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Experimental study of compressor electric current detection for a split-type air conditioner affects energy savings

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ABSTRACT

The paper presents an experimental study that aims to measure the compressor electric current of a split-type air conditioner for analyzing the various abnormal condition of the R-32 refrigerant pressure, especially for detecting compressor electric current while occurring dirt in the evaporator coil and condenser coil. The method was to install sensor devices to measure the temperature and humidity of inlet air and outlet air, and the velocity of the air outlet of the evaporator unit. In condenser unit was to measure the electric current compressor and electric power input. All data from sensors send to the Arduino board and using Parallax Data Acquisition (PLX-DAQ) Excel Macro for the record. The results show physical behavior and the changing of compressor electric current according to the abnormal condition of the refrigerant system, blocking of condenser and evaporator coil.

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1. INTRODUCTION

Nowadays, split-unit type air conditioners are being used to create comfortable environments in residential, commercial, and industrial applications. It is to become the major energy consumers' building in the world [1], [2]. The final energy consumption in Thailand [3] in the building and residential sectors of key assumptions (2010 to 2030) were an annual average gross domestic product (GDP) growth of 4.3%, and an annual average population increase of 0.3%. The energy efficiency of an air-conditioner is largely described in two ways, one is energy efficiency ratio (EER) by ISO 5151 [4], and the other is seasonal EER (SEER) by ISO 16358 [5], and ASHRAE 116 [6]. The most of energy consumption in the commercial buildings and factory is usage by air condition system [7]. The proportion of energy consumption was 70.9 % for air conditioning systems and 29.1% for others load systems. One of the primary parameters that influence the energy consumption of the air conditioner to be side has high efficiency compressor is the amount of R-32 refrigerant charge [8]. Most buildings, therefore, focus on reducing energy consumption in building activities and the design of air conditioning systems [9], [10] to be more efficient.

In the case of split air conditioners that use R-32 refrigerant, if multiple air conditioners are installed in a large office room or meeting room, and, if someone of air conditioning has fault detection [11], [12] such as low refrigerant in the system, no refrigerant in the system due to leak [13], [14] in the pipeline system, clogging in the cooling system or clogging in the condensing system, and which will cause the air conditioner to hard work all the time due to loss of energy and short the time life of the air conditioner. Abnormalities in the amount or pressure of the refrigerant will directly affect the cooling efficiency and electric power consumption. Therefore, this research article will test and measure the electric current of the compressor while the air conditioner is under the following conditions. First, abnormal conditions in the refrigerant system. The second is the condition of the fan coil clogging. Finally, the condition of the clogging of the ventilation system.

This research presents the detection of compressor current according to the change in refrigerant pressure of conventional split air conditioners, which is not the inverter air conditioner. It also focuses on detecting the electric current of the compressor while there is dirt on the evaporator coils and condenser coils. The results are analyzed and presented with a notification method for air conditioning maintenance that will allow the air conditioner to operate at full efficiency and with sustainable energy savings. The results are comparing the measurement of compressor electric current detection [15]–[17] while operating in abnormal conditions.

2. METHOD

2.1. System description and equation

Figure 1 shows the schematic diagram and block diagram of the split-type of air conditioner in which the main components are a compressor, condenser, evaporator, and expansion valve. The vapor compression refrigeration cycle [18]–[20] can be seen in the pressure-enthalpy diagram in Figure 1(a). Consider the equation of vapor compression from Figure 1(b) at the state points as follows.
State 1. Compressor or process at point 1 to point 2 can be calculated as (1).

$$\dot{W}_{comp} = \dot{m}_{ref}(h_2 - h_1) \quad (1)$$

State 2. Condenser or process at point 2 to point 3 can be calculated as (2).

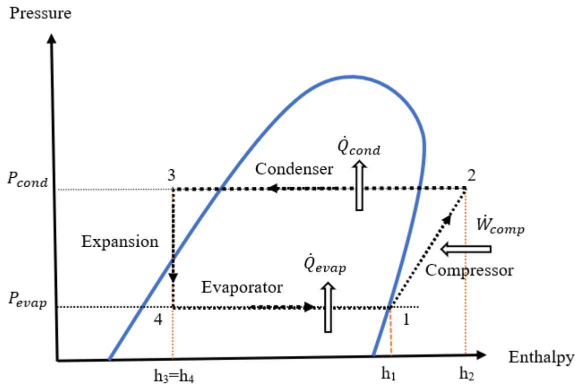
$$\dot{Q}_{cond} = \dot{m}_{ref}(h_2 - h_3) \quad (2)$$

State 3. Pressure reducing device or process at point 3 to point 4 can be calculated as (3).

$$h_3 = h_4 \quad (3)$$

State 4. Evaporator or process at point 4 to point 1 can be calculated as (4).

$$\dot{Q}_{evap} = \dot{m}_{ref}(h_1 - h_4) \quad (4)$$



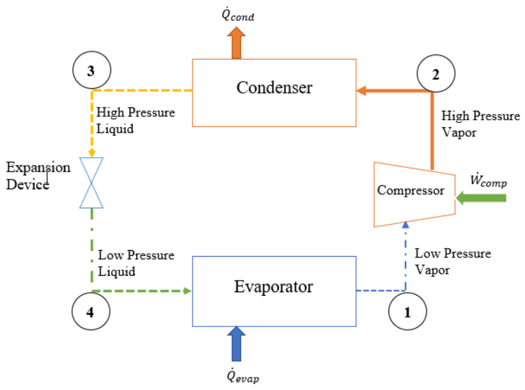


Figure 1. The schematic diagram in (a) P-h diagram and (b) block diagram of the vapor compression refrigeration

Coefficient of performance (COP) [21] of air conditioners is defined by (5) and (6).

$$COP = \frac{\dot{Q}_{evap}}{W_{comp}} \quad (5)$$

$$\dot{W}_{comp} = I_c . V . \cos\phi \quad (6)$$

Thus, instead of (6) into (5), we get

$$COP = \frac{\dot{Q}_{evap}}{I_c.V.\cos\phi} \tag{7}$$

where I_c is the compressor electric current (A), V is the electrical voltage input (V), $\dot{Q}_{evap}$ is the cooling capacity, $\dot{W}_{comp}$ is the compression work (kWhr), $\dot{Q}_{cond}$ is the heating capacity, $\dot{m}_{ref}$ is refrigerant flow rate (m^3/min), h is the specific enthalpy and $h_{1,2,3,4}$ meaning the specific enthalpy at the 1, 2, 3 and 4 states.

3. EXPERIMENTALLY SETUP

The experiment setup was designed in Figure 2. The experiment work using the split-unit type air conditioner utilized a standard 18,000 Btu/hr. The unit used R-32 refrigerant as the working refrigerant gas. The setup included sensors in specific locations to measure parameters such as temperature and humidity sensors, air flow rate sensors, refrigerant pressure (low and high), electric current sensors as well as electrical power input. In this experimental study, the air-conditioner indoor temperature setting was set to 25 °C and the blower fan was set at the lowest setting to provide more stable airflow. The descriptions of a split-type air conditioner was given in Table 1.

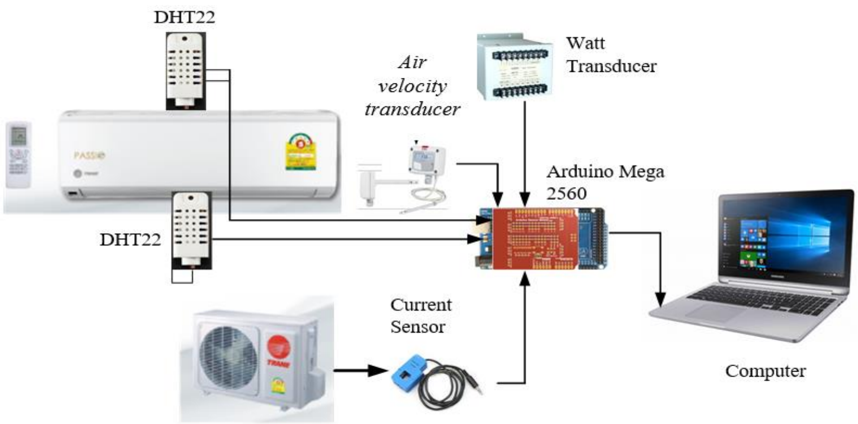


Figure 2. The sensor devices position and record data to computer

Table 1. Description of split type air conditioner

Components	Details
Cooling capacity (kW)	5.36
Cooling capacity (Btu/hr)	18,300
Running current (A)	7.2
Indoor unit	
Model	MCW518BB5
Air flow rate(m^3/min)	10.1
Dimension (H x W x D; mm)	298x940x200
Outdoor unit	
Model	TTK518BB5
Compressor type	Rotary type
Motor output (kW)	1.58
Dimension (H x W x D; mm)	700x963x340

The air-conditioning and refrigeration institute (ARI) Standard 210/240 has to be applied in any performance [22]–[25] testing of air-conditioning equipment. The experiment work utilized a standard split-type air conditioner. The setup included sensors in specific locations to measure parameters [26]–[28]. Figure 3 shows the position of measurement by sensors as point 1: current (A), point 2: air flow rate (m/s), point 3: temperature, T_s (°C), and relative humidity (%RH_s) on the supply air, point 4: temperature, T_r (°C) and relative humidity (%RH_r) measurement on the return air, point 5: power measurement (kW) and point 6: refrigerant pressure R-32. The sequence of experimental steps is described below.

a. Turn on the switch to open the circuit of the split-unit type air conditioner. The operating temperature was set to 25 °C.
b. Measure and record the temperature T_r (°C) and relative humidity RH_r (%) of the air inlet of a fan coil unit by using a thermometer and relative humidity of the air.
c. Measure and record the temperature T_s (°C) and relative humidity RH_s (%) of the air outlet of a fan coil unit by using a thermometer and relative humidity of the air.
d. Measure and record the air flow rate (m/s) passing through the return air inlet by using an air velocity transducer.
e. Measure and record the compressor electric current, I_c (A), and the electric power consumption, W_{comp} (W) of the compressor during the compressor operation (compressor part combined with the fan part) by using the electric current sensor and watt transducer, respectively.

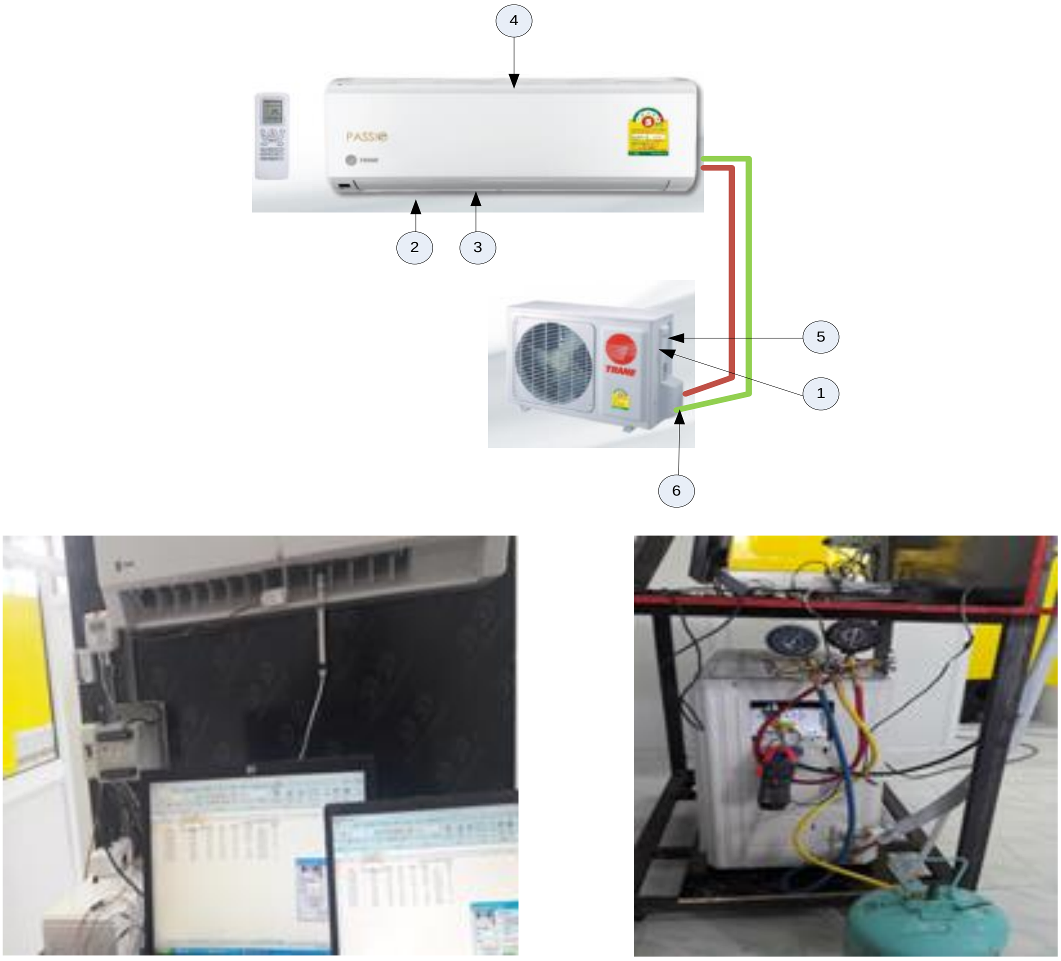


Figure 3. Position of data measurement sensor point

Figure 4 shows the measurement of R-32 refrigerator pressure by using a manifold gauge in various abnormal conditions. Figure 4(a) shows the measured refrigerant normal pressure at 72 psi. Figure 4(b) shows the measure of the refrigerant at the low pressure of 50 psi, Figure 4(c) shows the measured refrigerant at the low pressure of 20 psi, and Figure 4(d) shows the measure of the refrigerant at 0 psi.

Illustrated, Figure 5 (a) is shown to demonstrate the blocking of airflow of evaporating coil seems that reduced airflow. This effect causes poor cooling or a frozen coil, like a dirty evaporator coil. Figure 5(b) shows the blocking in the condenser coil or dirty condenser coil. The real-time instrumentation is using Parallax Data Acquisition (PLX-DAQ) data acquisition Excel Macro [29], where data can be acquired directly in real-time into Microsoft Excel (PLX-DAQ). The PLX-DAQ Excel Macro can acquire up to 26 channels of data from the microcontroller (PLX-DAQ). The structure of the equipment used in the instrumentation system is shown in Figure 6.

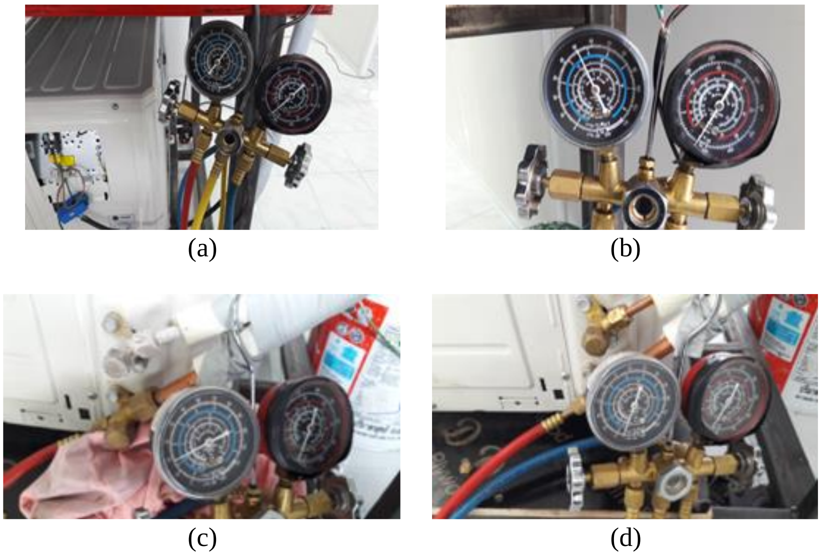


Figure 4. Measurement of R-32 refrigerant pressure in various conditions (a) the normal pressure at 72 psi, (b) the low pressure at 50 psi, (c) the low pressure at 20 psi, and (d) No refrigerant at 0 psi

Figure 5. Shows the blocking of airflow (a) the blocking in the evaporator coil and (b) the blocking in the condenser coil

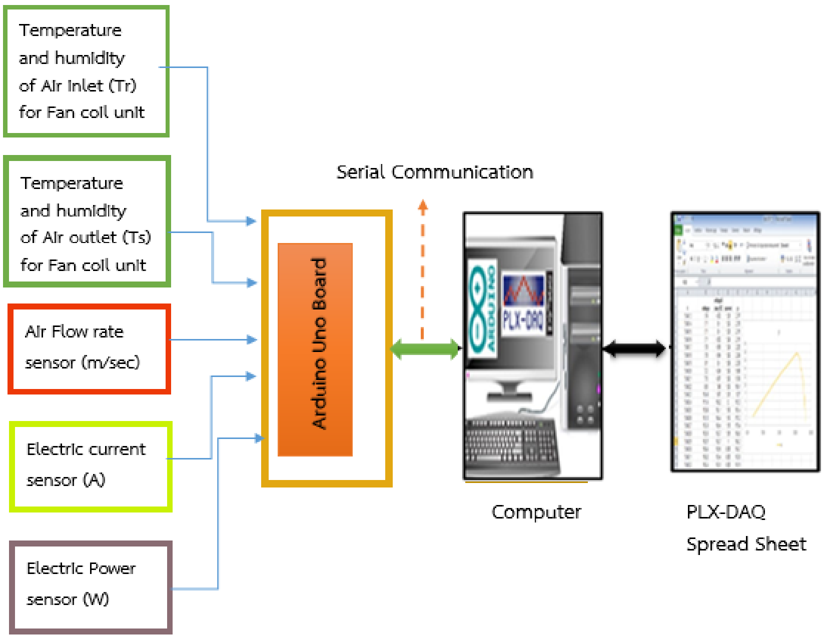


Figure 6. Schematic diagram of the experiment record data

The output of the five sensors is transmitted to the microcontroller of the Arduino Uno board. The PLX-DAQ Excel Macro allows communication between the microcontroller and an Excel spreadsheet using the universal asynchronous receiver-transmitter (UART) bus. Before testing and recording the results to the computer. First, you need to compare the measurement results with standard measuring instruments to measure the electric current, air flow velocity, temperature, and humidity as shown in Figure 7. During the acquisition process, the data obtained are stored and plotted in real-time in the Excel spreadsheet as shown in Figure 8. Illustrated, Figure 8(a) shows the results of measurement data from sensors in the normal operation of refrigeration pressure at 72 psi. Figure 8(b) shows the results of measurement data from sensors in the abnormal operation of no refrigeration at 0 psi. Figure 8(c) shows the results of measurement data from sensors in the abnormal operation of the blocking of the evaporator coil, and Figure 8(d) shows the results of measurement data from sensors in the abnormal operation of the blocking of the condenser coil.

Figure 7. Standard measurement devices are used for the calibration of sensors

Time	Ts(C)	RHs(%)	Tr(C)	RHr(%)	Icomp(A)	Power(W)	Air speed (m/s)
12:31:17	27.00	53.9	27.7	51.3	0	0	0
12:31:48	27.00	53.9	27.7	51.3	5.512	1212.69	7.9
12:32:19	19.10	64.7	27.5	50.3	5.354	1177.88	8.1
12:32:51	18.70	77	27.2	50.5	5.473	1204.04	7.9
12:33:22	17.80	78.9	26.9	50.9	5.651	1243.31	7.7
12:33:53	15.40	81.6	26.7	51.3	5.761	1267.38	7.6
12:34:25	15.00	88.5	26.6	51.4	5.802	1276.37	7.5
12:34:56	14.70	90.7	26.5	50.9	5.815	1279.22	7.5
12:35:27	14.30	91.8	26.4	50.7	5.914	1301.13	7.7
12:35:59	14.10	92.3	26.4	50.4	5.965	1312.29	7.6
12:36:30	13.50	92.1	26.3	50.2	6.047	1330.41	7.6
12:37:01	13.20	93.5	26.4	50.5	6.096	1341.17	7.5
12:37:33	12.70	93.2	26.3	49.4	6.167	1356.72	7.4
12:38:04	12.60	94.2	26.3	49.1	6.212	1366.59	7.3
12:38:35	12.40	94.5	26.4	49	6.233	1371.25	7.4
12:39:07	12.40	95.9	26.4	49.1	6.265	1378.37	7.4
12:39:38	12.30	95.3	26.4	48.4	6.303	1386.57	7.5
12:40:09	12.40	95.7	26.4	48.2	6.304	1386.87	7.5
12:40:41	12.50	96.3	26.5	48	6.332	1392.98	7.5

(a)

Time	Ts(C)	RHs(%)	Tr(C)	RHr(%)	Icomp (A)	Power(W)	Air speed (m/s)
13:30:31	21.40	56.3	26.4	46.4	0.283	62.16	0
13:31:02	21.50	57.6	26.3	46.5	3.037	668.08	7.1
13:31:34	21.00	76.7	26.1	47.7	3.089	679.63	7.5
13:32:05	22.40	72.8	26.1	48.8	3.096	681.02	7.7
13:32:36	22.90	69.5	26.1	49.2	3.119	686.18	7.6
13:33:08	23.30	66.8	26	49.5	3.128	688.16	7.7
13:33:39	23.50	64.7	26	49.4	3.128	688.08	7.7
13:34:10	23.70	63.2	26	49.3	3.143	691.53	7.6
13:34:42	23.90	61.9	26	49.3	3.141	690.94	7.8
13:35:13	24.10	60.7	26	49.3	3.162	695.53	7.6
13:35:44	24.20	59.9	26	49.4	3.146	692.17	7.8
13:36:16	24.40	59.1	26	49.4	3.152	693.36	7.8
13:36:47	24.50	58.3	26	49.2	3.164	696.06	7.8
13:37:19	24.60	57.5	26.1	49.2	3.174	698.37	7.9
13:37:50	24.70	57	26.1	49.1	3.163	695.93	7.8
13:38:21	24.80	56.4	26.1	48.8	3.174	698.35	7.8
13:38:53	24.90	55.8	26.1	48.8	3.171	697.53	7.9
13:39:24	25.00	55.5	26.1	48.9	3.168	696.99	7.9
13:39:55	25.10	55	26.1	48.9	3.171	697.56	7.9

(b)

Time	Ts(C)	RHs(%)	Tr(C)	RHr(%)	Icomp (A)	Power(W)	Air speed (m/s)
14:11:59	21.90	64.7	25.1	46.4	5.551	1221.24	1.7
14:12:30	17.00	51.7	25.1	45	5.53	1216.58	0.7
14:13:02	15.00	58.3	25.1	44.4	5.524	1215.2	2
14:13:33	13.80	63.6	25.2	44.6	5.475	1204.48	2
14:14:04	12.40	67.1	25.3	44.2	5.437	1196.25	1.5
14:14:36	11.50	70.1	25.4	43.3	5.444	1197.57	1.6
14:15:07	10.70	73.2	25.5	43.2	5.415	1191.3	1.5
14:15:38	10.20	75.7	25.5	43.4	5.402	1188.53	1.7
14:16:13	9.70	77.7	25.6	42.3	5.391	1186.04	1.9
14:16:41	9.50	80.2	25.6	42.4	5.373	1182.03	0.8
14:17:12	9.10	81.1	25.7	42.4	5.361	1179.34	2.1
14:17:44	9.10	83.9	25.7	42	5.33	1172.59	1.1
14:18:15	9.10	83.7	25.8	41.4	5.328	1172.26	1
14:18:46	9.50	85.3	25.8	41.5	5.304	1166.95	1.1
14:19:18	9.60	84.5	25.8	41.9	5.277	1161.02	1
14:19:49	9.60	84.4	25.8	41.5	5.265	1158.37	1.3
14:20:20	9.90	85.4	25.8	41.7	0.177	38.94	2.3
14:20:52	10.00	84.5	25.8	42.3	0.128	28.17	0.6

(c)

Time	Ts(C)	RHs(%)	Tr(C)	RHr(%)	Icomp (A)	Power (W)	Air speed (m/s)
13:14:44	13.10	99.9	23.9	66.2	0.283	62.25	0
13:15:15	13.40	99.9	24	89.1	0.075	16.53	7.3
13:15:46	19.70	99.9	24.1	52.3	0.04	8.77	7.1
13:16:18	18.70	99.9	24.2	50.2	7.38	1623.63	7.2
13:16:49	18.90	91.9	24.2	49.6	8.227	1809.9	7.9
13:17:20	16.60	82.7	24.2	50.7	9.423	2073.13	7.5
13:17:52	14.10	81.3	24.2	50.3	9.879	2173.39	7.3
13:18:23	12.90	84.6	24.2	49.4	10.118	2225.91	7.3
13:18:54	12.60	88.9	24.3	48.8	10.38	2283.71	7.1
13:19:26	12.60	93.4	24.3	48.8	10.559	2322.88	7
13:19:57	12.60	95.6	24.4	48.2	10.787	2373.19	7
13:20:28	12.70	96.4	24.4	48.2	10.834	2383.46	7.1
13:21:00	12.90	97.1	24.5	48.1	10.84	2384.84	7
13:21:31	13.10	97.7	24.6	48.2	0.183	40.29	0

(d)

Figure 8. Results of measurement data from sensors in (a) the normal operation of refrigeration pressure at 72 psi, (b) the abnormal operation of no refrigeration at 0 psi, (c) the abnormal operation of the blocking of the evaporator coil and (d) the abnormal operation of the blocking of the condenser coil

4. RESULTS AND DISCUSSION

The split-type air conditioner was normally operating at a refrigerant pressure of about 65-72 psi. Figure 9 shows the comparison of the compressor electric current while the condenser coil was blocked. The results of the experiment show the compressor electric current has changed significantly. When the condenser fan stopped working or the condenser coil was very blocked, the compressor electric current will be increased to 170 percent of the rated compressor electric current. Similarly, the condenser was less blocked, then the compressor electric current increased to 120 percent of the rated compressor electric current.

Figure 10 shows the comparison of the compressor electric current. The test results show that the compressor electric current has changed significantly. First, the split-type air conditioner was normally operating at a refrigerant pressure of about 65-72 psi. The electric current sensor can detect the compressor electric current at the rated electric current according to the nameplate coordinates at the condenser unit. Second, when the evaporator fan stopped working or the evaporator coil was very blocked. The result of compressor electric current was decreased to 83 percent of the rated electric current. Next, the refrigerant pressure was 50 psi, and the current will be reduced to 80 percent of the rated electric current during normal operation. Fourth, the refrigerant pressure in the system was lower to 20-30 psi, the compressor electric current was reduced to about 45 percent of the rated compressor electric current at normal operation. This case caused was ice stick on the suction tube. Finally, there was no refrigerant in the system. It is found that the compressor electric current only reduced to 50 percent of the rated compressor electric current at normal operation.

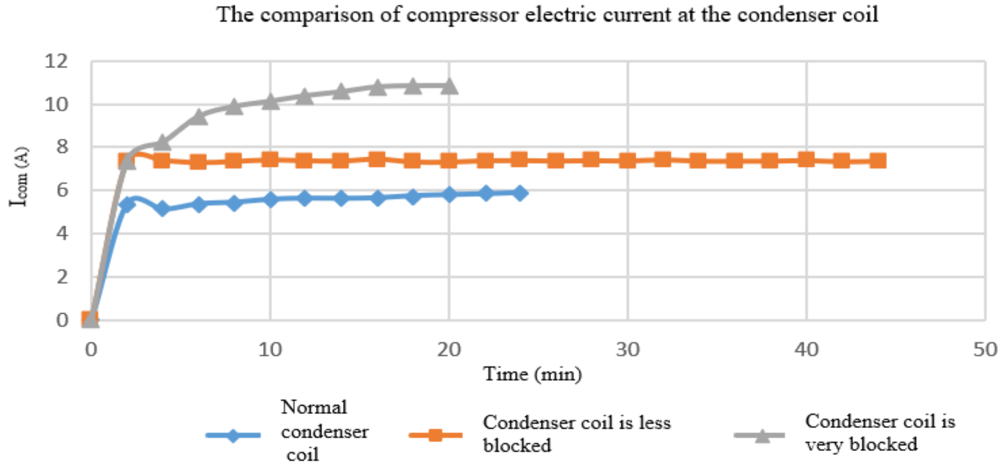


Figure 9. The measurement result of compressor electric current at the condenser coil

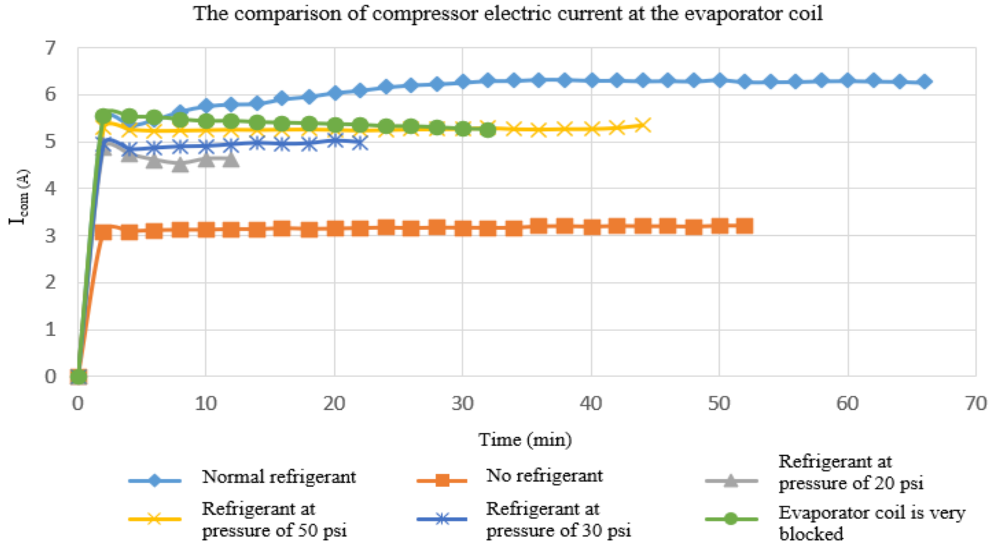


Figure 10. The measurement of compressor electric current at the evaporator coil

5. CONCLUSION

The seven cases of compressor electric current detection from an experimental study. If your evaporator coil is dirty, the cycles will last much longer and make your air conditioner run longer. The dirty condenser coil will affect an air conditioner to reduce the overall efficiency of the unit. When a condenser coil is dirty or blocked, the unit will have to work harder to achieve the same results. When the efficiency of the air conditioner is reduced, the unit will also cost the owner more money to maintain. Reduced efficiency means that the unit must work harder which requires more electricity and, in turn, this will result in higher utility bills. The problems that result from a dirty condenser coil can also impact the operating life of the unit. Similarly, the evaporator coil was dirty or blocked. When the evaporator was poor cooling and had a frozen coil, which affect the cycles of operation much longer and make the air conditioner run longer. This research paper presents an idea for using compressor electric current data to design alert maintenance for split-type air conditions by using the recommended algorithm as follows: if the compressor electric current is more than 170 percent of the rated compressor electric current, then notation as the condenser coil was blocked. If the compressor electric current is more than 120 percent of the rated compressor electric current then the notation as condenser coil was less blocked. If the compressor electric current is more than 83 percent of the rated compressor electric current, then the notation as evaporator coil was very blocked. If the compressor electric current is more than 80 percent of the rated compressor electric current, then the notation as refrigerant pressor was low pressure. If the compressor electric current is more than 50 percent of the rated compressor electric current, then the notation as refrigerant pressor was very low pressure. If the compressor electric current is more than 45 percent of the rated compressor electric current, then notation as no refrigerant. If the compressor electric current is more than 100 percent of the rated compressor electric current, then normal operation. If such notification occurs in sections 1 to 6 as shown in the recommended algorithm section above. The system will alert with a flashing lamp and if not operated, the system must stop the air conditioner immediately.

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