Investigation of Monitoring Instrumentation for the Solar Decathlon

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Abstract

Investigation of Monitoring Instrumentation for the Solar Decathlon. Kenneth Armstrong (James Madison University, Harrisonburg, VA 22807) Mark Eastment and Cecile Warner (National Renewable Energy Laboratory, Golden, Colorado 80401).

During an investigation of monitoring instrumentation for the Solar Decathlon, precise procedures were developed and implemented for inclusion in the rules and regulations. The rules and regulation document contained many governing principles for the Solar Decathlon that were unenforceable. Over the course of my internship, I investigated and experimented with power, flow, and temperature measurements that resulted in the establishment of a fair and concise competition. Temperature measurements within the refrigerator will project actual food temperatures. Power measurements for both direct and alternating currents can now be quantified and judged according to the rules and regulations for each individual contest. Flow from the hot water tank can now be measured to tell the judges how much and when hot water will be expelled from the holding tank. A Campbell data logger will be used in the competition to provide concise real-time data. This data logger can be linked to a network and the competition can be judged remotely. Now, with the ability to calculate temperature, power, and flow with the aid of a Campbell data logger judges can evaluate many of the contests in a fair and concise manner.

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Introduction

Even in today's technology-driven world, we are taking steps to use much "older" forms of energy. As a nation, we set an example and provide guidance to help rid the world of the adverse effects of pollution, waste, and destruction. Consequently, the ability to harness many of the Earth's abundant renewable resources becomes ever more important. The power surrounds us, contained within the sun, wind, water, biomass, and the Earth's core. At the National Renewable Energy Laboratory (NREL), renewable sources are investigated to help the nation and the world become more sustainable and more efficient. To further these goals, the U.S. Department of Energy (DOE) is hosting the Solar Decathlon, which challenges the students to integrate technologies of today in the home buildings of tomorrow.

The Solar Decathlon is a 10-part "race" that incorporates modern technology to challenge the intuition, ability, and creativity of diverse students around the nation. This competition will take place during a three-week period in early Fall 2002. The event, sponsored by DOE, NREL, BP Solar, and the American Institute of Architects (AIA), will test many of the issues that face homebuilders, engineers, and architects today. This competition will help to inform the nation about energy alternatives as our reliance on fossil fuels decreases.

To create impartial competition, careful consideration needs to be given to developing a set of rules and regulations as well as a set of test parameters that can be applied to each of the 10 contests that make up the competition. These guidelines and testing procedures will measure and evaluate the work of the competitors throughout the weeklong testing phase of the event.

The decathletes are restricted to producing energy by means of solar power. A solar homebuilder usually constitutes and considers solar electric panels, solar water heaters, as well as passive devices such as south-facing windows to make the home as livable as possible. Teams are required to design their homes to be sustainable; this means not only producing power independently of the electric company but also applying efficient devices and appliances to make better use of the limited power source. Techniques such as south-facing windows with an overhang can let insolation into the house in the winter and block solar rays in the summer when the extra heating is undesirable.

The first contest tests the design and livability of the home. A group of architects will actually rate the design, innovation, and aesthetics of the home. The careful integration of solar power into the overall design will be key in this event. The second competition will look at the design presentation and simulation. Judges will critique construction documents as well as the simulations performed over the course of the project. Third, graphics and communication will be tested. The contestants will be required to demonstrate and communicate how energy-efficient technologies were incorporated into their overall model house. The fourth, fifth, and sixth contests all require careful temperature measurements dealing with the livability of the home. The comfort zone test requires each home to maintain interior comfort through the temperature, humidity, and overall feel of the home. The hot water test will require each home to provide hot water for common uses around the house such as showers, laundry, and dishwashing. Refrigeration will also be required and tested. Data will be collected and analyzed to determine whether the refrigerator and freezer maintained adequate temperatures over the duration of the test.

The objective of the seventh test will be to begin and end the competition with the same amount of energy stored in the battery system. This will prove that the sun can provide all the energy needed to run a home, a business, and even some transportation. The lighting test is the eighth contest. The efficiency of the lighting and its overall appeal will be judged during the day and for a few of hours at night. In the ninth test, the students will incorporate a small business into their home. A home computer, fax machine, and other communicating equipment will be utilized to challenge teams to use solar power to run a home-based business.

Last but not least is the “getting-around” competition. Teams are asked to use their "extra" energy to charge a readily available electric car capable of transporting a member of the team around the area. Notice will be paid to the mileage recorded at the end of the contest. Each of these contests will test a certain element of the load one might expect within the average household. To win the competition, a team must excel in each of the above areas within the limitations of the contest.

All of the contests have been written into the competition's rules and regulations; the testing parameters, however, have not. Experiments are being conducted to determine criteria for testing and judging the competitive teams. The experimentation involves tools such as thermocouples, data loggers, flow meter, voltage dividers, shunts, and transducers. Developing such tools and a uniform way to apply each to the competition will help determine winners in a fair and professional manner.

Materials and Methods

Currently, the Solar Decathlon requires study and development of an instrumentation strategy for two of the contests; the refrigeration and hot water contests. Initially, I installed *Boxcar* software on my computer and manipulated a HOBO portable data logger by adjusting the measuring criteria. The first data logger could only hold 256 points and had just one sensor. A newer one preformed much better, having the ability to plug in four sensors and a capacity of 32,520 data points. Using the new data logger and two thermistor sensors, we could measure the temperature of both the refrigerator and the freezer at the same time. This data could then be downloaded to a computer and graphs could be constructed with the use of *Excel*.

We determined that the sensors were actually measuring air temperature and not food temperature; the sensors were therefore placed in a mass of water or antifreeze to emulate the temperature of food in the refrigerator. The thermistors were also placed in the mid-back of the freezer and refrigerator to better compensate for the losses occurring when the door was ajar. Careful attention was paid to the temperature measurement sensors, placing them out of the direct path of air intake.

Next, the use of Campbell (CR10X) data loggers was investigated. These data loggers have six differential channels that can be used for measuring sensors such as thermocouples, two pulse channels that can be used for flow meters, and three excitation channels that are able to switch equipment off and on. Type-T thermocouple wire was used to take temperature measurements. One wire was connected to channel 1 and one to channel 2 of the data logger to take the required temperature measurements of the refrigerator. *Campbell Scientific* software is used to control the data logger, and it is programmed to take data every second and average those measurements every minute.

Campbell Scientific has its own programming language that needs to be mastered in order to measure the various parts of the competition. This language, though confusing at first, finally flows more easily as users gain more experience in experiments. This software permits extensive customization, allowing the user to record from just about any sensor. One can even control how often data is collected, averaged, and stored.

The power consumption of the refrigerator was a consideration as well. To do this, we created a box with an extension cord, an electrical distribution block, and a terminal strip. Figure 1, denotes the electrical setup of the box. The two big cords are the spliced extension cord. One end is plugged into the wall outlet and the other into the refrigerator. Wires from the voltage difference within the cord and the current transformer are run to a transducer, where the voltage is multiplied by the current to get power. This power is converted to a DC voltage proportional to the AC power and connected to a Campbell data logger on channel 3. The data logger can now do all measurements for the refrigeration competition by itself, and data can be collected whenever it is desired.

With DC measurements, a transducer can be used but is not required as it is with the AC measurements. With DC, the current can run through a shunt, which is a very small resister, and with the voltage difference across the resistor, current can be calculated. Because, typical application voltage of 12, 24, or 48 volts is too high for the 2.5 volt limit of the Campbell, a voltage divider must be used. A circuit consisting of two resistors and a source is used to step down the voltage to a more measurable value. The schematic of the power box used to measure DC power is show below in Figure 2.

For the hot water competition, a flow meter/thermocouple set up was used to judge the individual components that make up the contest. The flow meter can sense when water is flowing and, when hooked up to a Campbell, it is able to totalize the amount of gallons used during a given period of time. The setup of the hot water measurement tools is illustrated in Figure 3. The output from the hot water tank first passes through a T-junction where a thermocouple is present and then through a flow meter.

Results

Figure 4 shows results for one of the early trials with the old HOBO data logger. The upper and lower control limits are 40^{o} F and 32^{o} F as denoted in the rules and regulations for the Solar Decathlon. The refrigerator was measured over the weekend for 6 hours to capture the data. Figure 4 shows an extreme change in temperature over time through which the competitor could lose many points. Figure 5 demonstrates what happens when the HOBO's temperature sensor is placed in a ½ ounce of water. This gives a better representation of the food temperature, rather then just the air around the food, and judges the competition a little more realistically. Figure 6 shows power vs. time recorded by the Campbell data logger recording from the power box/transducer, combination. This figure models the refrigerator's daily cycle of 15 minutes on, 15 minutes off. The peak demonstrated at 0222 hours is due to the defrost cycle cutting on. One can average all of this data over the course of an hour to get a power measurement in watt-hours. Figure 7 presents an example of the temperature for both the freezer and the refrigerator over the same time. One can see that a thermal mass is needed from the converging refrigerator and freezer temperatures.

Discussion and Conclusion

By focusing on the refrigeration contest and developing measurement procedures for evaluating it, one can apply similar measurement techniques to many other contests. For example, learning how to do power and temperature measurements makes it possible to measure at least half the contests in the competition. All power measurements will be taken just below the junction box and with the same measurement procedure described here.

For other measurements, such as temperature and flow, precise procedures need to be formed on experimental evidence. For example, although placing a thermocouple inside the refrigerator seems like a good way to measure its temperature, this would simply be an air-temperature measurement, not a measure of what the refrigerator was designed to do. By placing the thermocouple in water, one can get a better approximation of true food temperature measurement, and this is what the contestants should be judged on. The sensor also must be placed in the mid-back of the refrigerator so as not to be altered greatly by the opening of the door and the intake vent used to keep it cool.

Voltage and current must be measured to calculate how much power the refrigerator is using. By using the power box demonstrated in Figure 1, we can find the power use of anything plugged into the outlet cord relatively easily. This box was developed to keep potentially dangerous hot electrical wiring away from the hands of observers. Because of its safety, interconnect ability, and mobility, a similar sort of prefabricated box will be used for the Solar Decathlon.

For DC measurements, the same sort of box was used to make it easy to hook up. To get DC power, one needs a voltage difference and a current just like with AC. The only difference is that this box used a shunt instead of a current transducer. A shunt is a very small resistor, around $^{1}/_{1000}$ of an ohm. When the current of a circuit is run through the shunt, and the voltage difference across the resistor is measured, current can be calculated by

$$I = \frac{V}{R}, \tag{1}$$

where

I = current
V = voltage
R = resistance.

To get the voltage, the 12-volt source needs to be stepped down to a level that the Campbell is capable of reading. To do this, a voltage divider was used. A separate circuit was hooked up between the power source and two resistors in series. The voltage across the small resistor is measured and the real voltage is found with the equation

$$V_2 = \frac{V_1 \times R_2}{R_1 + R_2}. \tag{2}$$

Figure 8 shows the battery bank, two resistors in series, and the voltage difference across the small resister used to calculate voltage. The voltage from the shunt and voltage divider are connected to the Campbell and when inserted into the equations 2 one is able to calculate power.

$$P = I \times V \ , \quad (3)$$

where

P = power.

This power is averaged each hour in *Excel* and the output in watt-hours, is used to judge the different power competitions.

The hot water competition will be regulated by a thermocouple/flow meter configuration. A thermocouple will be installed into a T-junction on the outlet from each team's hot water tank. Because the temperature must be maintained at 120^{o} F or higher, the thermocouple will be referenced upon any draw of hot water governed by the flow meter. The flow meter will make sure each team is using the appropriate amount of hot water for the event or competition at hand.

By investigating how flow meters, thermocouples, and power-measuring tools may be used and manipulated, I was able to assist the Solar Decathlon rules and regulations committee in developing protocols for the competitions. My work into experimentation helped to create an impartial competition where a true winner becomes apparent over the course of the 6-day testing analysts.

Acknowledgements

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Figures

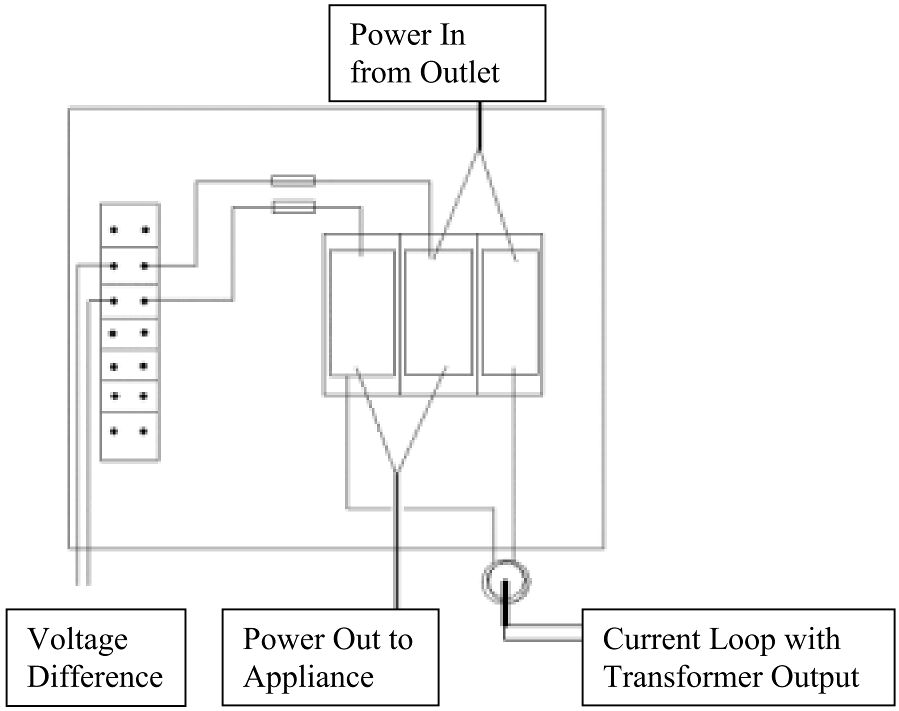

Figure 1. Power box used to measure the AC power of an appliance

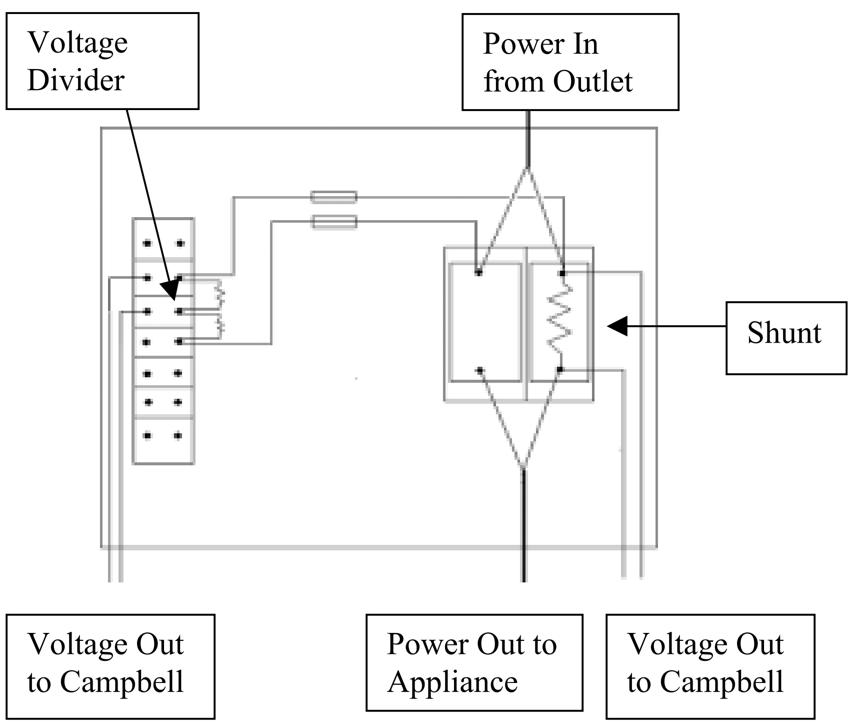

Figure 2. Power box used to measure the DC power of an appliance

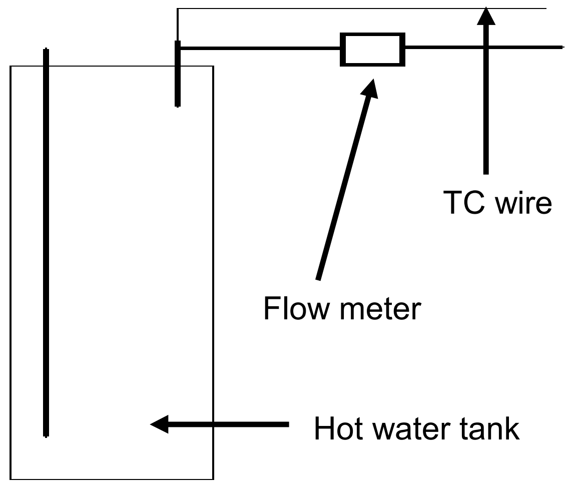

Figure 3. Hot water contest setup for calculating water temperature and flow

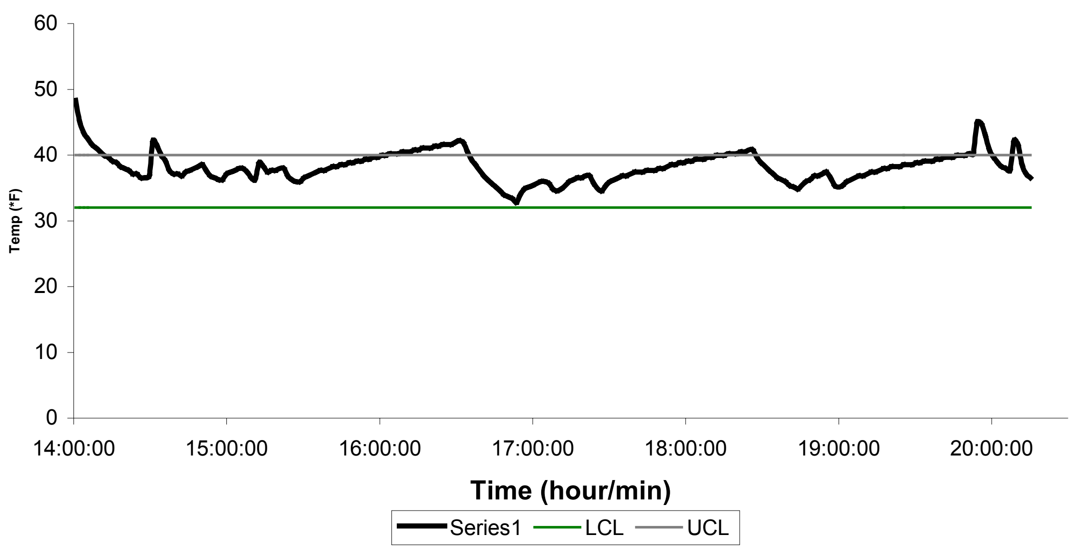

Figure 4. Temperature taken in refrigerator with HOBO

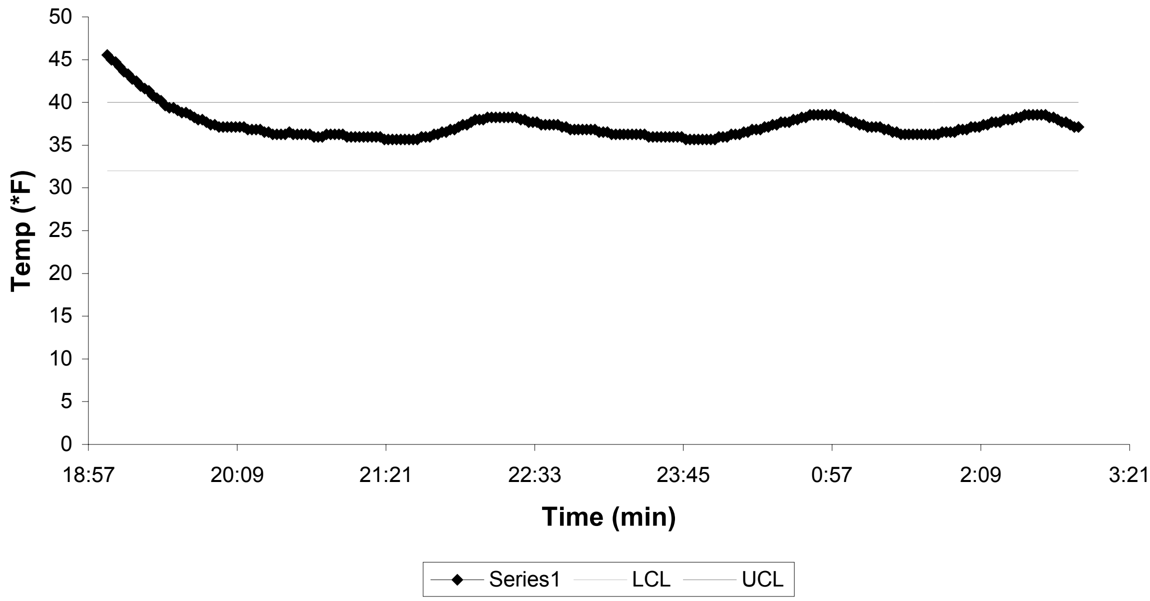

Figure 5. Temperature taken with TC in 1/2 ounce H_2O using HOBO.

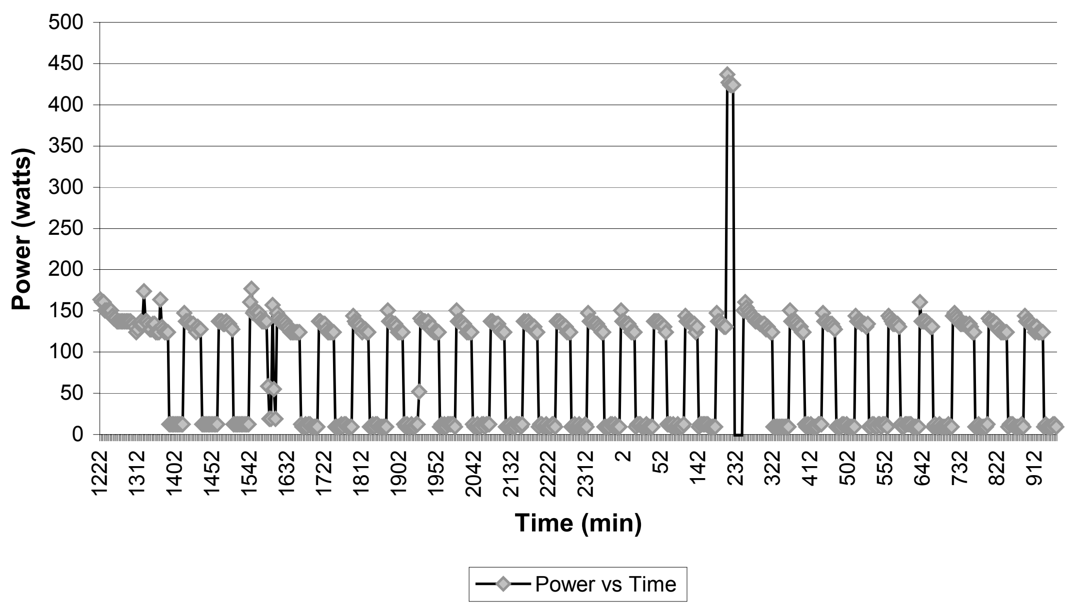

Figure 6. Power verse time for a typical refrigerator.

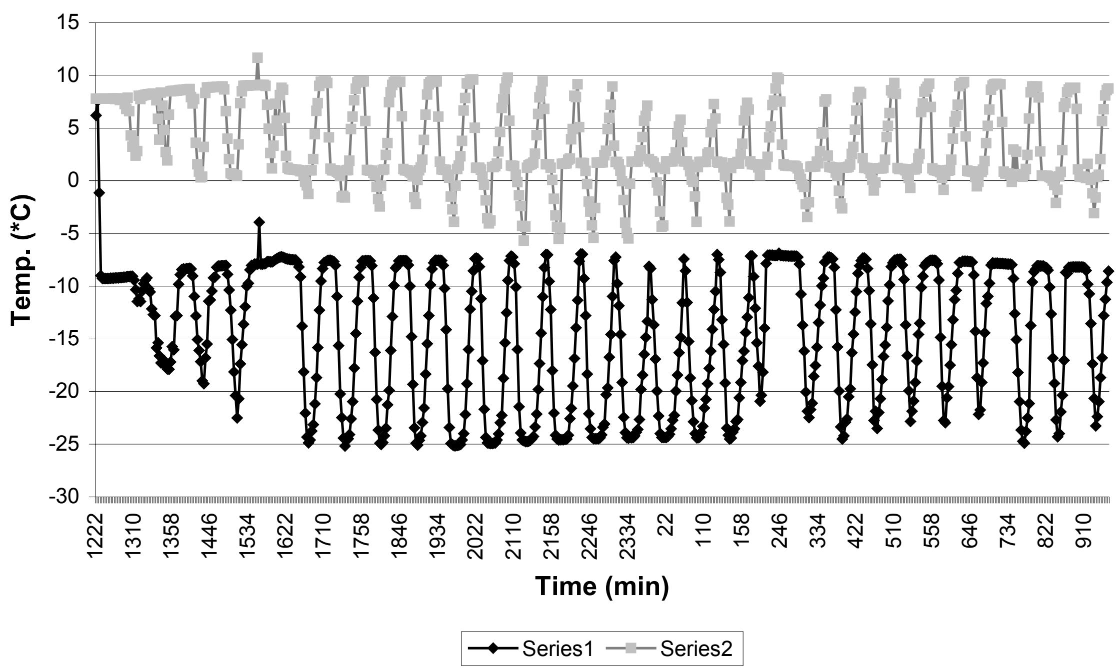

Figure 7. Temperature (ºC) verses time for the same refrigerator and time as in figure 6.

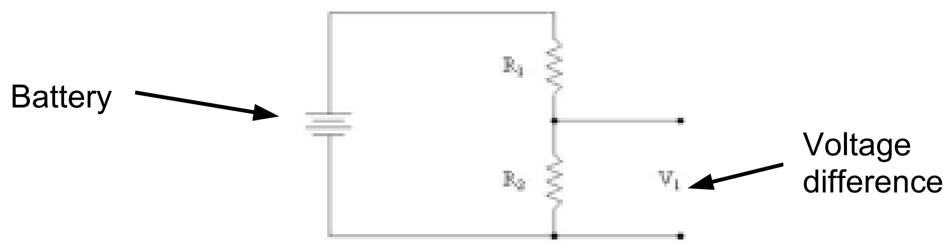

Figure 8 Voltage divider used to measure DC voltage.