National Kaohsiung University of Applied Sciences.
Research Report on WIRECARE.

Causes and Solutions for Circuit Heating

Improper use of electrical equipment is the primary cause of circuit heating. Extended use of electrical devices increases the load on the wires, especially with high-power appliances (e.g., hair dryers, induction cookers, kettles, etc.). If multiple high-power devices are plugged in simultaneously, the circuit of that outlet is highly likely to become overloaded. Therefore, it is important to manage electrical usage wisely and regularly check wires and outlets for issues such as aging wires or poor contact between plugs and sockets.

For circuits, electrical resistance is the main cause of wire heating. If wires had no resistance (superconductors), they wouldn't heat up. In addition to the material (which affects resistance), several factors contribute to wire heating: temperature, current, and the cross-sectional area of the wire. A wire with a larger cross-sectional area has lower resistance, which explains why high-power devices use thicker wires. According to the formula Q=I2·R·tQ = I^2 \cdot R \cdot tQ=I2·R·t, where QQQ is heat (in joules), III is current (in amperes), RRR is resistance (in ohms), and ttt is time (in seconds). This means that greater current and resistance, along with longer conduction time, result in more heat. Therefore, under certain temperatures and usage conditions, when impedance is too high, current is excessive, and the conduction time is prolonged, the wire is more likely to overheat. The solution is to use low-resistance, thick wires. Under normal conditions, power wires should not become excessively hot, ideally only 1-2 degrees higher than the ambient temperature. Overheating indicates excessive current or undersized wires and should be addressed promptly. Another cause of wire heating is poor contact at the power cord terminal. If overheating is detected, immediate action should be taken to prevent potential fire hazards. In domestic electrical use, overheating of wire connections is a significant cause of electrical fires, posing a serious safety threat that should not be ignored.

However, existing indoor wiring circuits generally have impedances below one ohm. Even aging circuits typically have impedances of only a few ohms. The focus of this research is to use circuit principles along with microcontrollers and sensing components to detect low impedance in existing circuits.

Low Impedance Detection Technology

Current low impedance measurement methods primarily rely on expensive and specialized impedance analyzers. The principle of impedance detection involves measuring the voltage difference across the test component at different frequencies using a two-wire or four-wire connection and a reliable constant current source to determine the impedance of the component. The main parameters of impedance detection are frequency range, impedance range, and accuracy of the impedance range. Professional impedance analyzers offer broad frequency ranges, extensive impedance ranges, and high precision, such as 0.05% basic accuracy, frequency ranges from 0 Hz to GHz, impedance measurement ranges from μΩ to TΩ, and phase accuracy of 10^-3 degrees. The measured impedance includes both the real and imaginary parts, as well as the phase difference between voltage and current. Some impedance parameters, such as reactance, inductive reactance, and capacitive reactance, can be directly calculated and displayed based on equivalent circuit models. Impedance analyzers can measure the impedance of components at different frequencies. Impedance is a critical parameter for electronic components, circuits, and materials.

Currently available low impedance measuring

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instruments include Germany's Burster 2316 and Japan's HIOKI RM3545, among others. However, these specialized instruments are expensive, bulky, and not portable, making them unsuitable for home indoor wiring impedance testing. Therefore, this study designs a device that is portable, cost-effective, and capable of performing calculations through a microcontroller, enabling the measurement of impedance, voltage difference, and current.

Principle and Implementation Analysis of Low Impedance Circuit Charge Measurement

The following describes the usage scenario and technical principles of the evaluated detector. Assuming a typical residential indoor wiring example, as illustrated in Figure 2, the circuit connects from the watt-hour meter to the external feed line, then to the indoor distribution board. After passing through a fuse-free switch (50A), it is distributed to one group of lights, two groups of general outlets, and two groups of dedicated outlets. The main purpose of the detector is to measure whether the impedance of the wiring from the outlet to the fuse-free switch exceeds the set value.

The measurement schematic is shown in Figure 3. Here, the distribution board voltage is VsV_sVs, the resistance load of outlet iii is RiR_iRi, the wiring current is Ii1I_{i1}Ii1, the load current is Ii2I_{i2}Ii2, and the voltages across the load are VzaV_{za}Vza and VzbV_{zb}Vzb, respectively. The switch SSS provides voltage and current measurements under different conditions to deduce the impedance of the indoor feed line. When the switch SSS is open, there is no current flowing through the test circuit, so the voltage VzaV_{za}Vza equals the distribution board voltage VsV_sVs. When the switch SSS is closed, the voltage difference across the load is (Vza−Vzb)(V_{za} - V_{zb})(Vza−Vzb). Since the load resistance RiR_iRi is known, Ii2I_{i2}Ii2 can be obtained. Because the wiring current and load current are the same, the wiring resistance RxR_xRx can similarly be calculated.

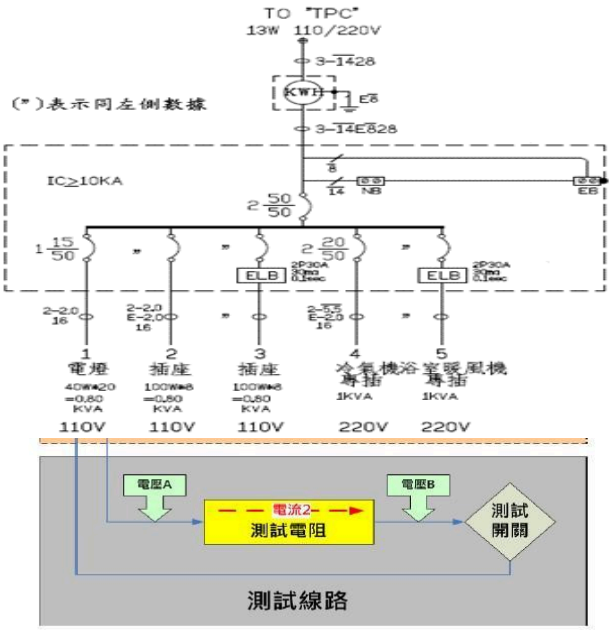

Figure 2: Schematic Diagram for Outlet Detection

To achieve the aforementioned measurement functionality, our research partner, ZEROPLUS Technology, utilizes a microcontroller combined with circuit design to implement the impedance detector. The system block diagram is shown in Figure 4.

In the diagram, AC represents the outlet under test, with a MOSFET used as a switch to control the opening or closing of the circuit, allowing the AC power to be directed into a bridge rectifier for full-wave rectification. Since this application involves an AC power environment, impedance measurement must be done in real-time by measuring the voltage difference across the impedance, rather than measuring the root mean square (RMS) value. Therefore, the speed of measurement and calculation on the microcontroller is crucial.

The microcontroller features two analog-to-digital converters that read the voltage across the load resistor into the microcontroller for calculation, determining the impedance voltage difference. Because the

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resistance of the load changes with temperature, a temperature sensor is included to provide the load temperature for correction, thus ensuring accurate load current measurements.

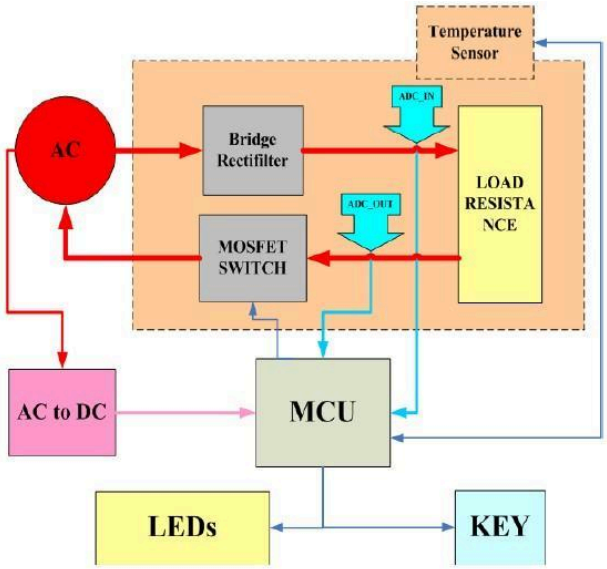

Figure 3: System Block Diagram of the Indoor Wiring Tester

The measurement software on the microcontroller performs three main functions:

1. **Real-time measurement of the voltage at the load terminals.**
2. **Calculation of the load current.**
3. **Correction and compensation of measurement values based on load temperature, or halting measurements under high temperature conditions.**

To achieve these functions, the software flow is planned as follows:

1. **Sample the voltage waveform x[n]x[n]x[n] and calculate the input AC voltage frequency.**
2. **Identify the maximum voltage value and its position.**
3. **Capture the voltage difference across the load.**
4. **Compensate the load resistance value based on environmental temperature.**
5. **Calculate the load current value.**
6. **Determine the wiring impedance value using the open-circuit voltage, the voltage difference across the load, and the load current.**

The operational conditions for the implemented hardware and software device are outlined in the table below:

Table 1: Operating Environment and Performance of the Detector

[illegible]	[illegible]
[illegible]	100- 240V
[illegible]	50- 60Hz
[illegible]	<5%

Generate the Following Outputs Based on the Obtained Wiring Impedance Value

Table 2: Output Indicator Conditions and Warning Messages

[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	>1. 75ohm	[illegible]
2	[illegible]	1. 51~1. 75ohm	[illegible]
3	[illegible]	1. 26~1. 51ohm	[illegible]
4	[illegible]	1. 01~1. 26ohm	[illegible]
5	[illegible]	0. 76~1. 01ohm	[illegible]
6	[illegible]	0. 51~0. 76ohm	[illegible]
7	[illegible]	0. 26~0. 51ohm	[illegible]
8	[illegible]	<0. 25 ohm	[illegible]

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Additional Auxiliary Indicators:

1. **Overtemperature Warning:** When the system detects that the operating temperature exceeds 60°C, all 8 LEDs will flash simultaneously 3 times and then stay lit in red, halting normal detection. Detection will resume automatically once the temperature drops.
2. **Power Supply Abnormality Warning:** If the outlet power supply voltage is below 90V or above 250V, or if the frequency is below 47Hz or above 63Hz, all 8 LEDs will display orange, and normal detection will stop.
3. **Device Fault Warning:** If the system detects a fault in the internal load resistor or MOS switch, all 8 LEDs will alternate flashing between green and red, and normal detection will stop.

Users only need to plug the detector into

various outlets in their home, and the detector will automatically perform measurements. The status will be indicated by lights showing three conditions: good, check, or warning. This provides users with a reference for the quality of their home's power supply. Based on the detection results, users can decide whether to notify a professional for maintenance or updating of the home power supply to reduce the risks associated with aging electrical circuits.

Experimental Results and Evaluation

Objective:

Due to the high cost, bulkiness, and need for specialized operation of commercially available low impedance detectors, ZEROPLUS Technology has designed a cost-effective, portable, and user-friendly detector for assessing the safety of outlet wiring in residential and office environments. This study aims to test this detector across various buildings of different ages—approximately 19 buildings with a total of 290 circuits and outlets in different conditions. The detector will be used to assess these outlet circuits, with status indicated by green, orange, or red lights, representing good, check, or warning conditions, respectively.

If the circuit detection result shows a green light, it indicates that the circuit can continue to be used safely. Conversely, if the light is red or orange, the impedance, current, and voltage difference of the outlet should be rechecked to determine whether professional assistance is needed for maintenance or repair. Finally, this study will analyze and discuss the effects of wire aging and deterioration over different years on circuit impedance values, using statistical analysis and cross-referencing of the collected data.

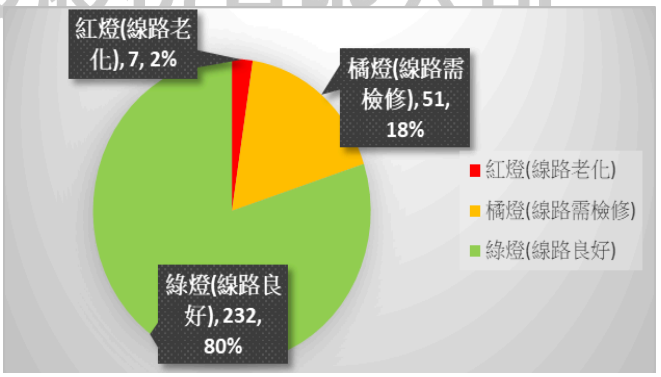
Experimental Design

To determine whether the developed detector accurately identifies aging circuits, ten teaching buildings and nine residential buildings were used as test data sources. This study utilizes the designed indoor wiring detector to allow the public to assess the safety of their home wiring. To achieve this goal, the experiment is divided into two phases.

Phase 1: The detector is inserted into the outlet of the circuit to be tested and activated to automatically measure the circuit impedance. If an abnormal circuit is detected, the experiment proceeds to Phase 2.

Phase 2: In this phase, a numerical measurement is performed and the impedance of the tested circuit is displayed.

In Phase 1, measurements typically take about 10 seconds. The results are presented through 8 LEDs on the detector, showing the condition of the outlet circuit. Different impedance values are indicated by different numbers and colors of lights: good (green), check (orange), and



warning (red). If the detector displays a check or warning light, an external monitor should be connected for Phase 2 testing to confirm the circuit impedance. If the impedance value from the second measurement exceeds 1.51 ohms, professional evaluation is required. If the evaluation recommends replacing the outlet or circuit, it is advised to proceed with the replacement to prevent electrical hazards due to aging outlets or wiring.

Results Analysis

A total of 290 test data points were collected in this study. Figure 5 shows the statistical results

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based on the indicator lights. Among the 290 data points measured, green lights accounted for 80%, orange lights for 18%, and red lights for 2%. This indicates that the majority of the circuits were found to be in good condition.

Figure 4: Detection Results for 290 Indoor Circuits

If classified by building, as shown in Figure 6, Building 1 had the highest number of red light occurrences, while Buildings 1, 2, 5, and 6 had the highest number of orange light occurrences. Therefore, the wiring in Building 1 requires immediate maintenance, while Buildings 2, 5, and 6 should exercise caution with their electrical equipment usage, reducing the use of high-power appliances.

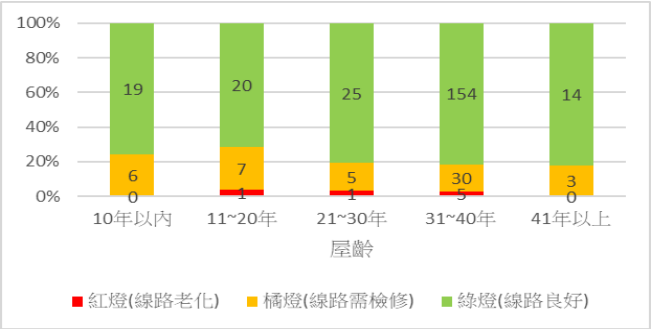

Figure 5: Detection Results by Building Classification

Building 1 had the highest number of red lights. When classified by building age as shown in Figure 7, it was found that red lights were most concentrated in buildings aged 11 to 40 years. Orange lights were most prevalent in buildings aged 31 to 40 years. Specifically, Figure 7 shows that buildings aged 33 years had the highest number of red lights. This indicates that older buildings require more frequent inspections, circuit replacements, and a reduction in the use of high-power appliances.

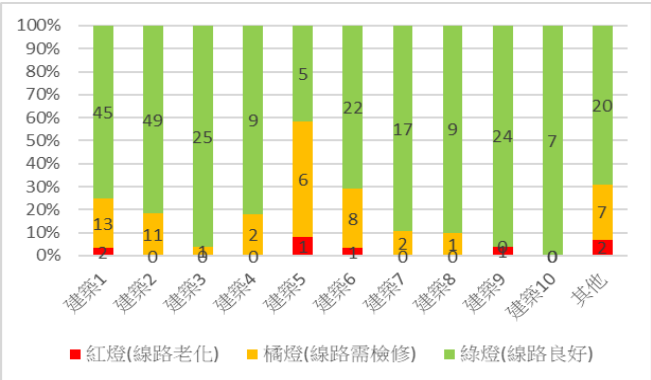

Figure 6: Detection Results by Building Age Classification

For buildings less than 10 years old, the occurrence of orange lights can be attributed to factors such as poor socket or wiring contact or the simultaneous use of high-power appliances on the same circuit. Based on experimental results, as shown in Figure 8, buildings older than 31 years accounted for 72% of red lights, and Figure 9 shows that buildings older than 31 years also accounted for 65% of orange lights. This indicates that the detector effectively shows warnings and anomalies for older buildings. For buildings less than 10 years old, the detected orange lights were ultimately determined to be due to poor wiring contact in the sockets.

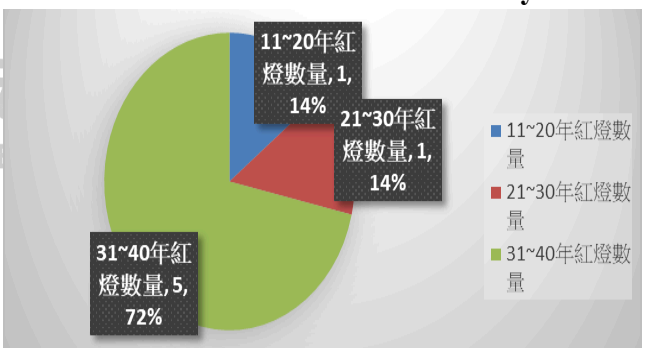

Figure 7: Red Light Statistics

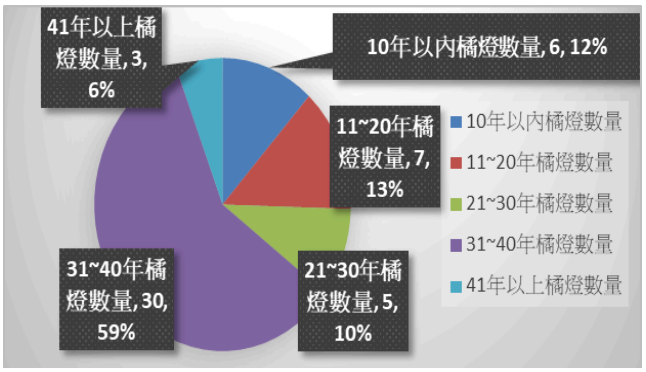

Figure 8: Orange Light Statistics

In the first stage of measurements, 7 circuits were identified with red light anomalies and 51 circuits with orange light warnings. To verify the accuracy of the circuit anomalies and warnings, Phase 2 measurements will use a test fixture to measure circuit impedance. One representative circuit from the orange light warnings and one from the red light anomalies will be selected for detailed analysis. The relevant data results are as follows:

1. Test Date: April 10, 2021
2. Test Location: Kaohsiung University of Science and Technology, Building Yuxian, Room 304, 3rd Floor (Building Age: 18 Years)
3. Original Use of Outlet: General classroom outlet
4. Indicator Light: Orange Light, Number of Segments: 5
5. Outlet Appearance: Normal with some dust accumulation

Figure 9: Abnormal Detection Results (1)

1. **Test Date:** April 10, 2021
2. **Test Location:** Kaohsiung University of Science and Technology, Building Yuxian, Room 404, 4th Floor (Building Age: 18 Years)
3. **Original Use of Outlet:** General classroom outlet
4. **Indicator Light:** Orange Light, Number of Segments: 5
5. **Outlet Appearance:** Normal with some dust accumulation

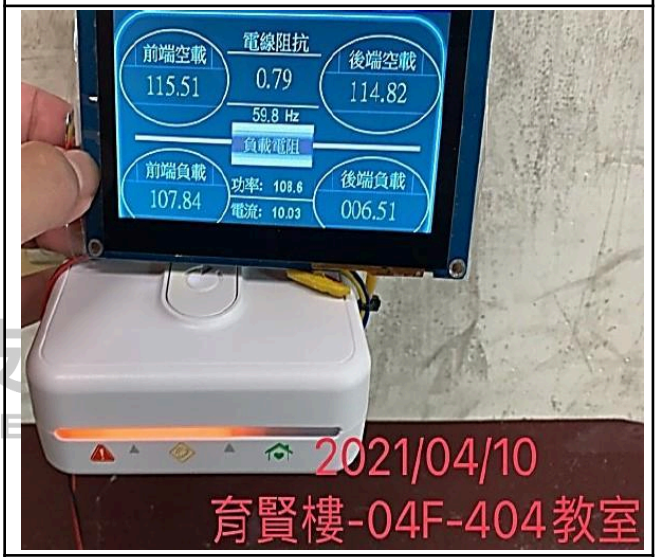

Figure 10: Abnormal Detection Results (2)

1. **Test Date:** April 10, 2021
2. **Test Location:** Kaohsiung University of Science and Technology, Activity Center, 6th Floor Corridor (Building Age: 29 Years)
3. **Original Use of Outlet:** Emergency evacuation indicator light
4. **Indicator Light:** Red Light, Number of Segments: 1
5. **Outlet Appearance:** Normal with some dust accumulation

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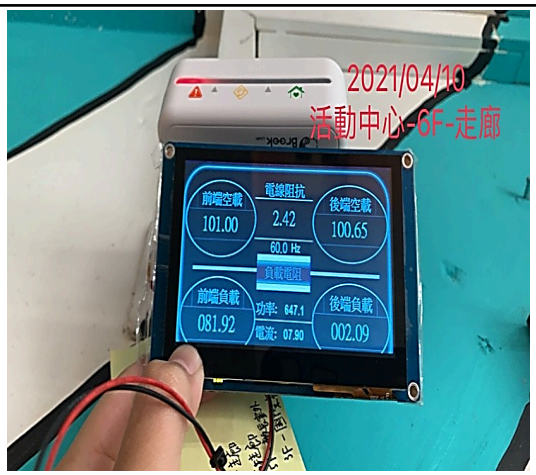

Figure 11: Abnormal Detection Results (3)

Figure 12: Abnormal Detection Results (4)

1. **Test Date:** April 15, 2021
2. **Test Location:** Kaohsiung University of Science and Technology, Activity Center, 7th Floor Corridor (Building Age: 29 Years)
3. **Original Use of Outlet:** Emergency evacuation indicator light
4. **Indicator Light:** Red Light, Number of Segments: 1
5. **Outlet Appearance:** Normal with some dust accumulation

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Conclusion

In this study, we collaborated with Pregnang Technology Co., Ltd. to analyze and evaluate the application of low impedance measurement technology for indoor wiring impedance measurement. We randomly selected 19 buildings of varying ages and tested 290 indoor wiring circuits and outlets for measurement and empirical analysis. The results indicate that (1) the proposed detector effectively provides warnings or abnormal messages for old wiring quality, (2) the test results reflect the aging proportion of indoor wiring circuits in old buildings, and (3) the wiring detector can conveniently assess and alert for electrical safety in older buildings. This study demonstrates that the proposed detector has significant application value.

Acknowledgments

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