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Performance analysis of an air conditioner with variable thermostat and ambient temperature

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Abstract: Air conditioners are used for maintaining a good Thermal Comfort (TC) and Indoor Air Quality (IAQ) inside the air conditioned room. Performance of air conditioner generally reflects the TC, IAQ inside the room and the power consumption by the air conditioner. In this study a Split Air Conditioner (SAC) of 1.5 ton (TR) is considered for experimentation. This study investigates how the power consumptions vary with the variation of thermostat temperature and ambient temperature. It is found that in the environment of Guwahati it is not necessary to keep the thermostat temperature always below 20^0C to maintain the thermal comfort. This investigation shows that a good amount of power and money can be shaved by controlling the Thermostat Temperature (TT) with respect to Ambient Temperature (AT). The finding indicates that at a constant ambient temperature of 32^0 C when the thermostat temperature set at 18^0 C, 22^0 C and 24^0 C, 21% and 35% of power can be shaved in case of 22^0 C and 24^0 C in comparison to 18^0 C. This paper further indicates that at constant thermostat temperature of 19 ^{0} C when the ambient temperature varies like 21^0 C, 24^0 C and 28^0 C, 15% and 41% power reduction occurs in case of 24^0 C and 21^0 C in comparison to 28^0C.

Keywords: TC, IAQ, SAC, TR, TT, AT

I. INTRODUCTION

Air conditioners are now days considered as one of the essential commodity which can maintain a good thermal comfort and indoor air quality. Performance of air conditioner is a great concern of today's life as 40% of the electricity is consumed by the buildings due to the air conditioners. Lot of power consumption is always threat to the society. As the uses of air conditioner are growing exponentially the power consumption growth rate is also increasing tremendously. For the increasing of global temperature the use of air conditioner is also increasing. Therefore the reduction of energy consumption in building is one of the way to reduce green house emission. The power consumed by an air conditioner can be minimized by efficient controlling of thermostat temperature. It also depends on the ambient weather temperature how the energy efficiency of the air conditioner will vary.

In 2014, QUANG T N,HE Cong-rong, KNIBBS L D,DEAR R D[1], had done an experimental investigation on co-optimisation of indoor environmental quality and energy consumption within urban office buildings.

In 2009,A Avgelis and AM Papadopoulos[2], discusses a study which aims to develop a method for choosing and managing in the best possible way Heating, Ventilating and Air Conditioning (HVAC) systems in new and existing buildings.This method utilizes a combination of two analysis tools, the multi-criteria decision making and building simulation towards the direction of a holistic assessment of a holistic assessment of HVAC systems. In 2016, Shailendra Singh Chauhan and S.P.S. Rajput [3], carried out experimental analysis of an vapour compression based combined air conditioning system for providing required human comfort conditions at comparatively low cost. They have experimentally analysed the combined system in an experimental setup at Bhopal, India. They found that the designed air conditioning system provides required human comfort condition from both temperature and humidity point of view and works well for around eight months in a year. In 2002, I P Knight and G N Dunn[4], presented a 3-year field monitoring programme researching the energy consumption of air conditioning systems in UK offices. Preliminary findings of the work indicates that laboratory system efficiency tests are not sufficient to predict whether one AC system will be more efficient than another when installed in a real building. The work suggests instead that the primary factors affecting A/C system energy performance "as installed" are system design, system control and the loads served by the system. In 2007, Ruey Lung Hwang and Ming Jen Chung[5], conducted field experiments in 29 air-conditioned offices ,used survey questionnaire and physical measurements to investigate ,workers subjective thermal responses and comfort perception. In 2013, Nan Wang, Jiangfeng Zhang and Xiaohua Xia[6] made an analysis on energy consumption calculation model of a data center in South Africa which is presented to estimate the energy consumption of air conditioners at different temperature set points. They found that coefficient of variation of root mean square error between the estimated data and measured test data is 11.5%.

In 2016, Xin Zhou, Da Yan and Xing Shi[7] focuses a study on three actual engineering projects of residential communities where centralized AC systems are adopted. This study shows that in residential buildings, at the point where the centralized feature of the system meets the decentralized feature of users' load, the problems of high energy consumption and low energy efficiency could easily occur.
In 2013, Brahim Mebarki, Belkacem Draoui, Boumediene Allaou and Lakhdar Rahmani[8] made an analysis to stimulate the air conditioning system impact on the power energy source of an electric vehicle powered by a lithium-ion battery.
In 2007, B.F Yu, Z.B Hu,M.Liu,H.L Yang and Y.H Liu[9] made an study on air-conditioning systems and indoor air quality control for healthy indoor environment.In this paper recent research is reviewed on air-conditioning system and indoor air quality control for indoor air quality control for healthy indoor air environment.
In 2016, Kwesi Mensah and Jong Min Choi[10] made an analysis to for reducing the energy consumption significantly according to increment of setting temperature of the chamber as well as ensuring system stability for temperature and humidity chambers

II. EXPERIMENTAL SETUP AND PROCEDURE

In this experiment a 1.5 ton split air conditioner is considered for the experimentation as shown in Figure.1. Here in this experiment two cases were considered. For case I at the fixed ambient temperature the power consumed by the air conditioner was measured when the thermostat temperature was set at different temperature for duration of one hour each. For case II the power consumed by air conditioner was measured when the thermostat temperature is kept fixed for different ambient temperature. The instrument used for the experimentation was hygrometer, clamp meter and thermocouple as shown in figure 2,3 and 4.

Figure1. Experimental set up

Figure2.Hygrometer

Figure3. Clamp meter

Figure4. Thermocouple

III.RESULT AND DISCUSSION

The refrigerant used in the AC is Refrigerant 22 (Monochlorodifluoromethane).
In order to calculate the total energy consumed by the Air Conditioning System at different thermal conditions it is required to calculate power, running time and stopping (Idle) time of the compressor and other electrical parameters like current, voltage etc, at those different thermal conditions (both ambient and thermal). In order to estimate this, two cases of experiments were considered.

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Case (A): Keeping the Ambient Temperature constant and having a varying Thermostat Temperature.
From the various experiments performed, only one pair of data was considered in this paper satisfying case (A) for proper energy performance analysis.
Ambient Temperature (constant) =32^0 C
(a) Thermostat Temperature (varying) = 18^0 C
(b) Thermostat Temperature (varying) = 22^0 C
(c)Thermostat Temperature (varying) = 24^0 C
Now for condition (a), the energy consumption obtained for duration of one hour is as shown in Table1 and the graphs were plotted to represent power and energy consumption versus time in Figure. 5 and 6.

Table 1: Power Consumption at 18^0 C thermostat temperature (at constant ambient temperature=32^0 C)

Compressor/Fan Condition	Time (in PM)=t	Power(in kW)=P	Current(in Amp)=I	Power Factor=p.f	Voltage (in volts)=V	Run Time(in min)=t_r	Idle Time(in min)=t_s	Energy consumed(in kWh)=E
Running	01:08	1.587	4.5	0.98	360			
Idle	01:39	0	0.2	0.71	0.022	31		0.8199
Running	01:43	1.57	4.4	0.98	364		4	
Idle	01:50	0	0.2	0.56	0.016	7		0.1832
Running	01:53	1.54	4.5	0.98	350		3	
Idle	01:59	0	0.2	0.54	0.015	6		0.1540
Running	02:02	1.516	4.6	0.98	333		3	
Idle	02:08	0	0.2	0.51	0.013	6		0.1516

Here,
Total running time of the compressor=t_{r1}=31+7+6+6=50 min
Total stopping time of the compressor=t_{s1}=4+3+3=10 min
Total energy consumed (in one hour) =$E_{1=}$0.8199+0.1832+0.1540+0.1516=1.3087 kW

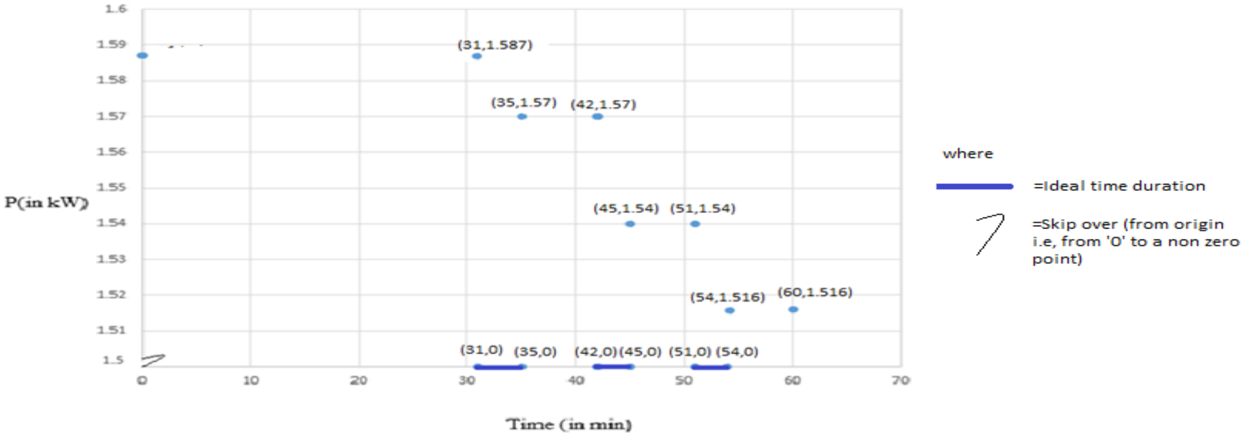

Fig 5: Power Vs Time Graph for 32^0 C Ambient temperature and 18^0 C thermostat temperature.

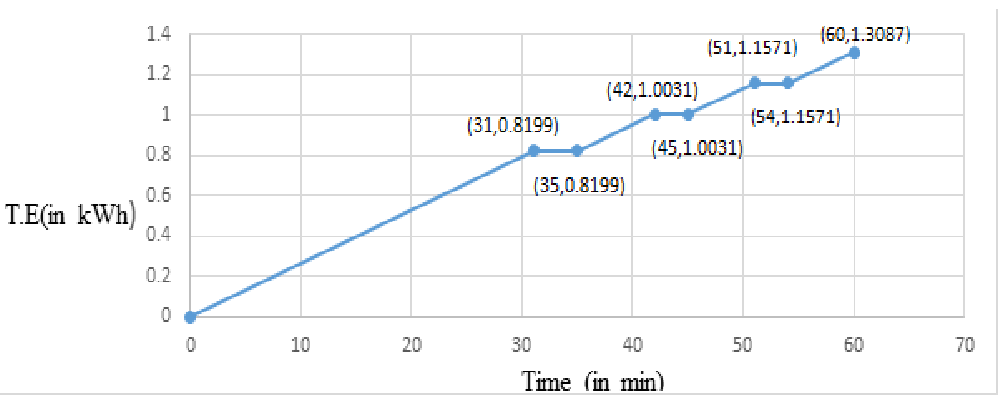

Fig 6: Total Energy Vs Time Graph for 32^0 C ambient temperature and 18^0 C thermostat temperature.

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As in above, for condition (b) the power consumed by the air conditioner for duration of one hour is shown in Table.2 and the graphs are plotted as shown in Figure.7 and 8.

Table 2: Power Consumption at 22^0 C thermostat temperature (at constant ambient temperature=32^0 C)

Compressor Condition	Time (in PM)=t	Power(in kW)=P	Current(in Amp)=I	Power Factor=p.f	Voltage (in volts)=V	Run Time(in min)=t_r	Idle Time(in min)=t_s	Energy consumed(in kWh)=E
Running	01:20	1.54	4.3	0.98	365			
Idle	01:40	0	0.2	0.71	0.022	20		0.5133
Running	01:45	1.529	4.6	0.98	340		5	
Idle	01:54	0	0.2	0.56	0.016	9		0.2294
Running	02:00	1.521	4.7	0.98	333.3		6	
Idle	02:07	0	0.2	0.54	0.015	7		0.1775
Running	02:13	1.517	4.8	0.98	322		6	
Idle	02:18	0	0.2	0.51	0.013	5		0.1264
Idle	02:20	0	0.2	0.51	0.013		2	0

Here,
Total running time of the compressor=t_{r2}=20+9+7+5=41 min
Total stopping time of the compressor=t_{s2}=5+6+6+2=19 min
Total energy consumed (in one hour) =E_2=0.5133+0.2294+0.1775+0.1264=1.0466 kWh

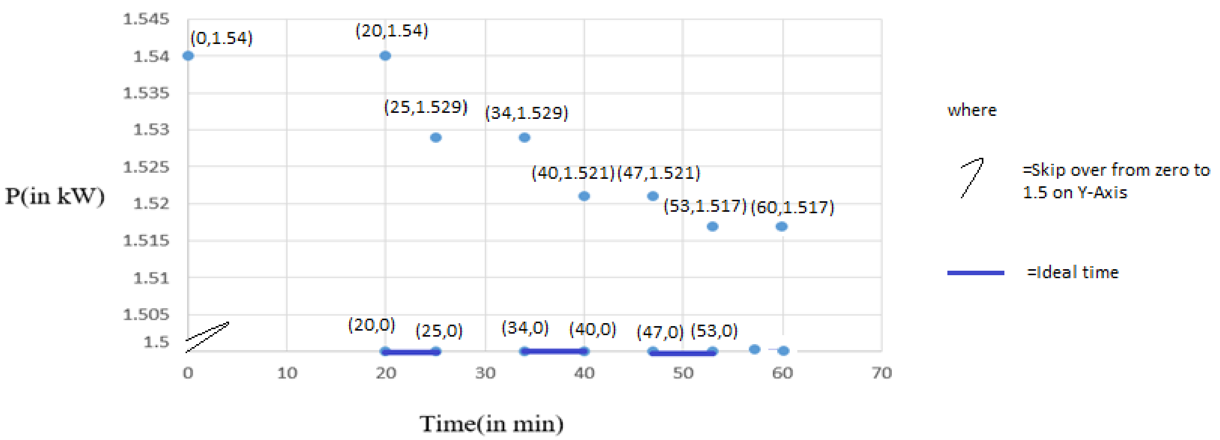

Fig 7: Power Vs Time Graph for 32^0 C ambient temperature and 22^0 C thermostat temperature.

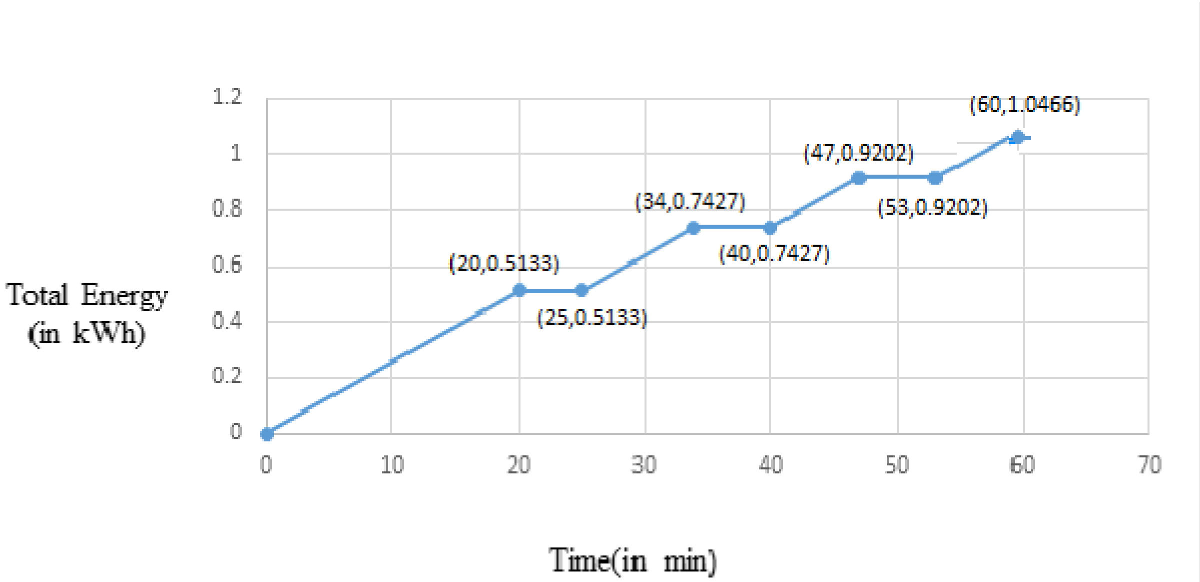

Fig 8: Total Energy Vs Time Graph for 32^0 C ambient temperature and 22^0 C thermostat temperature.

Now for condition (c), the power consumed by air conditioner for duration of one hour is shown in Table 5 and the graphical presentation is expressed in Figure.9 and 10.

Table 5: Power Consumption at 24^0 C thermostat temperature (and at constant ambient temperature=32^0 C)

Compressor Condition	Time (in PM)=t	Power(in kW)=P	Current(in Amp)=I	Power Factor=p.f	Voltage (in volts)=V	Run Time(in min)=t_r	Idle Time(in min)=t_s	Energy consumed(in kWh)=E
Running	01:32	1.35	4.3	0.98	322.3			
Idle	01:51	0	0.2	0.71	0.022	19		0.4275
Running	01:56	1.348	4.6	0.98	300		5	
Idle	02:04	0	0.2	0.56	0.016	8		0.1797
Running	02:10	1.319	4.5	0.98	303.2		6	
Idle	02:16	0	0.2	0.54	0.015	6		0.1319
Running	02:22	1.306	4.7	0.98	290.5		6	
Idle	02:27	0	0.2	0.51	0.013	5		
Idle	02:32	0	0.2	0.51	0.013		5	0.1088

Here,
Total running time of the compressor=t_{r3}=19+8+6+5=38 min
Total stopping time of the compressor=t_{s3}=5+6+6+5=22 min
Total energy consumed (in one hour) =$E_{3=}$0.4275+0.1797+0.1319+0.1088=0.8479 kWh

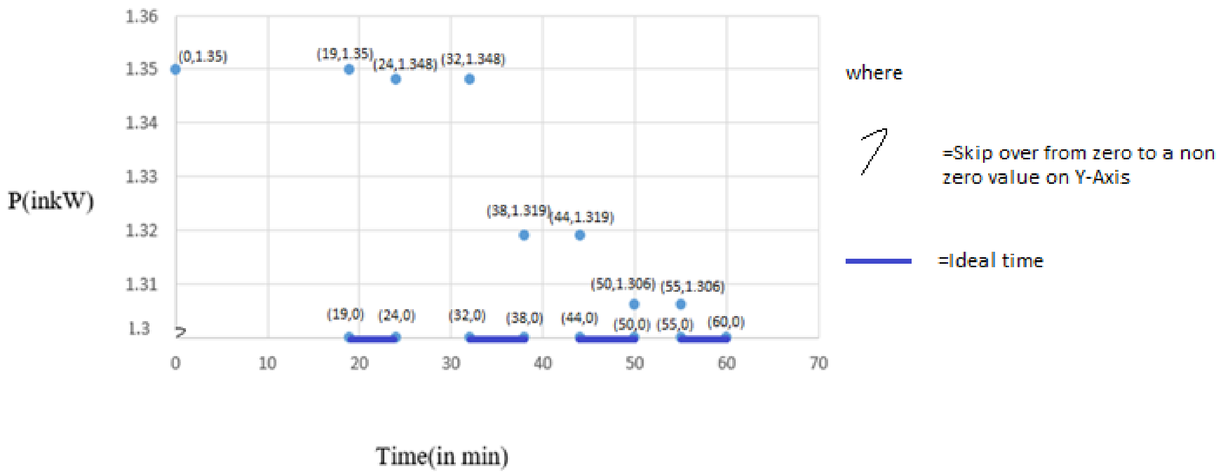

Fig 9: Power Vs. Time Graph for 32^0 C ambient temperature and 24^0 C thermostat temperature.

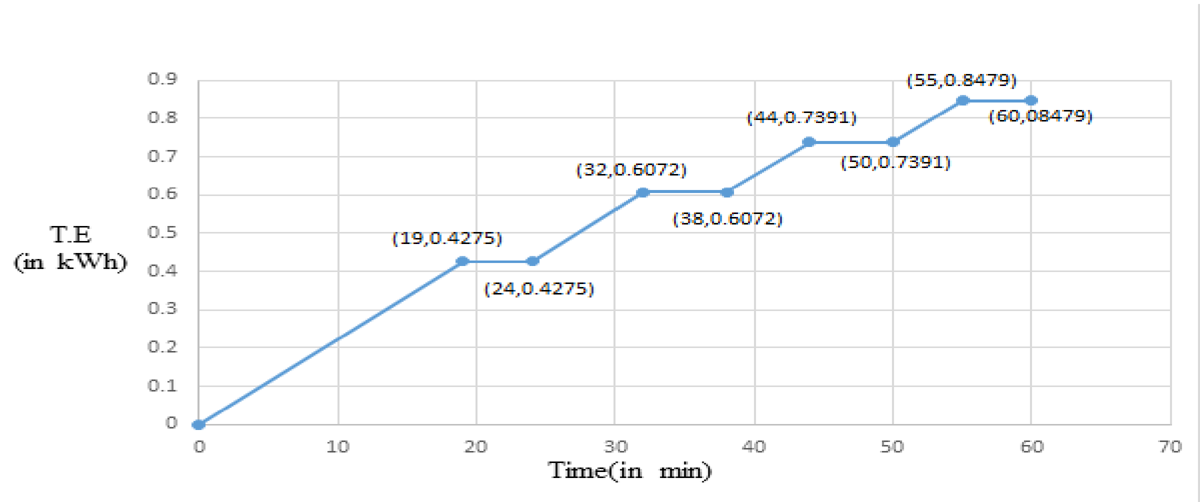

Fig10. Total Energy Vs Time Graph for 32^0 C ambient temperature and 24 ^{0} C thermostat temperature.

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Comparing the curves of Case (A) having a constant Ambient Temperature of 32℃, it is found that the total running time of the compressor was more when the thermostat temperature was at 22℃ than the total running time of the compressor when the thermostat temperature was at 24℃ i.e.($t_{r1}>t_{r2}>t_{r3}$). Therefore the total Idle time (or the stopping time) of the compressor was more when the thermostat temperature was at 24℃ than the total running time of the compressor when the thermostat temperature was at 22℃ i.e. ($t_{s3}> t_{s2}>t_{s1}$).The total energy consumed is more when the thermostat temperature is at 22℃ than the total energy consumed when the thermostat temperature is at 24℃ i.e. ($E_1>E_2>E_3$).
Case (B): Keeping the Thermostat Temperature constant and having a varying ambient temperature. From the various experiments performed, only one pair of data is considered to satisf case (B) for proper energy performance analysis.
Thermostat Temperature (constant) = 19^0 C
(a) Ambient Temperature (varying) =21℃
(b) Ambient Temperature (varying) =24℃
(c) Ambient Temperature (varying) = 28℃
For condition (a), the data has been collected for power consumption of air conditioner during one hour which has been shown in Table 6 with graphical presentation in Figure 11 and 12.

Table 6: Power Consumption at 21℃ Ambient Temperature (and at constant Thermostat Temperature=19℃)

Compressor Condition	Time (in PM)=t	Power(in kW)=P	Current(in Amp)=I	Power Factor=p.f	Voltage (in volts)=V	Run Time(in min)=t_r	Idle Time(in min)=t_s	Energy consumed(in kWh)=E
Running	01:26	1.354	3.7	0.94	366			
Idle	01:27	0	0.2	0.71	0.02	1		0.0226
Running	01:30	1.08	3.4	0.99	301		3	
Idle	01:36	0	0.2	0.7	0.021	6		0.108
Running	01:39	1.2	3.5	0.96	358		3	
Idle	01:44	0	0.2	0.69	0.021	5		0.1
Running	01:48	1.22	3.4	0.96	350		4	0.0813
Idle	01:52	0	0.2	0.71	0.021	4		
Running	01:58	1.21	3.5	0.98	352		6	0.0806
Idle	02:02	0	0.2	0.74	0.023	4		
Running	02:10	1.3	3.4	0.97	360		8	0.065
Idle	02:13	0	0.2	0.70	0.02	3		
Running	02:21	1.33	3.4	0.98	363.1		8	0.1108
Idle	02:26	0	0.2	0.69	0.021	5		

Here,
Total running time of the compressor=t_{r4}=1+6+5+4+4+3+5=28 min
Total stopping time of the compressor=t_{s4}=3+3+4+6+8+8=32 min
Total energy consumed (in one hour) =E_4=0.0226+0.108+0.1+0.0813+0.0806+0.065+0.1108=0.5683 kWh

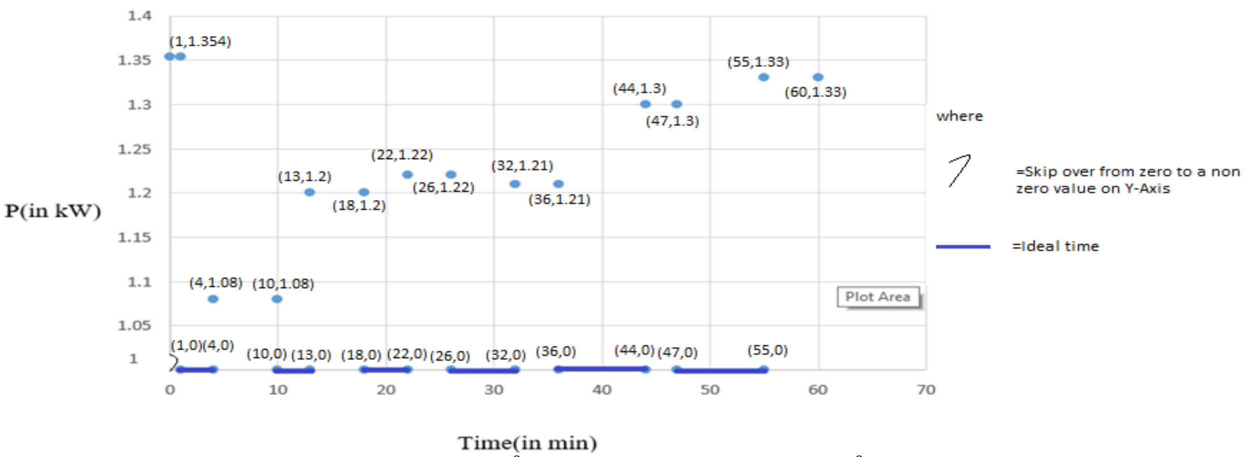

Fig11: Power Vs Time Graph for 21 ^{0}C ambient temperature and 19 ^{0}C thermostat temperature.

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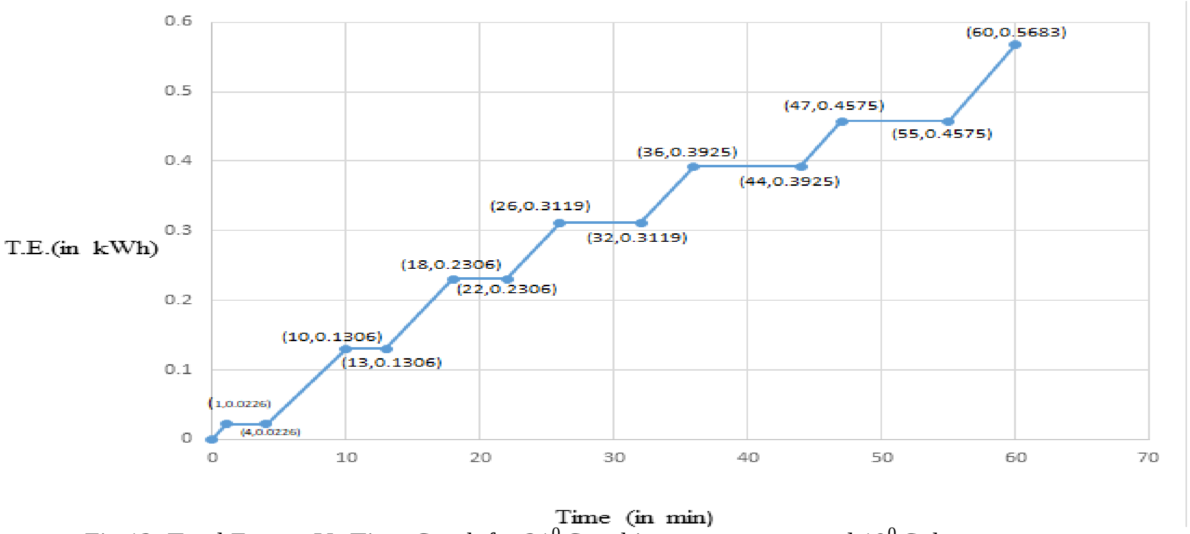

Fig 12: Total Energy Vs Time Graph for 21^{0}C ambient temperature and 19^{0}C thermostat temperature.

Now, for case (b), as in the earlier case the power and energy consumption by the air conditioner is shown in Table.7 with graphical presentation in Figure 13 and 14.

Table 7: Power Consumption at 24^{0}C ambient temperature (and at constant Thermostat Temperature=19^{0}C)

Compressor Condition	Time (in AM)=t	Power(in kW)=P	Current(in Amp)=I	Power Factor=p.f	Voltage (in volts)=V	Run Time(in min)=t_r	Idle Time(in min)=t_s	Energy consumed(in kWh)=E
Running	10:01	1.22	3.8	0.98	350			
Idle	10:10	0	0.2	0.73	0.019	9		0.183
Running	10:15	1.21	3.77	0.99	351		5	
Idle	10:23	0	0.2	0.69	0.02	8		0.1613
Running	10:31	1.22	3.8	0.98	351.2		8	
Idle	10:39	0	0.2	0.71	0.022	8		0.1627
Running	10:48	1.19	3.56	0.98	351.1		9	
Idle	10:55	0	0.2	0.79	0.02	7		0.1388
Running	11:00	1.23	3.7	0.98	353.1		5	
Running	11:01	1.23	3.7	0.98	0.019	1		0.0205

Here,
Total running time of the compressor=t_{r5}=9+8+8+7+1= 33 min
Total stopping time of the compressor=t_{s5}=5+8+9+5=27 min
Total energy consumed (in one hour) =E_5=0.183+0.1613+0.1627+0.1388+0.0205=0.6663kWh

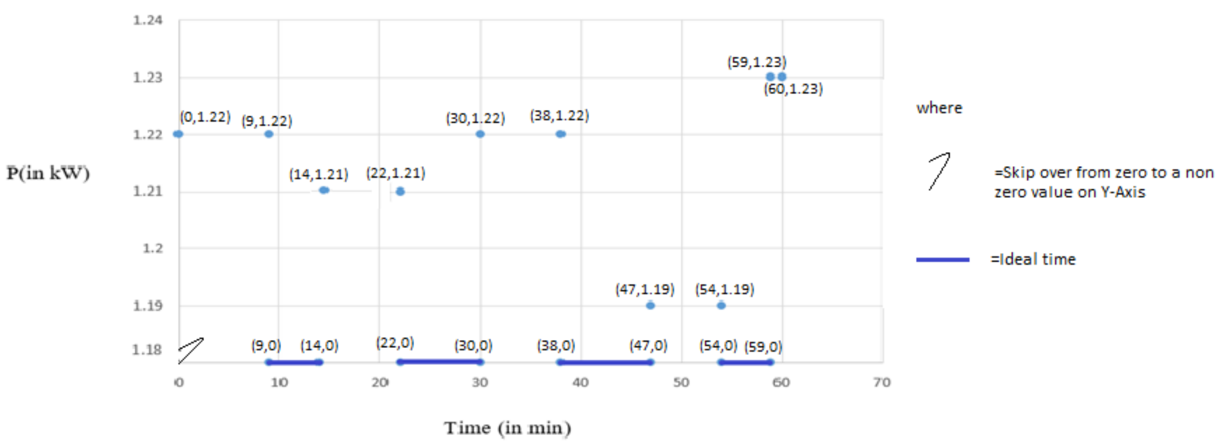

Figure13. Power Vs Time Graph for 24^{0}C ambient temperature and 19 ^{0}C thermostat temperature.

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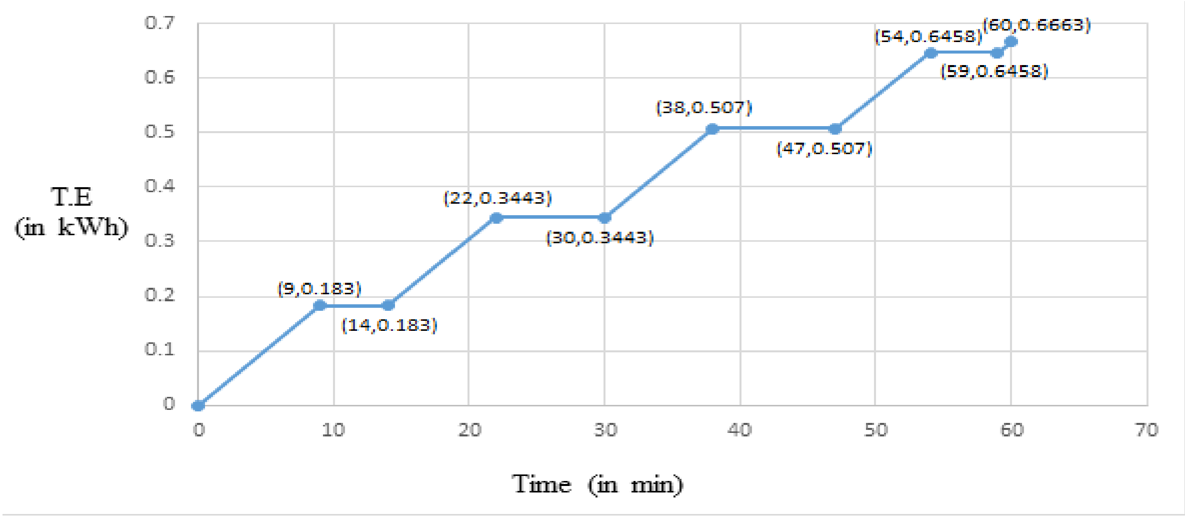

Figure14. Total Energy Vs. Time Graph for 24^0 C ambient temperature and 19^0 C thermostat temperature.

Now, for case (d), following data has been obtained in Table 8 and its graphical presentation is shown in Figure 15 and 16

Table8: Power Consumption at 28^0 C ambient temperature (and at constant thermostat temperature=19^0 C)

Compressor Condition	Time (in PM)=t	Power(in kW)=P	Current(in Amp)=I	Power Factor=p.f	Voltage (in volts)=V	Run Time(in min)=t_r	Idle Time(in min)=t_s	Energy consumed(in kWh)=E
Running	12:45	1.47	4.6	0.98	324.3			
Idle	12:57	0	0.2	0.71	0.022	19		0.4655
Running	01:02	1.46	4.5	0.98	331		3	
Idle	01:12	0	0.2	0.56	0.016	8		0.1947
Running	01:19	1.41	4.3	0.98	333.2		8	
Idle	01:27	0	0.2	0.54	0.015	8		0.188
Running	01:37	1.46	4.5	0.98	330.8		9	
Idle	01:45	0	0.2	0.51	0.013	5		0.1217

Here,
Total running time of the compressor=t_{r6}=19+8+8+5=40 min
Total stopping time of the compressor=t_{s6}=3+8+9=20 min
Total energy consumed (in one hour) =$E_{6=}$0.4655+0.1947+0.188+0.1217=0.9699 kWh

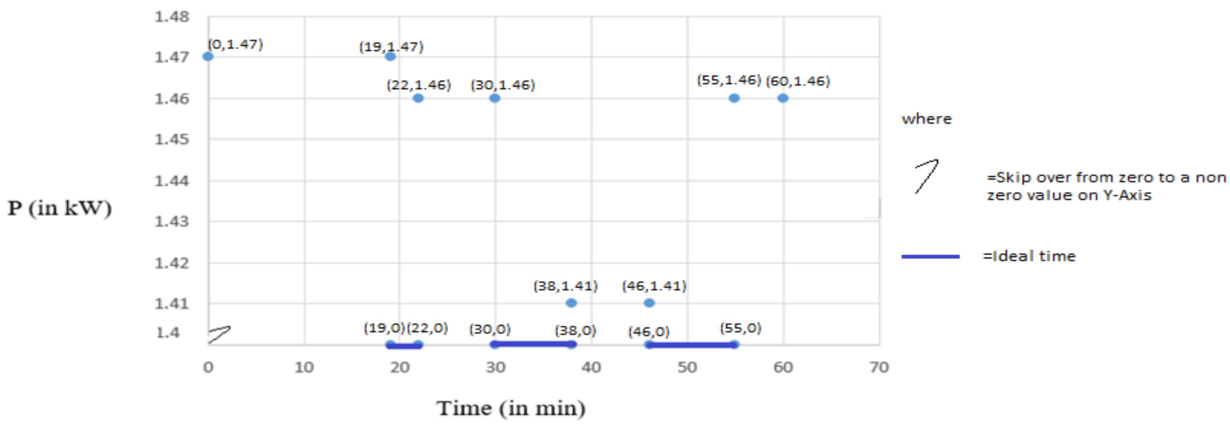

Figure15. Power Vs Time Graph for 28 ^{0} C ambient temperature and 19^0 C thermostat temperature.

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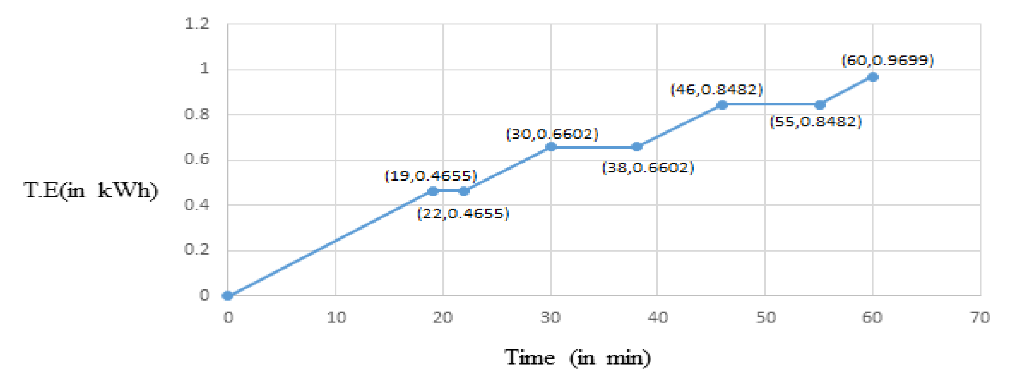

Figure16. Total Energy Vs Time Graph for 24^0 C ambient temperature and 19 ^{0} C thermostat temperature.

Comparing the curves of Case (B) having a constant thermostat temperature of 19℃,it is obtained that the total running time of the compressor was more when the ambient temperature was at 24℃ than the total running time of the compressor when the ambient temperature was at 21℃ i.e.(t_{r6}>t_{r5}>t_{r4}).Therefore the total Idle time (or the stopping time) of the compressor was more when the ambient temperature was at 21℃ than the total running time of the compressor when the ambient temperature was at 24℃ i.e. (t_{s4}>t_{s5}>t_{s6}). The total energy consumed is more when the ambient temperature is at 24℃ than the total energy consumed when the ambient temperature is at 21℃ i.e. (E_6>E_5>E_4). From the experiments it is seen that energy consumption of AC depends on run time of the compressor. Once the desired temperature is reached the compressor stops functioning. The compressor restarts once the thermostat detects increase in temperature. Table 9 and Table 10 show the total energy consumed varies for varying thermostat temperature and varying of ambient temperature.

Table9. Total energy consumed and percentage of energy reduction with varying thermostat temperature

At constant ambient temperature(32°C)	Total Energy consumed(per kwh)	Cost per unit(Rs 6.70)in Guwahati		Cost per month (Rs)	%of energy saved in comparison to 18°C
Varying thermostat temperature(°C)		In 1 hr(Rs)	In 8 hrs/day (Rs)		
18	1.3087	8.7682	70.1456	2104.36(Ref)	
22	1.0466	7.0122	56.0976	1682.92	25.04
24	0.8479	5.6809	45.4474	1363.42	54.34

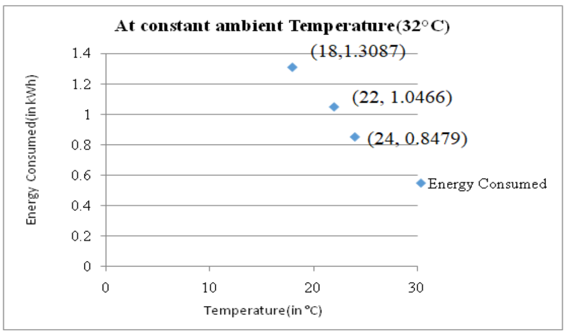

Figure17. Energy consumption vs. thermostat temp.

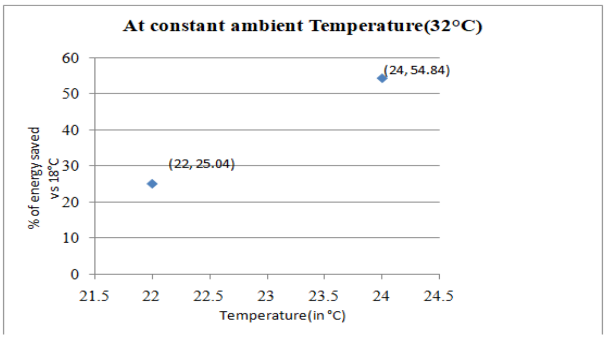

Figure18.Energy savings in higher temperature

In Figure 17 and 18 it shows that how the energy consumption of air conditioner can be reduced by controlling the thermostat temperature. Whereas in Figure 19 and 20 the plotted graph shows that energy consumption rate increases for the increasing of ambient temperature.

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Table10. Total energy consumed and percentage of energy reduction with varying thermostat temperature

At constant thermostat temperature(19°C)	Total Energy consumed (per kwh)	Cost per unit(Rs 6.70)in Guwahati		Cost per month (Rs)	%of energy saved in comparison to 28°C
Varying ambient temperature(°C)		In 1 hr(Rs)	In 8 hrs/day (Rs)		
21	0.5683	3.8076	30.4608	913.82	70.66
24	0.6663	4.4642	35.7136	1071.40	45.56
28	0.9699	6.4983	51.9866	1559.59(Ref)	

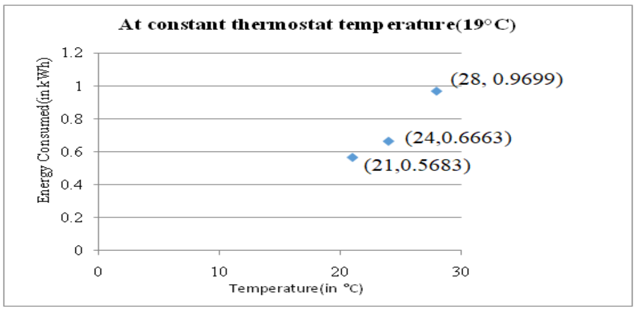

Figure19. Energy consumption vs. ambient temperature

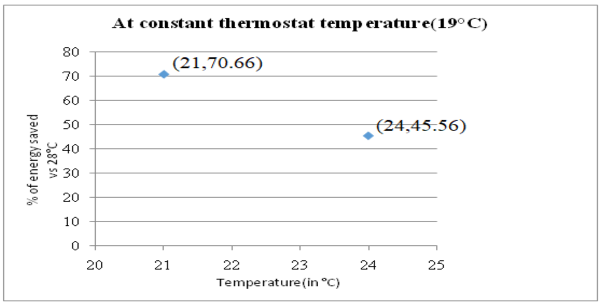

Figure20. Energy savings in lower temperature

IV. CONCLUSION

From the above results and discussion it is clear that the performance of air conditioner in terms of power consumption is not dependent only in the energy efficiency ratio (EER) of air conditioner but also hugely dependent on thermostat setting temperature and ambient temperature. Power consumed by the air conditioner can be controlled efficiently by controlling the thermostat temperature. It can be concluded that when the temperature difference between the ambient and the thermostat is more, the compressor running time is more which leads to more energy consumption .This is because when the temperature difference between the ambient and the thermostat is more, it implies that the compressor needs to run for a longer period in order to bring the temperature of the room from the ambient to the required thermostat temperature. From the experimental study it can be concluded that that at a constant ambient temperature of 32^0 C when the thermostat temperature set at 18^0 C, 22^0 C and 24^0 C, 21% and 35% of power can be shaved in case of 22^0 C and 24^0 C in comparison to 18^0 C. This paper further indicates that at constant thermostat temperature of 19 ^{0} C when the ambient temperature varies like 21^0 C, 24^0 C and 28^0 C, 15% and 41% power reduction occurs in case of 24^0 C and 21^0 C in comparison to 28^0C.

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