A practical calibration method of the room type calorimeter for testing the energy efficiency of room air conditioner

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Abstract. The room type calorimeter is generally used as the energy efficiency measurement standard equipment in the air conditioner industry. However, the calibration procedure is not investigated. In this study, based on the empty-load situation of calorimeter, the calibration model is proposed in order to restrain the error of heat balance caused by long-term use. Besides, two new parameters, which are background value of indoor-side and outdoor-side, are presented in accordance with the calibration model. Experiments are designed to obtain these two parameters and three heat leakage coefficients of partition wall, as well as the calibration procedure and application method of the parameters are illustrated. The corrected calorimeter measures ten different window type air conditioners in one year. The results show that the absolute value of heat balance is less than 2% in the cooling capacity range of 2000W~4500W and 1% in the range of 4500W~7000W.

1. Introduction

The room type calorimeter[1,3-4], as shown in figure 1, which provides approximate thermal insulators based on the conservation of energy and mass, converts the cooling capacity measurement into the measurements of electrical power, heat exchange of cooling coil, heat leakage of partition walls, heat transfer caused by evaporation and condensation water, et. al. Normally, the calorimeter has four test rooms, two of them are test chamber (shown as 2 and 10 in figure 1), and the other two are controlled-temperature air spaces (shown as 1 and 12 in figure 1). In order to decrease the heat leakages of partition wall, the air space can adjust the temperature to the test chamber’s. Although calorimeter has more measurement parameters than the indoor air enthalpy test method apparatus [2], the calorimeter is used as the energy efficiency measurement standard equipment in the room air conditioner industry because of the higher accuracy [5-6].

Various type of sensors and instruments are installed in the calorimeter, and the measurement parameters include electrical power, temperature, pressure, flow and mass. Due to the long-term use of calorimeter, the measurement results of the sensors and instruments possibly drift, and this situation can lead to the unpredictable error of cooling capacity measurement. Therefore, periodic check, calibration and correction for the sensors and instruments are essential to the accuracy of calorimeter. For now, the calibration procedure of calorimeter focus on the sensors and instruments which can be calibrated in the field, such as the resistance temperature detectors, the pressure transmitters and the digital power meters. The calibration method, which regards the sensors, the data acquisition unit and the software as a integrated system, conducts the field calibration with the external sources. This part of procedure, which is proven by the practical calibration, is well applied in China air conditioner industry.
However, a part of sensors are inappropriate to the field calibration because of the field restrictions. For example, the thermocouples on the partition walls, which are dispersive in position, and surround which the space is narrow and small for the calibration equipments. Another example, the flow meter of cooling water, which need to disassemble because of the deficiency of calibration ports in the cooling water pipeline. For these sensors, the field calibration is usually not conducted, or the period of calibration is extended in practice. But this handling way can result in some issues, around which the zero drift of heat balance measurement is most apparent, to the accuracy of calorimeter.

In this study, the calibration model, which converts the field calibration of thermocouples into the measurement of the coefficients of heat leakage, is proposed based on the empty-load situation of calorimeter. And the practical calibration procedure, which ensure the measurement accuracy of energy flow, improves the issue of heat balance zero drift. Finally, this procedure is applied to a calorimeter, and the heat balance measurement results verify its practicality.

2. The calibration model of calorimeter

The objective of calorimeter calibration is to guarantee the accuracy of heat flow measurement. The heat flow, which is related to the sensors unsuitable for filed calibration, is the heat leakage of partition wall. The heat leakage is the product of the temperature measurement results and the heat leakage coefficients. Under the condition that the temperature measurement sensors can not be calibrated, the accuracy of heat flow measurement also can be achieved through the adjustment of heat leakage coefficients.

Therefore, in order to obtain the coefficients of heat leakage, the calibration model of calorimeter is established based on the empty-load situation, under which the pressure equalization device and humidifier are closed. The energy flow chart of the empty-load is shown as figure 2.
Figure 2. This is the integrated calibration model under empty load, of which 1 indoor-side test chamber, 2 outdoor-side test chamber, 3 controlled-temperature air space, 4 pressure equalization device, 5 the separating partition of test chambers.

From figure 2, it can be seen that only three kinds of energy flow are involved, they are the electrical power flowing in the test chambers \( P_{in} \) and \( P_o \), the heat removed by cooling coils \( \phi_{ci} \) and \( \phi_{co} \) and the heat leakage of the partition walls \( \phi_{li}, \phi_{lo} \) and \( \phi_p \). According to the conservation of energy, the energy that flowing in a test chamber equals to the energy flowing out. As a result, the indoor-side cooling capacity can be expressed as

\[
\phi_{ci} = P_{in} - \phi_i + \phi_{k1} + \phi_p 
\]

Similarly, outdoor-side heating capacity can be expressed as

\[
\phi_{co} = P_o - \phi_o + \phi_{k2} + \phi_p 
\]

Bring \( \phi_k = L_1 \cdot (t_{i1} - t_{o2}) \), \( \phi_o = L_o \cdot (t_{o1} - t_{o2}) \) and \( \phi_p = L_p \cdot (t_{o3} - t_{o3}) \) into Eq.(1) and Eq.(2), we have

\[
\phi_{ci} = P_{in} - \phi_i + L_1 \cdot (t_{i1} - t_{o2}) + L_p \cdot (t_{o3} - t_{o3}) 
\]

\[
\phi_{co} = P_o - \phi_o + L_o \cdot (t_{o1} - t_{o2}) + L_p \cdot (t_{o3} - t_{o3}) 
\]

The Eq.(3) and Eq.(4) are the calibration model of calorimeter.

Moreover, in this model, the room type calorimeter is working under empty-load situation. In other words, there is no air conditioner under tested, which means indoor-side cooling capacity and outdoor-side heating capacity equal to zero. Then, the calibration model can be expressed as

\[
P_{in} - \phi_i + L_1 \cdot (t_{i1} - t_{o2}) + L_p \cdot (t_{o3} - t_{o3}) = 0 
\]

\[
P_o - \phi_o + L_o \cdot (t_{o1} - t_{o2}) + L_p \cdot (t_{o3} - t_{o3}) = 0 
\]

In Eq. (5) and Eq.(6), only three coefficients of heat leakage \( L_i, L_p \) and \( L_o \) are unknown, and the other parameters can be measured through the experiments. Then the coefficients of heat leakage can be obtained.

However, when these coefficients are brought back to Eq. (3) and Eq. (4) with the experiments data, the indoor-side cooling capacity\( \phi_{ci} \) and outdoor-side heating capacity\( \phi_{co} \) not equal to zero. And\( \phi_{ci} \) and\( \phi_{co} \) should be treated as the measurement background values of the calorimeter, which denoted by \( B_i \) and \( B_o \).

To sum up, the system parameters include three coefficients of heat leakages and two background values.

3. The measurement method of system parameters

According to Eq. (5) and Eq. (6), the coefficients of heat leakage and background values can be calculated by designed experiments. The set values of ambient temperature are shown in table 1.

| Experiment No. | Indoor-side test chamber | outdoor-side test chamber | Indoor-side air space | outdoor-side air space |
|---------------|-------------------------|---------------------------|-----------------------|-----------------------|
| 1             | 20                      | 40                        | 20                    | 40                    |
From table 1, under the conditions of experiment 1, the heat mainly flows from the outdoor-side test chamber into the indoor-side test chamber through partition wall because of the obvious temperature difference between the two test chambers. On the contrary, under the conditions of experiment 2, the heats mainly flow from the air spaces into the test chambers through the surrounding walls because of the obvious temperature difference between the two sides of surrounding walls. The experiment 3, which is similar to T1 Standard cooling capacity rating conditions [5], aims to obtain the background values of empty-load situation.

The coefficients of heat leakage can be obtained from the experiment No. 1 and experiment No. 2. For the purpose of measurement accuracy, the temperature difference are extended to 20°C shown in table 1. In accordance with Eq. (5) and Eq. (6), we have

\[ P_{i1} - \phi_{i1} + L_{i1} \cdot (t_{i1} - t_{i2}) + L_{p} \cdot (t_{o3} - t_{o1}) = 0 \]  
(7)

\[ \phi_{o1} - P_{o1} - L_{o} \cdot (t_{o1} - t_{o2}) + L_{p} \cdot (t_{o3} - t_{o1}) = 0 \]  
(8)

\[ P_{i2} - \phi_{i2} + L_{i2} \cdot (t_{i2} - t_{i3}) + L_{p} \cdot (t_{o3} - t_{o2}) = 0 \]  
(9)

\[ \phi_{o2} - P_{o2} - L_{o} \cdot (t_{o2} - t_{o3}) + L_{p} \cdot (t_{o3} - t_{o2}) = 0 \]  
(10)

where the subscript -c1 denotes the results of experiment 1, and the subscript -c2 denotes the results of experiment 2.

In experiment 1, the temperature differences of surrounding walls are very small. Similarly, in experiment 2, the temperature difference of partition wall is also very small. Then, Eq. (7) to Eq. (10) can be simplified as

\[ P_{i1} - \phi_{i1} + L_{p} \cdot (t_{o3} - t_{i3}) = 0 \]  
(11)

\[ \phi_{o1} - P_{o1} + L_{p} \cdot (t_{o3} - t_{i3}) = 0 \]  
(12)

\[ P_{i2} - \phi_{i2} + L_{p} \cdot (t_{i2} - t_{i3}) = 0 \]  
(13)

\[ \phi_{o2} - P_{o2} - L_{p} \cdot (t_{o2} - t_{i3}) = 0 \]  
(14)

Further, the coefficients of heat leakage are expressed as

\[ L_{p} = \frac{P_{i1} - \phi_{i1} - P_{o1} + \phi_{o1}}{2 \cdot (t_{i3} - t_{o3})} \]  
(15)

\[ L_{i1} = \frac{P_{i2} - \phi_{i2}}{t_{i3} - t_{i2}} \]  
(16)

\[ L_{o} = \frac{\phi_{o2} - P_{o2}}{t_{o3} - t_{o2}} \]  
(17)

The background values \(B_{i}\) and \(B_{o}\) can be measured through the experiment 3 with the coefficients which are obtained from experiment 1 and experiment 2. The background values can be expressed as

\[ B_{i} = P_{i3} - \phi_{i3} + L_{i} \cdot (t_{i3} - t_{i2}) + L_{p} \cdot (t_{o3} - t_{i3}) \]  
(18)

\[ B_{o} = \phi_{o3} - P_{o3} + L_{p} \cdot (t_{o3} - t_{o2}) - L_{o} \cdot (t_{o3} - t_{o2}) \]  
(19)

where the subscript -c3 denotes the results of experiment 3.

4. Results and application

4.1 The results of system parameters

In order to ensure the accuracy of measurement data, some preparations should be made before the measurements of the system parameters.
The calibration and correction to the electrical power measurement system. The sensors and instruments in electrical power measurement system normally includes the digital power meters and the current transformers, and they all should be calibrated and corrected.

The calibration and correction to the resistance temperature detectors which measure the inlet water temperature and the outlet water temperature of the cooling coil. We suggest the fitting correction for the purpose of the accuracy in the full range of temperature measurement.

Then, the pressure equalization device should be closed throughout the measurements of system parameters, and the ambient temperatures of the calorimeter should be set according to table 1. Besides, the mass flows of the cooling water for the cooling coils in indoor-side test chamber and outdoor-side test chamber are both set at 400 kg/h, and the temperature of the cooling water tank is set at 10℃. The measurement results are shown in tables 2, 3 and 4.

Table 2. Measurement results from experiment 1.

| No. | P_{in}(W) | \Phi_{e1}(W) | P_{o}(W) | \Phi_{co}(W) | t_{i1} (℃) | t_{i2} (℃) | t_{i3} (℃) | t_{o1} (℃) | t_{o2} (℃) | t_{o3} (℃) |
|-----|-----------|-------------|---------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 1   | 3549.9    | 3564.9      | 12977.2 | 12765.5     | 20.25       | 19.90       | 20.14       | 39.96       | 40.21       | 39.74       |
| 2   | 3556.4    | 3570.7      | 12988.7 | 12784.6     | 20.25       | 19.90       | 20.14       | 39.97       | 40.19       | 39.73       |
| 3   | 3547.6    | 3579.6      | 13018.0 | 12793.3     | 20.25       | 19.90       | 20.14       | 39.97       | 40.16       | 39.68       |
| 4   | 3748.8    | 3787.5      | 13373.1 | 13120.0     | 20.28       | 19.92       | 20.13       | 39.97       | 40.05       | 39.47       |
| 5   | 3755.1    | 3797.2      | 13253.5 | 13027.5     | 20.28       | 19.92       | 20.13       | 39.99       | 40.07       | 39.50       |
| 6   | 3765.2    | 3800.9      | 13163.5 | 12955.5     | 20.26       | 19.93       | 20.14       | 40.01       | 40.08       | 39.49       |
| 7   | 3792.9    | 3831.5      | 12369.8 | 12067.0     | 20.30       | 19.92       | 20.10       | 39.99       | 40.01       | 39.45       |
| 8   | 3793.7    | 3824.9      | 12311.3 | 12063.8     | 20.30       | 19.93       | 20.09       | 40.00       | 40.05       | 39.47       |
| 9   | 3784.3    | 3816.6      | 12280.8 | 12062.9     | 20.30       | 19.92       | 20.09       | 40.02       | 40.06       | 39.46       |
| Average | 3699.3 | 3730.4 | 12859.5 | 12626.7 | 20.27 | 19.92 | 20.12 | 39.99 | 40.10 | 39.55 |

Table 3. Measurement results from experiment 2.

| No. | P_{in}(W) | \Phi_{e1}(W) | P_{o}(W) | \Phi_{co}(W) | t_{i1} (℃) | t_{i2} (℃) | t_{i3} (℃) | t_{o1} (℃) | t_{o2} (℃) | t_{o3} (℃) |
|-----|-----------|-------------|---------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 1   | 3426.8    | 3760.5      | 3302.0  | 3777.9      | 39.68       | 19.20       | 19.90       | 39.62       | 20.44       | 19.95       |
| 2   | 3429.4    | 3755.1      | 3336.2  | 3761.4      | 39.69       | 20.19       | 19.87       | 39.90       | 20.42       | 19.92       |
| 3   | 3408.5    | 3744.0      | 3346.4  | 3746.4      | 39.69       | 20.19       | 19.87       | 39.61       | 20.39       | 19.90       |
| Average | 3421.6 | 3753.2 | 3328.2 | 3761.9 | 39.69 | 20.19 | 19.88 | 39.71 | 20.42 | 19.92 |

Table 4. Measurement results from experiment 3.

| No. | P_{in}(W) | \Phi_{e1}(W) | P_{o}(W) | \Phi_{co}(W) | t_{i1} (℃) | t_{i2} (℃) | t_{i3} (℃) | t_{o1} (℃) | t_{o2} (℃) | t_{o3} (℃) |
|-----|-----------|-------------|---------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 1   | 6540.4    | 6509.0      | 9996.7  | 9845.4      | 27.22       | 26.93       | 26.97       | 35.02       | 35.07       | 34.68       |
| 2   | 6533.7    | 6505.8      | 10017.8 | 9852.7      | 27.23       | 26.93       | 26.96       | 35.04       | 35.08       | 34.68       |
| 3   | 6511.8    | 6488.2      | 9990.1  | 9851.9      | 27.23       | 26.93       | 26.96       | 35.04       | 35.09       | 34.68       |
| 4   | 6528.3    | 6500.4      | 10001.1 | 9850.3      | 27.23       | 26.93       | 26.97       | 35.03       | 35.08       | 34.68       |
| Average | 6528.6 | 6500.9 | 10001.4 | 9850.1 | 27.23 | 26.93 | 26.97 | 35.03 | 35.08 | 34.68 |

Table 2 shows 9 groups of measurement results under the conditions of experiment 1. According to Eq. (15), the calculated results is in the range from 5.6 W/℃ to 8.8 W/℃, and the average value 6.8 W/℃ is used as the coefficient of heat leakage \( L_p \).
Table 3 shows 3 groups of measurement results under the conditions of experiment 2. According to Eq.(16) and Eq.(17), the calculated results of $L_i$ and $L_o$ are in the range from 16.7 W/℃ to 17.2 W/℃ and from 20.8 W/℃ to 24.8 W/℃ separately, the average value 17.0 W/℃ and 22.5 W/℃ are used as the coefficients of heat leakage $L_i$ and $L_o$.

4 groups of measurement results under the conditions of experiment 3 are shown in table 4. In accordance with Eq.(18) and Eq.(19), the measurement results of background value $B_i$ is in the range from 81.2 W to 88.8 W, and the average value is 85.2 W. And the measurement results of background value $B_o$ is in the range from -111.7 W to -84.6 W, and the average value is -97.8 W.

The results of system parameters are shown in table 5.

| $B_i$ (W) | $B_o$ (W) | $L_i$ (W/℃) | $L_o$ (W/℃) |
|----------|----------|-------------|-------------|
| 85.2     | -97.8    | 17.0        | 6.8         |
|          |          | 22.5        |             |

4.2 Application of the system parameters

The using conditions of the system parameters are determined based on the measurement situation of the calorimeter. Three coefficients of heat leakage should be applied to all of the measurement situation. The application of two background values is according to the working situation of the cooling coil in the test chamber.

In practice, the cooling coil in the indoor-side test chamber is possibly not working. For the basic situation, if the cooling coil does not remove heat from test chamber, the heating coil is not necessary. Under this basic situation, the energy flows of the indoor-side test chamber only include the heat leakages, which have been considered in the cooling capacity measurement. Therefore, the background value of indoor-side $B_i$ equals to zero.

The application of the system parameters, especially the application of the background values, can improves the issues of heat balance zero drift. To verify the effect of the system parameters, the results in table 5 is applied to the calorimeter. And 10 window type air conditioners are measured using the calorimeter in one year, the arrangement photos are shown in figure 3.

Figure 3. Arrangement photos of window type air conditioner in the calorimeter.

The heat balance results of the 10 measurements are shown in figure 4. The results show that the absolute value of heat balance is less than 2% in the cooling capacity range of 2000W~4500W and 1% in the range of 4500W~7000W.
5. Conclusions
In this study, the calibration model of the room type calorimeter is established based on the empty-load situation. In accordance with the model, the system parameters, which include three coefficients of heat leakage and two background values of test chamber, are proposed to improve the issue of heat balance zero drift. And the calibration procedure of system parameters, which is given by the designed experiments, is applied to the calorimeter. Then the using conditions of the parameters are analyzed. Finally, the parameters are applied to the calorimeter which measures 10 different window type air conditioners in one year. The results show that the absolute value of heat balance is less than 2% in the cooling capacity range of 2000W~4500W and 1% in the range of 4500W~7000W.

6. Appendices

| Symbol | Description |
|--------|-------------|
| \( \Phi_{ci} \) | indoor-side cooling capacity (W) |
| \( \Phi_{co} \) | outdoor-side heating capacity (W) |
| \( \Phi_{li} \) | heat leakage of indoor-side surrounding wall (W) |
| \( \Phi_{ci} \) | cooling capacity of indoor-side cooling coil (W) |
| \( \Phi_{lp} \) | heat leakage of separating partition wall (W) |
| \( B_i \) | Background value of indoor-side cooling capacity (W) |
| \( B_o \) | Background value of outdoor-side heating capacity (W) |
| \( L_i \) | coefficient of heat leakage through indoor-side surrounding wall |
| \( L_p \) | coefficient of heat leakage through partition wall |
| \( L_o \) | coefficient of heat leakage through outdoor-side surrounding wall |
| \( t_{i1} \) | external surface average temperature of indoor-side test chamber surrounding wall (°C) |
| \( t_{o1} \) | internal surface average temperature of indoor-side test chamber surrounding wall (°C) |
| \( t_{i2} \) | external surface average temperature of outdoor-side test chamber surrounding wall (°C) |
| \( t_{o2} \) | internal surface average temperature of outdoor-side test chamber surrounding wall (°C) |
| \( t_{i3} \) | indoor-side average temperature of partition wall (°C) |
| \( t_{o3} \) | outdoor-side average temperature of partition wall (°C) |

Table 6. Nomenclature and symbols.
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