Design of a new online monitoring system of COP based on Arduino Uno with application to split A/C

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Abstract. Air Conditioner (A/C) is a system of air conditioning which serves the need of thermal comfort inside a room. Until now, to determine COP of A/C is performed measurement of temperatures and pressures in A/C. Then, it is continued by calculating of COP. Unfortunately, the process take much time. Therefore, it is important to find any new method to obtain COP. In this paper, to solve the problem was designed a COP monitoring system. To do this, the Arduino Uno was uploaded a program of the monitoring system. The system was equipped sensors. And then to display COP was used a Laptop. The results showed that by using the proposed method and the traditional one, it was obtained that COP actual fluctuates about 3.3 in range from 3.14 to 3.51 and 3.2 to 3.5, respectively. In addition, it was predicted that the using of proposed method in illustrated situation can save time by 2 hours or 80%. It can be considered as a promising solution to determine the COP quickly and easily.

1. Introduction

Air Conditioner (A/C) is a system of air conditioning which serves the need of thermal comfort inside a room. One of the important indicators to know performance of A/C is by determining of the coefficient of performance (COP) of A/C. Until now, to determine the COP is performed measurement of temperatures and pressures in A/C. Then, it is continued by calculating of COP from the formula. Unfortunately, the process of both measurement and calculation take much time. This is caused measurements in many points must be conducted in sequence one by one. Besides, to calculate the COP is needed enthalpies which are determined based on the values of T and P on the PH diagram. This must be performed carefully. After that, they are substituted to formulation of COP. Thus, it needs much time consumption and accuracy in calculation. Therefore, it is important to find any new way to obtain COP so that it can reduce time consumption and guarantee of true and accurate calculation.

The effort to make easy in determining COP has been conducted [1]. However, that is still limited to measurement of Temperatures and Pressures by online, only. Whereas, to determine the COP must still be calculated by hand or manually.

In this paper, to solve the problem was designed a COP monitoring system. To do this, the Arduino Uno was uploaded a program in which contain algorithm of the COP monitoring system so that it can function as a real time COP monitor. The system is equipped sensors of temperatures, relative humidity, voltage and current. And then to display data of COP is used a Laptop that is installed Ms. Excel and
PLQ-DAQ. By using the proposed COP monitoring system, the determination of COP can be conducted much simpler. It only needs to attach sensors in measuring points, then the COP value is displayed immediately in real-time in a graph form. Note that, to design a program to be uploaded to Arduino Uno can be referred to the textbook [2].

2. The coefficient of performance

2.1. Determining COP

Before discussing COP, it is reviewed a refrigerating cycle. To do this, see figure 1.

![Figure 1. Diagram of Ph.](image)

Figure 1 shows a diagram of Ph that functions to determine heat on each process of refrigerating cycle. The variables in diagram of Ph are pressure, temperature dan enthalpy. Refrigeration cycle can be described in 4 points as shown in figure 1.

The coefficient of performance (COP) of a refrigerating cycle is an expression of the cycle efficiency [3,4]. It is stated as ratio of the refrigerating effect to the heat of compression. It is expressed in formula as follows.

\[
COP_{\text{actual}} = \frac{\text{Refrigerating effect}}{\text{Heat of compression}}
\]

In monitoring COP, this equation is modified to:

\[
COP_{\text{actual}} = \frac{\text{Refrigerating capacity}}{\text{Power supply to compressor}} = \frac{Q_e}{W}
\]

(1)

It is caused enthalpy \( h \) in the original formula that cannot be measured.

Next, all parameters or quantities in this COP monitoring are calculated using the following equations. The calculation consists of two main parts. First, to obtain the refrigerating capacity that is heat absorbed by evaporator is used an equation as follows.

\[
Q_e = \dot{m} \times q_e
\]

(2)

where:

- \( Q_e \) = the refrigerating capacity in \text{kJ/s} or \text{kW}
- \( \dot{m} \) = the mass flow rate in \text{kg/s}
- \( q_e \) = the refrigerating effect in \text{kJ/kg}

whereas, mass flow rate of air:

\[
\dot{m} = v \times A \times \rho
\]

(3)

where:

- \( v \) = air velocity in \text{m/s}
- \( A \) = surface area of air in \text{m}^2
- \( \rho \) = the density of air in \text{kg/m}^3

and refrigerating effect:
\[ q_e = h_1 - h_4 \]  \hspace{1cm} (4)

where:

- \( q_e \) = Refrigerating effect in kJ/kg
- \( h_1 \) = Enthalpy at point 1 in kJ/kg
- \( h_4 \) = Enthalpy at point 4 in kJ/kg

To determine enthalpies in eqs. 4 it is not used a Ph diagram as traditional way, instead they are calculated using formulae as follows [5,6].

To obtain enthalpy 1 is used:

\[ h_1 = (1.006 \times t_1) + \{ w_1 \times [2501 \times (1.805 \times t_1)] \} \]  \hspace{1cm} (5)

where:

- \( h_1 \) = the enthalpy at point 1 in kJ/kg
- \( t_1 \) = the temperature at point 1 in °C
- \( w_1 \) = the humidity ratio of air at point 1 in kg\text{water}/kg\text{air}

Then to obtain enthalpy 4 is used:

\[ h_4 = (1.006 \times t_4) + \{ w_4 \times [2501 \times (1.805 \times t_4)] \} \]  \hspace{1cm} (6)

where:

- \( h_4 \) = Enthalpy at point 4 in kJ/kg
- \( t_4 \) = Temperature at point 4 in °C
- \( w_4 \) = the humidity ratio of air at point 4 in kg\text{water}/kg\text{air}

And then to calculate humidity ratio 1:

\[ w_1 = RH_1 \times w_s \]  \hspace{1cm} (7)

where:

- \( w_1 \) = the humidity ratio of air at point 1 in kg\text{water}/kg\text{air}
- \( RH_1 \) = the relative humidity of air in percentage (%)
- \( w_s \) = the humidity ratio of air at saturation in kg\text{water}/kg\text{air}

Next, to get humidity ratio 4:

\[ w_4 = RH_2 \times w_s \]  \hspace{1cm} (8)

where:

- \( w_4 \) = the humidity ratio of air at point 4 in kg\text{water}/kg\text{air}
- \( RH_2 \) = the relative humidity of air in percentage (%)
- \( w_s \) = the humidity ratio of air at saturation in kg\text{water}/kg\text{air}

Second, to determine power supply to compressor is used an equation as follows.

\[ P = V \times I \]  \hspace{1cm} (9)

where:

- \( P \) = the compression power in kW
- \( V \) = the voltage in Volts
- \( I \) = the current in Amperes

Next, to determine the Carnot’s Coefficient of Performance (COP) is used an equation as follows [6]:

\[ COP_{\text{carnot}} = \frac{T_r}{T_o - T_r} \]  \hspace{1cm} (10)

where:

- \( T_r \) = the average temperature of evaporator in °C
- \( T_o \) = the average temperature of condenser in °C
Then, the above all equations will be used in an algorithm to design the program of calculation of COP. Variables or parameters that are needed at each equation will be measured by sensors and next be sent to Arduino Uno to be calculated and displayed on Ms. Excel and PLX-DAQ.

2.2. Block diagram of Monitoring COP
Monitoring is simply a measurement of object quantity that is performed continuously. Thus, it is difference from measurement that only get any data for any time, not continuous, but discrete. To do this, it is used Arduino Uno as a processor and laptop screen as a monitor. The monitoring diagram is shown in figure 2. In this case, the object quantity that is monitored is COP.

![Figure 2. Block diagram of monitoring system for COP.](image)

3. Design of a COP monitoring system
The design of COP monitoring system consists of two parts, namely design of hardware and software. The design of hardware includes selection of sensors, a processor and a display. This is called COP monitoring system based on processor. Whereas, the design of software is of computer program for the monitoring system so that it can represent character of a monitor. To do this, it is started by designing a algorithm of the monitoring system. Note that the design of this program will be conducted in the second part of design.

3.1. Design of hardware
In this design, the explanation focuses on designing of main components that is related to monitoring system. The main components are the Arduino and sensors. It is explained shortly reasons in selection of them. To display data is used a Laptop screen.

3.1.1. Selection of processor. The Arduino contains a microcontroller that functions as a computer. The microcontroller is a processor. Thus, it can process a computer program. Since, in this paper was designed a COP monitoring system using the program, then it is selected Arduino Uno as shown in figure 3 [7]. Next, to function as the monitoring system it must be installed with the related program. The Arduino has three memories with capacity of 35 KB. One of them to hold data is a static random-access memory (SRAM) and the others to save program are flash memory and erasable programmable read-only memory (EPROM). In addition, because the related program only need memories less than 35 KB, then, the Arduino can be selected to design the monitoring system.

3.1.2. Selection of temperature sensor. To measure room temperature is selected a sensor DS18B20 [8,9]. The sensor can measure temperature from -55°C to 125°C. It has typical accuracy +/- 0.5 °C. These specifications are relevant that are needed in monitoring the temperature. Connection of sensor DS18B20 with the Arduino UNO R3 is shown in figure 4.

![Figure 3. Arduino board UNO R3.](image)  ![Figure 4. Connection of sensor DS18b20 to Arduino.](image)
3.1.3. Selection of current sensor. To measure current of compressor is selected a sensor ACS712 [9,10]. The sensor can measure current from -30 A to 30 A. It has typical accuracy 1.5%. These specifications are relevant that are needed in monitoring the current. Connection of sensor ACS712 with the Arduino UNO R3 is shown in figure 5.

3.1.4. Selection of voltage sensor. To measure voltage of compressor is selected a sensor AC ZMPT101B [8-10]. The sensor can measure voltage from 0 V to 250 V. It has typical accuracy 1.5%. These specifications are relevant that are needed in monitoring the voltage. Connection of sensor AC ZMPT101B with the Arduino UNO R3 is shown in figure 6.

3.2. Design of software for COP monitoring
To monitoring COP is designed an algorithm in which contains the related formulae. Then, based on the algorithm is constructed the program of COP monitoring.

3.2.1. Algorithm of monitoring COP actual. The following is an algorithm of monitoring COP actual that is based on equation 1.

- Measure the voltage of compressor (V) at steady state in volt.
- Measure the current of compressor (I) at steady state in ampere.
- Measure the cos\(\phi\) of compressor using cos\(\phi\) meter.
- Calculate \(P = V \times I\).
- Measure \(t_1\) that is temperature of air output on Split AC.
- Measure \(t_4\) that is temperature of air input on Split AC.
- Measure RH\(_1\) that is relative humidity of air output.
- Measure RH\(_4\) that is relative humidity of air input.
- \(W_s\) is assumed be 1.
- Calculate \(w_1 = \%RH_1 \times W_s\)
- Calculate \(w_4 = \%RH_4 \times W_s\)
- Calculate \(h_1 = ((1.006 \times t_1) + (w_1 \times (2501 \times (1.805 \times t_1))))\)
- Calculate \(h_4 = ((1.006 \times t_4) + (w_1 \times (2501 \times (1.805 \times t_4))))\)
- \(\rho\) is assumed by 1.2.
- Calculate cross- sectional area (A) of air output at Split A/C in m\(^2\).
- Measure speed (v) of out air from evaporator at distance 1 m in front of Split A/C.
- Calculate \(\dot{m} = v \times A \times \rho\)
- Calculate \(Q_e = \dot{m} \times (h_1-h_4)\)
- Calculate COP = \(\frac{Q_e}{P}\)
- Be back to no. 1.

3.2.2. Algorithm of monitoring COP carnot. Monitoring of COP carnot based on equation 10 is conducted using an algorithm as follows:

- Measure \(t_1\) at output point of evaporator pipe.
- Measure $t_2$ at input point of evaporator pipe.
- Calculate $T_r = t_1 - t_4$.
- Measure $T_o$ at any point that closes condensation value.
- Calculate $COP_{carnot} = \frac{T_r}{T_0 - T_r}$.
- Be back to no. 1

4. Results and discussion

The test of performance of the designed COP-monitoring system was conducted with comparing the monitored COP to the traditional-measured COP. Besides, it was also predicted the time saving when using the designed system.

4.1. Monitoring COP actual

By using the designed program of COP-monitoring system, COP actual can be monitored by online on Laptop screen. The COP is displayed on Ms. Excel that cooperate with PLX-DAQ. The figure 7 shows the graph of COP actual that is obtained by online.

![Figure 7. The graph of COP actual using the COP-monitoring system.](image)

The graph shows the COP fluctuates about 3.3 and has range of COP in range from 3.14 to 3.51. Whereas for traditional method is obtained COP in range from 3.20 to 3.50. In this case, there is small difference in range from 0.06 to 0.36. Thus, the designed COP-monitoring system is accurate enough.

4.2. Monitoring COP carnot

Figure 8 shows the graph of COP carnot that is obtained using the designed COP-monitoring system. The graph shows the COP fluctuates about 5.3 and has range of COP in range from 5.2 to 5.5. While for traditional method is obtained COP in range from 5.22 to 5.60. It means that there is small difference in range from 0.02 to 0.4. Thus, as for COP actual, the designed COP-monitoring system has a good accuracy.

![Figure 8. The graph of COP carnot using the COP-monitoring system.](image)
4.3. Predicting of time saving
The use of the traditional method for obtaining 1 set data needs 12 minutes that consist of 6 minutes to take the data, 4 minutes to read h from psychometric chart and 2 minutes to calculate COP in formula. If 1 set data is collected every 3 minutes, then for 10 set data it takes (12 +3) x 10 = 150 minutes or 2.5 hours. Whereas, the use of the proposed method for 10 set data it takes (0+3) x 10= 30 minutes. In this case, the method is almost not time-consuming, except when starting it needs small time to attach sensors in measuring points. Thus, the proposed method can be time saving of 2 hours or 80%.

5. Conclusion
The results showed that the designed COP-monitoring system has satisfied the design objectives. First, to test performance of the designed COP monitoring system, it is conducted taking data using both the proposed method and the traditional method. For the proposed method, it is obtained that COP actual fluctuate about 3.3 in range from 3.14 to 3.51. Whereas, for the traditional method, COP actual fluctuate about 3.3 in range from 3.2 to 3.5. In this case, there is small error in range from 0.06 to 0.36. In addition, for COP Carnot, using the proposed method and the traditional method, it is obtained that COP Carnot was in range from 5.20 to 5.50 and 5.22 to 5.60, respectively. Moreover, it was predicted that the using of proposed method in illustrated situation can save time by 2 hours or 80%. It can be considered as a promising solution to determine the COP quickly and easily.

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