161.34	-151.06	3.81×10^{-9}
E_{as}	E_{aw}	-21.13	-10.86	-0.58	0.035
E_{bw}	E_{aw}	138.61	150.47	162.34	3.81×10^{-9}

Figure 4 shows the multiple comparison interactive graph of the four group means of average month-day electrical energies consumed. It can be deduced from Figure 4, that no group pairs, among the four group means overlap and therefore, all the group pairs were significantly different from each other.

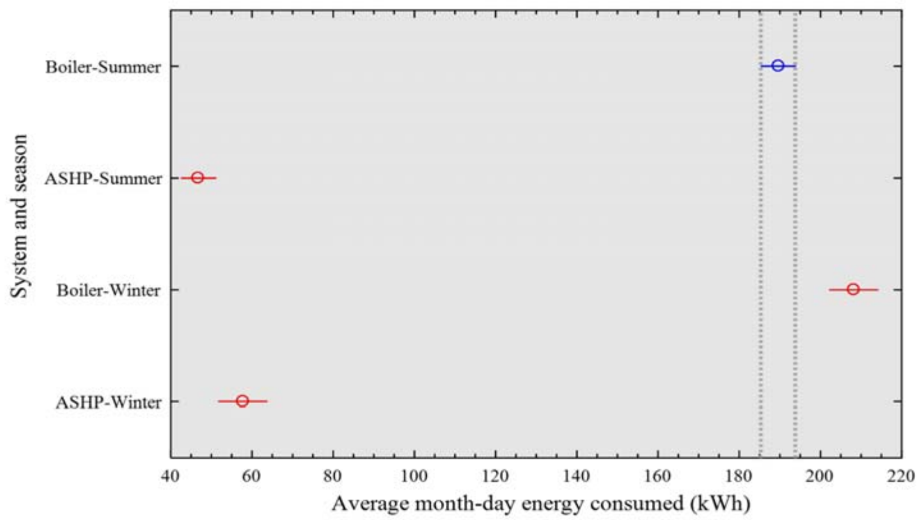

Figure 4. Multiple comparison plot of the four group means of average month-day energies consumed

C3. One-way ANOVA Test among the Derived Groups Means of Volumes of Hot Water Consumed

Table VI, shows that the sum of the squared for the between group means was 336364.5 while that of the within group means was 56615.5. The total sum of squared for the group means was 392980. The degree of freedom for the between group means and the within group means was 3 and 20. Hence, the total degree of freedom was 23. The mean squared between the group means was 112121.5 while the mean squared within the group means was 2830.8. The F-statistic of the group means of the average month-day volumes of hot water consumed was 39.61. The large value of the F-statistic revealed that the ratio of the mean squared of the between group means and the within group means for the distribution was large and resulted in a very small p-value of 1.33 x 10^{-8}. The very small p-value, justified that at least there exist a significant difference at a 5% significance level between the groups pairs, among the four group means.

TABLE VI. ONE-WAY ANOVA TABLE OF THE AVERAGE MONTH-DAY VOLUMES OF HOT WATER CONSUMED

Source	Sum Square SS	Degree Of Freedom Df	Mean Square MS	F-Statistic	P-Value (Prob > F)
Group (between)	336364.5	3	112121.5	39.61	1.33 x 10^{-8}
Error (within)	56615.5	20	2930.8		
Total	392980	23			

C4. Multiple Comparison Test among the Derived Group Means of Volumes of Hot Water Consumed

Table VII, shows the multiple comparison matrix among the four group means of average month-day volumes of water consumed (V_{bs}, V_{as}, V_{bw} and V_{aw}). The two groups pairs (V_{bs} and V_{as}; V_{bw} and V_{aw}) showed the 95% confidence intervals for the true difference of the means as [-26.25 122.66] and [-42.17 168.42], respectively. Each of the confidence intervals do contain 0, so the difference are not significant at 5% significance level. More so, the p-values of the groups means (V_{bs} and V_{as}) and (V_{bw} and V_{aw}) are 0.297 and 0.360. Since, the p-values are greater than the 0.05 significance level, there exist no significant different between the group means of (V_{bs} and V_{as}) and (V_{bw} and V_{aw}). In accordance to the interpretation for the group paired comparison, the confidence intervals of the group pairs (V_{bs} and V_{bw}; V_{bs} and V_{aw}; V_{as} and V_{bw}; V_{as} and V_{aw}), do not include 0 and their p-values are very smaller than the 5% significance level. We can conclude that these four group pairs (V_{bs} and V_{bw}; V_{bs} and V_{aw}; V_{as} and V_{bw}; V_{as} and V_{aw}), of average month-day volumes of hot water consumed are significantly different.

TABLE VII. MULTIPLE COMPARISON OF THE AVERAGE MONTH-DAY VOLUMES OF HOT WATER CONSUMED

Group	Group	Lower Confidence Interval	Estimate	Upper Confidence Interval	P-Value
V_{bs}	V_{as}	-26.25	48.20	122.66	0.297
V_{bs}	V_{bw}	-343.25	-252.06	-160.87	1.11 x 10^{-6}
V_{bs}	V_{aw}	-280.13	-188.94	-97.74	6.22x 10^{-5}
V_{as}	V_{bw}	-391.46	-300.26	-209.07	7.38 x 10^{-8}
V_{as}	V_{aw}	-328.33	-237.14	-145.95	2.74 x 10^{-6}
V_{bw}	V_{aw}	-42.17	63.12	168.42	0.360

Figure 5 shows the multiple comparison interactive graph of the four group means of average month-day volumes of hot water consumed. It can be depicted from Figure V, that two of the groups pairs (Vbs and Vas; Vbw and Vaw) among the four group means do overlap and therefore, exhibited no significant different. But, Figure V also showed that, four of the groups pairs (Vbs and Vbw; Vbs and Vaw; Vas and Vbw; Vas and Vaw) among the four group means are disjoint and hence, there exist significant different between each of the group pairs.

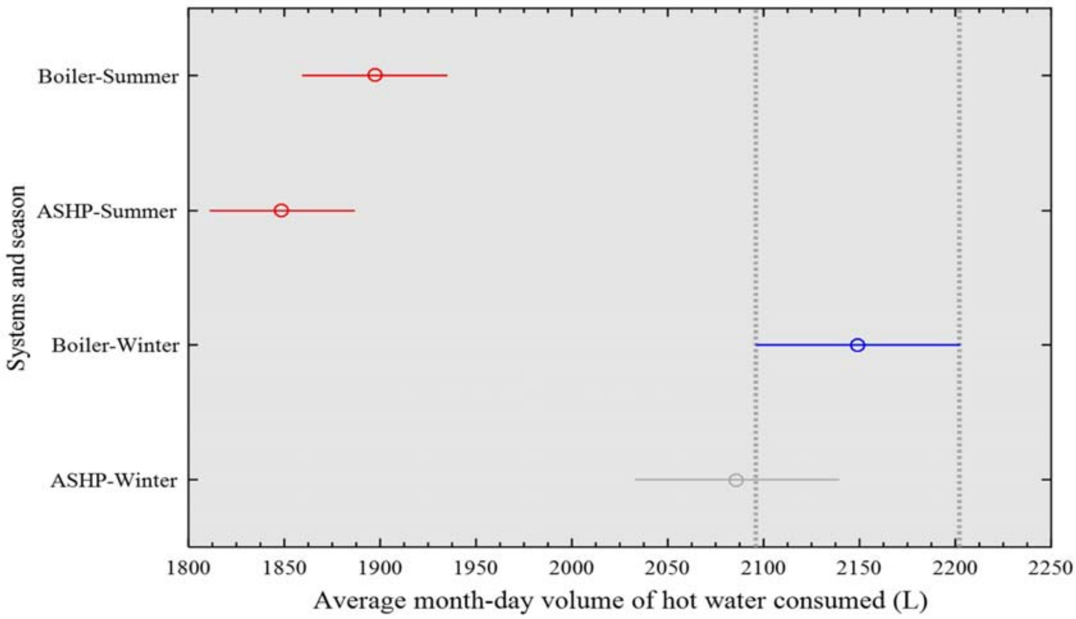

Figure 5. Multiple comparison plot of the group means of average month-day volumes of hot water consumed.

VI. CONCLUSION

It may be concluded that, the retrofitting of an existing electric boiler with an ASHP unit in a students' residence at the University campus, can lead to both reduction in electrical energy consumption and electricity cost saving. The average month electrical power and the annual energy saving, due to the retrofitting of the electric boiler by the ASHP unit, was 11.83 kW and 52117.63 kWh with reference to the consumption from the inefficient electric boiler. The implementation of the ASHP unit as an energy efficient and renewable energy technology, was accompanied by a decreased in the load factor. In addition to the very small p-value of 1.09×10^{-22} among the four group means of average month-day electrical energies consumed, it was concluded using the multiple comparison test that there exist a significant different between all the group pairs. Finally, the multiple comparison test among the four groups means of average month-day volumes of hot water consumed, demonstrated that not all the groups pairs among the groups means were significant difference.

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REFERENCES

[1] Rousseau, P.G. and Greyvenstein, G.P., 2000. Enhancing the impact of heat pump water heaters in the South African commercial sector. Energy, 25(1), pp.51-70. https://doi.org/10.1016/S0360-5442(99)00053-5
[2] Hiller, C.C., 2005. Comparing water heater vs. hot water distribution system energy losses. ASHRAE transactions, 111, p.407. Retrieved from https://search.proquest.com/docview/192580727?accountid=15731
[3] Shin, H.C., Park, J.W., Kim, H.S. and Shin, E.S., 2005. Environmental and economic assessment of landfill gas electricity generation in Korea using LEAP model. Energy policy, 33(10), pp.1261-1270. https://doi.org/10.1016/j.enpol.2003.12.002
[4] S. Tangwe, M. Simon and E. Meyer, "Quantifying residential hot water production savings by retrofitting geysers with air source heat pumps," 2015 International Conference on the Domestic Use of Energy (DUE), Cape Town, 2015, pp. 235-241. DOI: 10.1109/DUE.2015.7102986.
[5] Proctor, C.R., Dai, D., Edwards, M.A. and Pruden, A., 2017. Interactive effects of temperature, organic carbon, and pipe material on microbiota composition and Legionella pneumophila in hot water plumbing systems. Microbiome, 5(1), p.130. https://doi.org/10.1186/s40168-017-0348-5
[6] Willem, H., Lin, Y. and Lekov, A., 2017. Review of energy efficiency and system performance of residential heat pump water heaters. Energy and Buildings, 143, pp.191-201. https://doi.org/10.1016/j.enbuild.2017.02.023
[7] Ni, L., Dong, J., Yao, Y., Shen, C., Qv, D. and Zhang, X., 2015. A review of heat pump systems for heating and cooling of buildings in China in the last decade. Renewable Energy, 84, pp.30-45. https://doi.org/10.1016/j.renene.2015.06.043
[8] Bhatkar, V.W., Kriplani, V.M. and Awari, G.K., 2013. Alternative refrigerants in vapour compression refrigeration cycle for sustainable environment: a review of recent research. International Journal of Environmental Science and Technology, 10(4), pp.871-880. https://doi.org/10.1007/s13762-013-0202-7
[9] Zhang, J., Wang, R.Z. and Wu, J.Y., 2007. System optimization and experimental research on air source heat pump water heater. Applied

thermal engineering, 27(5-6), pp.1029-1035. https://doi.org/10.1016/j.applthermaleng.2006.07.031

[10] Van Eeden, S.J., Jacobsz, S.W., Rust, M. and Rust, E., 2016. Electricity generation as a beneficial post-closure land use option for a dormant tailings storage facility. Journal of the South African Institution of Civil Engineering, 58(1) pp 53-61. http://dx.doi.org/10.17159/2309-8775/2016/v58n1a6

[11] Tangwe, S., Simon, M. and Meyer, E., 2014. Analytical evaluation of the energy losses of an air source heat pump water heater: A retrofit type. Journal of Energy and Power Engineering, 8(7).

[12] Kalkan, N., Bercin, K., Cangul, O., Morales, M.G., Saleem, M.M.K.M., Marji, I., Metaxa, A. and Tsigkogianni, E., 2011. A renewable energy solution for Highfield Campus of University of Southampton. Renewable and sustainable energy reviews, 15(6), pp.2940-2959. https://doi.org/10.1016/j.rser.2011.02.040

[13] Gang, P., Guiqiang, L. and Jie, J., 2011. Comparative study of air-source heat pump water heater systems using the instantaneous heating and cyclic heating modes. Applied thermal engineering, 31(2-3), pp.342-347. https://doi.org/10.1016/j.applthermaleng.2010.09.020

[14] Hepbasli, A. and Kalinci, Y., 2009. A review of heat pump water heating systems. Renewable and Sustainable Energy Reviews, 13(6-7), pp.1211-1229. https://doi.org/10.1016/j.rser.2008.08.002

[15] Liang CH, Zhang XS, Li XW, Zhu X. Study on the performance of a solar assisted air source heat pump system for building heating. Energy and Buildings. 2011 Sep 1;43(9):2188-96. https://doi.org/10.1016/j.enbuild.2011.04.028

[16] Schibuola, L. and Scarpa, M., 2016. Experimental analysis of the performances of a surface water source heat pump. Energy and Buildings, 113, pp.182-188. https://doi.org/10.1016/j.enbuild.2015.12.048

[17] Wu, J., Xian, T. and Liu, X., 2019. All-weather characteristic studies of a direct expansion solar integrated air source heat pump system based on PCMs. Solar Energy, 191, pp.34-45. https://doi.org/10.1016/j.solener.2019.08.057

[18] Tangwe, S.L., 2018. Demonstration of residential air source heat pump water heaters performance in South Africa: Systems monitoring and modelling (Doctoral dissertation, University of Sunderland). http://sure.sunderland.ac.uk/id/eprint/10269

[19] Di Placido, A.M., Pressnail, K.D. and Touchie, M.F., 2014. Exceeding the Ontario Building Code for low-rise residential buildings: Economic and environmental implications. Building and environment, 77, pp.40-49. https://doi.org/10.1016/j.buildenv.2014.03.015

[20] Moore, D.S. and Kirkland, S., 2007. The basic practice of statistics (Vol. 2). New York: WH Freeman.

[21] Siraj, S., Mikhailov, L. and Keane, J., 2012. A heuristic method to rectify intransitive judgments in pairwise comparison matrices. European Journal of Operational Research, 216(2), pp.420-428. https://doi.org/10.1016/j.ejor.2011.07.034

[22] Melo, A.S., Rangel, T.F.L. and Diniz□Filho, J.A.F., 2009. Environmental drivers of beta□diversity patterns in New□World birds and mammals. Ecography, 32(2), pp.226-236. https://doi.org/10.1111/j.1600-0587.2008.05502

[23] Kachelmeier, S.J. and Messier Jr, W.F., 1990. An investigation of the influence of a non-statistical decision aid on auditor sample size decisions. Accounting review, pp.209-226. www.jstor.org/stable/247884

[24] Nahm, F.S., 2016. Nonparametric statistical tests for the continuous data: the basic concept and the practical use. Korean journal of anesthesiology, 69(1), p.8. doi: 10.4097/kjae.2016.69.1.8

[25] Gollier, C., 2010. Expected net present value, expected net future value, and the Ramsey rule. Journal of Environmental Economics and Management, 59(2), pp.142-148. https://doi.org/10.1016/j.jeem.2009.11.003

[26] Anderson, M.J., 2001. Permutation tests for univariate or multivariate analysis of variance and regression. Canadian journal of fisheries and aquatic sciences, 58(3), pp.626-639. https://doi.org/10.1139/f01-004.

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APPENDIX

Nomenclature	**Full meaning**
P	Average electrical power in kW
Pmax	Maximum electrical power consumed in kW
t	time taken in h
E	Electrical energy consumed in kWh
Q	Thermal energy consumed in kWh
T1	Water temperature of the inlet of ASHP in oC
T2	Water temperature of the outlet of ASHP in oC
m	Mass of water heated in kg
c	Specific heat capacity of water in kJ/kgoC
COP	Coefficient of performance
LF	Load factor
p-value	Probability of the F statistics
ANOVA	Analysis of variance
SST	Total sum of square among the group means
SSR	Sum of square between the group means
SSE	Sum of square within the group means
E_{bs}	Average month-day electrical energies consumed by electric boiler during summer in kWh
E_{as}	Average month-day electrical energies consumed by ASHP water heater during summer in kWh
E_{bw}	Average month-day electrical energies consumed by electric boiler during winter in kWh
V_{bs}	Average month-day volumes of hot water consumed from electric boiler during summer in L
V_{as}	Average month-day volumes of hot water consumed from ASHP water heater during summer in L
V_{bw}	Average month-day volumes of hot water consumed from electric boiler during winter in L
V_{aw}	Average month-day volumes of hot water consumed from ASHP water heater during winter in L