Product Manual

Sensor

HFP01

Soil Heat Flux Plate

Revision: 1/20
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WHEN MEASUREMENTS MATTER

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PLEASE READ FIRST

About this manual

Please note that this manual was originally produced by Campbell Scientific Inc. primarily for the North American market. Some spellings, weights and measures may reflect this origin.

Some useful conversion factors:

Area: 1 in^2 (square inch) = 645 mm^2

Length: 1 in. (inch) = 25.4 mm
1 ft (foot) = 304.8 mm
1 yard = 0.914 m
1 mile = 1.609 km

Mass: 1 oz. (ounce) = 28.35 g
1 lb (pound weight) = 0.454 kg

Pressure: 1 psi (lb/in^2) = 68.95 mb

Volume: 1 UK pint = 568.3 ml
1 UK gallon = 4.546 litres
1 US gallon = 3.785 litres

In addition, while most of the information in the manual is correct for all countries, certain information is specific to the North American market and so may not be applicable to European users.

Differences include the U.S standard external power supply details where some information (for example the AC transformer input voltage) will not be applicable for British/European use. *Please note, however, that when a power supply adapter is ordered it will be suitable for use in your country.*

Reference to some radio transmitters, digital cell phones and aerials may also not be applicable according to your locality.

Some brackets, shields and enclosure options, including wiring, are not sold as standard items in the European market; in some cases alternatives are offered. Details of the alternatives will be covered in separate manuals.

Part numbers prefixed with a "#" symbol are special order parts for use with non-EU variants or for special installations. Please quote the full part number with the # when ordering.

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Campbell Scientific Ltd can advise on the recycling of the equipment and in some cases arrange collection and the correct disposal of it, although charges may apply for some items or territories.

For further advice or support, please contact Campbell Scientific Ltd, or your local agent.

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Safety

DANGER — MANY HAZARDS ARE ASSOCIATED WITH INSTALLING, USING, MAINTAINING, AND WORKING ON OR AROUND **TRIPODS, TOWERS, AND ANY ATTACHMENTS TO TRIPODS AND TOWERS SUCH AS SENSORS, CROSSARMS, ENCLOSURES, ANTENNAS, ETC**. FAILURE TO PROPERLY AND COMPLETELY ASSEMBLE, INSTALL, OPERATE, USE, AND MAINTAIN TRIPODS, TOWERS, AND ATTACHMENTS, AND FAILURE TO HEED WARNINGS, INCREASES THE RISK OF DEATH, ACCIDENT, SERIOUS INJURY, PROPERTY DAMAGE, AND PRODUCT FAILURE. TAKE ALL REASONABLE PRECAUTIONS TO AVOID THESE HAZARDS. CHECK WITH YOUR ORGANIZATION'S SAFETY COORDINATOR (OR POLICY) FOR PROCEDURES AND REQUIRED PROTECTIVE EQUIPMENT PRIOR TO PERFORMING ANY WORK.

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General

- Prior to performing site or installation work, obtain required approvals and permits. Comply with all governing structure-height regulations, such as those of the FAA in the USA.
- Use only qualified personnel for installation, use, and maintenance of tripods and towers, and any attachments to tripods and towers. The use of licensed and qualified contractors is highly recommended.
- Read all applicable instructions carefully and understand procedures thoroughly before beginning work.
- Wear a **hardhat** and **eye protection**, and take **other appropriate safety precautions** while working on or around tripods and towers.
- **Do not climb** tripods or towers at any time, and prohibit climbing by other persons. Take reasonable precautions to secure tripod and tower sites from trespassers.
- Use only manufacturer recommended parts, materials, and tools.

Utility and Electrical

- **You can be killed** or sustain serious bodily injury if the tripod, tower, or attachments you are installing, constructing, using, or maintaining, or a tool, stake, or anchor, come in **contact with overhead or underground utility lines**.
- Maintain a distance of at least one-and-one-half times structure height, or 20 feet, or the distance required by applicable law, **whichever is greater**, between overhead utility lines and the structure (tripod, tower, attachments, or tools).
- Prior to performing site or installation work, inform all utility companies and have all underground utilities marked.
- Comply with all electrical codes. Electrical equipment and related grounding devices should be installed by a licensed and qualified electrician.

Elevated Work and Weather

- Exercise extreme caution when performing elevated work.
- Use appropriate equipment and safety practices.
- During installation and maintenance, keep tower and tripod sites clear of un-trained or non-essential personnel. Take precautions to prevent elevated tools and objects from dropping.
- Do not perform any work in inclement weather, including wind, rain, snow, lightning, etc.

Maintenance

- Periodically (at least yearly) check for wear and damage, including corrosion, stress cracks, frayed cables, loose cable clamps, cable tightness, etc. and take necessary corrective actions.
- Periodically (at least yearly) check electrical ground connections.

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Model HFP01 Soil Heat Flux Plate

1. Introduction

The HFP01 outputs a voltage signal that is proportional to the heat flux of the surrounding medium (usually soil). It is typically used for energy-balance or Bowen-ratio flux systems. Two sensors may provide spatial averaging. Sites with heterogeneous media may require additional sensors.

NOTE This manual provides information only for CRBasic data loggers. It is also compatible with retired Edlog data loggers. For Edlog data logger support, see an older manual at *www.campbellsci.com/old-manuals*.

2. Precautions

- READ AND UNDERSTAND the *Safety* section at the front of this manual.
- Care should be taken when opening the shipping package to not damage or cut the cable jacket. If damage to the cable is suspected, contact Campbell Scientific.
- Although the HFP01 is rugged, it should be handled as a precision scientific instrument.

3. Initial Inspection

- Upon receipt of the HFP01, inspect the packaging and contents for damage. File damage claims with the shipping company.
- The model number and cable length are printed on a label at the connection end of the cable. Check this information against the shipping documents to ensure the correct product and cable length are received.
- The HFP01 is shipped with a calibration sheet.

4. QuickStart

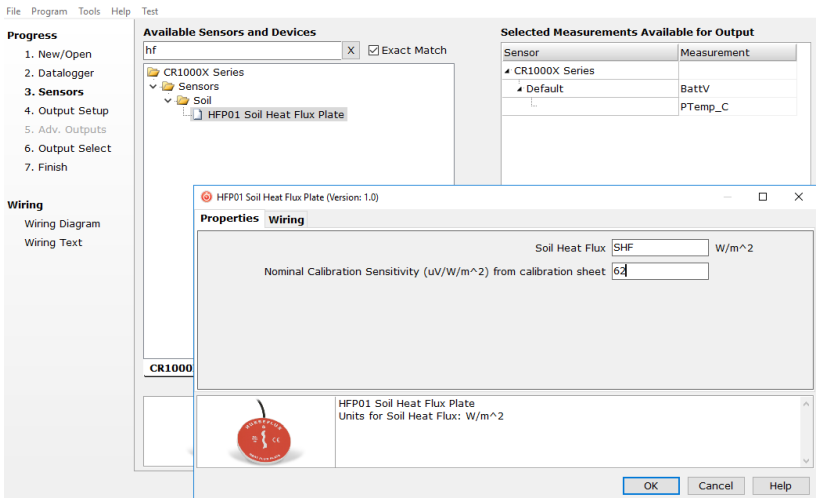
A video that describes data logger programming using *Short Cut* is available at: *www.campbellsci.eu/videos/cr1000x-datalogger-getting-started-program-part-3*. *Short Cut* is an easy way to program your data logger to measure the sensor and assign data logger wiring terminals. *Short Cut* is available as a download on *www.campbellsci.eu*. It is included in installations of *LoggerNet*, *RTDAQ*, *PC400*, or *PC200W*.

The following procedure also shows using *Short Cut* to program the sensor.

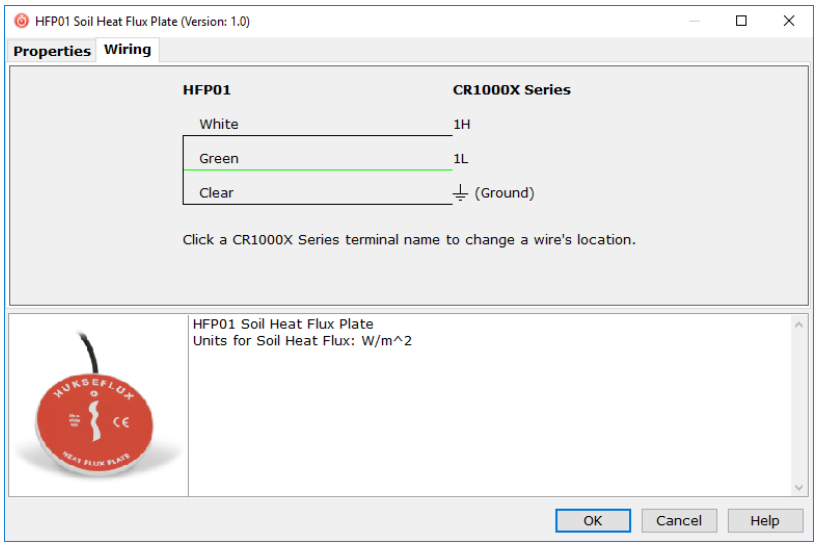
1. Open *Short Cut* and click **Create New Program**.

2. Double-click the data logger model.

3. In the **Available Sensors and Devices** box, type HFP01 or locate the sensor in the select **Sensors** > **Soil** folder. Double-click **HFP01 Soil Heat Flux Plate**. Type the sensitivity provided on the calibration sheet; this value is sensor specific.

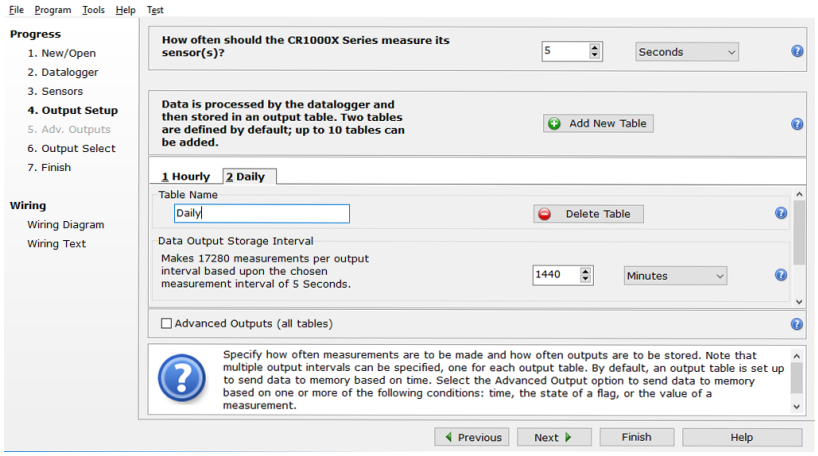


4. Click the **Wiring** tab to see how the sensor is to be wired to the data logger. Click **OK** after wiring the sensor.

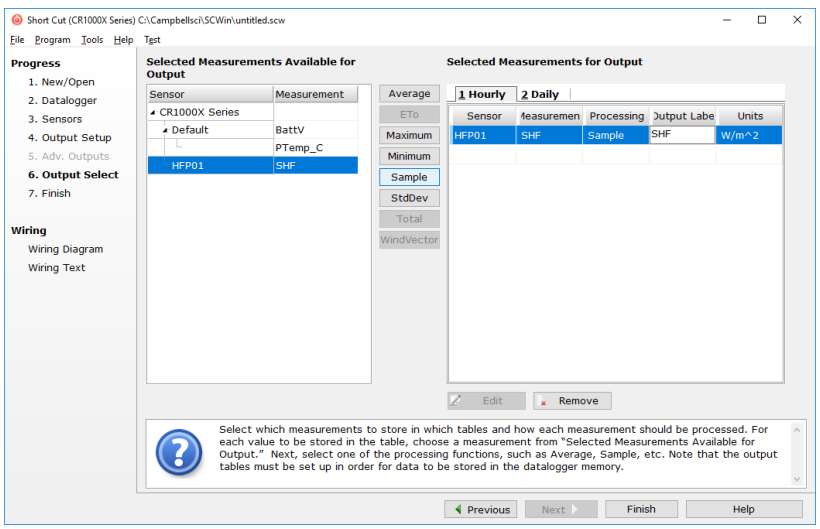


5. Repeat step three and four for other sensors.

6. In **Output Setup**, type the scan rate, meaningful table names, and **Data Output Storage Interval**.



7. Select the output options.



8. Click **Finish** and save the program. Send the program to the data logger if the data logger is connected to the computer.

9. If the sensor is connected to the data logger, check the output of the sensor in data display in *LoggerNet*, *RTDAQ*, *PC400*, or *PC200W* to make sure it is making reasonable measurements.

5. Overview

The HFP01 Soil Heat Flux Plate uses a thermopile to measure temperature gradients across its plate. Operating in a completely passive way, it generates a small output voltage that is proportional to this differential temperature. Assuming that the heat flux is steady, that the thermal conductivity of the body is constant, and that the sensor has negligible influence on the thermal flow pattern, the signal of the HFP01 is directly proportional to the local heat flux.

The HFP01 output is in millivolts. To convert this measured voltage to heat flux, it must be divided by the plate's calibration constant. A unique calibration constant is supplied with each sensor.

To get the soil heat flux at the surface, use an HFP01 to measure soil heat flux; a TCAV Averaging Soil Thermocouple to measure the temporal change in temperature of the soil layer above the HFP01; and a CS616, CS650, or CS655 water content reflectometer to measure soil water content. The temporal change in soil temperature and soil water content are used to compute the soil storage term.

NOTE A general discussion about the characteristics and principles of operation of heat flux sensors is shown in Appendix C, *General Theory of Heat Flux Sensors* *(p. C-1)*.

Features:

- Ideal for energy-balance or Bowen-ratio systems
- Compatible with Campbell Scientific CRBasic data loggers: CR6 series, CR3000, CR1000X, CR800 series, CR1000

6. Specifications

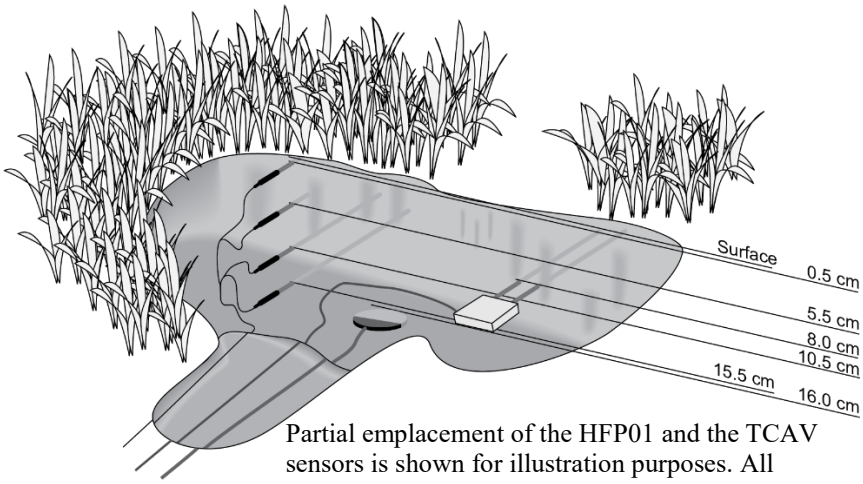
Operating Temperature:	–30 to 70 °C
Plate Thickness:	5.0 mm (0.20 in)
Plate Diameter:	80.0 mm (3.15 in)
Weight (without cable):	200 g (7.05 oz)
Sensor:	Thermopile
Measurement Range:	±2000 W m^{-2}
Sensitivity (nominal):	50 µV W^{-1} m^{-2}
Expected Typical Accuracy (12 hour totals):	Within –15% to +5% in most common soils
Nominal Resistance:	2 Ω
Sensor Thermal Resistance:	<6.25 x 10^{-3} Km^2W^{-1}

7. Installation

If you are programming your data logger with *Short Cut*, skip Section 7.2, *Wiring* *(p. 6)*, and Section 7.3, *Programming* *(p. 7)*. *Short Cut* does this work for you. See Section 4, *QuickStart* *(p. 1)*, for a tutorial.

7.1 Placement in Soil

The standard set of sensors for measuring soil heat flux includes an HFP01 Soil Heat Flux Plate, TCAV Averaging Soil Thermocouple, and CS616, CS650, or CS655 water content reflectometer. These sensors are installed as shown in FIGURE 7-1.



Partial emplacement of the HFP01 and the TCAV sensors is shown for illustration purposes. All sensors must be completely inserted into the soil face before the hole is backfilled.

FIGURE 7-1. Placement of the sensors

The location of the heat flux plate and thermocouple should be chosen to be representative of the area under study. If the ground cover is extremely varied, an additional set of sensors is required to provide a valid soil heat flux average.

Use a small shovel to make a vertical slice in the soil. Excavate the soil to one side of the slice. Keep this soil intact so that it can be replaced with minimal disruption.

The sensors are installed in the undisturbed face of the hole. Measure the sensor depths from the top of the hole. With a small knife, make a horizontal cut 16 cm below the surface into the undisturbed face of the hole. Insert the heat flux plate into the horizontal cut.

NOTE Install the HFP01 in the soil such that the side with the red label is facing the sky and the side with a blue label is facing the soil.

CAUTION To make quality soil heat flux measurements, the HFP01 plate must be in full contact with the soil.

Never run the sensor cable directly to the surface. Rather, bury the sensor cable a short distance back from the hole to minimize thermal conduction on the cable wires. Replace the excavated soil back into its original position after all the sensors are installed.

NOTE To protect sensor cables from damage caused by rodents, Campbell Scientific recommends burying them inside of flexible electrical tubing.

7.2 Wiring

Wire functions are shown in FIGURE 7-2. TABLE 7-1 provides the data logger connections for both single-ended and differential measurements. Typically, the differential measurements are used.

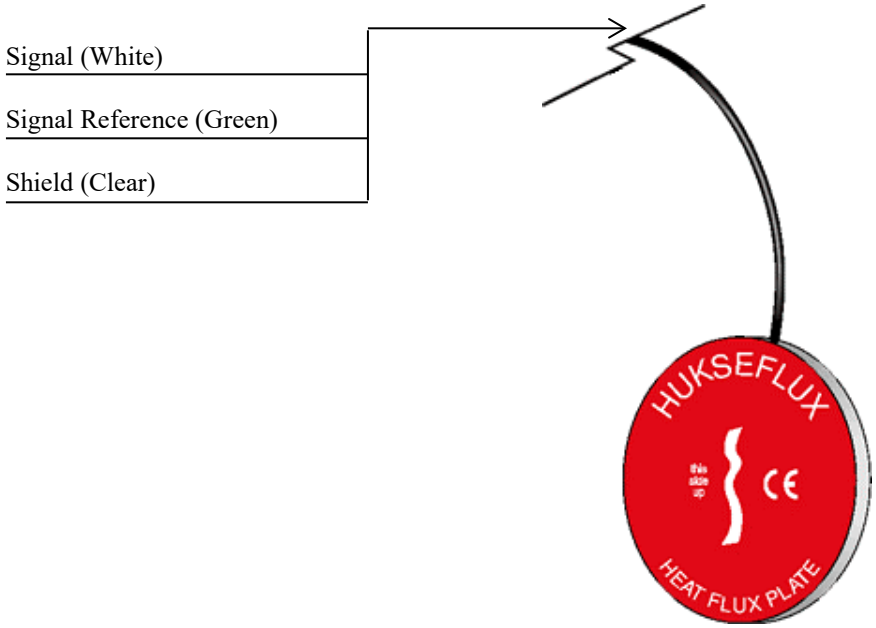


FIGURE 7-2. HFP01 plate to data logger connections

TABLE 7-1. Wire Colour, Function, and Data Logger Connections

Wire Colour	Wire Function	Data Logger Single-Ended Measurement	Data Logger Differential Measurement
White	Signal	**U** configured for single-ended analogue input[1], **SE** (single-ended, analogue input)	**U** configured for differential analogue input high[1], **DIFF H** (differential high, analogue input)
Green	Signal Reference	⏚ (analogue ground)	**U** configured for differential analogue input low[1], **DIFF L** (differential low, analogue input)
Clear	Shield	⏚ (analogue ground)	⏚ (analogue ground)

[1]**U** terminals are automatically configured by the measurement instruction.

7.3 Programming

Short Cut is the best source for up-to-date data logger programming code for the HFP01.

If your data acquisition requirements are simple and you are connecting the sensor to a pulse terminal, you can probably create and maintain a data logger program exclusively with *Short Cut*. If your data acquisition needs are more complex, the files that *Short Cut* creates are a great source for programming code to start a new program or add to an existing custom program.

NOTE *Short Cut* cannot edit programs after they are imported and edited in *CRBasic Editor*.

A *Short Cut* tutorial is available in Section 4, *QuickStart* *(p. 1)*. If you wish to import *Short Cut* code into *CRBasic Editor* to create or add to a customized program, follow the procedure in Appendix A, *Importing Short Cut Code Into CRBasic Editor* *(p. A-1)*.

Programming basics for CRBasic data loggers are in this section. A complete program example for a CRBasic data logger can be found in Appendix B, *Example Program* *(p. B-1)*. Programming basics and programming examples for Edlog data loggers are provided at *www.campbellsci.com/old-manuals*.

The HFP01 is measured using either a single-ended (**VoltSE**) or differential (**VoltDiff**) instruction. The differential measurement is recommended.

Syntax of the **VoltDiff()** instruction is:

```
VoltDiff(Dest, Reps, Range, DiffChan, RevDiff, SettlingTime,
    Integ/FNotch, Mult, Offset)
```

Syntax of the **VoltSE()** instruction is:

```
VoltSE(Dest, Reps, Range, SEChan, MeasOff, SettlingTime,
    Integ/FNotch, Mult, Offset)
```

For the multiplier, divide 1000 by the nominal calibration sensitivity (1000/sensitivity). The nominal calibration is unique for each HFP01.

Each sensor is accompanied with a calibration certificate and has a label on it with the calibration values. The label is located on the pigtail end of the sensor wires.

7.4 Soil Heat Flux and Storage

The soil heat flux at the surface is calculated by adding the measured flux at a fixed depth, d, to the energy stored in the layer above the heat flux plates. The specific heat of the soil and the change in soil temperature, ΔT_S, over the output interval, t, are required to calculate the stored energy.

The heat capacity of the soil is calculated by adding the specific heat of the dry soil to that of the soil water. The values used for specific heat of dry soil and water are on a mass basis. The heat capacity of the moist soil is given by:

$$C_s = \rho_b\left(C_d + \theta_m C_w\right) = \rho_b C_d + \theta_v \rho_w C_w \quad (1)$$

$$\theta_m = \frac{\rho_w}{\rho_b}\theta_v \quad (2)$$

where C_S is the heat capacity of moist soil, ρ_b is bulk density, ρ_w is the density of water, C_d is the heat capacity of a dry mineral soil, θ_m is soil water content on a mass basis, θ_v is soil water content on a volume basis, and C_w is the heat capacity of water.

This calculation requires site specific inputs for bulk density, mass basis soil water content or volume basis soil water content, and the specific heat of the dry soil. Bulk density and mass basis soil water content can be found by sampling (Klute, 1986). The volumetric soil water content is measured by the water content reflectometer. A value of 840 J kg^{-1} K^{-1} for the heat capacity of dry soil is a reasonable value for most mineral soils (Hanks and Ashcroft, 1980).

The storage term is then given by Eq. (3) and the soil heat flux at the surface is given by Eq. (4).

$$S = \frac{\Delta T_s C_s d}{t} \quad (3)$$

$$G_{sfc} = G_{8cm} + S \quad (4)$$

8. Maintenance

NOTE All factory repairs and calibrations require a returned material authorization (RMA) and completion of the "Declaration of Hazardous Material and Decontamination" form. Refer to the *Read First* page at the beginning of this manual for more information.

The HFP01 requires minimal maintenance. Check the sensor cable monthly for rodent damage. Recalibrate the HFP01 for every two years of continuous use.

9. References

Hanks, R. J., and G. L. Ashcroft, 1980: *Applied Soil Physics: Soil Water and Temperature Application.* Springer-Verlag, 159 pp.

Klute, A., 1986: *Method of Soil Analysis.* No. 9, Part 1, Sections 13 and 21, American Society of Agronomy, Inc., Soil Science Society of America, Inc.

Appendix A. Importing Short Cut Code Into CRBasic Editor

Short Cut creates a .DEF file that contains wiring information and a program file that can be imported into the *CRBasic Editor*. By default, these files reside in the C:\campbellsci\SCWin folder.

Import *Short Cut* program file and wiring information into *CRBasic Editor*:

1. Create the *Short Cut* program. After saving the *Short Cut* program, click the **Advanced** tab then the **CRBasic Editor** button. A program file with a generic name will open in CRBasic. Provide a meaningful name and save the CRBasic program. This program can now be edited for additional refinement.

NOTE Once the file is edited with *CRBasic Editor*, *Short Cut* can no longer be used to edit the program it created.

2. To add the *Short Cut* wiring information into the new CRBasic program, open the .DEF file located in the C:\campbellsci\SCWin folder, and copy the wiring information, which is at the beginning of the .DEF file.

3. Go into the CRBasic program and paste the wiring information into it.

4. In the CRBasic program, highlight the wiring information, right-click, and select **Comment Block**. This adds an apostrophe (') to the beginning of each of the highlighted lines, which instructs the data logger compiler to ignore those lines when compiling. The **Comment Block** feature is demonstrated at about 5:10 in the *CRBasic | Features* video.

Appendix B. Example Program

The nominal calibration sensitivity is 67.1 μV/W^{-2} for the HFP01#1 and 67.0 μV/W^{-2} for the HFP01#2. In CRBasic Example B-1, the nominal calibration sensitivity is 67.1 μV/W^{-2}.

TABLE B-1. Wiring for CRBasic Example B-1

Description	Colour	CR3000
Sensor Signal #1	White	7H
Sensor Signal Reference #1	Green	7L
Shield #1	Clear	⏚
Sensor Signal #2	White	8H
Sensor Signal Reference #2	Green	8L
Shield #2	Clear	⏚

CRBasic Example B-1. Sample CR3000 Program using Differential Measurement Instructions

```
'CR3000 Series Data Logger

'This data logger program measures two HFP01 Hukseflux soil heat flux sensors

'*** Constants ***
Const  HFP01_CAL_1 = 14.90  'Unique multiplier for HFP01 #1. 1000/sensitivity (1000/67.1)
Const  HFP01_CAL_2 = 14.92  'Unique multiplier for HFP01 #2. 1000/sensitivity (1000/67.0)

'*** Energy balance sensor variables ***

Public shf(2)
Dim shf_cal(2)  'Soil heat flux plate calibration coefficients.
Units shf = W/m^2

'*** Final Output Data Tables ***

DataTable (soil_hf,TRUE,-1)
  DataInterval (0,30,Min,10)
  Average (2,shf(1),IEEE4,FALSE)
EndTable

'*** Program ***

BeginProg

'Load the HFP01 factory calibration.
  shf_cal(1) = HFP01_CAL_1
  shf_cal(2) = HFP01_CAL_2

  Scan (1,Sec,3,0)

    'Measure the HFP01 soil heat flux plates.
    VoltDiff (shf(1),2,mV50C,7,TRUE,200,250,shf_cal(),0)

    CallTable soil_hf

  NextScan
EndProg
```

Appendix C. General Theory of Heat Flux Sensors

This appendix discusses the general theory and characteristics of heat flux sensors similar to the HFP01.

C.1 General Theory

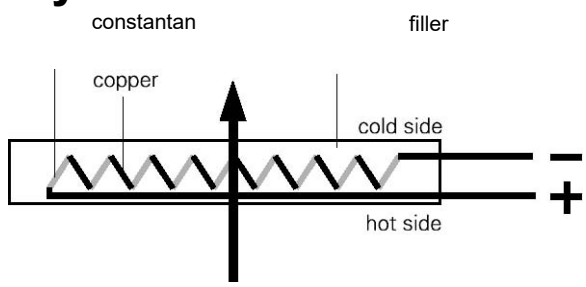


FIGURE C-1. General characteristics of a heat flux sensor

When heat is flowing through the sensor in the indicated direction, the filling material will act as a thermal resistance. Consequently, the heat flow, φ, will follow a temperature gradient across the sensor, flowing from the hot to the cold side. Most heat flux sensors are based on a thermopile—a number of thermocouples connected in series. A single thermocouple will generate an output voltage that is proportional to the temperature difference between the joints (copper-constantan and constantan-copper). Provided that errors are avoided, the temperature difference is proportional to the heat flux—depending only on the thickness and the thermal conductivity of the sensor. Using more thermocouples in series will enhance the output signal. In FIGURE C-1, the joints of a copper-constantan thermopile are alternatively placed on the hot and the cold side of the sensor.

The thermopile is embedded in a filling material, usually plastic.

Each individual sensor has its own sensitivity, E_{sen}, usually expressed in Volts output, V_{sen}, per Watt per square metre heat flux, φ. The flux is calculated:

$$\varphi = V_{sen}/E_{sen}$$

The sensitivity is determined by the manufacturer, and is found on the calibration certificate that is supplied with each sensor.

When used for measuring soil heat flux, heat flux sensors such as the HFP01 reach a limited level of accuracy. This is because thermal parameters of soil are constantly changing (soil moisture content) and the ambient temperature is not fixed. A realistic estimate of the error range is ±20% over a thermal conductivity range from 0.1 to 1.7 W/mK (dry sand to water-saturated sand) across the temperature range of –30 to 70 °C. The accuracy is better if the soil conditions are closer to the reference conditions (see the sensor specifications) and, in an actual experiment, the expected error range will probably be ±10%.

The reference conditions for the calibration are a thermal conductivity of 0.8 W/mK and a nominal temperature of 20 °C.

C.2 Extended Theory

Obviously, the sensor itself can significantly disturb the phenomenon that it is supposed to measure. By adding a sensor to the material under observation, you can add additional, and sometimes differing, thermal resistances.

The deflection error, as shown in FIGURE C-2, represents the effect that, as a result of differing resistances, the flow pattern will change, especially at the edges of the heat flux sensor. The order of magnitude of this error for strongly different thermal conductivity values between the sensor and its environment (for example 0.6 for a typical sensor and 0.03 for an insulating wall) is about 40%.

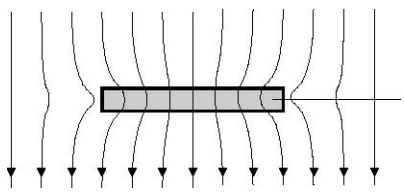


FIGURE C-2. Deflection error

The heat flux is deflected at the edges of the sensor. As a result, the heat flow at the edges is not representative.

Apart from the sensor thermal resistance, the contact resistance between the sensor and surrounding material require special attention.

The conductivity of air is approximately 0.02 W/mK which is ten times smaller than that of the heat flux sensor. It follows, therefore, that air gaps can form major contact resistances. In all cases, the contact between sensor and surrounding material should be as close and as stable as possible, so that it will not influence the measurements.

Aspects of differing thermal properties between sensor and its environment can also be dealt with during the measurement using a higher accuracy self-calibrating type of heat flux sensor.

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